The Biota of Canada – A Biodiversity Assessment. Part 1: The Terrestrial Arthropods

Edited by

David W. Langor, Cory S. Sheffield

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The Biota of Canada – A Biodiversity Assessment. Part 1: The Terrestrial Arthropods

Edited by David W. Langor, Cory S. Sheffield

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EDITORIAL

A peer-reviewed open-access journal
ZooKeys
Launched to accelerate biodiversity research

The Biota of Canada: Terrestrial Arthropods

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This work is dedicated to the visionaries who conceived and created

The Biological Survey of Canada.

Forty years ago, a group of visionary scientists, mostly entomologists and arachnologists, undertook an ambitious project to produce the monograph *Canada and its insect fauna* (Danks 1979). This landmark publication was the first large science product completed by the then-new Biological Survey of Canada (BSC). The large team and ambitious work plan was coordinated, and the product edited, by Hugh V Danks. Hugh's reputation for scientific rigor, organizational acumen, attention to detail, and synthesis are legendary and inspirational, and were critical to the success of the project. In 573 printed pages, this team of 60 specialists reviewed patterns and determinants of regional diversity, aquatic and terrestrial insect habitats, approaches to documenting the fauna, and the status of each group of terrestrial arthropods in Canada. The rest is history! The monograph has served as a benchmark for biodiversity science in Canada for four decades. The entire work and the individual chapters therein have been cited thousands of times, a testimony to the enormous impact of this product in Canada and beyond. Furthermore, *Canada and its insect fauna* (and many other BSC products to follow over nearly four decades) proves that great things can be achieved by communities of dedicated, capable, and passionate individuals who are willing to push aside sometimes-restrictive institutional impediments, rise above political undercurrents, and focus on delivering together something that is important and lasting. This approach to doing exceptional science continues to define the BSC.

Even after nearly 40 years, the content of *Canada and its insect fauna* is highly valuable. Nonetheless, some of the content of the 39 faunistics chapters, especially the information in the tables, required updating to reflect advances since 1979. Thus, in 2016, the BSC commenced planning a project to update those chapters. However, it was soon realized that the need to re-assess the state of knowledge of species diversity in Canada extended beyond the terrestrial arthropods to the entire biota, as the last assessment was published in 1995 (Mosquin et al. 1995). A number of other organizations were consulted and they endorsed the concept of a new biodiversity assessment for Canada. Thus, the Biota of Canada project was initiated, with the intent of reviewing and assessing the state of biodiversity knowledge of all groups of organisms in Canada in a series of volumes. The terrestrial arthropods were an obvious starting point to develop the 'proof of concept' as the 40th anniversary of the BSC was imminent and this was envisioned to be a product to commemorate the occasion.

A Biota of Canada Editorial Committee was established to develop some guidelines for preparation of manuscripts and to ensure that there was a standardised approach in terms of topics covered and data provided. Supported by a set of 'Instructions to Authors' and a sample manuscript to distribute to potential authors, the process of soliciting lead authors for papers went remarkably smoothly. Almost all authors first approached agreed to join the writing team, further indicating that the Biota of Canada project was perceived to be of broad value. Most papers were lead by specialists working in Canadian institutions, but for ten organismal groups there were no current or available Canadian experts so expertise was sought and obtained in other countries (China, Czech Republic, Norway, USA). Thus, the Biota of Canada is an international effort.

All authors were asked to review the state of knowledge of the diversity of their taxon in Canada with attention focused on advancements since Canada and its insect fauna was published (1979). Each author was asked to produce a table that provided for each family the following information for the Canadian fauna: number of species reported in 1979, number of described species currently known, number of DNA Barcode Index Numbers (BINs; Ratnasingham and Hebert 2013) attributed to Canadian specimens in the Barcode of Life Datasystems database (BOLD; Ratnasingham and Hebert 2007), the number of additional species expected to eventually be discovered in Canada, the general distribution by ecozone (Federal, Provincial, and Territorial Governments of Canada 2010), and important information sources that have advanced our understanding of the fauna since 1979. Authors were also asked to highlight important gaps and opportunities concerning knowledge of the Canadian fauna. Beyond a few standardized requirements, authors were free to develop their manuscripts as they saw fit. Some provided more detail than others and some provided additional faunal analyses. Together these papers provide a comprehensive overview of the state of knowledge of terrestrial arthropod biodiversity in Canada, and the body of work is analyzed and summarized in an included synthesis paper.

Some groups that were included in Canada and its insect fauna were excluded from the current work, namely tardigrades (water bears), which are not arthropods, and crustaceans. Terrestrial and freshwater crustaceans were covered in two chapters in Danks (1979), Pentastomida and Crustacea, but as the vast majority of crustaceans are marine, this subphylum will be treated in a future volume that includes all other animals in Canada.

It is expected that this work will serve multiple purposes. There is cause to celebrate as our knowledge of the Canadian terrestrial arthropod fauna has advanced significantly over the last 40 years, although not equally so for all groups. There are clearly more decades of focused work required before our fauna is documented well, i.e., on par with the state of knowledge for most European countries, but we expect that this assessment will have immediate value to support our national requirement of reporting on the status of biodiversity in Canada. We hope that the analyses of gaps and needs will help to guide decision-makers who have a mandate to document, report on, and preserve Canadian biodiversity so that future resourcing will be appropriately invested for maximum benefit. Finally, this work represents a marvelous example of the collaborative spirit that is alive and well amongst biodiversity scientists in Canada. We hope that this will inspire others to come along side and contribute to complete the ambitious Biota of Canada publication series.

The strategic direction of this project was guided by the Biota of Canada Editorial Board (Robb Bennett, Jeremy deWaard, José Fernández-Triana, Rémi Hébert, David Langor, Jade Savage, and Cory Sheffield). The editors would like to thank Jeremy deWaard for reviewing or providing data for the DNA barcode portions of almost all papers and the staff of Pensoft, particularly Yordanka Banalieva, Plamen Pankov, and Veselin Kostadinov for their highly competent help in the review and publication process. The entire authorship team thanks the many expert reviewers who provided valuable feedback that improved individual papers and hence the work as a whole. Funding for the publication of this work was provided by the home institutions of authors as well as by the BSC.

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EDITORIAL

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Le biote du Canada: les arthropodes terrestres

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Cet ouvrage est dédié aux visionnaires qui ont conçu et créé

la Commission biologique du Canada.

Il y a quarante ans, un groupe de scientifiques visionnaires, principalement composé d'entomologistes et d'arachnologues, a entrepris un ambitieux projet visant à produire la monographie *Canada and its insect fauna* (Danks 1979). Cette publication historique a été le remier grand ouvrage scientifique réalisé par la Commission biologique du Canada (CBC) peu de temps après sa création. Hugh V. Danks était responsable de la coordination de la vaste équipe et de l'ambitieux plan de travail ainsi que de l'édition de la publication. La réputation de Hugh pour sa rigueur scientifique, son sens de l'organisation, son souci du détail et son esprit de synthèse est légendaire et inspirante. Ses qualités se sont révélées essentielles au succès du projet. En 573 pages imprimées, cette équipe de 60 spécialistes a examiné les tendances et les déterminants de la diversité régionale, les habitats des insectes aquatiques et terrestres, les méthodes de documentation de la faune ainsi que le statut de chaque groupe d'arthropodes terrestres au Canada. Le reste appartient à l'histoire! La publication constitue la référence pour la science de la biodiversité au Canada depuis quatre décennies. L'ouvrage intégral et ses chapitres individuels ont été cités des milliers de fois, ce qui témoigne l'influence notable de cette publication au Canada et ailleurs. En outre, *Canada and its insect fauna,* tout comme les nombreuses autres publications de la CBC qui ont suivi sur près de quatre décennies, prouve que de grandes réalisations peuvent être accomplies par des communautés d'individus dévoués, compétents et passionnés ayant la volonté de surmonter des obstacles institutionnels parfois contraignants afin de réaliser quelque chose de remarquable et de durable. Cette approche scientifique exceptionnelle continue à définir la CBC.

Même après près de 40 ans, le contenu de *Canada and its insect fauna* est extrêmement précieux. Néanmoins, une partie du contenu des 39 chapitres relatifs à la faune, notamment les informations contenues dans les tableaux, devait être mise à jour afin de tenir compte des progrès réalisés depuis 1979. Ainsi, la CBC a commencé à planifier un projet de mise à jour de ces chapitres en 2016. On s'est cependant vite rendu compte que la nécessité de réévaluer l'état des connaissances sur la diversité des espèces au Canada dépassait le cadre des arthropodes terrestres pour couvrir l'ensemble du biote, la dernière évaluation ayant été publiée en 1995 (Mosquin et al. 1995). Un certain nombre d'autres organismes ont été consultés et ont approuvé le concept d'une nouvelle évaluation de la biodiversité pour le Canada. Le projet Biota of Canada a donc été lancé dans le but de passer en revue et d'évaluer l'état des connaissances sur la biodiversité de tous les groupes d'organismes au Canada en publiant une série de volumes. Les arthropodes terrestres constituaient un point de départ évident pour élaborer la «démonstration de faisabilité», puisque le 40^e^ anniversaire de la CBC approchait à grands pas et ce travail d'envergure devait servir à commémorer l'occasion.

Un comité de rédaction a été mis sur pied au sein de Biota of Canada afin d'élaborer des lignes directrices relatives à la préparation des manuscrits et de garantir une approche normalisée des sujets traités et des données fournies. Soutenu par un ensemble de «directives aux auteurs» et un exemple de manuscrit à distribuer aux auteurs potentiels, le processus de recherche des auteurs principaux s'est déroulé de manière remarquablement fluide. Presque tous les auteurs initialement sollicités ont accepté de se joindre à l'équipe de rédaction, ce qui montre à quel point le projet Biota of Canada était perçu comme ayant une grande valeur. La rédaction de la plupart des manuscrits a été dirigée par des spécialistes travaillant dans des établissements canadiens, mais il n'existait aucun expert canadien actuel ou disponible pour dix groupes d'organismes; des experts ont donc été recherchés et retenus dans d'autres pays (Chine, Norvège, États-Unis, République tchèque). Ainsi, Biota of Canada est un effort international.

Tous les auteurs ont été invités à examiner l'état des connaissances sur la diversité de leur taxon au Canada, en portant une attention particulière aux progrès réalisés depuis la publication de *Canada and its insect fauna* (1979). Chaque auteur a été chargé de produire un tableau fournissant pour chaque famille les informations suivantes sur la faune canadienne: le nombre d'espèces signalées en 1979, le nombre d'espèces décrites actuellement connues, le nombre de DNA Barcode Index Numbers (BINs; Ratnasingham et Hebert 2013) attribués aux spécimens canadiens figurant dans la base de données Barcode of Life Datasystems (BOLD; Ratnasingham et Hebert 2007), le nombre d'espèces supplémentaires qui devraient éventuellement être découvertes au Canada, leur répartition générale par écozone (Gouvernements fédéral, provinciaux et territoriaux du Canada 2010), et toute importante source d'information ayant fait progresser notre compréhension de la faune depuis 1979. Les auteurs ont également été invités à souligner les lacunes et les occasions importantes en matière de connaissance de la faune canadienne. Au-delà de quelques exigences normalisées, les auteurs étaient libres de rédiger leurs manuscrits comme il leur semblait approprié. Certains ont fourni plus de détails que d'autres ou des analyses zoologiques supplémentaires. Ensemble, ces documents offrent un aperçu complet de l'état des connaissances sur la biodiversité des arthropodes terrestres au Canada. L'ensemble des travaux est analysé et résumé dans un document de synthèse inclus.

Certains groupes inclus dans *Canada and its insect fauna* ont été exclus des travaux en cours, à savoir les tardigrades (oursons d'eau), qui ne sont pas des arthropodes, et les crustacés. Les crustacés terrestres et d'eau douce ont été traités dans deux chapitres de Danks (1979) intitulés «Pentastomida» et «Crustacea»; cependant, comme la grande majorité des crustacés sont marins, ce sous-phylum sera traité dans un futur volume incluant tous les autres animaux du Canada.

Cet ouvrage devrait servir à plusieurs fins. Il y a lieu de se réjouir que nos connaissances sur la faune d'arthropodes terrestres au Canada aient considérablement progressé au cours des 40 dernières années, quoique de façon inégale pour certains groupes. Il est clair que plusieurs décennies de travail ciblé seront nécessaires avant que notre faune soit bien documentée, c'est-à-dire comparable à l'état des connaissances de la plupart des pays européens. Nous nous attendons toutefois à ce que cette évaluation ait une valeur immédiate pour appuyer notre exigence nationale de production de rapports sur de la biodiversité au Canada. Nous espérons que les analyses des lacunes et des besoins contribueront à guider les décideurs dont le mandat est de documenter et de préserver la biodiversité canadienne et d'en faire rapport afin que les ressources futures soient investies de manière appropriée pour en maximiser les avantages. Enfin, ce travail représente un merveilleux exemple de l'esprit de collaboration bien vivant parmi les scientifiques œuvrant dans le domaine de la biodiversité au Canada. Nous espérons que cela inspirera d'autres à contribuer à compléter la série de publications ambitieuses de Biota of Canada.

Le comité de rédaction de Biota of Canada (Robb Bennett, Jeremy deWaard, José Fernández-Triana, Rémi Hébert, David Langor, Jade Savage et Cory Sheffield) a guidé l'orientation stratégique de ce projet. Les rédacteurs tiennent à remercier Jeremy deWaard d'avoir révisé ou fourni les données de codes à barres d'ADN pour presque tous les articles ainsi que le personnel de Pensoft, en particulier Yordanka Banalieva, Plamen Pankov et Veselin Kostadinov, pour leur grande aide dans le processus de révision et de publication. Toute l'équipe de rédaction remercie les nombreux réviseurs experts pour leurs précieux commentaires qui ont permis d'améliorer les articles individuels et, de ce fait, le travail dans son ensemble. Le financement de la publication de ce travail a été fourni par les établissements respectifs des auteurs ainsi que par la CBC.

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REVIEW ARTICLE

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The diversity of terrestrial arthropods in Canada

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Abstract

Based on data presented in 29 papers published in the *Biota of Canada* Special Issue of ZooKeys and data provided herein about Zygentoma, more than 44,100 described species of terrestrial arthropods (Arachnida, Myriapoda, Insecta, Entognatha) are now known from Canada. This represents more than a 34% increase in the number of described species reported 40 years ago (Danks 1979a). The most speciose groups are Diptera (9620 spp.), Hymenoptera (8757), and Coleoptera (8302). Less than 5% of the fauna has a natural Holarctic distribution and an additional 5.1% are non-native species. A conservatively estimated 27,000–42,600 additional species are expected to be eventually discovered in Canada, meaning that the total national species richness is ca. 71,100–86,700 and that currently 51–62% of the fauna is known. Of the most diverse groups, those that are least known, in terms of percent of the Canadian fauna that is documented, are Acari (31%), Thysanoptera (37%), Hymenoptera (46%), and Diptera (32–65%). All groups but Pauropoda have DNA barcodes based on Canadian material. More than 75,600 Barcode Index Numbers have been assigned to Canadian terrestrial arthropods, 63.5% of which are Diptera and Hymenoptera. Much work remains before the Canadian fauna is fully documented, and this will require decades to achieve. In particular, greater and more strategic investment in surveys and taxonomy (including DNA barcoding) is needed to adequately document the fauna.

Keywords

Arachnida, biodiversity assessment, Biota of Canada, checklists, Entognatha, Hexapoda, Insecta, Myriapoda, surveys, taxonomy, Zygentoma

Introduction

During the last glacial maximum, approximately 21,400 years ago, most of Canada was covered by ice sheets. Small glacial refugia that existed in Beringia and on offshore islands (Roberts and Hamann 2015), in the Cypress Hills of Alberta and Saskatchewan (Pielou 1991), and possibly in what is now northern British Columbia (Marr et al. 2008), contained some species that persisted during glaciation, but the vast majority of the species now living on land and in freshwater in Canada recolonized the area from the un-glaciated south (Matthews 1979). In addition, thousands of non-native species, mainly from Europe and Asia, were later unintentionally or intentionally introduced to North America subsequent to European colonization and are now established in Canada (e.g., Langor et al. 2009, 2014, Klimaszewski et al. 2010; D Langor unpubl. data). Thus, most habitats of Canada are relatively new and most of the resident biota emigrated from the south under warming post-glacial conditions, so there has been little time for speciation to occur in Canada. Given this biotic colonization history, the overall diversity of species is much lower in Canada than further south (Danks and Smith 2017). Nonetheless, the diversity of species that reside in Canada is impressive, especially for terrestrial arthropods.

Herein, the grouping 'terrestrial arthropods' includes the subphylum Hexapoda (insects and relatives), the class Arachnida (spiders, mites, and relatives), and the subphylum Myriapoda (centipedes, millipedes, and relatives). Together these groups account for approximately 53% of the known species in Canada (excluding viruses), including estuarine and marine habitats (Table 1; Mosquin et al. 1995, CESCC 2016). Terrestrial arthropods are present in all parts of Canada's landmass, except that which is permanently covered by snow and ice, and typically dominate in terms of species and trophic diversity. Despite their prevalence and importance, as a group, terrestrial arthropods are poorly known in Canada in terms of diversity and distribution, and detailed biology is known for only a tiny portion of the fauna.

The publication of *Canada and its insect fauna* (Danks 1979a) was a landmark for biodiversity science in Canada as it represented the first attempt to synthesize the state of knowledge about insect and other terrestrial arthropod diversity, distribution, and habitats in the country. Building in part upon Munroe (1956), Hugh Danks and his team of 60 authors synthesized a remarkable breadth and depth of knowledge in their review of: patterns of regional diversity in Canada; environmental and geological determinants of terrestrial arthropod habitats; and the diversity, distribution, and biology of each major terrestrial arthropod group in the country. Also remarkable is the fact that this work was accomplished without the benefits of personal computers, the Internet, and email.

The monograph, *Canada and its insect fauna*, has been highly influential and valuable to subsequent generations of scientists interested in the diversity of terrestrial arthropods (and biodiversity in general) in Canada. While the work still has enormous value, some parts, especially the chapters treating individual faunal groups, require updating as there has been enormous progress in the documentation of the Canadian fauna during the last 40 years. To address this need, in 2016, the Biological Survey of Canada (www.biologicalsurvey.ca) initiated a project to update the individual faunal chapters. This resulted in 29 papers that comprise the bulk of this Special Issue of ZooKeys, titled *The Biota of Canada – A Biodiversity Assessment. Part 1: The Terrestrial Arthropods* (Langor and Sheffield 2019), and those papers cover all terrestrial arthropod groups except the order Zygentoma (formerly called Thysanura). Zygentoma was not treated in a separate Biota of Canada paper because no authority could be found to lead it; however, the diversity of this order is briefly reviewed in Appendix I. Herein, I summarize and integrate the information and data presented in the Biota of Canada papers, highlight trends and patterns, and provide a future outlook.

Species diversity and faunal affinity

Current diversity

Authors of all Biota of Canada papers were asked to provide data that were current at time of writing (late 2017 to 2018) rather than relying solely on the most recent published checklist. The sources of these data are included in individual papers. The total numbers of species currently known from Canada for each group (Table 1) were extracted from those papers, with the exception of the Zygentoma (Appendix I). For all groups, only the number of described species (not subspecies) currently recorded from Canada are included in the tally. These totals were reported by family in each individual paper but were totalled mainly at the order and higher levels herein (Table 1), with the exceptions that the former orders Psocoptera and Phthiraptera are now considered to be part of the Order Psocodea (see discussion in Anonby 2019).

The total number of described species currently recorded from Canada is 44,103 with 88.3% represented by insects, 10.3% by arachnids, 1.1% by entognathous hexapods, and 0.3% by myriapods (Table 1). Remarkably, the proportional representation by these four faunal groups in Canada is similar to that for the global terrestrial arthropod fauna of ca. 1.2 M described species (global calculations based on data from Zhang (2011, 2013), from references provided within the other papers in the Biota of Canada issue, and from many other sources). For terrestrial arthropods, the described Canadian fauna represents 3.7% of the known global fauna. The six most diverse terrestrial arthropod groups in Canada are Diptera (21.8% of total Canadian fauna), Hymenoptera (19.9%), Coleoptera (18.8%), Lepidoptera (12.4%), Hemiptera (9.1%), and Acari (6.8%).

Change since 1979

Before comparing current described species diversity (Table 1) to that reported in Danks (1979b), it was necessary to adjust the earlier reported species numbers to correct some errors and inconsistencies that have recently come to light (see footnotes

Table 1. Diversity of terrestrial arthropods in Canada.

Taxon	Adjusted no. described species known in Canada in 1979	No. species currently known in Canada	Percent change since 1979	Percent (no.) non-native species	Est. no. undescribed or unrecorded species in Canada	Percent of Canadian fauna known	Information sources
Class Arachnida							
Order Araneae	1249[1]	1477	18.3%	5.5% (81)	300–350	81–83%	R Bennett et al. 2019; R Bennett pers. comm.
Order Opiliones	47	43	-8.5%	16.3% (7)	22	66%	Schultz 2019
Order Pseudoscorpiones	5	25	500.0%	4.0% (1)	27	48%	Cameron and Buddle 2019
Order Scorpiones	1	1	0	0	0	100%	Cameron and Buddle 2019
Order Solifugae	1	3	300.0%	0	4	43%	Cushing and Brookhart 2019
Subclass Acari	1917[2]	2999	56.6%	?	6629	31%	Beaulieu et al. 2019
Total Arachnida	**3220**	**4548**	**41.2%**	**5.7% (89)[3]**	**6982–7032**	**39%**	
Subphylum Myriapoda							
Class Chilopoda	30	54	80.0%	31.5% (17)	40	57%	Langor et al. 2019
Class Diplopoda	47	66	40.4%	31.8% (21)	29	70%	Langor et al. 2019
Class Pauropoda	0	23	–	17.4% (4)	17	58%	Langor et al. 2019
Class Symphyla	1	2	100.0%	100.0% (2)	7	22%	Langor et al. 2019
Total Myriapoda	**78**	**145**	**85.9%**	**30.3% (44)**	**93**	**61%**	
Subphylum Hexapoda							
Class Entognatha							
Subclass Collembola	195[4]	470	141.0%	?	180–204	70–72%	Turnbull and Stebaeva 2019; M Turnbull pers. comm.
Order Diplura	2	6	300.0%	?	10–12	33–38%	Sikes 2019
Order Protura	3	9	300.0%	?	10	47%	Sikes 2019
Total Entognatha	**200**	**485**	**142.50%**	**?**	**200–226**	**68–71%**	
Class Insecta							
Order Archaeognatha[5]	3	8	167.7%	25.0% (2)	8	50%	Bowser 2019
Order Zygentoma[6]	3[7]	4	33.3%	100.0% (4)	4	50%	Sweetman and Kulash 1944; Appendix I
Order Ephemeroptera	301	335	11.3%	0	66	84%	Jacobus 2019
Order Odonata	194	214	10.3%	0	15	93%	Cannnings 2019
Order Plecoptera	250	267	6.8%	0	34	89%	Kondratieff et al. 2019
Order Orthoptera[8]	205[9]	235	14.6%	4.3% (10)	15	94%	Miskelly and Paiero 2019
Order Phasmida[10]	1	1	0	0	1	50%	Miskelly and Paiero 2019
Order Dermaptera	5	6	20.0%	66.7% (4)	0	100%	Miskelly and Paiero 2019
Order Grylloblattodea[11]	2	2	0	50.0% (0)	2	50%	Schoville 2019

Taxon	Adjusted no. described species known in Canada in 1979	No. species currently known in Canada	Percent change since 1979	Percent (no.) non-native species	Est. no. undescribed or unrecorded species in Canada	Percent of Canadian fauna known	Information sources
Order Blattodea[12]	14	18	28.6%	50.0% (9)	6–8	69–75%	Miskelly and Paiero 2019
Order Mantodea[12]	3	3	0	66.7% (2)	1	75%	Miskelly and Paiero 2019
Order Hemiptera	3079	4011	30.3%	10.1% (405)	589	87%	Foottit et al. 2019
Order Thysanoptera	102	147	44.1%	19.0% (28)	255	37%	Foottit and Maw 2019
'Psocoptera'[13]	72	108	50.0%	15.7% (17)	67	62%	Anonby 2019
'Phthiraptera'[14]	362	463	27.9%	8.9% (41)	361[15]	56%	Galloway 2019a
Order Hymenoptera	6028[16]	8757	45.3%	4.6% (402)[17]	10,366–10,391	46%	A Bennett et al. 2019
Order Coleoptera[18]	6742	8302	23.1%	7.7% (639)	1078–1284	87–89%	Brunke et al. 2019
Order Strepsiptera[18]	6	27	333.3%	0	19	59%	Straka 2019
Order Raphidioptera	7	8	14.3%	0	4	67%	Blades 2019c
Order Neuroptera	75	101	34.7%	6.9% (7)	>48	<68%	Blades 2019b
Order Megaloptera	16	18	12.5%	0	7	72%	Liu 2019
Order Diptera	7056[19]	9620	36.3%	1.5% (147)[17]	5205–20,458	32–65%	Savage et al. 2019
Order Mecoptera	22	25	13.6%	0	>18	<58%	Blades 2019a
Order Siphonaptera	151[20]	154	2.0%	3.9% (6)	23	87%	Galloway 2019b
Order Lepidoptera	4107[21]	5455	32.8%	3.8% (207)	1400	80%	Pohl et al. 2019
Order Trichoptera	546	636	16.7%	0	129–181	78–83%	Sheffield et al. 2019
Total Insecta	**29,352**	**38,925**	**32.6%**	**5.0% (1931)**	**19,721–35,259**	**52–66%**	
Total Terr. Arthropods	**32,850**	**44,103**	**34.3%**	**5.1% (2064)[22]**	**26,990–42,604**	**51–62%**	

[1]Dondale (1979) reported 1256 species but later discovered an enumeration error; thus the 1979 number should have been 1249 (R Bennett et al. 2019). [2]The total for 1979 included both described and undescribed species and it is not possible to now determine the proportion that represented described species. Furthermore, in 1979, 1915 species were reported but this excluded two additional species mentioned in footnotes but not captured in the tally. See Beaulieu et al. (2019) for more details. [3]Acari were excluded from the calculation of percent of Arachnida that is non-native. [4]Richards (1979) estimated the number of Collembola species that should occur in Canada at 520. He did not do a tally based on available data. However, Christiansen and Bellinger (1980-81) reported 195 species from Canada and this more closely reflects the known species in 1979 so is used as an approximation of the known diversity at the time. [5]Archaeognatha was called Microcoryphia in 1979. [6]Zygentoma was called Thysanura in 1979. [7]Although only two species of Zygentoma were reported by Tomlin (1979), a third species was known from Canada but the record was missed by Tomlin (see details in Appendix I). [8]Includes Grylloptera which was recognized as a separate order in 1979. [9]The total number of Orthoptera + Grylloptera species reported in 1979 was 217; however, this likely included subspecies. The number of species was revised downward to 205 to represent known species at the time (see Miskelly and Paiero 2019). [10]Phasmida was called Cheleutoptera in 1979. [11]Grylloblattodea was called Notoptera in 1979. [12]Blattodea was called Dictyoptera (misspelled Dictuoptera) in 1979, and then included the Mantodea which is now a separate order. [13]Psocoptera is no longer considered an order but is now recognized as part of the order Psocodea, but it is herein reported on separately. [14]In 1979, there were two orders of lice recognized, Phthiraptera and Mallophaga. Currently all lice are placed in Phthiraptera which is now considered a part of the order Psocodea, but is herein reported on separately. [15]Galloway (2019a) did not estimate undescribed species. This number represents described species likely to be in Canada but yet undocumented. [16]Masner et al. (1979) neglected to include ca. 80 species of Eurytomidae known at the time; however, this omission is roughly balanced by the apparent overestimate of the number of species of Platygastroidea, Ceraphronoidea, Bethylidae, and Pompilidae because undescribed species were included for all of those groups (A Bennett et al. 2019). Thus, it is assumed that the total number of species actually known at the time was coincidentally close to that reported (6028) despite the enumeration errors. [17]Counts of non-native species for Diptera and Hymenoptera are based on information extracted from primary literature and in consultation with taxonomists. This information resides in an unpublished database (D Langor unpubl. data). [18]In 1979, Coleoptera included what is now the order Strepsiptera. [19]In 1979, 7058 species were reported from Canada but there was an addition error. [20]Revised downward from 180 species reported by Holland (1979) as his tally included subspecies and taxa from Greenland (see Galloway (2019b) for more details). [21]Revised downward from 4692 species reported by Munroe (1979) as his estimates included enumeration errors (see Pohl et al. (2019) for details). [22]Acari and Entognatha were excluded from the calculation of percent of terrestrial arthropods that is non-native.

of Table 1 for the details of adjustments). Danks (1979b) reported 33,577 terrestrial arthropod species from Canada, excluding Tardigrada, Pentastomida, and terrestrial Crustacea, which were covered in the earlier work but not herein. The adjusted total of 32,850 described species known in 1979 (Table 1) is still somewhat inflated as the 1915 species of Acari reported then (Lindquist et al. 1979) included both described and undescribed species, but it is not possible to now adjust this number downward to accurately reflect only described species known at the time (see Beaulieu et al. 2019).

The number of described terrestrial arthropod species in Canada is now at least 11,250 (34.3%) more than that known in 1979. The groups with the greatest growth in number of described species are Hymenoptera (2729 spp.), Diptera (2564), Coleoptera (1560), Lepidoptera (1348), Acari (>1082), and Hemiptera (932). In terms of proportional growth in described species, the groups (all of them with relatively low diversity) showing the largest increases are Pauropoda (no species reported in 1979, currently 23 spp.), Pseudoscorpiones (500% increase, currently 25 spp.), Strepsiptera (333%, 27 spp.), Diplura (300%, 6 spp.), Protura (300%, 9 spp.), and Solifugae (300%, 3 spp.). Most of the groups showing little or no increase in described species during the last 40 years are small groups (<25 species in Canada); however, notably the Siphonaptera (154 spp. currently known from Canada) show only a 2.0% increase in described species, despite considerable work on this group during the last 40 years, indicating that the fauna was already well documented by 1979 (Galloway 2019b).

Proportion of North American fauna in Canada

Approximately 37% of the described terrestrial arthropod fauna of North America north of Mexico occurs in Canada (estimate is based on data extracted from sources used in papers in Langor and Sheffield (2019), from authors directly via personal communications, and from other sources). The groups with the highest proportion of the known North American fauna present in Canada are: Ephemeroptera (51.1%; Jacobus 2019), Siphonaptera (50.8%; Galloway 2019b), Hymenoptera – Ichneumonidae + Braconidae + Chalcidoidea (48.3%; A Bennett pers. comm.), Odonata (45.8%; R Cannings 2019 pers. comm.), and Diptera (43.3%; Savage et al. 2019; A Borkent pers. comm.). Groups that have predominantly southern distributions in North America and have a low percentage of their fauna present in Canada include Scorpiones (1.1%; http://www.angelfire.com/tx4/scorpiones/states.html), Solifugae (1.5%; Cushing and Brookhart 2019), Diplura (3.5%; Sikes 2019), Diplopoda (4.4%; Langor et al. 2019), and Pseudoscorpiones (4.8%; Cameron and Buddle 2019).

Holarctic species

The large majority of the Canadian fauna is restricted to the Nearctic; however, there is also a significant proportion that has a naturally Holarctic distribution. While the

Holarctic component cannot be readily calculated for the entire fauna, it is relatively well known for some large groups: Lepidoptera – 4.8% (Pohl et al. 2019), Coleoptera – 5.1% (Bousquet et al. 2013), Hemiptera – 4.3% (E Maw pers. comm.), and Ichneumonoidea (Hymenoptera) – <5% (A Bennett pers. comm.). The Holarctic portion of the fauna is remarkably similar among these four highly diverse groups. In contrast, 21.9% of the 471 species of Collembola known from Canada have Holarctic distributions although it is not currently possible to discern what proportion of those are non-native versus naturally Holarctic (M Turnbull pers. comm.). Overall, we estimate that <5% of the total native Canadian terrestrial arthropod fauna is Holarctic. As more taxonomic revisions are undertaken that consider the Holarctic fauna, it will likely be discovered that for many groups some putative Nearctic species are synonymous with species described in the Palaearctic, thereby increasing the number of Holarctic species. Furthermore, other species currently considered Holarctic will likely to be discovered to be sibling species, one Palaearctic and one Nearctic, thereby decreasing the number of Holarctic species. Thus, the actual proportion of the fauna that is naturally Holarctic is likely slightly different from that currently estimated.

Non-native species

Many non-native terrestrial arthropod species have been introduced to Canada since the time of European colonization, most of them inadvertently and some intentionally, e.g., for biocontrol (Langor et al. 2009). The authors of most Biota of Canada papers considered and reported on the proportion of the fauna that is non-native. Two notable exceptions are the Diptera and the Hymenoptera. For these orders, the tally of known non-native species is based on information gathered from published literature and from consultation of taxonomists (D Langor unpubl. data); however, this database has not been updated since 2015 so it is likely that the numbers of non-native species are slightly under-estimated. In total, 2064 non-native terrestrial arthropod species (excluding Entognatha and Acari) are known from Canada and this represents ca. 5.1% of the total fauna (Table 1). The groups with the most non-native species are Coleoptera (639 spp.), Hemiptera (405 spp.), Hymenoptera (402 spp.), Lepidoptera (207 spp.), and Diptera (147 spp.). The groups with the highest proportion of their described fauna that is non-native are Zygentoma (100%), Dermaptera (67%), Mantodea (67%), and Blattodea (50%); these are mostly groups (with the exception of Mantodea) that have strong association with human dwellings, and many species have been transported around the world by human activities. For two groups, Acari and Entognatha, it is not yet possible to obtain good estimates of numbers of non-native species in Canada. The distribution of Entognatha (primarily soil-dwelling species and dominated by Collembola) is poorly understood and there are still serious gaps in taxonomy and distribution that prevent a meaningful assessment of which of the apparent Holarctic species are naturally Holarctic versus introduced. In the case of Acari, most groups are so poorly known in terms of taxonomy, distribution, biology, and phylogeny, that a meaningful analysis of geographic affinity cannot yet be undertaken (Beaulieu et al. 2019). The number of non-native parasitic Hymenoptera species is likely greatly underestimated, especially those that were intentionally introduced for the purposes of biocontrol as historical records are not complete (A. Bennett et al. 2019). For most groups of terrestrial arthropods it is likely that additional non-native species already occur in Canada or may soon spread to Canada from established populations in the northern contiguous USA. Undoubtedly some species currently believed to be non-native may prove to have natural Holarctic distributions; however, it is conceivable that more than 2500 non-native terrestrial arthropod species are already established in Canada.

DNA barcodes

One of the most significant scientific developments in biodiversity science since 1979, that is now greatly helping the process of documenting Canada's (and the world's) biota, is the use of DNA characters. Thus, in the current assessment of Canada's terrestrial arthropod diversity, genetic data have been reported and used to estimate species diversity (Table 1). For animals, the utility of mitochondrial DNA, particularly the COI region (cytochrome c oxidase subunit I) as a source of taxonomically-relevant characters was already well recognized and exploited by the mid-1990s (e.g., Langor and Sperling 1995, Sperling and Hickey 1995). Folmer et al. (1994) first called attention to a 658-bp region of COI that had high phylogenetic value for resolving species and higher taxonomic levels across a wide variety of metazoan invertebrates, and they developed a set of universal primers for polymerase chain reaction amplification of the region. This so-called 'Folmer region' was later promoted in the 'DNA barcode' concept of Hebert et al. (2003) and is now the focus of most global barcoding efforts for metazoan animals. Thus, the advent of DNA barcoding and the enormous strides in genomics methods and data management and analyses has greatly enhanced the collection and utilization of genetic data for the purposes of taxonomy, diagnostics, and phylogenetics (Wilson et al. 2017). Due to the rapidly increasing availability of molecular data, especially in the barcode region, taxonomic and phylogenetics publications are increasingly integrating both morphological and molecular data to address questions. As of November 2018, the Barcode of Life Data System (BOLD; Ratnasingham and Hebert 2007) contains more than 6.6 million barcodes worldwide and 1.9 million are from terrestrial arthropods collected in Canada (A Telfer pers. comm.).

An algorithm was developed to group DNA barcodes with high similarity into clusters, forming Operational Taxonomic Units that are assigned unique and persistent Barcode Index Numbers (BINs; Ratnasingham and Hebert 2013). BINs have high concordance with species in most groups (Ratnasingham and Hebert 2013), although amongst terrestrial arthropods the standard barcode region is sub-optimal for species resolution in Odonata (Rach et al. 2017) so BINs have relatively low concordance with odonate species in Canada (Cannings 2019). In other groups as well, there are cases where valid species share BINs and other cases where a single species may have several

Table 2. Number of Barcode Index Numbers (BINs; Ratnasingham and Hebert 2013) reported for terrestrial arthropods in Canada and the percent of families with assigned BINs. Data were extracted from each of the faunal papers published in Langor and Sheffield (2019) (see Table 1 for references for each taxon). BIN data were originally obtained from the Barcode of Life Data System (www.boldsystems.org).

Taxon	No. families with described species	Percent (no.) of families with BINs	No. BINs available for Canadian species	Ratio of BINs to described species
Class Arachnida				
Order Araneae	45	91%	1623	1.10
Order Opiliones	9	89%	64	1.78
Order Pseudoscorpiones	8	75%	46	1.84
Order Scorpiones	1	100%	1	1.00
Order Solifugae	1	100%	1	0.33
Subclass Acari	269	67%	7462	2.49
Total Arachnida	**333**	**71%**	**9197**	**2.02**
Subphylum Myriapoda				
Class Chilopoda	8	63%	60	1.11
Class Diplopoda	18	72%	65	0.98
Class Pauropoda	2	0%	0	0.00
Class Symphyla	2	100%	4	2.00
Total Myriapoda	**30**	**67%**	**129**	**0.89**
Subphylum Hexapoda				
Class Entognatha				
Subclass Collembola	23	74%	1265	2.69
Order Diplura	2	50%	6	1.00
Order Protura	2	50%	3	0.33
Total Entognatha	**27**	**70%**	**1274**	**2.63**
Class Insecta				
Order Archaeognatha	2	100%	10	1.25
Order Zygentoma	1	100%	2	0.50
Order Ephemeroptera	21	67%	328	0.98
Order Odonata	10	90%	150	0.71
Order Plecoptera	9	100%	166	0.62
Order Orthoptera	12	75%	157	0.67
Order Phasmida	1	100%	1	1.00
Order Dermaptera	3	100%	4	0.67
Order Grylloblattodea	1	100%	1	0.50
Order Blattodea	5	80%	13	0.72
Order Mantodea	1	100%	2	0.67
Order Hemiptera	86	80%	3275	0.82
Order Thysanoptera	6	67%	338	2.30
'Psocoptera'	18	100%	162	1.50
'Phthiraptera'	15	47%	13	0.03
Order Hymenoptera	83	90%	18,454	2.11
Order Coleoptera	120	87%	5750	0.69
Order Strepsiptera	5	80%	3	0.11
Order Raphidioptera	2	100%	10	1.25
Order Neuroptera	10	80%	141	1.40
Order Megaloptera	2	100%	10	0.56
Order Diptera	117	94%	29,583	30.75
Order Mecoptera	4	100%	24	0.96
Order Siphonaptera	7	43%	22	0.14
Order Lepidoptera	81	95%	5842	1.07
Order Trichoptera	25	92%	610	0.96
Total Insecta	**647**	**87%**	**65,071**	**1.67**
Total Terr. Arthropods	**1037**	**81%**	**75,671**	**1.72**

BINs (e.g., Foottit et al. 2008, Davis and Landry 2012, Prous et al. 2017, Zahiri et al. 2017). Nonetheless, BINs are generally highly representative of species diversity: for example, in Lepidoptera, BINs have ca. 93% congruence with named species (deWaard et al. 2011, Zahiri et al. 2017), in Quediina (Coleoptera: Staphylinidae) there was 92% congruence between BINs and named species (Brunke et al. 2019), and in Araneae BINs were able to discriminate 98% of 1018 Canadian species (Blagoev et al. 2016), which indicates the high value of DNA barcodes for providing taxonomic resolution.

More than 75,000 BINs have been assigned to terrestrial arthropod specimens from Canada, 86% of which are from insects (Table 2). The groups with the highest number of BINs assigned are Diptera (39.1% of total), Hymenoptera (24.4%), Acari (9.9%), Lepidoptera (7.7%), and Coleoptera (7.6%). At the other extreme, there are no barcodes from Canadian specimens of Pauropoda despite 23 known species from the country (Langor et al. 2019). The vast majority of BINs from terrestrial arthropods have family-level assignments. Of 1037 families with described species in Canada, 81% have associated BINs based on Canadian material (Table 2). Almost all families lacking BIN data from Canada are represented by 1–5 species and are uncommonly encountered. The percent of families with assigned BINs is highly variable across groups; the lower end of the range includes Pauropoda (0%), Siphonaptera (43%), Phthiraptera (47%), Diplura (50%), and Protura (50%). Groups with ≥10 families that have a high percentage of families with assigned BINs include Psocoptera (100%), Lepidoptera (95%), Diptera (94%), Trichoptera (92%), Araneae (91%), and Odonata (90%).

The association of BINs with known morphological species is ongoing and progress is highly variable from group to group. In most groups there are still many BINs that have not been assigned to species. The percent of described species in the Canadian fauna that currently have associated BINs is also highly variable amongst groups and has not been calculated for many groups. Of the moderately-to-highly diverse groups, at one extreme 92% of the described Araneae (1477 species) have associated BINs (R Bennett et al. 2019) while at the other extreme only ca. 10% of described Acari (2999 species) have associated BINs (Beaulieu et al. 2019). DNA barcode data have proven to be highly informative to resolve taxonomic issues (e.g., cryptic species, synonymy) and phylogenetic relationships (e.g., Hebert et al. 2004, Hajibabaei et al. 2007); however, as this database expands and is explored in detail (e.g., association of BINs with putative morphological species), its value as a tool to enhance documentation of the Canadian fauna will continue to grow rapidly.

Distribution

Although documentation of the composition of the terrestrial arthropod fauna of Canada is an enormous challenge, understanding the geographic distribution of each species within the country poses an even greater challenge. Many species recorded from Canada are known from only one or a few localities, and this is a reflection of several compounding factors: the large size of the country, much of which is difficult to access (e.g., northern areas, alpine and subalpine habitats); the relatively sparse dis-

Figure 1. Terrestrial ecozones of Canada as included in the Canadian Biodiversity Ecosystem Status and Trends 2010 report (Federal, Provincial, and Territorial Governments of Canada 2010). [Reprinted with permission from Environment and Climate Change Canada]

tribution of historical biological survey activities across the country, with the highest concentration in southern regions; and the relatively small number of people trained to expertly identify collected material resulting in enormous backlogs of unidentified material in practically every terrestrial arthropod collection in the country. Despite the challenges of understanding the distribution of species, Canada and its 13 provincial/territorial jurisdictions are required to report on the conservation status of its native biota every five years, and this requires knowledge about which native species occur in each jurisdiction and how widespread each species is within the jurisdiction (CESCC 2016). However, for the Biota of Canada publication (Langor and Sheffield 2019), where species diversity is reported at the family level, and therefore geopolitical affiliations are not so important, authors were asked to report distribution at the ecozone level as this is more ecologically meaningful. Ecozone designations and boundaries, as depicted in the Ecosystem Status and Trends Report (Federal, Provincial, and Territorial Governments of Canada 2010; Fig. 1), were chosen as the ecological template on which to describe family distributions in the Biota of Canada report. This map reflects the spatial representation of ecozones in Canada the last time that biodiversity in the country was assessed at a national level. In general, the distributions of families are relatively well known compared to those of species; however, even at the family level there are many uncertainties about distribution.

Conservation

At the time that *Canada and its insect fauna* was written, initiatives focused on species at risk and conservation were in their infancy in Canada. The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) was formed in 1977 but it was not until 2003 that the Species at Risk Act (SARA) was passed and COSEWIC was designated as the national body for identifying and assessing species status. Originally, COSEWIC's mandate covered only vertebrates and vascular plants, but this expanded in 1994 to cover other groups, including Lepidoptera, and again expanded in 2003 to include other arthropods (Government of Canada 2017). COSEWIC's designations, which are not by themselves legally binding, are taken into consideration by the Government of Canada in establishing the legal list of Species At Risk. As of 2017, 68 terrestrial arthropod species and subspecies (67 insects and one spider) have COSEWIC status in Canada (Table 3): four are extirpated, 42 are endangered, eight are threatened, and 15 are of special concern (one species is listed as endangered in one jurisdiction and of special concern in another). Half of the taxa are Lepidoptera (34) and the remainder are Coleoptera (10), Hymenoptera (9), Odonata (8), Orthoptera (3), Diptera (2), Hemiptera (1), and Araneae (1). Fifty species or subspecies have been designated under SARA as 'Species At Risk', including one species that was designated 'not at risk' by COSEWIC (Table 3).

The Canadian Endangered Species Conservation Council's National General Status Working Group (NGSWG), which has representation from all provincial and territorial governments in Canada as well as the federal government, plays a major role in evaluating and prioritizing species to recommend to COSEWIC for consideration (although recommendations may also come from other sources). The NGSWG engages experts in Canada to consider all available scientific evidence and use an objective process developed by NatureServe (www.natureserve.org) to assess the conservation status of species within each province and territory and in Canada as a whole. Every five years starting in 2000, the NGSWG has assessed the conservation status of many species for each province and territory and published its Wild Species report. In the most recent report, *Wild Species 2015* (CESCC 2016), the following terrestrial arthropod groups were assessed: Araneae, Ephemeroptera, Odonata, Plecoptera, Orthoptera, Neuroptera, Coleoptera, Lepidoptera, Trichoptera, some Hymenoptera, Mecoptera, and some Diptera (Table 4). In that report, 18,692 terrestrial arthropod species and subspecies were assessed, 17,734 of which were native taxa. Of the native taxa (species and subspecies), one was presumed 'extirpated', 37 (0.2%) were considered 'possibly extirpated', 177 (1.0%) were designated 'critically imperiled', and 261 (1.5%) were designated 'imperiled'. Of these 476 taxa, 53 were categorized as 'most at risk' and these represent taxa that have high priority for consideration by COSEWIC. Almost 50% of native taxa assessed had insufficient data to allow conservation ranks to be assigned. Among these unranked taxa there are likely many additional species at high risk, especially those that could have highly specialized habitats and very limited distributions, but their poor representation in collections limits ability to assess them according to current methods.

Table 3. Species and subspecies of terrestrial arthropods designated by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and those listed as 'at risk' under the Species At Risk Act (SARA). Data were extracted from the database maintained by Government of Canada (2018).

Species	Higher classification	COSEWIC status	Designation status by SARA	Historical Range of occurrence[1]
Nicrophorus americanus (Olivier)	Insecta: Coleoptera: Silphidae	extirpated	extirpated	ON, QC
Callophrys irus (Godart)	Insecta: Lepidoptera: Lycaenidae	extirpated	extirpated	ON
Lycaeides melissa samuelis (Nabokov)	Insecta: Lepidoptera: Lycaenidae	extirpated	extirpated	ON
Euchloe ausonides insulanus (Guppy & Shepard)	Insecta: Lepidoptera: Pieridae	extirpated	extirpated	BC
Cicindela marginipennis Dejean	Insecta: Coleoptera: Carabidae	endangered	endangered	NB
Cicindela parowana wallisi Calder	Insecta: Coleoptera: Carabidae	endangered	endangered	BC
Cicindela patruela Dejean	Insecta: Coleoptera: Carabidae	endangered	endangered	ON, QC
Coccinella novemnotata Herbst	Insecta: Coleoptera: Coccinellidae	endangered	no status	AB, BC, MB, ON, QC, SK
Sanfilippodytes bertae Roughley & Larson	Insecta: Coleoptera: Dytiscidae	endangered	endangered	AB
Brychius hungerfordi Spangler	Insecta: Coleoptera: Haliplidae	endangered	endangered	ON
Efferia okanagana Cannings	Insecta: Diptera: Asilidae	endangered	endangered	BC
Bombus affinis Cresson	Insecta: Hymenoptera: Apidae	endangered	endangered	ON, QC
Bombus bohemicus (Seidl)	Insecta: Hymenoptera: Apidae	endangered	endangered	all but NU
Epeoloides pilosulus (Cresson)	Insecta: Hymenoptera: Apidae	endangered	endangered	NS
Erynnis martialis (Scudder)	Insecta: Lepidoptera: Hesperiidae	endangered	no status	MB, ON, QC
Erynnis persius persius (Scudder)	Insecta: Lepidoptera: Hesperiidae	endangered	endangered	ON
Hesperia colorado oregonia (Edwards)	Insecta: Lepidoptera: Hesperiidae	endangered	no status	BC
Hesperia dacotae (L.)	Insecta: Lepidoptera: Hesperiidae	endangered	endangered	MB, SK
Hesperia ottoe (Edwards)	Insecta: Lepidoptera: Hesperiidae	endangered	endangered	MB
Oarisma poweshiek (Parker)	Insecta: Lepidoptera: Hesperiidae	endangered	threatened	MB
Plebejus saepiolus insulanus Blackmore	Insecta: Lepidoptera: Lycaenidae	endangered	endangered	BC
Satyrium behrii (Edwards)	Insecta: Lepidoptera: Lycaenidae	endangered	endangered	BC
Satyrium semiluna Klots	Insecta: Lepidoptera: Lycaenidae	endangered	endangered	AB, BC
Anarta edwardsii (Smith)	Insecta: Lepidoptera: Noctuidae	endangered	no status	BC
Copablepharon fuscum Troubridge & Crabo	Insecta: Lepidoptera: Noctuidae	endangered	endangered	BC
Copablepharon longipenne Grote	Insecta: Lepidoptera: Noctuidae	endangered	endangered	AB, MB, SK
Papaipema aweme (Lyman)	Insecta: Lepidoptera: Noctuidae	endangered	endangered	ON
Pyrrhia aurantiago (Guenée)	Insecta: Lepidoptera: Noctuidae	endangered	no status	ON
Schinia avemensis Dyar	Insecta: Lepidoptera: Noctuidae	endangered	endangered	AB, MB, SK
Schinia bimatris Harvey	Insecta: Lepidoptera: Noctuidae	endangered	endangered	MB
Coenonympha nipisiquit McDunnough	Insecta: Lepidoptera: Nymphalidae	endangered	endangered	NB, QC
Danaus plexippus (L.)	Insecta: Lepidoptera: Nymphalidae	endangered	special concern	all but NT, YT
Euphydryas editha taylori (Edwards)	Insecta: Lepidoptera: Nymphalidae	endangered	endangered	BC
Prays atomocella (Dyar)	Insecta: Lepidoptera: Plutellidae	endangered	no status	ON
Prodoxus quinquepunctellus (Chambers)	Insecta: Lepidoptera: Prodoxidae	endangered	no status	AB

Species	Higher classification	COSEWIC status	Designation status by SARA	Historical Range of occurrence[1]
Tegeticula corruptrix Pellmyr	Insecta: Lepidoptera: Prodoxidae	endangered	endangered	AB
Tegeticula yuccasella (Riley)	Insecta: Lepidoptera: Prodoxidae	endangered	endangered	AB
Apodemia mormo (Felder & Felder)[2]	Insecta: Lepidoptera: Riodinidae	endangered	endangered	BC
Hemileuca nuttallii (Strecker)	Insecta: Lepidoptera: Saturniidae	endangered	no status	BC
Hemileuca sp.	Insecta: Lepidoptera: Saturniidae	endangered	endangered	ON
Somatochlora hineana Williamson	Insecta: Odonata: Corduliidae	endangered	endangered	ON
Gomphus ventricosus (Walsh)	Insecta: Odonata: Gomphidae	endangered	endangered	NB
Phanogomphus quadricolor (Walsh)	Insecta: Odonata: Gomphidae	endangered	endangered	ON
Stylurus amnicola (Walsh)	Insecta: Odonata: Gomphidae	endangered	endangered	ON
Stylurus laurae Williamson	Insecta: Odonata: Gomphidae	endangered	no status	ON
Stylurus olivaceus (Selys)	Insecta: Odonata: Gomphidae	endangered	endangered	BC
Cicindela formosa gibsoni Brown	Insecta: Coleoptera: Carabidae	threatened	threatened	AB, SK
Omus audouini Reiche	Insecta: Coleoptera: Carabidae	threatened	threatened	BC
Bombus occidentalis occidentalis (Greene)	Insecta: Hymenoptera: Apidae	threatened	no status	AB, BC, SK
Lasioglossum sablense Gibbs	Insecta: Hymenoptera: Halictidae	threatened	threatened	NS
Grammia complicata Walker	Insecta: Lepidoptera: Erebidae	threatened	no status	BC
Euphyes vestris vestris (Boisduval)	Insecta: Lepidoptera: Hesperiidae	threatened	threatened	BC
Schinia verna Hardwick	Insecta: Lepidoptera: Noctuidae	threatened	threatened	AB, MB, SK
Trimerotropis huroniana Walker	Insecta: Orthoptera: Acrdidiae	threatened	no status	ON
Gnaphosa snokomish Platnick & Shadab	Arachnida: Araneae: Gnaphosidae	special concern	special concern	BC
Coccinella transversoguttata Faldermann	Insecta: Coleoptera: Coccinellidae	special concern	no status	all jurisdictions
Germaria angustata (Zetterstedt)	Insecta: Diptera: Tachinidae	special concern	special concern	YT
Aflexia rubranura (DeLong)	Insecta: Hemiptera: Cicadellidae	special concern	no status	MB, ON
Bombus occidentalis mckayi Ashmead	Insecta: Hymenoptera: Apidae	special concern	no status	BC, NT, YT
Bombus pensylvanicus (De Geer)	Insecta: Hymenoptera: Apidae	special concern	no status	ON, QC
Bombus terricola Kirby	Insecta: Hymenoptera: Apidae	special concern	special concern	all but NU
Dielis pilipes (Saussure)	Insecta: Hymenoptera: Scoliidae	special concern	no status	BC
Copablepharon grandis (Strecker)	Insecta: Lepidoptera: Noctuidae	special concern	special concern	AB, MB, SK
Limenitis weidemeyerii Edwards	Insecta: Lepidoptera: Nymphalidae	special concern	special concern	AB
Apodemia mormo (Felder & Felder)[2]	Insecta: Lepidoptera: Riodinidae	special concern	special concern	SK
Argia vivida Hagen	Insecta: Odonata: Coenagrionidae	special concern	no status	AB, BC
Ophiogomphus howei Bromley	Insecta: Odonata: Gomphidae	special concern	special concern	NB, ON
Hypochlora alba Dodge	Insecta: Orthoptera: Acrdidiae	special concern	special concern	AB, MB, SK
Melanoplus madeleineae Vickery & Kevan	Insecta: Orthoptera: Acrdidiae	special concern	no status	QC
Polites sonora (Scudder)	Insecta: Lepidoptera: Hesperiidae	not at risk	special concern	BC

[1] Jurisdictional abbreviations are as follows: AB – Alberta; BC – British Columbia; NB – New Brunswick; NS – Nova Scotia; NT – Northwest Territories; NU – Nunavut; MB – Manitoba; ON – Ontario; QC – Quebec; SK – Saskatchewan; YT – Yukon. [2] *Apodemia mormo* (Felder & Felder) is listed twice because of different species designation in BC and SK.

Table 4. Number of species of terrestrial arthropods and their conservation status as assessed by the Canadian Endangered Species Conservation Council's National General Status Working Group in its Wild Species 2015 report (CESCC 2016).

Taxon	No. species assessed	No. native species	Conservation status				No. high priority species	No. with insufficient data
			Extirpated	Possibly extirpated	Critically imperiled	Imperiled		
Araneae	1399	1328	0	0	7	37	4	460
Ephemeroptera	342	342	0	0	1	2	1	266
Odonata	213	212	0	1	11	15	0	4
Plecoptera	293	293	0	0	0	0	0	193
Orthoptera	269	255	0	8	12	12	6	29
Neuroptera	101	95	0	0	0	2	0	73
Coleoptera	7963	7339	0	22	78	53	19	3624
Hymenoptera: Formicidae	212	197	0	2	0	0	0	53
Hymenoptera: Anthophila	805	787	0	0	4	30	3	349
Hymenoptera: Vespidae	101	95	0	0	12	19	0	6
Trichoptera	688	688	0	0	0	1	0	470
Lepidoptera	5257	5066	1	2	33	56	15	3015
Mecoptera	25	25	0	0	1	2	1	8
Diptera: Simuliidae	160	160	0	0	1	4	1	42
Diptera: Culicidae	80	77	0	0	0	0	0	12
Diptera: Tabanidae	144	144	0	1	4	7	0	22
Diptera: Bombyliidae	116	116	0	1	9	6	0	48
Diptera: Syrphidae	524	515	0	0	4	15	3	189
Total	**18,692**	**17,734**	**1**	**37**	**177**	**261**	**53**	**8863**

How many species are in Canada?

It is a common phenomenon that people (usually taxonomists) who make an effort to estimate the number of unknown species within an area tend to be conservative, especially for groups that have large numbers of undocumented species (Danks 1979a). Certainly the vast majority of estimates provided in Danks (1979a) proved to be conservative 40 years later. Thus, many (perhaps most) estimates of undocumented species provided in the Biota of Canada papers (summarized in Table 1) are also conservative, and some authors state this explicitly. Some estimates are given as rounded numbers, some as ranges, some are open-ended (e.g., >48 Neuroptera), but most are given as a specific number. In the latter case, these numbers should not be interpreted as precise but rather as 'reasoned approximations'. For each terrestrial arthropod group, the authors described how the estimates were made, so individual papers should be consulted to understand the estimation processes. In at least two cases (Coleoptera, Diptera), authors consulted broadly among experts to gather a wide variety of opinions. In general, authors considered three main kinds of information/data in formulating estimates: literature records, undescribed material known to them, and BINs. Firstly, based on the published literature (including on-line databases/catalogues) it is evident that there are many species that occur in adjacent parts of the USA but are not yet known from Canada, even though the appropriate habitats/hosts occur here and the climate is suitable. It is anticipated that a large proportion of these species will eventually be discovered in Canada. Furthermore, non-native species that are established in the USA and are evidently spreading towards Canada, and can tolerate the Canadian climate, were also considered. Secondly, for most groups, authors also considered Canadian specimens that they had seen (or were aware of) in collections that likely represent undescribed species. Of course, without taxonomic revisions the number of undescribed species with populations in Canada can only be roughly estimated. Thirdly, given the relatively high concordance between BINs and species for most groups of terrestrial arthropods (see discussion above), authors gave consideration to the discrepancy between number of BINs and number of described species in families where BINs outnumbered known species. While generally every BIN does not represent a unique species, nor does every species have a unique BIN, the degree of concordance between BINs and species within taxon groups (e.g., families) can be used to approximate undocumented species diversity. None of these estimation methods represent an exact science, but together they lend credence to estimates and are therefore of more value than an under-considered guess. Furthermore, the estimates were provided by those who best know the Canadian fauna.

Altogether, an estimated ca. 27,000 to 42,600 additional undocumented terrestrial arthropod species are expected to occur in Canada, meaning that the country is home to between ca. 71,100 and 86,700 species. This is 9–32% higher than the species diversity estimated in 1979 (65,507 species; see Table 1 for adjusted described species totals for 1979 and see Danks (1979a, b) for estimates of undocumented species). Likely, 40 years from now, the experts of the time will see that our most current projections were also underestimates. Between 38% and 49% of the expected Canadian fauna remains undocumented. In 1979, an estimated 50% of the terrestrial arthropod fauna was unknown. Some may be inclined to point out that we may not be much better off now than we were in 1979 in terms of the percentage of our fauna that is documented. However, the fact is that more than 11,200 additional species have been documented from Canada during the last 40 years, a very significant achievement! Furthermore, there has been great advancement in understanding the true diversity of species in our country which has led to the realization that Canada is far more biodiverse than anticipated 40 years ago. The challenge is that there is plenty of work left to do.

Comparison of known (described) species richness to estimated species richness for each terrestrial arthropod group is helpful to understand the relative degree to which taxa are known (Table 1). Among the seven most diverse groups in Canada (groups with >1000 described species), the Acari is most poorly known with less than one third of species described. The percent of described Diptera ranges from 32% to 65%, so in the worse-case scenario flies are about as poorly known as mites; however, unlike the mites the largest proportion (perhaps even the majority) of undocumented flies are in one family [Cecidomyiidae, with 1000 to 16,000 additional species expected (Savage et al. 2019)]. Less than half (ca. 46%) of Hymenoptera in Canada are described. Of the moderately diverse groups (50–1000 species expected in Canada), Thysanoptera (37%) and Phthiraptera (56%) are relatively poorly known. In the case of Phthiraptera the proportion of the fauna that is known as much less than 56% as undescribed species were not estimated by Galloway (2019a) because there was no reasonable way to do so. Several groups with low diversity in Canada (< 50 species expected) are poorly known and most of these represent soil- and litter-dwelling species, including Symphyla (22%), Diplura (33–38%), Solifugae (43%), Protura (47%), Pseudoscorpiones (48%), and Archaeognatha (50%). The best known groups are the Scorpiones (100%, 1 species) and Dermaptera (100%, 6 species), but both have very low diversity and are well surveyed in Canada because they are conspicuous. Among the moderately-to-highly diverse groups, the best known are Orthoptera (94%) and Odonata (93%) which contain mainly large and conspicuous species. Other well-known groups are Plecoptera (89%), Coleoptera (87–89%), Hemiptera (87%), and Siphonaptera (87%). In particular, aquatic groups seem best known and soil- and litter-dwelling groups least known.

Looking to the future

With several tens of thousands of terrestrial arthropod species remaining to be discovered in Canada (many of them requiring description), and the distribution and conservation status of most of the currently documented species poorly known, we cannot rest on the laurels of our collective endeavour over the last four decades. There is much to do before our knowledge about diversity and distribution of the Canadian terrestrial arthropod fauna is as good as that which currently exists for the fauna of western Europe, likely the best documented large-scale regional fauna in the world and representing a state-of-knowledge that is reasonable to aspire towards. There are several key activities that Canada needs to continue investing in to ensure that work on documenting the terrestrial arthropod biota of Canada continues at a pace at least equivalent to that of the last 40 years, and hopefully at a much faster pace given mounting pressures on the environment and its constituent species and ecological communities. These activities are not specific to terrestrial arthropods but are broadly relevant to most groups of biota in Canada. To comprehensively document biodiversity in Canada it is necessary to survey it well throughout the country, continue to build the taxonomic/phylogenetic foundation to define and identify species and their relationships, and manage the wealth of data and information to allow ready access and use, and each of these activities is herein briefly discussed to summarize needs and provide some suggestions. Of course, these activities require financial resources and expertise so biodiversity science stakeholders in Canada must continue to work to ensure that the values and outcomes of these activities are appreciated by society in general and are clearly linked to government priorities and policies to ensure that their relevance is indisputable and that the rationale for investment is irrefutable. This is not a trivial job and will only be sufficiently successful through strategic coordination across the community of stakeholders, and there is much room for improving stakeholder engagement and strategic planning.

Surveys

The immense physical size of Canada and the difficult and expensive access to large portions of the country (e.g., high latitudes and high altitudes) means that the vast majority of survey effort has been done in the south of the country and around major population centers and along major roads further north. This survey bias is exemplified by a map (Figure 2) of 81,555 collection points for the 375 species of Cerambycidae (Coleoptera) in Canada that were extracted from 106 Canadian and USA collections (see list in Bousquet et al. 2017). Even in southern parts of the country, there are habitats that are under-sampled for terrestrial arthropods. Thus, whenever there is concerted survey activity, the results in terms of new jurisdictional records can be astounding. For example, even following many years of sampling of Coleoptera in the Maritime Provinces, over 300 new beetle records were recently reported for New Brunswick (Webster et al. 2016). Similarly, sampling in Newfoundland and Labrador, mainly from 2008 to 2014, resulted in 119 new provincial records, six new Canadian records, and 34 new species of aleocharine rove beetles (Klimaszewski et al. 2011, 2016) and at least 90 new provincial records for other subfamilies of rove beetles (D Langor unpubl. data). As another example, a long-term survey effort in Waterton Lakes National Park since 2005 has resulted in many new Canadian and provincial records and new species of insects (Pohl et al. 2018; G Pohl, J Klimaszewski, and D Langor unpubl. data). Surveys of spiders in British Columbia, including at high elevations, in recent years have resulted in many new Canadian and provincial records (R Bennett et al. 2019). There are many other examples of ongoing short- and long-term surveys in Canada that continue to yield new records of species. However, there are limited resources for surveying and the country is large, so prioritization and increased efficiency of survey effort is needed. Consideration should be given to where survey resources are best invested. Focus on biodiversity hotspots and threatened habitats (e.g., remnants of Carolinian forests and native grasslands), regions where there has been low sampling effort to date (e.g., alpine and subalpine zones, Arctic and Taiga ecozones), and undersampled habitats (e.g., hot springs, soils, saproxylic habitats, bird and mammal nests, and the bodies of vertebrates and invertebrates which are inhabited by many species, especially mites) may yield more value per unit of effort than further investment in surveys in areas and habitats that are relatively well sampled. There ought to be more discussion within the biodiversity community in Canada to prioritize and organize sampling efforts to make most efficient use of limited resources. This may also give direction and encouragement to growing numbers of citizen scientists who have the potential to immensely enhance biological surveys (see below).

In recent years, various survey initiatives have been developed to enhance sampling of biodiversity, including terrestrial arthropods. Since 2008, the Centre for Biodiversity Genomics (University of Guelph) has used its BIObus and teams to visit many biodiversity hotspots in Canada to sample specimens for DNA barcoding, and this effort has yielded hundreds of thousands of specimens and ca. 20,000 species (https://biobus.ca). Each year since 2007, the Alberta Biodiversity Monitoring Insti-

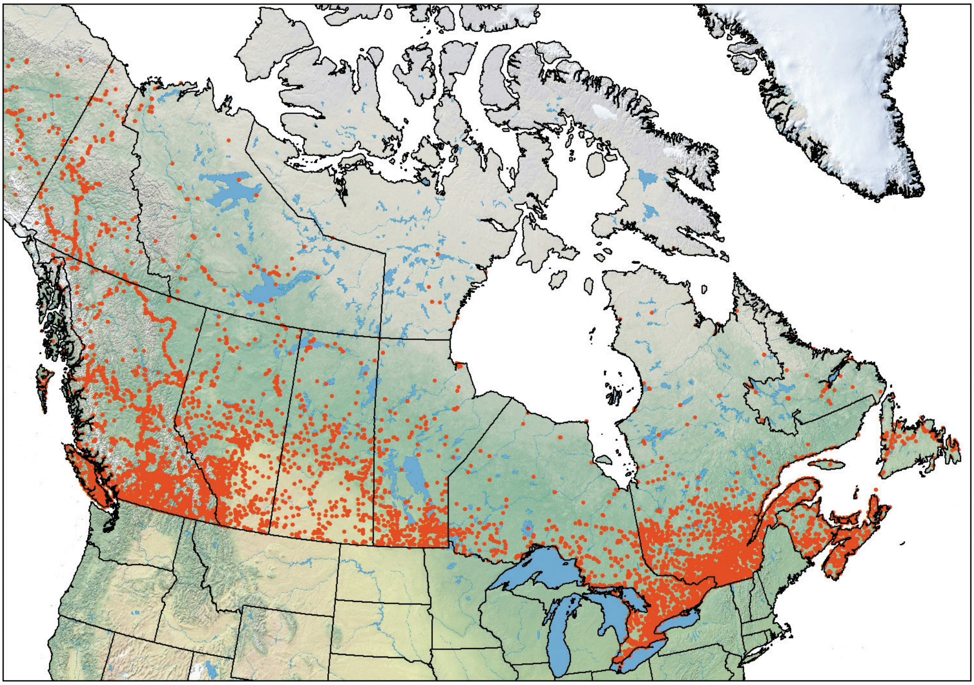

Figure 2. Collection points for the 375 species of Cerambycidae (Coleoptera) in Canada based on 81,555 records extracted from 106 Canadian and USA collections (Bousquet et al. 2017).

tute (ABMI) has systematically surveyed soil fauna across the province on a 20 km × 20 km plot grid, resulting in 400 soil samples each year from which invertebrates were extracted for monitoring purposes (T Cobb pers. comm.). This work has resulted in an enormous amount of information particularly about oribatid mite diversity and distribution (Walter et al. 2014). Furthermore, Bioblitzes have been organized by organizations such as the Biological Survey of Canada (eleven Bioblitzes since 2001; https://biologicalsurvey.ca) and Bioblitz Canada (35 Bioblitzes across the country in 2017 to mark the Canada 150 celebrations; www.bioblitzcanada.ca). Bioblitzes serve to bring together biodiversity experts and members of the public to focus on sampling the biota in a small region during a short period (normally 2–5 days). These have served to enhance surveys of the country's biota, bring attention to the importance of understanding Canada's biodiversity, and foster collaborations between professional biologists, students, and citizen scientists.

Another source of valuable specimens is from trap-based sampling programs established for a specific research or monitoring purpose. Frequently, only a subset of the taxa collected in experiments or for monitoring is utilized and the remainder (often called bycatch or residual) is discarded. Field sampling programs are expensive and often logistically challenging. Therefore, discarded specimens of non-target taxa represent missed opportunities to maximize return on investment, especially when such material is from regions and habitats that are generally poorly sampled. Clearly, saving bycatch has a cost in terms of additional processing time and storage, and when budgets are lean this additional cost can be prohibitive. However, there are also many people who are willing to make an effort to save some bycatch if they know that there is interest in the material by those who will make some effort to prepare and identify it and use the data. Where resource challenges could limit capacity to extract and store bycatch, creative solutions could be found through partnerships between those generating bycatch and those who have interest in it, e.g., through provision of funds for additional costs or in-kind supply of labour, to offset additional processing/storage costs. Opportunities to match supply and demand of bycatch require a communication network that serves as a clearinghouse service that connects people. An organization willing to perform this service could provide added benefit to survey activities in Canada.

Although historically the collection and examination of biological specimens has been the main source of data on presence and distribution of species, and remains the dominant source, increasingly photographs are yielding valuable information about the identity and location of species that on occasion reveals new jurisdiction records. Some of the best known initiatives that crowdsource data from primarily photos are iNaturalist (https://www.inaturalist.org/), which is global in coverage, includes plants, animals and fungi, and has nearly 90,000 users, and BugGuide (https://bugguide.net/node/view/15740) which is North American in scope and focuses on insects and other terrestrial arthropods. There are also initiatives that focus on particular taxa such as moths, e.g., Moth Photographers Group (http://mothphotographersgroup.msstate.edu/) and Mothing and Moth Watching (https://www.facebook.com/groups/137219092972521/). Within Canada there are several similar initiatives that are social-media-based and have much (or almost all) content focused on terrestrial arthropods, e.g., Alberta Bugs and Insects (https://www.facebook.com/groups/782992888444902/), Insects of Newfoundland (https://www.facebook.com/groups/717236451733098/), and NWT Species (https://www.facebook.com/groups/NWTSpecies/). As well, there are email listserves that have a similar purpose, e.g. Albertabugs and Albertaleps, both accessed through the University of Alberta. These initiatives serve two main purposes. First, they promote citizen science by encouraging public curiosity and information sharing and providing them with tangible rewards in terms of feedback from specialists concerning, e.g., identification and biological information. Secondly, on occasion photos reveal new or interesting records or natural history observations. However, identification depends on the quality of the photos and whether the species in question is identifiable based on a habitus, so only a small proportion of photos allow an accurate species determination. Thus, crowdsourcing of data through photographs will continue to provide a relatively small, albeit valuable, contribution to the future documentation of the Canadian fauna. However, through such citizen science initiatives that connect the enthusiastic public with appreciative and encouraging specialists, opportunities are created to encourage and train some 'citizens' to become more involved in surveys through the more traditional and data-rich method of collecting and preserving specimens to submit to specialists for identification. There are now cases where citizens who started as ad hoc sources of insect photos are now regularly collecting specimens that are contributing valuable records (G Pohl pers. comm.). The challenge is to encourage more specimen sampling by non-specialists by increasingly connecting specialists with the willing and capable public in mutually rewarding ways. While there is an investment required from the specialist to engage in training, provide some supplies (at least initially), respond to enquiries, provide identifications, etc., the potential for high return on the investment is excellent. More generally, the participation of enthusiastic specialists in public events such as Bioblitzes, science fairs, public lectures, natural history societies, school presentations, etc., and by creating products that have appeal to the 'nature-curious' public (e.g., field guides, websites, and videos), can potentially increase the participation of the public in natural science activities, including surveying of the biota.

For more than 41 years, the Biological Survey of Canada (BSC) has played important roles in promoting and fostering survey activities for terrestrial arthropods in Canada and synthesizing and distributing biodiversity information. The strength of the BSC is that it does not have institutional or departmental affiliation and therefore is not directed by top-down pressures to adhere to institutional or political agendas. As a network of frontline biodiversity workers, the collective expertise of the BSC self-organizes to focus on activities that fill important gaps in knowledge on Canada's biodiversity. The BSC has rallied resources to focus on specific regions (e.g., Yukon, Haida Gwaii, the Arctic, and Newfoundland and Labrador), habitats (e.g., springs, ectoparasites of vertebrates), biotic communities (e.g., grasslands), and topics (e.g., non-native species) that have helped foster focused survey activities, resulted in significant products (e.g., books, scientific papers, newsletters), and greatly improved the state of knowledge of Canada's terrestrial arthropod biodiversity (see Danks (2017) for the details of some of the accomplishments of the BSC). Particularly remarkable is the fact that in 1979 the BSC successfully engaged the Canadian biodiversity community to review the state of knowledge for terrestrial arthropod diversity in Canada, that resulted in the monograph *Canada and its insect fauna* (Danks 1979b), and is again doing so, 40 years later, through the current Biota of Canada initiative. There remain important roles for the BSC to play in promoting and coordinating national efforts to document the country's biota in partnership with other biodiversity stakeholders. As it has no institutional constraints or political agenda, the BSC is well-placed to serve as a needs-driven, impartial broker and catalyst to continue to provide focus and foster activities on important knowledge gaps concerning the biota of Canada.

Taxonomy, diagnostics, and DNA barcodes

It is relatively easy, in terms of time and skills, to sample huge numbers of terrestrial arthropod specimens, especially using traps; however, it can be very time-intensive to identify them, even for taxa for which modern identification tools exist. DNA barcoding is increasingly helping with the identification process if the specimens are of sufficient quality to barcode and when there are comprehensive barcode libraries. However, DNA barcoding (or molecular approaches in general) is not a replacement for traditional morphology-based taxonomy but rather they are complimentary (Roe et al. 2017). Taxonomy has suffered steep declines in recent years in Canada, especially in universities (Packer et al. 2009, Archambault et al. 2010), which is also the global trend (Kim and Byrne 2006). It is therefore necessary to continue Canadian investment in taxonomy that integrates molecular, morphological, and ecological evidence to distinguish species, organize them within a phylogenetic structure, and develop identification tools (e.g., keys, molecular profiles). Without this, we will never be able to document, understand and protect the enormous biodiversity that surrounds us and on which we depend for environmental services and a sound economy.

Survey activities have resulted in accumulation of specimens in collections at a faster rate than they can be processed and identified to species, especially for groups where there are no Canadian specialists or modern identification tools. Canadian and foreign collections contain huge numbers of Canadian specimens that are not prepared or are identified only to genus or higher levels because there are insufficient people to do authoritative identifications and a lack of modern revisions and identification tools. Undoubtedly, a large proportion of the conservatively estimated 27,000 to 42,600 undocumented terrestrial arthropod species in Canada are already represented by specimens that have been collected and now reside in collections, either in containers of preserved, unprepared material or as prepared and labelled specimens. Furthermore, large numbers of valuable records of documented species, even in groups that are well known and have Canadian specialists and modern identification tools, have not yet been recognized because of the huge backlog in diagnostics. The Canadian taxonomic and diagnostic capacity is simply overwhelmed, and this is especially evident for highly diverse and relatively poorly known groups such as Acari, Diptera and Hymenoptera.

During the last 40 years, between 11,000 and 12,000 terrestrial arthropod species were newly documented in Canada (Table 1). With equivalent effort per unit of time in the future, and given that 27,000 to 42,600 additional species (even the upper limit is likely a conservative estimate) are waiting to be discovered, it will take 90–150 years for the fauna to be documented. Although molecular approaches will increase the rate of documentation of the fauna, it will still be decades before we know the identity of species in the country, let alone know their full distribution, habitat associations, etc. This is sobering, especially against a backdrop of rapid ongoing environmental change that is altering habitats and likely species viability in the country. Do we need to document all taxa and assign species names? Are measures of genetic diversity (e.g., BINs) sufficient for some hyper-diverse groups where there are few specialists and no impetus to study them because they are not sufficiently attractive or have little or no adverse effects on humans (e.g., cecidomyiid flies which have 1000–16,000 undocumented species in Canada)? What are the priorities for taxonomic investment? Should priorities be based mainly (or solely) on importance to agriculture, forestry and health as they are today? Can we better harness the potential of citizen scientists to engage in taxonomic/diagnostic activity? More fundamentally, is the value of documenting and understanding diversity in the natural world, the challenges, and trade-offs sufficiently understood by society, funding agencies, and policy-makers to allow appropriate prioritization and sound investment decisions? All of these and other questions require discussion across the full range of biodiversity stakeholders as we collectively try to find the most efficient way forward to document our Canadian biodiversity.

DNA barcoding has made significant contributions to biosystematics and the documentation of the Canadian biota, and its influence will grow as the DNA barcode reference library grows and more people use it to help reconcile taxonomic problems, improve diagnostic capacity and speed, and understand phylogenetic relationships. Already for terrestrial arthropods there are more than 75,000 BINs based on Canadian specimens, but there remains a large job of reconciling BINs with morphological concepts to understand the degree to which DNA barcodes reflect species and to build comprehensive voucher libraries. Improvement of protocols (e.g., better primers) that increase the success rate of barcoding attempts for certain groups (e.g., Brunke et al. 2019) will provide a better return on barcoding investment. Approaches that allow improved DNA recovery and amplification for older specimens and those collected using suboptimal techniques/preservatives will enhance data accumulation. Currently barcoding efforts have not been evenly distributed across the country and sampling equitability is needed to characterize the Canadian biota and its distribution. Especially promising is the rapid development of next generation sequencing approaches that readily allows sampling of many genes (in organelles and the nucleus) through 'massively parallel sequencing', and which will increase the utility of molecular data in defining species concepts and relationships and providing diagnostic tools (Roe et al. 2017).

Species checklists

The development of species checklists is but one facet of the broader realm of specimen and data management wherein there are other important considerations and needs concerning, e.g., biological collections, data standards, and data mobilization; however, these topics have been well covered elsewhere (e.g., Suarez and Tsutsui 2004, Johnson 2017). The values of species checklists and the particular needs of this activity, however, have not been sufficiently discussed and promoted.

Even though checklists are not included in this Biota of Canada Special Issue, most authors relied upon existing checklists or created their own as a basis for summarizing and analyzing species richness data. It is widely appreciated that species checklists, whether hard copy or electronic in nature, represent a useful means of synthesizing and sharing information about diversity and distribution of species. Since 1979, almost all of the most species-diverse terrestrial arthropod groups have been the focus of cataloguing efforts in Canada that have resulted in national checklists that show jurisdictional distributions and provide current nomenclature and classification, e.g., Maw et al. (2000) for Hemiptera (currently being updated; R Foottit pers. comm.), Paquin et al. (2010) for Araneae (with subsequent updates; see R Bennett et al. (2019) for details), Bousquet et al. (2013) for Coleoptera, Pohl et al. (2018) for Lepidoptera, and A Bennett et al. (in prep.) for Hymenoptera. As well, in recent years, the National General Status Working Group has fostered the development of species lists for several orders of insects, including Ephemeroptera, Odonata, Plecoptera, Orthoptera, Neuroptera, Trichoptera, and Mecoptera as a necessary first step in assessing conservation status of individual species (CESCC 2016). Notably, Acari and Diptera, two of the six largest groups in the country, do not have national or provincial/territorial checklists. The state of knowledge of each these two highly diverse groups is too fragmented and preliminary to yet contemplate production of a national checklist for the entire group, although some portions (e.g., families) of these groups have been catalogued (Beaulieu et al. 2019, Savage et al. 2019).

Checklists of species, whether for a genus, family, order, or class, and whether national in scope or focused on a smaller geographic scale (e.g., province/territory, region, island, ecozone) or habitat, have high value. Checklist development requires synthesis of the body of evidence concerning diversity, classification and nomenclature, and therefore it represents a state-of-knowledge product. As a composite of collective knowledge, the process of creating a checklist tends to rally available expertise to collaborate and consider all available data and information. Checklists also fill federal, provincial and territorial needs as they are required by the NGSWG as the foundational first step in assessing conservation status of species, which is a national obligation. Furthermore, checklists serve to highlight gaps in the state of knowledge that can help prioritize future sampling and taxonomic endeavours. Finally, checklists provide a framework on which to organize new data (e.g., new records, new species, and changes in nomenclature and classification). Having a checklist that is publically available tends to challenge the biodiversity community (both professionals and citizen scientists) to improve on it, and this challenge usually engenders new sampling activity, makes it easy to determine if records are new, and encourages those with new records to make them known.

Checklists are outdated soon after they are published in terms of the included species, jurisdictional distribution, nomenclature, classification, etc. Soon after obtaining a newly published checklist, the knowledgeable user is soon filling the margins with notes concerning new and corrected information, and these notes summed across the community of users represent valuable improvements to the checklist. However, all notes and improvements are not usually available to all other users and thus the improvements of the checklist are not universally available until far into the future (usually decades) when the next edition of the checklist is published. Thus, to keep checklists current they need to be online and dynamic so that as new records (or other changes) are discovered, they are quickly vetted within the community of experts and incorporated. The development of virtual, dynamic checklists/catalogues in which to capture, organize and easily update information about Canada's biota represents an exciting challenge. There are many interesting models already available in Canada and globally that could be emulated or modified, although it is beyond the scope of this paper to review these. The two largest challenges are, firstly, for the community of data suppliers and users to form a consensus on what is needed (content, functionality, etc.) and, secondly, to find the resources to develop and sustain it long term. Without a broad base of support from a diversity of partners, the development and long-term maintenance of dynamic checklists will likely not be sustainable.

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Appendix I

Diversity of Zygentoma in Canada

Tomlin (1979) reported two species from Canada, both of which are non-native, cosmopolitan species that are domiciliary throughout much of the country and considered household pests: the silverfish, *Lepisma saccharina* L., and the firebrat, *Thermobia domestica* (Packard). Tomlin (1979) predicted that another ten species might occur in the country and specifically mentioned two non-native, cosmopolitan species that were possibly established in domiciles in Canada: *Ctenolepiaima urbana* Slasbaugh (now known as *Ctenolepisma longicaudata* Escherich, the grey silverfish) and *Ctenolepiaima quadriseriata* Packard (now known as *Ctenolepisma lineata* (Fabricius), the four-lined silverfish). These two species are now known to be established in Canada.

Sweetman and Kulash (1944) reported *C. lineata* (as *C. quadriseriata*) from "south-central Canada" but no specific localities were given. Numerous specimens of *C. lineata* from southern Ontario occur in the collections of the University of Guelph (S Paiero pers. comm.) and the Royal Ontario Museum (ROM), with the earliest collected in Toronto in 1929 (ROM; B Hubley, pers. comm). Thus, this species is confirmed from

Canada but does not represent a new record as it was reported as early as 1944, but the record was missed by Tomlin (1979). A photograph of what appears to be *C. longicaudata* was taken in Burnaby, British Columbia in 2013 and submitted to iNaturalist (https://www.inaturalist.org/observations/2588314). This species is likely also to occur in southern Ontario and Quebec.

The basis for Tomlin's (1979) estimate of a total fauna of 12 species in Canada is not known. Most of Canada can sustain only indoor populations of Zygentoma, but it is possible that southern parts of Ontario and British Columbia may have free-living species (MG Ricart pers. comm.). It seems unlikely that 12 species occur in Canada as only 18 species are known from North America and most of those have southern distributions (Arnett 2000). There is almost no information or data on which to base an informed estimate of Zygentoma faunal diversity in Canada as only two BINs are available (*Lepisma saccharina*: BOLD:ACB9678; *Thermobia domestica*: BOLD:ACJ0722) and the distribution and identity of species in adjacent parts of the USA is poorly known. Given that ca. 37% of the terrestrial arthropods in North America occur in Canada (see above), based on the currently known North American Zygentoma fauna (18 spp.), seven species would be predicted to occur in Canada. Using a second estimation approach, if it can be assumed that Zygentoma are as well known as Archaeognatha in Canada (50% of species known), then the total Zygentoma fauna is expected to be eight species (i.e., four species remain undocumented).

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Araneae of Canada

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Abstract

In 1979 nearly 1400 spider species in 32 families either had been recorded (1249) or were believed to occur (~140) in Canada. Twenty years later, although significant progress had been made in survey efforts in some regions, Canada's spider inventory had only increased by approximately 7% to roughly 1500 species known or expected to occur. The family count had increased to 38 but only two additions were truly novel (five family additions and one family deletion were the result of advances in family-level systematics). The first comprehensive taxonomic checklist of Canadian spider species was published in 2010 documenting the regional distributions of 1376 species representing 42 families (three novel since 1999). From 2010 through 2017 new national records steadily accumulated resulting in the current (2018) Canadian inventory of 1477 species classified in 45 families (one novel since 2010). Although there has been close to a 20% increase in the number of spider species recorded in Canada since 1979, much greater increases have occurred in some of the regional species checklists, indicating increasing knowledge of the regional distribution of species previously recorded elsewhere in Canada. For example the regional checklists for Newfoundland, British Columbia, and Prince Edward Island have increased by 69%, 339%, and 520%, respectively. The national and regional increases reflect significant advances in the first two decades of the 21st Century in spider faunistics research in previously under-sampled habitats and regions and the development of molecular techniques and consequent barcoding of spiders. Of the 1477 species recorded in Canada, 92% have been successfully DNA barcoded resulting in 1623 unique Barcode Index Numbers (BINs). At least 25 of the BINs are associated with relatively easily distinguished but undescribed morpho-species. The majority, however, appear to indicate the existence of many cryptic species within Canada's known spider fauna. These data, coupled with the fact that novel Canadian or even Nearctic spider species records (including of undescribed species) continue to accumulate annually (especially in habitat-diverse regions such as British Columbia), suggest that Canada's tally of spider species may approach or even exceed 1800.

Keywords

Araneae, BINs, biodiversity assessment, Biota of Canada, checklist, classification, DNA barcoding, faunistics, spiders

Introduction

Canadian national spider faunistics work commenced with Emerton's (1920) initial listing of the names of and basic locality data for the spider species then known to occur in Canada. Emerton's list was far from complete, reflecting the scant knowledge of Canada's spider fauna at that time. Nearly 60 years later the accumulation of sufficient data allowed production of the first reasonably comprehensive faunistic overview of the spiders of Canada (Dondale 1979). Subsequently, a series of increasingly detailed studies of the fauna has significantly improved the situation. Dondale (1979) provided the initial faunistics framework: a family-level table outlining general distributions and estimated species numbers for each, accompanied by a brief introduction to spiders, Canada's spider fauna, and basic biology of the major families.

Twenty years later, Bennett (1999) supplied a similar table with revised family-level nomenclature and species statistics, as well as more detailed family-level biology and comments on the then-current state of araneology in Canada. Subsequently, Paquin et al. (2010) published a checklist of all spider species found in Canada up to that date including species-level provincial and territorial distributional data, tables with summary family-level statistics, and a list of introduced species.

Most recently, the Canadian Endangered Species Conservation Council (2011, 2016) provided updated species-level checklists, including novel records and nomenclatural changes, as well as national and provincial/territorial conservation ranks for all species using NatureServe distribution and abundance analysis methodology (see Faber-Langendoen et al. (2012) for a description of NatureServe's methodology). Since then, two of us have maintained and updated the Canadian national and regional checklists (R Bennett and G Blagoev unpubl. data, summarised in Table 1). Unsurprisingly, the known Canadian spider fauna has been (and continues to be) dominated by species of Linyphiidae (Table 2).

Prior to 1979, regional spider species checklists existed for only two Canadian regions (Table 3): British Columbia (Thorne 1967, Bragg and Leech 1972) and the island of Newfoundland (Hackman 1954). Species-level data now exist for all Canadian provinces and territories (Table 3; Paquin et al. 2010) and a majority of these have series of three or more checklists showing increases in the accumulation of novel jurisdictional species records of greater than 20% (Alberta, Manitoba, Northwest Territories, Québec, and Yukon), nearly 70% (island of Newfoundland), to well over 300% (British Columbia) or 500% (Prince Edward Island).

Novel species records, including of undescribed species, continue to accumulate annually in Canada especially through the work of the University of Guelph's Centre for Biodiversity Genomics (CBG) at the national level and, regionally, where intensive spider inventory work is on-going, e.g., in British Columbia through the efforts of the Royal British Columbia Museum (RBCM). Ideally, faunistics research generates sufficient distribution and abundance data to allow for conservation ranking analyses. For more than one third of Canada's recorded spider species, however, only simple presence data exists and conservation ranks remain undetermined for those species. It is clear that much work remains to be done on Canadian spider faunistics. Canada's national and provincial/territorial spider species checklists will continue to grow, our knowledge of Canadian spider morphological and molecular taxonomy will continue to improve, and accumulating inventory data will allow for conservation ranking of a significant proportion of Canada's currently unranked spider fauna.

Here we present an overview of Canadian spider faunistics work from 1979 to 2018, focusing on the accumulation of national and regional species-level data. Classification follows Wheeler et al. (2017); nomenclature follows the World Spider Catalog (2018). Standard postal abbreviations are used for Canada's provinces and territories except for LB and NF, which refer to mainland Labrador and the island of Newfoundland, respectively: AB – Alberta, BC – British Columbia, MB – Manitoba, NB – New Brunswick, NS – Nova Scotia, NT – Northwest Territories, NU – Nunavut, ON – Ontario, PE – Prince Edward Island, QC – Québec, SK – Saskatchewan, and YT – Yukon.

In the beginning (Dondale 1979)

Although Emerton (1920) presented a cursory list, including basic locality data, of about 340 spider species then known to occur in Canada, the first serious summary of faunistics of Canada's spider species was published by Dondale (1979). The single table in that paper provided the faunistics framework for future studies of Canada's spider fauna: a list of the 32 families recorded to that date accompanied, for each family, with general Canadian ecological distribution data and the number of species known in Canada. Loxoscelidae (now Sicariidae), a 33rd family listed in the table, was then unrecorded in Canada and has not become established subsequently. Dondale predicted a total of about 1400 species for Canada's spider fauna: 1249 recorded (Table 3; number here revised down from 1256 because of enumeration errors in Dipluridae, Antrodiaetidae, Dysderidae, and Segestriidae (CD Dondale pers. comm.)) with a further 144 either known but undescribed or expected but not yet recorded.

Then, as is typical for the Holarctic region (Coddington and Levi 1991), entelegyne taxa, especially Linyphiidae (including Pimoidae and Dondale's "Erigonidae"), dominated the known Canadian spider fauna (Table 2): 445 of the species recorded (as well as more than half of the expected/undescribed species). Globally common and taxonomically fairly well-studied families accounted for a further 546 species (Table 2)

Table 1. Census of Araneae in Canada. Data as of March 2018 (R Bennett and G Blagoev unpubl. data). Primary references for all family-level and lower taxa are in the World Spider Catalog (2018) and Ubick et al. (2017).

Taxon[1]	No. species currently known from Canada[2]	No. BINs[3] available for Canadian species	Distribution by ecozone[4]
Suborder Opisthothelae			
Infraorder Mygalomorphae			
Superfamily Atypoidea			
Mecicobothriidae	1	1	Pacific Maritime
Antrodiaetidae	4	5	Pacific Maritime, southern Montane Cordillera
Atypidae	1	1	Mixedwood Plains
"Dipluroidea"			
Dipluridae	1	0	southern Montane Cordillera
Infraorder Araneomorphae			
Division Synspermiata[5]			
Superfamily Dysderoidea			
Segestriidae	1	1	southern Pacific Maritime
Dysderidae	1 (1)	2	southern Pacific Maritime, Mixedwood Plains; synanthropic
Oonopidae	2 (2)	0	southern Pacific Maritime, Mixedwood Plains; synanthropic
Superfamily Scytodoidea			
Scytodidae	2 (2)	1	Mixedwood Plains; synanthropic
"Pholcidoidea"			
Telemidae	1	3	Pacific Maritime, Montane Cordillera
Pholcidae	5 (3)	7	southern Montane Cordillera (native spp.); all southern ecozones (synanthropic spp.)
Division Entelegynae			
Superfamily Araneoidea			
Theridiidae	107 (19)	107	all ecozones
Anapidae	1	1	southern Pacific Maritime
Theridiosomatidae	1	2	Boreal Shield, Newfoundland Boreal, Mixedwood Plains, Atlantic Maritime
Araneidae	67 (5)	79	all ecozones
Pimoidae	3	5	Pacific Maritime, southern Montane Cordillera
Linyphiidae	569 (12)	624	all ecozones
Nesticidae	3 (1)	3	Pacific Maritime (native sp.), Mixedwood Plains (native and synanthropic spp.)
Mysmenidae	3	2	southern Pacific Maritime, southeastern Boreal Shield, and Mixedwood Plains
Mimetidae	9 (1)	7	all ecozones except Arctic
Tetragnathidae	26 (2)	72	all ecozones
Superfamily Oecobioidea			
Oecobiidae	2 (2)	0	southern Pacific Maritime, Mixedwood Plains; synanthropic
"Uloboroidea"			
Uloboridae	5 (1)	6	all ecozones south of Boreal Shield, Newfoundland Boreal, and Boreal Cordillera
"Titanoecoidea"			
Titanoecidae	4	4	all inland ecozones
Superfamily Zodarioidea[6]			
Zodariidae	1 (1)	1	southern Pacific Maritime, Mixedwood Plains; synanthropic
"Amaurobioidea"			
Amaurobiidae	14 (2)	13	all ecozones
"Desoidea"			
Desidae	1 (1)	0	Boreal Plains; synanthropic
Superfamily Agelenoidea[7]			
Dictynidae	62 (2)	79	all ecozones
Cybaeidae	22	24	Pacific Maritime, Montane Cordillera, Boreal Shield
Hahniidae	21	34	all ecozones
Agelenidae	20 (4)	15	all ecozones

Taxon[1]	No. species currently known from Canada[2]	No. BINs[3] available for Canadian species	Distribution by ecozone[4]
Superfamily Lycosoidea			
Oxyopidae	2	3	all southern ecozones
Thomisidae	66 (2)	81	all ecozones
Pisauridae	7	8	all ecozones
Lycosidae	104 (2)	103	all ecozones
"Salticoidea"[8]			
Salticidae	124 (7)	126	all ecozones
Philodromidae	47 (3)	54	all ecozones
Corinnidae	8	6	all southern ecozones
Eutichuridae	3 (1)	4	all southern ecozones
Miturgidae	1	1	southern Pacific Maritime, Montane Cordillera
"Anyphaenoidea"			
Anyphaenidae	7	8	all southern ecozones
Clubionidae	34 (2)	35	all ecozones
"Liocranoidea"			
Liocranidae	3	3	all ecozones
"Trochanterioidea"			
Trachelidae	3	6	southern Pacific Maritime, Mixedwood Plains, Atlantic Maritime
Phrurolithidae	16 (1)	14	all southern ecozones
Gnaphosidae	92 (3)	72	all ecozones including southern Arctic
Total	**1477 (81)**	**1623**	

[1]Classification follows Wheeler et al. (2017); taxon names in quotation marks are informal. [2]Parentheses enclose numbers of non-native species included in the total. [3]Barcode Index Number (Ratnasingham and Hebert 2013). [4]See figure 1 in Langor (2019) for a map of ecozones. [5]Haplogynae of older classifications. [6]Zodarioidea and all subsequent groups = "RTA Clade". [7]Dictynoidea of older classifications. [8]"Salticoidea" and all subsequent groups = "Dionycha Clade" (within RTA Clade).

Table 2. Changes in numbers of species for selected spider families in Canada (1979–2018).

Family	1979[1]	1999[2]	2010[3]	2016[4,5]	2018[6]	Increase (decrease)
Theridiidae	93	100	99	102	107	14
Araneidae	69	74	57	58	67	(2)
Linyphiidae	445	>500	527	542	569	124
Tetragnathidae	21	23	25	25	26	5
Thomisidae	63	68	65	65	66	3
Lycosidae	90	110	101	99	104	14
Salticidae	100	110	108	110	124	24
Philodromidae	47	47	48	46	47	0
Gnaphosidae	63	~100	88	90	92	29

[1] Dondale 1979. [2] Bennett 1999. [3] Paquin et al. 2010. [4] Canadian Endangered Species Conservation Council 2016. [5] Based on 2013 data. [6] R Bennett and G Blagoev unpubl. data.

representing, in combination with Linyphiidae, nearly 80% of the Canadian fauna. Species then classified in several other entelegyne families (especially Agelenidae, Dictynidae, Hahniidae, and Clubionidae) covered an additional approximately 15% but, because those families have proven to be non-monophyletic and subsequent species transfers have complicated the picture, family-level data for them from Dondale (1979) are not presented here. Families typical of warmer climates and/or austral regions, especially mygalomorph and synspermiate taxa (Dondale 1979), as well as a handful of entelegyne taxa, were represented by about two dozen species.

In 1979, only two Canadian jurisdictions, BC and NF (Table 3), had spider checklists, and these were not comprehensive for either province. Thorne (1967) listed 212 species in 20 families for BC, subsequently upgraded to 259 species by Bragg and Leech (1972). Thorne noted BC's spider fauna was poorly known and implied that significant increases to the provincial checklist would result from better knowledge, in general, of the province's northern interior and northern and eastern border areas and, in particular, of the province's erigonine linyphiid fauna (see Bennett (2001) for a brief history of araneological work in BC from the late 1800s to 2001). Hackman (1954) documented 216 species (originally 220, revised down by Pickavance and Dondale (2005)) in 19 families for NF. Because his study was based almost entirely upon only two sets of collections made over two summers (1949, 1951) by visiting scientists from Fennoscandia, it is clear that Hackman's (1954) checklist was not comprehensive.

Making progress (Bennett 1999)

Twenty years after Dondale's (1979) treatment of the national fauna, Bennett (1999) updated Canadian family-level spider species statistics. Estimates, rather than exact counts, were made for most of the larger entelegyne families (e.g., Dictynidae – "75–80", Linyphiidae – "> 500") and the total number of species then recorded in Canada was estimated to be approximately 1400 (Table 3). Bennett (1999) speculated that the

Table 3. Changes in Canadian national, provincial, and territorial spider species numbers over time and percent increase since 2010.

Time period	AB	BC	LB	MB	NB	NF[1]	NS	NT	NU	ON	PE	QC	SK	YT	CAN
1950–1979		212[6]				216[20]									
		259[7]													1249[27]
1980–1999		433[8]													
		570[9]		483[18]								549[23]		297[26]	~1400[28]
2000–2010		653[10]										620[24]			
	527[2]	656[11]				363[21]						654[25]			
	601[3]	700[12]	124[3]	531[3]	379[3]	363[3]	437[3]	267[3]	71[3]	746[3]	38[3]	677[3]	489[3]	335[3]	1376[3]
2011–2018		729[13]													**
		780[14]	213[17]												
	628[4]	859[15]	212[4]	605[4]	390[4]	364[4]	446[4]	321[4]	96[4]	757[4]	44[4]	666[4]	490[4]	357[4]	1399[4]
	656[5]	877[16]	*	593[19]	416[19]	*	472[19]	325[19]	98[19]	813[19]	198[22]	691[19]	507[19]	366[19]	1477[19]
% increase since 2010	10%	25%	71%	12%	10%	<1%	8%	22%	4%	9%	521%	2%	4%	9%	7%

[1]Excluding Labrador. [2]Buckle and Holmberg in Pickavance and Dondale 2005. [3]Paquin et al. 2010. [4]Canadian Endangered Species Conservation Council 2016. [5]R Bennett and G Blagoev unpubl. data. [6]Thorne 1967. [7]Bragg and Leech 1972. [8–9]West et al. 1984, 1988. [10]Bennett 2001. [11–16]Bennett et al. 2006, 2010, 2012, 2014, 2017, unpubl. data. [17]Perry et al. 2014, [18]Aitchison-Benell and Dondale 1990. [19]R Bennett and G Blagoev unpubl. data. [20]Hackman 1954 as revised in Pickavance and Dondale 2005. [21]Pickavance and Dondale 2005. [22]Bowden et al. in press. [23]Bélanger and Hutchinson 1992. [24]Paquin and Dupérré 2003. [25]Paquin and Dupérré 2006. [26]Dondale et al. 1997. [27]Dondale 1979 as revised this study. [28]Bennett 1999.

* Current (2018) data combine LB and NF together (total 434 species) and are not easily separable. Increase since 2010 for LB and NF combined = 18%.

** National and provincial/territorial species count data in Canadian Endangered Species Conservation Council (2011) are essentially unchanged from those in Paquin et al. 2010 and are not recorded here.

species count could reach 1500 with concerted inventory work in particular habitats, especially forest floors and canopies. Increases in species counts (Table 2) were, as expected, primarily in Linyphiidae (more than 50 species added) but also in groups that had been subject to significant taxonomic revision since 1979, such as Gnaphosidae (about 40 species added) and Lycosidae (20 species). Species counts for other families were relatively unchanged.

Although Bennett's (1999) checklist recorded 38 spider families in the Canadian fauna, six more than reported by Dondale (1979), only two families, Zoridae and Mysmenidae, were truly novel additions through the discovery of populations in BC of species known to be relatively widespread in the western United States. Five other family additions were not novel but the result, rather, of advances in spider systematics and classification: in Dondale (1979) Cybaeidae was classified in Agelenidae, Liocranidae and Corinnidae in Clubionidae, Titanoecidae in Amaurobiidae, and Pimoidae in Linyphiidae. Dondale's (1979) Erigonidae was not included in Bennett (1999) and subsequent lists because of its reclassification as a subfamily of Linyphiidae.

In the 1980s and 1990s, considerable progress was made on Canada's regional spider checklists (Table 3), a reflection of significant spider inventory work in some regions. BC's spider species count more than doubled to 570 (West et al. 1984, 1988) and initial checklists were produced for MB (483 species; Aitchison-Benell and Dondale 1990), QC (549; Bélanger and Hutchinson 1992), and YT (297; Dondale et al. 1997). As with the earlier checklists for BC and NF, the regional checklists of the 1980s and 1990s were still far from complete and major changes would be made through the next couple of decades.

The recent past (Paquin et al. 2010)

Early in the first decade of the 21st Century, DJ Buckle (pers. comm.) began compiling a checklist including the names and basic regional (Canadian provinces and territories and/or Alaska) presence data for all spider species then recorded in Canada and Alaska. The database was subsequently published (Paquin et al. 2010), making widely available for the first time a reasonably comprehensive Canadian national and regional species-level checklist. Thirty-six of the species were known from Alaska but not from anywhere in Canada (one species in each of Clubionidae and Dictynidae, three in Lycosidae, and 31 in Linyphiidae) and one South American species (Sicariidae, see above) was not established in Canada then and has not become so subsequently. Removing those 37 species from consideration, the 2010 checklist recorded 1376 species (Table 3) representing 42 families in one or more of Canada's provinces and territories. Although this species count was not appreciably different from Bennett (1999), four families were newly recorded by Paquin et al. (2010). Three of these families were first Canadian records of non-native species in Amphinectidae (one species, now classified in Desidae), Oonopidae (two species), and Zodariidae (one species). The addition of a fourth family, Miturgidae, was the result of advances in systematics (transfer of two well-known species from Clubionidae). Among the new introductions, the status of the desid and the oonopids is uncertain. No new records are known since the first (and only) record of the desid in AB in 1991. One of the oonopids has been collected only once, albeit from a natural (but disturbed) outdoor habitat in Victoria BC; the other species is known from a substantial indoor population in Toronto ON (Platnick et al. 2012) and is probably established there. The zodariid is almost certainly an established member of the Canadian fauna; it is now known from relatively natural habitats in southern localities in three provinces (R Bennett and G Blagoev unpubl. data) and appears to be well established in the northern United States (Ramseyer 2016). As in Bennett (1999), family-level species counts in Paquin et al. (2010) showed substantial increases only in Linyphiidae, up about 30 since 1999 (Table 2).

In addition to revising the species names and count data for regions with existing species-level checklists (AB, BC, MB, NF, QC, and YT), a major benefit of Paquin et al. (2010) was the provision of species-level data for those Canadian regions where spider species checklists had not previously existed (Table 3). The low species counts for PE and NU reflected the fact that no serious spider inventory work had yet been done in PE (Bowden et al. in press) and very little in NU (e.g., Leech 1966). The species numbers recorded in 2010 for the remaining "first-time" regions are an indication of substantial spider inventory work in those regions, largely led by CD Dondale and JH Redner of the Canadian National Collection (CNC) but also with significant input of specimens and data from CNC entomologists, Canadian Forest Service researchers, and non-government arachnologists such as DJ Buckle, R Holmberg, and RE Leech.

In the first decade of the 21st Century, Canadian regional spider faunistics work continued to be especially active in BC and QC where, by 2010, both provinces had recorded increases of about 130 species to 700 and 677, respectively (Table 3). In addition, a short burst of intensive spider faunistics work in NF resulted in an increase of more than 150 species for a total of 363 species on the island's spider checklist (Pickavance and Dondale 2005). Based primarily on large numbers of spider specimens collected during research in the 1990s in localised areas of southern and central BC led by DCA Blades (Blades and Maier 1996), GGE Scudder (unpublished), N Winchester (Copley 2010, Copley and Winchester 2010), and BS Lindgren and J Lemieux (Lindgren et al. 1999), Bennett (2001) and Bennett et al. (2006) updated, respectively, the BC spider species count and the checklist of names and locality data. Family and species-level nomenclature in Bennett et al. (2006) were in agreement with current World Spider Catalog (Platnick 2006) standards, thus simplifying tracking of taxonomic synonyms and other nomenclatural changes in preceding and subsequent BC spider checklists. Two of us (R Bennett and C Copley) and D Copley used locality data in Bennett et al. (2006) to map unsampled or poorly sampled regions and habitats in BC and plan a series of annual field surveys, primarily targeting alpine and subalpine habitats across the province, to address the knowledge gap. With support from the RBCM and a wide range of collaborators, these surveys commenced in 2008 and the first two field seasons resulted in the addition of more than 40 species to the known spider fauna of BC (Bennett et al. 2010), some of which were new records for Canada or even the Nearctic.

In QC, the significant efforts of the team of Paquin and Dupérré (2003, 2006) in the field (as well as in examining specimens in the CNC for overlooked new records) were largely responsible for the increases in the list of spider species known in QC.

The current era and into the future (Canadian Endangered Species Conservation Council 2016 and the rise of BINs)

In 2010, using a draft version of the species list in Paquin et al. (2010) as their baseline, attendees at an ad hoc workshop organised by NatureServe Canada produced an initial consensus-based assessment of the national and regional conservation status of all spider species recorded in Canada (Canadian Endangered Species Conservation Council 2011). In 2013, the Canadian Wildlife Service (Environment Canada) began a comprehensive reanalysis of the conservation status data using NatureServe methodology (Faber-Langendoen et al. 2012) and incorporating all available spider species distribution and abundance data as well as the significant number of novel species records that had accumulated since 2010. The results of the analysis included updated national and regional checklists recording 1399 spider species (Table 3) representing 42 families (data current to 2013; Canadian Endangered Species Conservation Council 2016) and, in 2018, this is the contemporary published resource for species-level faunistic data for Canadian spiders. Family number remained unchanged from 2010 although Zoridae was incorporated into Miturgidae and Anapidae was newly recorded for Canada. Notably, the anapid record, *Comaroma mendocino* (Levi), collected in BC, is one of the rarest of all native spider species in North America (see Lopardo and Coddington 2017). New records of Linyphiidae accounted for two thirds of the relatively minor increases in Canada's family-level spider species counts reported in the 2016 publication (Table 2).

Since 2013, i.e., data incorporated in Canadian Endangered Species Conservation Council (2016), new national records have accumulated rapidly. Seventy-eight new species records have been documented from across Canada (with the majority from BC) resulting in the current Canadian inventory of 1477 spider species in 45 families (Table 1). Linyphiid species account for more than one third (27) of the new records (Table 2) but some families which had not seen much change for several decades also show substantial increases, for example araneid and salticid species counts have increased by 9 and 23 (Table 2), respectively. All three of the new family names in Table 1 are the result of recent classification changes: Eutichuridae was previously classified in Miturgidae while Phrurolithidae and Trachelidae were extracted from Corinnidae.

As with previous checklists, the increased species counts largely reflect the continuation of serious regional spider inventory work. However, molecular data have become increasingly important in Canadian spider faunistics and systematics, and the current Canadian spider species checklist (R Bennett and G Blagoev unpubl. data) is the first to benefit from the use of molecular data. The molecular work, led by the CBG, has combined laboratory work with comprehensive sampling of arthropod specimens in a wide variety of often difficult-to-access and/or previously poorly known habitats in

Canada (deWaard et al. 2017). The RBCM has closely collaborated with the CBG since 2012, resulting in large amounts of novel regional as well as national species-level data (Bennett et al. 2017). In particular, molecular data have been critical in the identification of specimens of described species that previously were unidentifiable (or easily misidentified) because of the lack of good morphology-based diagnostic images or reliably identified voucher specimens (e.g., various linyphiid taxa).

More than 50,000 Canadian spider specimens have been analysed in the course of the barcoding work, representing 92% of the 1477 spider species currently recorded in Canada (Table 1; R Bennett and G Blagoev unpubl. data) and generating 1623 individual Barcode Index Numbers (BINs) (Ratnasingham and Hebert 2013). Unsurprisingly, because nearly 40% of all Canadian spider species are linyphiids, nearly one third of the sequenced specimens are Linyphiidae and those specimens account for nearly 40% of the resultant BINs. BINs in excess of known species-level taxon numbers usually indicate the potential for undescribed species and complexes of cryptic species. This is particularly evident among some smaller families (e.g., Telemidae, Theridiosomatidae, Tetragnathidae, and Trachelidae) which have generated 2–3 times as many distinct BINs as there are named species in the Canadian fauna of those families. Such BIN disparity can be particularly striking for individual species. For example, 18 BINs are associated with a single species, *Tetragnatha versicolor* Walckenaer. For this species, the disparity is not a big surprise: *T. versicolor* is well known for its morphological variability and probable masking of a cryptic species complex (Levi 1981). Similarly, 19 and 25 unique BINs have been generated from specimens of *Evarcha hoyi* (Peckham and Peckham) (Salticidae) and *Grammonota angusta* Dondale (Linyphiidae), respectively.

The accumulation of new provincial/territorial records across Canada has been especially impressive for some jurisdictions (Table 3). Most dramatically, the species count for PE increased by 521% between 2010 and 2018. This was almost entirely because of the combination of data accumulated through CBG's national barcoding project (Blagoev et al. 2016, deWaard et al. 2017) and a "BioBlitz" in 2015 targeting PE's previously poorly known spider fauna (Bowden et al. in press). (BioBlitzes, a relatively new faunistics tool, can be important sources of novel data. For example, in 2014 and 2015 the participation of a team of arachnologists in two BioBlitzes in the small area of Ojibway Park in Windsor ON resulted in the addition of twenty new species records (including six new genus records) to the checklist of Canadian spiders.) The annual intensive surveys of alpine and subalpine habitats in BC begun by the RBCM in 2008 have continued and, along with significant input of specimens and data from a wide variety of collaborators, have resulted in a series of provincial checklists documenting a 25% increase in BC's recorded spider fauna between 2010 and the end of the 2017 field season (Bennett et al. 2012, 2014, 2017, unpubl. data). Spider faunistics in northern Canada benefited from intensive surveys at arctic and subarctic sites by S Loboda and C Buddle (McGill University), R Wisseman (Aquatic Biology Associates, Inc., Corvallis), Perry et al. (2014), the CBG, and others; spider species number increases since 2010 of 71% (124 to 212) and 22% (267 to 325) for LB and NT, respectively, are largely the result of that work. The CBG has also continued to support regional work led by others, such as in BC and PE. This has been mutually beneficial, helping the CBG to complete its library of BINs for Canadian spider taxa and the provinces and territories to achieve a more complete understanding of their regional spider faunas.

Summary (and some predictions for the future)

The rate of increase in Canada's spider species count shows little sign of slowing down. In 2018 the count is well beyond the approximately 1400 predicted by Dondale (1979) and is rapidly closing in on Bennett's (1999) estimate of about 1500. For example, consider the case of BC, which has a longer and more consistent history of spider faunistics research than do other regions of Canada (Table 3) and is the nation's most ecologically diverse province (Morrison and Turner 1994). On average, more than 20 species (primarily linyphiids) have been added annually to the BC regional checklist since 2006 (many of the new records are the result of the RBCM's on-going collaboration with the CBG) and more than 70 of the additions to the BC checklist are of species not previously recorded in Canada and, in some instances, the Nearctic (Bennett et al. 2016, 2017). Although the inventory work conducted annually since 2008 by RBCM researchers and their colleagues has resulted in a major increase in the area of BC surveyed for spiders (see fig. 1 in Bennett et al. 2017), habitats in much of the province remain unsurveyed, especially in the province's Boreal Cordillera, Taiga and Boreal Plains, northern Montane Cordillera, and central Pacific Maritime ecozones. Nearly two thirds of all spider species recorded in Canada occur in BC (Table 3). The Nearctic region is home to close to 3800 spider species (Cushing 2018), nearly one quarter of which have been recorded in BC. Clearly, BC is an important region for Nearctic spider diversity and, assuming the RBCM-led work continues, the BC spider species count eventually is likely to exceed 1000, as first predicted by Bennett et al. (2012). Some proportion of those species will be novel Canadian or even Nearctic records. Although other regions of Canada lack BC's complex ecological diversity, with the exception of PE, all have vast amounts of habitat in which the spider fauna has never been surveyed (or only poorly so). Canada's boreal forest, southern hardwood forest, alpine/subalpine, and subarctic tundra habitats are excellent candidates for the discovery of novel regional and national species records given sufficient search effort. As well, provinces sharing borders and particular terrestrial habitats with the United States (e.g., BC's dry southern interior valleys; the southern grasslands of AB, SK, and MB; and southern ON's Carolinian forests and tallgrass prairies) have been the source of novel national species records historically (usually northern range extensions of southern species) and likely will continue to be so in a warming climate.

Finally, DNA barcoding has proven to be an effective complement to classic morphological techniques for identifying spiders and contributing to the advancement of Canadian spider faunistics (Barrett and Hebert 2005, Robinson et al. 2009, Blagoev et al. 2013, 2016, Blagoev and Dondale 2014). At this time the CBG's reference library, BOLD (Ratnasingham and Hebert 2007), contains DNA barcodes for 92% of Canada's 1477 known spider species. Many BINs, appear to reflect cryptic species complexes within well-known taxa (e.g., the example provided by *Tetragnatha versicolor*) but nearly 60 BINs are associated with Canadian taxa that remain unidentified for a variety of reasons. These have interim, temporary names in BOLD and eventually may be matched to named taxa pending sufficient laboratory detective work or future sequence matching. At least 25 of the BINs, however, are associated with species that are clearly new to science – unnamed and undescribed but morphologically easily discernible. For example, during the period 2014 to 2017 many hundreds of specimens of an unidentifiable but morphologically distinctive species of *Perro* Tanasevitch (Linyphiidae) were collected at alpine localities in northern BC and southern YT. DNA barcoding and associated taxonomic detective work at the CBG confirmed that this taxon, although morphologically distinctive and common and abundant in relevant habitat, is a Beringian species new to science. Another example is provided by the first Nearctic records of the Palaearctic genus *Mughiphantes* Saaristo and Tanasevitch (Linyphiidae), an undescribed species initially revealed in 2009 by barcoding of originally unidentifiable specimens from Churchill MB (Blagoev et al. 2013). Subsequent barcoding of further unidentified specimens from other localities has demonstrated that the species is relatively common and widespread in subarctic habitats in AB, BC, LB, MB, NF, QC, and YT.

Future additions to the checklist of Canadian spiders will likely follow the historical precedent shown in Table 2: dominance by linyphiids augmented by new data from difficult groups (e.g., salticids) or emerging from formal taxonomic revisions (e.g., such as occurred with gnaphosids and lycosids between 1979 and 1999). The most recent published estimate for the "actual total" number of spider species in the Canadian fauna (Paquin et al. 2010) is approximately 1720. This is probably a reasonable estimate, given the continuing accumulation of substantial numbers of named species to the checklist of the Canadian spider fauna and of species new to science and awaiting description prior to their addition to the national checklist. However, if most of the excess BINs reflect real but cryptic species, it will not be surprising to see the species count approach or exceed 1800. Tune in again in 20 or 30 years…

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Opiliones of Canada

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Abstract

The taxonomic diversity of the Opiliones fauna of Canada is reviewed and summarised. At present, 36 native and seven non-native species have been documented in Canada using traditional morphological taxonomy, although more than 20 species may remain undiscovered based on species diversity in the adjacent United States and evidence from DNA barcoding. Consequently, the native fauna is yet to be fully explored and the number, distribution and ecological effects of non-native species remain unclear. Until the 1960s, work on the Canadian Opiliones fauna was largely conducted by researchers based outside the country. From that time on, several Canadian workers became active. However, these taxonomists have now retired and no one has assumed their role. Thus, there is a need to invigorate taxonomic research on the harvestmen of Canada and for the production of easy-to-use identification tools for use by non-taxonomists.

Keywords

Arachnida, biodiversity assessment, Biota of Canada, harvestmen, Opiliones

The Opiliones, or harvestmen, encompass over 6600 described species and about 50 families worldwide (Kury 2013), with 42 species representing eight families currently known from Canada (Table 1). Harvestmen are among the most common and visible groups of poorly-studied arthropod, although interest in their biology was recently invigorated by the book *Harvestmen: The Biology of Opiliones* (Pinto-da-Rocha et al. 2007). Harvestman systematics has made significant progress in the last 20 years, after more than a century of neglect. As with many invertebrate groups, the rate of taxonomic progress suffers from a shortage of active taxonomists. This is particularly true in Canada, where the last major Canadian harvestman worker, Robert Holmberg, has retired.

In Danks' seminal survey of Canadian terrestrial arthropods (Danks 1979), Dondale (1979) summarised the status of harvestman systematics in Canada in fewer than 60 words and without literature citations. He suggested that there were approximately 50 species in the country, which may be close to the true total (Table 1). At the time, he judged that taxonomic instability within the order was too great to assign species reliably to families or to other higher taxa. Since then, harvestman taxonomy has improved greatly, although insights from molecular phylogenetic studies continue to inspire reorganisations at the subfamilial, familial, and even subordinal levels (e.g., Hedin et al. 2012, Schönhofer 2013, Groh and Giribet 2015).

The rate of discovering and cataloguing Canadian harvestmen has been a slow and largely international process that has tended to lag behind that of other western countries. The year in which each native species was first recorded, data mined primarily from Cokendolpher and Lee (1993), illustrates several trends. For each of 24 species native to both Canada and the USA, the first record from the USA preceded the first record from Canada by about 60 years; that is, 53.6 ± 37.4 (SD) years (range: 9-149 y). Only two species were discovered first in Canada, with a difference of 34.5 ± 2.1 years. For over a century (1860 to 1966), all first national records in Canada were established by non-Canadian workers, most from the USA (Banks 1902, 1916, Crosby 1907, Davis 1934, Crosby and Zorsch 1935, Bishop 1949), with the remainder based in Europe (Britain: Walker 1860; Germany: Roewer 1910, 1957; Switzerland: Schenkel 1951; Finland: Hackman 1956). Canadian workers mobilised in earnest in the 1960s and 1970s, with notable contributions from Judd (1966–1978) in Ontario and Bragg and Leech (1972) in British Columbia. Harvestman systematics in western Canada continued to benefit from the work of Phillip Bragg, Robert Holmberg and collaborators (Bragg and Holmberg 1974, 2009, Holmberg 1999, Holmberg et al. 1981, Holmberg and Buckle 2004, Holmberg and Cokendolpher 1997). In contrast, the harvestman fauna of the central and eastern provinces has been comparatively neglected. In fact, significant first national records in the east have been made by citizen scientists contributing photos to such web sites as BugGuide (https://bugguide.net), including first national records for *Crosbycus dasycnemus* (Crosby) by Brousseau (2011) and *Leiobunum nigropalpi* (Wood) by Hogue (2015).

The Opiliones are divided into four suborders with the following relationships: Cyphophthalmi, (Laniatores, (Dyspnoi and Eupnoi)). Thus, the current taxonomic hierarchy does not strictly reflect the generally accepted phylogeny. Laniatores, Dyspnoi, and Eupnoi form the clade Phalangida, which is the sister group to Cyphophthalmi, and the Dyspnoi and Eupnoi are united in the Palpatores, which is the sister group to Laniatores (Kury 2018).

The Cyphophthalmi, or mite harvestmen, are not known from Canada, although Bragg and Holmberg (2009) suggested that *Siro kamiakensis* (Newell) and *S. acaroides* (Ewing), with northern Washington populations of the latter now known as *S. boyerae* Giribet & Shear, 2010, might range into southern British Columbia. Global biogeo-

Table 1. Census in Opiliones in Canada.

Taxon[1]	No. species reported in Dondale (1979)[2]	No. species currently known from Canada[3]	No. BINs[4] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[5]	Information sources
Suborder Cyphophthalmi						
Sironidae		0	0	2	Pacific Maritime, Montane Cordillera	Bragg and Holmberg 2009, Giribet and Shear 2010
Suborder Laniatores						
Paranonychidae		2	1	2	Pacific Maritime, Montane Cordillera	Briggs 1971, Shear and Derkarabetian 2008, Bragg and Holmberg 2009, Derkarabetian and Hedin 2014
Travuniidae		0	0	1	Mixedwood Plains	Bishop 1949
Suborder Dyspnoi						
Ischyropsalididae		0	0	1	Pacific Maritime	Bragg and Holmberg 2009, Richart and Hedin 2013
Sabaconidae		3	6	3	Pacific Maritime, Boreal Plain, Boreal Shield?, Mixedwood Plains; Atlantic Maritime	Cokendolpher and Lee 1993, Holmberg 1999, Holmberg and Buckle 2004
Taracidae		5	2	1	Pacific Maritime, Montane Cordillera, Mixedwood Plains	Bragg and Leech 1972, Cokendolpher and Lee 1993, Brousseau 2011, Shear and Warfel 2016
Nemastomatidae		3 (1)	4	1	Pacific Maritime, Mixedwood Plains, Atlantic Maritime	Bragg and Holmberg 2009, Shear 2016
Acropsopilionidae		1	0	0	Mixedwood Plains, Boreal Shield, Atlantic Maritime?	Cokendolpher and Lee 1993, Shultz 2013
Suborder Eupnoi						
Caddidae		1	2	1	Mixedwood Plains, Boreal Shield, Atlantic Maritime	Cokendolpher and Lee 1993, Shultz 2013
Phalangiidae		12 (6)	16	4	all ecozones	Bragg and Holmberg 1974, 2009, Cokendolpher 1981b, 1985 Cokendolpher and Lee 1993, Shear 2016, Cokendolpher and Holmberg in press
Protolophidae		1	2	1	Pacific Maritime	Bragg and Holmberg 2009
Sclerosomatidae		15	31	5	Pacific Maritime, Montane Cordillera, Boreal Plains, Prairies, Boreal Shield, Mixedwood Plains, Atlantic Maritime	Davis 1934, Katayama and Post 1974, Cokendolpher 1981a, Cokendolpher and Lee 1993, Ingianni et al. 2011, Hogue 2015
Total	**47**	**43 (7)**	**64**	**22**		

[1]Classification follows Kury (2013), with subsequent modifications by Schönhofer (2013) and Groh and Giribet (2015). [2]Dondale (1979) did not report the number of species at lower taxonomic levels. [3]Numbers in parentheses represent the number of non-native species included in the total. [4]Barcode Index Number, as defined in Ratnasingham and Hebert (2013). [5]See figure 1 in Langor (2019) for a map of ecozones.

graphic patterns indicate that Sironidae is the only family likely to occur in Canada (Boyer et al. 2007).

The taxonomic diversity of the Laniatores, or armored harvestmen, is very high in the New World tropics and subtropics but diminishes significantly with increasing latitude (Kury 2003). The recently circumscribed Paranonychidae encompass the former triaenonychid subfamilies Paranonychinae and Sclerobuninae and is the only family likely to occur in western Canada. With the synonymisation of *Sclerobunus parvus* Roewer with *Paranonychus brunneus* (Banks) (Shear and Derkarabetian 2008), just two species are known from British Columbia. Two others known from the northern USA might extend into that province as well (Bragg and Holmberg 2009). Bishop (1949) recorded *Erebomaster flavescens* (Cope) (Cladonychiinae: Travuniidae) in southeastern New York, an observation that is often overlooked (e.g., Kury 2003). Given the great distance from its known congeners in the mid-Atlantic and mid-western USA, *Erebomaster* may be more widespread than is currently supposed, and might even range into southeastern Canada.

The morphologically diverse Holarctic suborder Dyspnoi contains three main lineages, Ischyropsalidoidea, Troguloidea, and Acropsopilionidae, with the latter recently transferred from Caddoidea (Eupnoi) (Groh and Giribet 2015). The family-level classification of Ischyropsalidoidea has undergone significant reorganisation (Schönhofer 2013). Sabaconidae now includes only *Sabacon* (not *Taracus*), with *Sabacon* species being widespread in Canada and with barcoding data suggesting the existence of greater species diversity than current taxonomy would suggest (Table 1). The Ceratolasmatidae, erected by Shear (1986), was disbanded and its components transferred to the new family Taracidae (*Crosbycus*, *Hesperonemastoma*, *Oskoron*, *Taracus*) and to the subfamily Ceratolasmatinae (*Acuclavella*, *Ceratolasma*) within the family Ischyropsalididae, which otherwise contains only the European *Ischyropsalis*. Among the four families in Troguloidea, only the Nemastomatidae occur in Canada, specifically the native ortholasmatines, *Dendrolasma* and *Ortholasma*, in British Columbia (Bragg and Holmberg 2009), and the non-native European nemastomatine, *Nemastoma bimaculatum* (Fabricius), in the East (Shear 2016). Only one acropsopilionid species, *Acropsopilio boopis* (Crosby), is known from Canada and no additional species are expected to occur there.

The suborder Eupnoi consists of two superfamilies, the species-poor Caddoidea, and the species-rich Phalangioidea. Caddoidea s. str. (Groh and Giribet 2015) contains one genus, *Caddo*, with two species. *Caddo agilis* Banks is known from southeastern Canada and *C. pepperella* Shear may eventually be found there, given its occurrence in New England and its recent discovery in northern Wisconsin (Shultz 2013). The family-level taxonomy within Phalangioidea is in flux, with three major lineages being relevant to the Canadian fauna: Phalangiidae (25% of known Canadian species), Sclerosomatidae (36% of known Canadian species), and at least one species of Protolophidae (Bragg and Hoffman 2009, Ratnasingham and Hebert 2013: Barcode Index Numbers (BINs) BOLD:ACJ0890, BOLD:ACJ0891). Six phalangiid species are native to Canada: *Mitopus morio* (Fabricius), *Odiellus pictus* (Wood), *Leptobunus borealis* Banks, *Leptobunus parvulus* (Banks), *Liopilio yukon* Cokendolpher, and *Liopilio glaber* Schenkel, and at least six appear to have been introduced from Europe: *Oligolophus tridens* (CL Koch), *Paroligolophus agrestis* (Meade), *Opilio parietinus* (DeGeer), *Phalangium opilio* Linneaus, *Lophopilio palpinalis* (Herbst), and *Rilaena triangularis* (Herbst) (Shear 2016, Cokendopher and Holmberg 2018). The leiobunine Sclerosomatidae are represented by five native genera: *Hadrobunus* (2 spp.), *Leiobunum* (9 spp.), *Leuronychus* (1 sp.), *Nelima* (2 spp.), and *Togwoteeus* (1 sp.).

Increases in the number of species known from Canada are most likely to come from four sources: range extensions into Canada, introductions, taxonomic revisions, and discovery of cryptic species. The discovery of native species already known from the adjacent USA is the most likely source of new Canadian records. Bragg and Holmberg (2009) listed six species currently known in the USA that might extend into British Columbia, although the taxonomy of several species has since changed and a targeted search for northern populations of one was unsuccessful, i.e., *Acuclavella* in Richart and Hedin (2013). An unusually thorough study of harvestman distributions in North Dakota (Katayama and Post 1974) showed *Eumesosoma roeweri* (Goodnight and Goodnight) and *Trachyrhinus* [*T. favosus* (Wood) and/or *T. marmoratus* Banks] (see Cokendolpher 1981) to be present in counties along the USA-Canadian border. This would add two genera and one subfamily (Gagrellinae) to the Canadian fauna. Canada also seems prone to the introduction and establishment of European harvestmen, especially phalangiids (Cokendolpher and Holmberg 2018). The presence of the European *Trogulus tricarinatus* (Linneaus) in New York and Massachusetts (Shear 2016) indicates that a similar introduction could occur in Canada. Taxonomic revisions can also increase or decrease species diversity. Shear and Warfel (2016) recorded two new Canadian *Taracus* species and a new genus, *Oskoron*, that might extend into Canada. Also, an ongoing revision of *Hadrobunus* (Sclerosomatidae) has revealed two species in Ontario (J Shultz unpubl. data), where only one was assumed to exist. On the other hand, in *Leiobunum* (Sclerosomatidae), *L. formosum* (Wood) and *L. nigripes* Weed were found to be junior synonyms of *L. verrucosum* (Wood) (Shultz 2008), which eliminated two nominal species from the Canadian fauna. Finally, genetic diversity revealed by analysis of molecular genetic data, including barcodes (e.g. Ratnasingham and Hebert 2013), may indicate the existence of cryptic species (Table 1).

Progress in the discovery and understanding of harvestman diversity in Canada will require the effort of one or more professional taxonomists to engage in active, modern research on the order. A particularly urgent goal is the production and distribution of accessible and easy-to-use tools for the identification of the harvestmen species known or likely to occur in Canada. The virtual absence of such resources has already had significant negative consequences. For example, of the 64 BINs of Canadian harvestmen in the Barcodes of Life Data systems (BOLD) (Ratnasingham and Hebert 2013), about 25% were considered either "unidentified", although they could be readily identified from photos of voucher specimens (ten BINs), or were identified incorrectly (six BINs). Indeed, the entry for *Leiobunum vittatum* (BOLD:AAM8191) contains no specimens of that species but encompasses at least three morphologically and geographically distinct species of *Hadrobunus*. Lastly, specimens in many BINs are identified to genus or species when, in fact, the photos show either juveniles or otherwise unidentifiable specimens. In some cases, the ambiguous specimens are determined as European adventives that are otherwise unrecorded from Canada, a situation that, if correct, could suggest an early stage in the expansion of a potential invasive species. In fact, results from barcoding based on accurate identifications (BOLD:AAM8194) revealed a previously unknown introduction and expansion of the European *Oligolophus tridens* in Alberta, Saskatchewan and extreme southeastern British Columbia. Clearly, surveys of the harvestman fauna should be undertaken throughout the country to establish the species composition of the native fauna as well as the distribution and environmental impacts of the comparatively numerous species that have been introduced into Canada.

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Pseudoscorpiones and Scorpiones of Canada

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Abstract

Twenty-five species of pseudoscorpions are known from Canada, a five-fold increase since an assessment from 1979. The diversity and distribution of Canadian species are poorly known and at least 27 more species are expected to be found in the country. Currently 46 Barcode Index Numbers are assigned to Canadian specimens, suggesting a high level of undocumented diversity. Only one scorpion species is known from Canada and no other species are expected.

Keywords

Arachnida, biodiversity assessment, Biota of Canada, Pseudoscorpiones, Scorpiones

Pseudoscorpiones

Pseudoscorpions are a group of small (i.e., typically less than 5 mm in length), carnivorous arachnids that have a cryptic nature and are therefore not frequently observed. Thus, pseudoscorpions remain undersampled and understudied globally (Harvey 2002). Harvey's (1990) catalogue was a major contribution for this taxon, and the first cladistics tests of the group, outlining two suborders, 24 families, 425 genera, and 3200 species worldwide, was done by Harvey soon after (Harvey 1992). More recent phylogenetic analyses of pseudoscopions were completed by Murienne et al. (2008). There are estimated to be over 500 species in North America (Harvey 2013).

The online Pseudoscopions of the World catalogue is the updated and comprehensive information source about pseudoscorpions (Harvey 2013).

Little is known about pseudoscorpion distribution, ecology, and taxonomy in Canada (Buddle 2005); however, some advances in knowledge of the Canadian fauna have been made since the group was reviewed by Dondale (1979). Some examples of research on pseudoscorpions in Canada include Koponen's (1994) assessment on the diversity and abundance of this group in Quebec peatlands, work by Koponen and Sharkey (1988) on northern records for some species, taxonomic work by Muchmore (1990, 1996), and ecological research by Buddle (2015). Buddle (2005) published a pseudoscorpion primer, which gives general information about ecology, morphology, collection, status, and distribution, and cites additional key literature about the taxon in Canada. Buddle (2010) published the first photographic key to family and genus for the pseudoscorpions of Canada and adjacent contiguous states of the United States of America.

Dondale (1979) surveyed literature and reported five species of pseudoscorpions from Canada, but he did not report family affiliations. At present, 25 species of pseudoscorpions from nine families occur in Canada, a five-fold increase in species since 1979 (Table 1). Chernetidae presently has the highest species richness in Canada, with eight known species, followed by the families Cheliferidae and Chthoniidae with four each. At least four species are known to be introduced to North America, one of which occurs in Canada, the cosmopolitan *Chelifer cancroides* (L.) (Cheliferidae) typically associated with human dwellings. Two other non-native species, *Roncus lubricus* L. Koch (Neobisiidae) and *Cheiridium museorum* (Leach) (Cheiridiidae), may occur in Canada.

In total, 46 Barcode Index Numbers (BINs) (Ratnasingham and Herbert 2013) have been assigned to Canadian pseudoscorpion specimens (Table 1). While this method of delineating Operational Taxonomic Units must be taken with caution with pseudoscorpions (Arabi et al. 2012), it remains one way to estimate broader taxonomic diversity within this taxon. The families with the most BINs represented are Neobisiidae (18), Chthoniidae (11), and Chernetidae (10) (Table 1). As the number of BINs is almost double the number of documented species, it is possible that many more species remain to be discovered or described in Canada. To estimate the number of undocumented species for each family, we considered BIN data as well as the presence of species in adjacent states of the USA that have not yet been recorded in Canada but are likely to be there. We also recognize that there may be Holarctic species yet to be discovered. Based on these information sources, we estimate at least 27 additional species will be documented in the country, many from the family Chernetidae (Table 1). As an example, although not yet known from Canada, we expect the family Garypinidae to eventually be found given the proximity to localities in the USA. Neobisiidae, and to a lesser extent Chthoniidae, show many more BINs than known species in Canada (Table 1), perhaps suggesting problems with this method for pseudoscorpions (e.g., Arabi et al. 2012). Other possible explanations include: undersampling, the indication that more species are present among collected material than recognized (e.g., cryptic species), and that there may be multiple BINs for a single species. More generally, the discrepancy indicates that these families could be the foci for careful and increased

Table 1. Census of Pseudoscorpiones and Scorpiones in Canada. Information sources are Buddle (2005, 2010).

Taxon[1]	No. species reported in Dondale (1979)[2]	No. species currently known from Canada[3]	No. BINs[4] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[5]
Order Pseudoscorpiones					
Cheiridiidae	?	1	1	0	Prairies, possibly Boreal Plains and others
Cheliferidae	?	4 (1)	3	3	most southern ecozones
Chernetidae	?	8	10	11–15	Taiga Plains, most southern ecozones
Chthoniidae	?	4	11	4	widespread, all southern ecozones
Garypinidae	0	0	0	1	Pacific Maritime, Montane Cordillera?
Larcidae	?	1	0	1	Prairies, Mixedwood Plains, possibly others
Neobisiidae	?	3	18	3	Taiga Plains, Boreal Plains, Boreal Shield, Newfoundland Boreal, Mixedwood Plains
Pseudogarypidae	?	1	0	0	Mixedwood Plains, Atlantic Maritime, possibly others
Syarinidae	?	3	3	0	Mixedwood Plains, Boreal Shield, Boreal Plains, possibly others
Total	**5**	**25 (1)**	**46**	**27**	
Order Scorpiones					
Vaejovidae	1	1	1	0	Prairies, Western Interior Basin

[1]Classification follows that of Harvey (1992). [2]Dondale (1979) did not provide family affiliations. [3]Numbers in parentheses denote numbers of non-native species included in the totals. [4]Barcode Index Number, as defined in Ratnasingham and Hebert (2013). [5]See figure 1 in Langor (2019) for a map of ecozones.

sampling and integrated taxonomic research. As such, estimates of expected number of species for these families are certainly conservative.

Dondale (1979) noted the order as being 'transcontinental' and, although distributions are still poorly known in Canada, the group as a whole is certainly transcontinental with a deep evolutionary history in North America. However, the 'ecological' distribution, and sampling of pseudoscorpions in North America, should indeed reveal that they are found in virtually all habitable space on the continent, perhaps other than the high Arctic. Individuals have been recorded from British Colombia to the Maritimes and Newfoundland as well as from the southern border to 67° N in the Yukon (Buddle 2015). Pseudoscorpions have been recorded in all ecozones, but data deficiency is a problem as known distributions are based on few published records. Therefore, the distributions included in Table 1 are incomplete for most (if not all) families for many reasons, including lack of interest and undersampling. Chernetidae and Neobisiidae are found as far north as the Taiga Plains ecozone. Others, such as Chthoniidae, are mostly recorded from southern ecozones where they are widespread, and survey work in caves may reveal even more species across a range of latitudes.

Although the composition and distribution of the Canadian fauna is better known now than it was in 1979, there are still enormous gaps in our knowledge. Due to their cryptic nature, and sometimes clumped distribution in a habitat, there are seldom systematic collections of pseudoscorpions, and museums have specimens waiting to be sorted and identified. Nonetheless, without directed sampling, especially in some ecozones and habitats, it will be a long time before the faunal composition and distribution is adequately known. As pseudoscorpions are encountered frequently in pitfall traps, Berlese and Tullgren extractions of litter and soil, during rearing from dead wood, in nests, caves, and phoretic on other animals, there are many opportunities to preserve such material for future study, thereby contributing to the body of knowledge specimen by specimen. Moreover, there is a large gap in knowledge of fundamental natural history of pseudoscorpions from Canada, although the foundation for ecological work which was well established by Muchmore (1973) and Weygoldt (1969) remains an important source. There are plentiful opportunities to learn about the ecology of these animals, including what they eat, how they live, and the relationships between pseudoscorpions and other animals (e.g., phoresy). Fundamentally, we need the curious mind to pay attention to these small and marvellous creatures.

Scorpiones

The northern scorpion, *Paruroctonus boreus* (Girard), is the only species of scorpion found in Canada, as reported by Dondale (1979). The species is found in the southern Prairies ecozone in Alberta and Saskatchewan and in the Western Interior Basin ecozone, specifically in the southern Okanagan Valley of British Colombia (Johnson 2004). No other species of scorpion is thought to live in Canada. Canadian specimens of this species have not yet been DNA barcoded.

In southern Alberta, the northern scorpion inhabits dry, eroded riverbed slopes and lives in rock fissures or narrow cavities and emerges at night to hunt (Johnson 2004). The species is not efficiently caught using pitfall traps and is best observed by flipping over stones or dried cattle dung (C Sheffield pers. comm.) in the daytime or with the use of ultraviolet lights at night (Johnson 2004).

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REVIEW ARTICLE

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Solifugae of Canada

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Abstract

The Solfugae fauna of Canada includes three known species: *Eremobates docolora* Brookhart and Muma, *E. scaber* (Kraepelin), and *Hemerotrecha denticulata* Muma. It is expected that as many as four additional species may be found in Canada. Only one Barcode Index Number is currently known from Canadian specimens.

Keywords

biodiversity assessment, Biota of Canada, camel spiders, solifugids

The arachnid order Solifugae, commonly known as camel spiders, wind scorpions, or sun spiders, is a relatively small order with over 1100 described species, about 200 of which occur in North America (Harvey 2003, Brookhart and Brookhart 2006, Cushing et al. 2015). The order has been documented from the western Canadian provinces ranging from southwestern Saskatchewan to southern British Columbia. This corresponds generally to the Canadian Prairies and Western Interior Basin ecozones. Currently three species, *Eremobates docolora* Brookhart and Muma from Alberta and Saskatchewan, and *E. scaber* (Kraepelin) and *Hemerotrecha denticulata* Muma from British Columbia, have been recorded from Canada, all in the family Eremobatidae (Dondale 1979, Holmberg and Buckle 1992, Brookhart and Brookhart 2006) (Table 1). Dondale (1979) reported *E. gladiolus* Muma and Holmberg and Buckle

Table 1. Census of Solifugae in Canada.

Taxon	No. species reported in Dondale (1979)	No. species currently known from Canada[1]	No. BINs[1] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[2]	Information sources
Eremobatidae	1	3	1	4	Western Interior Basin, Prairies	Dondale 1979, Holmberg and Buckle 1982, 1992, Brookhart and Brookhart 2006

[1]Barcode Index Number, as defined in Ratnasingham and Hebert (2013). [2]See figure 1 in Langor (2019) for a map of ecozones.

(1982) added *E. pallipes* (Say), *E. scaber* (Kraepelin) and the genera *Eremochelis* and *Hemerotrecha* from Canada. Subsequently, *E. gladiolus* was synonymized with *E. scaber* by Brookhart and Cushing (2004), and Holmberg and Buckle (1992) determined that their report of *E. pallipes* and *Eremochelis* was based on misidentification.

Four undescribed species, two *Eremobates* and two *Hemerotrecha*, have been proposed from Canada (Holmberg and Buckle 1992), although these have not been formally described. These were collected from dry grassland habitats in Saskatchewan, Alberta and British Columbia (Brookhart and Brookhart 2006). These records are the basis for the estimate of four additional species remaining to be described from Canada (Table 1).

Presently, there are six specimens in the Barcodes of Life Data (BOLD) System from British Columbia, represented by one Barcode Index Number (BIN) (Table 1). These specimens are identified in BOLD as *Eremobates gladiolus,* a junior synonym of *E. scaber*.

The low species diversity of this order of arachnids in Canada can be attributed to the lack of suitable habitats and climatic conditions in these northern latitudes for a group adapted to dry, warm, xeric conditions with open, sandy soils (Punzo 1998). Solifugae are best adapted to desert and semi-desert environments and are not well adapted to cold or temperate regions (Cloudsley-Thompson 1977), although at least one species, *Uspallata pulchra* Mello-Leitão, 1938 (Mummuciidae), has been reported from a high elevation site (3670 m) in Chile (Muma 1971). Future work on this order should focus on obtaining DNA barcode data from all taxa including the suspected new species.

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RESEARCH ARTICLE

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Acari of Canada

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Abstract

Summaries of taxonomic knowledge are provided for all acarine groups in Canada, accompanied by references to relevant publications, changes in classification at the family level since 1979, and notes on biology relevant to estimating their diversity. Nearly 3000 described species from 269 families are recorded in the country, representing a 56% increase from the 1917 species reported by Lindquist et al. (1979). An additional 42 families are known from Canada only from material identified to family- or genus-level. Of the total 311 families known in Canada, 69 are newly recorded since 1979, excluding apparent new records due solely to classification changes. This substantial progress is most evident in Oribatida and Hydrachnidia, for which many regional checklists and family-level revisions have been published. Except for recent taxonomic leaps in a few other groups, particularly of symbiotic mites (Astigmata: feather mites; Mesostigmata: Rhinonyssidae), knowledge remains limited for most other taxa, for which most species records are unpublished and may require verification. Taxonomic revisions are greatly needed for a large majority of families in Canada. Based in part on species recorded in adjacent areas of the USA and on hosts known to be present here, we conservatively estimate that nearly 10,000 species of mites occur in Canada, but the actual number could be 15,000 or more. This means that at least 70% of Canada's mite fauna is yet unrecorded. Much work also remains to match existing molecular data with species names, as less than 10% of the ~7500 Barcode Index Numbers for Canadian mites in the Barcode of Life Database are associated with named species. Understudied hosts and terrestrial and aquatic habitats require investigation across Canada to uncover new species and to clarify geographic and ecological distributions of known species.

Keywords
Astigmata, biodiversity assessment, Biota of Canada, DNA barcodes, Endeostigmata, Hydrachnidia, Mesostigmata, mites, Oribatida, Prostigmata, ticks

Introduction

With more than 54,000 described and 0.4–1.0 million estimated species worldwide (Zhang 2011, Walter and Proctor 2013), mites are among the most diverse groups of animals on the planet, and one of the least well known. Approximately 10,000 species were estimated to occur in Canada by Lindquist et al. (1979), 80% of which were thought to be unrecorded at the time. Correlated with their taxonomic diversity, mites are ecologically ubiquitous, with habitats ranging from bear fur and bird feathers to leaf domatia, to insect spiracles, and mountain tops to ocean trenches (Lindquist et al. 1979, Lumley et al. 2013, Walter and Proctor 2013). While their minute size has been a key ingredient in their evolutionary success, it has also been an impediment to taxonomic progress. In addition, small size means that mites are often overlooked by researchers other than acarologists, obscuring awareness of their impact on agriculture, forestry, wildlife, human health, and ecosystem services. Mites recycle nutrients in soil and other substrates, and regulate animal, fungal and plant populations as consumers or pathogen vectors (Moore et al. 1988, Hoy 2011). While several are pests that threaten agriculture by feeding on crops and livestock, others protect it as biocontrol agents of pests and weeds (Rosenthal 1996, Gerson et al. 2003). Some mites are also bioindicators of soil and freshwater health (Behan-Pelletier 1999, Beaulieu and Weeks 2007, Proctor 2007).

Herein, we treat Acari as a single group, following Lindquist et al. (1979) and other major references (e.g., Krantz and Walter 2009). However, the 'Acari' may represent two independent lineages of arachnids instead of a single monophyletic clade, a hypothesis supported by recent molecular analyses (e.g., Pepato and Klimov 2015), and possibly by morphology (Lindquist 1984, Dunlop and Alberti 2007). Based on fossil records, the origin of acariform mites dates back at least to the early Devonian (411 mya), possibly as detritivore-scavengers living in the interstices of beach sand or soil, after land was colonized by ancestral arachnids (Schaefer et al. 2010, Walter and Proctor 2013). Time of origin of the parasitiform lineage is more obscure, and this group is represented by fewer, more-recent fossils (~100 mya; Dunlop and Bernardi 2014, Peñalver et al. 2017).

Reliable identification of any given mite to species is difficult because of the general lack of identification tools, including species-level keys, adequate species descriptions and illustrations, as well as published checklists. This is in stark contrast with major groups of insects and spiders for which there are usually checklists available at the national or provincial levels for the entire order as well as many species-level identification keys. The slow progress in mite systematics reflects the dearth of acarological taxonomists in Canada and North America, the relatively rare inclusion of mites in biological surveys and student projects, and the small number of amateur collectors (Lumley et al. 2013).

While a broad first 'sweep' of collecting across Canada was done prior to the year 2000 (Lumley et al. 2013), sampling points are widely scattered with a few exceptions such as Vancouver Island (British Columbia) and Alberta for Oribatida (e.g., Walter et al. 2014, Lindo and Clayton 2017). Labrador is virtually unsampled for mites (Lindquist et al. 1979) and Saskatchewan is poorly explored (Lumley et al. 2013). Similarly, while past collecting efforts were ecologically broad, all habitats including plants and animals (both vertebrate and invertebrate) are in need of targeted exploration for uncovering additional species and clarifying species' ecological and geographical distributions (Lumley et al. 2013).

Since 1979, several regional assessments have been published for Canada, particularly for soil and freshwater mites of Montane Cordillera (Smith et al. 2011), Mixedwood Plains (Smith et al. 1996), and Atlantic Maritime ecozones (Behan-Pelletier 2010, Smith 2010); grasslands of western Canada (Behan-Pelletier and Kanashiro 2010); the Arctic (Behan 1978, Danks 1981) and Yukon (Behan-Pelletier 1997a); Sable Island (Majka et al. 2007); Cape Breton Highlands National Park (Behan-Pelletier et al. 1987); and the Churchill, Manitoba region (Young et al. 2012). More restricted ecological surveys have been published for mites in forest canopies of the Pacific coast (Fagan et al. 2006, Lindo and Winchester 2006, 2009), in soil and litter (e.g., St. John et al. 2002, Déchêne and Buddle 2009, Behan-Pelletier and Kanashiro 2010, Sylvain and Buddle 2010, Walter and Latonas 2012, Newton 2013, Meehan and Turnbull 2018), peatlands (Behan-Pelletier and Bissett 1994, Barreto and Lindo 2018, McAdams et al. 2018), in dung (Lindquist 1998), and on plants (Forest et al. 1982, Beaulieu and Knee 2014), bumble bees (Haas et al. in press), beetles (Lindquist and Wu 1991, Knee et al. 2013), and birds (Galloway et al. 2014, Knee and Galloway 2017b). For certain families or higher taxa of Acari, these publications represent a key source of information for species records in Canada.

Methods

Described species records in Canada were compiled based on a critical assessment of the literature as well as unpublished specimen records from collections, primarily the Canadian National Collection of Insects, Arachnids and Nematodes (CNC), but also from the following: the Royal Alberta Museum (PMAE), JB Wallis/RE Roughley

Museum of Entomology at the University of Manitoba, the Zoological Institute in St. Petersburg, Russia, H Proctor's collection (University of Alberta), Z Lindo's collection (Western University), the Habeeb Collection (New Brunswick Museum), the Ohio State University Acarological (Laboratory) Collection (OSAL; online database: available from https://acarology.osu.edu/database), the United States National Museum (USNM), and the University of Michigan Museum of Zoology (UMMZ). Note the difference between the general approach of Lindquist et al. (1979) and our approach for assessing the number of known species. Lindquist et al. (1979) provided an estimate of the number of species represented by specimens in hand (in addition to the rare published records), including the relatively few named species and variously identified morphospecies. In contrast, in this treatment 'known species' includes only named species. This explains some of the apparent decreases in the 'no. known spp.' between 1979 and current numbers for some families in Tables 2–6; other reductions are due to changes in family classifications of genera.

We have excluded mites that survive only on introduced hosts that do not occur naturally outdoors in Canada, or cannot become naturalized because of intolerance to our climate. This excludes numerous host-specific mites associated with exotic zoo animals, the pet trade (e.g., tropical birds and lizards), and with cultures of tropical insects. However, we have included mites that are regularly encountered in greenhouses or in stored products, even if some may not survive Canadian winters, because these species are more tractable and are from temperature-protected major 'agricultural environments'.

While estimates of unrecorded and undescribed species for each family are fairly subjective, they are often based on concrete information: (1) Canadian specimens determined to be new, undescribed species; (2) Canadian specimens not yet determined to species, or only tentatively, but that most likely represent a number of additional distinct species; (3) published or unpublished collection-based records (particularly from OSAL, USNM, UMMZ) of species from northern USA with ranges in close proximity to Canada, or from the USA and associated with host species that also occur in Canada. We also considered the habitats and hosts that are unexplored for particular mite groups and the level of host specificity for symbiotic mites, when available. In addition, we adjusted our estimates with the magnitude of faunal records for families that are better known in other regions of the world with a similar climate, e.g., European countries (Karg 1989, 1993, Biesiadka et al. 1997). Molecular data (BINs: Barcode Index Numbers) were used minimally to estimate unrecorded species, except when supported by morphological data that suggest delineation of undescribed species.

The information sources presented in Tables 2–6 are not exhaustive but are the most useful publications that include new records, species lists or taxonomic revisions. When a publication refers to many families of a given superfamily, it is listed for the superfamily. Additional relevant sources are presented in the main text. Note that collections, particularly the CNC, are an information source of unpublished species records for most families presented, but for the sake of simplicity were not indicated as sources in Tables 2–6.

Family, superfamily and higher-level classification mainly follow Lindquist et al. (2009a), as modified by Beaulieu et al. (2011) for Parasitiformes, Zhang et al. (2011)

for Trombidiformes, Walter et al. (2011) for Endeostigmata, and Schatz et al. (2011) for Oribatida. Further modifications were made based on more recent publications which are cited in the text or table footnotes. Names of the hyporders of Mesostigmata do not follow Beaulieu et al. (2011), but rather more traditional publications (e.g., Epicriina instead of Epicriae; see the endnotes in Lindquist et al. (2009a) for sources), similar to what Zhang et al. (2011) and Schatz et al. (2011) did for Trombidiformes and Oribatida.

The text below is generally divided into superfamilies except in cases where a broader, more inclusive treatment (e.g., Oribatida excluding Astigmata) was deemed more practical, for instance, because the ecology of the entire group is relatively homogeneous.

Because current species records are so patchy, determining the range of occupied ecozones for a given family is difficult and often required subjective extrapolation of the family's distribution across ecozones. For families of vertebrate symbionts (ticks and many Astigmata, Prostigmata, and Mesostigmata), ecozones occupied were often in part inferred from the known distribution of the host groups rather than from the typically limited collection records for the mites themselves. For those families, the host group was indicated in the ecozone column in order to be more informative. Note that an association to a vertebrate host can be parasitic, commensal (e.g., putatively most cases of phoresy), or even mutualistic. Extrapolation was also done for families which are not yet recorded in Canada, by inference from northern USA records and/or host ranges. Distribution across ecozones indicated in tables should therefore be interpreted with caution.

Overview of faunal diversity

There are 2999 named species from 269 families currently recorded in Canada, including at least 1082 new records since 1979, a 56% increase (Table 1). This increase would be even more substantial, if there were not a discrepancy in the method of reporting 'recorded species' in 1979 vs the present treatment (see Methods). An additional 42 families are represented only by material determined to family- or genus-level (these families have no known species included in Tables 2–6; see also footnote * under each table). Of the total 311 families known in Canada, as many as 69 are newly recorded since 1979, 27 of which are based on undetermined material only. These new family records exclude apparent new records due solely to classification changes.

Across higher taxa, the number of known species has increased 37–67%, except for the hyporder Astigmata, which has increased 211% (Table 1). This major taxonomic leap for Astigmata is essentially due to the ongoing collaborative research on feather mites, Pterolichoidea and Analgoidea (e.g., Galloway et al. 2014). There is also a major increase in recorded species of Oribatida associated with a series of published checklists and taxonomic revisions (e.g., Behan-Pelletier and Eamer 2009, Behan-Pelletier 2013, Walter et al. 2014, Lindo 2018). Among the Trombidiformes, the Hydrachnidia (water mites) is the group with most notable growth in knowledge (e.g., Smith 1992a, Smith et al. 2015), and recent work on Rhinonyssidae represents the most salient pro-

Table 1. Census of Acari in Canada.

Taxon	No. species reported in Lindquist et al. (1979)[1]	No. species currently known from Canada	No. BINs[2] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	No. families in Canada			
					with ≥1 named species	with undet. species only	with BINs	anticipated (not yet recorded)
Superorder Parasitiformes								
Order Ixodida	33	48	34	10	2	0	1	0
Order Mesostigmata	473	650	1409	967	46	8	36	4
Superorder Acariformes								
Order Trombidiformes[3]	802	1100	3261	2162	86	14	62	10
Order Sarcoptiformes								
Suborder Endeostigmata[3]	113	168	176	1049	8	2	≥4	2
Suborder Oribatida[4]	354	592	2429	1267	84	15	67	1
Hyporder Astigmata	142	441	153	1174	43	3	19	12
Total	**1917**	**2999**	**7462**	**6629**	**269**	**42**	**189**	**29**

[1]In 1979, the two column headings for species counts were "Estimated no. Can. species rec. (1) and uncoll. (2)"; the term "rec." included named species as well as, in many cases, species that were not assigned to species names but that represented distinct, and potentially undescribed, species; the term "uncoll." included potential species that were not represented by specimens. In contrast, for our current assessment, "No. spp. currently known" includes only named species (see Methods). [2]Barcode Index Number, as defined in Ratnasingham and Hebert (2013). [3]Lindquist et al. (1979) reported 913 species of 'Prostigmata', which included families now in Endeostigmata, as well as Eriophyoidea, also currently included in Endeostigmata, not in Trombidiformes (following Bolton et al. 2017, Klimov et al. 2018); furthermore, two additional species (of Linotetranidae and Camerobiidae) were recorded only in footnotes in Lindquist et al. (1979) and not included in the total of 913. [4]Values exclude Astigmata.

gress for Mesostigmata (Knee and Galloway 2017b). Our knowledge of Canadian ticks (Ixodida) benefited from the recent publication of a handbook with diagnoses and keys to all established species in Canada (Lindquist et al. 2016).

We estimate that over 6600 species of mites are as yet unrecorded or undescribed in Canada (Table 1). This represents ~70% of the total expected fauna. Our total estimate (known plus unknown species) of 9628 species is close to the ~9500 of Lindquist et al. (1979). We consider our estimate to be conservative and that as many as 15,000 species could be found in the country.

Molecular data for species delineation and diversity assessment

Since Lindquist et al. (1979), many molecular markers (e.g., ITS, COI, 16S, 18S, 28S) have been used to help elucidate species boundaries in the Acari (Navajas and Fenton 2000, Cruickshank 2002, Navajas and Navia 2010, dos Santos and Tixier 2017, Lehmitz and Decker 2017). In particular, the 658 bp 'barcode' region of COI (cytochrome *c* oxidase subunit I) has been promoted as a reliable determinant of species boundaries in animals (Hebert et al. 2003); however, compared to other arthropod groups (Virgilio et al. 2010, Wilson et al. 2017), the paucity of barcode data available for Acari worldwide is striking (e.g., Navajas and Navia 2010). This also applies to Canada, where 70–80% of all named Canadian Lepidoptera, Coleoptera and Araneae have been barcoded and assigned BINs, with each BIN representing a 'barcode cluster' for a putative species (Ratnasingham and Hebert 2013, Blagoev et al. 2015, Brunke et al. 2019, Pohl et al. 2019), whereas fewer than 10% of named Acari have assigned BINs. Nevertheless, 7462 BINs from 189 families have been sequenced for Canadian Acari (Tables 1–6; available in BOLD). Interestingly, the BIN richness is well above past and present predictions of species richness for many families in Canada (see further notes in respective taxonomic sections below; Lindquist et al. 1979). Note also that available BINs are based on a limited number of samples, habitats and hosts surveyed. For instance, ~900 of these BINs were generated from a single barcode study of mites at one location in subarctic Canada (Young et al. 2012).

Because of variation in mutation rates among mite taxa, variable retention of ancestral polymorphisms, and past hybridization events, the BIN algorithm may overestimate species richness in some groups. High intraspecific divergences in mites (7–20%) have been observed in some cases (e.g., Heethoff et al. 2007, Niedbała and Dabert 2013, Rosenberger et al. 2013, Zhang and Zhang 2014), possibly reflecting higher rates of mitochondrial evolution in mites than in most other animal taxa (Young and Hebert 2015), or long-term consequences of reproductive systems such as haplodiploidy (Tixier et al. 2017) and thelytoky (Palmer and Norton 1992). On the other hand, it is plausible that cases of high BIN richness, at least in part, reflect cryptic diversity that is not yet resolved morphologically (e.g., Ratnasingham and Hebert 2013, Ondrejicka et al. 2016). Indeed, species distinguished by only minor morphological differences, or cryptic species, are common and sometimes associated with narrower host ranges than previously thought (Knee et al. 2012a, Miller et al. 2013).

The barcode region has been useful for delineating species in various groups of parasitiform and acariform mites (e.g., Roy et al. 2009, Knee et al. 2012a, Glowska et al. 2014, Doña et al. 2015, Ondrejicka et al. 2016, Fisher et al. 2017). In Canada, approximately 60–70% of 230 morphologically recognized species of oribatids across 45 families are currently supported by barcode clusters (M Young and L Lumley unpubl. data). The rapidly growing barcode reference library for the Acari of Canada is therefore of considerable use. However, the most important and possibly most onerous step, the association of DNA sequences with morphological concepts, has to be addressed for most taxa in order to test the effectiveness of barcode-based species identifications. To strengthen analyses, a multigene approach should be favoured in the future, especially given the fast development of next-generation sequencing technology (Marcus 2018). With such increasing ease in obtaining sequences, it is more critical now than ever to build morphologically verified voucher libraries that will enable sequencing results to be taxonomically and ecologically meaningful.

Adventive species

Like almost all biota of this previously largely ice-covered country, the acarofauna of Canada has been recovering from glaciation since ice sheets began retreating ~14,000 years ago (Menounos et al. 2017). Consequently, determining which species have been introduced through recent human activity is often impossible, complicated by a lack of geographic, taxonomic, phylogenetic or host data (Langor et al. 2009, Beaulieu and Knee 2014). Even cases of mites specific to animal or plant hosts that have been introduced may present difficulties, because of uncertainties in the mite species boundaries, the actual host range, or biogeographical history of the host (Mironov et al. 2005, Navajas et al. 2010, Miller et al. 2013). Undoubtedly, many mite species have been inadvertently introduced to Canada with soil or water ballasts emptied near ports; with vertebrate hosts introduced intentionally as livestock, as pets or for hunting, or accidentally with imported goods, e.g., rodents (Navajas et al. 2010); and with invertebrate hosts on which they are parasitic or phoretic, such as fly pests, wood-boring beetles, or dung beetles introduced to accelerate decomposition of cattle dung (Humble and Allen 2006, Floate 2011). Widespread agricultural pests, such as the two-spotted spider mite, and many of the cosmopolitan mites breeding in stored grains, insect or fungal cultures, or bee hives (e.g., *Varroa*, *Acarapis* spp.), clearly originate from outside Canada (Langor et al. 2009, Beaulieu and Knee 2014). A few species have been intentionally introduced for biocontrol of agricultural pests or weeds (McClay and De Clerck-Floate 2013). In Europe, 96 species of mites have so far been identified as adventive, most of which are associated with agricultural commodities (Navajas et al. 2010). Given international plant trade, and the small size, cryptic habits and dispersal potential (e.g., phoresy, wind) of mites (Navajas et al. 2010, Beaulieu and Knee 2014, NAPPO 2014), we can expect a considerable number of non-native mites to be present already in Canada, and that their numbers will increase.

Superorder Parasitiformes

Parasitiform mites represent one of the two currently recognized and apparently phylogenetically distant acarine lineages. Only two of the four orders are present in Canada, the Ixodida (ticks) and Mesostigmata. The majority of Parasitiformes feed on fluids taken from their prey or hosts, depending on whether they are predators or parasites—the two dominant lifestyles of parasitiforms. A few taxa (e.g., some ameroseiids, ascids, melicharids, phytoseiids, uropodines) feed on pollen, nectar or fungal tissues, including some that ingest particulate matter, and some insect symbionts ('paraphages') may feed on secretions of their hosts.

Order Ixodida

Ticks, the most infamous mites of all, are obligate blood-feeding ectoparasites of terrestrial vertebrates, primarily birds and mammals, but also reptiles and amphibians. Ticks are major threats to wildlife and public health, as they can harm their hosts through exsanguination, paralysis, and transmission of pathogens, including the causative agent of Lyme disease, *Borrelia burgdorferi* (Nicholson et al. 2009, Lindquist et al. 2016). The recent handbook to the ticks of Canada by Lindquist et al. (2016) represents a much-needed update from Gregson (1956) and includes identification keys to all instars as well as information on the species' life histories, distributions, hosts, and pathogens transmitted.

The known diversity of Ixodidae, or hard ticks, in Canada has increased from 26 in Lindquist et al. (1979) to 41 species (Table 2). However, from this number, approximately 10 *Amblyomma* and five *Ixodes* species represent extralimital records. These species have been reported primarily from migratory birds and, therefore, it is unlikely they have established year-round populations in Canada (Scott and Durden 2015a, b, Lindquist et al. 2016). In the past 20 years, the blacklegged tick, *Ixodes scapularis* Say, a major vector of the agent of Lyme disease, has significantly expanded its range northward from the USA and has become established from Manitoba to Atlantic Canada (Leighton et al. 2012).

Argasidae, soft ticks, are generally nocturnal and more rapid feeders than ixodids, and mainly parasitize bats and birds. The number of known species in Canada has not changed since Lindquist et al. (1979), remaining at seven. However, over half of known argasid species are represented by only one or two records, suggesting that this apparently poor diversity may be in part a result of the lack of study in the country (Lindquist et al. 2016). The absence of BINs generated for Argasidae in Canada supports this hypothesis (Table 2). In contrast, a majority of Ixodidae has been studied molecularly, with at least 26 of the 34 BINs generated assigned to named species (Ondrejicka et al. 2016). It is expected that a few additional species of ticks in both families will eventually be found or recognized in Canada (Table 2).

Table 2. Census of the superorder Parasitiformes (Acari) in Canada.

Taxon[1]	No. species reported in Lindquist et al. (1979)	No. species currently known from Canada	No. BINs[2] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[2A] and vertebrate host range	Information sources
Order Ixodida						
Superfamily Ixodoidea						Lindquist et al 2016
Argasidae	7	7	0	2	Boreal ecozones and southward; birds, bats, other mammals	
Ixodidae	26[3]	41	34	8	all ecozones; mammals, birds	Guglielmone et al. 2004
Order Mesostigmata						
Suborder Sejida						
Superfamily Sejoidea						
Ichthyostomatogasteridae*	1[4]	0	0	1	Mixedwood Plains	
Sejidae	1	3	3	5	Taiga ecozones and southward	
Uropodellidae	?[4]	0	0	1	Mixedwood Plains	
Superfamily Heterozerconoidea						
Heterozerconidae*	0	0	0	1	Mixedwood Plains	Gerdeman and Klompen 2003
Suborder Trigynaspida						
Infraorder Cercomegistina						
Superfamily Cercomegistoidea						
Cercomegistidae	0	0	1	1	Pacific Maritime, Mixedwood Plains	Kinn 1970
Infraorder Antennophorina						
Superfamily Antennophoroidea						
Antennophoridae	0	1	0	3	Pacific Maritime, Prairies (Cypress Hills), Mixedwood Plains	Wheeler 1910, Wisniewski and Hirschmann 1992
Superfamily Celaenopsoidea						
Diplogyniidae	4	1	1	4	Mixedwood Plains	
Euzerconidae	1	1	0	0	Mixedwood Plains	Funk 1980
Superfamily Paramegistoidea						
Paramegistidae	0	0	0	1	Mixedwood Plains	Nickel and Elzinga 1970
Superfamily Parantennuloidea						
Parantennulidae	1	1	0	1	Mixedwood Plains	
Philodanidae	1	1	0	0	Mixedwood Plains	Kethley 1977

Taxon[1]	No. species reported in Lindquist et al. (1979)	No. species currently known from Canada	No. BINs[2] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[2A] and vertebrate host range	Information sources
Suborder Monogynaspida						
Infraorder Uropodina						Halliday 2015, 2016
Superfamily Microgynioidea						
Microgyniidae	1	1	7	3	Montane Cordillera, Western Interior Basin, Boreal Shield	Meehan and Turnbull 2018
Superfamily Thinozerconoidea						
Protodinychidae	1	1	0	0	Mixedwood Plains, Boreal Shield	Hutu and Calugar 2002
Superfamily Uropodoidea						
Cillibidae	0	0	0	2	Mixedwood Plains	
Dinychidae	?[5]	3	19	15	all ecozones	
Discourellidae	?[5]	5	0	5	Pacific and Atlantic Maritime, Mixedwood Plains	Hiramatsu and Hirschmann 1979
Metagynuridae	0	0	0	2	Mixedwood Plains	
Oplitidae	0	0	2	10	Prairies, Boreal Shield, Atlantic Maritime	
Polyaspididae	15[6]	0	6	10	most ecozones	
Trachytidae	>2[6]	10	14	25	Montane Cordillera, Taiga Plains, Mixedwood Plains, Atlantic Maritime	Hutu 2000
Trachyuropodidae	1	1	1	20	Prairies, Mixedwood Plains, Atlantic Maritime	Kontschan et al. 2010
Trematuridae[7]	?[5]	30	31	40	Boreal ecozones and southward	Hirschmann 1978, Hirschmann and Wisniewski 1987, Knee et al. 2012a, c, 2013
Urodiaspididae	?[5]	2	0	5	Pacific and Atlantic Maritime	
Urodinychidae[8]	?[5]	10	9	35	Boreal ecozones and southward	Hirschmann 1979, Knee et al. 2012a, b
Uropodidae	29[5]	3	5	25	Mixedwood Plains, Atlantic Maritime	Majka et al. 2007
Superfamily Diarthrophalloidea						
Diarthrophallidae	1	1	0	0	Mixedwood Plains	Schuster and Summers 1978
Infraorder Gamasina						
Hyporder Epicriina						
Superfamily Epicrioidea						
Epicriidae	2	5	1	5	Boreal ecozones and southward	Moraza and Johnston 2004, Moraza 2005

Taxon[1]	No. species reported in Lindquist et al. (1979)	No. species currently known from Canada	No. BINs[2] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[2A] and vertebrate host range	Information sources
Superfamily Zerconoidea						
Coprozerconidae*	0	0	0	1	Mixedwood Plains; woodrat nests	Moraza and Lindquist 1998
Zerconidae	30	41	62	50	all ecozones	Diaz-Aguilar and Ujvari 2010, Sikora 2014
Hyporder Arctacarina						
Superfamily Arctacaroidea						
Arctacaridae	2	2	3	5	Boreal ecozones and northward	Makarova 2003
Hyporder Parasitina						
Superfamily Parasitoidea						
Parasitidae	35	51	123	100	all ecozones	Richards and Richards 1976, Poprawski and Yule 1992, Walter and Latonas 2012
Hyporder Dermanyssina						
Superfamily Veigaioidea						
Veigaiidae	10	9	22	15	all ecozones	Hurlbutt 1984
Superfamily Rhodacaroidea						
Digamasellidae	20	39	181	60	Taiga ecozones and southward	Shcherbak 1985, Knee et al. 2012c, 2013
Halolaelapidae	10	2	24	40	all ecozones	
Ologamasidae	10	7	35	20	all ecozones; mammals (phoresy)	Hagele et al. 2005
Rhodacaridae	5	1	9	25	Boreal ecozones and southward	
Superfamily Eviphidoidea						
Eviphididae	5	7	8	15	Boreal ecozones and southward	Rigby 1996
Macrochelidae	15	26	31	35	Boreal ecozones and southward; mammals (phoresy)	Krantz 1998, Majka et al. 2007, Knee 2017a
Pachylaelapidae	5	1	20	15	Pacific and Atlantic Maritime, Prairies, Mixedwood Plains	
Parholaspididae	7	4	13	20	Boreal ecozones and southward	Marshall 1964, Marshall and Kevan 1964
Superfamily Ascoidea						
Ameroseiidae	10	5	22	20	Boreal ecozones and southward; rodents (phoresy)	Elsen and Whitaker 1985, Mašán 2017
Ascidae	60[9]	40	131	40	all ecozones	Beaulieu et al. 2008, Lindquist and Makarova 2011, Makarova and Lindquist 2013
Melicharidae	20[9]	26	55	20	all ecozones; rodents, birds (phoresy)	Lindquist and Wu 1991, Lindquist 1995, Karg 2005

Taxon[1]	No. species reported in Lindquist et al. (1979)	No. species currently known from Canada	No. BINs[2] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[2A] and vertebrate host range	Information sources
Superfamily Phytoseioidea						
Blattisociidae	20[9]	32	85	25	all ecozones	Lindquist 2003
Otopheidomenidae*	1	0	0	3	Mixedwood Plains	Treat 1975
Phytoseiidae	75	110	320	75	all ecozones	Chant and Hansell 1971, Chant et al. 1974, Denmark and Evans 2011
Podocinidae	0	1	1	0	Mixedwood Plains	Lindquist and Wu 1987
Superfamily Dermanyssoidea						
Dermanyssidae	4	11	2	3	all ecozones; birds, mammals	Moss 1978, Knee 2008
Entonyssidae	0	1	0	3	Montane Cordillera; snakes	Fain 1961, Fajfer 2012
Haemogamasidae	9	10	0	10	all ecozones; small mammals	Williams et al. 1978
Halarachnidae	4[10]	3	0	5	Taiga ecozones and southward; mammals	Kim et al. 1980
Iphiopsididae	?[11]	0	0	5	Boreal Shield, Mixedwood Plains	Farfan and Klompen 2012
Ixodorhynchidae	5	3	0	2	Mixedwood Plains; snakes	Johnston 1962
Laelapidae	38[11]	61	155	60	all ecozones; small mammals, birds	Crozier 1989, Whitaker et al. 2007
Macronyssidae	7	11	2	20	all ecozones; birds, bats and other small mammals, snakes	Knee and Proctor 2007, Czenze and Broders 2011
Rhinonyssidae	3	61	4	50	all ecozones; birds	Knee 2008, 2018, Knee et al. 2008, Knee and Galloway 2017b
Spinturnicidae	2	4	0	5	Boreal ecozones and southward; bats	Poissant and Broders 2008, Czenze and Broders 2011
Varroidae	0	1	1	0	Boreal ecozones and southward	Currie et al. 2010
Total	**506**	**698**	**1443**	**977**		

*These families are anticipated for Canada although no specimens have been collected to date; for other families with 0 known species, some undetermined material has been collected in Canada.
[1]Classification mostly follows Lindquist et al. (2009b), as slightly modified by Beaulieu et al. (2011), with exceptions mentioned in footnotes 7 and 8. [2]Barcode Index Number, as defined in Ratnasingham and Hebert (2013). [2A]See figure 1 in Langor (2019) for a map of ecozones. [3]Includes former Amblyommidae. [4]Probably represents *Uropodella* sp., which is now placed in Uropodellidae. [5]Dinychidae, Discourellidae, Trematuridae, Urodiaspididae and Urodinychidae were included in Uropodidae. [6]Trachytidae was included in Polyaspididae, and current Trachytidae includes former Dithinozerconidae. [7]Includes Nenteriidae (based on H Klompen pers. comm.). [8]Includes Uroactiniidae (based on H Klompen pers. comm.). [9]Melicharidae and Blattisociidae were included in Ascidae (100 total species reported in 1979), with ~20 species each. [10]Includes former Raillietidae. [11]Iphiopsididae was included in Laelapidae.

Order Mesostigmata

This order of mites includes the most diverse group of predatory arthropods in soils and other detrital habitats (e.g., rotting wood, dung, carcasses, nests), a large component of plant-dwelling predators (mostly Phytoseiidae), as well as various lineages of vertebrate parasites (within Dermanyssoidea) and arthropod symbionts including numerous species that disperse phoretically on their hosts. Mesostigmata (= Gamasida) represents the bulk of the Parasitiformes, with 650 species in 46 families currently recorded in Canada, compared to 473 species in 1979, with many more unrecorded (Table 2). An additional eight families are represented in Canada by undetermined species. Taxonomic knowledge has strikingly improved for the bird-parasitic family Rhinonyssidae (Knee and Galloway 2017b) and significantly for Phytoseiidae (Denmark and Evans 2011), Trematuridae, Digamasellidae, Macrochelidae, and Laelapidae, although records for the latter five families are largely based on unpublished CNC specimen data. We anticipate an overall diversity of more than 1600 species of Mesostigmata, of which at least 60% are to be identified.

Molecular work generated 1409 BINs from 36 families of Mesostigmata (Tables 1, 2), most of which are not assigned to named species. These data indicate high genetic diversity that contrasts with our morphology-based assessments for the families Parasitidae (123 BINs), Digamasellidae (181), Ascidae (131), Blattisociidae (85), Phytoseiidae (320), and Laelapidae (155). For instance, the number of BINs for Phytoseiidae is almost twice the total number of known and unrecorded (estimated) species.

Suborder Sejida

Sejida is a relatively species-poor but biologically heterogeneous lineage of mites associated with dead wood and litter, mostly as predators (Sejidae, Uropodellidae) or millipede symbionts (Heterozerconoidea) (Walter and Proctor 1998, Lekveishvili and Klompen 2004). Of the two families in Canada, Sejidae has three identified species, and Uropodellidae is known only from one undetermined species (Table 2). A few additional species of Sejidae are expected from Canada. One species of *Asternolaelaps* (Ichthyostomatogasteridae) known from Michigan is expected to occur at least in neighbouring parts of Canada. Similarly, Heterozerconidae may occur here, based on one species recorded from the millipede *Narceus annulatus* Rafinesque in central Ohio (Gerdeman and Klompen 2003); this millipede occurs in southern Canada (Shelley et al. 2006).

Suborder Trigynaspida

Trigynaspids are early-derivative Mesostigmata that are mostly restricted to subtropical-tropical regions (Kim 2004, Lindquist et al. 2009b). They are typically arthropod associates, and the few species whose distribution extends into southern Canada are putatively commensals of scolytine, scarab, carabid, tenebrionid, and passalid beetles, as well as ants. They feed as paraphages, cleptoparasites, or as predators of small invertebrates in their beetle host's tunnels (Kinn 1971, Kim 2004, Seeman 2007). While only a few additional species are anticipated to be found in southern Canada, their biology and distribution remain largely unknown. Within the infraorder Antennophorina, six families are currently recorded in Canada, though Paramegistidae is represented by an undetermined specimen (Table 2). The infraorder Cercomegistina is only known from one undetermined species of Cercomegistidae.

Suborder Monogynaspida: Infraorder Uropodina

Monogynaspida is the largest suborder and contains two infraorders, Uropodina and Gamasina, both of which are well-represented in Canada. Uropodines represent a heterogeneous lineage of mites, with four superfamilies in the present treatment. Following evidence from molecular analysis (Klompen et al. 2007), Diarthrophalloidea and Microgynioidea are here included in Uropodina.

Superfamilies Microgynioidea, Thinozerconoidea, Diarthrophalloidea

Microgyniidae is a small Holarctic family of mites, with a few representatives in Canada associated with forest litter and dead wood. The superfamily Thinozerconoidea is represented by one species in Canada, *Protodinychus ainscoughi* (Hutu and Calugar 2002), collected from beaver lodges and from beetles in the lodges. Diarthrophallidae, intimately associated with passalid beetles (Schuster and Summers 1978), though with poorly understood relationships, is also represented by one species, *Diarthrophallus quercus* (Pearse and Wharton), associated with the only passalid present in Canada, *Odontotaenius disjunctus* (Illiger).

Superfamily Uropodoidea

Members of this group have strong dorsal and ventral shields with excavations into which the legs and gnathosoma can be withdrawn, giving them the common name 'tortoise mites'. Their classification is unstable, with poorly resolved generic and family concepts, although important steps to address this confusion have been taken recently (Halliday 2015, 2016). Some of the families presented here (Table 2) may therefore be synonymized in the future. While uropodoid mites thrive in many soil habitats of the southern hemisphere (Beaulieu 2012), in temperate regions, including in Canada, the core of their diversity resides in patchy, transient habitats such as ant hills, dead wood, stored products, compost, carrion, and vertebrate nests. Deutonymphs of these species are phoretic on insects or vertebrates and can be readily collected from these animals.

Although poorly known, feeding habits range from predation to omnivory, including fungi or other microbes in their diet (Lindquist et al. 2009b). Most of what we know of uropodoids in Canada involves those associated with beetles and ants. Further sampling of litter and particularly insects as carriers is expected to quadruple the number of species in Canada from 64 named species to an estimated total of 258 (Table 2).

Suborder Monogynaspida: Infraorder Gamasina

Among Mesostigmata, the infraorder Gamasina comprises the great majority of species in temperate to polar regions of the world, including Canada. It represents a monophyletic group, although the boundaries of some families and their relationships are still unclear (Klompen et al. 2007, Lindquist et al. 2009b, Dowling and OConnor 2010a).

Superfamilies Epicrioidea, Zerconoidea, Arctacaroidea

One family of each of these superfamilies is recorded in Canada. At least eight new species of Zerconidae have been described from Canada since Halašková's (1977) revision of the family in the Nearctic region, and many more are to be discovered and described (Table 2; Z Ujvari pers. comm.). Two species of Arctacaridae and five of Epicriidae are known from Canada, and a few additional species of each family are anticipated in Canada, especially in the alpine and northern regions for Arctacaridae. It was recently discovered that epicriids are predators that use their elongate forelegs to ensnare collembolan prey (Alberti 2010). At least some zerconid mites show preferences for nematodes (Walter 1988a). The feeding habits of arctacarids are unknown, although predation is suspected, given their strong, serrate chelicerae. Coprozerconidae, currently known only from one species found in *Neotoma* woodrat nests in Kentucky (Moraza and Lindquist 1998), may also occur in Canada (Table 2).

Superfamilies Parasitoidea, Veigaioidea

While there is some work done on the diverse fauna of Parasitidae in North America and nearby Greenland (Hennessey and Farrier 1988, 1989, Makarova 2015), and many specimens are identified to species in Canadian collections, the bulk of the taxonomic work remains to be done. This applies as much to the free-living soil predators (members of the subfamily Pergamasinae) as to those that live in patchy nutrient-rich habitats (e.g., animal nests, carcasses, dung) and disperse phoretically as deutonymphs on insects (Parasitinae). Since 1979, only a few additional records have been published (Poprawski and Yule 1992, Walter and Latonas 2012). Currently 51 species are known from Canada and almost twice as many await discovery (Table 2; I Juvara-Bals pers. comm.).

Like many parasitids, veigaiids are fast-moving, aggressive soil-dwelling predators, thriving especially in temperate forests, but also as far north as the Arctic tundra

(Danks 1981, Hurlbutt 1984, Lindquist et al. 2009b). There are nine species known from Canada and at least another 15 expected.

Superfamily Rhodacaroidea

The increase of known Digamasellidae in Canada from 20 in 1979 to the current total of 39 species (Table 2) is due more to ecological surveys than to taxonomic revisions. Examination of insects, especially beetles, for phoretic deutonymphs should reveal an even richer digamasellid fauna, including undescribed species (e.g., Knee et al. 2012c, 2013). Two new species of Ologamasidae were recently described from small mammals (e.g., moles, voles, shrews) in western Canada (Hagele et al. 2005), on which they probably simply disperse, as deutonymphs, to get to and develop in the host's nest. Other ologamasids are typically free-living predators in forest or grassland soils, although some are phoretic on carabid beetles, and others inhabit littoral sands (CNC, Haq 1965). Rhodacaridae, adapted for moving through interstitial spaces of deeper soils, have not been studied in Canada. As well, there is likely an undocumented diversity of Halolaelapidae from litter, dung, carcasses, tidal debris, and the arthropods on which they disperse (Krantz 2016).

Superfamily Eviphidoidea

Except for a few scattered records in the literature (Table 2), this group has been largely unstudied in Canada. Based on studies elsewhere (e.g., Krantz and Whitaker 1988, Masan and Halliday 2010), soil-litter habitats, as well as animal dung and nests, carrion, beach wrack, and coprophilous and necrophagous insects on which eviphidids and macrochelids tend to disperse phoretically, should yield a considerable species diversity in Canadian landscapes. There are 38 species known from four families, and 85 additional species are expected in the country (Table 2).

Superfamily Ascoidea

At the time of Lindquist et al. (1979), this superfamily included species now spread across two superfamilies, Ascoidea and Phytoseioidea (Lindquist et al. 2009b, Beaulieu et al. 2011). Ascoidea is now represented by three families in Canada. Ascidae are mostly predators, with 40 species known from Canada and perhaps as many more expected (Table 2). New records include several Arctic species in the aptly-named genus *Arctoseius* (e.g., Lindquist and Makarova 2011) as well as new species phoretic on carabids. Other species are anticipated, from genera (*Anystipalpus*, *Maxinia*) recorded from Eurasia with similar habitats or hosts occurring in Canada (Lindquist and Moraza 2009, Lindquist and Makarova 2012).

Species of Ameroseiidae in Canada are known from bracket fungi, animal nests, compost, stored grain and litter, where they apparently feed on fungi. Since Lindquist et al. (1979), moderate increases in species numbers have been recorded. There are five species recorded and at least 20 more expected (Table 2). So far, genera of flower-associated ameroseiids known from Europe (Karg 1993) and subtropical-tropical regions have not been found in Canada.

Among Melicharidae recorded from Canada, *Proctolaelaps* dominates in species richness and diversity of habits, some having diverged from predation and adapted to feeding on fungi and pollen in associations with beetles and bumble bees. Some recently described *Proctolaelaps* from Canada were collected from rodents (Karg 2005; Table 2). Other melicharid species recorded since Lindquist et al. (1979) include symbionts of *Monochamus* beetles, and a fungivore living in the pore tubes of bracket fungi (Table 2). One or two species of *Rhinoseius* or *Tropicoseius*, which feed on nectar and disperse on hummingbirds (Naskrecki and Colwell 1998), may be present in Canada.

Superfamily Phytoseioidea

The ecologically diverse family Blattisociidae includes predators, fungivores, and insect symbionts (Lindquist 1963, Makarova 2004, Lindquist et al. 2009b). Many species of the subfamily Platyseiinae are adapted to subaquatic habitats, including two *Platyseius* species recently described from the west and east coasts of Canada (Lindquist 2003). Blattisociinae are parasitic on arthropods, such as *Blattisocius patagiorum* Treat, which infests noctuoid moths (Treat 1975). Blattisociids need revision in North America, with 32 species recorded and at least 25 more expected in Canada (Table 2).

Otopheidomenidae are obligate parasites of insects. No species are known from Canada; the species recorded by Lindquist et al. (1979) appears to belong to another family, probably Laelapidae. We anticipate a few species in southern Canada, including one recorded in northeastern USA that lives in the tympanic cavities of noctuoid moths (Treat 1975), and possibly others that parasitize various lygaeid, pyrrhocorid and nabid bugs (Krantz and Khot 1962; Table 2).

Among species-rich families of Mesostigmata worldwide, Phytoseiidae is probably the best known, and this applies to Canada too. This is largely because of their known and potential roles as biocontrol agents of agricultural pests (Gerson et al. 2003). The known diversity of phytoseiids in Canada has significantly increased since 1979 to 110 species (Table 2), thanks to taxonomic revisions (e.g., Chant and Yoshida-Shaul 1984, Denmark and Evans 2011) and newly identified specimens in the CNC, which now includes Don Chant's collection. Despite this fundamental work, distribution and host records of phytoseiids in North America are scattered. We predict another 75 species may be recorded in Canada in the future.

Lindquist et al. (1979) anticipated that a species of Podocinidae may occur in southern Canada, and this was confirmed by a record from Rondeau Provincial Park (Lindquist and Wu 1987). The same species is expected to occur in south coastal British Columbia.

Superfamily Dermanyssoidea

This taxonomically and ecologically diverse group of parasitic and predatory mites includes 11 families and 166 recorded species in Canada (Table 2). The large majority of families consist of strictly blood-feeding parasites found on the skin and in the respiratory tracts of birds, mammals, and reptiles (Radovsky 1994, Lindquist et al. 2009b, Dowling and OConnor 2010b). Some are of medical and veterinary importance. Since 1979, there has been moderate increase in the number of species recorded from bats (Macronyssidae, Whitaker et al. 2007; and Spinturnicidae), birds (Dermanyssidae; Knee 2008), and small mammals (Haemogamasidae), most of which are not published. Most notably, the records for Rhinonyssidae, which inhabit birds' respiratory tracts, have leaped from three to 61 species in Canada (Table 2), thanks to recent research. One species of Entonyssidae, *Entophionyssus hamertoni* (Radford), is known from the respiratory passage of the common garter snake in western Canada (Fain 1961); this record was apparently missed by Lindquist et al. (1979).

Laelapidae includes facultative and obligate ectoparasites of mammals (Laelapinae, Hirstionyssinae), species of which are commonly found in their nests. However, the most diverse genera of laelapids are soil-dwelling predators (most Hypoaspidinae) and symbionts of arthropods, particularly ants (other Hypoaspidinae). Species records of Laelapidae in Canada are largely unpublished, and possibly 60 additional species remain to be identified or described in the country (Table 2). A few studies of parasites of rodents and other mammals, of bumble bee associates, and soil surveys have increased records of laelapids in Canada (Jones and Thomas 1982, Whitaker and French 1982, Haas et al. in press). At least three species are sold as biocontrol agents of greenhouse pests, one of which was discovered in Canada (Beaulieu 2009). The large proportion of species identified with uncertainty in Canadian soil surveys (e.g., St. John et al. 2002) is indicative of the need for taxonomic revisions for Laelapidae, especially the free-living Hypoaspidinae.

Although several species of Iphiopsididae are expected to occur in Canada, the only one recorded is an unidentified species of *Narceolaelaps* collected from millipedes. Varroidae is another new family record for Canada since Lindquist et al. (1979). The highly invasive pest of western honey bees, *Varroa destructor* Anderson and Trueman, was recorded in the USA in 1987 and has spread across Canada as of 1989 (Sanford 2001, Rosenkranz et al. 2010).

Superorder Acariformes: Order Trombidiformes

The superorder Acariformes comprises two lineages, the Trombidiformes and the Sarcoptiformes, which together are far more diverse taxonomically and ecologically than Parasitiformes or any other lineage of arachnids. Like most other arachnids, the vast majority of Trombidiformes feed on fluids (with the possible exception of some Sphaerolichida), but they do so in almost every conceivable way, from predation to mycophagy to plant and animal parasitism. The Trombidiformes consists mostly of the Prostigmata, but includes also Sphaerolichida, which comprises two small families with ambiguous relationships.

Suborder Sphaerolichida

Sphaerolichidae and Lordalycidae were previously included in the Endeostigmata, in part based on superficial resemblance, but were later transferred to Trombidiformes (OConnor 1984), as they share derived characters with Prostigmata. Molecular work supports this relationship (Pepato and Klimov 2015), and at least Lordalycidae may belong within the traditional Prostigmata (Klimov et al. 2018). These small, globular mites are common in soil, litter and moss worldwide but are rarely studied. The presence of fungal materials in the guts of some of these animals suggests that they are fungivorous (Theron 1979, Walter 1988b). However, it has also been theorized that members of *Sphaerolichus* are ambush predators (Walter et al. 2009). Lordalycids have been collected across Canada, but have not been identified (Table 3). Sphaerolichids, in contrast, are known from just two undetermined specimens from Quebec. A couple more species may be expected for each family.

Suborder Prostigmata

Prostigmatans display an exceptional diversity of lifestyles and ecological niches, and include herbivores (e.g., Tetranychoidea); fungivores (e.g., many Tydeoidea, Heterostigmata); an array of (proven and putative) predators in soils, on plants, and in fresh and marine waters; arthropod symbionts; diverse lineages of invertebrate (Parasitengona, some Heterostigmata) and vertebrate parasites (e.g., Cheyletoidea, Myobiidae). Based on species records alone, taxonomic knowledge has most notably improved since 1979 for Rhagidiidae, Tydeoidea, Hygrobatoidea, Cheyletoidea, Myobiidae, Stigmaeidae, Tetranychidae, and Tarsonemidae. There are currently 1100 species of Prostigmata recorded in Canada (increased from 800 in 1979), belonging to 86 families (Table 3). This excludes the Eriophyoidea, which, based on recent data (see Bolton et al. 2017, Klimov et al. 2018), appears to belong to Sarcoptiformes. An additional 12 families of Prostigmata are represented in Canada, although by as yet undetermined species, and 10 other families are anticipated. A total of 13 families represent new records since 1979, four of which are based on undetermined material only.

Molecular work yielding barcodes has produced 3261 BINs for 62 families of Trombidiformes (Tables 1, 3). For many families, the number of BINs is well above predictions of total species richness based on morphology, particularly Bdellidae (169 BINs), Cunaxidae (96), Eupodidae (520), Rhagidiidae (165), Tydeidae (217), Anystidae (61), Erythraeidae (313), Trombidioidea (122), and Pygmephoridae (112). We estimate a total diversity of over 3200 species of Prostigmata in Canada, about two thirds of which are yet undocumented.

Table 3. Census of the order Trombidiformes (Acari: Acariformes) in Canada.

Taxon[1]	No. species reported in Lindquist et al. (1979)	No. species currently known from Canada	No. BINs[2] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[2A] and vertebrate host range	Information sources
Suborder Sphaerolichida						
Superfamily Lordalycoidea						
Lordalycidae	2	0	0	2	Taiga ecozones and southward	Marshall and Kevan 1964
Superfamily Sphaerolichoidea						
Sphaerolichidae	0	0	0	2	Mixedwood Plains	
Suborder Prostigmata						
Infraorder Labidostommatina						
Superfamily Labidostommatoidea						
Labidostommatidae[3]	1	1	0	3	Pacific Maritime, Boreal Cordillera, Arctic, Mixedwood Plains	Bertrand 1990
Infraorder Eupodina						
Superfamily Bdelloidea						
Bdellidae	15	20	169	25	all ecozones	Hernandes et al. 2016
Cunaxidae	10	16	96	40	all ecozones	Skvarla et al. 2014
Superfamily Eupodoidea						
Eupodidae	35	13	520	30	all ecozones	Behan 1978, Moseley 2007
Penthaleidae	1	2	13	4	most ecozones	Behan 1978
Penthalodidae	2	2	21	5	all ecozones	Jesionowska 2010
Rhagidiidae	25[4]	51	165	30	all ecozones	Behan 1978, Zacharda 1986, 1995a, b, 1996, 1997
Strandtmanniidae	?[4]	0	0	1	Prairies, Atlantic Maritime	Zacharda 1979, Newton 2013
Superfamily Tydeoidea						
Ereynetidae	7	9	23	40	all ecozones; birds	Knee et al. 2008, Knee and Galloway 2017b
Iolinidae	?[5]	12	3	20	all ecozones	Marshall 1970, Forest et al. 1982, Momen 1990, Momen and Sinha 1991, Silva et al. 2016
Triophtydeidae	?[5]	2	18	5	Boreal ecozones and southward	
Tydeidae	20[5]	30	217[6]	40	all ecozones	
Infraorder Anystina						
Hyporder Anystae						
Superfamily Adamystoidea						
Adamystidae	1	0	0	1	Montane Cordillera, Western Interior Basin, Boreal Shield	Ueckermann 1989

Taxon[1]	No. species reported in Lindquist et al. (1979)	No. species currently known from Canada	No. BINs[2] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[2A] and vertebrate host range	Information sources
Superfamily Anystoidea						
Anystidae	2[7]	1	61	3	Boreal ecozones and southward	
Erythracaridae	?[7]	0	8	6	most ecozones	Otto 1999a, b, c
Pseudocheylidae	1	2	0	1	Mixedwood Plains	Van Dis and Ueckermann 1991
Teneriffiidae*	0	0	0	1	Montane Cordillera, Western Interior Basin	Walter et al. 2009
Superfamily Caeculoidea						
Caeculidae	1	2	2	2	Montane Cordillera, Prairies	McDaniel and Boe 1990
Superfamily Pomerantzioidea						
Pomerantziidae	0	2	0	1	Pacific Maritime, Prairies, Mixedwood Plains	Fan and Chen 2005
Superfamily Paratydeoidea						
Paratydeidae	1	2	0	3	Pacific and Atlantic Maritime, Montane Cordillera, Prairies, Mixedwood Plains	Khaustov 2017
Unplaced superfamily						
Superfamily Halacaroidea[8]						
Halacaridae	10	10	1	100	most ecozones	Bartsch 2011, Chatterjee et al. 2011
Hyporder Parasitengona						
Parvorder Erythraeina						Mąkol and Wohltmann 2012
Superfamily Calyptostomatoidea						
Calyptostomatidae	1	1	13	2	Boreal ecozones and southward	
Superfamily Erythraeoidea						
Erythraeidae	10	5	313	50	all ecozones	Southcott 1992b
Smarididae	1	0	14	5	Prairies (Cypress Hills), Mixedwood Plains, Atlantic Maritime	
Parvorder Trombidiina						Mąkol and Wohltmann 2012
Superfamily Tanaupodoidea						
Amphotrombiidae	0	0	0	2	Pacific Maritime, Boreal Shield	
Tanaupodidae	0	0	0	5	Atlantic Maritime	
Superfamily Trombiculoidea						
Johnstonianidae	3	1	22	8	most ecozones	
Leeuwenhoekiidae	?[9]	1	0	15	Boreal ecozones and southward; bats, rodents, amphibians	Walters et al. 2011

Taxon[1]	No. species reported in Lindquist et al. (1979)	No. species currently known from Canada	No. BINs[2] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[2A] and vertebrate host range	Information sources
Neotrombidiidae*	0	0	0	4	Mixedwood Plains, Atlantic Maritime	Lindquist and Vercammen-Grandjean 1971
Trombellidae*	0	0	0	1	Mixedwood Plains	Southcott 1987
Trombiculidae	7[9]	20	9	70	Taiga Cordillera and southward; mammals incl. bats, birds, herps	Brennan and Jones 1955, Wrenn 1987, Walters et al. 2011
Walchiidae*	0	0	0	1	Boreal Shield, Mixedwood Plains, Atlantic Maritime; rodents, opossum	
Superfamily Trombidioidea						
Microtrombidiidae	?[10]	7	80	20	all ecozones	Southcott 1991, 1992a, 1993
Trombidiidae	10[10]	3	42	15	all ecozones	
Parvorder Hydrachnidia[11]						Smith 1987b, 1991c, 2010, Smith et al. 2011
Superfamily Arrenuroidea						
Acalyptonotidae	2	3	1	2	most ecozones	Smith 1983e
Arrenuridae	100	97	137	125	all ecozones	
Athienemanniidae	5	6	0	1	Taiga ecozones and southward	Smith 1989a, 1990a, 1992a
Chappuisididae[12]	1	5	0	1	Taiga ecozones and southward	Smith 1983b, 1992b
Krendowskiidae	3	3	3	3	Mixedwood Plains, Atlantic Maritime	Smith 1983a
Laversiidae	1	1	1	1	Taiga ecozones and southward	
Mideidae	3	2	2	1	most ecozones	
Mideopsidae	12[13]	16	22	15	Taiga ecozones and southward	
Momoniidae	3	9	1	3	Taiga ecozones and southward	Smith 1989b, c, d, 1991b
Neoacaridae	3	9	0	5	Taiga ecozones and southward	Smith 1983d, 2003
Nudomideopsidae	?[13]	2	1	0	Taiga ecozones and southward	Smith 1990b
Superfamily Eylaoidea						
Eylaidae	6	9	23	20	all ecozones	Smith 1986
Limnocharidae	3	5	6	2	Taiga ecozones and southward	Smith and Cook 2005a, b
Piersigiidae	1	1	1	2	Boreal Shield, Taiga Shield, Mixedwood Plains, Atlantic Maritime	
Superfamily Hydrachnoidea						
Hydrachnidae	15	23	21	20	Taiga ecozones and southward	Conroy and McKillop 1984, Smith 1987a
Superfamily Hydrovolzioidea						
Hydrovolziidae	3	2	0	1	Boreal ecozones and southward	

Taxon[1]	No. species reported in Lindquist et al. (1979)	No. species currently known from Canada	No. BINs[2] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[2A] and vertebrate host range	Information sources
Superfamily Hydryphantoidea						
Hydrodromidae	2	1	12	4	Taiga ecozones and southward	
Hydryphantidae	30	42	82	20	Taiga ecozones and southward	Smith 1983c, Smith and Cook 1998, 1999a, b, 2009b
Rhynchohydracaridae	0	1	0	2	Pacific and Atlantic Maritime, Mixedwood Plains	
Thermacaridae	0	1	1	0	Montane Cordillera	Heron and Sheffield 2016
Superfamily Hygrobatoidea						
Aturidae	30	40	25	40	Taiga ecozones and southward	Smith 1984a, Radwell and Smith 2012
Feltriidae	15	35	3	35	all ecozones	
Frontipodopsidae	0	1	0	0	Pacific Maritime, Montane Cordillera	
Hygrobatidae	20	25	60	60	Taiga ecozones and southward	Conroy 1982a, Conroy and Bilyj 1992, 1998, Smith and Cook 2006
Lethaxonidae	0	1	0	0	Pacific Maritime	
Limnesiidae	15	20	60	40	Taiga ecozones and southward	Smith and Cook 1994
Pionidae	60[14]	65	153	75	all ecozones	Smith 1976, Conroy 1982b, 1984, Smith and Cook 2009a
Unionicolidae	25	35	108	35	Taiga ecozones and southward	Conroy 1991a, b, 1992a, b
Wettinidae	?[14]	2	2	1	Taiga ecozones and southward	
Superfamily Lebertioidea						Smith 1982
Anisitsiellidae[15]	5	10	8	10	Taiga ecozones and southward	Smith 1979b
Lebertiidae	15	20	59	60	all ecozones	
Oxidae	10	9	24	15	Taiga ecozones and southward	
Rutripalpidae	0	1	0	0	Atlantic Maritime	Smith 1991a
Sperchontidae	20	25	28	50	all ecozones	
Teutonidae	2	3	0	3	Taiga ecozones and southward	
Torrenticolidae	15	37	14	25	Taiga ecozones and southward	
Parvorder Stygothrombiina						
Superfamily Stygothrombioidea						
Stygothrombiidae	?[10]	1	1	10	Taiga ecozones and southward	

Taxon[1]	No. species reported in Lindquist et al. (1979)	No. species currently known from Canada	No. BINs[2] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[2A] and vertebrate host range	Information sources
Infraorder Eleutherengona						
Hyporder Raphignathina						
Superfamily Cheyletoidea						
Cheyletidae	23[16]	35	9	40	Boreal ecozones and southward; birds, mammals	Thewke and Enns 1979, Bochkov and Galloway 2001
Demodecidae	1	4	0	20	all ecozones; mammals	Gentes et al. 2007, Desch et al. 2010
Harpirhynchidae	2	15	0	40	all ecozones; birds, snakes?	Byers and Proctor 2013, Bochkov et al. 2015
Psorergatidae	4	7	0	40	Boreal Shield, Prairies; mammals	Kok et al. 1971, Giesen et al. 1983
Syringophilidae	0	13	0	300	all ecozones; birds	Skoracki 2011, Zmudzinski and Skoracki 2017
Superfamily Myobioidea						
Myobiidae	7	19	0	30	all ecozones; small mammals	Lukoschus et al. 1980, 1988, Whitaker et al. 2007
Superfamily Pterygosomatoidea						
Pterygosomatidae*	0	0	0	1	Mixedwood Plains	Newell and Ryckman 1966
Superfamily Raphignathoidea						
Barbutiidae	0	1	0	2	Montane Cordillera, Prairies, Mixedwood Plains, Atlantic Maritime	Fan et al. 2003
Caligonellidae	3	4	0	5	Boreal ecozones and southward	
Camerobiidae	1[17]	0	1	6	Pacific and Atlantic Maritime, Montane Cordillera, Western Interior Basin, Prairies	Bolland 1986, 1991
Cryptognathidae	2	2	0	5	Boreal ecozones and southward	Doğan 2008, Walter and Latonas 2012
Dasythyreidae	0	0	0	1	Western Interior Basin, Prairies, Mixedwood Plains	Walter and Gerson 1998, Walter and Latonas 2012
Dytiscacaridae*	0	0	0	1	Boreal ecozones and southward	Mortazavi et al. 2018
Eupalopsellidae	1	1	4	3	most ecozones	
Homocaligidae	2	1	1	2	Boreal ecozones and southward	Fan and Zhang 2004
Raphignathidae	5	4	3	4	Boreal ecozones and southward	McClure 1943
Stigmaeidae	25	40	56	30	all ecozones	Wood 1972, Fan et al. 2016

Taxon[1]	No. species reported in Lindquist et al. (1979)	No. species currently known from Canada	No. BINs[2] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[2A] and vertebrate host range	Information sources
Superfamily Tetranychoidea						Smith et al. 2011, Beaulieu and Knee 2014
Linotetranidae	1[17]	0	0	2	Boreal and Montane Cordilleras, Prairies	Leetham and Milchunas 1985
Tenuipalpidae	5	12	20	40	Taiga ecozones and southward	Beard et al. 2012
Tetranychidae	25	48	154	45	all ecozones	Baker and Tuttle 1994
Tuckerellidae*	0	0	0	1	Prairies	McDaniel et al. 1975
Hyporder Heterostigmata						
Superfamily Dolichocyboidea						
Crotalomorphidae*	0	0	0	1	Mixedwood Plains	Lindquist and Krantz 2002, Husband and Husband 2005
Dolichocybidae	1	0	0	5	Prairies, Mixedwood Plains	Magowski and Moser 1993
Superfamily Heterocheyloidea						
Heterocheylidae	1	1	0	0	Mixedwood Plains	Lindquist and Kethley 1975
Superfamily Pyemotoidea						
Acarophenacidae	2	3	0	5	Boreal ecozones and southward	Cross and Moser 1971, Walter and Seeman 2017
Caraboacaridae	0	0	0	2	Mixedwood Plains	Nickel and Elzinga 1969
Pyemotidae	3[18]	6	0	5	Boreal ecozones and southward	Moser et al. 1987
Superfamily Pygmephoroidea						
Microdispidae	2	0	3	10	Boreal ecozones and southward	Mahunka and Philips 1978, Smiley and Moser 1984, Uppstrom 2010
Neopygmephoridae	?[18]	9	0	25	all ecozones	Mahunka 1975, Whitaker et al. 2007
Pygmephoridae	25[18]	21	112	50	all ecozones; mammals (phoresy)	Mahunka 1975, Smiley and Whitaker 1984, Whitaker et al. 2007
Scutacaridae	25	6	145	90	all ecozones	Delfinado and Baker 1976, 1978, Ebermann and Jagersbacher-Baumann 2015
Superfamily Tarsocheyloidea						
Tarsocheylidae	4	4	5	4	Mixedwood Plains, Boreal Shield, Atlantic Maritime	Delfinado and Baker 1974

Taxon[1]	No. species reported in Lindquist et al. (1979)	No. species currently known from Canada	No. BINs[2] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[2A] and vertebrate host range	Information sources
Superfamily Tarsonemoidea						
Podapolipidae	1	7	0	20	all ecozones	Husband 1998, Husband and Husband 2004, 2007
Tarsonemidae	40	53	79	70	all ecozones	Lindquist 1969a, b, 1970, 1986
Superfamily Trochometridioidea						
Trochometridiidae	0	1	0	1	Western Interior Basin, Prairies	Cross and Bohart 1979, Lindquist 1985
Unplaced superfamily						
Superfamily Cloacaroidea						Bochkov and OConnor 2008
Cloacaridae*	0	0	0	4	most ecozones; turtles, birds	
Epimyodicidae*	0	0	0	2	Taiga ecozones and southward; small mammals	
Total	**802**	**1100**	**3261**	**2162**		

*These families are anticipated for Canada although no specimens have been collected to date; for other families with 0 known species, some undetermined material has been collected in Canada.
[1]Classification mostly follows Walter et al. (2009), as modified by Zhang et al. (2011), with the exceptions mentioned in footnotes 7, 8, 12 and 15, and of Eriophyoidea transferred to Endeostigmata (Table 4), based on Bolton et al. (2017) and Klimov et al. (2018). [2]Barcode Index Number, as defined in Ratnasingham and Hebert (2013). [2A]See figure 1 in Langor (2019) for a map of ecozones. [3]As Nicoletiellidae in Lindquist et al. (1979), see Lindquist and Sidorchuk (2015). [4]Strandtmanniidae was included in Rhagidiidae. [5]Iolinidae and Triophtydeidae were included in Tydeidae. [6]A limited number of BINs may have been misidentified and may represent Triophtydeidae or Iolinidae. [7]Erythracaridae was included in Anystidae; Erythracaridae here treated as a separate family following Pepato and Klimov (2015). [8]Transferred from Eupodina to Anystina, based on Pepato and Klimov (2015). [9]Leeuwenhoekiidae was included in Trombiculidae. [10]Microtrombidiidae and Stygothrombiidae were included in Trombidiidae. [11]Papers listed here include extensive information and lists of primary references for most or all water mite families that occur in Canada. [12]Includes Uchidastygacaridae. [13]Nudomideopsidae was included in Mideopsidae. [14]Wettinidae was included in Pionidae. [15]Includes Bandakiopsidae. [16]Includes former Cheyletiellidae. [17]Undetermined species of Camerobiidae and Linotetranidae were recorded in Lindquist et al. (1979) in footnotes only, p. 273. [18]Neopygmephoridae was included in Pygmephoridae, in part, and Pyemotidae.

Infraorder Labidostommatina

The one family in this group, Labidostommatidae, is a distinct, early-derivative assemblage of heavily armoured, predatory mites (Walter et al. 2009). The most recent comprehensive work on labidostommatids is by Bertrand (1990), but no specimens from Canada are mentioned. Based on Canadian records alone, this family appears to be restricted to the west, with specimens from coastal British Columbia, Yukon, and the Northwest Territories; however, as Lindquist et al. (1979) noted, species occurring in the northeastern USA may extend into southern Ontario. One species is presently known from Canada and as many as three more may occur.

Infraorder Eupodina

Superfamily Bdelloidea

This superfamily includes two families, Cunaxidae and Bdellidae, known as the 'snout mites' due to their elongate gnathosomas. The group is of uncertain monophyly (Pepato and Klimov 2015, Klimov et al. 2018, E Lindquist pers. obs.). Cunaxids and bdellids are predators in soil and litter, but also on plant surfaces (Walter et al. 2009). In their recent catalogue, Hernandes et al. (2016) list only seven species of Bdellidae from Canada. In contrast, Lindquist et al. (1979) included 15 species, and we include 20 recorded species with an additional 25 species expected (Table 3). Similarly, Cunaxidae are represented in Canada by at least 16 described species, with as many as 40 undescribed and/or unrecorded species expected, which is a steep increase since 1979 (M Schwarzfeld and V Nowell unpubl. data; Table 3).

Superfamily Eupodoidea

Eupodoid mites live in a range of habitats, including extreme arctic, alpine, coastal and cave environments. Their diet is poorly known but varies from small invertebrate prey (Rhagiididae, perhaps some Eupodidae) to plant tissues (Penthaleidae) and fungi, algae or lichens (suspected in some Penthalodidae and Eupodidae) (Walter et al. 2009). The five known families in Canada include 68 recorded species, which account for roughly half of the expected diversity (Table 3). Within this lineage, Eupodidae and Rhagidiidae are the most species-rich families and are in great need of taxonomic work, as indicated by the number of undescribed species at hand in the CNC and the surprisingly high number of BINs for each. Rhagidiidae was the focus of revisions by Zacharda (Table 3), which included the description of 16 new species from Canada, but clearly much work remains to document this family fully. The putatively predatory family Strandtmanniidae was described by Zacharda (1979); it has been recorded from Alberta (Newton 2013) and New Brunswick, although not identified to named species. While little has changed since 1979 for the depauperate families Penthaleidae and Penthalodidae, the relatively high number of BINs for each suggests additional species remain to be identified.

Superfamily Tydeoidea

Tydeoids are small, soft-bodied mites, ecologically diverse, and currently divided into four families (Walter et al. 2009, Zhang et al. 2011), all of which occur in Canada (Table 3). Most appear to be free-living scavengers, predators and omnivores and are common on plant substrates, in soil, moss and lichens. At least 10 species of Iolinidae and Tydeidae have been recorded from stored grains in Canada, including six described as new (Momen 1990, Momen and Sinha 1991). In contrast to the three other families, Ereynetidae also includes vertebrate parasites, six species (subfamily Speleognathinae) of which are recorded as intranasal parasites of birds in Canada (Knee et al. 2008, Knee and Galloway 2017b), and at least another recorded species belongs to a genus (Ereynetinae: *Riccardoella*) of which members are typically blood-feeding parasites of snails and slugs (Table 3). Other newly recorded tydeoids are associated with insects in Canada, including some ereynetids that live beneath tree bark and are phoretic on bark beetles. Also, two genera of iolinids collected from the tympanum of noctuoids in Massachussetts (Treat 1975) probably occur here. In addition to the 53 species of tydeoids known in Canada, we predict that ~100 species will be recorded in the future (Table 3).

Infraorder Anystina: Hyporder Anystae

This lineage includes seven families in Canada, five of which are represented by named species (Table 3). Most taxa are considered predatory and inhabit dry, often exposed, habitats (Walter et al. 2009). Pomerantziidae is newly recorded for Canada (unpublished CNC records), with at least two species collected from deep soils. Anystidae, or whirligig mites, is represented by one commonly collected species, *Anystis baccarum* (L.), thought to be an important biocontrol agent (Gerson et al. 2003). However, molecular data (BINs) suggest that additional anystid species may occur here (Table 3). Erythracaridae, previously treated as a subfamily of Anystidae, was recently elevated to family status (Pepato and Klimov 2015) and is known from Canada based on undetermined material. Known species richness of the families Adamystidae, Pseudocheylidae, Paratydeidae and Caeculidae in Canada has not changed significantly since Lindquist et al. (1979), although one new species of caeculid is being described from Alberta (J Bernard and L Lumley unpubl. data). One additional family, Teneriffiidae, will likely be found on the west coast, as it occurs nearby in the northwestern USA.

Infraorder Anystina: Unplaced superfamily

Superfamily Halacaroidea

The single family Halacaridae may be more closely related to Parasitengona than to Eupodina (Pepato and Klimov 2015). The majority of Halacaridae known worldwide are from marine littoral or deeper ocean waters (Bartsch 2009); however, half of the 10 recorded species in Canada are from fresh waters, including lakes, rivers and groundwater. It appears the taxonomy of marine taxa is even more poorly known than for freshwater species in Canada, the latter of which were reviewed by Bartsch (2011) for North America. While most halacarids are free-living in sediments or among vegetation as predators or algivores, some are putative parasites as they have been found on or within larger invertebrates, e.g., gastropods, crayfish, and hydrozoans (Walter et al. 2009, Walter and Proctor 2013). As many as 100 additional species are anticipated to be found in freshwater, littoral and marine environments of Canada (Table 3).

Infraorder Anystina: Hyporder Parasitengona

Mites of this hyporder have larvae that contrast morphologically and ecologically with the adults. The larvae of most groups are ectoparasitic whereas the deutonymphs and adults are predatory. Parasitengona include many of the largest mites in Canada (2–3 mm) and are often conspicuously coloured, either actively walking on litter, plants or walls (terrestrial parasitengones, including velvet mites), or swimming in freshwater (water mites). Some trombidiids (*Allothrombium*) are biocontrol agents of orchard pests (Zhang 1992).

Terrestrial forms (parvorders Erythraeina and Trombidiina)

The adults and deutonymphs of terrestrial Parasitengona mainly inhabit litter, soil and moss throughout Canada where they feed on other arthropods, but a few feed on pollen (Erythraeidae: *Balaustium*; Yoder et al. 2012). Others (e.g., Calyptostomatidae, Johnstonianidae) favour wet habitats near freshwater where hosts (subaquatic Nematocera) occur. Larvae of most families parasitize a wide variety of arthropods whereas those of Trombiculidae and Leeuwenhoekiidae parasitize diverse vertebrate hosts, including humans, and are commonly known as 'chiggers'.

Families of Erythraeina and Trombidiina have few species known from Canada except Trombiculidae, which represent the only notable increase in recorded species since 1979 (Table 3). Walters et al. (2011) surveyed the literature and provided a summary of known hosts and distributions of chiggers in North America, which includes a few new records from small rodents (Gyorkos and Hilton 1982, Whitaker and French 1982). Based on many undetermined CNC specimens, as well as the numerous records from neighbouring parts of the USA (Walters et al. 2011, Mąkol and Wohltmann

2012), nearly 200 additional species of terrestrial Parasitengona are anticipated for Canada, over half of which are likely to be erythraeids (50 species) and trombiculids (70 species). Since 1979, Tanaupodidae and Amphotrombiidae have been recorded from Canada based on unidentified material from the east coast, and Neotrombidiidae, Trombellidae and Walchiidae are anticipated to be found in Canada (Table 3).

Aquatic forms (parvorders Hydrachnidia and Stygothrombiina)

Numerous species in 36 families (Table 3) representing all seven superfamilies of Hydrachnidia, or true water mites, occur in Canada, along with a few species of the enigmatic interstitial family Stygothrombiidae, which is currently classified in a separate monobasic taxon (Walter et al. 2009) and based on molecular data, falls outside of the Hydrachnidia proper (Dabert et al. 2016). Adults and deutonymphs of water mites are active predators of a wide variety of invertebrates in all types of freshwater habitats throughout Canada. Larval water mites are typically parasites of adult aquatic insects but in some cases also utilize immature insects as hosts. Hosts include a variety of insects, especially Diptera, aquatic and semi-aquatic Hemiptera, Odonata and Coleoptera. Stygothrombiidae parasitize Plecoptera.

Knowledge of the identities and distribution of water mite species in Canada has improved substantially since 1979 although much remains to be discovered and published. Comprehensive keys to Nearctic genera have been published (Smith and Cook 1991, Smith et al. 2001, 2010, 2016) and recent improvements in the classification, biology and ecology are summarized in Walter et al. (2009), Smith et al. (2015), and Proctor et al. (2015). Since 1979, several additional families of water mites have been reported from Canada, including Rhynchohydracaridae from streams (Smith 2010, Smith et al. 2011), Thermacaridae from hot springs in the northern Rocky Mountains (Heron and Sheffield 2016), Frontipodopsidae and Lethaxonidae from interstitial waters in western Canada (Cook et al. 2000, Smith et al. 2011), and the first Nearctic record of Rutripalpidae from springs in Nova Scotia (Smith 1991a, 2010). Research is underway on the lebertioid family Torrenticolidae, the hygrobatoid families Feltriidae, Pionidae and Aturidae, as well as the arrenuroid families Mideopsidae, Krendowskiidae, Neoacaridae (*Volsellacarus*) and the extremely diverse genus *Arrenurus* (Arrenuridae). Whereas 568 named species are known to be present in Canada, nearly 700 additional species are expected to be documented in the future (Table 3).

Infraorder Eleutherengona: Hyporder Raphignathina

Superfamily Cheyletoidea

All five families of Cheyletoidea include ectoparasites associated with the skin of their hosts. However, Cheyletidae includes many species that are free-living predators in stored grains, nests, tree bark, bracket fungi, litter, and on insects, especially beetles, e.g., bark beetles, tenebrionids (CNC records; Walter et al. 2009). Other cheyletids are skin parasites of domesticated mammals (e.g., *Cheyletiella*) and of birds, including two new species described from Manitoba (Bochkov and Galloway 2001). Cheyletidae currently comprises 35 known species in Canada, a ~50% increase since 1979, and another 40 species are expected (Table 3).

Canadian records of Demodecidae (four species) are scarce, and include records from hair follicles and sebaceous glands in humans, and from cattle and mule deer (Kennedy and Kralka 1986; Table 3). Certainly many more species occur across the country on mammalian hosts, sometimes causing skin diseases such as demodectic mange and alopecia (Gentes et al. 2007, Walter et al. 2009). The family Psorergatidae, sometimes called itch mites, is represented by seven species in Canada but many more are expected to be found in the skin of mammals (Giesen et al. 1983, Walter et al. 2009).

Harpirhynchidae is another infrequently reported family found on or in the skin of birds, with several new records in Canada since 1979 (Table 3; Bochkov and Galloway 2013). The North American harpirhynchid fauna is poorly known (Bochkov and OConnor 2013), and we expect many more species to be collected in Canada given the diversity of their potential avian hosts. This family may also be discovered infesting snakes in Canada, as in Eurasia (Beron 1974).

Syringophilidae was not recorded from Canada in 1979 but 13 species are now known from the country, and as many as 300 more are anticipated (Table 3; Bochkov and Galloway 2004). Syringophilids live in the quills of feathers, and species tend to be highly host-specific (Skoracki 2011). Unfortunately, they are rarely encountered because collecting these mites usually requires dissection of the quills.

Superfamily Myobioidea

The cosmopolitan family Myobiidae comprises blood- and lymph-feeding ectoparasites that cling to the fur of small mammals using forelegs modified for clasping (Bochkov and Fain 2003). Although infrequently collected in Canada, they are known from species of rodents, bats and insectivores that have broad geographic ranges. The known diversity of myobiids in Canada (19 species) has more than doubled since Lindquist et al. (1979), and we expect 30 or more species to be discovered in the future (Table 3).

Superfamily Pterygosomatoidea

Pterygosomatidae, the only representative of the superfamily, contains mainly parasites of lizards, but some species parasitize arthropods (Walter et al. 2009). In Canada, they are known only from captive, non-native animals (e.g., chuckwalla:

Sauromalus sp.) and the family is therefore not considered recorded here. However, one species, *Pimeliaphilus sanguisugae* Newell and Ryckman, has been identified from free-living kissing bugs (*Triatoma sanguisuga* LeConte) in Michigan, in close proximity to southeastern Canada (Table 3).

Superfamily Raphignathoidea

Nine families of raphignathoids are recorded from Canada (Table 3), including two (Barbutiidae, Dasythyreidae) newly recorded since Lindquist et al. (1979), although dasythyreids are known only from unidentified material. While most species are thought to be predatory, some are bryophagous (Lindquist et al. 1979, Walter et al. 2009), including four species of Stigmaeidae described from Canada (Gerson 1972, Wood 1972). The known diversity of the Raphignathoidea in Canada has changed little since Lindquist et al. (1979), except for the arboreal and soil-dwelling family Stigmaeidae, for which the number of known species has increased by over 50%. A few additional species are anticipated to occur for most raphignathoid families, though we expect as many as 30 more for Stigmaeidae (Table 3). Furthermore, a new family of mites, Dytiscacaridae, living as subelytral parasites of dytiscid beetles in the USA (Mortazavi et al. 2018), may later be found in Canada, since some of their host species occur here.

Superfamily Tetranychoidea

This is one of the two major groups of Acari that has evolved strict phytophagy, the other being the Eriophyoidea. Three of the five known families are recorded from Canada, with two widespread in the country and representing the bulk of the fauna (Table 3). They include troublesome pests of fruit trees, berries, fields and pastures, greenhouse crops, and ornamentals, as well as potentially invasive species associated with imported commodities, and others that transmit plant viruses (Zhang 2003, Beard et al. 2012, Thistlewood et al. 2013).

The number of known species in this superfamily in Canada has doubled since 1979, and many more species are anticipated (Table 3). Although Tetranychidae, or spider mites, have been revised for the United States (Baker and Tuttle 1994), knowledge of the full North American fauna is limited, with scattered information on the taxonomy, hosts and species distribution (Smith et al. 2011, Beaulieu and Knee 2014). It is thought that approximately half of the Canadian fauna is documented (Table 3).

Tenuipalpidae, commonly called flat mites, is also an understudied group (Gerson 2008, Beard et al. 2012), in part because they are easily overlooked as they are even smaller than spider mites and occupy more cryptic habitats. The fauna of flat mites is known to be considerably more diverse in Canada than was expected in 1979, with many more species to be described, especially in the large genus *Brevipalpus* (Table 3).

Linotetranidae, associated with grass roots (Baker 1953, Leetham and Milchunas 1985), occur in Canada as far north as Yukon, but species are yet to be confirmed (Table 3). The Tuckerellidae, aptly called 'peacock mites' for their fan of ornamental setae, are not yet recorded here, but records from South Dakota grasslands suggest they may occur in Canadian prairies (McDaniel et al. 1975, Lindquist et al. 1979).

Infraorder Eleutherengona: Hyporder Heterostigmata

Heterostigmata comprises seven superfamilies, all represented in Canada, many with highly specialized symbioses with insects (Kaliszewski et al. 1995, Walter et al. 2009).

Superfamily Dolichocyboidea

Of the two families constituting this group, the monobasic Crotalomorphidae is a subelytral parasite of carabid beetles recorded from as far north as Michigan and is anticipated to occur in adjacent areas of Canada (Table 3). Dolichocybidae is known in Canada from an undetermined species, and a few additional species are expected. Although closely associated phoretically with insects, dolichocybids seem to be fungivorous, living in habitats conducive to fungal growth (Kaliszewski et al. 1995).

Superfamily Heterocheyloidea

Members of the monogeneric family Heterocheylidae evidently live as parasites under the elytra of passalid beetles in decaying wood in widespread areas of temperate and tropical forests, excluding western North America and Europe (Schuster and Lavoipierre 1970, Lindquist and Kethley 1975). As reported previously by Lindquist et al. (1979), only one known species extends with its host into southeastern Canada, and no further species are projected to occur in Canada (Table 3).

Superfamily Pyemotoidea

Of the three families in Canada provisionally included in this group, adult female Acarophenacidae (three species) and Pyemotidae (six species) are parasitoids of immature instars of holometabolous terrestrial insects, including various grain-infesting insects and subcortical beetles. A few additional species of these two families are anticipated (Table 3), and a new genus of Pyemotidae remains to be described, based on identification records acquired by Lindquist in 1990–1992 and reported by Barker (1993). Undetermined Caraboacaridae have been collected from litter in Ontario, and we expect more representatives to be collected from harpaline carabid beetles, their usual hosts (Nickel and Elzinga 1969).

Superfamily Pygmephoroidea

Following Khaustov (2008), four families are now recognized in this group, all represented widely across Canada, but with many species identified only to family, including all Microdispidae (Table 3). Members of these families occur mostly in soil or galleries of insects, but species of *Pygmephorus* (Pygmephoridae) are specialized nest associates and phoretic on mammals (Whitaker and French 1982). Generally thought to be fungivorous, the feeding habits of nearly all species of these families are unknown. Females of the genus *Siteroptes* (Pygmephoridae) are economically significant as carriers of fungal pathogens of cereals and other grasses. A much larger variety of taxa of these families is anticipated to occur in Canada.

Superfamily Tarsocheyloidea

The one family and two genera of free-living predators that constitute this cosmopolitan group are both represented in Canada (four species; Table 3), where they occur in moss, humus and rotting wood and are sometimes associated with passalid beetles (Lindquist 1976). Although there is no change in number of recorded species, they have been more widely recorded across southern parts of Canada since Lindquist et al. (1979).

Superfamily Tarsonemoidea

Of the two families constituting this group, all members of Podapolipidae are obligate parasites of insects (Walter et al. 2009). Although some species have been recorded in Canada since Lindquist et al. (1979) bringing the total to seven, as many as 20 additional species in at least four genera are expected to occur in Canada (Husband 1998; Table 3). Tarsonemidae encompasses many genera with disparate feeding habits, including fungivores, phytophages, parasites and parasitoids of insects, and even predators of other tiny mites (Lindquist 1986). There are 53 species recorded from Canada (Table 3), a modest increase since Lindquist et al. (1979), including records of three additional genera. As many as 70 more species may occur in Canada, possibly including representatives of a newly described tribe living as parasites on tetrigid grasshoppers (Seeman et al. 2018).

Superfamily Trochometridioidea

The only family in Canada (Trochometridiidae) was not recorded at the time of Lindquist et al. (1979). First noted by Lindquist (1985), the record of *Trochometridium* from a halictid bee in Penticton, British Columbia, remains the only record for Canada. These associates of ground-nesting bees (Cross and Bohart 1979) are anticipated to occur in arid southern areas of British Columbia and Alberta (Table 3).

Infraorder Eleutherengona: Unplaced superfamily

Superfamily Cloacaroidea

This superfamily consists of specialized parasites of the subcutaneous and mucosal tissues of turtles, birds and small mammals. Some species appear to use the cloacal region of their hosts to disperse between hosts during mating (Bochkov and OConnor 2008). Neither Cloacaridae nor Epimyodicidae have been recorded from Canada, although four species of cloacarids and two species of epimyodicids have hosts that occur in the country.

Superorder Acariformes: Order Sarcoptiformes

This order unites the large suborder Oribatida, which also includes the Astigmata, with the suborder Endeostigmata. Sarcoptiform mites are unusual among arachnids in that basal groups are particulate-feeders, but fluid-feeding has evolved in several lineages and led to vast radiations on plants (Eriophyoidea) and animal hosts (Astigmata: Psoroptida).

Suborder Endeostigmata

Endeostigmata represents an early-derivative assemblage of tiny, soft-bodied mites (Walter 2009b). The group is probably not monophyletic and is not well understood phylogenetically, such that its infraorders and superfamilies remain tentative (Pepato and Klimov 2015, Bolton et al. 2017). Since 1979, it has undergone significant classification change, including some family names (Pachygnathidae is now Alycidae), although most constituent genera and families remain the same. The most extraordinary change here is our provisional placement of the Eriophyoidea within Endeostigmata, following recent molecular and morphological evidence that suggests a close relationship between Eriophyoidea and the endeostigmatan family Nematalycidae, both of which consist of worm-like mites that feed on fluids (Bolton et al. 2017, Klimov et al. 2018). In contrast, most sarcoptiform mites swallow particles of food and form discrete gut boluses, although fluid-feeding occurs in some Endeostigmata (e.g., Nanorchestidae, Alycidae: *Bimichaelia*) and several lineages of parasitic Astigmata.

A total of 176 BINs is assigned to at least four families of Endeostigmata (Tables 1, 4), but BINs for Eriophyoidea were not assigned to family level because the families of most specimens need to be verified. Except for Eriophyoidea, which has relatively few BINs compared to known and anticipated species diversity, the other families of Endeostigmata with molecular data (Alycidae, Nanorchestidae, Terpnacaridae) show a contrastingly high number of BINs compared to total expected diversity as inferred from morphological assessment.

Endeostigmata in the traditional sense (unplaced families)

Mites of these families are found in soil, litter and moss, but also in extreme conditions such as sand dunes, rocky seashores and High Arctic tundra. From limited information, they feed on fungi, unicellular algae, and/or small invertebrates such as nematodes (Walter 2009b). They are taxonomically poorly known in Canada, with minimal progress since Lindquist et al. (1979) and only 17 species from four families so far recorded (Table 4). Few additional species are expected for Alicorhagiidae and Terpnacaridae, whereas more within the larger families Alycidae and Nanorchestidae may be discovered in the future. Two other families are recorded only from unidentified specimens at hand, and two more are anticipated based on records from nearby USA (Table 4).

Superfamily Eriophyoidea

Eriophyoids are often called gall mites or rust mites, referring to the conspicuous galls and deformities induced by many species on their hosts. They are the largest, most ubiquitous group of obligate plant-feeding mites. Their classification is unstable, including family, generic and species concepts, as well as the phylogenetic placement of the superfamily within Acari, which has traditionally been considered a member of Trombidiformes (Lindquist 1996); however, recent data suggest it belongs with the Sarcoptiformes (Klimov et al. 2018). The superfamily is widespread in Canada, likely occurring wherever their hosts occur, which probably includes the large majority of plant species. Some eriophyoids can be especially devastating to agriculture because they vector plant viruses (Oldfield and Proeseler 1996). On the other hand, other species are useful as biocontrol agents of noxious weeds (e.g., Rosenthal 1996, McClay and De Clerck-Floate 2013).

The early-derivative Nalepellidae, herein separated from the angiosperm-associated Phytoptidae (Chetverikov et al. 2015), have diversified on conifer hosts and appear relatively well known in Canada due to a review by Marshall and Lindquist (1972) and to work conducted by Smith (e.g., Smith 1979a, 1984b) (Table 3). Phytoptidae and Diptilomiopidae, each with only six recorded species in Canada, are more poorly known and approximately 25 and 75 species, respectively, are anticipated in the country. Most of the known (113 species) and anticipated diversity (900 species), however, resides in the Eriophyidae. The high proportion of species that could not be identified during a survey of plant-feeding mites in the Prairies of Canada illustrates the need for taxonomic revision of the superfamily (Beaulieu and Knee 2014). Similar to the estimate of Lindquist et al. (1979), we expect over 1000 unrecorded eriophyoid species to occur in Canada based on the large number of potential plant hosts from which mites have not yet been collected, combined with the high host specificity of eriophyoid mites (Oldfield 1996).

Table 4. Census of the suborder Endeostigmata (Acari: Acariformes: Sarcoptiformes) in Canada.

Taxon[1]	No. species reported in Lindquist et al. (1979)	No. species currently known from Canada	No. BINs[2] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[2A]	Information sources
Unplaced families						Walter 2009b
Alicorhagiidae	2	3	0	2	Taiga ecozones and southward	Danks 1981
Alycidae[3]	4	4	24	10	all ecozones	McDaniel 1980, Walter and Latonas 2012
Micropsammidae	0	0	0	1	Prairies	
Nanorchestidae	5	8	86	8	all ecozones	Strandtmann 1982
Nematalycidae*	0	0	0	1	Mixedwood Plains	Bolton et al. 2014
Oehserchestidae	0	0	0	1	Mixedwood Plains	Osler et al. 2008
Proteonematalycidae*	0	0	0	1	Mixedwood Plains	Kethley 1989
Terpnacaridae	2	2	14	5	all ecozones	Walter and Latonas 2012
Superfamily Eriophyoidea						Beaulieu and Knee 2014
Diptilomiopidae	10	6		75	all ecozones	
Eriophyidae	60	113		900	all ecozones	Marshall et al. 1998, Beaulieu et al. 2016
Nalepellidae[4]	?[5]	26	52	20	Taiga ecozones and southward	Marshall and Lindquist 1972, Smith 1984b
Phytoptidae[4]	30[5]	6		25	all ecozones	Smith 1977
Total	**113**	**168**	**176**	**1049**		

*These families are anticipated for Canada although no specimens have been collected to date; for other families with 0 known species, some undetermined material has been collected in Canada.
[1]Classification is modified from Walter et al. (2011), with the inclusion of Eriophyoidea (previously in Trombidiformes) in Endeostigmata, based on Bolton et al. (2017) and Klimov et al. (2018); and division into infraorders and superfamilies of Walter et al. (2011) is not followed, because of unclear support (Bolton et al. 2017). [2]Barcode Index Number, as defined in Ratnasingham and Hebert (2013). [2A]See figure 1 in Langor (2019) for a map of ecozones. [3]As Pachygnathidae in Lindquist et al. (1979). [4]The early-derivative Nalepellidae is herein separated from the angiosperm-associated Phytoptidae, following Chetverikov et al. (2015). [5]Nalepellidae was included in Phytoptidae.

Suborder Oribatida (excl. Astigmata)

Oribatids represent the core lineage of Sarcoptiformes. The numbers presented in this section do not include the hyporder Astigmata, which is taxonomically placed within the infraorder Desmonomata (Norton 1998, Schatz et al. 2011). Due to significant life history differences of the Astigmata compared to the rest of the Oribatida, Astigmata is considered separately (see next section). Oribatid mites inhabit many habitats in addition to their traditional soil-litter environment, such as freshwater (Behan-Pelletier and Eamer 2007) and marine littoral (Pfingstl 2017), and canopy habitats (Behan-Pelletier and Winchester 1998, Lindo and Winchester 2007). They are also the dominant arthropods in peatlands (Behan-Pelletier and Bissett 1994, Barreto and Lindo 2018). Based on their feeding behaviour as a group, they have been referred to as selective generalists (Schneider and Maraun 2005) to reflect the opportunistic feeding strategies of many species within their detrital environment, contributing to decomposition and nutrient cycling processes. Oribatid mites are predominantly detritivore-saprophages, variously feeding on detritus, fungi, algae, and other substrates associated with decaying organic matter, although predation of nematodes is also common. Unique among the Acari and other arthropods is a high prevalence of asexual (thelytokous) reproduction (~9% of species studied), with families or genera for which only females are known (Cianciolo and Norton 2006). Most surprising, however, is the re-evolution of sexual reproductive modes (Domes et al. 2007) arising from within asexual groups, the best example of which is the sexual hyporder Astigmata from within the asexual Desmonomata (Norton 1998). Whether sexual or asexual, many oribatid mites are long-lived for invertebrates (1–7 years; Behan-Pelletier 1999), with slow development and low reproductive rates (iteroparous).

Despite soil biodiversity in general being relatively understudied (Eisenhauer et al. 2017), the Oribatida have historically been, and remain, one of the better-known groups of soil acarines in Canada, due to concerted sampling efforts. This includes the works of N Banks in the earlier 20th century, as well as some more contemporary sampling efforts by M Hammer (1950s), VG Marshall and colleagues (1960–1970s), M Mitchell (1970s), RA Norton (1970–1980s), and VM Behan/Behan-Pelletier (1970s–present). Sampling continues to focus on Oribatida, likely due to their charismatic morphology, high diversity, and life-history traits (e.g., K-strategists) that allow them to be included as bioindicators in environmental monitoring. Notable are the extensive works of Behan-Pelletier and colleagues, including west coast canopy sampling by Z Lindo, and the efforts of DE Walter and colleagues in conjunction with the incorporation of Oribatida into current monitoring programs such as that of the Alberta Biodiversity Monitoring Institute (ABMI) (Walter and Latonas 2012, Walter et al. 2014). Oribatid mites have also often been used for general ecological studies of human and/or natural disturbance (e.g., forestry, agricultural, or industrial practices), and as model taxa for diversity studies (e.g., Behan-Pelletier 1999, Battigelli et al. 2003, Déchêne and Buddle 2009, McAdams et al. 2018).

Table 5. Census of the suborder Oribatida, excluding Astigmata (Acari: Acariformes: Sarcoptiformes) in Canada.

Taxon[1]	No. species reported in Lindquist et al. (1979)	No. species currently known from Canada	No. BINs[2] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[2A]	Information sources
Infraorder Palaeosomata						
Superfamily Acaronychoidea						
Acaronychidae	0	1	0	0	Pacific Maritime	
Archeonothridae	0	1	0	0	Pacific Maritime	
Superfamily Palaeacaroidea						
Palaeacaridae	1	1	0	1	most ecozones	
Superfamily Ctenacaroidea						
Adelphacaridae	0	0	0	1	Pacific Maritime	
Aphelacaridae	1	1	0	0	Pacific Maritime, Montane Cordillera, Prairies	
Ctenacaridae	0	0	0	1	Mixedwood Plains	
Infraorder Enarthronota						
Superfamily Brachychthonioidea						
Brachychthoniidae	25	38	95	57	all ecozones	Marshall et al. 1987, Walter et al. 2014
Superfamily Atopochthonioidea						
Atopochthoniidae	1	1	0	0	Pacific and Atlantic Maritime, Boreal Cordillera, Mixedwood Plains	
Pterochthoniidae	1	1	0	0	Pacific Maritime, Boreal Cordillera, Boreal Plains, Mixedwood Plains	
Superfamily Hypochthonioidea						
Eniochthoniidae	2	3	8	5	Boreal ecozones and southward	Norton and Behan-Pelletier 2007
Hypochthoniidae	2	2	4	3	all ecozones	
Lohmanniidae*	0	0	0	1	Mixedwood Plains	
Mesoplophoridae	2[3]	2	1	1	Boreal Cordillera, Prairies, Mixedwood Plains, Atlantic Maritime	Niedbała 2002
Superfamily Protoplophoroidea						
Cosmochthoniidae	2[4]	1	0	1	Montane Cordillera, Mixedwood Plains	
Haplochthoniidae	1	0	0	1	Prairies	
Sphaerochthoniidae	0	1	0	1	Prairies	

Taxon[1]	No. species reported in Lindquist et al. (1979)	No. species currently known from Canada	No. BINs[2] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[2A]	Information sources
Superfamily Heterochthonioidea						
Arborichthoniidae	0	1	0	0	Mixedwood Plains	Norton 1982
Trichthoniidae	?[4]	1	0	0	Boreal Shield, Mixedwood Plains, Atlantic Maritime, Newfoundland Boreal	Marshall and Reeves 1971
Infraorder Parhyposomata						
Superfamily Parhypochthonioidea						
Gehypochthoniidae	1	2	0	1	Pacific Maritime, Taiga Cordillera, Arctic, Boreal Shield, Mixedwood Plains	
Parhypochthoniidae	1	2	0	1	Pacific and Atlantic Maritime, Boreal Plains, Prairies, Mixedwood Plains	
Infraorder Mixonomata						
Superfamily Eulohmannioidea						
Eulohmanniidae	1	1	0	1	Pacific and Atlantic Maritime, Arctic, Taiga Cordillera, Mixedwood Plains	
Superfamily Perlohmannioidea						
Perlohmanniidae	0	1	2	2	Pacific and Atlantic Maritime, Arctic, Taiga Cordillera	
Superfamily Epilohmannioidea						
Epilohmanniidae	1	1	2	2	Pacific Maritime, Taiga Cordillera, Prairies, Mixedwood Plains	
Superfamily Euphthiracaroidea						Niedbała 2002
Euphthiracaridae	6	19	30	17	all ecozones	
Oribotritiidae	4	13	11	7	Taiga ecozones and southward	
Synichotritiidae	0	2	4	4	Pacific Maritime	
Superfamily Phthiracaroidea						
Phthiracaridae	10	28	68	37	all ecozones	Niedbała 2002
Infraorder Desmonomata						
Hyporder Nothrina						
Superfamily Crotonioidea						
Crotoniidae	12[5]	24	70	25	all ecozones	Colloff 1993
Hermanniidae	3	5	7	4	Pacific and Atlantic Maritime, Arctic	
Malaconothridae	3	3	22	13	all ecozones	Marshall et al. 1987

Taxon[1]	No. species reported in Lindquist et al. (1979)	No. species currently known from Canada	No. BINs[2] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[2A]	Information sources
Nanhermanniidae	2	3	4	4	most ecozones	
Nothridae	5	10	41	22	all ecozones	Marshall et al. 1987, Walter et al. 2014
Trhypochthoniidae	4	7	29	10	all ecozones	Norton et al. 1988, 1996, Behan-Pelletier and Bissett 1994, Walter et al. 2014
Hyporder Brachypylina						
Superfamily Hermannielloidea						
Hermanniellidae	3	5	25	13	Boreal ecozones and southward	
Plasmobatidae	0	0	0	1	Mixedwood Plains	
Superfamily Neoliodoidea						
Neoliodidae[6]	4	2	9	5	Boreal ecozones and southward	
Superfamily Plateremaeoidea						
Gymnodamaeidae	7	11	40	23	all ecozones	Walter 2009a
Licnodamaeidae	1	0	1	1	Pacific and Atlantic Maritime	
Plateremaeidae	0	0	0	1	Mixedwood Plains, Boreal Shield	
Superfamily Damaeoidea						
Damaeidae	24[7,8]	23	77	54	all ecozones	Behan-Pelletier and Norton 1983, 1985
Superfamily Eutegaeoidea						
Anderemaeidae	1	0	4	1	Pacific and Atlantic Maritime, Mixedwood Plains	
Compactozetidae[9]	5	9	23	14	all ecozones	Walter et al. 2014
Superfamily Polypterozetoidea						
Nodocepheidae	0	1	0	0	Pacific Maritime	
Podopterotegaeidae	0	1	0	0	Boreal Shield, Atlantic Maritime, Newfoundland Boreal	
Polypterozetidae	0	0	0	1	Boreal Cordillera	
Superfamily Microzetoidea						
Microzetidae	0	1	0	1	Pacific Maritime, Mixedwood Plains	
Superfamily Ameroidea						
Ameridae	0	1	0	0	Mixedwood Plains	Chen et al. 2004
Caleremaeidae	?[8]	2	3	3	Pacific Maritime, Cordillera ecozones, Arctic, Newfoundland Boreal	

Taxon[1]	No. species reported in Lindquist et al. (1979)	No. species currently known from Canada	No. BINs[2] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[2A]	Information sources
Damaeolidae	1	1	0	1	Pacific Maritime, Boreal Plains, Mixedwood Plains	
Eremobelbidae	1	1	9	9	Mixedwood Plains	
Eremulidae	1	1	3	3	Mixedwood Plains	
Hungarobelbidae	0	0	0	3	Pacific and Atlantic Maritime, Montane Cordillera	
Superfamily Zetorchestoidea						
Eremaeidae	5	32	89	30	all ecozones	Behan-Pelletier 1993
Megeremaeidae	1	5	3	3	Pacific Maritime, Cordillera ecozones, Boreal Shield, Mixedwood Plains	Behan-Pelletier 1990
Zetorchestidae	0	0	0	1	Mixedwood Plains	
Superfamily Gustavioidea						
Astegistidae	3	5	21	12	all ecozones	Marshall et al. 1987
Gustaviidae	1	1	8	5	Pacific Maritime, Boreal Plains, Prairies, Mixedwood Plains	
Kodiakellidae	0	1	0	0	Pacific Maritime	
Liacaridae	7[10]	8	36	25	all ecozones	
Peloppiidae[11]	8	17	66	35	all ecozones	Lindo et al. 2010, Lindo 2011, 2015, 2018
Tenuialidae	3	2	11	7	Boreal ecozones and southward	
Superfamily Carabodoidea						
Carabodidae	4	16	32	12	all ecozones	Reeves 1992, Reeves and Behan-Pelletier 1998
Superfamily Oppioidea						
Autognetidae	3	5	9	7	all ecozones	Behan-Pelletier 2015
Machuellidae	0	0	0	1	Mixedwood Plains	
Oppiidae	20[12]	16	144	60	all ecozones	Marshall et al. 1987, Behan-Pelletier 2010, Walter et al. 2014
Quadroppiidae	?[12]	3	9	5	all ecozones	
Thyrisomidae	5	7	6	5	all ecozones	Marshall et al. 1987, Behan-Pelletier 2010, Walter et al. 2014
Superfamily Trizetoidea						
Suctobelbidae	25	13	70	48	all ecozones	Marshall et al. 1987

Taxon[1]	No. species reported in Lindquist et al. (1979)	No. species currently known from Canada	No. BINs[2] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[2A]	Information sources
Superfamily Tectocepheoidea						
Tectocepheidae	3	2	131	30	all ecozones	
Superfamily Limnozetoidea						
Hydrozetidae	2	4	8	6	most ecozones	
Limnozetidae	1	10	7	7	most ecozones	Behan-Pelletier 1989b
Superfamily Ameronothroidea						
Ameronothridae[13]	3	4	5	3	Boreal Plains, Arctic, Newfoundland Boreal	Marshall et al. 1987
Selenoribatidae	0	0	0	1	Pacific Maritime	
Tegeocranellidae	0	1	0	1	Mixedwood Plains, Atlantic Maritime	Behan-Pelletier 1997b
Superfamily Cymbaeremaeoidea						
Cymbaeremaeidae	1	8	36	18	all ecozones	Behan-Pelletier 1987, 1989a, Norton et al. 2010
Superfamily Licneremaeoidea						
Dendroeremaeidae	0	1	4	4	Pacific Maritime	Behan-Pelletier et al. 2005
Eremellidae	0	1	2	1	Mixedwood Plains	
Licneremaeidae	0	0	0	1	Pacific Maritime	
Micreremidae	1	1	3	1	Mixedwood Plains, Atlantic Maritime	
Passalozetidae	1	2	2	2	Boreal and Montane Cordilleras, Boreal Plains, Boreal Shield, Prairies	
Scutoverticidae	1	1	7	7	Montane Cordillera, Prairies	
Superfamily Phenopelopoidea						
Phenopelopidae[14]	3	8	85	47	all ecozones	Norton and Behan-Pelletier 1986
Unduloribatidae	0	1	0	0	Taiga ecozones and southward	Behan-Pelletier and Walter 2009
Superfamily Achipterioidea						
Achipteriidae	4	12	53	20	all ecozones	Lindo et al. 2008
Tegoribatidae	5	6	40	25	all ecozones	Behan-Pelletier and Walter 2013, Behan-Pelletier 2017
Superfamily Oribatelloidea						
Oribatellidae	12	22	46	23	all ecozones	Behan-Pelletier 2011, 2013, Behan-Pelletier and Walter 2012
Superfamily Oripodoidea						
Haplozetidae	5	12	39	35	all ecozones	Walter and Latonas 2013

Taxon[1]	No. species reported in Lindquist et al. (1979)	No. species currently known from Canada	No. BINs[2] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[2A]	Information sources
Mochlozetidae	1	2	8	5	Arctic, Prairies, Boreal Plains, Boreal Shield, Mixedwood Plains	
Oribatulidae	26[15]	11	175	92	all ecozones	Marshall et al. 1987, Behan-Pelletier et al. 2002
Oripodidae	2[16]	1	16	10	Pacific and Atlantic Maritime, Prairies, Boreal Shield, Mixedwood Plains	
Parakalummidae	4	2	37	20	most ecozones	
Scheloribatidae	?[15,16]	13	184	93	all ecozones	Marshall et al. 1987, Behan-Pelletier et al. 2002, Knee 2017b
Superfamily Ceratozetoidea						
Ceratokalummidae	0	0	7	4	Boreal Cordillera, Mixedwood Plains	
Ceratozetidae	35[17]	53	245	70	all ecozones	Behan-Pelletier 1984, 1985, 1986, 2000, Behan-Pelletier and Eamer 2009
Chamobatidae	1	1	40	21	Taiga ecozones and southward	
Euzetidae	0	0	2	2	Boreal Plains, Boreal Shield, Mixedwood Plains, Atlantic Maritime	
Humerobatidae	?[17]	2	2	2	Pacific and Atlantic Maritime, Boreal Cordillera, Mixedwood Plains	Marshall et al. 1987
Punctoribatidae[18]	10	35	35	30	all ecozones	Behan-Pelletier 1988, 1994, Behan-Pelletier et al. 2001, Behan-Pelletier and Eamer 2005, 2008
Zetomimidae	1	5	21	21	Taiga ecozones and southward	Behan-Pelletier 1996, Behan-Pelletier and Eamer 2003
Superfamily Galumnoidea						
Galumnidae	8	5	93	52	all ecozones	Marshall et al. 1987
Total	**354**	**592**	**2429**	**1267**		

*This family is anticipated for Canada although no specimens have been collected to date; for other families with 0 known species, some undetermined material has been collected in Canada.
[1]Classification follows Schatz et al. 2011, with the addition of modifications by Walter and Latonas (2009) for Haplozetidae; Behan-Pelletier (2013) for Oribatellidae; Norton and Ermilov (2014) for Eutegaeoidea; Behan-Pelletier (2017) for Tegoribatidae. [2]Barcode Index Number, as defined in Ratnasingham and Hebert (2013). [2A]See figure 1 in Langor (2019) for a map of ecozones. [3]Includes former Archoplophoridae. [4]*Trichthonius* previously included in Cosmochthoniidae, now in Trichthoniidae. [5]Includes former Camisiidae. [6]As Liodidae in Lindquist et al. (1979). [7]Includes former Belbidae and parts of Belbodamaeidae. [8]Caleremaeidae includes parts of former Belbodamaeidae (*Veloppia*). [9]As Cepheidae in Lindquist et al. (1979). [10]Includes former Xenillidae. [11]As Metrioppiidae in Lindquist et al. (1979). [12]Quadroppiidae was included in Oppiidae. [13]Includes former Podacaridae. [14]As Pelopidae in Lindquist et al. (1979). [15]Scheloribatidae was included in Oribatulidae. [16]*Parapirnodus* previously included in Oripodidae, now in Scheloribatidae. [17]*Humerobates* previously included in Ceratozetidae, now in Humerobatidae. [18]As Mycobatidae in Lindquist et al. (1979).

Marshall summarized the Oribatida in the Acari section by Lindquist et al. (1979) and reported 71 (+10 expected) families and 354 described species in Canada, with an estimated total diversity of 1554 species. Marshall considered nearly all families (except Kodiakellidae from coastal British Columbia) as probably transcontinental, and the majority of families to have a northern latitudinal range, either to treeline (nine families), to within the Arctic (32 families), or to High Arctic (nine families). The remaining 30 families were considered restricted to southern latitudes. In comparison, of the 100 currently documented or anticipated families in Canada, 44 families are represented in most or all ecozones including the Arctic, 47 families are restricted to boreal and southward, and the remaining nine families are known from only a few ecozones but ranging from southern Canada to as far north as Taiga or Arctic ecozones (Table 5).

Records of Oribatida of Canada up to 1986 were also captured in the *Catalogue of the Oribatid Mites of Canada and the USA* (Marshall et al. 1987), wherein was listed ~300 spp. from 160 genera from published records from Canada. Updates to species and distributional records by province, through to the early 2000s, are available online through the *Diversity of Oribatida in Canada* (DOC) website (Behan-Pelletier and Eamer 2004).

A total of 592 described species from 84 families are recorded in Canada, a 67% increase since 1979 (Table 5). Another 1267 species are expected to be recorded in the future, approximately 300 of which represent undescribed species or morphospecies currently in collections that need identification or verification. An additional 15 families are known in Canada, based on unidentified specimens, and Lohmanniidae is anticipated to be found. As many as 27 families, including 12 with undetermined species only, represent new records since 1979. The 99 families known in Canada represent 58% of the known world families (currently 172; Norton and Behan-Pelletier 2009). The families with the highest documented diversity in Canada include (Table 5): Ceratozetidae (53 species), Brachychthoniidae (38), Punctoribatidae (35), Eremaeidae (32), Phthiracaridae (28), Crotoniidae (24), Damaeidae (23), and Oribatellidae (22). Several of these groups have been extensively reviewed by Behan-Pelletier for North America (Ceratozetidae, Punctoribatidae, Eremaeidae, Damaeidae, and Oribatellidae) and those works contain keys to genera and species (references listed in Table 5).

Families where the number of species has substantially increased since Lindquist et al. (1979) are the Euphthiracaroidea, Crotoniidae, Eremaeidae, Carabodidae, Oribatellidae, and Scheloribatidae (Table 5). Increased species richness in these families is in part due to the taxonomic efforts of VM Behan-Pelletier, M Colloff, M Reeves, and W Niedbała, concomitant with the exploration of previously unexplored habitats (e.g., canopy habitats). On the other hand, reductions in the number of species in some families (e.g., Suctobelbidae, Oribatulidae) are mostly due to revisions in our understanding of the species concept and/or reassessment and placement of species into other taxonomic groups based on new diagnoses.

Molecular data (BINs) suggest that a large portion of the Canadian oribatid diversity remains undescribed or at least unrecorded, with a total of 2429 BINs recorded across 67 families surveyed so far (Tables 1, 5). However, there are discrepancies between the number of BINs and morphology-based identifications for several families of Oribatida, notably Oppiidae (144 BINs), Tectocepheidae (131), Oribatulidae (175), Scheloribatidae (184), and Ceratozetidae (245). For instance, the low diversity of recorded Tectocepheidae (three known spp.) is in contrast to 131 BINs, despite Tectocepheidae containing only two known genera with a total of 16 described species worldwide (Subías 2004). Within this family, known species in Canada reproduce via thelytokous parthenogenesis, and the number of BINs may indicate high within-lineage diversification (Fontcuberta Garcia-Cuenca et al. 2016). It is interesting to note that while Ceratozetidae has the highest number of described species (53 species) and Punctoribatidae, a closely related family, has similarly high diversity (35 species), the number of BINs recorded for Ceratozetidae is 245 while there are only 35 BINs for Punctoribatidae.

Taking into account the increase in discovered and described species over the last 40 years and the high number of BINs recorded so far, we estimate the diversity of Oribatida in Canada to be at least 1800 species, and possibly as many as 3000 species, with at least two thirds yet unrecorded (Table 5). A comparison of the Canadian oribatid fauna with a recent publication by Krisper et al. (2017) on the Oribatida of Austria, where they document over 677 species, supports the assertion that much of the Canadian fauna is still unknown, given that Canada has ~120 times the area of Austria and contains many more ecozones.

Hyporder Astigmata

The Astigmata originated within the oribatid lineage, Desmonomata, and then radiated morphologically and ecologically, adapting to a remarkable diversity of niches (OConnor 2009). Adult astigmatans are similar in appearance to immature oribatids, and hence this clade is thought to have arisen via neoteny. Their evolutionary success can be attributed in part to the evolution of a non-feeding deutonymphal stage for dispersal and for enduring adverse environmental conditions. These traits facilitated colonization of the patchy, transient habitats in which free-living astigmatans thrive, such as animal nests, decaying wood, carrion, fungal sporocarps, and stored products. Many species disperse on insects and have developed relationships with them beyond simple phoresy. Similarly, several lineages of Astigmata have evolved commensal and parasitic relationships with vertebrates, living on and in the skin, fur and feathers of mammals and birds (Psoroptidia: Sarcoptoidea and feather mites). Most non-parasitic Astigmata are assumed to be fungivorous or saprophagous, though vertebrate commensals may also feed on sebaceous oils (OConnor 2009). In Canada, we now know of 441 species of Astigmata from 43 families, compared to a mere 142 species in 1979 (Table 6). In addition, three other families are recorded in Canada, based on unidentified material. The concepts of several families and their placement in superfamilies have changed substantially since 1979. Canestriniidae (Canestrinioidea) was predicted to occur in Canada by Lindquist et al. (1979); we do not expect it to occur here, with the nearest known locality being in the southeastern USA (B OConnor pers. comm.).

The most notable improvements in taxonomy of Astigmata in Canada are for mites associated with the plumage and skin of birds (Analgoidea, Pterolichoidea) (Table 1). There are significant, mostly unpublished, additions in other families, especially Acaridae and Chirodiscidae. The case of feather mites demonstrates how little is known and published and how much work is left to do for the taxonomy of Astigmata in Canada: Galloway et al. (2014) published 118 new records for Canada and mentioned 38 undescribed species of feather mites from grassland birds in Alberta and Manitoba alone! Molecular work conducted for Astigmata in Canada has been relatively limited, with only 153 BINs generated from 19 families; most of these have not yet been confidently assigned to named species. The Acaridae is well represented, encompassing about one third of BINs for Astigmata. In contrast, many families are poorly represented by BINs, compared to the diversity of known or anticipated species. This may be in part due to the limited sampling of Astigmata, which typically live as symbionts of vertebrates or in cryptic, patchy habitats. We estimate that over 1600 species of Astigmata occur in Canada, most of which (>70%) are yet to be discovered.

Superfamily Histiostomatoidea

The one family in Canada, Histiostomatidae, consists of filter-feeding microbivores associated with moist decaying substrates and aquatic microhabitats. In Canada, they have been found associated with decaying bulbs, pitcher plants, insect and worm cultures, as well as with insects such as bark beetles, bees, carrion- and dung-breeding flies on which they disperse. New records since 1979 include two new species phoretic on amphipods (Fain and Colloff 1990) and one described from sphaerocerid flies (Samsinak 1989). Only 21 named species are known from Canada, but four times that many are unrecorded or undescribed (Table 6).

Superfamily Hemisarcoptoidea

Five families of Hemisarcoptoidea have described species recorded in Canada (Table 6). This group includes fungivores in stored products (Carpoglyphidae, Hemisarcoptidae, Winterschmidtiidae), on foliage and in bark crevices (Winterschmidtiidae), algivores in littoral habitats (Hyadesiidae), parasites of coccinellid beetles and scale insects (Hemisarcoptidae), and various associates of subcortical beetles (OConnor 2009). Some winterschmidtiids (subfamily Ensliniellinae) are obligate associates of Hymenoptera, and include a species described from leafcutter bees (Megachilidae) in Nova Scotia which feeds on moulds growing on pieces of leaves in the bee nests (OConnor

Table 6. Census of the hyporder Astigmata (Acari: Acariformes: Sarcoptiformes: Oribatida) in Canada.

Taxon[1]	No. species reported in Lindquist et al. (1979)	No. species currently known from Canada	No. BINs[2] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[2A] and vertebrate host range	Information sources
Superfamily Histiostomatoidea						
Histiostomatidae[3]	20	21	17	80	all ecozones	Fain and Colloff 1990, Walter and Latonas 2012
Superfamily Hemisarcoptoidea						
Algophagidae	0	0	0	3	Boreal ecozones and southward	Fashing and Wiseman 1980
Carpoglyphidae	1	1	0	1	Boreal ecozones and southward	Baker and Delfinado 1978, Beaulieu and Knee 2014
Chaetodactylidae	1	3	1	3	Taiga Plains, Mixedwood Plains	Klimov and OConnor 2008
Hemisarcoptidae	1	3	19	25	Boreal ecozones and southward	Parent 1979, OConnor and Houck 1989
Hyadesiidae	1	1	0	5	Pacific and Atlantic Maritime, Newfoundland Boreal	Fain and Ganning 1989
Winterschmidtiidae	15[4]	9	2	20	all ecozones	OConnor and Eickwort 1988, Walter and Latonas 2012, Beaulieu and Knee 2014
Superfamily Glycyphagoidea						
Aeroglyphidae	?[5]	1	0	0	Boreal ecozones and southward	Beaulieu and Knee 2014
Chortoglyphidae	1	3	0	4	Taiga ecozones and southward; rodents	Fain and Spicka 1977, Krantz et al. 2003, Whitaker et al. 2007
Echimyopodidae*	1	0	0	3	Taiga ecozones and southward; squirrels	Fain and Philips 1977
Euglycyphagidae*	0	0	0	1	Mixedwood Plains; bird nests	Fain and Philips 1977
Glycyphagidae	17[5,6]	20	0	20	all ecozones; small mammals	Whitaker et al. 2007, Walter and Latonas 2012, Beaulieu and Knee 2014
Rosensteiniidae	0	0	0	4	Taiga ecozones and southward; bats	Dood and Rockett 1985
Superfamily Acaroidea						Walter and Latonas 2012
Acaridae	45[7]	56	58	40	all ecozones	Beaulieu and Knee 2014
Gaudiellidae	0	1	0	0	Mixedwood Plains	Haas et al. in press
Lardoglyphidae	?[7]	1	0	1	Prairies, Mixedwood Plains	Iverson et al. 1996
Suidasiidae	?[7]	2	0	3	Boreal ecozones and southward	Beaulieu and Knee 2014
Superfamily Hypoderatoidea						
Hypoderatidae	0	1	0	15	Taiga ecozones and southward; a few bird orders	Pence and Gray 1996, Pence et al. 1997
Superfamily Sarcoptoidea						Whitaker et al. 2007, Bochkov 2010
Atopomelidae*	0	0	0	1	Mixedwood Plains; opossum, nutria	

Taxon[1]	No. species reported in Lindquist et al. (1979)	No. species currently known from Canada	No. BINs[2] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[2A] and vertebrate host range	Information sources
Chirodiscidae	1	11	0	12	Taiga ecozones and southward; bats, beaver, mustelids	Fain and Whitaker 1988
Gastronyssidae*[8]	0	0	0	4	most ecozones; rodents, bats	Bochkov et al. 2008
Listrophoridae	7	11	0	15	Taiga ecozones and southward; small mammals	Fain and Yunker 1980, Whitaker and French 1982
Myocoptidae	5	8	0	4	all ecozones; small mammals	Whitaker and French 1982
Pneumocoptidae*	0	0	0	3	Taiga ecozones and southward; rodents	Baker 1951, Bochkov et al. 2008
Psoroptidae	3	4	1	1	Taiga ecozones and southward; mammals	
Rhyncoptidae*[9]	0	0	0	2	Taiga ecozones and southward; bears, raccoons	Fain and Wilson 1979, Yunker et al. 1980
Sarcoptidae	2	4	1	6	all ecozones; bats, other mammals	
Superfamily Pterolichoidea						Galloway et al. 2014
Ascouracaridae	0	1	0	10	Boreal ecozones and southward; caprimulgiform birds	Gaud and Atyeo 1996
Cheylabididae	0	1	0	1	all ecozones; accipitriform birds	Peterson et al. 1980
Eustathiidae	0	2	0	10	Boreal ecozones and southward; caprimulgiform birds	Peterson et al. 1980
Falculiferidae	0	3	0	15	Boreal ecozones and southward; columbiform birds	
Freyanidae	0	8	0	40	all ecozones; anseriform and pelecaniform birds	Buscher 1965, Bourgeois and Threlfall 1981
Gabuciniidae	0	7	0	25	all ecozones; accipitriform, caprimulgiform, falconiform and passerine birds	Mironov et al. 2007
Kramerellidae	0	10	2	15	all ecozones; several bird orders	Atyeo and Philips 1984
Pterolichidae	2	19	0	70	all ecozones; several bird orders	Dabert and Ehrnsberger 1999
Ptiloxenidae	0	5	0	5	all ecozones; charadriiform birds	
Rectijanuidae	0	0	0	15	Boreal ecozones and southward; anseriform birds	
Syringobiidae	0	9	0	30	all ecozones; charadriiform birds	Dabert and Ehrnsberger 1995
Superfamily Analgoidea						Galloway et al. 2014
Alloptidae	3	22	1	60	all ecozones; several aquatic bird orders	Peterson 1971
Analgidae	1	40	13	90	all ecozones; several bird orders	Wheeler and Threlfall 1986
Apionacaridae*	0	0	0	5	all ecozones; quail (Odontophoridae) and charadriiform birds	

Taxon[1]	No. species reported in Lindquist et al. (1979)	No. species currently known from Canada	No. BINs[2] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[2A] and vertebrate host range	Information sources
Avenzoariidae	3[10]	27	1	80	all ecozones; several aquatic bird orders and osprey	Ballard and Ring 1979
Cytoditidae*	0	0	0	5	Taiga ecozones and southward; several bird orders	Pence 1975
Dermationidae	?[11]	2	1	20	all ecozones; apodiform, charadriiform, passerine and piciform birds	Mironov et al. 2005
Dermoglyphidae	0	1	0	20	all ecozones; several bird orders	
Epidermoptidae	2[11]	7	1	10	all ecozones; several bird orders	Mironov et al. 2005, Knee and Galloway 2017a, Goater et al. 2018
Gaudoglyphidae*	0	0	0	1	all ecozones; domestic chicken	Bruce and Johnston 1976
Knemidokoptidae[12]	0	2	0	10	all ecozones; passerine birds	Mironov et al. 2005, Knee and Proctor 2006
Laminosioptidae*	0	0	0	20	all ecozones; several bird orders	Lukoschus and Lombert 1980, Skoracki et al. 2014
Proctophyllodidae	3	61	22	150	all ecozones; mostly passerines with a few exceptions	Wheeler and Threlfall 1986, Valim and Hernandes 2010
Psoroptoididae	0	4	1	40	all ecozones; owls, and gruiform and passerine birds	Wheeler and Threlfall 1986, Mironov 2011
Pteronyssidae	?[10]	20	3	30	all ecozones; apodiform, charadriiform, passerine and piciform birds	Mironov and Galloway 2006
Ptyssalgidae*	0	0	0	5	Boreal ecozones and southward; hummingbirds	
Pyroglyphidae	5	4	1	5	all ecozones; bird and mammal nests	Gaud and Atyeo 1996
Trouessartiidae	0	8	7	50	all ecozones; passerine birds	Wheeler and Threlfall 1986
Turbinoptidae	1	2	0	10	Taiga ecozones and southward; accipitriform and charadriiform birds	Pence 1975, Knee and Galloway 2017b
Xolalgidae	1	15	1	50	all ecozones; several bird orders	
Unplaced family						
Heterocoptidae*	0	0	0	1	Mixedwood Plains	
Total	**142**	**441**	**153**	**1174**		

*These families are anticipated for Canada although no specimens have been collected to date; for other families with 0 known species, some undetermined material has been collected in Canada.
[1]Classification mostly follows OConnor (2009), as slightly modified by Schatz et al. (2011), with exception mentioned in footnote 12. [2]Barcode Index Number, as defined in Ratnasingham and Hebert (2013). [2A]See figure 1 in Langor (2019) for a map of ecozones. [3]As Anoetidae in Lindquist et al. (1979). [4]Includes former Saproglyphidae. [5]Aeroglyphidae was included in Glycyphagidae. [6]Includes former Labidophoridae, Fusacaridae and Ctenoglyphidae. [7]Lardoglyphidae and Suidasiidae were included in Acaridae. [8]As Yunkeracaridae in Lindquist et al. (1979). [9]As Audycoptidae in Lindquist et al. (1979). [10]Pteronyssidae was previously included in Avenzoariidae. [11]Dermationidae was previously included in Epidermoptidae. [12]Included in Epidermoptidae in OConnor (2009) and Schatz et al. (2011).

and Eickwort 1988; Table 6). A recent revision of Chaetodactylidae has three new Canadian records of obligate cleptoparasites or parasitoids of leafcutter bees, including two new species (Klimov and OConnor 2008). In total, 17 hemisarcoptoid species are known from Canada and over 50 more species in these five families are expected (Table 6). A sixth family, Algophagidae, has at least one unidentified species in Canada, and a few representatives in the neighbouring USA from water-filled treeholes or tree sap flux likely occur here.

Superfamily Glycyphagoidea

Ancestrally associated with vertebrate nests, this superfamily includes numerous nest-dwelling fungivore-detritivores, as well as forms that evolved parasitism in the hair follicles of their mammalian hosts (Chortoglyphidae, Echimyopodidae). In addition to inhabiting nests, they can be found on mammals (more rarely birds) or insects on which they are phoretic, as well as in litter and anthropogenic habitats such as house dust and stored products (a few Glycyphagidae, Aeroglyphidae, Chortoglyphidae) (OConnor 2009).

Three families have a total of 24 recorded species in Canada, including several new records of glycyphagids and chortoglyphids from rodent hosts such as muskrats, beavers and mountain beavers since 1979 (Table 6). Rosensteiniidae, associated with bats and their guano, is newly recorded from southern Canada, but as an undetermined species. Echimyopodidae and Euglycyphagidae are anticipated for Canada. Overall, an additional 32 species of glycyphagoids are expected for Canada (Table 6).

Superfamily Acaroidea

The family Acaridae is the most diverse family within the Acaroidea at both the global and national levels. It is agriculturally the most important group of astigmatic mites because of their role as pests of bulbs, greenhouse vegetables, and stored products (e.g., grains, cheese, meat), where they can feed directly on the cereal grain itself or on green plant tissues (Sinha 1979, Beaulieu and Knee 2014). Most acarid mites are fungivore-saprophages and breed where fungi and other microbes abound, including soil and patchy habitats such as compost, rotting wood, tree bark, bracket fungi, phytotelmata, beetle galleries, and hymenopteran and avian nests. Some Acaridae and Suidasiidae feed on pollen inside bee nests in Canada. There are only a small number of scattered Canadian records of Acaridae and other Acaroidea published since 1979 (often identified only to genus level). Over 40 additional species are expected in Canada, mostly of Acaridae (Table 6). One family, Gaudiellidae, associated with bumble bees, has been newly recorded since 1979. The superfamily is in dire need of revision.

Superfamily Hypoderatoidea

The sole family, Hypoderatidae, comprises parasites of birds and desert-dwelling rodents (OConnor 2009). This family was not recorded from Canada in 1979 but since then one species has been recorded from the skin of a kingfisher in Ontario (Pence and Gray 1996). Many of the species so far recorded from adjacent states of the USA are anticipated to occur in Canada on the same bird hosts (Table 6).

Superfamily Sarcoptoidea

This group includes 'fur mites' (Chirodiscidae, Listrophoridae, Atopomelidae) which live in the fur of mammals and feed on sebaceous materials (OConnor 2009, Bochkov 2011). Other sarcoptoids obtain fluids from the skin surface (Myocoptidae, Psoroptidae), live in hair follicles (Rhyncoptidae), or burrow in the skin (Sarcoptidae) of their mammalian hosts. More invasive forms colonize the ears of various mammals (some Psoroptidae), nasal passages and lungs of rodents (Gastronyssidae, Pneumocoptidae), or the eye orbits and stomach of bats (Gastronyssidae). The effects of these mites on their hosts vary from relatively benign, such as the irritation caused by ear mites (Psoroptidae: *Otodectes*) of domestic animals, to highly detrimental, such as sarcoptic mange (caused by *Sarcoptes scabiei* [L.]) which can cause skin hyperkeratosis and hair loss and lead to population declines in domestic and wild mammals (OConnor 2009, Murray and St Clair 2017).

Five of the 12 globally recognized families of Sarcoptoidea are known in Canada and four others are anticipated to occur (Table 6). Currently, 38 species are recorded from Canada, more than double that recorded in 1979. Chirodiscidae experienced the largest increase since 1979, with 10 of 11 species currently recorded being restricted to beavers (Table 6; CNC). Eight more species of *Schizocarpus* may occur on beavers in Canada (Fain and Whitaker 1988, Bochkov 2010). Other new Canadian records since 1979 are from mustelids (Chirodiscidae), small rodents (Myocoptidae, Listrophoridae), rabbits, and bovid and cervid hosts (Psoroptidae). Representatives of four families not yet recorded in Canada are expected to occur here, based on nearby USA records: Atopomelidae, Rhyncoptidae, Pneumocoptidae, and Gastronyssidae. Overall, approximately 50 additional species are expected to be found in Canada (Table 6).

Superfamilies Pterolichoidea, Analgoidea

With 280 species from 25 families recorded (Table 6), these two superfamilies represent almost two thirds of all known species and more than half of the families of Astigmata in Canada. They dominate the diversity of acarofauna living on birds, with up to 10 species recorded from a given host species in Canada (SV Mironov, HC Proctor, and TD Galloway unpubl. data). Most families consist of the true "feather mites", which are mostly paraphagous commensals, feeding on uropygial gland secretions, as well as on fungi and other organic material (algae, pollen) found on the feathers (Proctor 2003, OConnor 2009). A few families include true parasites that feed on or in the skin (Dermationidae, Epidermoptidae, Knemidocoptidae, Laminosioptidae), consume pith inside quills (Ascouracaridae, Dermoglyphidae, Syringobiidae), or eat live tissues in respiratory tracts (Cytoditidae, Turbinoptidae). Some of these mites significantly affect their wild and domestic hosts, causing dermatitis, scaly-leg and -face diseases of birds, or possibly weaken feather quills after feeding on the inner pith (Proctor and Owens 2000, Proctor 2003). Pyroglyphid mites are unique among the Analgoidea in that most species live as scavengers in the nests of their hosts (birds and mammals) rather than on their bodies, eating skin flakes, hair, and other organic debris. Some pyroglyphids (*Dermatophagoides* spp. and other dust mites) have adapted to living in houses where they feed on shed human skin that has been colonized by fungi, and are the culprits behind many respiratory allergies (Colloff 2009). Taxonomic knowledge of the two superfamilies in Canada has grown an order of magnitude since 1979, thanks to the work of Mironov, Proctor, and Galloway. The known fauna increased from a mere two to 65 species of Pterolichoidea and from 19 to 215 species of Analgoidea, with 12 of the 25 families in Canada representing new records for the country (Table 6).

Astigmatan feather mites, nasal mites, skin and quill mites are now recorded from at least 252 of the 690 bird species occurring in Canada (Lepage 2018), with a sampling bias for birds of the Prairie Provinces where most of the relevant research has been conducted (Galloway et al. 2014; Mironov, Proctor and Galloway unpubl. data). Most bird families that occur in Canada have been sampled for mites. Mironov, Proctor and Galloway have aimed for taxonomic breadth of hosts, which should parallel taxonomic breadth of mites. Most members of Analgoidea and Pterolichoidea known from Canada have been collected by washing the bodies of birds that were either found dead or that died in wildlife rehabilitation centres rather than by targeted collecting from particular species of birds. The most notable increase among families is for the world's largest family of feather mites, Proctophyllodidae, the species of which inhabit wing feathers of passerines and hummingbirds (Galloway et al. 2014; Table 6). This is followed by the Analgidae, which inhabit downy feathers (Mironov and Galloway 2002). Next are the Alloptidae and Avenzoariidae, mostly associated with various aquatic birds (OConnor 2009; Table 6). The only Ascouracaridae recorded is a potentially host-specific quill mite collected from a threatened bird in Canada, the whip-poor-will (*Caprimulgus vociferus* Wilson). Families of mites that live on or in skin or in quills may be underrepresented due to sampling bias. Adult females of some species of Epidermoptidae are hyperparasitic on hippoboscid flies or lice and can be collected from these hosts, including two species recently reported from Canada (Knee and Galloway 2017a, Goater et al. 2018; Table 6). The family Pyroglyphidae may also be underrepresented since nests are less often targeted than birds.

Five additional families are anticipated in Canada (Table 6): Gaudoglyphidae, represented by one species living in the quills of domestic chickens (Bruce and Johnston 1976); Laminosioptidae, subcutaneous and follicular parasites (Skoracki et al. 2014); Apionacaridae, quill mites (Mironov 2001); Ptyssalgidae, hummingbird-specific quill mites (Atyeo and Gaud 1979); and Cytoditidae, inhabiting the nasal cavity, lungs or air sacs of birds. Based on a number of undescribed species at hand as well as their prevalence, level of host specificity observed so far, and the potential number of host species, we anticipate ~900 additional species of analgoids and pterolichoids on birds in Canada (Table 6).

Heterocoptidae

At least one representative of the unplaced family Heterocoptidae probably occurs in southern Canada, since an undescribed species of the family has been found on a beetle in nearby Michigan (B OConnor pers. comm.). Heterocoptids are presumably paraphagic on their beetle hosts (OConnor 2009).

Knowledge gaps and opportunities

Although the increase in known species of Acari in Canada is substantial, there are still major taxonomic gaps for all higher mite taxa, except ticks, with the majority of families requiring review or revision in Canada. Even for some of the better known acarine families in North America (e.g., Mesostigmata: Phytoseiidae; Prostigmata: Bdellidae, Tetranychidae, Trombiculidae), there are no species checklists available for Canada. There are large numbers of unpublished records for species present in Canada, but not reported in the world or North American catalogues (Denmark and Evans 2011, Walters et al. 2011, Hernandes et al. 2016, Demite et al. 2018, Migeon and Dorkeld 2018).

Based on the estimated diversity of unrecorded species (Tables 2–6), as well as the need for clarifying species concepts and improving classification, the following taxa are the most notable in requiring revision in Canada. Within the Mesostigmata, it is the Parasitidae, Laelapidae, and families of Uropodoidea, Rhodacaroidea and Ascoidea. Many groups of Prostigmata need particular attention: Cunaxidae, Eupodidae, Tydeoidea, Halacaridae, Erythraeidae, Trombiculidae, Cheyletoidea, Tenuipalpidae, Pygmephoroidea, and Tarsonemidae. Future research priorities in water mites include Hygrobatidae, Lebertiidae and Sperchontidae. The Eriophyoidea, now tentatively in the Endeostigmata, urgently needs revision. The greatest uncertainty in species numbers for Oribatida lies in smaller-bodied and/or highly diverse families (e.g., Brachychthoniidae, Oppiidae, Suctobelbidae, Oribatulidae, Scheloribatidae), but also significant efforts for revisions are required within the Damaeidae, Liacaridae, and Galumnidae. Furthermore, despite considerable progress in several families (e.g., Ceratozetidae, Peloppiidae, Eremaeidae), we suspect that large numbers of species remain unrecorded for these families. While feather mites (Analgoidea, Pterolichoidea) are undergoing major, needed revisions, other Astigmata that require particular focus are Acaridae, Histiostomatidae and Glycyphagidae.

We anticipate an additional 29 families of mites in Canada (indicated by * in Tables 2–6): Mesostigmata (4 families), Trombidiformes (10), Oribatida (1), Astigmata (12) and Endeostigmata (2). Based on our estimates (Table 1), the majority of all species of Mesostigmata (60%), Trombidiformes (66%), Endeostigmata (86%; due mostly to Eriophyoidea), Oribatida (68%), and Astigmata (73%) are yet to be discovered, identified or described in Canada. This represents at least six times the number of species newly recorded in Canada in the ~40 years since Lindquist et al. (1979)!

Many habitats are vastly underexplored for mites, often because the habitat is cryptic, or hard to reach physically. In particular, we anticipate new species discoveries in the following habitats: deep soils; arboreal, littoral and alpine habitats; groundwater and hyporheic zones of fresh water; all marine habitats; cave system substrates; angiosperm hosts, including their flowers; patchy habitats such as dung, dead wood, fungal sporocarps, plant galls, tree sap flows; and vertebrate and invertebrate nests/burrows and their insect residents. Many of the thousands of aquatic and terrestrial invertebrate species in Canada, particularly moths, dipterans, coleopterans, hymenopterans, but also millipedes, spiders, amphipods and gastropods are hosts to commensal and parasitic mites that are expected to occur in Canada but have not yet been recorded. Among vertebrate hosts, birds are now better targeted (Galloway et al. 2014), but surveys for mites on reptiles, amphibians and especially mammals, including bats and aquatic species (e.g., pinnipeds), are relatively rare in Canada. Overall, there is a dearth of information on the distribution, habitat, host associations, feeding biology, life history and immature stages of most species of Acari in Canada.

Addressing the deficiency in taxonomic and faunistic knowledge of Acari in Canada will require major efforts towards the following: (1) targeted exploration of many more habitats and hosts across all ecozones; (2) integrated approaches combining morphological, molecular and ecological data to elucidate species boundaries, including for cryptic species; and (3) species-level assessments and confirmation for taxa collected during biological surveys and ecological studies (Gotelli 2004). Beyond such taxonomic endeavours, studies targeting the feeding habits as well as host relationships of selected species or assemblages are necessary to refine our understanding of the diverse roles of mites in Canadian ecosystems. Finally, "to fulfill our national and worldwide duties of classifying and describing…species, particularly to address agricultural (pests, invasive species) problems before they get out of hand (or to be ready when they arise), and to address conservation and biodiversity questions before the biodiversity disappears" (Lumley et al. 2013), we will need to enhance and accelerate efforts in acarology. The foremost approach for this will not be to simply maintain, but to increase the level of acarological expertise in the country.

Contributions of authors

The tables and text for each section were mostly prepared by the following authors: Parasitiformes by F Beaulieu, W Knee, and E Lindquist; Trombidiformes by F Beaulieu, V

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REVIEW ARTICLE

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Myriapoda of Canada

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Abstract

The currently documented fauna of described species of myriapods in Canada includes 54 Chilopoda, 66 Diplopoda, 23 Pauropoda, and two Symphyla, representing increases of 24, 23, 23, and one species, respectively, since 1979. Of the 145 myriapod species currently documented, 40 species are not native to Canada. The myriapods have not been well documented with DNA barcodes and no barcodes are available for Pauropoda. It is conservatively estimated that at least 93 additional myriapods species will be discovered in Canada: Chilopoda (40), Diplopoda (29), Pauropoda (17), and Symphyla (seven). In general, there is a serious dearth of knowledge about myriapods in Canada, and systematics research and surveys continue to be needed to help document the diversity and distribution of these groups in the country.

Keywords

biodiversity assessment, Biota of Canada, centipedes, Chilopoda, Diplopoda, millipedes, Pauropoda, Symphyla

Introduction

The subphylum Myriapoda contains four extant, monophyletic classes, all of which have representatives in Canada and on all continents except Antarctica: Diplopoda (millipedes), Chilopoda (centipedes), Pauropoda (pauropods), and Symphyla (garden centipedes or pseudocentipedes). Phylogenetic relationships among myriapod classes have been largely unsettled in recent years; however, the most recent phylogenomic analyses based on morphological and molecular data show strong support for Diplopoda and Pauropoda as sister groups (=Dignatha), with Symphyla most closely related to Dignatha, and Chilopoda most basal (Fernández et al. 2018).

The earliest records of myriapods from Canada are two species of millipedes described by Newport (1844) based on material in the British Museum: *Polydesmus canadensis* (now *Pseudopolydesmus canadensis*) and *Iulus canadensis* (now *Uroblaniulus canadensis*). Wood (1862) published the first record of a centipede from Canada, describing *Strigamia chionophila* based on material from Fort Simpson, Northwest Territories. This material was collected by the explorer and naturalist Robert Kennicott between 1859 and 1862 during his expedition to the Canadian north. No additional myriapod species had been recorded from Canada by 1865 as Wood (1865) listed only the three aforementioned species in his treatise on the Myriapoda of North America. Brodie and White (1883) provided the first checklist of myriapods of Canada and listed five centipede and five millipede species from the country. Three species of Chilopoda and nine of Diplopoda were collected by Geological Survey of Canada personnel (mainly by JB Tyrrell) in 1882–1883 (Chamberlin 1920). Only two of these species were included in the list of Brodie and White (1883). These collections were from British Columbia, Alberta, Ontario, and Quebec and included three millipede species new to science with two type localities in Alberta (Bow River, Waterton Lake) and one in British Columbia (Columbia Valley). Other early country records were reported by Bollman (1887) who described one species of millipede and one centipede from Glacier, British Columbia, although the dates of collection were not indicated.

In Canada, all four classes of myriapods are relatively poorly studied as there has been relatively little sampling of the fauna in the country and there hasn't been anyone in Canada who has focused on the systematics of these groups. Diplopoda is the best known of the four classes. There are numerous Chilopoda and Diplopoda samples from Canada awaiting identification in Canadian collections. In contrast, Pauropoda and Symphyla, which are small in size and live in cryptic habitats, are very poorly represented in Canadian collections, so knowledge of the fauna and its distribution and ecology is fragmentary. All four classes of myriapods were briefly summarized in *Canada and its insect fauna* (Danks 1979), with 47 reported species of Diplopoda (Hoffman 1979), 29–31 of Chilopoda (Kevan 1979), one of Symphyla (Scheller 1979b), and none of Pauropoda (Scheller 1979a). The number of documented species in Canada has increased since 1979 for all groups. Kevan and Scudder (1989) provided illustrated keys to families of Canadian myriapods, which are still useful despite the more recent addition of several newly recorded families and a modified family structure for some Diplopoda and Chilopoda (Tables 1, 2).

All four myriapod classes are associated with soils and epigaeic habitats, and at least some Chilopoda and Diplopoda are associated with rotting wood. Centipedes are largely predaceous and are venomous (Undheim et al. 2015). The other three classes are largely detritivores, although a few millipedes are known to consume living or dead animal tissue (Hoffman and Payne 1969). Some symphylans feed on roots (fine roots and root hairs) and can damage plants, including crops (Beirne 1972).

The current synopsis is based on literature records, examination of authoritatively identified material in a few Canadian collections, and DNA barcode data in the Barcode of Life Data System (BOLD) database (Ratnasingham and Hebert 2007; http://www.boldsystems.org/). Species lists have not been included in this work but are available from the corresponding author upon request.

Chilopoda

The statement, "The centipedes are among the least studied of the larger Canadian arthropods…" is lamentably just as true now as it was 38 years ago when Kevan (1979) wrote it to introduce his treatment of the Chilopoda of Canada. While the Canadian fauna is somewhat better known today, it is estimated that only a little more than half of the Canadian fauna is documented (Table 1). This relatively poor state of knowledge is attributed to the weak taxonomic foundation for Chilopoda in North America in general, and the paucity of effort focused on surveying and documenting the Canadian centipede fauna. These two causes are undoubtedly interlinked as the lack of a solid taxonomic foundation and identification tools for most groups of North American centipedes likely does not engender interest in the group by professional and amateur taxonomists.

A few chilopodologists made enormous strides in the 20th century to describe North American species. For example, of the 556 native species of centipedes reported from North America by Mercurio (2010), 405 were described by Ralph Chamberlin and 21 by Ralph Crabill. Unfortunately, however, there is a distinct shortage of modern taxonomic revisions, and many genera and some families remain inadequately circumscribed. One notable exception is the relatively small order Scolopendromorpha which, thanks largely to the efforts of Rowland Shelley, is relatively well studied in North America, and modern illustrated keys to species are available (e.g., Shelley 2002a). An annotated catalog of the centipedes of North America (Mercurio 2010) is of enormous help to those interested in working on this group. Furthermore, the well-illustrated key to myriapod orders and families in Canada (Kevan and Scudder 1989) is a useful resource to help those interested in chilopod identification. The on-line database, Chilobase 2.0 (Bonato et al. 2016; http://chilobase.biologia.unipd.it/) contains much current information about the classification and nomenclature of Chilopoda, but it is incomplete with respect to the distribution of the North American fauna. Thus, those interested in the general distribution of North American centipedes should consult Mercurio (2010). For the Geophilomorpha, Bonato and Minelli (2014) provide an overview of the order in Europe, which is the most current source of information about non-native species of this order in North America. Bonato et al. (2012) provide an overview of the relatively large genus *Strigamia*, which has representation in Canada, and resolves a number of taxonomic and nomenclature problems within this genus and related genera. The illustrated synopsis of anatomical terminology for centipedes is useful for those working on taxonomy and identification (Bonato et al. 2010).

In Canada, centipedes have received very little attention taxonomically or ecologically. From the publication of the first checklist of Canadian species (Brodie and White

Table 1. Census of Chilopoda in Canada.

Taxon[1]	No. species reported in Kevan (1979)[2]	No. species currently known from Canada[3]	No. BINs[4] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[5]	Information sources[6]
Order Geophilomorpha						
Geophilidae[7]	10	16 (6)	13	10	most ecozones	Carl and Guiguet 1956; CNCI
Himantariidae	1	1 (1)	0	1	Boreal Shield	
Mecistocephalidae	0	0	0	1		
Schendylidae	1	2 (1)	5	2	Boreal Shield, Mixedwood Plain, Taiga Cordillera, Boreal Cordillera	Pereira and Hoffman 1993; CNCI
Order Lithobiomorpha						
Henicopidae	2	2 (1)	4	3	Pacific Maritime, Prairies, Taiga Plains, Montane Cordillera	
Lithobiidae	12	27 (3)	37	20	most ecozones	CNCI
Order Scolopendromorpha						
Cryptopidae	2	3 (3)	0	2	Pacific Maritime, Boreal Shield, Mixedwood Plains	Shelley 2002a
Scolopocryptopidae	1	2 (1)	0	1	Pacific Maritime, Mixedwood Plains	Shelley 2002a
Order Scutigeromorpha						
Scutigeridae	1	1 (1)	1	0	domiciliary in several ecozones	
Total	**30**	**54 (17)**	**60**	**40**		

[1]Classification follows that indicated in Chilobase 2.0 (Bonato et al. 2016). [2]This does not include species listed by Kevan (1979) as "probable". [3]The numbers in parentheses represents the number of non-native species included in the total. [4]Barcode Index Number, as defined in Ratnasingham and Hebert (2013). BIN data were extracted from BOLD on August 20, 2018. [5]See figure 1 in Langor (2019) for a map of ecozones. [6]Literature published before 1979 is usually not included, with one exception, as it was considered by Kevan (1979, 1983a). Kevan (1983a), Kevan and Scudder (1989), Behan-Pelletier (1993) and Mercurio (2010) are applicable to most families but are not listed in the table due to space considerations. CNCI refers to specimens present in the Canadian National Collection of Insects, Arachnids and Nematodes, Ottawa, Ontario. [7]Includes Chilenophilidae, Dignathodontidae and Linotaeniidae.

1883), it was almost a century before the next synopsis of the Canadian fauna (Kevan 1979), although there was an earlier review of the fauna of Newfoundland (Palmén 1954), the only Canadian jurisdiction to receive such an inventory of its centipede fauna. Kevan (1983a) produced a more complete list of species known from Canada and Alaska, and this was updated by Behan-Pelletier (1993). Snyder (2014) provided a synopsis of species known and expected to be present in Canadian grasslands.

Currently, there are 54 species known to be established in Canada, including *Scutigera coleoptrata* (Linnaeus) which is limited to human domiciles (Table 1). In comparison, there are 633 species (including non-native species) known from North America (Mercurio 2010) and 3110 species globally (Minelli 2011). The Lithobiomorpha represents the largest proportion of the Canadian fauna (53.7%), followed by Geophilomorpha (35.2%), Scolopendromorpha (9.3%) and Scutigeromorpha (1.8%), and this proportional representation is very similar to that for the North American fauna as a whole (Mercurio 2010). About 31% of the documented Canadian fauna is not native compared to 12% for the North American fauna (Mercurio 2010). Undoubtedly other non-native species are established in Canada but are yet undocumented.

Compared to the 1979 assessment, the number of species documented in Canada has increased by 24 (80%), with the greatest increases within the families Lithobiidae and Geophilidae. Most of the changes to the fauna since 1979 were reported by Kevan (1983a) and Behan-Pelletier (1993), and mainly represent Canadian species occurrences already reported in earlier literature that were missed by Kevan (1979). All of these authors, however, overlooked the records of two Geophilidae, *Cheiletha kincaidi* Chamberlin and *Geophilus glyptus* (Chamberlin), recorded from Bunsby Islands, British Columbia by Carl and Guiguet (1956), the specimens of which were identified by Chamberlin. With the exception of the Scolopendromorpha, our collective knowledge of the diversity and distribution of Canadian centipedes has not increased much over the last 25 years. While most major terrestrial arthropod collections in Canada contain small-to-moderate numbers of centipede samples, the majority of those are not authoritatively identified. Most Canadian records come from southern Quebec, Ontario, British Columbia, and the island of Newfoundland, the latter thanks to the Fennoscandinavian expeditions of 1949 and 1951 as reported by Palmén (1954). All ecozones of Canada are poorly known in terms of their centipede faunas.

The number of additional species expected to be in Canada but yet undocumented (either undiscovered or undescribed) was estimated by examination of the distribution of species reported in Mercurio (2010) and references contained therein. Some species collected in the USA within 100 km of the Canadian border, and which have broad distributions in the USA (i.e., not likely to be local endemics), were deemed to be likely present in Canada and this forms the basis of the conservative estimate of undocumented species for Canada (Table 1). Thus, it is estimated that 43% of the Canadian fauna (40 species) is yet undocumented, mostly members of the families Lithobiidae and Geophilidae (Table 1).

The generation of DNA barcodes for Canadian centipedes is still in the early stages as material has been provided from only a small number of specimens and localities.

Nonetheless, 60 Barcode Index Numbers (BINs; see Ratnasingham and Hebert 2013) are represented based on Canadian specimens (Table 1). In the Schendylidae, Henicopidae, and Lithobiidae there are more BINs than documented species, which may be indicative of undocumented species diversity. Clearly much work remains to fully document the Canadian fauna of centipedes.

Diplopoda

The taxonomic foundation for reliably identifying Diplopoda found in Canada is in much better shape than for Chilopoda. Fortunately, there has been considerable taxonomic research in the USA, especially by Ralph Chamberlin, Nell Causey, Richard Hoffman, Petra Sierwald, William Shear, and Rowland Shelley, that has greatly aided knowledge of the Canadian fauna. Nonetheless, many families can benefit from modern taxonomic revisions that consider molecular and morphological characters. A catalogue of North and Middle American Diplopoda is available (Hoffman 1999) and, although now almost 20 years old and a bit dated, is still an enormously helpful resource. The on-line database Millibase (www.millibase.org/), which covers the global fauna, is also a helpful resource but is incomplete with respect to capturing published knowledge about the Canadian fauna.

As with Chilopoda, there has been a dearth of targeted survey work on millipedes in most of Canada so the fauna of all ecozones is incompletely known. The only Canadian jurisdiction that experienced a faunal inventory is the island of Newfoundland, which was extensively surveyed during the Fennoscandinavian expeditions of 1949 and 1951 (Palmén 1952). Beyond that, most current Canadian records are from southwestern British Columbia and southern Ontario and Quebec. The Canadian fauna was summarized by Hoffman (1979) who reported 47 species in 15 families and six orders; however, the species numbers were reported only at the order level and no species list was included. Furthermore, he predicted that another 22–23 species likely occurred in Canada for a total fauna of 69–70 species. Shortly thereafter, and based on literature records and authoritative examination of holdings of some Canadian collections, Kevan (1983b) published a list of 65 species known from Canada, several of which were subsequently synonymized and others identified only to genus. Shelley (1988) published a species list for eastern Canada (Ontario and eastward), including 38 species. Shelley (1990a) gave distributions for species in British Columbia. Kevan and Scudder (1989) published some faunal updates and Behan-Pelletier (1993) provided a revised list of species in Canada and their known provincial and territorial distributions. The most recent treatment of the Canadian fauna was by Shelley (2002b) who reviewed the central Canadian fauna (Alberta, Saskatchewan and Manitoba) in detail and also provided a list of the known and expected species for the entire country that included 62 recorded species and another 11 species that were considered likely in Canada based on distributions in the USA.

Currently, there are 66 described species in 18 families and six orders known in Canada (Table 2), in comparison to ~1500 species known from North America (an

Table 2. Census of Diplopoda in Canada.

Taxon[1]	No. species reported in Hoffman (1979)[2]	No. species currently known from Canada[3]	No. BINs[4] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[5]	Information sources[6]
Order Polyxenida						
Polyxenidae	1	2 (1)	2	0	Atlantic Maritime, Mixedwood Plains, Pacific Maritime	
Order Glomeridesmida						
Glomeridesmidae	0	0	0	1	Pacific Maritime	Shelley et al. 2007a
Order Polyzoniida						
Hirudisomatidae	?	1	2	0	Pacific Maritime	Shelley 1995, 1996
Polyzoniidae	?	2	1	0	Boreal Shield, Mixedwood Plains	
Sub-total Polyzoniida	**2**	**3**	**3**	0		
Order Julida						
Superfamily Blaniuloidea						
Blaniulidae	?	5 (5)	2	0	widespread south of taiga ecozones	Shelley and Smith 2011
Okeanobatidae	?	1	0	0	Boreal shield, Mixedwood Plains	
Superfamily Juloidea						
Julidae	?	8 (8)	26	1	widespread south of taiga ecozones	Shelley and Whitney 1994, Shelley and Smith 2011
Superfamily Nemasomatoidea						
Nemasomatidae	?	1	3	1	Montane Cordillera, Pacific Maritime	Enghoff 1985
Superfamily Paeromopodoidea						
Paeromopodidae	0	0	0	2	Montane Cordillera, Pacific Maritime	
Superfamily Parajuloidea						
Parajulidae	?	12	1	4	widespread south of taiga ecozones	Carl and Guiguet 1956, Shelley and Smith 2016
Total Julida	**20**	**27 (13)**	**32**	**8**		
Order Spirobolida						
Spirobolidae	1	1	1	0	Boreal Shield, Mixedwood Plains	Shelley et al. 2006
Order Spirostreptida						
Cambalidae	0	0	0	2	Pacific Maritime	
Order Callipodida						
Abacionidae	0	0	0	2	Mixedwood Plains	

Taxon[1]	No. species reported in Hoffman (1979)[2]	No. species currently known from Canada[3]	No. BINs[4] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[5]	Information sources[6]
Order Chordeumatida						
Suborder Craspedosomatidea						
Superfamily Anthroleucosomatoidea						
Anthroleucosomatidae	0	0	0	1	Pacific Maritime	
Superfamily Brannerioidea						
Branneriidae	0	0	0	1	Mixedwood Plains	
Microlympiidae	0	0	0	1	Pacific Maritime	
Tingupidae	0	0	0	1	Pacific Maritime	Shear and Shelley 2007, Shelley et al. 2009b
Superfamily Cleidogonoidea						
Cleidogonidae	0	0	4	2	Mixedwood Plains	
Trichopetalidae	?	1	0	0	Atlantic Maritime, Mixedwood Plains, Newfoundland Boreal	Shear 2010
Superfamily Craspedosomatoidea						
Craspedosomatidae	?	1 (1)	2	0	Mixedwood Plains	Shelley 1990b, Hoffman 1999
Suborder Heterochordeumatidea						
Superfamily Conotyloidea						
Conotylidae	?	6	0	3	widespread south of taiga ecozones	Shelley and LeSage 1996, Shear 2004, Shelley et al. 2009a
Suborder Striadiidea						
Superfamily Caseyoidea						
Caseyidae	?	4	0	0	widespread south of taiga ecozones	Shelley 1993, Shelley et al. 2007b, 2009
Urochordeumatidae	0	0	0	1	Pacific Maritime	CNCI
Superfamily Stiarioidea						
Rhiscosomididae	?	1	0	0	Pacific Maritime	Shelley 1990a, Shelley et al. 2009a
Striariidae	0	0	0	1	Pacific Maritime	
unplaced Chordeumatida			7			
Total Chordeumatida	**6**	**17 (1)**	**13**	**6**		BOLD[7]
Order Polydesmida						
Suborder Leptodesmidea						
Superfamily Xystodesmoidea						
Xystodesmidae	?	6	6	3	Mixedwood Plains, Montane Cordillera, Pacific Maritime,	Shelley 1990a, Shelley et al. 2009a, Marek et al. 2014, Shelley and Smith 2018

Taxon[1]	No. species reported in Hoffman (1979)[2]	No. species currently known from Canada[3]	No. BINs[4] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[5]	Information sources[6]
Suborder Polydesmidea						
Infraorder Polydesmoides						
Superfamily Polydesmoidea						
Macrosternodesmidae	0	3 (1)	2	0	Pacific Maritime, Montane Cordillera, Newfoundland Boreal	Carl and Guiguet 1956, Whitney and Shelley 1995, Shelley 1994
Polydesmidae	?	10 (4)	4	2	widespread south of taiga ecozones	Judd 1967, Shelley 1996, 2007, Shelley and Smith 2011, Shelley and Snyder 2012
Suborder Strongylosomatidea						
Paradoxosomatidae	0	1 (1)	2	0	Atlantic Maritime, Mixedwood Plains, Newfoundland Boreal, Pacific Maritime	Judd 1967, Shelley 1990a
Total Polydesmida	**17**	**20 (6)**	**14**	**5**		
Total	**47**	**66 (21)**	**65**	**29**		

[1]Classification follows that indicated in Millibase (www.millibase.org/index.php) with the exception that Nearctodesmidae is included as a subfamily of Macrosternodesmidae which is placed in Polydesmoidea as suggested by Shear and Reddell (2017). [2]Hoffman (1979) provided species tallies only by order. Thus, many family level tallies are not available. [3]The numbers in parentheses represents the number of non-native species included in the total. [4]Barcode Index Number, as defined in Ratnasingham and Hebert (2013). BIN data were extracted from BOLD on August 20, 2018. [5]See figure 1 in Langor (2019) for a map of ecozones. [6]Literature published before 1979 is usually not included, with one exception, as it was considered by Hoffman (1979) and Kevan (1983b). Kevan (1983b), Kevan and Scudder (1989), Behan-Pelletier (1993), Hoffman (1999), and Shelley (1988, 2002b) are applicable to most families but are not listed in the table due to space considerations. CNCI refers to specimens present in the Canadian National Collection of Insects, Arachnids and Nematodes, Ottawa, Ontario. [7]BOLD: Barcode of Life Data Systems (http://www.boldsystems.org/).

estimate based mainly on information in Hoffman (1999)) and 15,982 species known globally (Sierwald and Spelda 2018). The Parajulidae represents about 18.2% of the described Canadian fauna, followed by Polydesmidae (15.2%) and Julidae (12.1%). About 32% of the described Canadian fauna is non-native compared to only 2% for the North American fauna (Snyder and Hendrix 2008); however, this high proportion is likely because a large portion of the native Canadian fauna is unknown. The current species total is a 40% increase over that reported by Hoffman (1979), highlighting a substantial increase in knowledge of the fauna over the last ca. 40 years. In addition to described species, material has been collected in Canada representing four additional families (Glomeridesmidae, Striariidae, Tingupidae, and Urochordeumatidae; Table 2) but it is not known if this material represents described species. Taking into account this unidentified material, the opinion of Shelley (2002b) concerning species likely to be present in Canada, and supplemented by examination of species distributions documented in subsequent publications about the North American fauna, we conservatively estimate that at least 29 additional species reside in Canada, including seven additional families. This means that Canada should have a millipede fauna of at least 95 species and is thus roughly equivalent to the estimated species richness of the Canadian centipede fauna (94 species; Table 1). However, as there are about three times as many millipedes as centipedes known from North America (Snyder and Hendrix 2008, Mercurio 2010), the Canadian millipede fauna is likely to be much more diverse than estimated herein.

Only 65 BINs representing 14 of the 22 families of millipedes known from Canada are available (Table 2), and only 12 BINs are associated with material identified to species level. Clearly, much work remains to adequately barcode Canadian millipedes. Notably, 26 BINs are associated with Julidae, a family not native to Canada, which is much higher than the eight documented species recorded from Canada.

The ecology of millipedes has received little attention in Canada; however, in a study of the influence of *Harpaphe haydeniana* Wood on litter decomposition in the coastal forests of British Columbia, Cárcamo et al. (2000) found that this species consumed as much as 36% of the annual litter fall.

Pauropoda

Pauropods are soft-bodied, small (0.5–2.0 mm long) detritivores found in soils (Scheller 1979a). Worldwide there are about 835 known species (Scheller 2011a), and about 100 species are known from the USA (Scheller 2011b), however, the fauna is poorly documented at both regional and global scales (Scheller 2011a, b). The Canadian fauna is poorly known in terms of species composition, distribution, and ecology, although some progress has been made since 1979. The earliest record from Canada is from the Yukon where Hilton (1931) described a new species, *Stylopauropus dawsoni*; however, as his type material is considered lost and the description is very superficial, this species is considered to be *nomen dubium* (Scheller 1984). Scheller (1979a) reported no named

Table 3. Census of Pauropoda in Canada.

Taxon[1]	No. species currently known from Canada[2]	No. BINs[3] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[4]	Information sources
Order Tetromerocerata					
Brachypauropodidae	1 (0)	0	4	Pacific Maritime	Scheller 1984, 1985, 1986a
Eurypauropodidae	0	0	2		Scheller 1985
Pauropodidae	22 (4)	0	11	Boreal Shield, Mixedwood Plains, Pacific Maritime, Western Interior Basin	Scheller 1984, 1985, 1986a
Total	**23 (4)**	**0**	**17**		

[1]Classification that of Scheller (2008). [2]The numbers in parentheses represents the number of non-native species included in the total. [3]Barcode Index Number, as defined in Ratnasingham and Hebert (2013). BIN data were extracted from BOLD on August 20, 2018. [4]See figure 1 in Langor (2019) for a map of ecozones.

Table 4. Census of Symphyla in Canada.

Taxon[1]	No. species reported in Scheller (1979b)	No. species currently known from Canada[3]	No. BINs[2] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[3]	Information sources[4]
Order Cephalostigmata						
Geophilellidae	0	0	0	2		Kevan 1983a
Scolopendrellidae	0	1 (1)	3	1	Mixedwood Plains	Kevan 1983a
Scutigerellidae	1	1 (1)	1	4	likely all ecozones south of taiga and Boreal Cordillera	Beirne 1972, Kevan 1983a, Morris and Morry 1983; BOLD
Total	**1**	**2 (2)**	**4**	**7**		

[1]Classification follows that of Millibase (www.millibase.org/index.php). [2]Barcode Index Number, as defined in Ratnasingham and Hebert (2013). BIN data were extracted from BOLD on August 20, 2018. [3]See figure 1 in Langor (2019) for a map of ecozones. [4]BOLD: Barcode of Life Data Systems (http://www.boldsystems.org/).

species from Canada but estimated that around 20 species could be found there. Based on examination of 320 specimens from three Canadian collections in British Columbia, Ontario and Quebec, Scheller (1984) reported 23 species in two families (Table 3) from those three provinces, including six species new to science, and also provided keys to known families and genera in Canada. It is possible that four species are non-native based on known distribution. Six additional species have wide distributions (cosmopolitan in some cases) and some of these may also be non-native in Canada. This material could not be located in Canadian collections so may still be in the private collection of Ulf Scheller in Sweden. No new species have since been reported from the country. Also, no Canadian specimens of Pauropoda have been DNA barcoded.

Based on a survey of the literature treating Pauropoda in the continental USA (Scheller 1985 and references therein) and Alaska (Scheller 1986a), it is conservatively estimated that at least 17 additional species and one additional family (Eurypauropodidae) will be found in Canada (Table 3).

It is clear from a quick inventory of some major Canadian collections that pauropods have been seldom collected and preserved in Canada as there is little material accessioned. Records exist for only British Columbia, Ontario, Quebec and Yukon. In Alberta, the Alberta Biodiversity Monitoring Institute has been conducting a systematic survey of soil fauna across the entire province on a 20 km × 20 km grid since 2007. In support of this provincial-scale survey, taxonomists at the Royal Alberta Museum extract approximately 800 soil samples each year for invertebrates, particularly oribatid mites. A recent census of residual material from 194 of these samples yielded no Pauropoda or Symphyla (T Cobb pers. comm.), underscoring the difficulty in collecting these organisms using soil cores. By comparison, Chilopoda and Diplopoda were extracted from about 2% of samples.

Symphyla

Symphyla are also small (1–10 mm long) soil-dwellers and are usually infrequently collected. However, the most wide-spread species in Canada, the non-native and cosmopolitan *Scutigerella immaculata* (Newport), can be abundant in greenhouses and outdoors in more moderate climates and can cause significant damage to roots of many vegetable crops especially in southern British Columbia and Ontario (Beirne 1972).

Symphyla is the least diverse class of myriapods with about 35 species known from North America (Scheller 1986b) and 195 globally (Szucsich and Scheller 2011). Scheller (1979b) reported one species from Canada, *S. immaculata*, which is now likely to be distributed across southern Canada from coast to coast (Beirne 1972, Morris and Morry 1983). Subsequently, Kevan (1983a) reported the cosmopolitan and likely introduced *Symphylella vulgaris* (Hansen) based on a specimen in the Lyman Entomological Museum (McGill University) collected from a southern Quebec hardwood forest. Since then, no more species have been recorded from Canada, although undoubtedly additional species occur here. In addition to reporting one species, Scheller (1979b) estimated about 10 undocumented species in Canada. Kevan (1983b) mentions seven species and one more family (Geophilellidae) that are likely in Canada (Table 4) and we adopt his estimate herein. Only four specimens from Canada have been DNA barcoded and each represents a different BIN, three within Scolopendrellidae and one within Scutigerellidae (Table 4).

Gaps and opportunities

Given the paucity of knowledge about the faunal composition, taxonomy, distribution, and ecology of all myriapod classes in Canada, there are plentiful opportunities to add to this body of knowledge by collecting and studying these fascinating creatures. All myriapod classes are poorly sampled over all of Canada, meaning that any specimens encountered are likely to represent useful records. Even the North may have considerable diversity, especially in Beringian areas. Centipedes and millipedes are frequently encountered by turning rocks and logs, picking apart highly rotten logs, sifting dead leaves, and using pitfall traps. Pauropoda and Symphyla are much less frequently encountered or detected. Sometimes rolling deeply embedded rocks will reveal specimens of these two classes, and sifting of litter is a useful approach. Tullgren and Berlese funnel extractions of organic and mineral soil layers may also yield specimens. We implore those who encounter myriapods to make an effort to preserve specimens in ethanol and accession them into a publically accessible collection. The other challenge with working with myriapods is the poor state of taxonomy and relative paucity of taxonomic resources and local expertise. Diplopoda has a much better taxonomic foundation and better availability of taxonomic resources than the other groups. In North America there are a few people who actively study taxonomy of millipedes. For centipedes there is very little taxonomic work ongoing in North America and for Pauropoda and Symphyla there is essentially none. We encourage others to seek out, observe, collect and study these fascinating creatures in Canada and more broadly in North America.

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Collembola of Canada

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Abstract

The state of knowledge of diversity of Collembola in Canada was assessed by examination of literature and DNA barcode data. There are 474 described extant Collembola species known from Canada, a significant change compared to the 520 species estimated to occur in Canada in 1979 (Richards 1979) and the 341 reported in the most recent national checklist (Skidmore 1993). Given the number of indeterminate or cryptic species records, the dearth of sampling in many regions, and the growing use of genetic biodiversity assessment methods such as Barcode Index Numbers, we estimate the total diversity of Collembola in Canada to be approximately 675 species. Advances in Collembola systematics and Canadian research are discussed.

Keywords

biodiversity assessment, Biota of Canada, Collembola, springtails

Collembola, commonly known as springtails, is a class of small, entognathous, wingless hexapods that is a sister group to Insecta. They are found in most terrestrial systems and are most commonly associated with plant litter and soils, although some species are found in caves, decaying wood, tree canopies, and on the surfaces of snow and ponds. There are currently more than 8800 described Collembola species worldwide (Bellinger et al. 1996–2018). Considering that three new families and approximately 600 species have been described since 2011 (Janssens and Christiansen 2011), it is likely that many thousands of species are yet to be discovered.

The study of Collembola in Canada has a long history. Much of the work before 1979 was reviewed by Richards (1979), but additional mention should be made of the pioneering investigations of Arctic species (Wahlgren 1907, Folsom 1919, James 1938), the ground-breaking works of Hammer (1953, 1955), and further advances made during the International Biological Program (Oliver 1963, McAlpine 1964, Challet and Bohnsack 1968, Addison 1977). As noted by Richards (1979), early taxonomic and faunistic efforts created a strong foundation for modern research, but the paucity of widespread sampling in Canada makes accurate estimation of true diversity difficult. This statement remains true even today, although the situation is slowly improving.

The most important single work about Nearctic Collembola taxonomy produced since Richards (1979) is undoubtedly that of Christiansen and Bellinger (1998). The first edition of their treatment of the Collembola of North America was published in 1980–1981, the second in 1998, and continued errata and addenda have been published online up to 2003. Christiansen and Bellinger's (1998) guide includes extensive notes, dichotomous keys, species descriptions, and distribution estimates. Despite numerous changes to species names and systematics, this work is still the most important publication for the study of Canadian collembolan taxonomy, with 840 total known species recorded for North America, and 235 species recorded for Canada (approximately 27.9% of total North American diversity).

There have been several more recent publications that have specifically focused on Canadian Collembola. The primary national list (Skidmore 1995) includes 412 species, a number often cited as total Canadian diversity; however, only 341 species in 16 families in this list were recorded in Canada, with the remainder from Alaska. While it is likely that some of the Alaskan species are also found in northwestern Canada, further sampling is needed to confirm occurrences. Additionally, several species from Skidmore's (1995) list were later found to be synonyms, or derived from unverified records (A Babenko pers. comm.). Skidmore (1993) also published the first catalogue of type materials of collembolan species described from Canada and stored in the Canadian National Collection of Insects, Arachnids, and Nematodes (CNC). New information about type materials of 69 collembolan species at the CNC was recently published (Stebaeva et al. 2016).

Following Skidmore's national list (Skidmore 1995), provincial and regional species lists emerged: Therrien et al. (1999) for Quebec; Cannings (2010) for British Columbia; and Lindo (2014) for prairie grasslands in Alberta. Diversity of Arctic species has been a strong area of research, with significant contributions by Fjellberg (1986) and Babenko (1994). As a result of their review, Babenko and Fjellberg (2006) were able to correct numerous synonymous and incorrect species definitions for Canadian fauna. Several new Nearctic species have been described, for example, by Rusek and Marshall (1976), Rusek (1985, 1991), Potapov (1997), Pomorski (2001), and Fjellberg (2010).

Much of the recent research on Canadian Collembola pertains to their role in agriculture, especially as indicators of soil health and as model organisms for soil toxicity assays (Behan-Pelletier 2003). Research has also been devoted to the diversity of Collembola in different forest types (e.g., Setälä et al. 1995, Puvanendran et al. 1997, Chagnon et al. 2000, Addison et al. 2003), and in response to different silviculture practices (e.g., Addison et al. 2006, Huebner et al. 2012). Some progress was made defining the paleontological history of Collembola through study of fossilized remains (Christiansen and Pike 2002). This includes ancient representatives from extinct genera of the extant families Brachystomellidae, Neanuridae s. lato, Isotomidae, Tomoceridae s. lato, and Sminthuridae s. lato, as well as the extinct family Oncobryidae (Christiansen and Pike 2002).

New collections, online resources, and genetic tools have enhanced our understanding of Collembola systematics. The leading online resource is the *Checklist of the Collembola of the World* (Bellinger et al. 1996–2018), curated by Frans Janssens. Incorporating new keys, photos, citations, species synonyms, and contact information for the expert community, it remains the most up-to-date resource for collembolan taxonomy, to which older research should be reconciled. The CNC maintains an excellent collection of about 2500 slides, including type materials of 69 species, 46 of which are from Canada (Stebaeva et al. 2016). Other collections of varying size and coverage are in academic and government institutions, including significant amounts of undetermined material.

Classification of Collembola has undergone significant changes since Richards (1979), including its elevation to class level in the subphylum Hexapoda, rather than being an order of Insecta (Bellinger et al. 1996–2018, Janssens and Christiansen 2011). Richards (1979) recognized only nine families in two orders, Arthropleona and Symphypleona; Arthropleona is now recognized as artificial and divided into the orders Entomobryomorpha and Poduromorpha, while Symphyleona was split into the orders Symphyleona and Neelipleona.

Many new families with Canadian representatives have been elevated or erected, including Tullbergiidae, Pachytullbergiidae, Odontellidae, Oncopoduridae, Tomoceridae, Orchesellidae, Seiridae, Lepidocyrtidae, Mackenziellidae, Sminthurididae, Arrhopalitidae, Katiannidae, Bourletiellidae, and Dicyrtomidae. This has been accompanied by changes at the superfamily level and corrections at lower taxonomic levels too numerous to list here. Significant systematics work continues thanks to international Apterygota colloquia (Deharveng 2004) and high level morphological study combined with genetic analyses (e.g., Schneider et al. 2011, Zhang and Deharveng 2015, Yu et al. 2016).

New genetic tools are gradually being applied to the study of collembolan phylogeny. Efforts are now being made to determine the global amount of cryptic diversity undescribed for Collembola (Cicconardi et al. 2013, Porco et al. 2014). In Canada, research using DNA barcoding to estimate species richness has been performed on Collembola from: Igloolik, Cornwallis, and Somerset islands in Nunavut (Hogg and Hebert 2004); Churchill, Manitoba (Porco et al. 2014); and northern Ontario (Telfer et al. 2015). These studies have demonstrated a high likelihood that the majority of Collembola species are undescribed; true global diversity may be an order of magnitude greater than the 50,000 global species previously estimated (Hopkin 2002, Cicconardi et al. 2013).

In addition to these peer-reviewed studies, there have been DNA barcode data submissions to the Barcode of Life Data System (BOLD) from science outreach efforts (including Bioblitz programs and the University of Guelph's BIObus), academic researchers, and government ministries (Ratnasingham and Hebert 2007). There are a total of 70,864 specimen records from Canada in this database at the time of writing, with 1265 unique Barcode Index Numbers (BINs) representing 148 named species. Sampling has not been uniform; Ontario and British Columbia account for 48.3% and 15.8% of specimen records, respectively, whereas the territories collectively account for only 2.0% of records. Collection efforts are more likely to target larger surface-dwelling (epiedaphic) Collembola such as the family Entomobryidae (68.4% of records). Soil-dwelling (euedaphic) taxa, which are thought to be highly diverse, remain under-sampled; for example, the entire euedaphic order Poduromorpha represents only 6.1% of records. There is also a relatively high proportion of specimens that are not fully identified (41.3%) or are listed as unspecified. These data represent a tremendous opportunity for meta-analyses of collembolan distribution, diversity, species discovery rates, and the proportion of cryptic diversity.

Our research has resulted in a list of approximately 474 documented, described species (plus eight fossil species) in 23 families, compared to the 520 species in nine families estimated by Richards (1979) (Table 1), and 341 species in 16 families listed by Skidmore (1995). The 520 species reported by Richards (1979) represented an estimate of the total fauna, known and unknown. The actual number of described species known from Canada in 1979 is unknown as Richards did not publish a checklist. However, in the first edition of *The Collembola of North America North of the Rio Grande*, Christiansen and Bellinger (1980–1981) reported 195 described species from Canada. Thus, over the last nearly 40 years, the described fauna of Canada has increased by approximately 143%.

Distributions of Collembola species in Canada are difficult to determine as many specimens come from only a single location and species may be entered onto provincial lists with few and/or questionable records. There is also a high likelihood that seemingly widely distributed species only appear cosmopolitan due to morphological convergences with disparate species, and such problems will be best solved by study of morphological and genetic characters. Despite the challenges with delimiting species ranges, the majority of Canadian Collembola families are thought to be widely distributed, with representatives in most ecozones. There are, however, cases of region-specific records at lower taxonomic levels. From available published records, there are three genera currently recorded only in the Atlantic Maritime ecozone and several other species are known from only one jurisdiction: Manitoba (7 spp.), Alberta (11), Nunavut (15), Quebec (30), and Ontario (30) (e.g., Skidmore 1995, Christiansen and Bellinger 1998, Therrien et al. 1999, Babenko and Fjellberg 2006, Lindo 2014). British Columbia contains the most species not recorded in other areas; three families, 22 genera, and 103 of the 248 species recorded in the province have not been recorded from other Canadian jurisdictions (Cannings 2010). Species found only in one ecozone or jurisdiction should not be construed as endemic but may only appear as such simply because there is insufficient knowledge about distribution. For example, there are only 13 species records published from New Brunswick, five from Saskatchewan, and none

Table 1. Census of Collembola in Canada. Information sources for all families are Bellinger et al. (1996–2018), Christiansen and Bellinger (1998), and Deharveng (2004).

Taxon[1]	No. species reported by Richards (1979)	No. species currently reported from Canada	No. BINs available for Canadian species[2]	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[3]
Order Poduromorpha					
Superfamily Poduroidea					
Poduridae	1	1	5	1–3	most ecozones
Superfamily Hypogastruroidea					
Hypogastruridae	65	71	98	18–22	most ecozones
Superfamily Onychiuroidea					
Onychiuridae[4]	50	36	36	16–17	most ecozones
Tullbergiidae	?[4]	20	6	6	most ecozones
Pachytullbergiidae	?[4]	1	0	0	Pacific Maritime
Superfamily Neanuroidea					
Brachystomellidae[5]	22	2	6	0	Montane Cordillera, Pacific Maritime, Western Interior Basin
Neanuridae[6]	65	57	91	35–39	most ecozones
Odontellidae	?[5]	9	22	4	most ecozones
Order Entomobryomorpha					
Superfamily Isotomoidea					
Isotomidae	120	141	258	40–62	most ecozones
Superfamily Tomoceroidea					
Oncopoduridae	?[7]	1	0	0	Pacific Maritime
Tomoceridae	?[7]	12	70	0	most ecozones
Superfamily Entomobryoidea					
Orchesellidae	?[7]	11	0	1	most ecozones
Seiridae	?[7]	1	0	0	Pacific Maritime
Lepidocyrtidae	?[7]	19	0	3–4	most ecozones
Entomobryidae[7]	80	32	240	11–16	most ecozones
Order Neelipleona					
Neelidae	2	3	17	3	most ecozones
Order Symphypleona					
Superfamily Sminthuridoidea					
Mackenziellidae	?[8]	1	0	0	southern Arctic, Taiga Plains
Sminthurididae	?[8]	12	78	13	most ecozones
Superfamily Katiannoidea					
Arrhopalitidae	?[8]	11	16	7	most ecozones, few records in Arctic
Katiannidae	?[8]	10	87	4	most ecozones
Superfamily Dicyrtomoidea					
Dicyrtomidae	?[8]	8	78	3	most ecozones, few records in Arctic and Taiga ecozones
Superfamily Sminthuroidea					
Sminthuridae[8]	115	8	23	5–6	most ecozones, few records in Arctic and Taiga ecozones
Bourletiellidae	?[8]	7	133	8	most ecozones
Total	**520**	**474**	**1265**	**180–204**	

[1]Classification follows (Bellinger et al. 1996–2018). [2]All data are from BOLD (Ratnasingham and Hebert 2007) and current as of April 4, 2018. Data are Barcode Index Numbers (BINs), as defined in Ratnasingham and Hebert (2013). [3]See figure 1 in Langor (2019) for a map of ecozones. [4]The definition of Onychiuridae used by Richards (1979) likely included members of the modern Tullbergiidae. [5]Richards (1979) very likely followed Salmon (1964) and included in Brachystomellidae some species of the modern family Odontellidae. [6]Richards (1979) reported 65 species of Pseudachorutidae, which is now a subfamily of Neanuridae. [7]Richards (1979) undoubtedly included in Entomobryidae some species of the modern families, Oncopoduridae, Tomoceridae, Orchesellidae, Seiridae, and Lepidocyrtidae. [8]Richards' concept of Sminthuridae undoubtedly included species currently placed in Sminthurididae, Arrhopalitidae, Katiannidae, Dicyrtomidae, and Bourletiellidae.

from Prince Edward Island (e.g., Skidmore 1995, Christiansen and Bellinger 1998). This apparent lack of diversity is more reflective of a paucity of available regional expertise and sampling effort than true distributions.

We estimate there are approximately 180–204 existing records of Collembola in Canada, which were either not described to species level or were misidentified as existing species when they may in fact represent undocumented species. We consider this to be a conservative estimate of the undocumented Canadian springtail fauna. However, it is likely that there is a high number of cryptic species that will require advanced genetic techniques to differentiate (e.g., Cicconardi et al. 2013, Porco et al. 2014). For example, given there are 1265 BINs associated with the 148 specimens assigned species names on BOLD, and that theorized interspecies divergences for Collembola range from 8% (Hogg and Hebert 2004) to 14% (Porco et al. 2014), many of these named specimens are likely to represent multiple morphologically cryptic species. There is a ratio of approximately 8.5 BINs per identified springtail species in BOLD. If a similar ratio of BINs per described species is assumed for the 474 documented Collembola species in Canada, there would be approximately 4051 BINs expected for the currently described national fauna. If it is conservatively assumed that 80% of these BINs represent distinct species, it is possible that there are up to 3240 Collembola species in the Canadian fauna, meaning that over 2700 species have yet to be described. Although this estimate is based on several assumptions, we consider it to be reasonable given that a global fauna of 65,000 species of Collembola was estimated based on BIN data (Porco et al. 2014). We expect much of this undiscovered diversity to lie in under-sampled euedaphic taxa in the Maritimes and northern interiors of the western provinces. Collembola is a group full of opportunities for aspiring researchers, and there is serious need of a new generation of taxonomists who can integrate both morphological and genetic data.

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REVIEW ARTICLE

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Diplura and Protura of Canada

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Abstract
A literature review of the Diplura and Protura of Canada is presented. Canada has six Diplura species documented and an estimated minimum 10–12 remaining to be documented. The Protura fauna is equally poorly known, with nine documented species and a conservatively estimated ten undocumented. Only six and three Barcode Index Numbers are available for Canadian specimens of Diplura and Protura, respectively.

Keywords
biodiversity assessment, Biota of Canada, Diplura, Protura

Diplura, sometimes referred to as two-pronged bristletails, and Protura, sometimes called coneheads, are terrestrial arthropod taxa that have suffered from lack of scientific attention in Canada as well as globally. As both groups are undersampled and understudied in Canada, the state of knowledge is considered to be poor, although there have been some modest advances since 1979. Both of these taxa are soil dwelling, and, given the repeated glaciations over most of Canada, the Canadian diversity is expected to be relatively low except possibly in unglaciated areas. Nonetheless, the vast majority of the country has been poorly sampled which leaves boundless opportunities for those who develop an interest in these fascinating animals.

Diplura

There are around 800 species of Diplura known worldwide (Chapman 2009) and approximately 170 species in North America (Allen 2002). Tomlin (1979a) reported there were no published records of Diplura in Canada; however, as unidentified specimens of the families Campodeidae and Japygidae were known from Canada, based on specimens in public and private collections, he recorded two species, presumably one from each family, from the country in 1979. Overlooked by Tomlin were at least four species that had been documented from Canada before 1979, two campodeids, *Haplocampa drakei* Silvestri and *Tricampa rileyi* (Silvestri), and two japygids, *Occasjapyx americanus* (MacGillivary) and *Evalljapyx saundersi* Pagés (Silvestri 1933, 1948, Saunders 1946, Condé 1973, Reddell 1983, Pagés 1996). More recently, Alberto Sendra identified two additional campodeid species from Ontario, *Campodea fragilis* Meinert and *Campodea plusiochaeta* (Silvestri), based on DNA barcoded Canadian specimens in the Barcode of Life Data System (BOLD; Ratnasingham and Hebert 2007). These species are known from US states bordering Canada (Allen 2002) and bring the total to six identified species for Canada.

To estimate the size of the complete fauna, I evaluated reports of incompletely identified Canadian dipluran specimens, DNA barcoded Canadian specimens in BOLD, and species known from near the Canadian border, but not yet recorded from Canada. Subsequent to Tomlin's (1979a) report, Tomlin and Nagy (1979) reported a japygoid from Ontario that they thought was a species close to or presumably in *Parajapyx*. There continues to be uncertainty about the identity of this species. A *Parajapyx* is also said to occur in British Columbia (Cannings and Scudder 2006), but is most likely a misidentification of *Evalljapyx saundersi* Pagés. Additionally, there are seven DNA barcoded specimens identified as *Tricampa rileyi* which fall into two Barcode Index Numbers (BINs) that are each other's nearest neighbors but are over 12% divergent (BIN BOLD:ACK8620, from Waterton Lakes National Park, Alberta; and BIN BOLD:ACX3814 known from Darkwoods Conservation Area and Glacier National Park, British Columbia). The very large genetic distance between these two BINs suggests they may correspond to different species. This could be the result of

Table 1. Census of Diplura in Canada.

Taxon[1]	No. species reported in Tomlin (1979a)	No. species currently known from Canada	No. BINs[2] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[3]	Information sources
Suborder Rhabdura						
Campodeidae	1	4	6	9–11	Mixedwood Plains, Montane Cordillera, Boreal Plains	Allen 2002; BOLD
Suborder Dicellurata						
Japygidae	1	2	0	0	Pacific Maritime, Montane Cordillera	Pagés 1996, Allen 2002
Parajapygidae	0	0	0	1	Hudson Plains	Tomlin and Nagy 1979
Total	**2**	**6**	**6**	**10–12**		

[1]Classification follows that of Allen (2002). [2]Barcode Index Number, as defined in Ratnasingham and Hebert (2013). [3]See figure 1 in Langor (2019) for a map of ecozones.

misidentification(s), lab mix-up, cryptic species (taxonomic undersplitting) or unusually high within-species genetic diversity. At least one specimen in each BIN was identified by Alberto Sendra, a taxonomist of Diplura, with the remainder identified by their DNA barcodes. For counting purposes, I refer to one of these BINs, which could otherwise be an unaccounted-for Canadian dipluran species, as *Tricampa* cf. *rileyi*.

Two BINs of Canadian diplurans remain unidentified below the family Campodeidae (BOLD:AAN6530, BOLD:ACZ3071). The first of these BINs may correspond to *Haplocampa drakei*, already known from Canada, because it corresponds to specimens collected from 1074m in Jasper National Park, Alberta, and *H. drakei* is known from Banff, Alberta, so this is a possible match. The second BIN corresponds to a specimen from Toronto, Ontario and likely represents one of the eight campodeid species that Allen (2002) reports but have yet to be recorded from Canada, although they are known from states bordering Canada.

Sikes and Allen (2016) reported the northern-most records for Diplura in North America based on Alaskan specimens of *Metriocampa allocerca* Conde & Geeraert, which was described from northwestern Montana (Allen 2002), so it may occur in Canada.

To summarize the Canadian Diplura fauna, there are six species identified and 10–12 additional species expected to occur based on six BINs of DNA barcoded specimens, incompletely identified Canadian specimens, and species known from near the Canadian border. Thus, the Canadian dipluran fauna could be as high as 18 species, making 40–66% of this fauna undocumented. Although considerable progress has been made relative to the report of Tomlin (1979a), much of this has been based on discovery of overlooked literature, and clearly much work remains to be done to fully document the Canadian fauna.

Protura

Despite work by many eminent entomologists since the discovery of Protura in 1907, much remains unknown about these organisms (Pass and Szucsich 2011). Szeptycki (2002) estimated that only 10% of the world's species have been described. Only 743

Table 2. Census of Protura in Canada.

Taxon[1]	No. species reported in Tomlin (1979b)	No. species currently known from Canada	No. BINs[2] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[3]	Information sources
Order Acerentomata						
Acerentomidae	2	6	0	5	Taiga Cordillera, Pacific Maritime, Hudson Plains	Szeptycki 2007
Order Eosentomata						
Eosentomidae	1	3	3	5	Hudson Plains	Szeptycki 2007; BOLD
Total	**3**	**9**	**3**	**10**		

[1]Classification follows that of Szeptycki (2007) with one recent update in the text from Shrubovych et al. (2014). [2]Barcode Index Number, as defined in Ratnasingham and Hebert (2013). [3]See figure 1 in Langor (2019) for a map of ecozones.

species are known worldwide (Szeptycki 2007), and there are approximately 92 species described from North America (Allen 2006, Szeptycki 2007). Tomlin (1979b) reported three species of Protura known from Canada, two species of Acerentomidae: *Verrucoentomon canadense* (Tuxen) and *Vesiculentomon condei* (Tuxen) (Shrubovych et al. 2014), both known from the unglaciated Richardson Mountains of the Yukon and known only from Canada, where they were described in 1955, and one unidentified eosentomid: *Eosentomon* sp.

Overlooked by Tomlin (1979b) were at least three additional species that had been described from Canada before 1979 by Rusek (1974): *Nippoentomon bifidum*, and *Nippoentomon kevani*, both known only from their type locality of Vancouver, British Columbia (BC), and *Vesiculentomon marshalli* Rusek, known only from its type locality of Victoria, BC.

Since Tomlin's summary (1979b), two additional species were described from Canada by Nosek (1984), *Eosentomon bernardi* and *Eosentomon canadense*, both known only from their type localities of Ste-Anne-de-Bellevue, Québec, and one widespread species, *Acerentuloides americanus* (Ewing), reported from Québec by Nosek and Kevan (1984), but also known from several states of the USA. Behan-Pelletier (1993) listed nine species of Protura from Canada, one of which, *Acerentomon* sp., appears to be unique to her list, but no Nearctic species in this genus is listed in Szeptycki (2007) so this species cannot be reconciled, leaving eight identified Canadian species known as of 1993.

Bernard and Guzowski (2002) described *Eosentomon heatherproctorae*, which is known only from its type locality at the Queen's University Biological Station near Kingston, Ontario. Thus, the known Canadian fauna totals nine species, eight of which are known only from Canada (Table 2). All nine of these species are reported from Canada in Szeptycki's comprehensive world catalog (Szeptycki 2007). Although Allen (2006) published a catalog of North American Protura, it was missing a number of the above records, omitted the species *E. heatherproctorae* entirely, contained some apparent typographic errors in relation to the Canadian fauna, and was entirely superseded by Szeptycki (2007).

The Protura fauna of Alaska comprises 15 species (Szeptycki 2007), none of which have yet been reported from Canada, but some of them may occur in adjacent unglaciated parts of the Yukon. Nineteen species are known from US states in close proximity to the southern Canadian border, 17 from Michigan and one each from Idaho and Vermont, and some of these species also may occur in southern Canada. As the interior of Alaska wasn't glaciated, it isn't surprising that it has a large Protura fauna. However, in contrast, Michigan was entirely buried under the Laurentide Ice Sheet during the Wisconsin Glacial Period, yet it has almost twice the known species richness of Canada. This indicates that substantial post-glacial recolonization from the south has occurred and that species richness in southern Canada is likely much higher than we know. Of the 32 Protura species known from Alaska, Michigan, Idaho, and Vermont that are not recorded from Canada, it is conservatively estimated that 10 species, five in each family, may occur in Canada. Thus at least 53% of the Canadian fauna remains undocumented.

There are three BINs of Canadian Protura based on specimens collected in Ontario, all identified as family Eosentomidae (BOLD:ACY5591, BOLD:ADA0787, BOLD:ADA0788), and all between 17–20% divergent from their nearest neighbors. These BINs could represent species reported from Canada, but species-level determinations are not yet available.

In summary, the poor state of knowledge about the Canadian (and North American) Diplura and Protura fauna offers many opportunities to explore the diversity, distribution, and biology of these tiny but fascinating creatures. In particular, Berlese, Winkler, and Tullgren funnel extractions of litter and decaying wood will greatly aid the documentation of the Canadian fauna. Those who sample more commonly studied soil and litter creatures, such as mites and Collembola, are well-situated to enhance Canadian collections of other poorly studied litter arthropods by saving by-catch of groups such as Protura and Diplura and forwarding it to those willing to study and identify the material using traditional or molecular methods. Given the difficulty of collecting intact specimens that retain enough appendages to allow morphology-based identification, their small size, and the scarcity of taxonomists interested in diplurans and proturans, it is expected that genetic data will play an increasingly important role in advancing our understanding of the Canadian fauna for these taxa.

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REVIEW ARTICLE

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Archaeognatha of Canada

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Abstract

Current knowledge of the Canadian bristletail (Archaeognatha) fauna is summarized and compared with Tomlin's 1979 chapter on the group in *Canada and Its Insect Fauna*. Since that time the number of species known from Canada has increased from three to eight. While much work remains to be done to document an estimated eight additional species from Canada, this can be accomplished using an integrated approach.

Keywords

Archaeognatha, biodiversity assessment, Biota of Canada, jumping bristletails, Microcoryphia

Introduction

Substantial progress has been made in our understanding of the bristletail fauna of Canada since Tomlin's (1979) chapter in *Canada and its insect fauna*, but a great deal of work remains to be done before this fauna is well documented.

Tomlin (1979) reported three species known from Canada and estimated that there were an additional ten species yet to be documented or described. He had considered all Canadian members of the order Microcoryphia (= Archaeognatha) to be in the family Machilidae, but it is unclear whether this was because he differed in opinion regarding the family Meinertellidae proposed by Verhoeff (1910) or because he was not aware of any meinertellid species from Canada at that time.

The one Canadian species mentioned by Tomlin (1979), *Machilis variabilis* Say, has since been considered unidentifiable because the type material has been lost and Say (1821) did not describe taxonomically useful characters to distinguish this species (see Wygodzinsky and Schmidt 1980). However, it may still be possible to associate this name with an existing species based on the type locality. Say (1821) provided a broad type locality of "probably in almost every temperate part of North America" but specifically included Florida. It is highly probable that this material came from the northeast corner of Florida, where Say had made one collecting trip over the winter of 1817–1818 (Bennet 2002). An unidentified species of *Neomachilellus*, the only archaeognathan besides *M. variabilis* reported from Florida, was later reported from the eastern Florida-Georgia border area (Wygodzinsky 1967, Sturm 1984) and is likely the same species as some of Say's original types of *M. variabilis*.

North American Archaeognatha are presently a difficult group to work with due to a lack of modern descriptions for some species and inherent challenges of recognizing morphologically similar species. Most progress on the North American fauna since 1979 has been due to the work of Pedro Wygodzinsky and Helmut Sturm, both experts on this group working at a worldwide scope. Wygodzinsky and Schmidt (1980) published the only modern regional treatment applicable to Canadian bristletails, covering the northeastern United States and adjacent provinces of Canada. More recent work by Sturm and others pertaining to the Canadian fauna (Sturm 1991, 2001, Sturm and Bach de Roca 1992, Sturm and Bowser 2004) has been incremental, with additions of species and treatment of one genus (*Mesomachilis* Silvestri).

A total of eight species of bristletails are now known from Canada, representing two families (Table 1). Of these, two species were introduced from the Palearctic to the east coast of North America, apparently in ship ballast material (Wygodzinsky and Schmidt 1980). No species in the Canadian fauna are known to be widespread across Canada; most appear to be restricted to defined ecological zones. Distinct bristletail assemblages are present in the Pacific Maritime, Western Interior Basin, and Montane Cordillera ecozones.

There are few DNA barcodes for Canadian bristletails. Ten BINs (Barcode Index Numbers) of bristletails have been obtained from Canada, only two of which have been associated with accepted species names. Some of the unidentified BINs will likely be eventually identified as previously described species, but some likely represent undescribed species. DNA barcode sequences from the two Palearctic species established in eastern Canada have been obtained from elsewhere but not yet from Canada.

The author is aware of six potentially undescribed species: two entities in the genus *Petridiobius* Paclt represented by the BINs BOLD:AAV1529 and BOLD:AAV1531 from the Canadian Rockies; specimens representing one of two BINs BOLD:AAV1528 and BOLD:ACJ4257 from coastal British Columbia (BC) that are indistinguishable from the original description of *Pedetontus submutans* Silvestri; a *Mesomachilis* sp. and a species of *Pedetontoides* Mendes from the Western Interior Basin ecozone of British Columbia (BC); and a species similar to *Leptomachilis* Sturm from Kootenay National Park represented by BIN BOLD:AAV1530. More species are likely to be found in Canada, especially in regions with complex glacial history, a situation that has led to high species diversity of bristletails in the European Alps (Wachter et al. 2012, Gassner et al. 2014, Dejaco et al. 2016).

Table 1. Census of Archaeognatha in Canada.

Taxon[1]	No. species reported in Tomlin (1979)	No. species currently known from Canada	No. BINs[2] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[3]	Information sources[4]
Machilidae	3	7 (2)	9	7	southern Canada from Pacific Maritime to Atlantic Maritime	Wygodzinsky and Schmidt 1980, Sturm 1991, Sturm 2001, Chlebak 2013; specimens in DEBU, RBCM, UBCZ
Meinertellidae	0	1	1	1	Pacific Maritime, Western Interior Basin, Prairies	Sturm and Bach de Roca 1992, Acorn 2011; specimens in DEBU, RBCM; observations on iNaturalist.org
Total	**3**	**8 (2)**	**10**	**8**		

[1]Classification follows Sturm and Machida (2001). [2]Barcode Index Number, as defined in Ratnasingham and Hebert (2013). [3]See figure 1 in Langor (2019) for a map of ecozones. [4]Data source collection codens: DEBU, University of Guelph; RBCM, Royal BC Museum; UBCZ, University of British Columbia, Spencer Museum.

Dejaco et al. (2012, 2016) and Gassner et al. (2014) have recently demonstrated success in discriminating among morphologically similar species of bristletails using an integrated approach incorporating multiple morphometric and molecular methods. Appropriate next steps toward improving our understanding of the Canadian archaeognathan fauna would be to collect high-quality specimens that are suitable for both morphological and molecular methods, then apply an integrated taxonomic approach to produce treatments which include identification keys. Areas where additional collecting would be most helpful include the Western Interior Basin and Montane Cordillera ecozones, apparently home to the greatest diversity of Canadian bristletails; the Prairies ecozone, where bristletails are known (Acorn 2011) but have neither been DNA barcoded nor identified to species; and the Atlantic Maritime ecozone, from which no bristletail specimens have been DNA barcoded. While Tomlin's (1979) concluding remark regarding the Canadian bristletails that, "obviously much work remains to be done in this group", remains true today, fortunately tools are now available to complete this work much more satisfactorily.

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REVIEW ARTICLE

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Ephemeroptera of Canada

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Abstract

Thus far, 335 currently valid species in 82 genera and 21 families of mayflies (Ephemeroptera) have been documented from Canada, remarkably representing a little more than half of the combined species richness of Canada, Mexico and the USA. The current known species richness for Canada represents an increase of 11.3% as compared to that reported in 1979. Species richness is greatest in the families Heptageniidae (83), Baetidae (76) and Ephemerellidae (45). A total of 328 DNA Barcode Index Numbers (BINs) are available for Canadian mayfly species. The greatest net gains anticipated for future species tallies are for Baetidae (25), Heptageniidae (10) and Leptophlebiidae (10). A total of 66 more species overall is anticipated for Canada, with greatest gains potentially coming from lentic habitats across Canada and from far eastern and far western areas in general. However, even metropolitan areas should not be overlooked for the potential of discovery.

Keywords

aquatic insects, biodiversity assessment, Biota of Canada, Ephemeroptera, mayflies

"Great strides" have been made in our understanding of the Canadian mayfly fauna since Lehmkuhl (1979) used this phrase in his review of the status of this order as part of the larger work by Danks (1979). At the time, Lehmkuhl (1979) indicated that there was "no comprehensive treatment of the Canadian fauna." That situation has since been remedied with a continually updated Canada species list that has been available online since 1995 (McCafferty 1996, McCafferty and Jacobus 2018). Ecological and biological information was summarized by Waltz and Burian (2008) and others in previous editions of that work. Peters (1988) provided a biogeographic discussion of the Canada fauna that remains largely applicable today. McCafferty et al. (1990) discussed the status and needs of mayfly systematics in North America north of Mexico, including Canada. A history of mayfly science in Canada was summarized by McCafferty and Randolph (1998) and further reviewed by McCafferty (2001).

Thus far, 335 currently valid species in 82 genera and 21 families have been documented from Canada, remarkably representing a little more than half the combined species richness of Canada, Mexico and the USA (McCafferty and Jacobus 2018). Two species described from Canada are considered nomen dubia, and thus, they are not included in species counts (McCafferty and Bae 1992, Jacobus and McCafferty 2007). At least 15 of the species documented from Canada have a Holarctic distribution (e.g., Kluge 1980, Novikova and Kluge 1987, Kluge and Novikova 2011, Bauernfeind and Soldán 2012, Kjærstad et al. 2012, Savolainen et al. 2014, Cordero et al. 2016). Eight of the Canadian species have geographic distributional ranges that extend south to Central America (McCafferty and Jacobus 2018). Ten of the Canadian species are not yet known outside Canada, but the number of truly endemic species probably is much lower, because most of these ten have been collected near the southern border and likely occur in the United States also (Jacobus 2018). Low endemism in Canada is not surprising, considering the recent glacial history of Canada and therefore the large degree to which the current fauna reflects dispersal and post-glaciation recolonization events (Peters 1988, McCafferty and Randolph 1998). No non-native species are known from Canada (Randolph et al. 2002).

The current known species richness for Canada represents an increase of 11.3% as compared to that reported in 1979. The families with the largest net increase in species numbers are Heptageniidae (10), Caenidae (6) and Baetidae (5). Ameletidae probably has nearly as great an increase as Heptageniidae (Zloty 1996, Zloty and Harper 1999), but current and 1979 species numbers could not be compared due to the way data were classified in the 1979 report (see footnote 7 in Table 1).

The current family and genus classifications used here for the Ephemeroptera of Canada are quite different from those that were hypothesized nearly 40 years ago, as reflected in the work of Lehmkuhl (1979). Current family-level classifications in North America, and Canada in particular, primarily reflect the work of McCafferty (1991b), with subsequent revisions or significant review by Landa and Soldán (1985), Peters and Peters (1993), Wang and McCafferty (1995), and McCafferty (2004). Higher classification remains tentative and contentious in many cases, as reviewed by Ogden et al. (2009), and the higher classification followed here borrows from various sources (see footnote 1 in Table 1) to best reflect the most recent phylogenetic hypotheses (Jacobus and McCafferty 2006, Ogden et al. 2009: fig. 7, Miller et al. 2018).

The classification of species into genera also has changed markedly in the last 40 years. The family Baetidae has seen the greatest number of changes, with multiple new genera described, several more recent generic revisions, and some species going back and forth between genera several times. McCafferty and Waltz (1990) provided a summary of these changes up to that point, along with some of their own, and that work marks the starting point for Baetidae references cited in Table 1; the reference list is long but not exhaustive, providing a strong starting place for understanding the current generic classification applied to the species found in Canada. Heptageniidae also has seen considerable changes in generic classification of species, and most of the current genus-level systematics for Canada are reflected in Webb and McCafferty (2008). Sun and McCafferty (2008) made significant changes to genera of the subfamily Brachycercinae in the family Caenidae, and Jacobus and McCafferty (2008) most recently revised the generic classification of Ephemerellidae. The classification of species into genera across the order remains inconsistent and somewhat contested globally (e.g., Bauernfeind and Soldán 2012, Jacobus 2015, 2016).

The number of new species described and named from Canada has been relatively few since 1979, but the most notable gain has been in the genus *Ameletus* Eaton (Ameletidae) (Zloty 1996, Zloty and Harper 1999). In contrast to new species descriptions, a remarkable number of species synonyms have been proposed for the Canadian fauna, and these are reflected in the complete species synonymies given by McCafferty and Jacobus (2018). However, it should be noted that new evidence, especially from DNA barcoding, challenges many of these concepts of highly variable species, and some of the current concepts of single species may be split into multiple species after more research is completed (Webb et al. 2012). Recently collected mayfly specimens from Canada have played an important role in the generation of regional DNA barcode libraries (Ball et al. 2005, Zhou et al. 2009, 2010, Webb et al. 2012) and discovering trans-Atlantic species distributions (e.g., Kjærstad et al. 2012, Savolainen et al. 2014, Cordero et al. 2016).

While a list of species for Canada that reflects current species concepts has been maintained online for over 20 years (see above), only coarse geographic distributions have been indicated there, with Canada divided into eastern, western, and far northern regions, essentially following those indicated by Edmunds et al. (1976: 50) and McCafferty and Waltz (1990: fig. 1). McCafferty and Randolph (1998), however, provided a comprehensive listing of species for each of the Canadian territories and provinces at that time. Subsequent notable contributions for each include the following for Alberta (Webb and McCafferty 2003, McCafferty et al. 2004, 2012, McCafferty 2009, Webb et al. 2012), British Columbia (Jacobus and McCafferty 2001, McCafferty et al. 2012), Manitoba (Flannagan et al. 2001, Jacobus and McCafferty 2001, McCafferty et al. 2004, McCafferty 2009, Zhou et al. 2009, 2010, Webb et al. 2012, Kjærstad et al. 2012), New Brunswick (Jacobus and McCafferty 2001, McCafferty 2009, Webb et al. 2012, Burian 2017), Newfoundland and Labrador (Lomond and Colbo 2000, McCafferty 2009, 2011b, Webb et al. 2012, Burian 2017), the Northwest Territories (Randolph and McCafferty 2001, Bowman et al. 2010, Gorski et al. 2015, Burian 2017, Giberson and Burian 2017), Nova Scotia (Jacobus and McCafferty 2001, McCafferty et al. 2004), Nunavut (Randolph and McCafferty 2001, Giberson et al. 2007, McCafferty 2011a, Burian 2017), Ontario (McCafferty et al. 2008, McCafferty 2009, Webb et

Table 1. Census of Ephemeroptera in Canada.

Taxon[1]	No. species reported in Lehmkuhl (1979)	No. species currently known from Canada[2]	No. BINs[3] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[4]	Information sources
Suborder Pisciforma[5]						
Superfamily Baetoidea						
Baetidae	71	76	87	25	most ecozones	McCafferty and Waltz 1990, Lugo-Ortiz and McCafferty 1998, Randolph et al. 2002, Jacobus and McCafferty 2005, McCafferty et al. 2005, 2010, Guenther and McCafferty 2008, McCafferty 2011a, Burian and Myers 2011, Jacobus and Wiersema 2014, Cruz et al. 2017, Webb et al. 2018
Superfamily Siphlonuroidea						
Acanthametropodidae[6]	1	1	0	1	Boreal Plains, Prairies	Lehmkuhl 1976, McCafferty 1991a
Ameletidae[7]		23	18	5	nearly all ecozones	Zloty and Harper 1999
Ametropodidae	2	2	1	0	central & western Boreal & Taiga ecozones	Jacobus 2013
Metretopodidae	3	3	3	1	most ecozones	Berner 1978, Engblom et al. 1993, Kluge 1996
Siphlonuridae[7]	35	20	12	1	nearly all ecozones	Traver 1935, Kondratieff and Voshell 1981, Provonsha and McCafferty 1982, McCafferty and Edmunds 1997, Newell and Anderson 2009, Burian 2017
Suborder Setisura[5]						
Superfamily Oligoneurioidea[5]						
Isonychiidae[8]	5	6	4	1	most ecozones south of taiga	Kondratieff and Voshell 1984
Oligoneuriidae	1	1	0	1	Prairies	Edmunds 1951
Superfamily Heptagenioidea						
Arthropleidae[9]	1	1	0	0	Taiga Shield, Boreal Shield, Hudson Plains, Atlantic Maritime, eastern Boreal Plains	Ide 1930, Wang and McCafferty 1995
Heptageniidae[10]	73	83	82	10	nearly all ecozones	Burian et al. 2008, Webb and McCafferty 2008, 2011

Taxon[1]	No. species reported in Lehmkuhl (1979)	No. species currently known from Canada[2]	No. BINs[3] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[4]	Information sources
Pseudironidae[11]	1	1	0	0	Boreal Plains, Prairies, western Boreal Shield	Pescador 1985
Suborder Carapacea						
Baetiscidae	7	6	2	0	most ecozones south of Taiga Plains and Taiga Shield	Pescador and Berner 1981, Baumann and Kondratieff 2000, Webb and McCafferty 2003
Suborder Furcatergalia						
Infraorder Lanceolata						
Superfamily Leptophlebioidea						
Leptophlebiidae	24	27	34	8	nearly all ecozones	Traver 1935, Allen 1973, McCafferty 1992, Burian 2000, Tiunova and Kluge 2016, McCafferty et al. 2017
Infraorder Scapphodonta						
Superfamily Potamanthoidea						
Potamanthidae	3	4	0	0	Atlantic Maritime, Mixedwood Plains, extreme southern Boreal Shield	Bae and McCafferty 1991
Superfamily Ephemeroidea						
Ephemeridae[12]	11	9	8	2	most ecozones south of Arctic	McCafferty 1975, 1994
Palingeniidae[13]	1	1	0	0	southern Boreal Shield, eastern Prairies	McCafferty 2004
Polymitarcyidae	3	3	4	0	Prairies, Boreal Plains, Boreal Shield, Mixedwood Plains, Atlantic Maritime	McCafferty 1975, 1994, Molineri 2010
Infraorder Pannota						
Superfamily Caenoidea						
Caenidae	10	16	15	4	nearly all ecozones	Provonsha 1990, Sun and McCafferty 2008

Taxon[1]	No. species reported in Lehmkuhl (1979)	No. species currently known from Canada[2]	No. BINs[3] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[4]	Information sources
Neoephemeridae	1	1	0	0	Mixedwood Plains	Schmude et al. 2012
Superfamily Ephemerelloidea						
Ephemerellidae	44	45	50	5	nearly all ecozones	Jacobus and McCafferty 2008, Jacobus 2010
Leptohyphidae[14]	4	6	8	2	most ecozones, except for Arctic, Taiga Cordillera, Taiga Plains, and Boreal Cordillera	Alba-Tercedor and Flannagan 1995, Wiersema and McCafferty 2000, 2005, Baumgardner et al. 2003, Baumgardner 2009
Total	**301**	**335**	**328**	**66**		

[1]Mayfly higher classification is far from resolved. This classification is a synthesis based on Sun et al. (2006), Ogden et al. (2008, 2009: Figs 1, 7), Prisecaru et al. (2014), Miller et al. (2018). [2]Based on Mayfly Central species list for North America (McCafferty 1996, McCafferty and Jacobus 2018). [3]Barcode Index Number, as defined in Ratnasingham and Hebert (2013). Only those BINs that include Canada specimens are included in counts. Counts accurate as of 30 April 2018. [4]See figure 1 in Langor (2019) for a map of ecozones. [5]Taxon known to be paraphyletic, even when considering only North American fauna, north of Mexico. [6]Recorded in 1979 as Siphlonuridae, subfamily Acanthametropodinae. [7]Due to changes in family-level classification, the 1979 report of species in the subfamily Siphlonurinae now applies to species in the current families Ameletidae and Siphlonuridae. For simplicity, the pooled 1979 total of 35 species has been inserted for Siphlonuridae and nothing has been entered for Ameletidae. [8]Recorded in 1979 as Siphlonuridae, subfamily Isonychiinae. [9]Recorded in 1979 as Heptageniidae, subfamily Arthropleinae. [10]Today this family excludes taxa that were reported as Arthropleinae and Pseudironinae in 1979. Thus, the number of species reported herein for 1979 includes only those reported for Heptageniinae and Anepeorinae. [11]Recorded in 1979 as Heptageniidae, subfamily Pseudironinae. [12]Recorded in 1979 as Ephemeridae, subfamily Ephemerinae. [13]Recorded in 1979 as Ephemeridae, subfamily Pentageniinae. [14]Recorded in 1979 as Tricorythidae.

al. 2012, Klubertanz 2016b), Prince Edward Island (Jacobus and McCafferty 2001), Quebec (Jacobus and McCafferty 2001, Randolph et al. 2002, Burian 2017), Saskatchewan (McCafferty et al. 2004, Webb et al. 2004, 2007, McCafferty 2009, Miyazaki and Lehmkuhl 2011, Webb et al. 2012), and Yukon Territory (McCafferty et al. 2004, Giberson and Burian 2017). Other scattered reports of new provincial and territorial records can be found in a variety of sources, including those listed in Table 1. The general distributions detailed in Table 1 are based on Canadian ecozones, as are the general distributions given for other taxa in this series of papers. Published records of species, as reviewed above, were used to determine the ecozones inhabited by each family.

Beyond those already reported in the scientific literature, an additional 66 species of mayflies are expected to be added to the list of Canadian species (Table 1). This tally includes named species known to occur in adjacent parts of the USA that will be found predictably in adjoining Canada (L Jacobus unpubl. data, SK Burian pers. comm., JM Webb pers. comm.), and it includes known, but unnamed, species likely new to science, especially from the families Ameletidae, Baetidae, Caenidae (Brachycercinae), Ephemerellidae and Heptageniidae (Jacobus et al. unpubl. data). For most of these unnamed species, more material is needed to allow a final decision and to facilitate descriptions; others simply are awaiting completion of formal scientific descriptions. A couple of southeastern United States species likely to occur in Canada have been diagnosed tentatively, however, and given informal designations by McCafferty et al. (2017).

Lehmkuhl (1979) indicated that very few descriptions of larvae were "adequate for taxonomic purposes. Therefore the state of knowledge…[was]…not tabulated" at that time. Major advances in our knowledge of the larval stages have occurred since then (McCafferty et al. 1990), and in fact the larva is now the most commonly and widely studied metamorphic stage of mayflies. Morphological identifications of larvae of most species from Canada can be made using two recent workshop manuals (Jacobus et al. 2014, Jacobus 2017), both available by request, and the works cited therein. Jacobus (2017) relies heavily on integrating two recently published identification keys (Klubertanz 2016a, McCafferty et al. 2017). Specimens collected from Manitoba must be identified with all these sources cautiously, given the mix of eastern and western species in the province. Although the knowledge of larvae is generally good, certain taxa still require better description, and a variety of cryptic species complexes require resolution (Webb et al. 2012, 2018). Morphological identifications of mayfly subimagos and female adults to the species level are usually very difficult to impossible at the present, and morphological identification of male adults is possible only via the use of a variety of published literature and unpublished research notes, some of which remains unavailable outside private libraries.

Looking to the future, additional work is needed on lentic habitats throughout Canada because unusual new taxa continue to be discovered from lakes throughout North America (Hill et al. 2010, McCafferty 2011a). Northern Canada in general requires much more work before its fauna will be documented adequately (McCafferty et al. 1990, Cordero et al. 2016, Giberson and Burian 2017), but even less remote areas continue to yield new records of species (e.g., Klubertanz 2016b). Provinces such as Newfoundland and British Columbia have less documented species richness than might be expected, based on richness of surrounding areas (McCafferty and Randolph 1998, Meyer and McCafferty 2007, McCafferty et al. 2012) and may provide opportunities for considerable discovery that will add to species numbers, including new country records for Canada. Although our knowledge of the larval stage of mayflies has improved drastically since Lehmkuhl's (1979) assessment, association of larvae with male adults should remain a priority, even in geographic areas that are considered easily accessible and mostly well known. The Ottawa and Montreal regions, for example, contain type localities for species still unknown as larvae (e.g., McDunnough 1925).

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REVIEW ARTICLE

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Odonata of Canada

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Abstract

Since Corbet's thorough 1979 overview of Canadian Odonata, hundreds of regional works on taxonomy, faunistics, distribution, life history, ecology and behaviour have been written. Canada records 214 species of Odonata, an increase of 20 since the 1979 assessment. Estimates of unrecorded species are small; this reflects the well-known nature of the fauna. A major impetus for surveys and analyses of the status of species is the work of the Committee on the Status of Endangered Wildlife in Canada which provides a scientifically sound classification of wildlife species potentially at risk. As of 2017, six species have been designated "Endangered" and two "Special Concern" (only five of which are officially listed under the Federal Species at Risk Act (SARA)). The Order provides a good example of molecular barcoding effort in insects, as many well-accepted morphological species in Canada have been barcoded to some degree. However, more barcoding of accurately identified specimens of many species is still required, especially in most of the larger families, which have less than 70% of their species barcoded. Corbet noted that the larvae of 15 Canadian species were unknown, but almost all larvae are now well, or cursorily, described. Extensive surveys have greatly improved our understanding of species' geographical distributions, habitat requirements and conservation status but more research is required to better define occurrence, abundance and biological details for almost all species.

Keywords

barcoding, biodiversity assessment, Biota of Canada, climate change, identification, Odonata, species at risk

Philip Corbet (1979), in his treatment of the Odonata in *Canada and its insect fauna*, noted that the order was well-known over much of the earth. Although this was true then, it is even more accurate today, for in the past four decades, dragonflies and damselflies have become the focus of much phylogenetic, behavioural, ecological, faunistic, and conservation study. Naturalists and photographers and others in the general public have taken a strong interest in the order and their documentation of distribution and status of species has greatly improved our knowledge of the group. Corbet also noted that the order was a small one and stated that "the world fauna probably does not greatly exceed the 5000 or so species now described". Although today the Odonata is still considered a relatively small order of insects, it now consists of approximately 6000 named species in 30 families worldwide (Dijkstra et al. 2013). Estimates suggest that ca. 1000 to 1500 species remain to be named and, based on the fact that ca. 40 species have been described annually since 1970, 95% of the world's species will probably be named by 2030 (Kalkman et al. 2008).

The order is predominantly tropical in distribution and is less diverse at higher latitudes. For example, as of October 2017, Canada recorded 214 species (Table 1; R Cannings unpubl. data) and the United States (including Alaska) listed 464, while Brazil had 736 species (DR Paulson pers. comm.). In addition, tropical countries, compared to temperate ones, generally have a much higher number of unrecorded and undescribed species.

Trueman and Rowe (2009) and Dijkstra et al. (2013) summarize the issues and relevant literature in Odonata phylogenetics; the latter outlines the most recent and probably the most widely accepted classification. Odonata is monophyletic and is divided into three suborders: Anisoptera (true dragonflies), Anisozygoptera and Zygoptera (damselflies), although some controversy over this classification remains (Dijkstra et al. 2013). Anisoptera and Zygoptera occur in Canada.

Canada has been a centre of odonatological research for at least 150 years. Léon Provancher (1874, 1878) studied the Québec fauna at least as early as the 1870s and Edmund Walker laboured for 70 years on important systematic and distribution works, especially monographs on *Aeshna* (1912) and *Somatochlora* (1925) and his monumental *The Odonata of Canada and Alaska* (Walker 1953, 1958) the last volume of which was completed by Philip Corbet (Walker and Corbet 1975). Walker's important amateur collaborator, Francis Whitehouse (1941, 1948), primarily studied Odonata in Alberta and British Columbia. Corbet, along with Adrien Robert (1963) in Québec, acted as transitional researchers between the first half of the 1900s and the second half, when odonatology expanded dramatically in the nation.

The growth of organized international research and communication since the mid-1970s has stimulated study in Canada. This began with the creation of the International Odonatological Society (SIO) in Europe and its spread around the world. International symposia were held every two years; two were organized in Canada – Montréal (1979) and Calgary (1983). A Canadian newsletter, *Walkeria*, was disseminated twice a year from the mid-1980s to the late 1990s, when the society dissolved worldwide because of internal conflicts. Nevertheless, the SIO journals, *Odonatologica* and *Notulae odonatologicae,* continue to be published. International activity in Canada largely switched in the 1990s to the Dragonfly Society of the Americas (begun in 1989) and the Worldwide Dragonfly Association (1997).

Table 1. Census of Odonata in Canada.

Taxon[1]	No. species reported in Corbet (1979)	No. species currently known from Canada	No. BINs[2] available for Canadian species	Est. no. undescribed or unrecorded species in Canada[3]	General distribution by ecozone[4]	Information sources[5]
Order Odonata						
Suborder Zygoptera						
Calopterygidae	4	5	4	0	Montane Cordillera, Taiga Plains, Boreal Shield, Hudson Plains, Newfoundland Boreal and ecozones southward, except Pacific Maritime	Walker 1953, 1958, Walker and Corbet 1975, Cannings et al. 1991, Brunelle 1997, Pilon and Lagacé 1998, Catling and Brownell 2000, Catling et al. 2004, 2005; AADIP, OC, NSC, specimens and databases from various collections
Lestidae	9	12	11	0	all ecozones except Arctic	see sources for Calopterygidae
Coenagrionidae	38	43	27	4	all ecozones including southern part of Arctic	see sources for Calopterygidae
Suborder Anisoptera						
Petaluridae	2[6]	1	0	1	Pacific Maritime, Western Interior Basin	Cannings 2002; NSC, OC, specimens in RBCM, UBC
Aeshnidae	24	24	25[7]	0	all ecozones including southern part of Arctic	see sources for Calopterygidae
Gomphidae	36	41	26	4	all ecozones except Taiga Cordillera and Arctic	see sources for Calopterygidae
Cordulegastridae	4	5	5	1	Pacific Maritime, Montane Cordillera, Western Interior Basin, Boreal Shield, Mixedwood Plains, Atlantic Maritime	see sources for Calopterygidae
Macromiidae	4	4	3	2	Pacific Maritime, Montane Cordillera, Western Interior Basin, Boreal Shield, Mixedwood Plains, Atlantic Maritime	see sources for Calopterygidae
Corduliidae	28	33	20	2	all ecozones including southern part of Arctic	see sources for Calopterygidae
Libellulidae	45	46	30	1	all ecozones including southern part of Arctic	see sources for Calopterygidae
Total	**194**	**214**	**151**	**15**		

[1]Classification follows that of Dijkstra et al. 2013; Catling et al. 2005. [2]Barcode Index Number, as defined in Ratnasingham and Hebert (2013). [3]Several unrecorded species may occur, especially in extreme southern central and eastern Canada; others might arrive from the USA in the next several years as their ranges expand. Undescribed species are unlikely. [4]See Figure 1 in Langor (2019) for map of ecozones. [5]ADIP – Atlantic Dragonfly Inventory Program, NSC – NatureServe Canada Conservation Data Centres (see http://www.natureserve.org/natureserve-network/canada/about-our-cdcs), OC – OdonataCentral (see http://www.odonatacentral.org), RBCM – Royal British Columbia Museum, UBC – University of British Columbia. See Cannings (2004) for a list of Canadian collections with significant holdings of specimens and data. [6]*Tachopteryx thoreyi* (Hagen), originally reported from Québec, was discussed by Savard (1987) and discounted by Pilon and Lagacé (1998). [7]Species and BINs do not completely align; see text for explanation.

Cannings (2004) summarized the resources available to dragonfly and damselfly workers in Canada, including the most significant collections of specimens. On the North American scale, the most useful field books are Dennis Paulson's (2009, 2011) guides to western and eastern species, which have eclipsed most others in quality and comprehensiveness; the distribution maps are small but carefully and accurately rendered. There are now dozens of other field guides available, some useful in both the USA and Canada; Lam (2004) is one of the best. Needham et al. (2000) and Westfall and May (2006) give the most detailed identification keys for adults and larvae of the continent's fauna, and Garrison, von Ellenrieder and Louton (2006, 2010) provide illustrated keys and authoratative taxonomic summaries for all the New World genera. Corbet's (1999) masterpiece, *Dragonflies: Behavior and Ecology of Odonata*, is the culmination of the long career of a prominent dragonfly biologist and is the critical resource for any research on the biology of the Odonata and its evolutionary context. The Internet is replete with valuable Odonata websites of all descriptions. OdonataCentral (http://www.odonatacentral.org/) disseminates information on distribution, biogeography, biodiversity, and identification of New World Odonata. Species distributions are mapped with submitted specimen and photograph records and an identification application based on the extensive database is available. The site hosts the web pages of the Dragonfly Society of the Americas, which publishes the journals *Argia* and the *Bulletin of American Odonatology* (with much Canadian content) and sponsors the official checklist of North American Odonata. The listserve Odonata-l (https://mailweb.ups.edu/mailman/listinfo/odonata-l) is a useful way to keep abreast of topics in the field.

Hundreds of regional works on taxonomy, faunistics, distribution, life history, ecology and behaviour have appeared since around the time of Corbet's treatment. A few examples are mentioned here. In the West, Cannings and Stuart (1977) analyzed the British Columbia fauna and Cannings (2002) produced a British Columbia and Yukon guide for beginners. Cannings et al. (2000, 2007, 2008) undertook detailed inventories, from 1996 to 2005, jointly sponsored by the Royal British Columbia Museum and the British Columbia Conservation Data Centre. A provincial list and distribution maps for the province's species are posted on E-Fauna BC (http://ibis.geog.ubc.ca/biodiversity/efauna/). The fauna of the largest provincial ecozone, the Montane Cordillera, was treated in Cannings and Cannings (2011); that of saline lakes in the province's interior was investigated in Cannings and Cannings (1987) and the Odonata of a coastal glacial refugium was reported in Cannings and Cannings (1983). Many other publications document the British Columbia fauna; a few include Cannings et al. (1980), Paulson and Cannings (1980), and Simaika and Cannings (2004).

In the Prairie Provinces, two significant books have stimulated additional studies: Acorn (2004), a fine examination of the Zygoptera of Alberta; Hutchings and Halstead (2011), a field guide to the Odonata of the boreal forest of Saskatchewan. The most recent species lists for Alberta, Saskatchewan and Manitoba are those produced by the general status program (Canadian Endangered Species Conservation Council 2016), which are also available through the provincial Conservation Data Centres (NatureServe Canada: http://www.natureserve.org/natureserve-network/canada/about-our-cdcs). A Manitoba list (Hughes and Duncan 2003) gives additional data and the Manitoba Dragonfly Survey (http://www.naturenorth.com/dragonfly/) encourages the participation of naturalists in Odonata study. Numerous papers, including Acorn (1983), Hilton (1985), Hutchings (2004), Catling and Kostiuk (2004) and Hughes and Catling (2005) have helped improve our knowledge of the Odonata of the Great Plains. The predominant odonatologist of the prairies, Gordon Pritchard (e.g., 1989), authored, with his students, many elegant papers on the life histories and development of Odonata. Hornung and Rice (2003) studied wetland quality and Odonata in Alberta. The fauna of Canadian grasslands was summarized by Cannings (2014).

Ontario has been a leader in Odonata study ever since E.M. Walker's superb work started the trend. Catling and Brownell (2000) published a summary of species and distribution that compliments the volumes of *Ontario Odonata* (Catling et al. 2000–2007), a discontinued annual summary of Odonata records published by the Toronto Entomologists' Association. This publication also supplied notes on observations, range extensions and regional lists and is still a useful resource, PDF versions of which are available online (http://ontarioinsects.org/odonata_sum.htm). The Natural Heritage Information Centre, Ontario Ministry of Natural Resources and Forestry, maintains the provincial species list as well as the Ontario Odonata Atlas Database, which contains more than 80,000 records dating back to 1886. The field guides for southwestern Ontario (Carmichael et al. 2002) and Algonquin Provincial Park and environs (Jones et al. 2013) are examples of the detailed interest in Odonata study in Canada, as are websites such as those for Ojibway Prairie (Pratt 2013) and for regional Ontario lists (Pratt 2012). Many other publications document the Ontario fauna; a few include Skevington and Carmichael (1997), Cannings (1989, 2014), Catling (2001), and Jones and Burke (2004).

With the strong foundation of Provancher and Robert, Québec odonatology has flourished for many decades and, since the 1970s, *Fabreries* and *Nouv'Ailes* have been important sources of odonatological information; these are journals of L'Association des Entomologistes Amateurs du Québec. The major recent work on the province's fauna is Pilon and Lagacé (1998). Entomofaune du Québec (http://entomofaune.qc.ca/entomofaune/odonates/odoindex.html) produces much valuable material on Québec odonates, including the provincial list and the atlas database. A preliminary atlas (Savard 2011) set the stage for a future, more comprehensive, biogeographical work. Hutchinson and Ménard (2014) is an excellent summary of Québec larvae. Numerous systematic notes and papers have appeared on the province's fauna, from larval studies (e.g., Pilon and Legris 1987), general biology (Hutchinson 1991) and distributional works (Hutchinson and Ménard 1994) to phenology (Savard 1986), annotated lists (Ménard 1996, Perron et al. 2005) and reproduction (Hilton 1983, 1984).

The Atlantic Provinces have seen some of the most intensive Odonata surveying in Canada, thanks in large part to the contributions of amateurs in the past 20 years. However, Newfoundland and Labrador has a more boreal, less diverse fauna than the Maritime Provinces to the southwest and is not so well collected. Paul Brunelle amassed a dataset of records and inspired many of the region's naturalists to collect data through the Atlantic Dragonfly Inventory Program (ADIP), which he launched in the early 1990s.

That dataset contains ca. 37,500 records (including historical ones) representing 12,700 visits to 4,800 sites (PM Brunelle pers. comm.) and has vastly improved our understanding of species distribution and status in eastern Canada. Much of the data are available through the Atlantic Canada Conservation Data Centre and, in the near future, will be housed, along with the specimens, at the New Brunswick Museum. Brunelle (1997) set the stage for this odonatological renaissance, and his superb treatment of species diversity in the Atlantic Maritime Ecozone (Brunelle 2010) is a testament to the success of ADIP. Many other publications on the region have appeared, of course, including those on distribution (Hilton 1990), population dynamics (Conrad and Herman 1996), habitat/ecology (Catling et al. 2006) and important new records (e.g., Harding 2007). A useful website on the fauna of New Brunswick is at http://www.odonatanb.com/.

The fauna of the territories has not escaped notice. Cannings et al. (1991) and Cannings and Cannings (1997) documented the surveys organized by the Biological Survey of Canada in the Yukon. Catling (2003) produced an atlas of the species in the Northwest Territories and, subsequently, an annotated checklist (Catling et al. 2004). In Nunavut, with its poor access and low Odonata diversity, there has been hardly any collecting. Only a few specimens of six species have been recorded north of treeline, including the James Bay islands. There have been no surveys in the potentially productive boreal forest in the southwest corner of the Territory.

Treatments of Odonata in particular habitats include those of Canadian peatlands and marshes (Hilton 1987), peatlands of the northern Cordillera (Cannings and Cannings 1994), saline lakes in British Columbia (Cannings and Cannings 1987) and Canadian grasslands (Cannings 2014).

The first comprehensive published annotated list of Canadian Odonata, Catling et al. (2005), listed 208 species and included the first general status ranks produced by the National General Status Program of Environment and Climate Change Canada. At the end of 2017, the number of species recorded in Canada (214) has increased by 20 since Corbet's 1979 assessment (Table 1). All families show increases except the Aeshnidae (unchanged) and the Petaluridae (decrease from 2 to 1 owing to an error in the interpretation of specimen data). Seven species are considered vagrants or wanderers and presumably do not breed in Canada, although they may appear year after year. A few of the additions to the national list are rare, hard-to-find species that probably have been in Canada a long time, e.g., *Somatochlora hineana* Williamson, *Williamsonia lintneri* (Hagen); more have recently moved northwards from the USA (e.g., *Archilestes californicus* McLachlan). Estimates of unrecorded species are small (Table 1) and reflect the well-known nature of the fauna. Several species, especially in extreme southern central and eastern Canada, probably occur but have not yet been recorded or might arrive from the USA in the next few years. An example is *Enallagma divagans* Selys, which occurs just across the USA border near Detroit (CD Jones pers. comm.). One species, the gomphid *Stylurus plagiatus* Selys, formerly known from Ontario, has apparently been extirpated from the country (Canadian Endangered Species Conservation Council 2016). *Crocothemis servilia* (Drury), an Asian libellulid established in Florida and the only odonate introduced to the New World, was imported to Québec in a shipment of aquatic plants kept indoors (Perron et al. 2003). The record was rejected by Catling et al. (2005) and, although *C. servilia* is listed in Wild Species 2015 (Canadian Endangered Species Conservation Council 2016) as the first and only alien species in Canada, it is not accepted herein. The sole species discovered in Canada and first described from Canadian material since the 1979 assessment is *Neurocordulia michaeli* Brunelle (Brunelle 2000), a crepuscular corduliid from eastern Canada.

The Order Odonata provides a good example of DNA barcoding effort in a group of insects. Many well-accepted Canadian species (based on morphological and reproductive characters) have been DNA barcoded to some degree. Barcode Index Numbers (BINs) are clusters of barcode sequences that usually show concordance with species; the system therefore can be used to verify species identifications (Ratnasingham and Hebert 2013). Table 1 suggests that BINs are available for approximately 70% of the Odonata species recorded in Canada. Most species that are sequenced correspond reasonably well with BINs. However, some anomalies are hidden in the numbers. For example, in the Aeshnidae, which appears to have all 24 species represented by BINs, at least four species are not included and some BINs are not linked to species. Some BINs suffer from containing too few sequences. Results show that the Odonata is susceptible to BINs not aligning with recognized species, either by lumping well-known morphological species in a single BIN or by dividing a single species into several separate BINs. Although I know of no studies analyzing DNA barcoding in Odonata, overviews in other taxa, such as bees (Sheffield et al. 2017), show similar results. In Canadian Odonata, distinct morphological species, *Aeshna interrupta* and *A. eremita*, are placed in a single BIN. Both are common, transcontinental species and whereas the latter is morphologically similar across its wide range, the former has three subspecies, although these are problematic (Catling et al. 2005). *Aeshna umbrosa*, another common, transcontinental species, is morphologically uniform over most of North America; however, west of the Rockies, it has an additional colour form, which has been considered a subspecies. Material from across Canada is assigned to a single BIN, except in New Brunswick, where sequences are divided into several separate BINs, even though current taxonomic understanding suggests cryptic species would be highly unlikely. Clearly, additional work is required to resolve these questions. The numbers presented in Table 1 for some other families likely represent anomalies similar to those found in the Aeshnidae. More barcoding of more well-identified specimens of many species is still required, especially in most of the larger families, which indicate only moderate completion: Coenagrionidae (63%), Gomphidae (63%), Corduliidae (61%), and Libellulidae (65%). Currently available molecular data do not suggest the possibility of undescribed cryptic species. Despite some problems, the Odonata, unlike some other orders, is known well enough that, with some concentrated work, all Canadian species might ultimately be supported with DNA barcodes.

A major impetus for surveys and analyses of the status of Odonata species is the work of the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) (http://www.cosewic.gc.ca/default.asp?lang=en&n=F3AE41D5-1#) which provides a scientifically sound classification of wildlife species potentially at risk. Under the Species at Risk Act (SARA), COSEWIC serves as an independent body of experts responsible for identifying and assessing such species. COSEWIC produces comprehensive status reports of species and results are reported to the Canadian government and the public; if the Minister of Environment and Climate Change designates the species under Schedule 1 of the Act, the species may then qualify for legal protection and recovery under SARA. Assessments of Odonata began in 2004. As of 2018, five species have been designated as Endangered: *Phanogomphus quadricolor* (Walsh) (Ontario), *Gomphurus ventricosus* (Walsh) (New Brunswick), *Somatochlora hineana* Williamson (Ontario), *Stylurus amnicola* (Walsh) (Ontario) and *Stylurus olivaceus* (Selys) (British Columbia). *Ophiogomphus howei* Bromley (Ontario, New Brunswick) is designated Special Concern. Two species have COSEWIC status but have yet to be designated under SARA: *Stylurus laurae* Williamson (Ontario: Endangered) and *Argia vivida* Hagen (British Columbia and Alberta: Special Concern) (Species at Risk Public Registry: http://www.registrelep-sararegistry.gc.ca/sar/index/default_e.cfm). An associated national effort is the General Status of Species in Canada. A report, *Wild Species*, is produced every five years. Odonata were first included in 2005; the most recent report was produced in 2015 (Canadian Endangered Species Conservation Council 2016). Occurrence and status for each odonate species known in Canada is given for all provinces and territories. The list is slightly out-of-date; 213 species are documented.

The taxonomy of the Nearctic Odonata is relatively well-known compared to that of many other insect groups. In Canada, certain closely related pairs of taxa such as *Erythemis collocata* (West) and *E. simplicicollis* (East) and, especially, *Amphiagrion abbreviatum* (West) and *A. saucium* (East) require more study to ascertain if they should remain separate species. Phylogenetic examination lumped the widespread *Sympetrum occidentale* Bartenev (West) with *S. semicinctum* (East) (Pilgrim and von Dohlen 2007) but further work on these and other such variable species in Canada is desirable. *Aeshna interrupta* is another good example of a species with widespread geographic variation (Catling et al. 2005). Genetic work may also help determine the relationships among Palaearctic and Nearctic species, as was done with the separation of the Nearctic *Enallagma annexum* from the Palaeartic *E. cyathigerum* (Charpentier) (Turgeon et al. 2005).

The identification of adults of both sexes has been significantly enhanced by the many excellent field guides and photo websites produced by experienced field biologists (see above). Although not specific to odonates, BugGuide (https://bugguide.net) and iNaturalist (inaturalist.ca) offer photograph identification services and help improve distributional knowledge. Cellphone applications are popular; Birdseye (http://www.birdseyebirding.com/apps/dragonfly-id-app/) produces a comprehensive one based on data from OdonataCentral, the premier site for Odonata distribution in North America.

Corbet (1979) noted that the larvae of 15 Canadian species were unknown, but most of these are now documented in detail (e.g., Cannings and Doerksen 1979, Charlton and Cannings 1993, Kenner et al. 2000). Thus, almost all larvae are now well, or cursorily, described (K Tennessen pers. comm.) Larvae of all Canadian Zygoptera have been described or characterized; in the latter category are a few diagnosed only in the keys in Westfall and May (2006). Larval descriptions and identification keys can be improved; those dealing with instars younger than the final one are particularly needed.

Most gaps in knowledge indicated by Corbet in the 1979 synopsis still need work. Our understanding of most species' geographical distribution, habitat requirements and conservation status has been greatly improved since 1979 owing to the extensive surveys and amateur observations noted above. However, more research is required to better define occurrence, abundance and biological details for almost all species of odonates. Detailed, annotated site lists developed over several years would be extremely valuable in all regions, as would autecological research on species to determine habitat requirements. In the face of climate change, baseline data on distribution and habitat (with detailed vegetation and water characteristics) are of high value. For example, Cannings et al. (2016) discuss the range expansion of *Libellula pulchella* (Drury) in British Columbia, Alberta and Saskatchewan in the context of the proliferation of man-made ponds and other wetlands as well as climate warming. They note that, in addition, recent wet conditions have created more suitable habitat for this dragonfly on the western Great Plains. The continuous monitoring of selected study sites for changes in species composition and habitat details would be most useful. Monitoring of conservation status is a priority as habitats and climate fluctuate in character. Studies examining the effects of disturbance and habitat change on species are needed. As indicated above, COSEWIC has studied several species and more status reports from this national committee, or allied provincial agencies, will be required if drying wetlands and reduced stream flows begin to affect populations of rare species.

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REVIEW ARTICLE

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Plecoptera of Canada

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Abstract

Currently, a total of 267 stonefly species are known for Canada. The biodiversity hotspot of Canadian stoneflies is British Columbia with at least 138 species, nearly 52% of all species known from Canada. Four families, the Perlodidae, Capniidae, Chloroperlidae, and Nemouridae, contain nearly 75% of all species known to occur in Canada. The family with the fewest species represented in Canada is the Peltoperlidae. The stonefly fauna of Canada consists of two major faunal assemblages, west and east. The western clade consists of those species inhabiting Manitoba, all provinces to the west, and the three territories. The eastern clade consists of species from Ontario eastward. The two clades share only 29 species (10.9% of the Canadian total), suggesting a separate origin for each clade. The available taxonomic literature for the stoneflies of Canada is reviewed.

Keywords

biodiversity assessment, Biota of Canada, Plecoptera, stoneflies

The order Plecoptera, or stoneflies, a small group of hemimetabolous insects, includes approximately 3700 extant, valid species placed in 16 families worldwide (Fochetti and Tierno de Figueroa 2008, DeWalt et al. 2018). Diversity is often highest in temperate montane regions of the world (Fochetti and Tierno de Figueroa 2008). More than for any other order of insects, larval stoneflies are typical inhabitants of lotic habitats (Hynes 1976); larvae of some species are also known to inhabit cold, oligotrophic lakes at high latitudes and altitudes, such as in the Canadian boreal and alpine areas (Harper 1979, Donald and Anderson 1980, Dosdall and Lehmkuhl 1987, Stewart and Oswood 2006). Most North American stonefly families have also radiated into warmer streams as a result of the evolution of physiological traits such as embryonic or larval diapause (Stewart and Stark 2002). This adaptation to a wide range of conditions makes stoneflies useful for monitoring water quality (Baumann 1979).

All Canadian stoneflies belong to one of the two suborders, the Arctoperlaria, which is further separated into two "groups" (DeWalt et al. (2018) consider them infraorders), the Systellognatha and Euholognatha (Zwick 2000). Larvae of the former are generally predaceous on other aquatic invertebrates, while the latter are detritivores, eating dead leaves and wood conditioned by microbes (Stewart and Stark 2002).

The stoneflies of North America, north of Mexico, are relatively well-known with at least 778 extant, valid species and subspecies (DeWalt et al. 2018). The earliest mention of a species of stonefly occurring in Canada was that of the Holarctic *Diura bicaudata* (Linnaeus, 1758). Ricker (1964) provided the first comprehensive review of the stoneflies of Canada, including a historical overview of Canadian stoneflies. Ricker (1964) indicated that about 202 species were known from Canada at that time, and estimated that perhaps 12 additional species had been collected but were yet undescribed.

Fourteen years later, Harper (1979) indicated that 250 species were known from Canada, and estimated that another 60 species were likely present but were yet undescribed or undiscovered. He indicated that 124 species were known from eastern Canada and 135 from the west, the overlap of taxa in central Canada being only nine species. Unfortunately, he did not state how he delineated the eastern and western regions of Canada.

Stonefly species lists or records are available for all ten Canadian provinces and three territories: Alberta (Ricker 1946, Donald and Anderson 1977, Stewart and Oswood 2006, Dosdall and Giberson 2014a, b), British Columbia (Banks 1907, Ricker 1939, 1943, Ricker and Scudder 1975, Scudder 1994, Stewart and Oswood 2006, Baumann and Stark 2010, Dosdall and Giberson 2014a, b), Manitoba (Ricker 1946, Flannagan 1978, Burton 1984, Flannagan and Cobb 1983, Dosdall and Giberson 2014a, b), New Brunswick (Ricker 1948, Kondratieff and Baumann 1994, Giberson and Garnett 1996), Newfoundland and Labrador (Banks 1908, Ricker 1944, 1948, Brinck 1958), Northwest Territories (Ricker and Judd 1955, Stewart and Oswood 2006, Vinke et al. 2015), Nova Scotia (Ricker 1948, Kondratieff and Baumann 1994), Nunavut (Stewart and Oswood 2006), Prince Edward Island (Kondratieff and Baumann 1994, Dobrin and Giberson 2003), Ontario (Harper and Ricker 1994), Québec (Ricker et al. 1968, Harper et al. 1975, 1991a, b, Harper 1990), Saskatchewan (Ricker 1946, Dosdall 1976, Dosdall and Lehmkuhl 1979, 1987, Miyazaki and Lehmkuhl 2011, Dosdall and Giberson 2014a, b), and the Yukon (Stewart and Ricker 1997, Stewart and Oswood 2006).

Additional useful treatments of regional stonefly faunas that include Canadian species are Hitchcock (1974) for eastern Canada, Jewett (1959) and Baumann et al. (1977) for British Columbia and Alberta, and Szczytko and Stewart (1979) for western North American *Isoperla* Banks. Recently, Szczytko and Kondratieff (2015a, b) revised the eastern North American species of the Isoperlinae based on adults, recording 20 species from Canada. Baumann and Stark (2013) revised the genus *Megaleuctra* Neave and provided records for Alberta, British Columbia, and possibly Manitoba. Stewart and Oswood (2006) provided much information about the stoneflies of western Canada. Additionally, Dosdall and Giberson (2014a, b) provided a useful synopsis of the stoneflies of Alberta, Saskatchewan, and Manitoba. Danks (1981) presented a list of known Canadian Arctic plecopteran species.

Reliable keys exist for identification of both adult and larval stoneflies. Larvae can be identified to genus using Stewart and Stark (2002, 2008) and DeWalt and Kondratieff (in press); most adults to species using Stark and Armitage (2000, 2004) and Stewart and Oswood (2006). Many of the classic publications in North American plecopterology (e.g., Needham and Claassen 1925, Frison 1942, Ricker 1952, Ross and Ricker 1971) are also useful for studying the Canadian fauna. Harper and Hynes (1971a–d) provide keys to adults and immatures of euholognathan species of eastern Canada.

Despite the stoneflies of Canada being relatively well documented, additional collecting is required to fully understand the fauna. For example, *Isoperla citronella* (Newport) described from St. Martins Falls, Ontario is still apparently known from only two female specimens (Harper and Ricker 1994, Szczytko and Kondratieff 2015a), and no adult male has been positively associated. Canadian regions that need additional surveys include the Prairie Provinces, coastal British Columbia, western and northern Ontario, and the more remote areas of the Yukon and Northwest Territories. Particular attention in the eastern provinces should be paid to study of the small, summer emerging perlids *Neoperla* Needham and *Perlesta* Banks, both of which are surely represented by more species than are currently known.

A general discussion of stonefly biology and ecology is presented in DeWalt et al. (2015), while a synopsis of the ecological information for North American stoneflies, including Canadian species, is presented in Stewart and Stark (2002). Specific ecological information is available for about 50 Canadian species. For example, life histories for many species have been reported by Harper and Magnin (1969), Coleman and Hynes (1970), Harper and Pilon (1970), Harper and Hynes (1972), Harper (1973a, b), Barton (1980), Mutch and Pritchard (1982, 1984), Harper et al. (1991a, b), and Dobrin and Giberson (2003).

A presence/absence species-by-province data matrix was created using data stored in Plecoptera Species File (PSF), a web-based, global resource for information about stoneflies (DeWalt et al. 2018). The list of species known from each province is available as Suppl. material 1 in Comma Separated Values format. The relationship of province assemblages to each other was analyzed using the R package *vegan*. A Jaccard distance matrix for pairwise distances between samples was constructed using the *vegdist* function. This matrix was used to perform an agglomerative cluster analysis based on Jaccard average linkage with the function *hclust*. The province relationships were displayed as a dendrogram.

Currently, a total of 267 stonefly species have been recorded from Canada (Table 1). Four families, Perlodidae, Capniidae, Chloroperlidae, and Nemouridae contain nearly 75% of all species known to occur in Canada (Fig. 1). The family with the fewest species represented in Canada is the Peltoperlidae.

Efforts have been made to barcode North American species of stoneflies including Canadian taxa (i.e., Ratnasingham and Hebert 2013, Zhou et al. 2009, Cordero et al. 2017). To date, 166 Barcode Index Numbers (BINs) from Canadian specimens are included in the Barcode of Life Data (BOLD; Ratnasingham and Hebert 2013) database, suggesting that 62% of the recorded number of species found in Canada is represented in their sequence library (Table 1). The Perlidae and Chloroperlidae appear to be well represented with BINs accounting for up to 72% of the recognized fauna. Alternatively, the Capniidae and Perlodidae are under-represented with only 36% and 40% representation, respectively. The number of BINs indicates that there

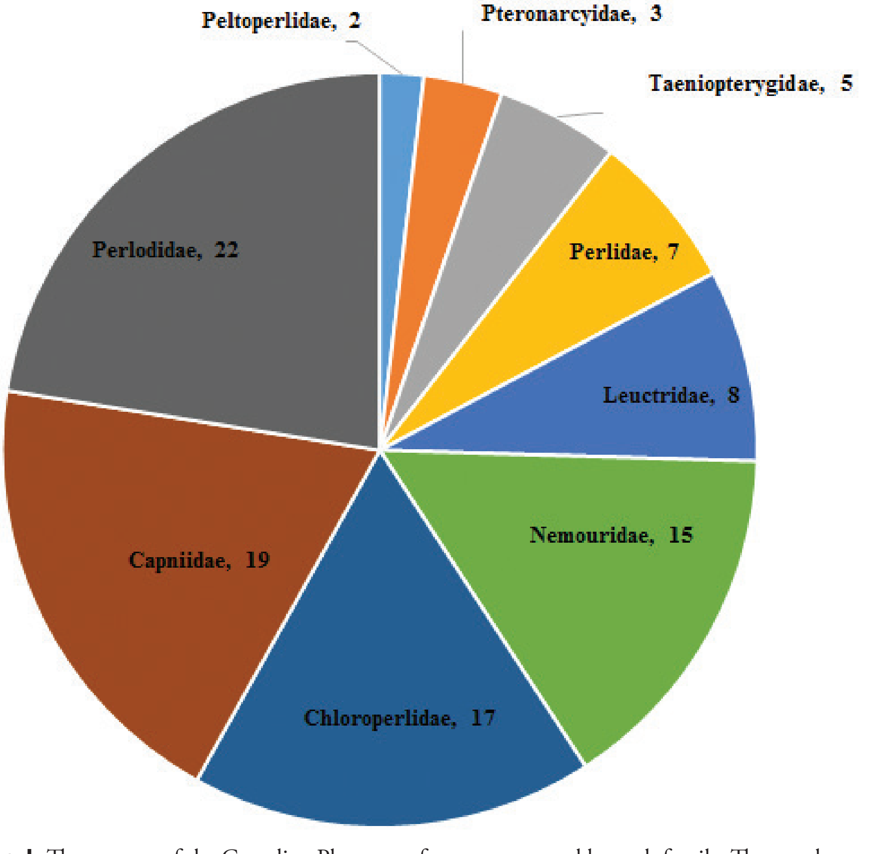

Figure 1. The percent of the Canadian Plecoptera fauna represented by each family. The numbers represent rounded percentages and do not total 100.

Table 1. Census of Plecoptera in Canada.

Taxon[1]	No. species reported in Harper (1979)	No. species currently known from Canada	No. BINs[2] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[3]	Information sources
Order Plecoptera						Baumann et al. 1977, Stewart and Stark 2002, Stewart and Oswood 2006, DeWalt et al. 2018, DeWalt and Kondratieff (in press)
Suborder Arctoperlaria						
Infraorder Euholognatha						
Capniidae	49	52	19	2	all ecozones	
Leuctridae	21	22	20	2	all but Arctic	
Nemouridae	32	41	45	5	all ecozones	
Taeniopterygidae	15	14	9	0	all but Arctic	Stewart 2000
Infraorder Systellognatha						
Peltoperlidae	4	5	1	0	Pacific Maritime, Montane Cordillera, Boreal Shield	Stewart 2000
Pteronarcyidae	9	9	2	0	all ecozones	Nelson 2004, Myers and Kondratieff 2017
Chloroperlidae	44	46	33	5	all but Arctic	Surdick 2004
Perlidae	15	18	13	10	all but Arctic	Stark 2004
Perlodidae	61	60	24	10	all ecozones	Kondratieff 2004, Szczytko and Kondratieff 2015a, b
Total	**250**	**267**	**166**	**34**		

[1]Classification from DeWalt et al. (2018). [2]Barcode Index Numbers as defined by Ratnasingham and Hebert (2013). [3] See figure 1 in Langor (2019) for a map of ecozones.

are potentially five additional species of Nemouridae in Canada than are currently recognized (Table 1).

The biodiversity hotspot of Canadian stoneflies is British Columbia with at least 138 species, nearly 52% of all species known from Canada (Fig. 2). This is due to the great density of high gradient streams that dominate the province. Alberta supports the second highest number of species in Canada, and much of its diversity is contained within the eastern extension of the Montane Cordillera ecozone. Other provinces in the west hold fewer species. The Yukon Territory, dominated by Boreal and Taiga Cordillera ecozones with many swiftly flowing streams, support only 71 species. It is probable that this territory holds many more species yet undiscovered due to difficult access to much of the land-base. Northwest Territories and Nunavut are both dominated by Taiga Plains, Taiga Shield, and Arctic ecozones. Streams in these areas are lower gradient and/or frozen for all but a few months of the year, conditions not conducive to a rich stonefly fauna. Difficult access to these territories limits complete understanding of the faunal composition. Reported stonefly diversity in the

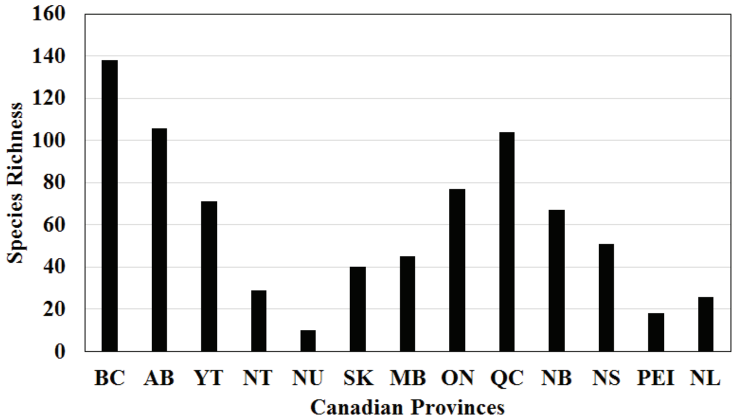

Figure 2. Plecoptera species richness by Canadian provinces. Abbreviations: AB – Alberta, BC – British Columbia, MB – Manitoba, NB – New Brunswick, NL – Newfoundland and Labrador, NS – Nova Scotia, NT – Northwest Territories, NU – Nunavut, ON – Ontario, PEI – Prince Edward Island, QC – Quebec, SK – Saskatchewan, and YT – Yukon.

prairie provinces of Saskatchewan and Manitoba is apparently low, but greater than that of the two territories to their north.

The province of Quebec (104 species, 39.0% of the national fauna) has the highest species richness of the eastern provinces. The presence of the northern extensions of the Appalachian Mountains and rugged Boreal Shield topography has resulted in a relative diverse assemblage of stoneflies. Ontario is also relatively rich by eastern standards. Despite being well collected, there has not been a detailed treatment of the Ontario fauna since the late 1960s. Many revisions and descriptions of new species have occurred since then that could increase the number of species known in the province by 10–15% (R DeWalt unpubl. data). Further eastward, the Atlantic provinces of New Brunswick and Nova Scotia support a substantial subset of the Quebec assemblage. Conversely, the province of Newfoundland and Labrador supports a much smaller number of stoneflies, perhaps owing to the regional composition of Taiga Shield and Arctic ecozones. Prince Edward Island, with a total area of only 5600 km^2, has had most of its larger streams impacted by sedimentation due to agricultural activities (Eedy and Giberson 2007). Higher stonefly diversity does occur in cold spring-brooks (Dobrin and Giberson 2003), but represents a small fraction of eastern Canadian stonefly species. Isolation from mainland colonization sources also limits the stonefly fauna of this island.

The Canadian Plecoptera consists of two distinct faunal assemblages, west and east (Fig. 3). Here we define the western fauna as those species inhabiting Manitoba, all provinces to the west, and the three territories. The eastern fauna consists of species from Ontario eastward. These clades are distinctive, sharing only 29 species (10.9% of the Canadian total), 21 species with eastern affinity, suggesting separate origins for each clade. This break in eastern and western clades was also found, though less distinctly, by Nelson (2008).

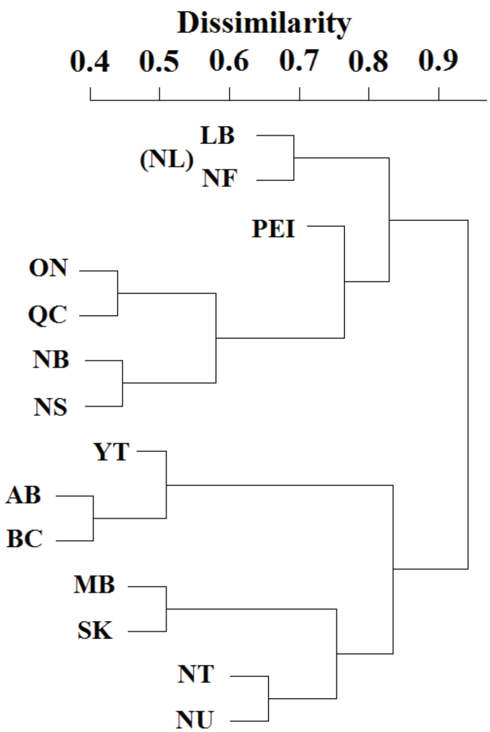

Figure 3. Cluster analysis of Plecoptera assemblages for Canadian provinces. For meaning of province abbreviations, see Figure 2 legend. The assemblages of Newfoundland (NF) and Labrador (LB) were kept separate in this analysis.

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Supplementary material 1

List of species known from each province

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REVIEW ARTICLE

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Mantodea, Blattodea, Orthoptera, Dermaptera, and Phasmida of Canada

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Abstract

In the last 40 years, the number of species in the orthopteroid orders has increased by ~10% from that known in 1979. The largest order, the Orthoptera, has increased from 205 to 235 species known in Canada. The number of Blattodea has increased from 14 to 18 species, while Dermaptera has increased from 5 to 6 species. The number of species of Mantodea (3) and Phasmida (1) known in Canada have remained unchanged. Most new species records reported in Canada since 1979 have resulted from new collections along the periphery of the range of more widespread species. Some species reported since 1979 are recent introductions to Canada, including species restricted to homes or other heated buildings. The taxonomy of these orders has also changed, with only the Dermaptera having maintained its order definition since the 1979 treatment. Additional orthopteroid species are likely to occur in Canada, particularly in the orders Orthoptera and Blattodea. DNA barcodes are available for more than 60% of the species known to occur in Canada.

Keywords

biodiversity assessment, Biota of Canada, Blattodea, cockroaches, crickets, Dermaptera, earwigs, grasshoppers, katydids, mantids, Mantodea, Orthoptera, Phasmida, stick insects, termites

Introduction

The insects treated here represent part of the cohort Polyneoptera, a group that also includes the orders Embioptera, Grylloblattodea, Mantophasmatodea, Plecoptera, and Zoraptera (Song et al. 2016), with the Canadian representatives of Plecoptera and Grylloblattodea being treated elsewhere in this series. The orders of the Polyneoptera dealt with here are informally referred to as the "orthopteroids", based on the obsolete and paraphyletic superorder Orthopteroidea (Eades 2018), but for the convenience of dealing with this paraphyletic assemblage we continue to use it here. Since 1979, the order-level taxonomy has changed for most of the orthopteroids. The Mantodea (mantids) was reviewed as a part of the Dictyoptera (spelled Dictuoptera in the original) by Kevan (1979b) but is now treated as a separate order (Zhang 2013, Otte et al. 2018, Wieland and Svenson 2018). Kevan (1979b) also included the Blattodea (cockroaches) and Isoptera (termites) within the Dictyoptera, but they are now treated together as the Blattodea (Inward et al. 2007, Djernæs et al. 2012). Kevan (1979c, d) presented saltatorial orthopteroids as two orders, Orthoptera s. str. and Grylloptera. The current taxonomic system recognizes both of these within the order Orthoptera, and treats Kevan's divisions as the suborders Caelifera (grasshoppers) and Ensifera (crickets and allies), respectively (Cigliano et al. 2018). The order Phasmida (stick insects) was reviewed under the name Cheleutoptera by Kevan (1979a) but now follows Brock et al. (2018), while the Dermaptera (earwigs) has remained unchanged.

Shortly after the 1979 reviews (Kevan 1979a, b, c, d, Lamb 1979), an authoritative information source was published, covering all of the Polyneoptera of Canada except Plecoptera (Vickery and Kevan 1985). This manual brought together for the first time all of the known ecological and distributional information available, and keys to all Canadian species. It also provided species lists that were based on largely the same information as the 1979 reviews and, due to the short period of time between the two publications, serve as a good proxy for the information available at the time of the 1979 reviews for comparison with the current examination. The work by Vickery and Kevan (1985) provided the foundation for virtually all subsequent study of orthopteroid orders in Canada. Advances in taxonomy and discoveries of new species have resulted in some current limitations to the 1985 manual, but there remains no single reference that can replace it.

Research in recent decades has benefitted from tools not available to earlier authors. Genetic evidence has revealed cryptic species (e.g., Guillet et al. 2000) and clarified higher taxonomic relationships (e.g., Djernæs et al. 2012). The proliferation of DNA barcoding and the development of the Barcode Index Number (BIN) system have proved useful in the recognition of new species (Hebert et al. 2003, Ratnasingham and Hebert 2007, 2013), and further exploration of the BIN data may improve the understanding of Canadian orthopteroids.

Most of the orthopteroid orders are relatively species-poor and well-sampled in Canada. As a result, our understanding of the diversity and distribution of these orders in Canada has changed little since the 1979 review, with the most substantial species increases occurring in the Orthoptera. The orthopteroid orders are much more diverse in warmer climates with an estimated 40,000 species worldwide (Zhang 2013). The highest diversity in Canada is in the southern parts of British Columbia (BC), the Prairie Provinces, and Ontario (ON). Despite southern BC and ON being the most intensively sampled areas, they remain the areas where most new species are found and where most potential additional species are likely to be found. Additionally, due to their low diversity, relatively large body size, and ease of identification, there is a lot of active interest in the orthopteroids within both the scientific and naturalist communities, especially in the Orthoptera due to their acoustic abilities and behaviours. As a result, new ecological and distributional data are being documented not just in the scientific literature, but also in photograph-sharing fora such as BugGuide.net and iNaturalist, where citizen scientists are contributing to our understanding of these orders.

Mantodea

There has been no change to the number of mantid species known in Canada since Kevan's (1979b) review, with one native and two introduced species recorded (Table 1). The European mantis, *Mantis religiosa* (Linnaeus), was listed by Kevan (1979b) as occurring only in ON and Quebec (QC), but was subsequently mapped by Vickery and Kevan (1985) as also occurring in a small area of BC. This mantid has since expanded its range dramatically in southern BC (Cannings 2007). The native ground mantid, *Litaneutria minor* Scudder, was listed as occurring in both BC and Alberta by Kevan (1979b) and Vickery and Scudder (1987); however, some publications have stated that the species' Canadian range is restricted to BC only (Vickery and Kevan 1985, Cannings and Cannings 1995). A subsequent record from Saskatchewan (Hooper 2003) was an incorrectly identified mantispid (C Sheffield pers. comm.). *Tenodera sinensis* Saussure, is an Asian species established in ON and QC. One additional species, *Tenodera angustipennis* Saussure, an Asian species established as far north as New York (Gurney 1951), may eventually be found in Canada.

The Mantodea of Canada represent 15% of the 20 species known from North America north of Mexico (Iowa State University 2003–2018). BINs are available for both of the introduced mantids in Canada, but the native ground mantid has not been barcoded to date (BOLD Systems 2018) (Table 1).

Table 1. Census of Mantodea in Canada.

Taxon[1]	No. species reported by Kevan (1979b)	No. species currently known in Canada[2]	No. BINs[3] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[4]	Information sources
Mantidae	3	3 (2)	2	1	Pacific Maritime, Montane Cordillera, Western Interior Basin, Prairies, Mixedwood Plains, Hudson Plains, Atlantic Maritime	Vickery and Kevan 1985, Cannings 2007

[1]Classification follows Otte et al. (2018). [2]The number in parentheses represents the number of established non-native species included in the total. [3]Barcode Index Number, as defined in Ratnasingham and Hebert (2013). [4]See figure 1 in Langor (2019) for a map of ecozones.

Blattodea

The Blattodea fauna of Canada, including the cockroaches and termites, is well known. Although largely perceived as pests due to a number of non-native species that either occur in human dwellings or damage lumber, Canada has several native species that occur in and around forest environments. This native element of the Canadian fauna has remained relatively unchanged since Kevan (1979b), while the introduced fauna has grown due to the establishment of recently introduced species to North America. Vickery and Kevan (1985) provide keys, natural history information, and distributional data for most of the Canadian cockroach and termite species, and Hoebeke and Carter (2010) provide keys to the *Ectobius* cockroach species that have become established in North America. Important resources on general cockroach biology, distributional data and natural history include Bell et al. (2007) and Cockroach Species File Online (Beccaloni 2014). Important resources for termite biology and identification of North America termites include Weesner (1965), Constantino (1998), Bignell et al. (2011), Evans et al. (2013) and Krishna et al. (2013).

There are also a number of species that occur in Canada but are not considered established outside of cultures. A number of cockroach species (~10–20 species) are actively cultured as pets or as a food source in the pet trade for reptiles and amphibians in North America, and some may escape these cultures to become established for short periods in buildings. Cockroaches are also regularly intercepted from international shipments into Canada; Vickery and Kevan (1985) provided a list of 18 cockroach species that have been intercepted in Canada but are not known to be established. Among the termites, several termite species recognized as pests to lumber products in the USA have occasionally been transported into Canada (Vickery and Kevan 1985, Grace et al. 1991) but have never successfully established. All of these species are excluded from Table 2.

In total, the Canadian Blattodea consists of 18 breeding species, including 12 cockroaches and six termites (Table 2). This is an increase of five breeding species (three cockroaches and two termites) from Kevan (1979b). *Periplaneta brunnea* Burmeister was apparently treated as established in Kevan (1979b) but actually did not successfully establish in Canada (Vickery and Kevan 1985). The Canadian established cockroach fauna represents ~18% of the 66 North American cockroach species based on Pratt (1988) plus recently introduced species, and the termite fauna represents ~13% of the 46 North American species based on Constantino (1998). Only four cockroach species and five termite species recorded in Canada are native, with the remainder introduced. Additional species may become established in Canada, including several of the cultured cockroach species (Pratt 1988) that could potentially become established in human dwellings. Two additional species of *Ectobius* introduced to the northeastern United States (Hoebeke and Nickle 1981, Hoebeke and Carter 2010) may also occur in eastern Canada. One new termite species in the family Archotermopsidae has been documented in BC and the western United States (Szalanski et al. 2006) based on genetic profiles but currently remains undescribed. All 12 Canadian cockroach species and six termite species have corresponding BINs (Table 2).

Table 2. Census of Blattodea in Canada.

Taxon[1]	No. species reported in Kevan (1979b)	No. species currently known in Canada[2]	No. BINs[3] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[4]	Information sources
Superfamily Blaberoidea						
Blaberidae	1	1 (1)	0	0	domiciliary; Mixedwood Plains, Pacific Maritimes, likely in other southern ecozones	Vickery and Kevan 1985, Cannings and Scudder 2005a, Paiero and Marshall 2014
Ectobiidae	5	8 (4)	7	4–5	Hudson Plains; domiciliary in all southern ecozones	Vickery and Kevan 1985, Chandler 1992, Cannings and Scudder 2005a, Hoebeke and Carter 2010, Klassen and Sharanowski 2014, Paiero and Marshall 2014, Clements et al. 2017
Superfamily Blattoidea						
Epifamily Blattoidae						
Blattidae	4	3 (3)	2	1–2	domiciliary in all southern ecozones	Kevan 1979b, Vickery and Kevan 1985, Cannings and Scudder 2005a, Paiero and Marshall 2014
Epifamily Termitoidae						
Archotermopsidae	2	2	1	0	Pacific Maritime, Montane Cordillera, Western Interior Basin	Vickery and Kevan 1985, Cannings and Scudder 2005c
Rhinotermitidae	2	4 (1)	3	1	Pacific Maritime, Mixedwood Plains	Vickery and Kevan 1985, Cannings and Scudder 2005c, Szalanski et al. 2006
Total	**14**	**18 (9)**	**13**	**6–8**		

[1]Classification follows that indicated in Beccaloni 2014 and Engel 2011. [2]The number in parentheses represents the number of established non-native species included in the total. [3]Barcode Index Number, as defined in Ratnasingham and Hebert (2013). [4]See figure 1 in Langor (2019) for a map of ecozones.

Orthoptera

Much more is known about the Orthoptera (grasshoppers, locusts, crickets, katydids) of Canada today than when Kevan reviewed this group in 1979 (Kevan 1979c, d). New field work has improved our understanding of species' distributions within Canada: in the north (Vickery 1997, Catling 2008), BC (Miskelly 2012), the Prairie Provinces (Johnson 2001, 2002, 2003), ON (Marshall et al. 2004, Paiero and Marshall 2014), and Atlantic Canada (McAlpine and Ogden 2012, Catling et al. 2013, McAlpine et al. 2015). Other studies have focussed on the biogeographical affinities and ecological associations of this group (Vickery 1986, Scudder and Vickery 2011, Miskelly 2014). A great deal of research has also been done in the fields of behaviour and acoustics (e.g., Gwynne 1977, 1982, Tuckerman et al. 1993, Morris et al. 2002, Judge 2011).

The 1979 assessment listed the known Orthoptera of Canada as 217 species in eleven currently recognized families (Table 3), with an estimated 24 additional unreported or undescribed species expected. However, because the original review did not present an actual species list, it is difficult to interpret potential changes in taxonomy or species identifications since 1979. Luckily, there were few known changes between the 1979 review and the publication of Vickery and Kevan (1985). The species lists contained in that reference are presumed to be very similar to the information that formed the basis of the 1979 review. Based on the species lists available in Vickery and Kevan (1985), it appears that the species number used in the 1979 may have been inflated by the inclusion of subspecies. Since the publication of the Vickery and Kevan (1985), a lot of changes have been made in the recognition of subspecies. Many subspecies that likely contributed to species counts in Vickery and Kevan (1985), and likely also in Kevan (1979c, d) are no longer recognized, while some others have been raised to species status. In addition, several species believed by Vickery and Kevan to occur in Canada were based on misidentifications (Miskelly 2012). A review of Vickery and Kevan (1985) shows that only 205 currently-recognized species were known to occur in Canada at the time of the original review, which would reduce the species recognized in 1979 by 14. In 2018, the known Orthoptera of Canada total 235 species in 12 families (Table 3). This number represents 19% of the roughly 1200 species known to occur in North America north of Mexico (Iowa State University 2003–2018).

The number of additional species expected in Canada (Table 3) but which are yet undocumented (undiscovered or undescribed) was estimated by examination of the distribution maps and records contained in Vickery and Kevan (1985), Iowa State University (2003–2018), and Walker (2018). The species considered most likely to eventually be found in Canada are those that occur close to the Canadian border in habitats that also occur in Canada, as well as non-native species that are spreading rapidly in the United States. Several undescribed or unrecognized species are also believed to already exist in Canadian collections. These include recent collections that have not yet been definitively identified, as well as potential cryptic species whose existence is suggested by DNA barcoding results.

Table 3. Census of Orthoptera in Canada.

Taxon[1]	No. species reported in Kevan (1979c, d)[2]	No. species currently known in Canada[3]	No. BINs[4] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozones[5]	Information sources
Suborder Caelifera						
Acrididae	117	129 (1)	83	4	all ecozones	Vickery and Scudder 1987, Miskelly 2012, Paiero and Marshall 2014
Tetrigidae	7	7	7	0	all ecozones except Arctic	Vickery and Scudder 1987, Miskelly 2012, Paiero and Marshall 2014
Tridactylidae	2	3	0	0	Mixedwood Plains	Vickery and Scudder 1987, Paiero and Marshall 2014
Suborder Ensifera						
Gryllidae	11	16 (2)	11	2	all ecozones south of taiga	Vickery and Scudder 1987, Miskelly 2012, Paiero and Marshall 2014
Trigonidiidae	7	9 (2)	8	1	all ecozones south of taiga	Vickery and Scudder 1987, Miskelly 2012, Paiero and Marshall 2014
Gryllotalpidae	1	1	0	0	Mixedwood Plains	Paiero and Marshall 2014
Myrmecophilidae	1	2	1	1	Pacific Maritime, Western Interior Basin, Mixedwood Plains	Miskelly 2012, Paiero and Marshall 2014
Prophalangopsidae	2	2	4	1	Pacific Maritime, Western Interior Basin, Montane Cordillera	Vickery and Scudder 1987, Miskelly 2012
Gryllacrididae	0	1	0	0	Mixedwood Plains	Paiero and Marshall 2014
Stenopelmatidae	2	2	1	0	Pacific Maritime, Western Interior Basin, Prairie	Vickery and Scudder 1987, Miskelly 2012
Tettigoniidae	36	44 (4)	29	6	all southern ecozones, reaching northern limit in Boreal Plains	Vickery and Scudder 1987, Miskelly 2012, Paiero and Marshall 2014
Rhaphidophoridae	19	20 (1)	13	0	all southern ecozones, reaching northern limit in Boreal Plains	Vickery and Scudder 1987, Miskelly 2012, Paiero and Marshall 2014
Total	**205**	**235 (10)**	**157**	**15**		

[1]Taxonomy follows Cigliano et al. (2018). [2]This number has been reconciled with Vickery and Kevan (1985) to exclude subspecies (see text for further explanation). [3]The number in parentheses represents the number of established non-native species included in the total. [4]Barcode Index Number, as defined in Ratnasingham and Hebert (2013). [5]See figure 1 in Langor (2019) for a map of ecozones.

DNA barcodes have been generated for the majority of Canadian Orthoptera species, resulting in 157 BINs (Table 3) (BOLD Systems 2018). The most common species in Canadian collections are, of course, the species most represented in the database. For species rarely collected in Canada, such as members of the families Gryllacrididae and Gryllotalpidae, there are no BINs that correspond to Canadian specimens; however, some of these species have BINs corresponding to specimens collected in the United States.

The Orthoptera of Canada are most diverse in the southern parts of BC, ON, and the Prairie Provinces, and these are the areas where the majority of new species added to the Canadian list since 1979 have come from (Vickery and Scudder 1987, Marshall et al. 2004, Miskelly 2012, 2013, Paiero and Marshall 2014). The great majority of Orthoptera species in Canada are native. Of the known introduced species, four are established species that live outdoors, and three are domiciliary species that don't persist outdoors. Two species are accidental introductions that are known only from butterfly conservatories, where they live in artificially maintained tropical conditions (Paiero and Marshall 2014). Because these species are not cultured or deliberately maintained, they are included in Table 3. Only two Canadian species have Holarctic distributions and three species are endemic to Canada (Vickery and Kevan 1985). One species, *Melanoplus spretus* (Walsh), that was formerly found in Canada and USA is believed to be extinct (Lockwood and Debrey 1990). Dead individuals of this species are known to occur in glaciers in USA, and could occur in similar situations in the Canadian Rocky Mountains (Lockwood et al. 1991).

Dermaptera

The earwig fauna of Canada has changed very little since 1979. As a relatively small order of relatively large and conspicuous insects, the earwigs of North America are well known and well documented, with several regional keys available, including to species of Canada (Vickery and Kevan 1985) and eastern North America (Hoffman 1987). Engel (2003) also provides a key to the earwig genera of North America, while Hoffman (1987) provides a checklist for North America, but additional adventitious species have certainly been recorded since (e.g., Choate 2001). The biology and behaviour of Canadian earwigs was covered in detail by Vickery and Kevan (1985). New records and distributional information comes from recent regional checklists of ON (Paiero and Marshall 2016) and BC (Cannings and Scudder 2005b) while Guillet et al. (2000) discuss the differences in behaviour of the two *Forficula* species established in Canada.

For Canadian species, Vickery and Kevan (1985) provide keys and distributional data for all of the established species, and the distributions have changed very little. The fauna consists of six breeding species, an increase from the five species that Lamb (1979) recorded (Table 4). Most of the species were inadvertently introduced to Canada. The only change to our breeding fauna is the treatment of the European Earwig (*Forficula auricularia* Linnaeus) as a pair of cryptic species (Guillet et al. 2000),

Table 4. Census of Dermaptera in Canada.

Taxon[1]	No. species reported in Lamb (1979)[2]	No. species currently known in Canada[3]	No. BINs[4] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[5]	Information sources
Anisolabididae	2	2 (1)	1	0	in greenhouses; Pacific Maritime, Mixedwood Plains	Cannings and Scudder 2005b, Paiero and Marshall 2014, Vickery and Kevan 1985
Forficulidae	2	3 (2)	2	0	urban areas and buildings in all ecozones south of taiga	Cannings and Scudder 2005b, Paiero and Marshall 2014, Vickery and Kevan 1985
Sphongiphoridae	1	1 (1)	1	0	urban areas and buildings in all southern ecozones	Cannings and Scudder 2005b, Paiero and Marshall 2014, Vickery and Kevan 1985
Total	**5**	**6 (4)**	**4**	**0**		

[1]Classification follows that of Hopkins et al. (2018). [2]Lamb (1979) did not provide a breakdown by family. [3]The number in parentheses represents the number of stablished non-native species included in the total. [4]Barcode Index Number, as defined in Ratnasingham and Hebert (2013). [5]See figure 1 in Langor (2019) for a map of ecozones.

only separable by genetic or phenotypic characters. Two additional species have been recorded in Canada, *Doru taeniatum* (Dohrn) and *Marava arachidis* (Yersin) (Paiero and Marshall 2014), but these were apparently short term indoor establishments. Vickery and Kevan (1985) also include two other species (*Chelidurella acanthopygia* (Gene) and *Doru davisi* Rehn and Hebard) as adventitious. *Chelidurella acanthopygia* was recorded from intercepted goods but it is unclear if *D. davisi* was intercepted or if it was an adventive. None of these four species are included in the species total in Table 4 as they were either intercepted individuals or are no longer established. In total, the Canadian fauna represents ~35% of the 17 North American species based on Hoffman (1987), with 80% of the Canadian fauna (including adventitious species) non-native. There are currently only four BINs available for Canadian earwig species (Table 4), representing 66% of the fauna.

Phasmida

There has been no change to the number of phasmid species in Canada or to the known distribution since the original review by Kevan (1979a). There remains a single Canadian species, *Diapheromera femorata* (Say), that is native to ON, QC, and Manitoba (MB) (Vickery and Kevan 1985) (Table 5). Kevan (1979a) stated that two other species may eventually be found in Canada. *Diapheromera vellii* Walsh is recorded from prairie remnants as far north as Minnesota (Vickery and Kevan 1985) and should be looked for in similar habitat in MB and western ON. *Carausius morosus* (Sinety) is native to India, sometimes cultivated in the pet trade, and has become established in California as far north as the San Francisco area (Headrick 2011); however, as this species has not spread into any area that regularly experiences freezing weather in the winter, it is not likely to become established in Canada and is not included in Table 5.

The single species of Phasmida in Canada represents 3% of the 29 species known from North America north of Mexico (Iowa State University 2003–2018). This species is represented in the Barcode of Life Database as a single BIN (BOLD Systems 2018) (Table 5).

Table 5. Census of Phasmida in Canada.

Family[1]	No. species Reported by Kevan (1979a)	No. species currently known in Canada	No. BINs available for Canadian species[2]	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[3]	Information sources
Diapheromeridae	1	1	1	1	Mixedwood Plains, Prairies	Vickery and Kevan 1985

[1]Classification follows Brock et al. (2018). [2]Barcode Index Number, as defined in Ratnasingham and Hebert (2013). [3]See figure 1 in Langor (2019) for a map of ecozones.

Future studies and opportunities

With the expanding interest in orthopteroids, our knowledge of the natural histories of Canadian species will benefit from the various web portals that allow professional and citizen scientists to share information. This includes expanding our understanding of habitat requirements for native species, along with the impact that non-native species, such as the recently established *Ectobius* species, may have on our natural areas. Additional advancements can be made in documenting the full distribution of our native species, especially those that are not easily recognized and rarely encountered. Interest in orthopteroids can also be further enhanced with digital guides to the Canadian fauna.

While the orthopteroid fauna is relatively small and well known in Canada, compared with several of the larger orders, we do expect that there will be additional species, both native and non-native, that will occur here, especially within the Orthoptera. Continued sampling in natural areas along the southern regions of Canada, especially ON and BC, will likely document additional native species whose northern limits extend just across the American border. Further sampling in some provinces will also help fill gaps in our distributional data. Continued sampling of both urban and natural areas may also find additional non-native species and help document the spread of already established species. Finally, while we continue to utilize morphological characters to recognize the majority of species, the utilization of additional behavioural and molecular datasets may help us recognize previously undocumented cryptic species, such as in the Orthoptera (e.g., *Oecanthus*) where several species within a species complex are expected to occur in Canada.

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Grylloblattodea of Canada

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Abstract

The enigmatic insect order Grylloblattodea comprises two described species in Canada, which are limited to the Montane Cordillera and Pacific Maritime ecozones. One of the described species has three Canadian subspecies of uncertain taxonomic ranking, and there are two additional undescribed or unreported species known in close proximity to the Canadian border in western Alberta and British Columbia that likely also occur in Canada. Thus, as much as 50% of the total taxonomic diversity of Grylloblattodea in Canada is still undocumented. Targeted surveys and taxonomic work, as well as studies that describe the ecology and conservation status of Grylloblattodea are important goals for future research.

Keywords

biodiversity assessment, Biota of Canada, Grylloblattodea, ice crawler, Notoptera

In June of 1913, on Sulphur Mountain in Banff National Park, Canada, the entomologists Edmund M. Walker and Takatsuna B. Kurata discovered an unusual insect under stones on a talus slope: "*…Kurata called me to see an insect he had found under a stone… I knew at once that this creature was something new – unlike anything ever found before*" (Hutchinson 2014). This discovery would both captivate and puzzle entomologists for the next century, due to the difficulty in placing it within the phylogeny of insects (Rentz 1982). The "*peculiar wingless thysanuriform insect*" was immediately noted for the presence of an ovipositor in adult females and unusual combination of morphological characters, and so it was described in a new family Grylloblattidae as *Grylloblatta campodeiformis* Walker (1914). Walker argued that the grylloblattid's morphological features were similar to those found in several "orthopteroid" lineages, to such a degree that he named them by combining the Latin word for cricket (*gryllus*) and roach (*blatta*). They are now placed as sister to the African heel walkers, order Mantophasmatodea, itself discovered in 2002 (Klass et al. 2002, 2003). There is strong genetic support for the Grylloblattodea lineage diversifying from other polyneopteran insects around 150 million years ago (Misof et al. 2014). The common name for North American grylloblattids is widely recognized to be "ice crawler" due to their strong affinities to snowfield habitats, while the more common name "rock crawler" has been used for both Asian and North America lineages that as a group prefer habitats with rocky terrain (Schoville 2010).

Since Kevan (1979) reviewed existing knowledge of the Grylloblattodea (as 'Notoptera') in Canada, there has been considerable advancement of our understanding of the evolutionary history and distribution of this group (Kamp 1979, Wipfler et al. 2014), although much remains to be learned about the systematics, ecology and conservation status of these insects (Schoville 2014). Several studies have shown the strong impact of glacial climate history on species diversification and range shifts in both North American and Asian taxa (Schoville and Roderick 2010, Schoville et al. 2013). Notably, the global distribution of Grylloblattodea has been expanded to include the Altai and Sayan Mountains in Southern Siberia, where the Asian genus *Grylloblattella* Storozhenko and Oliger (1984) is found. Additionally, the Korean genus *Namkungia* Kim and Lee (2006) has been described. In North America, five new species of *Grylloblatta* have been described from California and Oregon (Schoville 2012, Marshall and Lytle 2015), bringing the total number of species to 33. One species, *G. campodeiformis*, has four recognized subspecies. In Canada, the number of species has not increased since 1979, remaining at two (Table 1). However, it is widely recognized that a large number of species remain undescribed in North America (Jarvis and Whiting 2006, Schoville and Graening 2013), and the three recognized subspecies of *G. campodeiformis* in Canada (Table 1) are of uncertain taxonomic rank.

Collection records now suggest that ice crawlers are widespread in montane habitats of western Alberta and British Columbia (Schoville and Graening 2013; C Copley unpubl. data). These records remain patchy and are based on passive sampling, making assessments of the distribution, abundance and conservation status of populations difficult. One of the most interesting Canadian localities is Mt. St. Paul in Kamloops, British Columbia (BC), where ice crawlers can be found as low as 400m elevation on south-facing slopes during fall and winter (Gregson 1938, Campbell 1949). It remains to be seen how widespread ice crawlers are in Canada at such low elevation. In addition, a few Canadian distributional records remain disputed, i.e. Forbidden Plateau, Vancouver Island, and Grouse Mountain on the mainland (Spencer 1945, Kamp 1979).

Table 1. Census of Grylloblattodea in Canada.

Taxon	No. species reported in Kevan (1979)	No. species currently known from Canada[1]	No. BINs[2] available for Canadian species	Est. no. undescribed or unrecorded[3] species in Canada	General distribution by ecozone[4]	Information sources
Grylloblattidae	2	2	1	2	Montane Cordillera, Pacific Maritime	Kamp 1979, Kevan 1979, Schoville and Graening 2013; www.gbif.org; S Schoville unpubl. data

[1]One species, *G. campodeiformis*, has three subspecies reported from Canada. [2]Barcode Index Number, as defined in Ratnasingham and Hebert (2013). [3]Also, a fourth subspecies of *G. campodeiformis* is expected to occur in Canada. [4]See figure 1 in Langor (2019) for a map of ecozones.

A better understanding of how and when to survey for ice crawlers has emerged in recent years (Schoville and Graening 2013), but it is continually improving with biodiversity studies that focus on winter invertebrate ecology. While traditionally viewed as dependent on snow fields or caves with permanent ice, extensive survey work by Kamp (1973) pointed to the close association of ice crawlers with subterranean rocky environments (hypolithion), where cool and humid conditions maintain viable microhabitats. Our knowledge was recently advanced by a study that discovered extensive foraging activity of ice crawlers in infested and dead conifers in mid-elevation Canadian forests (Esch et al. 2018), and a previous study that showed that ice crawlers are often abundant in these forests even when they are managed for timber harvesting (Huggard and Klenner 2003). Suitable habitats occur in boreal forest, alpine talus slopes, lava fields and other cave sites (Schoville and Graening 2013), though ice crawlers are only likely to be surface active following frost events or when snow is on the ground. Ice crawlers are most readily found at night foraging, but can also be found by turning stones or downed wood, or by searching caves where they are active during daylight hours.

To develop an estimate of the expected number of species in Canada, both distributional data and genetic data (Schoville and Graening 2013, S Schoville unpubl. data) were examined. Due to the close proximity of the type locality of *G. campodeiformis occidentalis* Silvestri (1931) on the northern slope of Mt. Baker in Washington, this subspecies undoubtedly occurs in adjacent parts of BC. An undescribed species is known from Mt. Spokane, Washington (S Schoville unpubl. data) and is likely to extend throughout the Selkirk Mountains into BC (Pritchard and Scholefield 1978). There are at least two additional undescribed species in the North Cascades of Washington, which are likely to extend into BC. Thus, as much as 50% of the total taxonomic diversity of Grylloblattodea in Canada is still undocumented.

One Barcode Index Number (BIN) is available for Canadian ice crawlers, representing the taxon *G. campodeiformis campodeiformis*. It should be noted that GenBank holds a large number of accessions for the COII mitochondrial locus, which has been used to diagnose species in both North America and Asia.

An important future effort will be to expand our knowledge of ice crawler species ranges in Canada, as well as invest in ecological studies that measure local abundance and assess possible conservation threats. Further efforts to catalogue, determine the distribution, and genetically sample *Grylloblatta* in Canada are likely to provide general insight into insect biodiversity patterns, especially cold-specialized species, due to the limited dispersal capacity, high levels of endemism throughout North America, and strong genetic structure reflecting past environmental change (Jarvis and Whiting 2006, Schoville and Roderick 2010). A particular focus of surveys in the Coast, Cascade, and Columbia mountain ranges are important to developing knowledge of species distributions and potential zones of sympatry. Complimented with morphological and genetic data, such surveys would help resolve the status of subspecies and potentially identify undescribed species. Perhaps the greatest needs, however, lie in expanding our knowledge of the ecology of ice crawlers and the impacts of ongoing environmental change.

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REVIEW ARTICLE

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Hemiptera of Canada

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Abstract

The Canadian Hemiptera (Sternorrhyncha, Auchenorrhyncha, and Heteroptera) fauna is reviewed, which currently comprises 4011 species, including 405 non-native species. DNA barcodes available for Canadian specimens are represented by 3275 BINs. The analysis was based on the most recent checklist of Hemiptera in Canada (Maw et al. 2000) and subsequent collection records, literature records and compilation of DNA barcode data. It is estimated that almost 600 additional species remain to be discovered among Canadian Hemiptera.

Keywords

Barcode Index Number (BIN), biodiversity assessment, Biota of Canada, DNA barcodes, Hemiptera, true bugs

The order Hemiptera, the true bugs, is a relatively large order. Worldwide there are an estimated 106,970 described species (Henry 2017, Bartlett et al. 2018, Hardy 2018). The recognised Canadian Hemiptera fauna (Table 1) has been greatly expanded since the review by Scudder (1979), with an increase of 937 species above the 3079 then known. The checklist of Canadian Hemiptera (Maw et al. 2000) provided comprehensive lists and distributions for all species recognised at that time. Here we present updated totals, including a number of additional unpublished records represented by specimens in the Canadian National Collections of Insects, Arthropods and Nematodes (CNCI) in Ottawa. Gwiazdowski et al. (2015) presented a detailed analysis of all Hemipteran DNA barcodes available for the Canadian fauna.

A further 590 species are estimated to occur in the country, with the majority expected in the large families Aphididae, Cicadellidae, and Miridae. Estimates of the number of unrecorded species for the less diverse families is based mainly on known but undescribed species and presence of species in adjacent climatologically and ecologically similar parts of the United States, and known distributions of host plants. Molecular data and analysis of host plant usage provides evidence of additional cryptic diversity in the more speciose phytophagous groups. For some families, presence of unnamed clusters in the DNA barcode data suggests additional species, assuming that in most cases Barcode Index Numbers (BINs), as defined by Ratnasingham and Hebert (2013), correspond to one or more species (Gwiazdowski et al. 2015).

The classification used here follows Psyl'list (Ouvrard 2018) for Psylloidea, Aphid Species File (Favret 2018) for Aphidomorpha, ScaleNet (García Morales et al. 2016) for Coccoidea, Bartlett et al. (2018) for higher classification of Auchenorrhyncha, Bartlett et al. (2014) for species level delimitation in Fulgoromorpha, Dmitriev (2018) for species level delimitation in Cicadomorpha, and Henry (2017) for higher level classification of Heteroptera. There have been several changes in higher level classification since Scudder (1979). Homoptera, no longer recognised as a formal taxon, is now treated as two suborders, namely Sternorrhyncha and Auchenorrhyncha. Although not followed here, some authors (after Sorensen et al. 1995) separate the Auchenorrhyncha into suborders Clypeorrhyncha and Archaeorrhyncha. Among Sternorrhyncha, many new families of scale insects have been erected; species in Canada formerly included in Margarodidae are now dispersed among Matsucoccidae, Steingeliidae and Xylococcidae; Putoidae was formerly included in Pseudococcidae. Schemes for the subdivision of family Aphididae, such as that of Heie (1980) (and used in the Hemiptera checklist of Maw et al. 2000), have been proposed, but largely ignored in the absence of a clear consensus on the relationships among aphid subgroups. Within the Fulgoroidea, the Acanaloniidae, Dictyopharidae, and Kinnaridae are now recognised in Canada, with their species removed from the Issidae, Fulgoridae, and Cixiidae, respectively. The broadly constituted Cercopidae has been divided, with most Canadian species now placed in the Clastopteridae and Aphrophoridae. In the Heteroptera, most former lygaeid subfamilies have been given family status so that Lygaeidae of Scudder (1979) is now represented by eight families (Henry 1997); the further segregation of Ischnorhynchidae and Orsillidae (Sweet 2000) from Lygaeidae is not recognised here. Lyctocoridae and Lasiochilidae have been separated from Anthocoridae. On the other hand, Aradidae now includes Meziridae, Miridae includes Isometopidae, and Reduviidae includes Phymatidae and Ploiariidae.

The 419 non-native species of Hemiptera represents a significant proportion of the total fauna. In Aphididae, about 19% of the species are non-native. An overview of the non-native aphid fauna of North America was provided by Foottit et al. (2006) and updated by Skvarla et al. (2017). The non-native Heteroptera of Canada (about 7% of the total fauna) were treated by Scudder and Foottit (2006).

Sternorrhyncha

Worldwide, the Sternorrhyncha are represented by about 18,690 species (Hardy 2018), with about 2950 species in North America (approximate composite number based on Foottit et al. 2006, García Morales et al. 2016, Skvarla et al. 2017, Mallory 2018, Ouvrard and Martin 2018). Currently, 1120 species of Sternorrhyncha are known from Canada compared to 834 in 1979, and it is expected that a further 215 species will be eventually found in the country (Table 1).

In Canada, the Aphididae and Adelgidae are relatively well known. Foottit and Maw (1997, 2014) contributed syntheses of the Yukon and grassland faunas of Aphididae. Aphids and adelgids are well represented by DNA barcodes (Foottit et al. 2008, 2009a, b), and, in general, barcode diversity in these groups corresponds well to morphological species concepts. However, several currently recognised aphid species are represented by more than one BIN, as defined by Ratnasingham and Hebert (2013). In two such cases, subsequent morphological analysis and addition of other genetic loci has resulted in the recognition of new species (Foottit et al. 2010, Foottit and Maw 2018). Conversely, members of several aphid species groups are not distinguishable by COI sequence divergence (Foottit et al. 2008).

The Psylloidea have not been subjected to extensive taxonomic or faunal analysis in Canada, except for work by Hodkinson (e.g., Hodkinson 1976) in British Columbia and Alberta. The identifiable forms of Coccoidea (adult female) and of Aleyrodidae (immatures) are sessile or subterranean and thus not captured by the usual general collecting methods. Consequently, the national fauna and regional distribution of species in these two groups are poorly known, and even limited efforts can yield new records. Kozár et al. (1989) identified several species of scale insects new to Canada based on brief collecting efforts in southern British Columbia. In a recent study of ant–sternorrhynch associations at a single grassland site in Alberta, two of the four species of Pseudococcidae found were newly recorded for Canada (Newton et al. 2011). The number of available BINs (see Table 1), largely based on untargeted sampling by the Biodiversity Institute of Ontario (University of Guelph), has indicated that current knowledge greatly under-represents the true fauna of Psyllidae and Aleyrodidae if BIN diversity can be considered a good approximation of species diversity in these groups.

Auchenorrhyncha

Worldwide there are about 43,024 species of Auchenorrhyncha (Bartlett et al. 2018), but an estimate for North America is currently not available. In Canada, Hamilton (1997, 2014) analysed the cicadellid fauna of the Yukon and the Canadian Prairie Ecozone, respectively, Gareau (2008) documented that of Quebec, and Wilson (1997) treated the Yukon Delphacidae. The taxonomic status of several auchenorrhynch groups has been updated. A number of papers by Hamilton (e.g., Hamilton 1983, 1994, 1998) have revised many groups of Cicadellidae. As well, the large and difficult tribe Erythroneurini has been completely revised by Dmitriev and Dietrich (2007, 2009, 2010). The

Table 1. Census of Hemiptera in Canada.

Taxon[1]	No. species reported in Scudder (1979)[2]	No. species currently known from Canada[3]	No. BINs[4] available for Canadian species	Est. no undescribed or unrecorded species in Canada	General distribution by ecozone[4A]	Information sources[5]
Suborder Sternorrhyncha						
Superfamily Psylloidea						CNCI
Aphalaridae[6]	50	37 (1)	19	10	all ecozones but Arctic	
Calophyidae[6]	?	1	0	0	Mixedwood Plains	
Liviidae[6]	4	14 (3)	6	2	all ecozones but Arctic	
Psyllidae[6]	35	52 (5)	65	20	all ecozones but Arctic	
Triozidae	18	25 (1)	13	10	all ecozones but Arctic	
Superfamily Aleyrodoidea						
Aleyrodidae	3	13 (4)	40	40	all ecozones south of taiga	CNCI
Infraorder Aphidomorpha						
Superfamily Adelgoidea						
Adelgidae	22	18 (5)	14	1	all ecozones but Arctic	
Superfamily Aphidoidea						
Aphididae	650	847 (164)	758	100	all ecozones	CNCI
Superfamily Phylloxeroidea						
Phylloxeridae	6	8 (2)	11	4	Pacific Maritime, Mixedwood Plains, Boreal Plains (1 sp.)	
Infraorder Coccomorpha						
Superfamily Coccoidea						
Asterolecaniidae	1	2 (2)	0	0	Pacific Maritime, Mixedwood Plains	
Coccidae	15	26 (12)	7	5	all ecozones, mostly south of Arctic	
Cryptococcidae	?	2 (2)	0	0	Mixedwood Plains, Atlantic Maritime	
Dactylopiidae	1	1	0	0	Prairies	
Diaspididae	16	30 (10)	4	10	all ecozones, mostly south of taiga	
Eriococcidae	3	3 (2)	2	0	Pacific Maritime, Mixedwood Plains, Atlantic Maritime	
Kermesidae	0	4	0	1	Mixedwood Plains	
Margarodidae	4[7]	0	0	0		
Matsucoccidae[7]	?	2	0	0	Mixedwood Plains, Atlantic Maritime	
Ortheziidae[8]	3	5	2	0	all ecozones but Arctic	
Pseudococcidae	13[9]	25 (9)	11	10	all ecozones, mostly south of taiga	Newton et al. 2011; CNCI

Taxon[1]	No. species reported in Scudder (1979)[2]	No. species currently known from Canada[3]	No. BINs[4] available for Canadian species	Est. no undescribed or unrecorded species in Canada	General distribution by ecozone[4A]	Information sources[5]
Putoidae[9]	?	2	0	0	Montane Cordillera, Boreal Cordillera	
Rhizoecidae	0	1	0	2	Pacific Maritime	CNCI
Steingeliidae[7]	?	1 (1)	0	0	Mixedwood Plains	
Xylococcidae[7]	?	1	0	0	Atlantic Maritime	
Total Sternorrhyncha	**844**	**1120 (223)**	**955**	**215**		
Suborder Auchenorrhyncha						
Superfamily Fulgoroidea						
Acanaloniidae[10]	?	2	2	0	Mixedwoods Plains	
Achilidae	17	19	15	3	all ecozones but Arctic	
Caliscelidae	7	11	7	0	mostly south of boreal	
Cixiidae	25[11]	31	14	5	all ecozones but Arctic	
Delphacidae	81	138 (1)	102	30	all ecozones	
Derbidae	14	21	17	3	all ecozones south of taiga; most in Mixedwood Plains	
Dictyopharidae[12]	4	8	5	1	widespread south of taiga	
Flatidae	1	3	3	0	Mixedwoods Plains	
Issidae	3[10]	2	1	0	Mixedwoods Plains	
Kinnaridae[11]	?	1	0	0	Western Interior Basin	
Infraorder Cicadomorpha						
Superfamily Cicadoidea						
Cicadidae	9	21	10	7	mostly south of taiga, Taiga Plains (1 sp.)	
Superfamily Cercopoidea						
Aphrophoridae[13]	?	23 (4)	19	2	all ecozones but Arctic	
Cercopidae	33[13]	1	0	0	Mixedwoods Plains	
Clastopteridae[13]	?	12	8	2	all ecozones south of taiga	
Superfamily Membracoidea						
Cicadellidae	800	1097 (76)	1144	150	all ecozones	Dmitriev 2018, specimens in CNCI
Membracidae	70	101 (1)	65	20	widespread south of boreal, few in Boreal Shield and Boreal Plains	Dmitriev 2018
Total Auchenorrhyncha	**1064**	**1491 (82)**	**1412**	**223**		

Taxon[1]	No. species reported in Scudder (1979)[2]	No. species currently known from Canada[3]	No. BINs[4] available for Canadian species	Est. no undescribed or unrecorded species in Canada	General distribution by ecozone[4A]	Information sources[5]
Suborder [?] Heteroptera						Scudder 2008 and references included therein, Scudder 2012, Roch 2017
Infraorder Enicocephalomorpha						
Superfamily Enicocephaloidea						
Aenictopecheidae	0	1	0	0	Boreal Plains (single collection)	
Enicocephalidae[14]	1	1	2	1	Mixedwood Plains, Atlantic Maritime	
Infraorder Dipsocoromorpha						
Superfamily Dipsocoroidea						
Ceratocombidae[15]	1	1	7	5	Pacific Maritime, Mixedwood Plains	
Schizopteridae	0	1 (1)	0	0	Pacific Maritime	
Infraorder Gerromorpha						
Superfamily Gerroidea						
Gerridae	19	22	13	1	all ecozones but Arctic	
Veliidae	6	8	6	0	all ecozones south of taiga	
Superfamily Hebroidea						
Hebridae	4	5	2	0	all ecozones south of taiga	
Superfamily Hydrometroidea						
Hydrometridae	1	1	1	0	Pacific Maritime, Prairies, Mixedwood Plains, Atlantic Maritime	
Superfamily Mesovelioidea						
Mesoveliidae	2	2	2	0	all ecozones south of taiga	
Infraorder Nepomorpha						
Superfamily Corixoidea						
Corixidae	72	79	57	2	all ecozones but Arctic	
Superfamily Naucoroidea						
Naucoridae	0	1	1	0	Mixedwood Plains	
Superfamily Nepoidea						
Belostomatidae	3	4	2	0	all ecozones but Arctic	
Nepidae	7	4	6	1	Mixedwood Plains, southern Boreal Shield	
Superfamily Notonectoidea						
Notonectidae	12	12	10	0	all ecozones but Arctic	

Taxon[1]	No. species reported in Scudder (1979)[2]	No. species currently known from Canada[3]	No. BINs[4] available for Canadian species	Est. no undescribed or unrecorded species in Canada	General distribution by ecozone[4A]	Information sources[5]
Pleidae	2	1	1	0	Mixedwood Plains, southern Boreal Shield	
Superfamily Ochteroidea						
Gelastocoridae	1	1	1	0	Pacific Maritime, Prairies, Mixedwood Plains	
Ochteridae	0	1	0	0	Mixedwood Plains	
Infraorder Leptopodomorpha						
Superfamily Saldoidea						
Saldidae	36	38	23	2	All ecozones, mostly south of Arctic	
Infraorder Cimicomorpha						
Cimicoidea						
Anthocoridae	41[16]	39 (7)	36	1	widespread south of taiga	
Cimicidae	4	7	3	0	widespread south of taiga	
Lasiochilidae[16]	?	1	0	0	Mixedwood Plains	
Lyctocoridae[16]	?	6	2	0	all ecozones south of taiga	
Superfamily Naboidea						
Nabidae	12	22 (3)	19	2	all ecozones south of Arctic	
Superfamily Microphysoidea						
Microphysidae	0	3 (3)	1	0	near Pacific and Atlantic ports of entry	
Superfamily Miroidea						
Miridae	601[17]	706 (57)	414	100	mostly south of Arctic, widespread	
Tingidae	46	52 (6)	30	10	all ecozones south of taiga	
Superfamily Reduvioidea						
Reduviidae	26[18]	29 (3)	20	0	all ecozones south of taiga	
Infraorder Pentatomomorpha						
Superfamily Aradoidea						
Aradidae	47[19]	51	13	2	all ecozones but Arctic	
Superfamily Coreoidea						
Alydidae	10	9	7	0	all ecozones but Arctic	
Coreidae	11	15	14	0	all ecozones but Arctic	
Rhopalidae	9	19 (1)	14	2	all ecozones but Arctic	
Superfamily Lygaeoidea						
Artheneidae	0	1 (1)	1	0	all ecozones south of taiga	
Berytidae[20]	3	5 (1)	6	0	all ecozones south of boreal	
Blissidae[21]	?	6	4	0	all ecozones south of boreal	

Taxon[1]	No. species reported in Scudder (1979)[2]	No. species currently known from Canada[3]	No. BINs[4] available for Canadian species	Est. no undescribed or unrecorded species in Canada	General distribution by ecozone[4A]	Information sources[5]
Cymidae [21]	?	5	4	0	all ecozones south of taiga	
Geocoridae [21]	?	10	5	0	all ecozones but Arctic	
Heterogastridae [21]	?	2 (1)	0	0	Pacific Maritime	
Lygaeidae	100 [21]	27 (1)	18	2	all ecozones, most south of Arctic	
Oxycarenidae [21]	?	5 (1)	1	0	all ecozones but Arctic	
Pachygronthidae [21]	?	3	4	1	all ecozones but Arctic	
Piesmatidae	1	4	1	0	all ecozones south of taiga	
Rhyparochromidae [21]	?	71 (10)	52	7	all ecozones but Arctic	
Superfamily Pentatomoidea						
Acanthosomatidae	5	5 (1)	3	0	all ecozones but Arctic	
Cydnidae	7	12 (1)	13	3	Pacific Maritime, Mixedwood Plains	
Pentatomidae	63 [22]	77 (1)	68	5	all ecozones but Arctic	
Scutelleridae	9	13	9	2	all ecozones but Arctic, mostly south of taiga	
Thyreocoridae [23]	9	11	12	2	all ecozones but Arctic, mostly south of taiga	
Total Heteroptera	**1171**	**1400 (100)**	**908**	**151**		
Total Hemiptera	**3079**	**4011 (405)**	**3275**	**589**		

[1]Classification follows Ouvrard (2018, Psylloidea), Favret (2018, Aphidomorpha), García Morales et al. (2016, Coccoidea), Bartlett et al. (2018, Auchenorrhyncha), and Henry (2017, Heteroptera). [2]Some families not recognised by Scudder (1979) but which contain species included by him within other families, are indicate by ? in this column. [3]Numbers in parentheses indicate the number of non-native species included in the total. Phytophagous species known only from indoor plants are not included. [4]Barcode Index Numbers, as defined by Ratnasingham and Hebert (2013). [4A]See figure 1 in Langor (2019) for a map of ecozones. [5]The baseline data for all groups is the most recent comprehensive checklist of Hemiptera in Canada (Maw et al. 2000). Sources given here are for subsequent additions to the known fauna. Collection abbreviation: CNCI, specimens in Canadian National Collection of Insects, Arachnids and Nematodes. [6]As the delineation of families of Psylloidea has changed since Scudder (1979), the number of species reported in 1979 for each family are not comparable to current totals with the exception of Triozidae. [7]In Scudder (1979), the count for Margarodidae included Matsucoccidae, Steingelliidae, and Xylococcidae; no Canadian species remain in Margarodidae. [8]Misspelled as Arthezidae in Scudder (1979). [9]In Scudder (1979), the count for Pseudococcidae included Putoidae. [10]In Scudder (1979), the count for Issidae included Acanaloniidae. [11]In Scudder (1979), the count for Cixiidae included Kinnaridae. [12]Treated under Fulgoridae in Scudder (1979); there are no Canadian species of Fulgoridae *s.str.* [13]In Scudder (1979), the count for Cercopidae included Aphrophoridae and Clastopteridae. [14]Enicocephalidae was listed under Reduvioidea in Scudder (1979). [15]Ceratocombidae was treated as part of Dipsocoridae in Scudder (1979). [16]In Scudder (1979), the count for Anthocoridae included Lasiochilidae and Lyctocoridae. [17]Scudder (1979) reported on Miridae (600 spp.) and Isometopidae (1 spp.) separately; however, we have combined these counts for 1979 under Miridae. [18]Scudder (1979) reported on Reduviidae (13 spp.), Phymatidae (3 spp.), and Ploiariidae (10 spp.) separately; however, as these are all currently included in Reduviidae, we have combined the count for 1979. [19]Scudder (1979) reported on Aradidae (46 spp.) and Merizidae (1 spp.) separately; however, we have combined these counts for 1979 under Aradidae. [20]Scudder (1979) reported this family as Berytinidae. [21]In Scudder (1979), the count for Lygaeidae included Artheneidae, Blissidae, Cymidae, Geocoridae, Heterogastridae, Oxycarenidae, Pachygronthidae, and Rhyparochromidae. [22]Scudder (1979) reported on Pentatomidae (61 spp.) and Podopidae (2 spp.) separately; however, we have combined these counts for 1979 under Pentatomidae. [23]Scudder (1979) reported this family as Corimelaenidae.

Cercopoidea were completely revised and a handbook published by Hamilton (1982). Progress on the Fulgoroidea includes a review of the North American fauna (Bartlett et al. 2014), which provides illustrated keys to all genera including the first comprehensive key to delphacid genera in the region. The known diversity of Canadian Auchenorrhyncha has increased since Scudder (1979), mostly as a result of taxonomic progress and improved knowledge of distributions. Currently, 1491 species are known from Canada compared to 1060 in 1979, and it is expected that a further 223 species will be eventually found in the country (Table 1). Most of the increases are in line with estimates of unrecorded species provided by Scudder (1979). The highest proportional increase is among the Cicadidae from nine to 21 recorded species; this increase is entirely due to improved knowledge of distribution (Hamilton 2010, Sanborn and Phillips 2013) as little taxonomic work has been done on the family in Canada. The highest numerical increase is among the Cicadellidae with an increase of 297 species; this is due to a combination of significant taxonomic research, greatly increased knowledge of distributions, and a small number of recently introduced species. We expect this family to hold the largest number of still unrecorded species (estimated at 150 species), particularly among the under-studied and under-collected subfamily Typhlocybinae.

Significant progress has been made in DNA barcoding of the Canadian Auchenorrhyncha. Data for 691 species have been released (Foottit et al. 2014, Gwiazdowski Heteroptodea et al. 2015) and unpublished data for additional species is available in Barcode of Life Data System (Ratnasingham and Hebert 2007). A simple comparison between the number of BINs and recorded species suggests that more than half the Canadian species have been barcoded in most families, and an impressive 91% of the highly diverse Cicadellidae. However, caution is required in interpreting these numbers. Single BINs have been shown to include multiple morphologically distinct species in a number of cicadellid genera (Foottit et al. 2014). Conversely, preliminary examination of BINs for the Typhlocybinae suggests that single species may be represented by multiple BINs. Thus, the number of BINs may not be predictive of the number of distinct species within these groups.

Heteroptera

There are about 45,254 described species of Heteroptera in the world. The most recent published comprehensive catalog for the group in North America (Henry and Froeschner 1985) includes 3834 species. About 1400 species are currently known to occur in Canada compared to 1171 in 1979, and it is expected that a further 151 species will be eventually added (Table 1). Most families of this suborder are relatively well known in the country. However, representatives of two families have been found in Canada only recently: Schizopteridae in 2010 (Scudder 2010a) and Aenictopecheidae in 2016 (Scudder and Štys 2016). Roch (2017) recently documented the Heteroptera of Quebec. Detailed analyses of the faunas of the Yukon, grasslands, Atlantic Maritime Ecozone and Montane Cordillera Ecozone have appeared (Scudder 1997, 2010b, 2011, 2014), and the aquatic and semiaquatic Heteroptera of Canadian peatlands and marshlands and the aquatic Heteroptera of the prairies and parklands were documented by Scudder (1987) and Scudder et al. (2010). Kelton (1980) provided a handbook of the Miridae of the Prairie Provinces. A major on-line database of the mirid fauna of North America (Schuh 2002–2013) includes records for a major portion of the holdings of the CNCI. DNA barcodes for the 334 species of Heteroptera drawn from CNCI (mainly Canadian species) were presented by Park et al. (2011) and reanalysed by Gwiazdowski et al. (2015).

The predicted number of Miridae constitutes the bulk of the estimate for Heteroptera overall, but this number is speculative and may be an underestimate if there are a significant number of undetected cryptic species within the more speciose genera.

Summary and opportunities

Despite the significant increase in knowledge of Hemiptera in Canada since 1979, a substantial amount of the country's biodiversity still awaits discovery. Some groups of Hemiptera are relatively well documented in Canada, while others are quite poorly known. However, even in the well-studied, but highly diverse phytophagous families (such as Aphididae and Miridae), there is probably unrecognised cryptic diversity associated with host plants and geographic variation. Several large genera in these families, such as *Lygus*, continue to present taxonomic difficulties (Schwartz and Foottit 1998) and opportunities for application of new approaches and technologies. Because many species of Hemiptera are current or potential pests, continuing research on detection, identification, quarantine and management of these groups will be required.

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Abstract

The known Canadian Thysanoptera fauna currently consists of 147 species, including 28 non-native species, and there are five additional species found only indoors. DNA barcoding data, presence of species in adjacent regions, and preliminary evidence of the presence of host-associated cryptic species suggest that there may be as many as 255 additional species awaiting discovery or description in Canada.

Keywords

Barcode Index Number (BIN), biodiversity assessment, Biota of Canada, DNA barcodes, thrips, Thysanoptera

The order Thysanoptera (commonly known as 'thrips', not to be confused with the genus *Thrips*) is relatively small, with 6200 species known worldwide (Mound 2018). However, the order is most diverse in the tropical zones where the faunas have received relatively little attention; thus many additional species are expected. About 765 species are recorded in North America north of Mexico (unpublished records for the United States collated by Richard zur Strassen and presented in ThripsWiki 2018, plus 16 additional species in Canada based on specimens in the Canadian National Collection of Insects [CNCI]). The number of species of Thysanoptera known from Canada has increased by about 45% (Table 1) since Heming's (1979) synopsis. One species of

Table 1. Census of Thysanoptera in Canada.

Taxon[1]	No. species reported in Heming (1979)	No. species currently known from Canada[2]	No. BINs[3] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[4]	Information sources[5]
Suborder Terebrantia						
Aeolothripidae	13	17	41	30	widespread south of Arctic	Chaisson 1986; CNCI, UASM
Heterothripidae	0	1	0	4	Mixedwood Plains	Chaisson 1986; CNCI
Thripidae	59	85 (20)	192	120	all ecozones including a few species in the southern Arctic	Chaisson 1986; CNCI, UASM, USNM
Merothripidae	0	1	0	0	Mixedwood Plains	CNCI
Melanthripidae	0	0	1	0	Pacific Maritime	BIOUG
Suborder Tubulifera						
Phlaeothripidae	30	43 (8)	104	100	all ecozones except Arctic	Chaisson 1986; CNCI, UASM, USNM
Total	**102**	**147 (28)**	**338**	**255**		

[1]Classification follows Mound (2018). [2]Number in parentheses indicates number of non-native species included in total. The totals do not include three species of Thripidae and two species of Phlaeothripidae found only on ornamental plants indoors. [3]Barcode Index Numbers, as defined in Ratnasingham and Hebert (2013). [4]See figure 1 in Langor (2019) for a map of ecozones. [5]Data source collection codens: BIOUG, Biodiversity Institute of Ontario, University of Guelph; CNCI, Canadian National Collection of Insects, Ottawa; UASM, University of Alberta, Strickland Museum; USNM, National Museum of Natural History (Thysanoptera specimens housed at Agricultural Research Service, Beltsville, MD).

each of two small families, Heterothripidae and Merothripidae, have been detected since then, with an additional family, Melanthripidae, currently represented by an unidentified species of *Ankothrips* based on a DNA sequence in the Barcode of Life Data System database (www.boldsystems.org).

Since 1979, there have been several important advances in the knowledge of Canadian thrips diversity. Chiasson (1986) made a major contribution to the knowledge of the Canadian fauna, providing keys and descriptions of the genera, and collection data for all species known at that time. She reported 140 identified species, with an additional 42 undetermined or undescribed species, and estimated that 65 more species should occur in this country based on distributions of Thysanoptera in the northern USA. The current total (147 identified established species plus five occurring indoors) is only a marginal increase since Chiasson's (1986) work.

DNA Barcode Index Numbers (BINs) which give a label to clusters of similar mitochondrial COI sequences (DNA barcodes) correspond approximately to species in many groups (Ratnasingham and Hebert 2013). The relationship between BINs and species concepts has not been critically assessed in Thysanoptera. However, assuming that BIN diversity approximates species diversity (see Ratnasingham and Hebert 2013), derived mainly from untargeted sampling by the Biodiversity Institute of Ontario, University of Guelph, suggests that the number of species sampled could potentially be more than twice the current recognized fauna. There is also preliminary evidence that at least a few species consist of complexes of host-associated lineages (R Foottit and E Maw unpubl. data). Based on the presence of species in adjacent parts of the United States, and on the geographic and taxonomic distribution of unidentified BINs in the DNA barcoding data, we estimate that a further 255 species may eventually be found in Canada (Table 1). However, the Phlaeothripidae, many of which are associated with fungi and decaying wood, are particularly poorly collected, and the estimate of 100 undetected phlaeothripid species in Canada is quite imprecise.

Recent revisions affecting the Canadian fauna have been published for *Thrips* (Nakahara 1994), for *Anaphothrips* (Nakahara 1995), and for *Chirothrips* and related genera (Nakahara and Foottit 2012), including descriptions of new species which occur in Canada (*Thrips aurentulus* Nakahara, *Thrips fallaciosus* Nakahara, *Thrips intricatus* Nakahara, *Chirothrips hemingi* Nakahara and Foottit).

Most recent literature on Thysanoptera in Canada treats arising economic issues. The eastern species *Echinothrips americanus* Morgan became a problem in greenhouses in British Columbia (Opit et al. 1997). The non-native *Taeniothrips inconsequens* (Uzel) was reported as a significant pest on sugar maple (Nystrom and Syme 1994). Old World *Frankliniella intonsa* (Trybom) has become established in the Fraser Valley of British Columbia (Nakahara and Foottit 2007) and has recently been found in Québec (specimens in CNCI). *Drepanothrips reuteri* Uzel now occurs on grapes in British Columbia (Lowery 2015). Burgess and Weegar (1988) surveyed the Thysanoptera associated with canola crops in Saskatchewan.

This analysis clearly indicates that the Thysanoptera of Canada are understudied. Much of the non-agricultural regions of the country are only sparsely sampled, and the relative knowledge of species occurring in the various provinces and regions is not uniform. The best known region is the province of Alberta (87 species, or about 60% of the species known to occur in Canada; specimens in the Strickland Museum, University of Alberta and CNCI) due primarily to the efforts of Bruce Heming. There are no recent identification tools available for most groups in the order.

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We would like to dedicate this work to the late Dr. Bruce Heming (1939-2018), for his contributions to the understanding of Thysanoptera biology and the fauna of Canada. The authors express their thanks to Jeremy deWaard for updates to the number of available Barcode Index Numbers. We thank David Langor and Cory Sheffield for their critical comments.

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REVIEW ARTICLE

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Psocoptera of Canada

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Abstract

At present, 108 species of Psocoptera are known from Canada, an increase of 50% from the known fauna reported in 1979. Of these, 56 have been barcoded, representing 162 Barcode Identification Numbers (BINs). An additional 67 species are expected to occur in Canada but remain undiscovered or undescribed, meaning that only 62% of the fauna is currently documented.

Keywords

bark lice, biodiversity assessment, Biota of Canada, book lice, Psocoptera

Psocoptera, commonly known as bark lice and book lice, comprised about 4400 species known worldwide by the time the World catalogue was published, with 294 species in North America (Lienhard and Smithers 2002). By the end of 2015, the worldwide species number had increased to 5958 (C Lienhard pers. comm.). Mockford (2012) lists 397 species from North America south to the Tropic of Cancer.

Psocoptera are generally herbivores or detritivores, feeding on microflora and organic debris. Species associated with human dwellings, most belonging to the suborders Trogiomorpha and Troctomorpha, often feed on molds as well as dead insects. The outdoor-living species, mostly of the suborder Psocomorpha, may be classified as either bark-dwellers or leaf-dwellers, with associated differences in feeding habits (e.g., Mockford 1993, Lienhard 1998). Many domiciliary species are found outdoors if conditions are favourable. Since indoor species are readily spread by human commerce around the world, it may often be difficult to say where they originally came from, and whether they are native or introduced species or populations.

Although classified as an order for much of recent history, Yoshizawa and Lienhard (2010) showed that Phthiraptera, the true lice, have evolved within the Troctomorpha suborder of Psocoptera. Phthiraptera and the family Liposcelididae of Psocoptera are probably sister groups, or various lines of Phthiraptera may have budded off independently in the infraorder Nanopsocetae within Troctomorpha. To maintain monophyly, the former orders of Psocoptera and Phthiraptera are now placed in the order Psocodea. For practical reasons, however, since true lice and psocids have quite different ecology, and are studied by different methods and by different experts, Psocoptera is still typically treated as a group in the traditional way, but referred to as Psocodea: 'Psocoptera'. This practical approach is also adopted in the present work.

Since the last review of Canadian Psocoptera (Mockford 1979), there has been relatively little effort focused on this group in Canada, and Canada has never had an expert working on this group. However, fortunately there have been some advances in understanding the composition, distribution, identification, and biogeographical affinities of the Canadian fauna through the work of Edward L. Mockford (USA). His handbook for identification of North American Psocoptera is mainly based on studies in the USA (Mockford 1993). However, since species numbers of Psocoptera generally decrease rapidly with latitude, and there seems to be few species that are restricted to the boreal or northwards, the handbook covers Canadian species very well. The handbook divided the North American Psocoptera species into distinct distribution patterns, whose corresponding geographic areas extended into Canada to various degrees, as well as listed introduced species. The biogeographic analysis was further developed in Mockford (2012) who discussed modes of dispersal, which is relevant to understanding the Canadian fauna as part of the North American and worldwide fauna. The website http://Psocodea.SpeciesFile.org provides much information on Psocodea: 'Psocoptera', although it is not very specific for the Canadian fauna.

Mockford (1979) reported 72 known species from Canada and estimated that an additional 31 species remained to be discovered or described from the country, thus predicting a total fauna of about 103 species. Lienhard (2016) found that the world catalogue by Lienhard and Smithers (2002) contained references to 83 species reported from Canada. However, the report of *Blastopsocus semistriatus* (Walsh) in Mockford (2002) had gone unnoticed since it was published too late to be included in the catalogue. The number of Canadian Psocoptera species known by 2016 was therefore 84.

I collected more than 4000 specimens of Psocoptera during two months in Canada in 1993, mainly from British Columbia and Ontario with a few samples from Alberta and Yukon. The material was identified by me, with more difficult cases confirmed or corrected by Edward Mockford. Although the records were not published,

Table 1. Census of Psocoptera in Canada.

Taxon[1]	No. species reported in Mockford (1979)	No. species currently known from Canada[2]	No. BINs[3] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[4]	Information sources
Suborder Trogiomorpha						
Lepidopsocidae	2	3	3	1	Pacific Maritime, Mixedwood Plains, Boreal Shield, Atlantic Maritime	Lienhard 2016; BOLD[5]
Trogiidae	3	4 (2)	6	2	outdoor spp.: Pacific Maritime, Western Interior Basin, Mixedwood Plains, Atlantic Maritime; some domiciliary	Lienhard 2016; Anonby unpubl. data
Psyllipsocidae	0	2 (2)	1	0	domiciliary. Very few records.	Anonby unpubl. data; BOLD
Suborder Troctomorpha						
Liposcelididae	2	6 (1)	15	9	outdoor spp: Western Interior Basin, Boreal Plains, Mixedwood Plains, Boreal Shield, Atlantic Maritime; some domiciliary	Lienhard 1998, 2016; Anonby unpubl. data
Suborder Psocomorpha						
Epipsocidae	2	2	5	2	Montane Cordillera, Boreal Shield, Mixedwood Plains, Atlantic Maritime	Lienhard 2016
Caeciliusidae	13	14	19	8	probably all ecozones	Mockford 1999, Lienhard 2016; Anonby unpubl. data; BOLD
Stenopsocidae	0	1 (1)	2	1	Pacific Maritime, Western Interior Basin, Montane Cordillera, Mixedwood Plains, Atlantic Maritime	Lienhard 2016
Amphipsocidae	1	1	1	0	southern, but reaching boreal ecozones.	Mockford 1993, Lienhard 2016
Dasydemellidae[6]	1	1	2	1	Boreal Shield and all ecozones south of boreal, except Prairies.	Mockford 1993, Lienhard 2016
Lachesillidae	11	16 (1)	27	13	probably all ecozones	Lienhard 2016; Anonby unpubl. data; BOLD
Ectopsocidae	2	5 (1)	6	1	Pacific Maritime, Mixedwood Plains, Atlantic Maritime	Lienhard 2016; Anonby unpubl. data; BOLD
Peripsocidae	5	6 (1)	7	2	Boreal Plains, Boreal Shield and all ecozones south of boreal	Lienhard 2016
Trichopsocidae	0	1 (1)	1	0	Pacific Maritime	BOLD
Philotarsidae	2	4	5	1	Pacific Maritime, Western Interior Basin, Montane Cordillera, Mixedwood Plains, Atlantic Maritime	Lienhard 2016; BOLD
Elipsocidae	3	8 (4)	11	5	Pacific Maritime, Western Interior Basin, Montane Cordillera, Mixedwood Plains, Atlantic Maritime	Lienhard 2016; BOLD
Mesopsocidae	2	3 (1)	6	2	probably all ecozones except Arctic	Lienhard 2016
Psocidae	22	29 (2)	41	18	probably all ecozones except Arctic	Lienhard 2016; Anonby unpubl. data; BOLD
Myopsocidae	1	2	3	1	Mixedwood Plains, Atlantic Maritime	Lienhard 2016
Total	**72**	**108 (17)**	**162**	**67**		

[1]Classification follows Lienhard and Smithers (2002) but infraorders are not indicated. [2]Numbers in parentheses represent the number of non-native species (according to Mockford 1993) included in the total. [3]Barcode Index Number, as defined in Ratnasingham and Hebert (2013). [4]See figure 1 in Langor (2019) for a map of ecozones. [5]Barcode of Life Data Systems database (www.boldsystems.org). [6]Dasydemellidae was split off from Amphipsocidae by Mockford (1993).

this collection added 12 additional described species to the national checklist, not counting an *Anomopsocus* sp. from the Montane Cordillera of British Columbia that may represent a new species.

The Barcode of Life Data System database (BOLD) (Ratnasingham and Hebert 2007) contains more than 14,000 DNA barcodes for specimens of Psocoptera from Canada. Among the 162 BINs represented by Canadian specimens, there are another 12 named species that represent new Canadian records of described species. Thus, the number of currently known species of Canadian Psocoptera is 108, an increase of 50% since 1979 (Table 1).

Although a large number of Canadian specimens have been barcoded, there are still 52 recorded species that have not yet been sampled genetically. Furthermore, some of the barcoded Canadian material has not yet been identified to species, and in some cases identification is incorrect, so it is possible that once these identifications are confirmed or corrected, additional known Canadian species will have associated BINs. The estimates of yet-undocumented species in Canada were calculated based on available number of BINs not yet assigned to Canadian species and consideration of the number of species (21) present in adjacent states of the USA but still not found in Canada but likely to be there. Undocumented species will likely include unidentified described species and undescribed taxa (including cryptic species). Using an approach that recognizes the likelihood that not every BIN represents a unique species, that species may share BINs, and that not every species in Canada has been barcoded, it is conservatively estimated that another 67 species occur in Canada, representing 38% of the total anticipated fauna (Table 1).

In general, the Psocoptera fauna of Canada is not well sampled so that even modest inventory effort could result in new jurisdictional records. New species remain to be discovered and described in all ecozones. New taxa may sometimes be found in places where they are not expected, and where there are not many insects at all, such as in caves and other underground habitats. The Arctic ecozone should not be forgotten, even though the number of species may be very low. Odd-looking, winged Psocoptera have been found on barren rocks in mountains north of the tree line in Norway (J Anonby unpubl. data), so it is likely that sampling various habitats in the vast northern parts of Canada will reveal new species which are rare or absent farther south. Continued barcoding efforts will help identify cryptic species, elucidate intraspecific genetic diversity, and help detect rare and relict species that may require conservation measures as well as non-native species that may be threatening natural ecosystems. The distinction between native and introduced species may be particularly demanding in Psocoptera, given regular long-distance dispersal in many species.

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REVIEW ARTICLE

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Phthiraptera of Canada

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Abstract

There are approximately 463 species of parasitic lice recorded in Canada, in three suborders: Amblycera, six families; Ischnocera, two families; Anoplura, eight families. At least an additional 361 species may eventually be recorded based on presence of suitable hosts and proximity to known distributions. Approximately 41 species are introduced non-native species. Only about 54% of the expected chewing louse fauna has been recorded, and considerable collecting effort is needed, especially for lice infesting passerine birds, shorebirds, and seabirds. The sucking louse fauna is well known, with approximately 88% of the expected fauna recorded. Investigations into ecology of lice and the nature of relationships with their hosts are badly needed. Barcode Index Numbers are available for only 13 species of parasitic lice in Canada.

Keywords

biodiversity assessment, Biota of Canada, lice, Phthiraptera

Lice are ubiquitous, obligate external parasites of birds and mammals. At one time, they were treated as two separate orders (see discussion in Palma and Barker 1996), the Mallophaga (chewing lice, parasites of birds and mammals) and the Anoplura (sucking lice, parasites of mammals). They have been consolidated within the order Phthiraptera, divided into four suborders: Anoplura (sucking lice, parasites of mammals), Amblycera, Ischnocera (both chewing lice infesting birds and mammals) and Rhynchophthirina (chewing lice infesting elephants and warthogs, and not known to occur in Canada) (Palma and Barker 1996). Although there is support for combining Psocoptera and

Phthiraptera into one order, Psocodea, based on morphological and molecular evidence (Yoshizawa and Johnson 2010, Trautwein et al. 2012), Phthiraptera as an order for parasitic lice is retained here.

Lice have never received a great deal of attention in Canada, and the fauna, especially chewing lice (Amblycera and Ischnocera), is not well known. Based on the compilation of species by Martin (1979), Galloway and Danks (1990) identified chewing lice as one of two highest priority groups of arthropod ectoparasites that warranted particular investigation, and this situation remains unchanged today. There are several studies where lice were collected locally in general surveys (e.g., Twinn 1935, Judd 1953, Teskey 1960, Thompson 1968) or from specific hosts (e.g., Buscher 1965, Judd 1968, Ballard and Ring 1979, Dick 1981, Colwell et al. 2008, Yunik et al. 2016). In regional initiatives, Spencer (1928, 1939, 1948, 1957) collected intensively in British Columbia, and species lists of chewing lice were compiled for Quebec by Rayner (1932) and Whitehead (1934, 1954) and for Alberta by Brown and Wilk (1944). William Threlfall and his students recorded lice from a number of hosts in Newfoundland (e.g., Andrews and Threlfall 1975, Bourgeois and Threlfall 1981, Eveleigh and Threlfall 1974, Fitzpatrick and Threlfall 1977, Threlfall et al. 1979, Threlfall and Wheeler 1986, Wheeler and Threlfall 1986). Galloway et al. (2014) provided a list of species of chewing list infesting grassland birds in Canada. There are a number of recent studies on lice infesting several species of birds in Manitoba (Galloway 2007, 2012, Galloway and Palma 2008, Galloway and Lamb 2014, 2016). The most comprehensive compilations of species of lice found in Canada are those of Wheeler and Threlfall (1989) for birds, and Kennedy (1986) and Kennedy and Newman (1986) for domestic and terrestrial mammals, respectively.

There are many publications to aid identification of lice in Canada. Kim et al. (1986) provided a well-illustrated manual for the identification of the species of Anoplura of North America. With the checklists for the Anoplura and their mammal hosts by Durden and Musser (1994a, b), it should be possible to identify all of the species known to occur in Canada. Unfortunately, there is no such guide to the identification of chewing lice found on birds; keys to the genera are found in Keirans (1966), Ledger (1980), and Price et al. (2003a), but these keys are specialised and not always well illustrated so it takes a considerable length of time to become sufficiently familiar with the terminology to use the keys effectively. Keys to the species of lice on birds are scattered throughout the primary literature, usually focused on species in individual genera, or on species found on selected hosts. No attempt to summarise these is made here. Earlier checklists for the chewing lice by Emerson (1972a, b, c, d), Price and Graham (1997) and Poole (1997a, b) have been eclipsed by the outstanding checklist of Price et al. (2003a). Nomenclature in this latter checklist is adopted here.

There is considerable disagreement about the application of subspecies names to louse taxa. It is assumed that Martin (1979) did not include subspecies as separate taxa in his totals. I have not attempted to address this issue, and therefore ignore all subspecies for the current biodiversity assessment, even where the evidence for their validity is strongly supported (e.g., in some taxa of *Actornithophilus*, *Quadraceps*, and *Saemundssonia*).

There has been little attention on taxonomy at the molecular level for species of lice collected specifically in Canada, with only 13 Barcode Index Numbers (BINs) in the Barcode of Life Data Systems (BOLD) database (Table 1). Grossi et al. (2014) synonymised two species of *Anatoecus* infesting anseriforms in Canada, based on molecular analysis using sequence data from the COI region of mitochondrial DNA.

In compiling the following data on lice in Canada, certain decisions were made about what species should be included. Because lice are permanent ectoparasites of their hosts, they go wherever their hosts go. During winter, many species of birds are far away on their overwintering grounds, so their lice are no longer present in Canada. Many species of birds disperse from their breeding ranges in Eurasia and the United States, for example, and occur in Canada with varied degrees of frequency, though not necessarily to breed. The current list of the louse fauna includes species on such avian hosts, however infrequently they might actually occur within the geographic boundaries of Canada. Therefore, lice from all native and non-native mammals (Banfield 1974) and birds (Godfrey 1986) known to occur in Canada are cited here, including domestic animals and naturalised non-native birds (e.g., rock pigeon, *Columba livia* Gmelin; European starling, *Sturnus vulgaris* Linnaeus; house sparrow, *Passer domesticus* (Linnaeus)) and mammals (e.g., house mouse, *Mus domesticus*; Norway rat, *Rattus norvegicus* Linnaeus). Not all species of lice known to infest non-native introduced hosts are known to occur currently in Canada (Paterson et al. 1999). Some of those may already be present and undetected and others may be introduced in the future (see Galloway and Palma 2008). There is extensive trade and importation of exotic animals into Canada, and although these animals may pass through strict quarantine, it is possible that their lice may initially escape detection. I have made no attempt to compile the records from these exotic species.

Our knowledge of the louse fauna in Canada has only modestly progressed since 1979 (Martin 1979), especially for chewing lice. Currently 463 species of lice, 41 of which are non-native, are known from Canada, 418 of which are chewing lice and only 45 are sucking lice (Table 1). In comparison, Martin (1979) reported 362 species, 329 and 33 of which were chewing and sucking lice, respectively. Although the exact composition of species included by Martin (1979) is not known, he estimated that only 45% of the chewing louse fauna of Canada had been recorded. I estimate about 54% of the chewing lice fauna to be documented (Table 1). In comparison, the sucking lice fauna was believed to have been 94% documented in 1979 (Martin 1979) and 88% documented today (Table 1), the decrease attributed to the fact that the total fauna is now believed to be larger than anticipated in 1979.

There are many specimens of undescribed species in collections and there are many more awaiting discovery. Kim et al. (1990) estimated the numbers of species of lice in North America by extrapolation from known host/parasite associations. I have refrained from adopting their strategy in this paper. In the case of chewing lice on birds, there are a great many host species, especially among the Passeriformes, for which no lice have been recorded. It is not known whether this is because of insufficient collect-

Table 1. Census of Phthiraptera in Canada.

Taxon[1]	No. species reported in Martin (1979)	No. species currently known from Canada[2]	No. BINs[3] available for Canadian species	Est. no. described but unrecorded species in Canada[4]	General distribution by ecozone[5] and host range	Information sources[6]
Suborder Amblycera						
Menoponidae	100	116 (5)	2	110	all ecozones; birds	Klockenhoff (1984), Martinho Guimarães (1988), Price et al. (2002, 2003a), Price and Dalgleish 2007, Cicchino and González-Acuña (2012), Gustafsson and Olsson (2012); CNCI, WRME
Ricinidae	3	15	1	15	all ecozones but perhaps barren-ground; passerine birds, hummingbirds	Nelson (1972), Price et al. (2003); CNCI, WRME
Laemobothriidae	2	6	0	2	all ecozones; coots, eagles, hawks, falcons	Nelson and Price (1965), Price et al. (2003a); CNCI, WRME
Gyropidae	2	2 (2)	0	1	caviomorph rodents	Price et al. (2003a); CNCI, WRME
Boopiidae	1	1 (1)	0	0	domestic dogs	Price et al. (2003a); CNCI, WRME
Trimenoponidae[7]	1	0	0	0		Price et al. (2003a); CNCI, WRME
Suborder Ischnocera						
Philopteridae	200	250 (17)	6	223	all ecozones; birds	Cicchino (1980), Eichler and Vasjukova (1981), Balát (1982), Mey (1982), Price et al. (2003a, b), Gustafsson and Olsson (2012), Gustafsson and Bush (2017); CNCI, WRME
Trichodectidae	20	31 (7)	1	4	all ecozones; mammals	Hopkins (1960), Lyal (1985), Price et al. (2003a); CNCI, WRME
Suborder Anoplura						
Echinophthiriidae	3	6	0	0	widespread in marine and estuarine habitats; marine mammals	Kim et al. (1986), Durden and Musser (1994a); CNCI, WRME
Enderleinellidae[8]	?	5	0	0	all ecozones; small mammals	Kim et al. (1986), Durden and Musser (1994a); CNCI, WRME
Polyplacidae[8]	?	13 (1)	1	3	all ecozones; small mammals	Kim et al. (1986), Durden and Musser (1994a); CNCI, WRME
Haematopinidae	3	3 (3)	0	1	all ecozones; hoofed mammals, including domestic animals	Kim et al. (1986), Durden and Musser (1994a); CNCI, WRME
Hoplopleuridae[8]	19	7	1	1	all ecozones; small mammals	Kim et al. (1986), Durden and Musser (1994a); CNCI, WRME
Linognathidae	6	9 (5)	0	1	most ecozones; hoofed mammal and canids, including domestic animals	Kim et al. (1986), Durden and Musser (1994a); CNCI, WRME
Pediculidae	1	1	1	0	all ecozones; humans	Kim et al. (1986), Durden and Musser (1994a); CNCI, WRME
Pthiridae	1	1	0	0	all ecozones; humans	Kim et al. (1986), Durden and Musser (1994a); CNCI, WRME
Total	**362**	**463 (41)**	**13**	**361**		

[1]Classsifcation follows that of Price et al. (2003) for chewing lice and Durden and Musser (1994a) for sucking lice. [2]The numbers in parentheses represents the number of non-native species included in the total. [3]Barcode Index Number, as defined in Ratnasingham and Hebert (2013). [4]No attempt was made to include undescribed species that may occur in Canada. [5]See figure 1 in Langor (2019) for a map of ecozones. [6]References are relevant to species described since 1979 and are known or suspected to occur in Canada. WRME – Wallis/Roughley Museum of Entomology, University of Manitoba, Winnipeg, Manitoba; CNCI – Canadian National Collection of Insects, Arachnids, and Nematodes, Ottawa, Ontario. [7]Martin (1979) listed one species of Trimenoponidae in his table. There are no endemic species of this family in Canada. The only record I can find of a trimenoponid in the CNCI, for *Harrisonia uncinata* Ferris, 1922, is from Trinidad. This family is not included in the current list. [8]Martin (1979) presumably included the Enderleinellidae and Polyplacidae as subfamilies of Hoplopleuridae, by inference from his reference to Ferris (1951). Since Martin provided no tally of species included in each subfamily, only his total number of species for Hoplopleuridae is presented here.

ing, or whether these hosts, in fact, are parasitised by few or no species of lice. Until such gaps are addressed and data are produced, extrapolations based on the known fauna may result in artificially inflated estimates of numbers of taxa.

It is likely that there are many undescribed species of lice, especially in some of the hyperdiverse genera, e.g., *Myrsidea*, *Brueelia* (see Valim and Weckstein 2013, Bush et al. 2016, Gustafsson and Bush 2017). Advanced tools used to explore the molecular basis for species separation should also clarify some relationships among species of lice and add to the growing list of new species. As populations of birds and mammals continue to decline and the numbers of threatened and endangered species increase, many of which are hosts for a great diversity of ectosymbionts, including parasitic lice, it is important that the recommendations of Galloway and Danks (1990) not be forgotten. Of course, having a list of species with relevant geographic and host associations is only the first step in understanding the real nature of the complex relationships among ectoparasites and their hosts.

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Hymenoptera of Canada

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Abstract

A summary of the numbers of species of the 83 families of Hymenoptera recorded in Canada is provided. In total, 8757 described species are recorded compared to approximately 6000 in 1979, which is a 46% increase. Of the families recognized in 1979, three have been newly recorded to Canada since the previous survey: Anaxyelidae (Anaxyleoidea), Liopteridae (Cynipoidea), and Mymarommatidae (Mymarommatoidea). More than 18,400 BINs of Canadian Hymenoptera are available in the Barcode of Life Data Systems (Ratnasingham and Hebert 2007) implying that nearly 9650 undescribed or unrecorded species of Hymenoptera may be present in Canada (and more than 10,300 when taking into account additional species that have not been DNA barcoded). The estimated number of unrecorded species is very similar to that of 1979 (10,637 species), but the percentage of the fauna described/recorded has increased from 36% in 1979 to approximately 45% in 2018. Summaries of the state of knowledge of the major groups of Hymenoptera are presented, including brief comments on numbers of species, biology, changes in classification since 1979, and relevant taxonomic references.

Keywords

ants, bees, biodiversity assessment, Biota of Canada, DNA barcodes, Hymenoptera, survey, wasps

Introduction

Hymenoptera constitutes one of the most speciose orders in Canada and the world (Forbes et al. 2018). During the last assessment of this order in Canada (Masner et al. 1979), 6028 species were reported, although the approximately 80 species in the family Eurytomidae were inadvertently omitted and the numbers of species of Platygastroidea, Ceraphronoidea, Bethylidae, Cynipoidea and Pompilidae were overestimated as it appears that undescribed species were included. Thus, the known richness in 1979 was approximately 6000 species. The most comprehensive faunal inventory of Hymenoptera in Canada is the *Catalog of the Hymenoptera in America North of Mexico* (Krombein et al. 1979) which listed general distributions of species up to 1972 to 1976 (the cut-off date depending on the superfamily). No complete distributional survey of the species of Hymenoptera in North America (or Canada) has followed, although the species lists and distributions on which the analysis in this manuscript is based will be published in a forthcoming series of checklists of the Hymenoptera of Canada, Alaska, and Greenland (A Bennett unpubl. data). Nonetheless, a tremendous amount of data has been produced since 1979 on the taxonomy, nomenclature, and distribution of particular groups of Hymenoptera, including the presence of species in Canada. Some of the most important sources are noted in the respective sections on major taxa (see below as well as in Table 1). In some instances in which major references were not included in Masner et al. (1979), these references have also been included in Table 1.

The survey of Masner et al. (1979) gave estimates on the number of undescribed or unrecorded species in Canada, with the caveat "Such estimates are especially difficult (because so many families of Hymenoptera are inadequately known)…" The same caveat applies to the current survey; however, the use of Barcode Index Numbers (BINs) (Ratnasingham and Hebert 2013) based on 2% or greater sequence divergence of DNA barcodes in the Barcode of Life Data System (BOLD) provides us with new tools to help estimate hitherto unrecorded species diversity for some groups. For the purposes of this assessment, rather than add a somewhat subjective value for each family, the numbers of unrecorded species for most families were calculated based on the number of known BINs minus the number of described recorded species. This method is used for all families except those for which ongoing revisionary studies or faunal surveys have indicated that the number of BINs is not a good estimate of the total number of unrecorded species in Canada (these values noted in Table 1 with an asterisk). The BIN totals are current as of July 2018, but are likely underestimated for most superfamilies (see discussion at end of Faunal Analysis section).

The distribution of Hymenoptera families across ecozones in Canada (Rankin et al. 2011) is incompletely known. The species data in the checklists on which Table 1 is based were sorted by political unit, not ecozone, and it was not possible to go back and determine precise ecozones based on specimen locality data for all taxa (although this was done for the smaller families). In some cases, such as for the families of sawflies, knowledge of host plant distributions helped us make judgements on the ecozone ranges. For most families, there is no supporting information such as host distributions, habitats, or climatic ranges that can help discern whether range gaps are due to lack of sampling or whether a species is actually absent from an ecozone. Therefore, subjective decisions were made concerning whether to extrapolate the known range to encompass areas where there are sampling gaps. Most large Hymenoptera families span all the southern ecozones of Canada and some of them also range into the Arctic.

The information sources from which the data in Table 1 were taken is not exhaustive but instead contains the most important sources. Additional sources are noted for many taxa in the main body of text. In addition to the literature, specimens of all families in the Canadian National Collection of Insects, Arachnids and Nematodes (CNC), Ottawa were also examined, providing a rich source of data to aid completion of Table 1. Family and superfamily level classification mainly follows Goulet and Huber (1993), except as noted in the footnotes of Table 1.

Overview of Hymenoptera diversity

The current study reports 8757 described species compared to approximately 6000 in 1979 (once omissions and overestimates in Masner et al. (1979) are taken into account). The approximately 2750 new records of Canadian Hymenoptera added since 1979 represent a 46% increase and an average of 71 new records/year. These figures indicate that Hymenoptera is one of the most diverse and relatively least known orders of insects in Canada. Masner et al. (1979) estimated 10,637 undescribed/unrecorded species which, when combined with the 6000 recorded species totalled 16,637 species for Canada. This means that in 1979, approximately 36% of the total estimated species were described/recorded. Currently, we estimate 10,366–10,391 undescribed/unrecorded species (Table 1) in an estimated total fauna of 19,148 species, of which approximately 46% are described/recorded.

Sawflies (previously suborder Symphyta)

All sawflies are herbivorous as larvae, except for members of the superfamily Orussoidea which are parasitoids of larval wood-boring Coleoptera and Hymenoptera (Middlekauff 1983, Goulet 1993). Sawflies occupy a paraphyletic grade at the base of the phylogeny of Hymenoptera, and Xyeloidea is consistently recovered as the sister group to all other Hymenoptera (Sharkey et al. 2012, Peters et al. 2017). Global estimates for species richness range between 8000 and 8300 species (Taeger et al. 2010, Huber 2017). Species of all seven superfamilies of sawflies and 12 of the 14 extant families, except Blasticotomidae and Megalodontesidae, are recorded in Canada. Masner et al. (1979) recorded eleven families in Canada; Anaxyelidae (*Syntexis libocedrii* Rohwer) was subsequently recorded from southern British Columbia (Goulet 1992). Furthermore, Masner et al. (1979) recorded 443 described species of sawflies, whereas the current survey has 710, an increase of 60.3% (Table 1). As in most parts of the world (especially the northern hemisphere), the sawfly fauna of Canada is dominated by the family Tenthredinidae, representing 75% or more of the total species.

Table 1. Census of Hymenoptera in Canada.

Taxon[1]	No. species reported in Masner et al. (1979)	No. species currently known from Canada	No. BINs[2] available for Canadian species	Est. no. undescribed or unrecorded species in Canada[3]	General distribution by ecozone[3A]	Information sources[4]
Sawflies (previously suborder Symphyta)						Smith 1979a, Goulet 1987, Taeger et al. 2010, Blank et al. 2012
Superfamily Anaxyleoidea						
Anaxyelidae	0	1	0	0	Western Interior Basin	Goulet 1992
Superfamily Cephoidea						
Cephidae	16	12	8	0	all except Arctic	Ries 1937, Smith 1986, Smith and Solomon 1989, Smith and Schiff 2005
Superfamily Orussoidea[5]						
Orussidae	3	5	4	0	south of Boreal Cordillera and Taiga ecozones, except Atlantic Maritime	Middlekauff 1983, Skvarla et al. 2015
Superfamily Pamphilioidea[6]						
Pamphiliidae	47	54	33	0	all except Arctic	Middlekauff 1958, 1964, Eidt 1969
Superfamily Siricoidea[5]						
Siricidae	14	20	25	4	all except Arctic	Schiff et al. 2012, Goulet et al. 2015
Xiphydriidae	5	7	3	0	all except Arctic	Smith 1976
Superfamily Tenthredinoidea						
Argidae	14	27	17	0	all except Arctic	Smith 1969a, 1971a, 1989
Cimbicidae	4	8	15	7	southern Arctic and south	Smith 1979a
Diprionidae	22	25	14	0	southern Arctic and south	Ross 1955, Smith 1974
Pergidae	5	3	4	1	Mixedwood Plains, Atlantic Maritime	Smith 2006
Tenthredinidae	300	532	528	200*	all ecozones	Goulet 1986, 1996, Smith 1969b, c, 1971b, 1979b
Superfamily Xyeloidea[6]						
Xyelidae	13	16	11	0	all except Arctic	Burdick 1961, Smith 1977, Smith and Schiff 1998
Total Sawflies	**443**	**710**	**662**	**212***		

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Suborder Apocrita						
Superfamily Ichneumonoidea						
Braconidae	830	1165	3411	2246	all ecozones	Marsh 1979a, b, Wharton et al. 1997, Yu et al. 2016
Ichneumonidae	2001	3037	4748	1705*	all ecozones	Carlson 1979c, Dasch 1979, 1984, 1988, 1992, Townes 1983, Townes et al. 1992, Schwarzfeld 2014, Yu et al. 2016
Total Ichneumonoidea	**2831**	**4202**	**8159**	**3951***		
Superfamily Diaprioidea[7]						
Diapriidae[8]	150	177	760	583	southern Arctic and south	Masner 1991, 1993a, Johnson 1992, Masner and García 2002, Sharkey 2007, Sharkey et al. 2012
Ismaridae[8]	?	8	3	0	south of Arctic and Boreal Cordillera	Masner 1976a
Total Diaprioidea	**150**	**185**	**763**	**583**		
Superfamily Platygastroidea[9]						
Platygastridae[10]	250	160	2287	2127	southern Arctic and south	Masner 1976b, 1983a, b, Townes and Townes 1981, Ritchie and Masner 1983, Johnson 1992, 2018
Superfamily Proctotrupoidea[11]						
Heloridae	2	2	2	0	all except Arctic	Townes 1977b, Johnson 1992
Pelecinidae	1	1	1	0	Boreal Shield, Mixedwood Plains, Atlantic Maritime	Johnson 1992, Johnson and Musetti 1999
Proctotrupidae	60	67	63	0	southern Arctic and south	Townes and Townes 1981, Johnson 1992
Roproniidae	2	2	1	0	Boreal Shield, Mixedwood Plains	Townes 1948, Johnson 1992
Vanhorniidae	1	1	0	0	Boreal Shield, Mixedwood Plains	Townes and Townes 1981, Johnson 1992
Total Proctotrupoidea	**66**	**73**	**67**	**0**		
Superfamily Chalcidoidea						Gibson et al. 1997, Noyes 2017
Aphelinidae	30	37	130	93	all ecozones	Gordh 1979, Rosen and Debach 1979, Schauff et al. 1996, Shirley et al. 2017
Azotidae[12]	?	1	1	0	Mixedwood Plains	Jarvis 1907, Heraty et al. 2013

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Chalcididae	22	37	18	0	southern Arctic and south	Burks 1979d, Halstead 1990,Delvare and Bouček 1992
Encyrtidae	65	102	265	163	all ecozones	Trjapitzin and Gordh 1978a, b, Gordh 1979, Noyes and Woolley 1994
Eucharitidae	10	7	6	0	all except Arctic	Burks 1979h, Heraty 1985, 2002
Eulophidae[13]	173	373	1373	1000	all ecozones	Burks 1979h, Yoshimoto 1983, Peck 1985, Schauff 1991, LaSalle 1994, Triapitsyn and Headrick 1995, Hansson 1987, 1988, 1989, 1994a, b, 1995, 1996a, b
Eupelmidae	14	29	24	0	south of Taiga ecozones	Burks 1979g, Gibson 1989, 1995, 2002, 2010, 2011
Eurytomidae[14]	0	90	107	17	southern Arctic and south	Bugbee 1967, Burks 1979c, Zhang et al. 2017
Leucospidae	1	1	1	0	Pacific Maritime, Western Interior Basin, Prairies, Boreal Shield, Mixedwood Plains, Atlantic Maritime	Bouček 1974, Burks 1979e
Megastigmidae[15]	?	21	2	0	southern Arctic and south	Milliron 1949, Burks 1979c, Janšta et al. 2017
Mymaridae	15	93	369	276	all ecozones	Burks 1979i, Huber and Fidalgo 1988, Huber and Lin 2000, Huber 2004, 2012, Triapitsyn et al. 2007, Triapitsyn 2017
Ormyridae	5	9	11	2	south of Taiga Cordillera and Arctic	Burks 1979b, Hanson 1992
Perilampidae	11	20	25	5	south of Taiga ecozones	Burks 1979b, Darling 1983, 1999, Darling and Miller 1991
Pteromalidae	110	293	697	404	all ecozones	Burks 1979b, Heydon 1989, 1995, Heydon and LaBerge 1988, Darling 1991, Bouček 1993, Gibson and Vikberg 1998, Gibson 2000, 2003, 2009, Gibson and Floate 2001,
Signiphoridae	4	1	7	6	Mixedwood Plains	Gordh 1979, Woolley 1988
Tetracampidae	2	4	4	0	Montane Cordillera, Boreal Shield, Mixedwood Plains, Atlantic Maritime	Yoshimoto 1978, Bouček 1993

Taxon[1]	No. species reported in Masner et al. (1979)	No. species currently known from Canada	No. BINs[2] available for Canadian species	Est. no. undescribed or unrecorded species in Canada[3]	General distribution by ecozone[3A]	Information sources[4]
Torymidae	32	58	148	90	southern Arctic and south	Grissell 1976, 1979, 1995, 2000, Janšta et al. 2017
Trichogrammatidae	6	34	113	79	southern Arctic and south	Burks 1979j, Pinto 1999, 2004
Total Chalcidoidea	**500**	**1210**	**3301**	**2135**		
Superfamily Mymarommatoidea[16]						
Mymarommatidae[16]	0	2	1	0	Boreal Shield, Mixedwood Plains, Atlantic Maritime	Gibson et al. 2007, Huber et al. 2008
Superfamily Ceraphronoidea						
Ceraphronidae	35	26	275	249	southern Arctic and south	Dessart 1975, Muesebeck 1979, Dessart and Cancemi 1987, Johnson and Musetti 2004
Megaspilidae	35	21	101	80	southern Arctic and south	Muesebeck 1979, Dessart 1981, 1987, Dessart and Cancemi 1987, Johnson and Musetti 2004
Total Ceraphronoidea	**70**	**47**	**376**	**329**		
Superfamily Cynipoidea						
Cynipidae[17]	110	62	133	71	southern Arctic and south	Burks 1979a, Shorthouse and Ritchie 1984, Ritchie 1993, Melika and Abrahamson 2002, Ronquist et al. 2015
Figitidae[18]	36	60	620	560	all ecozones	Burks 1979a, Ferrer-Suay et al. 2012, 2014, Ritchie 1993, Ros-Farré and Pujade-Villar 2009, 2011, 2013
Ibaliidae	4	4	2	0	all except Arctic	Burks 1979a, Liu and Nordlander 1992, 1994, Ritchie 1993
Liopteridae	0	1	0	0	Mixedwood Plains	Burks 1979a, Ritchie 1993, Liu et al. 2007
Total Cynipoidea	**150**	**127**	**755**	**631**		
Superfamily Evanioidea						
Aulacidae	17	18	6	0	southern Arctic and south	Townes 1950, Carlson 1979a, Smith 2001, Deans et al. 2018
Evaniidae	4	4	2	0	Mixedwood Plains	Townes 1949b, Carlson 1979a, Deans 2005, Deans et al. 2018
Gasteruptiidae	10	8	8	0	all except Arctic	Townes 1950, Deans et al. 2018
Total Evanioidea	**31**	**30**	**16**	**0**		

Taxon[1]	No. species reported in Masner et al. (1979)	No. species currently known from Canada	No. BINs[2] available for Canadian species	Est. no. undescribed or unrecorded species in Canada[3]	General distribution by ecozone[3A]	Information sources[4]
Superfamily Stephanoidea						
Stephanidae[19]	2	2	0	0	Pacific Maritime, Western Interior Basin, Mixedwood Plains	Townes 1949a, Carlson 1979d, van Achterberg 2002, Aguiar 2004
Superfamily Trigonaloidea						
Trigonalidae[20]	4	4	4	0	Pacific Maritime, Boreal Shield, Mixedwood Plains, Atlantic Maritime	Townes 1956, Carlson 1979b, Carmean 1995, Carmean and Kimsey 1998
Aculeata						
Superfamily Chrysidoidea[21]						
Bethylidae	35	27	83	56	all except Arctic	Evans 1978, Krombein 1979a,
Chrysididae[22]	33	84	101	17	all except Arctic	Krombein 1979a, Bohart and Kimsey 1982, Kimsey and Bohart 1991
Dryinidae	35	50	150	100	all except Arctic	Krombein 1979a, Olmi 1984
Embolemidae	2	2	0	0	south of Taiga ecozones	Krombein 1979a, Olmi 1995
Total Chrysidoidea[21]	**105**	**163**	**334**	**173**		
Superfamily Apoidea						
Apoidea: Apiformes						Hurd 1979, Sheffield et al. 2017
Andrenidae	250	182	153	20–40*	southern Arctic and south	Bouseman and LaBerge 1979, LaBerge 1969, 1973, 1977, 1980, 1986, 1987, 1989, LaBerge and Bouseman 1970, LaBerge and Ribble 1972, 1975, Donovan 1977, Ribble 1968, 1974
Apidae[23]	189	206	213	50*	all ecozones	Cockerell 1903, LaBerge 1956a, b, 1961, Mitchell 1962, Daly 1973, Rightmyer 2008, Williams et al. 2014
Colletidae	45	54	50	5–10*	all ecozones	Stephen 1954, Mitchell 1960, Snelling 1966a, b, 1970
Halictidae	110	200	184	15*	all ecozones	Mitchell 1960, Roberts 1972, 1973, McGinley 1986, Gibbs 2010, Dumesh and Sheffield 2012, Gibbs et al. 2013, Heron and Sheffield 2015

Taxon[1]	No. species reported in Masner et al. (1979)	No. species currently known from Canada	No. BINs[2] available for Canadian species	Est. no. undescribed or unrecorded species in Canada[3]	General distribution by ecozone[3A]	Information sources[4]
Megachilidae	150	210	209	20*	All ecozones	Sandhouse 1939; Michener 1938a, b, c, 1939, 1947; Timberlake 1943; Mitchell 1962; Rightmyer et al. 2010; Sheffield et al. 2011; Gonzalez and Griswold 2013
Melittidae	2	3	3	0	Montane Cordillera, Prairies, Mixedwood Plains, Atlantic Maritime	Michez and Patiny 2005, Michez and Eardley 2007, Payette 2013, Sheffield and Heron 2018
Total Apiformes	**746**	**855**	**812**	**110–135***		
Apoidea: Spheciformes						Bohart and Menke 1976, Krombein 1979d, Pulawski 2018, Sann et al. 2018
Ammoplanidae[24]	?	5	4	0	Western Interior Basin, Prairies, Mixedwood Plains	Smith 2008, 2009
Ampulicidae[24]	?	2	0	0	Boreal Shield, Mixedwood Plains	Kohl 1893, Rohwer 1917, Bradley 1934, Buck 2004
Astatidae[24]	?	19	12	0	southern Arctic and south	Parker 1962, 1969, 1972, Steiner 1973, Finnamore 1982, 1997, Buck 2004, Ratzlaff 2016, Sheffield 2017
Bembicidae[24]	?	81	56	0	southern Arctic and south	Parker 1917, Bradley 1920, Bohart and Horning 1971, Finnamore 1982
Crabronidae s. str.[24]	?	181	127	0	southern Arctic and south	Finnamore 1982, 1997, Bohart 1976, Leclercq 2000, 2006, 2008, 2012
Mellinidae[24]	?	2	2	0	Prairies, Mixedwood Plains	Strickland 1947, Finnamore 1982, Buck 2004
Pemphredonidae[24]	?	53	58	0	southern Arctic and south	Strickland 1947, Finnamore 1982, Buck 2004
Philanthidae[24]	?	56	26	0	southern Arctic and south	Scullen 1965, 1968, Bohart 1966, Bohart and Grissell 1975
Psenidae[24]	?	34	27	7	southern Arctic and south	Finnamore 1980, 1982, 1983, Buck 2004, Ratzlaff 2016
Sphecidae	225	64	50	0	southern Arctic and south	Menke 1965
Total Spheciformes	**225**	**497**	**362**	**7**		
Total Apoidea	**971**	**1352**	**1174**	**117–142***		

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Vespoidea s. lat.[25]						
Superfamily Formicoidea						
Formicidae	139	212	302	90	southern Arctic and south	Francoeur 1997, Glasier and Acorn 2014, Glasier et al. 2013, 2016, Canadian Endangered Species Conservation Council 2016, AntWeb 2018, Bolton 2018; J Heron pers. comm.
Superfamily Pompiloidea[26]						
Mutillidae[27]	30	26	13	0	south of Boreal Cordillera and Taiga ecozones except Pacific Maritime	Krombein 1979b, Pitts 2007, Williams et al. 2012, Brothers and Lelej 2017
Pompilidae	150	107	107	0	southern Arctic and south	Evans 1950, 1951a, b, Townes 1957, Krombein 1979c, Wasbauer and Kimsey 1985, Finnamore 1997, Paiero et al. 2010
Sapygidae	6	7	9	2	all except Arctic	Krombein 1979b, Kurzenko 1996
Superfamily Scolioidea[28]						
Scoliidae	2	4	2	0	Western Interior Basin, Mixedwood Plains	Krombein 1979b, MacKay 1987
Superfamily Tiphioidea[26]						
Sierolomorphidae	1	2	4	2	Pacific Maritime, Boreal Cordillera, Boreal Plains, Prairies Mixedwood Plains	Evans 1961, Krombein 1979b, Finnamore 1997, Buck et al. 2005, Lelej and Mokrousov 2015
Tiphiidae[29]	25	31	13	0	south of Boreal Cordillera and Taiga ecozones	Allen 1966, 1968, 1971, Krombein 1979b, Kimsey and Wasbauer 2006
Superfamily Thynnoidea[26]						
Chyphotidae[30]	?	1	0	4*	Western Interior Basin, Prairies	Mickel 1967, Krombein 1979b
Thynnidae[29]	?	3	3	2*	south of Taiga ecozones except Pacific Maritime	Pate 1947, Krombein 1979b, Kimsey 2009

Taxon[1]	No. species reported in Masner et al. (1979)	No. species currently known from Canada	No. BINs[2] available for Canadian species	Est. no. undescribed or unrecorded species in Canada[3]	General distribution by ecozone[3A]	Information sources[4]
Superfamily Vespoidea s. str.						
Rhopalosomatidae	2	1	0	2*	Mixedwood Plains	Townes 1977a, Lohrmann et al. 2012
Vespidae	100	96	102	6	southern Arctic and south	MacLachlan 1980, Buck et al. 2008, Buck et al. 2012, Kimsey and Carpenter 2012, Canadian Endangered Species Conservation Council 2016, R Longair pers. comm.
Total Vespoidea s. lat.[25]	**455**	**490**	**555**	**108**		
Total Aculeata	**1531**	**2005**	**2063**	**398–423**		
Total Hymenoptera	**6028**	**8757**	**18,454**	**10,366–10,391**		

[1]Classification mostly follows Goulet and Huber (1993), except Cynipoidea follows Ronquist (1999), Vespoidea s. lat. follows Pilgrim et al. (2008), except for Myrmosidae which is now considered part of Mutillidae (Brothers and Lelej 2017), Diaprioidea follows Sharkey (2007), Platygastroidea follows Sharkey et al. (2012), Chalcidoidea follows Heraty et al. (2013) and Janšta et al. (2017) and "Spheciformes" follows Sann et al. (2018). [2]Barcode Index Number, as defined in Ratnasingham and Hebert (2013). [3]Undescribed/unrecorded species numbers calculated using number of BINs minus recorded species except for families marked with an asterisk (*) for which additional taxonomic and/or faunal information was available to modify estimate. [3A]See figure 1 in Langor (2019) for a map of ecozones. [4]References listed for taxa above the family level are major works such as catalogues, distributional checklists, revisions and online taxonomic resources that cover multiple families within the higher taxon (usually all families). References in family rows are generally species-level revisions, checklists or catalogues of entire families, subfamilies, tribes or genera including most or all species recorded in Canada at the time of their publication. [5]Orussoidea (Orussidae) part of Siricoidea in Masner et al. (1979). [6]Pamphilioidea called Megalodontoidea in Masner et al. (1979) and including Xyeloidea (Xyelidae). [7]Diaprioidea of current study equivalent to Diapriidae of Masner et al. (1979). [8]Diapriidae of Masner et al. (1979) also included Ismaridae of current study. [9]Platygastroidea of current study equivalent to Scelionidae + Platygastridae of Masner et al. (1979). [10]Platygastridae of current study includes Scelionidae totals of Masner et al. (1979) (synonymized by Sharkey 2007). [11]Proctotrupoidea of Masner et al. (1979) included Platygastroidea and Diaprioidea of current study, but omitted Pelecinidae. [12]Azotidae previously part of Aphelinidae (Heraty et al. 2013), but not known from Canada in 1979 (Gordh 1979). [13]Eulophidae of current study includes Elasmidae totals of Masner et al. (1979) (synonymized by Gauthier et al. 2000). [14]Eurytomidae mistakenly omitted from Masner et al. (1979). About 80 species were recorded from Canada at the time. [15]Megastigmidae previously part of Torymidae (Janšta et al. 2017). Number of species recorded in Torymidae by Masner et al. (1979) uncertain. [16]Mymarommatidae (= Mymarommidae) included in Chalcidoidea by Masner et al. (1979). [17]Unclear what taxa were included in Cynipidae by Masner et al. (1979), but likely part of current Figitidae. [18]Eucoilidae and Alloxystidae recognized by Masner et al. (1979), but included in Figitidae in totals of current study. [19]Stephanidae included in Ichneumonoidea in Masner et al. (1979). [20]Trigonalidae included in Chrysidoidea (= Bethyloidea) in Masner et al. (1979). [21]Chrydidoidea referred to as Bethyloidea in Masner et al. (1979). [22]Chrysididae of current volume includes Chrysididae and Cleptidae totals of Masner et al. (1979). [23]Apidae of current volume includes Apidae, Anthophoridae and Xylocopidae of Masner et al. (1979). [24]All families in "Spheciformes" included in Sphecidae in Masner et al. (1979) (uncertain how many of each family were recorded). [25]Vespoidea s. lat. value for Masner et al. (1979) equal to sum of their Scolioidea, Formicoidea and Vespoidea. Species totals for superfamilies in Vespoidea s. lat. not calculated because of major differences in composition between current study and Masner et al. (1979). [26]Superfamily not recognized in Masner et al. (1979). See text for discussion of how classification differs from Pilgrim et al. (2008). [27]Mutillidae total from Masner et al. (1979) may include some species that are now placed in Chyphotidae. Also includes Myrmosidae of Pilgrim et al. (2008), now considered part of Mutillidae (Brothers and Lelej 2017). See text for how these taxa are related. [28]Scolioidea of Masner et al. (1979) includes Mutillidae, Rhopalosomatidae, Sapygidae, Scoliidae, Sierolomorphidae and Tiphiidae. [29]Tiphiidae total from Masner et al. (1979) may include some species that are now placed in Thynnidae. See text for how these taxa are related. [30]Masner et al. (1979) likely included Chyphotidae in Mutillidae totals.

Masner et al. (1979) estimated only 131 undescribed/unrecorded sawfly species, which was a significant underestimate as more than twice as many species (267) have been subsequently recorded from Canada. This large increase was a result of extensive work by many authors, most notably David R. Smith, who authored the Nearctic catalogue (Smith 1979a) and many revisions (e.g., Smith 1979b, 1989), and Henri Goulet (e.g., Goulet 1986, 1996). In addition, extensive collecting and faunal surveys (e.g., Goulet 1987) have contributed to our knowledge. A catalogue of world species (Taeger et al. 2010) and an accompanying searchable, electronic taxonomic database ECatSym (Blank et al. 2012) is also a rich source of information about all sawflies, including the Canadian fauna.

Examining DNA barcode data alone, it may appear that most of the diversity of Canadian sawflies has now been discovered as the number of BINs is lower than recorded species in all families except Siricidae, Cimbicidae, and Pergidae, all of which have fewer than 30 described species. This is likely misleading as surveys of Tenthredinidae in northern Europe, which has been surveyed much more intensively than northern North America, reveal a much greater diversity than northern Canada (e.g., Prous et al. 2017), suggesting that the Canadian fauna includes many more species than currently known. Ongoing revisions indicate that at least 200 undescribed species of Tenthredinidae are present in Canada, mostly in the subfamilies Nematinae and Tenthredininae (H Goulet pers. comm.) which emphasizes the fact that more collecting and DNA barcoding of Canadian sawflies is required.

Apocrita

Ichneumonoidea

In terms of described species, Ichneumonoidea is the largest superfamily of Hymenoptera, both in Canada (4202 species) (Table 1) and the world (47,177 species) (Yu et al. 2016). It is also the largest superfamily of insects in Canada comprising an impressive 10.8% of the 38,925 described insect species recorded (Langor 2019). There are two families, Ichneumonidae and Braconidae. Almost all ichneumonoids are parasitoids of other insects (Wahl and Sharkey 1993), the exceptions being a few genera that are parasitoids of spiders or prey on arachnid eggs (Townes 1969) and a few that are known to be phytophagous (e.g., Marsh 1991). The electronic catalogue of Ichneumonoidea (Yu et al. 2016) is an invaluable resource for accessing knowledge of the superfamily, including taxonomy, nomenclature, distribution, biology, references, etc.

Braconidae is the second largest family of Hymenoptera in Canada (1165 described species recorded; Table 1) and the world (21,221 described species; Yu et al. 2016). The current total is a 40.4% increase over the 830 species reported by Masner et al. (1979). Masner et al. (1979) estimated that there were 3200 undescribed/unrecorded braconid species in Canada. The number of BINs of Braconidae recorded in Canada in BOLD is 3411 (2246 more BINs than the number of described species recorded in Canada). Therefore, even though the estimate of undescribed Canadian braconid species by Masner et al. (1979) may appear to be a slight overestimate, studies on the percentage of undescribed microgastrine braconids in Canada and elsewhere in the world (e.g., Rodriguez et al. 2013) indicate that the number of undescribed braconids in Masner et al. (1979) may be accurate or even conservative. Good progress has been made on Canadian Braconidae since Masner et al. (1979) including a catalogue of all Nearctic species (Marsh 1979a, b) and keys to all New World genera (Wharton et al. 1997).

There are 25,285 described species of Ichneumonidae worldwide (Yu et al. 2016) and the actual fauna is estimated to be greater than 100,000 species (Gauld et al. 2002). Based on described, recorded species, Ichneumonidae is the most speciose family in Canada with 3037 species (Table 1) which represents approximately 35% of all described species of Hymenoptera recorded in Canada and 7.8% of all described species of insects (Langor 2019). The number of described, recorded species of ichneumonids reported in Masner et al. (1979) was 2001, including one species of "Pachylommatidae", now called Hybrizontinae, that is considered part of Ichneumonidae (Sharkey and Wahl 1992). Since 1979, the number of described species of ichneumonids recorded in Canada has increased by 1036 (51.8%). Most of this increase was because of major revisions of Nearctic taxa (e.g., Dasch 1979, 1984, 1988, 1992, Townes 1983, Townes et al. 1992) as well as increased distributional knowledge via faunal surveys (e.g., Schwarzfeld 2014).

Masner et al. (1979) estimated that there were 5000 undescribed or unrecorded species of ichneumonids in Canada, but no discussion was provided to justify the estimate. There are 4748 known BINs for Canadian Ichneumonidae, ~1700 more BINs than recorded species (Table 1). Comparing the number of BINs to the estimated total number of species from Masner et al. (1979) (2001 known + 5000 anticipated = 7001), the current study has a shortfall of 2253 species. Whether an additional 2253 species of Canadian Ichneumonidae await discovery is unclear, but certainly, considering the very high diversity of Ichneumonidae in northern latitudes (e.g., 97 morphospecies recorded from Ellesmere Island, Nunavut; Timms et al. 2013), it is likely that many more species of Ichneumonidae remain to be collected and DNA barcoded in the less well-sampled regions of Canada (especially the North).

Diaprioidea

Historically, Diaprioidea was grouped within Proctotrupoidea (e.g., Masner et al. 1979, Muesebeck 1979); however, Sharkey (2007) found that Proctotrupoidea was polyphyletic and therefore removed Diapriidae and related families to a new superfamily. Diaprioidea includes four families (Sharkey 2007, Sharkey et al. 2012) of which Diapriidae is the most speciose, with 2048 species reported by Huber (2017), the other three families accounting for an additional 61 species. Two families are known in Canada, Diapriidae and Ismaridae (Table 1). Masner et al. (1979) considered Ismaridae part of Diapriidae, but the phylogenetic analysis of Sharkey et al. (2012) raised the subfamily Ismarinae to family status within Diaprioidea. Almost all Diaprioidea, for which the biology is known, are parasitoids of Diptera, although Ismaridae are hyperparasitoids of Dryinidae (Hymenoptera) parasitizing leafhoppers (Hemiptera: Cicadellidae) (Masner 1993a).

Masner et al. (1979) recorded 150 described species of Diapriidae (including Ismaridae) in Canada. The current study records 177 described species of Diapriidae and eight Ismaridae, which together is a 23.3% increase from 1979. The ratio of BINs to described species is 4.1 (763 BINs) implying that many undescribed/unrecorded species of diaprioids occur in Canada. Despite the relatively poor state of knowledge of Diaprioidea in Canada, there are some valuable resources on the group including keys to the New World genera of Diapriinae (Masner and García 2002) and a world catalogue with species distributions by biogeographical region (Johnson 1992). All information on Diapriidae has been updated and placed by N Johnson and colleagues on Hymenoptera Online (various contributors 2018), including additional distributional information and relevant literature. Masner (1976a) revised the world species of Ismaridae.

Platygastroidea

Masner et al. (1979) and Muesebeck (1979) classified Platygastridae and Scelionidae within Proctotrupoidea, but later classifications (e.g., Masner and Huggert 1989) separated these two families from Proctotrupoidea to form Platygastroidea. Sharkey (2007) synonymized the two on the basis of paraphyly of Scelionidae with respect to Platygastridae. Almost all known Platygastroidea are egg parasitoids of a variety of insect orders as well as of spiders (Masner 1993b). Huber (2017) indicated that there are 5385 known species worldwide.

Masner et al. (1979) recorded 150 described species of Scelionidae and 100 Platygastridae in Canada. The current study records only 160 described species combined, which means that the numbers reported by Masner et al. (1979) included undescribed species. Masner et al. (1979) estimated that there may be up to 300 unrecorded species of Platygastroidea in Canada, i.e., more unrecorded species than recorded. The ratio of BINs to recorded species in the current study supports the fact that Platygastroidea are very poorly known in Canada and, in fact, this value (14.3) is the highest of any Hymenoptera superfamily in Canada (2287 BINs). Based on this, there may be more than 2,100 undescribed/unrecorded species of Platygastroidea in Canada, making it the third largest superfamily of Hymenoptera in the country (after Ichneumonoidea and Chalcidoidea), and easily the most poorly known. Despite the apparent dearth of knowledge of the group, there have been many studies of Platygastroidea since 1979, such as a world revision of Platygastridae s. str. (Townes and Townes 1981), the world catalogue of Johnson (1992) that included species in the former Scelionidae (but not Platygastridae s. str.), keys to world genera of Scelioninae (Masner 1976b) and many revisions of Nearctic genera (e.g., Masner 1983a, b, Ritchie and Masner 1983). All information on Platygastroidea is available on an extensive website devoted to the systematics of the superfamily (Johnson 2018) and much of this knowledge has also been uploaded into Hymenoptera Online (various contributors 2018).

Proctotrupoidea

Proctotrupoidea is comprised of eight families (Huber 2017), of which five are present in Canada (Table 1). Huber (2017) recorded 448 described species worldwide. Masner et al. (1979) placed Pelecinidae within its own superfamily but it is now classified within Proctotrupoidea (Johnson and Musetti 1999). Conversely, Masner et al. (1979) included Platygastridae, Scelionidae, and Diapriidae in Proctotrupoidea but the first two families now comprise Platygastroidea (Masner 1993b) and the latter is placed in Diaprioidea (Sharkey 2007).

All proctotrupoids are parasitoids. Species of Proctotrupidae have been reared from Coleoptera and Diptera (Masner 1993a). Pelecinidae parasitizes Scarabaeidae (Coleoptera) (Johnson and Musetti 1999), Heloridae has been reared from Chrysopidae (Neuroptera) (Townes 1977b), Roproniidae from a sawfly (Masner 1993a), and Vanhorniidae from Eucnemidae (Coleoptera) (Deyrup 1985).

There are 73 described species of Proctotrupoidea in Canada, compared to 66 reported in Masner et al. (1979) (Table 1). Proctotrupidae is the largest family with 67 species and the other four families have one or two species each. The ratio of BINs to described species for the superfamily is 0.92. The world catalogue by Johnson (1992) summarizes the species and regional distributions, and additional references on the superfamily can be found on Hymenoptera Online (various contributors 2018).

Chalcidoidea and Mymarommatoidea

Chalcidoidea is comprised of 23 extant families (Heraty et al. 2013, Janšta et al. 2017), of which 18 are present in Canada (Table 1). Masner et al. (1979) included Mymarommatidae (as Mymarommidae) as a family within Chalcidoidea, but Gibson (1986) removed Mymarommatidae from Chalcidoidea, and Noyes and Valentine (1989) were the first to treat the taxon as a superfamily. Chalcidoidea have been reared as parasitoids from a wide variety of insect orders as well as some Arachnida and the nematode family Anguinidae, but a few are predators (using more than one host to complete development) and some are phytophagous (Gibson 1993). The biology of Mymarommatoidea is unknown although one has been reared from a bracket fungus and most are collected in shady, moist areas such as deciduous forests (Gibson et al. 2007, Huber et al. 2008).

Chalcidoidea is one of the world's most diverse superfamilies of organisms. More than 22,700 species are described (Huber 2017), but Heraty et al. (2013) estimated that there may be as many as 500,000 species worldwide. Masner et al. (1979) recorded 16 families of Chalcidoidea in Canada (not including Mymarommatidae) but neglected to include Eurytomidae in their treatment. Other differences include Elasmidae (*Elasmus* Westwood), now classified within Eulophidae (Gauthier et al. 2000), Azotidae (*Ablerus* Howard), now classified in its own family instead of within Aphelinidae (Heraty et al. 2013), and Megastigminae removed from Torymidae and classified as Megastigmidae (Janšta et al. 2017). Masner et al. (1979) recorded 500 described species of Chalcidoidea in Canada, whereas the current survey records 1210 (a 142%

increase which is the largest percentage increase of new species records over that time period for any Hymenoptera superfamily in Canada). The great increase in the number of recorded Chalcidoidea is a reflection of the large amount of work that has been done on this group (see Table 1). Chapters in the Nearctic catalogue were provided by Burks 1979b-j, Gordh 1979, and Grissell 1979, including distributional ranges in Canada. A key to the genera of Nearctic Chalcidoidea was published by Gibson et al. (1997). These publications have facilitated biological and faunal distributional studies for many taxa. All of the literature and taxonomic information to date is freely available in an online catalog, Universal Chalcidoidea Database (Noyes 2017). Despite the great amount of progress made on Canadian Chalcidoidea since 1979, the number of BINs (3301) is 2.7 times the number of recorded species and, based on this number, it is estimated that an additional 2135 undescribed/unrecorded species occur in the country (Table 1). The most speciose families in Canada based on BINs are Eulophidae (1373), Pteromalidae (697), and Mymaridae (369).

Mymarommatoids are very small wasps with a body length less than 1 mm (Gibson 1993). Huber (2017) reported ten described species worldwide. In Canada, they are only recorded in the east (Gibson et al. 2007), but they are also known in Montana (Hatten et al. 2010); therefore their range likely spans Canada from west to east. Masner et al. (1979) recorded no described species of Mymarommatidae in Canada, but predicted one unrecorded species to be present. The current survey records two species in Canada (Table 1) and Huber et al. (2008) provided keys to the described Nearctic species. There is one BIN for Mymarommatoidea from Canada in BOLD.

Ceraphronoidea

Ceraphronoidea is comprised of two families, Ceraphronidae and Megaspilidae, and there are 603 described species worldwide (Huber 2017). All ceraphronoids are parasitoids, most usually of Diptera, or hyperparasitoids of Hymenoptera, but they have also been associated with Hemiptera, Thysanoptera, Lepidoptera, Neuroptera and Mecoptera (Masner 1993c). There are 47 recorded Canadian species of Ceraphronoidea (Table 1), but this is one of the most poorly studied groups of Hymenoptera which is reflected in a BIN to recorded species ratio of 8.0 (10.6 for Ceraphronidae and 4.8 for Megaspilidae). This implies that there are over 375 species of Ceraphronoidea in Canada, of which most (329) remain to be described/recorded. Masner et al. (1979) recorded 70 described species in Canada (35 for each family), but this number included undescribed species based on their knowledge of the literature and examination of specimens in the CNC. Muesebeck (1979) provided a catalogue for the Nearctic species with Canadian distributions and Johnson and Musetti (2004) published a world catalog with distributions by region. Dessart and Cancemi (1987) provided keys to genera.

Cynipoidea

Cynipoidea (gall wasps and allies) is another understudied group of Hymenoptera. There are approximately 3200 species described globally (Huber 2017). The biology of the superfamily is diverse, with Cynipidae being mostly phytophagous gall-makers (but also inquilines in galls of other insects), whereas species in other families are parasitoids (e.g., Ibaliidae on siricid and anaxyelid sawflies; eucoiline Figitidae on cyclorrhaphous Diptera) (Ritchie 1993, Ronquist 1999). The current study records 127 described species of Cynipoidea in Canada which is slightly fewer than the total (150) reported in Masner et al. (1979). The number of BINs of Cynipoidea is 755, which, if representative of the total number of species, means that there could be as many as 631 unrecorded species in Canada (Table 1). The BIN to described species ratio is 5.9 showing that Cynipoidea is the third most poorly known superfamily in Canada, after Platygastroidea and Ceraphronoidea.

The classification of the families of Cynipoidea was previously contentious, but appears to have been stabilized with recognition of five families worldwide (Ronquist 1999) of which four are recorded in Canada: Cynipidae, Figitidae (including the former Charipidae, Eucoilidae and Alloxystidae), Ibaliidae and Liopteridae (Ritchie 1993, Ronquist 1999). Liopteridae was not recorded from Canada in Masner et al. (1979), but one specimen (now lost) was collected near Hamilton, Ontario (Liu et al. 2007). There have been a few revisions and reviews since 1979 for Cynipidae (e.g., Melika and Abrahamson 2002, Ronquist et al. 2015). Figitidae is the largest family and has the most gaps in knowledge. Some subfamilies are well-studied, e.g., Aspiceratinae (Ros-Farré and Pujade-Villar 2009, 2011, 2013). A world catalogue is available for Charipinae (Ferrer-Suay et al. 2012) as are keys to Nearctic genera and a species checklist (Menke and Evenhuis 1991). In contrast, other subfamilies are lacking in revisions and literature, especially the diverse Eucoilinae. Up to date nomenclature and literature has been added to Hymenoptera Online (various contributors 2018) but the last Nearctic catalogue with distributional data for the entire superfamily was Burks (1979a).

Evanioidea

Evanioidea (ensign wasps and allies) is a small superfamily with 1130 species globally (Huber 2017) that, for Canada at least, appears to be relatively well-known. This is mainly because the group is mostly tropical and only a few genera and species have ranges that extend to northern latitudes. There are three families, all of which are present in Canada: Aulacidae, Evaniidae (ensign wasps), and Gasteruptiidae. Aulacidae are parasitoids of wood-boring Coleoptera and sawflies, Evaniidae lay their eggs in the oothecae of cockroaches, and Gasteruptiidae have been reared from nests of solitary bees or wasps where they prey on one or more eggs or larvae (Mason 1993). There are 30 described species of Evanioidea in Canada, compared to 31 reported by Masner et al. 1979 (Table 1). The ratio of BINs to recorded species is only 0.53 (16 BINs vs 30 recorded species) which shows that more DNA barcode sampling is required. This is most evident for Evaniidae for which only two Canadian DNA barcodes are present in BOLD, despite four recorded species. Few or no unrecorded Canadian species of Evanioidea are expected. In terms of literature, keys to the Nearctic species are available, for Aulacidae (Townes 1950), Gasteruptiidae (Townes 1950, Smith 1996) and Evaniidae (Townes 1949). Carlson (1979a) provided the Nearctic catalogue for Evanioidea, Deans (2005) updated the nomenclature for Evaniidae, and Smith (2001) published a world catalogue of Aulacidae. Up to date information about Evanioidea is available at Evanioidea Online (Deans et al. 2018).

Stephanoidea

Stephanoidea is a small, mostly tropical group of Hymenoptera comprised of one family, Stephanidae; 342 species are known globally (Huber 2017). They are long, slender insects (body length up to 2 cm) that parasitize wood-boring Coleoptera (Mason 1993). There are two species in Canada (Table 1), the same number reported by Masner et al. (1979). One species is in the west and one in the east. There are keys to the Nearctic species (Townes 1949a) and no additional species are expected in Canada. An updated key to world genera is provided by van Achterberg (2002) and Aguiar (2004) published a world catalog including distributions by country. A summary of literature on the family is found online (Aguiar 2005). Stephanidae was included in Ichneumonoidea by Masner et al. (1979) but this classification is no longer commonly accepted (Aguiar 2005).

Trigonaloidea

Trigonaloidea, comprised of one family, Trigonalidae, lay eggs on leaves which are eaten by caterpillars or sawfly larvae. Except for some extralimital species which are primary parasitoids of pergid sawflies (Raff 1934), eggs of most trigonalid larvae do not continue development following ingestion unless the host is parasitized by an ichneumonoid wasp or tachinid fly or is captured by a vespid wasp (Carmean 1995). Globally there are 92 known species (Huber 2017). There are four species of Trigonalidae recorded in Canada (Table 1), the same number reported by Masner et al. (1979) and also four BINs from Canadian specimens in BOLD. Townes (1956) provided keys to the four Nearctic species. It is unlikely that additional species will be recorded from Canada.

Aculeata

Aculeata is a demonstrably monophyletic group (Branstetter et al. 2017) comprised of the superfamilies Chrysidoidea, Apoidea, and the assemblage of families that previously comprised the Vespoidea (hereafter called Vespoidea s. lat.). Aculeata includes many of the most recognizable groups of Hymenoptera, including the bees, ants, and vespid wasps. There are 2005 described species of Aculeata recorded in Canada which represents 22.9% of all recorded described Hymenoptera species (Table 1). Except for the Chrysidoidea, the group is relatively well-known based on the ratios of BINs to recorded species.

Chrysidoidea

Chrysidoidea includes 6780 species worldwide (Huber 2017) classified into seven families (Gauld and Hanson 1995), of which four are present in Canada (Table 1). They are parasitoids (or occasionally kleptoparasites) of a wide range of insect orders including Coleoptera, Lepidoptera, Hymenoptera, Phasmatodea, Embioptera (for the extralimital Sclerogibbidae), and Hemiptera (Finnamore and Brothers 1993, Gauld and Hanson 1995). Based on molecular data, they are hypothesized to be the sister group to the rest of Aculeata (Heraty et al. 2011, Peters et al. 2017) or a paraphyletic grade of two clusters of families at the base of Aculeata (Branstetter et al. 2017).

There are 163 described species of Chrysidoidea recorded in Canada, compared to 105 reported by Masner et al. (1979), a 55.2% increase. All Nearctic families have been revised since 1979. For Chrysididae (cuckoo wasps), a Nearctic revision was published (Bohart and Kimsey 1982) as well as a world review with species checklists (Kimsey and Bohart 1991). Olmi (1984) published a world revision of Dryinidae, with a supplement (Olmi 1991). The other major family in Canada, Bethylidae, was revised for the Nearctic by Evans (1978), and it appears that the number of described species in Canada reported by Masner et al. (1979) (35) was a slight overestimate of the number of Canadian species currently known (27 based on Evans (1978) and material in the CNC). Finally, Olmi (1995) revised the small family Embolemidae, but his revision did not change the number of species recorded in Canada (two). In terms of undiscovered diversity in Canada, the proportion of BINs to described species is 2.04 for the superfamily, indicating that there may be as many as 173 undescribed/unrecorded species of Chrysidoidea present in Canada, most of which belong to Bethylidae and Dryinidae.

Apoidea

Just under 30,000 described species of Apoidea are known globally (Huber 2017), with approximately two thirds representing the bees (Michener 2007). In total, the number of Apoidea species recorded for Canada has increased by approximately 39% since 1979 (1352 vs 971). Within this superfamily, the Spheciformes grade (Sphecidae sensu Masner et al. 1979) is now regarded as multiple families (Sann et al. 2018). The Crabronidae s. lat. was until recently the largest of the families, with many more than 400 species in Canada. However, the recent splitting of Crabronidae (Sann et al. 2018) resulted in several subfamilies being raised to family level as follows: Astatidae, Bembicidae, Crabronidae s. str. (previously Crabroninae), Mellinidae, Pemphredonidae, Philanthidae, and Psenidae. In addition, the subtribe Ammoplanina (previously in Pemphredoninae) was also raised to family status. Collectively, these eight families are represented by 431 species in 68 genera (Table 1). In addition to the families in the former Crabronidae, the eleven genera of Sphecidae s. str. are represented by 64 species, with a BIN to recorded species ratio of 0.78. Finally, there are two species of Ampulicidae (in two genera) from Canada but neither have been barcoded yet and no other species are expected in Canada (the only other two Nearctic species known are both from the southern United States (Krombein 1979d).

Classification of bees (Apiformes) has also changed since Masner et al. (1979), specifically with the merging of the non-corbiculate apid families Anthophoridae and carpenter bees (i.e., Xylocopidae sensu Masner et al. 1979) with the corbiculate apids (i.e., bumble bees and honey bee) into the single family Apidae (Michener 2000, 2007), resulting in six families of bees in Canada: Andrenidae, Apidae, Colletidae, Halictidae, Megachilidae, and Melittidae. Sheffield et al. (2017) recently summarized the bees of Canada, indicating that there were 855 species, though the number is likely higher when unique BINs without accompanying species-level identification are considered, especially for the poorly studied taxa *Sphecodes* Latreille (Halictidae), *Nomada* Scopoli (Apidae), and *Osmia* Panzer (Megachilidae).

Both Spheciformes and Apiformes are relatively well known; for the former, a global catalogue of species and distributional information, based on published literature, is well-maintained (Pulawski 2018). This resource, in addition to works published since 1979 (e.g., Finnamore 1983, 1997, Buck 2004, Ratzlaff 2016), has increased our knowledge of sphecid wasps (Sphecidae s. lat.), and was used to provide the summaries in Table 1. For Apiformes, Sheffield et al. (2017) provided a recent summary of Canadian species, including information on DNA barcodes, and an online catalogue for species is also available (Sheffield 2018). For bees, many revisions have occurred since Masner et al. (1979), specifically for the Canadian fauna (e.g., Gibbs 2010, Sheffield et al. 2011, Dumesh and Sheffield 2012, Onuferko 2017), or those that have included Canada in their coverage (e.g., Gibbs 2011, Rehan and Sheffield 2011, Gibbs et al. 2013).

Vespoidea s. lat.

Vespoidea s. lat. is comprised of all Aculeata that do not belong to Chrysidoidea or Apoidea (i.e., all superfamilies listed below), and is globally represented by more than 29,000 species (Huber 2017). Historically, the monophyly of the group has been equivocal. The catalogue of Hymenoptera of America North of Mexico (Krombein et al. 1979) divided the group into separate superfamilies, as did the survey of Masner et al. (1979), although these two studies differed slightly in the composition of several superfamilies. Later, morphology-based, cladistic analyses either refuted Vespoidea's monophyly (e.g., Rasnitsyn 1988), or supported it (Brothers and Carpenter 1993). With the introduction of molecular data and a re-evaluation of the way in which characters were divided into states and polarized in earlier morphological studies (e.g., Brothers and Carpenter 1993), a consensus appears to have been reached that Vespoidea is not monophyletic, and alternative classifications have been suggested (e.g., Pilgrim et al. 2008). More recent molecular phylogenetic analyses (Branstetter et al. 2017, Peters et al. 2017) have also refuted the monophyly of Vespoidea but ambiguity still exists about the relationships of the taxa and how they relate to Apoidea, in particular because of differences in taxon choice between analyses and differences in topology correlated with differing phylogenetic methods. Because of this, the classification used here follows the suggested arrangement of Pilgrim et al. (2008) with the exception of Myrmosidae which is considered a subfamily of Mutillidae (Brothers and Lelej 2017). There are 490 described species of Vespoidea s. lat. recorded in Canada.

Formicoidea

Formicidae (the ants) was placed by itself in all molecular studies noted above, either as the sister group of Apoidea (Branstetter et al. 2017, Peters et al. 2017) or, in the preferred topology of Pilgrim et al. (2008), as sister group to Apoidea + Scolioidea. Formicidae is one of the great radiations of Hymenoptera with more than 16,000 described species (AntWeb 2018), but they are relatively poorly represented in Canada with only 212 described species recorded (Canadian Endangered Species Conservation Council 2016, J Heron pers. comm.), compared to 139 reported by Masner et al. (1979), a 52.5% increase (Table 1). In addition to the 2016 report on the conservation status of all Canadian species by province and territory, several regional checklists are available (Francoeur 1997 for the Yukon, Glasier and Acorn 2014 for the grasslands, Glasier et al. 2016 for Saskatchewan) as well as keys to workers of Alberta (Glasier et al. 2013). Our study records 302 BINs for ants (ratio to described species = 1.42), therefore there are likely ca. 90 additional species yet to be recorded in Canada. Considering the relatively good knowledge of ant taxonomy and distributional ranges, especially in northern latitudes, this is somewhat surprising, but it illustrates that even for supposedly well-known groups, our knowledge of the Canadian fauna is not complete. The ant taxonomic community is one of the most well-organized in entomology, with many resources including an online taxonomic and bibliographic catalogue (Bolton 2018) and an online database of specimen records, images and biological information (AntWeb 2018).

Pompiloidea

This group includes the velvet ants (Mutillidae), spider wasps (Pompilidae), and sapygid wasps (Sapygidae). Pompiloidea was not recognized by Masner et al. (1979). Instead, Pompilidae was placed with Vespidae in their Vespoidea s. str., and the other taxa were included in Scolioidea.

All pompiloids are parasitoids: Pompilidae on spiders (Day 1988), or in one case, a Phalangiidae (Opiliones) (Evans 1948); Mutillidae on other Aculeata, but also less commonly on Diptera, Lepidoptera, Coleoptera and Blattodea (Brothers and Finnamore 1993); and Sapygidae on bees and vespid wasps (Krombein 1979b). Some Pompilidae are kleptoparasitoids of other pompilids (Townes 1957).

The majority of Canadian diversity in this superfamily is in Pompilidae, with 107 of the 140 species (Table 1). Masner et al. (1979) listed 150 described species from Canada, but this appears to have been a slight overestimate. Pompilidae is a relatively poorly studied group in North America with only a few Nearctic faunal surveys since 1979 (e.g., Wasbauer and Kimsey 1985 for California, Finnamore 1997 for the Yukon, Sugar et al. 1999 for oak savannahs in southern Ontario). Nearctic identifications rely on the revisions of Evans (1950, 1951a, b) and Townes (1957). The most current Nearctic catalogue is Krombein (1979c), but many taxon names in this work are no longer valid and must be updated with reference to more recent, non-Nearctic catalogues (e.g., Wahis 1986, 2006). The ratio of BINs to recorded species is 1.0; however, as it is the second largest family in the Vespoidea s. lat. and it is relatively poorly studied, there could certainly be undescribed/unrecorded species.

Masner et al. (1979) recorded 30 described species of Mutillidae (including Chyphotidae) in Canada. The current study records 26 mutillids and one chyphotid (the latter now considered part of Thynnoidea). The number of recorded mutillids includes those of the subfamily Myrmosinae. This group was considered its own family by Pilgrim et al. (2008), but was moved back into Mutillidae by Brothers and Lelej (2017). There are only 13 BINs of Mutillidae from Canada on BOLD, and more sampling of this family is required. Mutillidae is a relatively well-studied family in North America with recent revisions of several major taxa (e.g., Pitts 2007, Williams et al. 2012); therefore, there is a good taxonomic foundation for surveying the Canadian fauna. Finally, Masner et al. (1979) recorded six species of Sapygidae and the current study has seven (Table 1), but there are nine BINs, therefore barcoded voucher specimens at Guelph need to be examined to determine which undescribed/unrecorded species may be present in Canada. Sapygidae is a relatively poorly studied family. Krombein (1979b) catalogued the Nearctic species including five Canadian species and Kurzenko (1996) provided a key to the Nearctic genera.

Scolioidea

Scolioidea, as defined by Pilgrim et al. (2008), consists of only one family, Scoliidae, in Canada (Krombein 1979b). Scolioidea of Masner et al. (1979) included six families (see footnote 28 in Table 1). Four species of Scoliidae are recorded from Canada, an increase from two species in Masner et al. (1979) (Table 1). All scoliids are parasitoids of Coleoptera, mostly Scarabaeoidea, but rarely Curculionoidea (Brothers and Finnamore 1993). Only two BINs have so far been recorded for Scoliidae from Canada, therefore more sampling is required. Historically, the classification of the family has been unstable, but there is now some consensus following publication of a world checklist (Osten 2005). There are 560 known species globally (Huber 2017). Very few studies on the Nearctic fauna have been done since the catalogue of Krombein (1979b), although MacKay (1987) treats the species of the southwestern US and has a key that includes all four species recorded in Canada.

Tiphioidea

Pilgrim et al. (2008) found that the family Tiphiidae was polyphyletic. The subfamilies Tiphiinae and Brachycistidinae clustered together, and therefore, these taxa were placed in Tiphiidae s. str. Their study related Tiphiidae s. str. to the monotypic family Sierolomorphidae, placing both families within Tiphioidea. Tiphioidea was not recognized by Masner et al. (1979). See Thynnoidea (below), for discussion of the placement of the other subfamilies previously belonging to Tiphiidae.

Tiphiidae are ectoparasitoids of Coleoptera (Brothers and Finnamore 1993). The current study records 31 species of Tiphiidae in Canada (Table 1). This compares to 25 species reported by Masner et al. (1979), a total which likely included one or more species that are now classified in Thynnidae. The ratio of BINs to recorded species is only

0.42, suggesting a need for more collecting and DNA barcoding. There have been no major revisions of Nearctic Tiphiinae since HW Allen's efforts in the 1960s and 1970s (e.g., Allen 1966, 1971). Kimsey and Wasbauer (2006) provided a taxonomic checklist of the Brachycistidinae of the western Hemisphere.

Two species of Sierolomorphidae are currently recorded from Canada, up from one species reported by Masner et al. (1979); however, BOLD has four BINs from Canada for this family suggesting that undescribed/unrecorded species exist. Evans (1961) provided keys for the six Nearctic species. The hosts are unknown.

Thynnoidea

Phylogenetically, the five other subfamilies of Tiphiidae s. lat. (Kimsey 1991) clustered together in Pilgrim et al. (2008) and the valid name for this group is Thynnidae. Furthermore, Pilgrim et al. (2008) found that Thynnidae was the sister group of two subfamilies of Bradynobaenidae (Chyphotinae and Typhoctinae) which together, were raised to family status with the valid name Chyphotidae. Thynnoidea was not recognized by Masner et al. (1979).

In Canada, only three species of Thynnidae are recorded (Table 1), although a further two species are known (C Sheffield unpubl. data). Most Thynnidae are parasitoids of beetles (e.g., Methocinae on Cicindelinae), although one species of the extralimital subfamily Diamminae has been reared from mole crickets (Orthoptera: Gryllotalpidae) (Brothers and Finnamore 1993). Only three BINs are currently recorded for Thynnidae in Canada. Pate (1947) provided keys to the Nearctic genera.

One species of the family Chyphotidae is known from Canada (Mickel 1967) (Table 1). Little is known of the biology of Chyphotidae, but a species of the extralimital genus *Typhoctes* Ashmead has been found on immature Solifugae (Arachnidae) (Brothers and Finnamore 1993). Likely the Canadian species was included in Masner et al. (1979) as one of the species of Mutillidae recorded from Canada. There are no BINs for Chyphotidae from Canada. There are four species known from states bordering southwestern Canada (Mickel 1967), therefore more species are likely to occur in Canada.

Vespoidea s. str.

The analyses of Pilgrim et al. (2008) and Branstetter et al. (2017) found that Vespidae and Rhopalosomatidae are sister groups. In contrast, Vespoidea s. str. of Masner et al. (1979) was comprised of Vespidae and Pompilidae.

There are 96 species of Vespidae (yellow jackets, potter wasps, hornets, paper wasps, and allies) known from Canada (Canadian Endangered Species Conservation Council 2016, R Longair pers. comm.). The current number is slightly fewer than the number cited in the 2016 report (101) because the current list excludes several adventive species that are not considered to be established. Masner et al. (1979) recorded 100 species and the number of BINs is 102. The relative similarity of these totals illustrates the good level of knowledge that exists for Canadian Vespidae, especially for the northeastern Nearctic (Buck et al. 2008, 2012).

Rhopalosomatidae is a small family with only four genera worldwide (Brothers and Finnamore 1993). It has previously been proposed as the sister group of Pompilidae (Brothers 1999), related to Formicidae, Scoliidae, and Vespidae (Brothers and Carpenter 1993) or related to Mutillidae, Sapygidae, Scoliidae, Sierolomorphidae, and Tiphiidae (Masner et al. 1979). Very little is known of the biology of the family, and the only known hosts are crickets (Orthoptera: Gryllidae) (Townes 1977a). Only one species of Rhopalosomatidae is recorded from Canada, the brachypterous *Olixon banksii* (Brues) from southern Ontario (Lohrmann et al. 2012). Masner et al. (1979) listed two species from Canada, which we assume included *Rhopalosoma nearcticum* Brues, but we have not seen Canadian specimens of this species. It is recorded from Kentucky and Maryland, so its range could extend into Canada. A third genus, *Liosphex* Townes, is also recently recorded from Kentucky (*L. boreus* Lohrmann) (Lohrmann and Ohl 2010), therefore this genus may also be discovered in Canada in the future. There are no Canadian BINs for Rhopalosomatidae.

Faunal analysis

The results of the current survey have re-confirmed that Hymenoptera is one of the major constituents of biodiversity in Canada with 8,757 described species recorded (Table 1). The percentage of the Nearctic Hymenoptera fauna that is present in Canada cannot be determined precisely because Nearctic species totals have not been updated for some families since Krombein et al. (1979). However, total described species numbers for North America north of Mexico are known for two of the largest superfamilies, Ichneumonoidea and Chalcidoidea, which together comprise approximately two thirds of all described species recorded in Canada. Approximately 55% of Nearctic ichneumonoids are recorded in Canada (4202 of 7647) and approximately 34% of the chalcidoids (1210 of 3567). Together, 48.3% (5412 of 11,214) of these two superfamilies are recorded in Canada. If similar percentages exist for the remaining one third of species, then it can be estimated that roughly half of the described species of Hymenoptera in the Nearctic north of Mexico are recorded in Canada. At a global level, Canada has approximately 5.7% of the 153,410 described species of Hymenoptera in the world as tabulated by Huber (2017).

In terms of composition of the Hymenoptera of Canada, just over three quarters of the described, recorded species (77.3%) belong to three superfamilies: Ichneumonoidea (4202 species: 48.0%), Apoidea (1352 species: 15.4%) and Chalcidoidea (1210 species: 13.8%). The sawfly superfamily Tenthredinoidea is the fourth largest with 595 species (6.8% of total species) and Vespoidea s. lat. is fifth (490 species: 5.6%). The overall composition of Hymenoptera in Canada differs slightly if one considers total species (recorded species plus our estimates of unrecorded species). There are as many as 19,148 species with the following proportions: Ichneumonoidea (42.6%), Chalcidoidea (17.5%), Platygastroidea (12%), Apoidea (7.8%), and Tenthredinoidea (4.2%).

Canada's Hymenoptera faunal structure is similar to other countries in northern latitudes. For example, Broad (2014) found the following proportions for described species recorded from Britain and Ireland: total species (7764), Ichneumonoidea (3913 species: 50.4 %), Chalcidoidea (1717 species: 22.1%), Tenthredinoidea (492 species: 6.4%), Apoidea (385 species: 4.9%) and Platygastroidea (362 species: 4.7%). The higher percentage of Apoidea recorded in Canada relative to Britain and Ireland is probably a reflection of greater diversity of habitats in Canada, especially hot, dry regions such as the Western Interior Basin, Prairies, and Mixedwood Plains ecozones which have a high diversity of Apoidea relative to cooler, more northern areas (Buck 2004, Sheffield et al. 2014). Relative to the whole world, Canada has a much higher percentage of described species of Ichneumonoidea (48.0% in Canada vs 30.8% for the whole world), slightly fewer Apoidea (15.4% vs 19.3%), approximately the same percentage of Chalcidoidea (13.8% vs 14.8%) and slightly more Tenthredinoidea (6.8% vs 4.7% worldwide). The higher percentage of Ichneumonoidea in northern latitudes compared to the tropics was discussed by previous authors (e.g., Janzen 1981, Gauld 1987), but more recent work on tropical ichneumonoids has demonstrated that this pattern is likely artefactual because of incomplete surveying of parasitoids in tropical areas of the world (Santos and Quicke 2011, Veijalainen et al. 2012, Timms et al. 2016). Apart from Ichneumonoidea, the other major difference between the composition of Hymenoptera in Canada compared to that of the entire world is the percentage of Vespoidea s. lat. (5.6% in Canada vs 19.0% in the entire world). Most vespoid families are predominantly tropical (Brothers and Finnamore 1993) and some, such as Chyphotidae, Rhopalosomatidae, Scoliidae, and Thynnidae have only one or a few species with ranges barely extending to southern Canada (see Table 1).

With respect to quantification of the number of introduced species of Hymenoptera in Canada, these numbers are available for some groups (e.g., sawflies, ants, bees and vespid wasps), but they are very poorly known for the parasitoid groups which encompass greater than 80% of the described species diversity of Hymenoptera in Canada. The reason for this lack of knowledge is a combination of poor distributional and taxonomic knowledge in many groups (both in Canada and elsewhere), as well as more than 100 years of well-meaning, but poorly documented, deliberate introductions of species for biological pest control that have obscured the native ranges of species in many groups. We can state that approximately 5% of sawflies appear to be introduced to Canada (H Goulet pers. comm.), and the Wild Species 2015 report (Canadian Endangered Species Conservation Council 2016) provided the following percentages: 7% of ants, just more than 2% of bees, and 5% of vespid wasps.

The 46% increase (8757 vs 6000) in recorded, described species since 1979 indicates that a great deal of work has been done in the last 39 years to document Canada's Hymenoptera, but the high number of BINs (18,454) and estimated, unrecorded species (10,366–10,391) suggests that much more work is required as fewer than half of the total species are currently recorded. At the suprafamilial level, the following groups have had relatively few newly recorded species since 1979: Ceraphronoidea, Cynipoidea, Diaprioidea, Evanioidea, Platygastroidea, Proctotrupoidea, Stephanoidea, Trigonaloidea, bees (Apoidea: Apiformes), and Vespoidea s. lat. In contrast, other groups have had significant increases in the number of recorded species (values in parentheses are the percentage increases of recorded species in the current study compared to 1979): Chalcidoidea (142%), Apoidea: Spheciformes (121%), sawflies (60%), Chrysidoidea (55%), and Ichneumonoidea (48%). The great increase in the number of recorded species in these taxa indicates a relatively low level of taxonomic and distributional knowledge in 1979 coupled with a strong research effort since that time, especially publication of the *Catalog of Hymenoptera of America North of Mexico* (Krombein et al. 1979) and many revisionary studies in these groups (see references in Table 1).

Despite the great amount of research that has been performed on many groups of Canadian Hymenoptera, some groups require much more investigation, as indicated by high ratios of total estimated species (unrecorded plus recorded species) to recorded species: Platygastroidea (14.3), Ceraphronoidea (8.0), Cynipoidea (5.9), Diaprioidea (4.1), Chalcidoidea (2.7), Chrysidoidea (2.0), and Ichneumonoidea (1.9). All other suprafamilial taxa have ratios of approximately 1.2 or less, implying that they are relatively well documented in Canada. However, the ratio of total estimated species to recorded species is not the sole indicator of taxa in most need of taxonomic and survey work. Species richness must also be considered. For example, the ratio of total estimated species to recorded species for Ichneumonidae is 1.56 which is not even in the top ten ranking for families. However, in terms of the absolute number of unrecorded species estimated in this study, Ichneumonidae (1705 unrecorded species) ranks third behind only Braconidae (2246) and Platygastridae (2127).

Although we rely heavily on BIN data to estimate the number of undocumented species in most families, we realize that this approach may not provide good estimates of species richness in Canada for all families because of incomplete DNA barcoding libraries for some families and/or inability of DNA barcodes to distinguish all species correctly. Given the relatively short length of time that DNA barcoding has been in widespread use (Hebert et al. 2003), it is not surprising that some groups, especially those that are speciose in understudied regions, e.g., Ichneumonidae in the high Arctic (Timms et al. 2013), are not completely sampled and therefore are incompletely represented in the DNA barcode library. Also, there are taxa for which the DNA barcoding region of cytochrome oxidase I does not correctly distinguish all species. For example, 50–60% of 90 species of northwestern European sawflies of the genus *Pristiphora* Latreille could not be distinguished using DNA barcodes (Prous et al. 2017, and also see the general discussion on DNA barcoding of sawflies by Schmidt et al. 2017). Within the bees, *Ceratina* Latreille, *Lasioglossum* Curtis, and *Bombus* Latreille contain some problematic taxa in which multiple species share a single BIN (Sheffield et al. 2017), but these instances are rare and barcodes still permit identification to a sibling species pair or species group. In general, a large majority of hymenopteran species were able to be discriminated by barcoding in prior studies (e.g., 97.3% of European bees; Schmidt et al. 2015). In addition, hymenopteran specimens are notoriously difficult to barcode, exhibiting only a 65% recovery rate, roughly 30% lower than some orders like Lepidoptera and Diptera (Hebert et al. 2016). This poor barcode recovery is likely the product of their high adenine-thymine (AT) content (that complicates sequencing) and the demonstrated difficulties in PCR primer binding, both associated with the high rates of mitochondrial molecular evolution in Hymenoptera (Kaltenpoth et al. 2012). This low recovery rate compounds the challenge of comprehensively sampling the DNA of Hymenoptera across Canada, and thus underscores that estimation of the unknown Canadian fauna cannot rely on BINs alone. In summary, the percentage of the fauna that is documented (46%) may be under- or over-estimated; however, the actual percentage does not matter nearly as much as the stark fact that an enormous amount of work is required to document thousands of species that are hitherto unknown.

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Coleoptera of Canada

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Abstract

The beetle fauna of Canada was assessed, including estimates of yet unreported diversity using information from taxonomists and COI sequence clusters in a BOLD (Barcode of Life Datasystems) COI dataset comprising over 77,000 Canadian records. To date, 8302 species of Coleoptera have been recorded in Canada, a 23% increase from the first assessment in 1979. A total of 639 non-native beetle species have become established in Canada, with most species in the Staphylinidae (153 spp.), Curculionidae (107 spp.), Chrysomelidae (56 spp.) and Carabidae (55 spp.). Based on estimates from the taxonomic community and our BOLD dataset, we estimate that slightly more than 1000 beetle species remain to be reported from Canada, either as new records or undescribed species. Renewed enthusiasm toward and financial support for surveys, especially in the central and western provinces of Canada will be critical for detecting, documenting and describing these species. The Barcode of Life database is still far from comprehensive for Canadian Coleoptera but substantial progress has been made and the number of Barcode Index Numbers (BINs) (as candidate species) has reached nearly 70% of the number of species reported from Canada. Comparison of BINs to observed species in a group of Canadian Staphylinidae suggests that BINs may provide a good estimate of species diversity within the beetles. Histeridae is a diverse family in Canada that is notably underrepresented in BOLD. Families such as Mordellidae, Scraptiidae, Latridiidae, Ptiliidae and Scirtidae are poorly known taxonomically in Canada and are represented in our BOLD dataset by many more BINs than recorded species.

Keywords

beetles, biodiversity assessment, Biota of Canada, Coleoptera

Campbell et al. (1979) provided the first thorough assessment of the biology and diversity of Canadian beetles. That important contribution, based on unpublished lists of Canadian beetle species, was followed by two checklists of Canadian beetle species (Bousquet 1991, Bousquet et al. 2013) that form the foundation of the results presented below. New Canadian records published since Bousquet et al. (2013) are listed in Table 1 under the respective families. Beetle classification has changed significantly over recent decades and continues to improve based on results of phylogenetic analyses of ever-larger datasets. Generally, we follow the classification used in Bousquet et al. (2013) with the following changes: Georissidae, Helophoridae and Hydrochidae separate from Hydrophilidae (Short and Fikáček 2013); Biphyllidae and Byturidae as Cleroidea (Robertson et al. 2015); Cybocephalidae distinct from Nitidulidae (Cline et al. 2014); cerylonid series families as superfamily Coccinelloidea (Robertson et al. 2015); Murmidiidae and Euxestidae distinct from Cerylonidae (Robertson et al. 2015); Teredidae distinct from Bothrideridae (Robertson et al. 2015); Anamorphidae and Mycetaeidae distinct from Endomychidae (Robertson et al. 2015); Cimberididae distinct from Nemonychidae (Shin et al. 2018).

Coleopterists within the taxonomic community were asked for estimates of undescribed and unreported Canadian beetles in their group of specialisation (contributors listed in Acknowledgments). Estimates accounted for both unrecognised distribution records and undescribed species, including those indicated by BINs (see below). In cases of multiple estimates, a range was reported to show the minimum and maximum values. We stress that these values were not intended to be precise but were included to provide the reader with an estimate of how well each group is known taxonomically in Canada. A dataset comprised of 77,626 Canadian Coleoptera records associated with a BIN (Barcode Index Number, Ratnasingham and Hebert (2013)) in BOLD (Barcode of Life Datasystems) was also used to estimate beetle diversity in Canada. Number of BINs was used as a proxy for species diversity in Canada with the caveat that there will be instances where closely related species may share a BIN or a single species may be represented by multiple BINs. Beetle families with fewer reported species than BINs were estimated to contain in Canada at least as many undescribed or unreported species as BINs. Families with many more described species than BINs are considered to be underrepresented in BOLD and would benefit from focused sequencing and collecting effort in the future.

Canadian beetles are classified in the suborders Archostemata, Adephaga, and Polyphaga (Table 1). Currently, 8302 species have been recorded in Canada (Table 1), a 23% increase from 6742 in 1979, 13% from 7326 in 1991 and 1.8% from 8149 in 2013). The number of Canadian species in the families Anthicidae, Clambidae, Corylophidae, Hydraenidae, Leiodidae, Psephenidae, Ptiliidae, and Scirtidae have more than doubled since 1979 (Table 1). The four most diverse families of beetles in Canada are the Staphylinidae (1774 spp.), Carabidae (983 spp.), Curculionidae (826 spp.) and Chrysomelidae (595 spp.) (Table 1). Of these, the number of Canadian Staphylinidae has increased most since 1979 (by 840 species, 90%) and the total number of species in Canada might eventually exceed 2000 (Table 1). The number of BINs in the BOLD

Table 1. Census of Coleoptera in Canada. Information sources refer to those available since the publication of Bousquet et al. (2013).

Taxon[1]	No. species reported in Campbell et al. (1979)	No. species currently known from Canada[2]	No. BINs[3] available for Canadian species	Est. no. undescribed or unrecorded in Canada	General distribution by ecozone[3A]	Information sources
Suborder Archostemata						
Cupedidae	3	3	3	0	Mixedwood Plains, Montane Cordillera	
Micromalthidae	1	1	0	0	Pacific Maritime	
Suborder Adephaga						
Amphizoidae	3	3	2	0	Pacific Maritime, Boreal Cordillera, Montane Cordillera	
Carabidae	861[4]	983 (55)	652	150	all ecozones	Lewis et al. 2015
Dytiscidae	285	280	181	7	all ecozones	
Gyrinidae	30	34	29	0	all except Arctic	
Haliplidae	38	35	20	0	southern Arctic and southward	van Vondel and Alarie 2016
Noteridae	0	2	1	0	Mixedwood Plains	
Rhysodidae	?[4]	2	1	0	Pacific Maritime, Mixedwood Plains	
Trachypachidae	?[4]	2	2	0	Boreal Plains, Mountain Cordillera	
Suborder Polyphaga						
Superfamily Scirtoidea						
Eucinetidae	5	7 (1)	6	2	Boreal ecozones and southward	
Clambidae	3	7 (2)	6	0	Boreal ecozones and southward	
Scirtidae[5]	12	25 (1)	46	21	Taiga ecozones and southward	
Superfamily Hydrophiloidea						
Histeridae	87	137 (12)	22	11	all except Arctic	Brousseau et al. 2014
Georissidae	1	1	0	0	Montane Cordillera, Prairies	
Helophoridae	?[6]	27 (1)	22	0	southern Arctic and southward	
Hydrochidae	?[6]	8	4	0	Boreal ecozones and southward	
Hydrophilidae	180[6]	113 (18)	89	3	southern Arctic and southward	
Sphaeritidae	1	1	0	0	Pacific Maritime, Montane Cordillera, Western Interior Basin	
Superfamily Staphylinoidea						
Agyrtidae	?[7]	7	2	0	Cordilleras and Mixedwood Plains	
Hydraenidae	13	27	8	0	all except Arctic	
Leiodidae	83[8]	181 (2)	131	15	all except Arctic	Peck and Newton 2017
Ptiliidae	20	48 (12)	69	75	all except Arctic	
Silphidae	27[7]	27 (1)	21	2	all except Arctic	Sikes et al. 2016

Taxon[1]	No. species reported in Campbell et al. (1979)	No. species currently known from Canada[2]	No. BINs[3] available for Canadian species	Est. no. undescribed or unrecorded in Canada	General distribution by ecozone[3A]	Information sources
Staphylinidae	934[9]	1774 (153)	1135	370	all ecozones	Klimaszewski et al. 2018, A Davies pers. comm.
Superfamily Scarabaeoidea						
Geotrupidae	?[10]	12 (1)	10	2	all ecozones south of boreal	
Glaphyridae	?[10]	1	0	1	Pacific Maritime	
Glaresidae	?[10]	2	1	3	Montane Cordillera, Prairies	
Hybosoridae	?[10]	1	1	0	Mixedwood Plains	
Superfamily Scarabaeoidea						
Lucanidae	10	14	10	2	southern Taiga ecozones, Hudson Plains and southward	
Ochodaeidae	?[10]	4	2	0	Montane Cordillera, Prairies, Mixedwood Plains	
Passalidae	1	1	0	0	Mixedwood Plains, Prairies	
Scarabaeidae	210[10]	220 (23)	173	24	all except Arctic	
Trogidae	?[10]	15	6	2	south of Taiga ecozones and Boreal Cordillera	
Superfamily Dascilloidea						
Rhipiceridae	1	1	0	0	Mixedwood Plains	
Superfamily Buprestoidea						
Buprestidae	200	178 (6)	128	6–18	southern Arctic and southward	Lyons et al. 2014
Superfamily Byrrhoidea						
Byrrhidae	31	26 (3)	25	3	southern Arctic and southward	
Dryopidae	3	6 (1)	0	0	Boreal ecozones and southward	
Elmidae	16	32	14	0	Hudson Plains, Boreal ecozones and southward	
Heteroceridae	16	28	9	0	Hudson Plains, Boreal ecozones and southward	
Superfamily Byrrhoidea						
Limnichidae	5	3	0	0	Boreal Plains, Boreal Shield, Mixedwood Plains	
Lutrochidae	0	1	1	0	Mixedwood Plains	
Psephenidae	1	4	3	0	Mixedwood Plains, Atlantic Maritime	

Taxon[1]	No. species reported in Campbell et al. (1979)	No. species currently known from Canada[2]	No. BINs[3] available for Canadian species	Est. no. undescribed or unrecorded in Canada	General distribution by ecozone[3A]	Information sources
Ptilodactylidae	2	4	8	4	south of Boreal in the west, Boreal Shield, Mixedwood Plains	
Superfamily Elateroidea						
Artematopodidae	4	5	5	0	south of Boreal in the west, Boreal Shield, Mixedwood Plains	
Cantharidae	111	151 (3)	103	5	southern Arctic and southward	
Elateridae	350	385 (7)	302	20–58	southern Arctic and southward	Webster et al. 2016b
Eucnemidae	30	39	27	4	Boreal ecozones and southward	Webster et al. 2016b
Lampyridae	26	32 (1)	31	2	Hudson Plains, Boreal and southward	
Lycidae	23	29	37	8	Boreal ecozones and southward	
Phengodidae	2	1	2	1	Mixedwood Plains	
Throscidae	8	8	19	11	Boreal ecozones and southward	
Superfamily Derodontoidea						
Derodontidae	6	8 (1)	4	0	Boreal ecozones and southward	
Nosodendridae	1	2	0	0	Montane Cordillera, Mixedwood Plains	
Superfamily Bostrichoidea						
Bostrichidae	24[11]	24 (4)	13	1–2	Taiga ecozones and southward	
Dermestidae	39	47 (16)	29	3–5	southern Arctic and southward	
Endecatomidae	?[11]	1	0	0	Prairies, Boreal Shield, Mixedwood Plains, Atlantic Maritime	
Ptinidae	85[12]	99 (19)	64	6–9	Taiga ecozones and southward	Webster et al. 2016b
Superfamily Lymexyloidea						
Lymexylidae	1	1	1	0	Boreal Shield, Boreal Plains, Mixedwood Plains, Atlantic Maritime	
Superfamily Tenebrionoidea						
Aderidae[13]	8	11 (2)	11	1	Boreal Shield and southwards in the east, south of boreal in the west	Barber and Bouchard 2017
Anthicidae	25	65 (3)	33	12	Taiga ecozones and southward	
Boridae	?[14]	2	2	0	Taiga ecozones and southward	
Ciidae	23	29 (1)	25	0	Taiga ecozones and southward	

Taxon[1]	No. species reported in Campbell et al. (1979)	No. species currently known from Canada[2]	No. BINs[3] available for Canadian species	Est. no. undescribed or unrecorded in Canada	General distribution by ecozone[3A]	Information sources
Superfamily Tenebrionoidea						
Ischaliidae	?[15]	2	2	0	Montane Cordillera, Western Interior Basin, Boreal Shield, Mixedwood Plains, Atlantic Maritime, Pacific Maritime	
Melandryidae	35[16,19]	43	40	0	Taiga ecozones and southward	
Meloidae	40	46	34	0	Boreal ecozones and southward	
Mordellidae	50[17]	75	107	42	Boreal ecozones and southward	
Mycetophagidae	10	16 (2)	15	0	Boreal ecozones and southward	
Mycteridae	2	4	2	0	Montane Cordillera, Mixedwood Plains, Atlantic Maritime	
Oedemeridae	15	13 (1)	7	0	Boreal ecozones and southward	
Prostomidae	1	1	0	0	Pacific Maritime	
Pyrochroidae	21[15]	21	15	0	Boreal ecozones and southward	
Pythidae	?[14]	6	9	3	Boreal ecozones and southward	
Ripiphoridae	7	11	2	0	Boreal Shield and southwards in the east, south of boreal in the west	
Salpingidae	10[14]	10 (1)	9	0	Taiga ecozones and southward	
Scraptiidae	?[14,17]	20	48	30	Boreal ecozones and southward	
Stenotrachelidae[18]	6	9	6	0	Boreal ecozones and southward	
Synchroidae	?[19]	2	1	0	Boreal Shield, Prairies, Mixedwood Plains, Atlantic Maritime	
Tenebrionidae	106[20]	137 (15)	92	10	Taiga ecozones and southward	Bousquet et al. 2018
Tetratomidae	8	20 (1)	16	0	Boreal ecozones and southward	
Zopheridae	23[21,22]	19 (1)	6	0	Boreal ecozones and southward	
Superfamily Cleroidea						
Biphyllidae	1	1	0	2	Mixedwood Plains, Atlantic Maritime	
Byturidae	2	1	1	0	Boreal ecozones and southward	
Cleridae	40	52 (6)	36	3	Boreal ecozones and southward	
Melyridae	30	53 (2)	46	0	Boreal ecozones and southward	
Trogossitidae	23	22	4	0	Taiga ecozones and southward	
Superfamily Cucujoidea						
Cucujidae	25[24]	8	6	0	Taiga ecozones and southward	
Cryptophagidae	45	68 (10)	71	5	Taiga ecozones and southward	
Cybocephalidae	?[25]	1	4	3	Montane Cordillera, Prairies, Mixedwood Plains	

Taxon[1]	No. species reported in Campbell et al. (1979)	No. species currently known from Canada[2]	No. BINs[3] available for Canadian species	Est. no. undescribed or unrecorded in Canada	General distribution by ecozone[3A]	Information sources
Erotylidae	17	28 (1)	20	0	Boreal ecozones and southward	
Kateretidae	?[25]	8 (2)	5	2	Taiga ecozones and southward	
Laemophloeidae	?[24]	13 (3)	13	0	Boreal Shield and southwards in the east, south of boreal in the west	
Monotomidae[26]	15	27 (5)	13	6	Montane Cordillera, Western Interior Basin, Mixedwood Plains, Atlantic Maritime, Pacific Maritime	
Nitidulidae	95[25]	99 (11)	78	12	Taiga ecozones and southward	Webster et al. 2016c
Passandridae	?[24]	1	1	0	Mixedwood Plains	
Phalacridae	10	8	19	11	Boreal Shield and southwards in the east, south of boreal in the west	
Superfamily Cucujoidea						
Sphindidae	3	6	5	0	south of Boreal ecozones	
Silvanidae	?[23]	16 (6)	8	0	Boreal ecozones and southwards	
Superfamily Coccinelloidea						
Anamorphidae	?[26]	2 (1)	2	0	Mixedwood Plains, Atlantic Maritime	
Bothrideridae	?[22]	3	0	0	Montane Cordillera, Western Interior Basin, Pacific Maritime, Mixedwood Plains	
Cerylonidae	6[27]	4	5	1	Boreal ecozones and southward	
Coccinellidae	120	162 (10)	136	0	Taiga ecozones and southward	Ratzlaff et al. 2016
Corylophidae	5	16 (2)	24	8	Boreal ecozones and southward	
Endomychidae	10[26]	13	9	1	Boreal ecozones and southward	
Euxestidae	?[27]	2	0	0	Mixedwood Plains, Atlantic Maritime	
Latridiidae	45	60 (21)	83	23	Taiga ecozones and southward	
Mycetaeidae	?[26]	1 (1)	0	0	Boreal Shield, Mixedwood Plains, Atlantic Maritime, Pacific Maritime	
Murmidiidae	?[27]	2 (1)	1	0	Boreal Shield, Mixedwood Plains	
Teredidae	?[22]	1	0	0	Pacific Maritime	
Superfamily Curculionoidea						
Anthribidae	18	22 (1)	20	2	Boreal ecozones and southward	Webster et al. 2016c
Attelabidae	?[28]	14	14	2	Boreal Shield and southwards in the east, south of boreal in the west	
Brachyceridae	?[28]	18 (2)	10	0	Taiga ecozones and southward	
Brentidae	?[28]	48 (8)	54	15	Taiga ecozones and southward	

Taxon[1]	No. species reported in Campbell et al. (1979)	No. species currently known from Canada[2]	No. BINs[3] available for Canadian species	Est. no. undescribed or unrecorded in Canada	General distribution by ecozone[3A]	Information sources
Cimberididae[29]	4	8	7	0	Boreal ecozones and southward	
Curculionidae	1113[28]	826 (107)	433	75	southern Arctic and southward	Webster et al. 2016c, de Tonnancour et al. 2017
Dryophthoridae	?[28]	27 (3)	10	0	Boreal ecozones and southward	
Superfamily Chrysomeloidea						
Cerambycidae	350	375 (9)	306	10–30	southern Arctic and southward	Bousquet et al. 2017
Chrysomelidae	588[30]	595 (56)	339	40–170	southern Arctic and southward	Marshall and Paiero 2016
Megalopodidae	?[30]	7 (1)	4	0	Boreal Shield and southwards in the east, south of boreal in the west	
Orsodacnidae	?[30]	1	1	0	Boreal Shield and southwards in the east, south of boreal in the west	
Total	**6742**	**8302 (639)**	**5750**	**1078–1284**		

[1]Classification following Bousquet et al. (2013) with updates from Short and Fikáček (2013), Robertson et al. (2015), Cline et al. (2014), Shin et al. (2018). [2]Current Canadian richness based on Bousquet et al. (2013) with updates from the literature indicated under 'Information sources', the number in parentheses represents the number of non-native species included in the total. [3]Barcode Index Number, as defined in Ratnasingham and Hebert (2013).

[4–30]Family-level classification in Campbell et al. (1979) differing from the present study includes: [4]Rhysodidae and Trachypachidae as Carabidae; [5]Scirtidae as former Helodidae; [6]Helophoridae and Hydrochidae as Hydrophilidae; [7]Agyrtidae as Silphidae; [8]former Leptinidae treated separately; [9]former Pselaphidae, Scydmaenidae, Micropeplidae and Scaphidiidae treated separately; [10]all scarabaeoid families except Lucanidae and Passalidae treated as Scarabaeidae; [11]Endecatomidae as Bostrichidae and former Lyctidae treated separately; [12]former Anobiidae treated separately; [13]Aderidae as former Euglenidae; [14]Boridae and Pythidae treated as Salpingidae; [15]former Pedilidae treated separately and Ischaliidae as Pyrochroidae; [16]some Scraptiidae as Melandryidae; [17]some Scraptiidae as Mordellidae ; [18]Stenotrachelidae as former Cephaloidae; [19]Synchroidae as Melandryidae; [20]former Alleculidae and Lagriidae treated separately; [21]former Colydiidae treated separately; [22]Bothrideridae and Teredidae as former Colydiidae; [23]Laemophloeidae, Passandridae and Silvanidae as Cucujidae; [24]Kateretidae and Cybocephalidae as Nitidulidae; [25]Monotomidae as former Rhizophagidae; [26]Anamorphidae and Mycetaeidae as Endomychidae; [27]Euxestidae and Murmidiidae as Cerylonidae; [28]former Platypodidae and Scolytidae treated separately, and Attelabidae, Brachyceridae, Apioninae (Brentidae) and Dryophthoridae as Curculionidae; [29]Cimberididae as subfamily Cimberidinae of Nemonychidae; [30]Megalopodidae and Orsodacnidae as Chrysomelidae, and former Bruchidae treated separately.

database (Table 1) for Canadian Coleoptera is nearly 70% of the number of known beetle species for Canada. All of the higher groups of Canadian beetles have associated BINs except for the polyphagan superfamily Dascilloidea, with the single Canadian species *Sandalus niger* Knoch.

Although our knowledge of Canadian beetle diversity has steadily increased between 1979, 1991, 2013 and 2018, significant contributions can still be made in each province and territory as sampling has been far from exhaustive (for overall estimates of undescribed or unrecorded beetle species, see Table 1). Most biomes in Canada are still only superficially sampled, especially those in central and western Canada. Despite much recent survey work over the past 15 years, more than 300 species were added to the provincial beetle fauna of New Brunswick only two years ago (Webster et al. 2016a). Continued survey work, using a variety of collection techniques, will be necessary for Canada to respond to important changes to its dynamic fauna, such as new invasive species and thermophilic species expanding their range northward in response to global climate change.

In total, 639 non-native beetle species are established in Canada (Table 1), although some of these may eventually be proven to be naturally Holarctic. While a few were introduced intentionally for the biological control of weeds and insects (e.g., De Clerck-Floate and Cárcamo 2011), most have been introduced into North America accidentally through various pathways including dry ballast, wood packing material, and agricultural and horticultural commodities such as stored grain, moss and plant stock (e.g., Klimaszewski and Brunke 2018). The families with the highest number of non-native species in Canada are Staphylinidae (153 spp.), Curculionidae (107 spp.), Chrysomelidae (56 spp.), and Carabidae (55 spp.).

Nineteen beetle families are currently not or only poorly represented in BOLD by Canadian specimens, i.e., the number of BINs is <20% of the number of recorded species in Canada, making it difficult to use barcode data to assess overall taxonomic knowledge (Table 1). These families typically contain few known species in Canada based on published taxonomic data (Table 1). Sixteen of these families are not represented in BOLD by Canadian specimens: Micromalthidae (Archostemata); Georissidae and Sphaeritidae (Hydrophiloidea); Glaphyridae and Passalidae (Scarabaeoidea); Rhipiceridae (Dascilloidea); Dryopidae and Limnichidae (Byrrhoidea); Nosodendridae (Derodontoidea); Endecatomidae (Bostrichoidea); Biphyllidae (Cleroidea); Prostomidae (Tenebrionoidea); Bothrideridae, Euxestidae, Mycetaeidae, and Teredidae (Coccinelloidea). Efforts are underway to generate DNA barcodes for these families based on Canadian specimens. The family Histeridae, which has more than 130 species in Canada, is particularly underrepresented, with only 22 BINs (i.e., approximately 16% of the known diversity) currently available in BOLD. Most members of this family are small, and live in microhabitats that are not sampled frequently such as mammal and bird nests, or under bark (Bousquet and Laplante 2006). This lack of representation could also be partly due to sequencing bias against Histeridae resulting from primer mismatch, or differences in DNA preservation at the collecting and archiving stages. For example, only 3% (8/256) of a diverse sample of Histeridae specimens from the Canadian National Collection of Insects, Arachnids and Nematodes (CNC, Agriculture and Agri-Food Canada) yielded barcode-compliant (and therefore BIN-compatible) sequences, versus 22% of submitted CNC Staphylinidae (522/2356).

Based on the number of BINs in BOLD for Canadian specimens, sixteen beetle families are more diverse in Canada than would appear from the recorded number of species (Table 1). The families where the number of BINs most greatly exceeds the number of species reported in Canada are: Mordellidae (+32 BINs) and Scraptiidae (+28 BINs) (Tenebrionoidea), Latridiidae (+23 BINs) (Coccinelloidea), Ptiliidae (+21 BINs) (Staphylinoidea), and Scirtidae (+21 BINs) (Scirtoidea). These families, generally with poorly known and small-sized species, require focused taxonomic studies because they may contain many undescribed species or described species yet unreported from Canada. This work should reconcile the unidentified BIN clusters with available names and describe any species new to science to adequately document the Canadian fauna. Researchers at the CNC and the Canadian Museum of Nature have made numerous contributions to the knowledge of Canadian Coleoptera. However, because most federal employees in Canada focus their research on agriculturally-significant taxa (see Bouchard et al. (2017) for plant-feeding taxa with high economic concern in Canada and in agroecosystems of our trading partners), beetle groups without either plant pests or well-known beneficial species have been given a lower taxonomic research priority. Canadian universities have until recently included taxonomic research on non-economically important beetles, although they currently support a minute fraction of research on Canadian Coleoptera.

The total estimated number of undescribed and unreported beetle species for Canada is 1080 to 1280 species (Table 1) based on expert estimates and species predicted by BINs including Canadian specimens in BOLD. The beetle families with the greatest number of taxonomist-estimated unrecognised diversity in Canada include the Staphylinidae, Carabidae, Ptiliidae, Curculionidae and Chrysomelidae, most of which include either plant pests or beneficial predators and parasitoids. These numbers represent the best available estimate of unrecorded Coleoptera diversity, although they must be interpreted with respect to limitations of expert opinion, BOLD database sampling, potential inaccuracies of the most current checklist (Bousquet et al. 2013), and BIN calculation methods. While we expect the exact numbers to change with further taxonomic research, the general trends reported herein should not.

Reconciling BINs with morphological data – a Canadian example

Barcode reference libraries for beetles and bees in taxonomically well-studied Central Europe (Hendrich et al. 2014, Schmidt et al. 2015) show that most BIN clusters are highly congruent with taxa already recognised by science. There, most discordance between BINs and recognised taxa likely reflects cases of unrecognised species diversity or species pairs with very similar COI sequences that, while considered one BIN due to shallow divergence, still clustered into species (Hendrich et al. 2014). However, it will be important to assess whether BINs closely approximate real taxa in other regions. We anticipate that barcoding will be similarly effective for characterising the Canadian fauna since both regions are climatologically and topographically similar with shared glaciation history, and with many beetle genera in common.

One DNA barcoding-related discovery is a cryptic species of burying beetle (Silphidae: *Nicrophorus* Fabricius) that was discovered in North America based on congruent evidence from ecological data, mating studies, morphology and DNA barcode data (Sikes et al. 2016). *Nicrophorus* is considered taxonomically very well studied in North America but the cryptic lineage was first highlighted by a different BIN than specimens from the Palaearctic and Alaska (Sikes et al. 2016). We anticipate that the taxonomic integration of DNA barcode data will provide many other insights about the Canadian fauna. The pressing need to carefully and authoritatively link Linnaean taxonomy with molecular reference databases such as BOLD through taxonomic research was stressed by Somervuo et al. (2017) and is re-emphasised here. This need was recently recognised in Canada, with over 5000 beetle species (summarised by Bouchard et al. 2017) added to BOLD in recent years. Although a general, species-focused analysis of the Canadian beetle fauna (similar to Hendrich et al. 2014) is premature, it is possible to examine the congruence of BINs with the taxonomy of a group of well-revised but diverse beetles.

We can partially test BIN congruence using the subtribe Quediina (sensu Brunke et al. 2016), a diverse lineage of rove beetles (Staphylinidae) and the subject of modern taxonomic revision in North America, including critical examination of male genitalia for species concepts (Smetana 1971a, b, 1973, 1976, 1978, 1981, 1990). They are generalist predators, may be important predators of pest insects and are often abundant in decaying organic matter (Smetana 1971a). Currently, 64 species of *Quedius* and *Quedionuchus* are recorded from Canada (Bousquet et al. 2013) and of these, 42 (66%) are represented in BOLD by sequences of authoritatively identified specimens. A total of 52 BINs represent Canadian Quediina in BOLD and most BIN incongruence with existing taxonomy is due to unrecognised species diversity. Although four 'well-known' species are currently considered Holarctic in distribution, Nearctic specimens form separate BINs from their Palaearctic counterparts in three of these. One Canadian *Quedius* has two traditionally recognised subspecies for which BINs are 6% divergent and will likely be considered morphologically diagnosable species. Another four BINs correspond to still unidentified species and further work is needed to discern whether they belong to described or undescribed taxa. Two Palaearctic *Quedius* species appear present but unverified and unreported from Canada. Four cases exist where a valid species of *Quedius* contains two BINs that do not correspond to morphological differences. In these cases, BOLD may have oversplit species due to algorithm artifacts based on material limited in number and geographic coverage, and BINs may be later combined in BOLD when additional sequences are included. Taxonomic research involving these putative lineages, including study of type specimens for available names, is in progress. No described species of Quediina shared BINs with any other species, indicating that the species are not 'oversplit', likely due to informative variation in male genitalia. Thus, only 7.7% of BINs were incongruent with species level clusters after cases of unrecognised species diversity were removed (a further 11.5%). A similar result was found for the well-studied Quediina of Central Europe where similar diversity (71 species, Assing and Schülke 2012) was represented by about 51% coverage (36 species with 39 BINs) in BOLD and only 7.7% of BINs (involving two species) were incongruent with prevailing species concepts (Hendrich et al. 2014).

The utility of BOLD as a proxy for biodiversity should be demonstrated over a broader taxonomic and geographic scale (Bergsten et al. 2012), as the BOLD database is highly skewed toward Canadian specimens. However, it is promising that gaps in the variation of male genitalia of rove beetles, typically used by taxonomists, correspond remarkably well to gaps in sequence variation identified by BINs. This suggests that BINs may provide a proxy for beetle diversity in North America and could be useful for highlighting taxonomic groups needing research attention (as done above by family).

Future priorities

The number of known species from Canada will continue to increase as new species are described, new populations of described species are discovered and species arrive as a result of climate change or global trade. While further taxonomic work on Staphylinoidea, Cucujoidea, Chrysomeloidea and Curculionoidea will continue to add many species to the Canadian fauna, new biosystematics work on several poorly studied families (e.g., Mordellidae, Scraptiidae, Latridiidae, Ptiliidae, and Scirtidae) is greatly needed. Although recent collecting in eastern Canada has yielded many discoveries, these biomes and, especially, those of central and western Canadian provinces remain inadequately sampled. A renewed effort toward exploring the Canadian beetle fauna will be critical for the documentation of the more than 1000 unrecorded or undescribed species that are estimated to be undetected or undescribed in Canada. Since DNA barcoding is a useful tool for assessing species diversity and appears to be highly compatible and synergistic with traditional morphological taxonomy, knowledge of beetle diversity in Canada will further benefit from continued development of the DNA barcode library through focused collecting, authoritative vouchering and continued integrative taxonomic research. However, improved and continued documentation of the Canadian fauna can only be achieved with new funding for surveys, including a variety of sampling methods, and by hiring or otherwise supporting scientists that include taxonomic work on the Canadian fauna as part of their research profile.

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REVIEW ARTICLE

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Strepsiptera of Canada

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Abstract

In Canada, the order Strepsiptera consists of 27 known species representing five families: Corioxenidae (1 species), Elenchidae (1 species), Halictophagidae (5 species), Stylopidae (15 species), and Xenidae (5 species). These totals represent an increase of 21 species since the 1979 assessment. Half of these species represent unpublished records recently discovered by study of stylopized hosts in museum collections and DNA barcoded species. It is estimated that as many as 19 more species will eventually be discovered in Canada. DNA barcode sequences are available for 4 Canadian species. The fauna of Canada is poorly surveyed and there is a need to fill knowledge gaps with increased examination of museum specimens for stylopized hosts, broader field surveys (including use of pheromone-baited traps), and more effort to obtain DNA samples.

Keywords

biodiversity assessment, Biota of Canada, Strepsiptera, twisted-wing parasite

The order Strepsiptera, commonly known as twisted-wing parasites, are all endoparasites of other insects, especially those in the orders Hemiptera, Hymenoptera, and Zygentoma (Kinzelbach 1978). Strepsiptera have been often considered rare (Campbell 1979) based on scarcity of collection records; however, this is only an illusion as recent advances in understanding the biology of this group, including isolation of sex pheromones for some species (Straka et al. 2011, Cvačka et al. 2012, Lagoutte et al.

2013, Hrabar et al. 2015), has revealed that they are more common than previously thought. General information about the phylogenetic history of the order was reviewed by Pohl and Beutel (2013), morphology was comprehensively described by Kinzelbach (1971), and various aspects of their biology was summarized by Riek (1970), Kinzelbach (1978), Kathirithamby (2009), and Straka et al. (2011).

The status of this taxon and its relationship to other insects has been a topic of considerable debate (Pohl and Beutel 2013). For instance, when the Canadian diversity of this group was reviewed by Campbell (1979), he classified the taxon as a superfamily (i.e., Stylopoidea) of Coleoptera, though others had previously considered the group to be a separate order (e.g., Pierce 1964). The ordinal status of this group is now well accepted, and the relationship of Strepsiptera to other insect orders has been recently clarified by phylogenomic research which showed that the order is a sister lineage to the Coleoptera (Misof et al. 2014).

Worldwide, this order contains about 600 described species in nine extant families (Pohl and Beutel 2005, Bravo et al. 2009, Kathirithamby et al. 2012). The first comprehensive review of world Strepsiptera (Pierce 1909) included all species known from North America to that date. The North American species, including descriptions of new species since Pierce (1909), were later published and reviewed by Bohart (1941), Kinzelbach (1971) and Kathirithamby and Taylor (2005). These publications focused on species known mainly from the United States of America, but also included some Canadian records and species described from Canadian material. Several species such as *Stylops leechi* Bohart, *Loania canadensis* Kinzelbach, and *Stenocranophilus canadensis* Kinzelbach were described exclusively from Canada (Bohart 1941, Kinzelbach 1970, 1971).

Campbell (1979) reported only six species of Strepsiptera (from the family Stylopidae) from Canada, but predicted that an additional 10 species would likely be found in the country. Peck (1991) published the first checklist of Strepsiptera from Canada that included 11 species in three families (Peck 1991); however, he overlooked the record of *Xenos peckii* Kirby from British Columbia (Leech 1966). Subsequently, Kenner (2002) reported *Stylops shannoni* (Pierce) from British Columbia, resulting in a total of 13 species of Strepsiptera reported from Canada.

As a result of examination of material from the Canadian National Collection of Insects, Arachnids and Nematodes (Ottawa, Ontario, Canada) and the Kansas University Natural History Museum (Lawrence, Kansas, USA), an additional 13 new Canadian species records have recently been discovered (J Straka unpubl. data), 10 from Stylopidae and three from Xenidae. One more species new to Canada was obtained from data collected in Barcode of Life Data System (BOLD; Ratnasingham and Hebert 2007). This species from BOLD belongs to the family Elenchidae, which has never been reported from Canada before. Thus, in total, 27 species from five families of Strepsiptera are now known from Canada, 15 of which are in the Stylopidae (Table 1). This represents more than four times the number of species reported by Campbell (1979), and greatly exceeds his prediction of the number of species likely to be in Canada. There are no known non-native species in the Canadian fauna. It is estimated that 19 more species of Strepsiptera will eventually be found in Canada,

Table 1. Census of Strepsiptera in Canada.

Taxon[1]	No. species reported in Campbell (1979)	No. species currently known from Canada	No. BINs[2] available for Canadian species[3]	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[4]	Information sources[5]
Suborder Stylopidia						
Corioxenidae	0	1	0	1	Boreal Shield	Kinzelbach 1970, Peck 1991
Elenchidae	0	1	1	4	Boreal Shield, Montane Cordillera	BOLD
Halictophagidae	0	5	1	4	Prairies, Boreal Shield, Boreal Plains	Bohart 1941, Kinzelbach 1971, Peck 1991; specimens in CNCI
Stylopidae	6	15	0 (1)	6	most ecozones except Arctic	Pierce 1909, 1919, Bohart 1941, Peck 1991, Kenner 2002; specimens in CNCI and KUNHM
Xenidae	0	5	1	4	Atlantic Maritime, Mixedwood Plains, Boreal Shield, Prairies, Pacific Maritime, Western Interior Basin, Montane Cordillera	Peck 1991, Kenner 2002; specimens in CNCI and KUNHM
Total	**6**	**27**	**3 (1)**	**19**		

[1]Classification follows that indicated in Pohl and Beutel (2005). [2]Barcode Index Number, as defined in Ratnasingham and Hebert (2013). [3]The number in parentheses represents number of barcoded species for which BINs have not yet been assigned. [4]See figure 1 in Langor (2019) for a map of ecozones. [5]BOLD: Barcode of Life Data System (http://www.boldsystems.org; Ratnasingham and Hebert (2007)); CNCI: Canadian National Collection of Insects, Arachnids, and Nematodes; KUNHM: Kansas University Natural History Museum.

either by discovery of overlooked species, expansion of species in the northern United States of America into adjacent parts of southern Canada, or recognition of sibling species within currently known species. The detection of cryptic sibling species will be enhanced by DNA barcoding and application of phylogenetic reconstructions based on DNA (Jůzová et al. 2015, Straka et al. 2015a, b). Three Barcode Index Numbers (BINs) are assigned for Canadian species (Ratnasingham and Hebert 2013). One more Canadian species has already been barcoded but no BIN has been assigned to this species (Jůzová et al. 2015, Straka et al. 2015b).

In general, the strepsipteran fauna of Canada has not been well surveyed and all regions will benefit from increased sampling. As a starting point, it is recommended that pinned collections of common host groups, e.g., bees, wasps, leafhoppers and true bugs, be examined to locate stylopized individuals. As well, increased effort to obtain DNA barcodes as well as genome sequencing of Canadian Strepsiptera is needed. Finally, a sex pheromone of Strepsiptera that has been isolated and synthesized (Cvačka et al. 2012, Lagoutte et al. 2013, Hrabar et al. 2015) may be used in lures attached to traps to attract males, thereby aiding field sampling efforts.

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REVIEW ARTICLE

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Raphidioptera of Canada

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Abstract
There are eight species in two families of Raphidioptera known from Canada, an increase of one species since the prior assessment in 1979. Another four species are likely to occur in Canada based on DNA evidence and distributional records. The Barcode of Life Data System currently lists ten Barcode Index Numbers for Canadian Raphidioptera.

Keywords
biodiversity assessment, Biota of Canada, Raphidioptera, snakeflies

Raphidioptera, commonly referred to as snakeflies, is a small order of insects containing two extant families: Raphidiidae and Inocelliidae. Species are confined to the northern hemisphere with the greatest diversity around the Mediterranean Sea and in eastern Asia. The North American species only occur west of the Rocky Mountains from about 53° N latitude south to Guatemala. North-central California is the area of greatest diversity in western North America (Aspöck and Aspöck 2014, Wu and Liu 2016). Members of both Raphidiidae (*Agulla*) and Inocelliidae (*Negha*) occur in Canada. All Canadian species are restricted to Pacific Maritime, Western Interior Basin, and Montane Cordillera ecozones south of 53° N in British Columbia and one, *Agulla adnixa* (Hagen), with a range extending eastward into the western edge of the Prairies ecozone in southern Alberta (Table 1). All Canadian species can be found across most

Table 1. Census of Raphidioptera in Canada.

Taxon[1]	No. species reported in Kevan (1979)	No. species currently known from Canada	No. BINs[2] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[3]	Information sources[4]
Raphidiidae	6	6	9	3	Pacific Maritime, Western Interior Basin, Montane Cordillera, Prairies	Penny et al. 1997, Scudder and Cannings 2009; specimens in UBC, RBCM, CNC, NFRC
Inocelliidae	1	2	1	1	Pacific Maritime, Western Interior Basin, Montane Cordillera	Penny et al. 1997, Scudder and Cannings 2009; specimens in UBC, RBCM, CNC
Total	**7**	**8**	**10**	**4**		

[1]Classification follows that indicated in Kevan (1979). [2]Barcode Index Number, as defined in Ratnasingham and Hebert (2013). [3]See figure 1 in Langor (2019) for a map of ecozones. [4]UBC – University of British Columbia Spencer Entomological Collection, Vancouver, BC; RBCM – Royal British Columbia Museum, Victoria, BC; CNC – Canadian National Collection of Insects, Arachnids, and Nematodes, Ottawa, ON; NFRC – Northern Forestry Centre, Edmonton, AB.

of southern British Columbia with the exception of *Agulla crotchi* (Banks), found only in the Western Interior Basin ecozone. *Agulla adnixa* and *A. assimilis* (Albarda) are the most commonly collected and widespread species.

Raphidioptera require a cold period to develop properly and pupate. Most species spend two years as larvae and have 10 to 15 instars. According to Carpenter (1936) habitat specificity of the larvae limits the range of snakeflies to forested portions of western North America; however, it is now known that only the Inocelliidae and a few Raphidiidae are restricted to the bark of trees as larvae while most other species can also be found on or under the soil surface feeding on small arthropods (Aspöck 2002, Aspöck et al. 2012a). Adult Raphidiidae are also predaceous on small insects whereas adults of Inocelliidae eat pollen or do not feed at all (Aspöck et al. 2012b). The lifespan of adult Inocelliidae is only a few days, a characteristic which may explain the relative rarity of the single genus *Negha* in museum collections in North America.

When the Raphidioptera of Canada were last assessed (Kevan 1979), there were 168 extant species (151 Raphidiidae; 17 Inocelliidae) known worldwide (Aspöck 1986). According to Aspöck (1986) there were certainly no more than 200 species. Approximately 30 years later, the number of described, extant species was 248 (206 Raphidiidae; 42 Inocelliidae) and the estimated total global fauna is nearly 300 species (Aspöck and Aspöck 2014, Engel et al. 2018). In that same period, the number of species known from North America decreased from 19 to 18 as a result of taxonomic revision (Kevan 1979, Penny et al. 1997).

According to the paleobiology database (https://fossilworks.org), the fossil record contains 119 species of Raphidioptera in eight families worldwide. In North America 15 species are listed in the fossil record database. Of the three known Canadian specimens, two Cretaceous Mesoraphidiidae were found in Alberta and Labrador and *Archiinocellia oligoneura* Handlirsch (family uncertain) from the Paleogene in British Columbia (https://fossilworks.org; Aspöck et al. 2012a).

Very little research has been done on the snakeflies of North America since the 1970s (Penny et al. 1997, Aspöck and Aspöck 2014). This is reflected by the small change in number of species known from Canada over this period (Table 1). Kevan (1979) synonomised *Negha inflata* (Hagen) and *N. longicornis* (Albarda). These two *Negha* species are now regarded as distinct, resulting in an increase in known Inocelliidae (Penny et al. 1997; ITIS database: https://www.itis.gov; BOLD: http://www.boldsystems.org). Half of the known Canadian species have associated Barcode Index Numbers (BINs). Seven BINs of *Agulla* are not currently placed to species, which indicates that there are undescribed species in this taxon. It is likely that intensive collecting efforts and taxonomic revision of the group in North America will uncover at least a few new species and range extensions. It is estimated that an additional two species occur in Canada. If predictions of climate change are correct some southern species may be expected to eventually appear in Canada as their ranges shift northward.

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REVIEW ARTICLE

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Neuroptera of Canada

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Abstract
The Neuroptera of Canada consists of 101 extant species, an increase of 26 (35%) since the previous assessment of the fauna in 1979. More than 48 additional species are believed to occur in Canada based largely on recent DNA evidence and new distribution records. The Barcode Of Life Data System (BOLD) currently includes 141 Barcode Index Numbers (BINs) for Canadian Neuroptera. Canadian fossils have thus far yielded 15 species in three families of Neuroptera.

Keywords
antlion, aphidlion, biodiversity assessment, Biota of Canada, lacewing, mantidfly, Neuroptera, owlfly

The order Neuroptera, including the lacewings, antlions, owlflies and relatives, contains approximately 6400 extant species worldwide (Oswald and Machado 2018), and approximately 350 in America north of Mexico (Penny et al. 1997). As of 2017, the Canadian fauna consists of 101 extant species, an increase of nearly 35% since the previous assessment by Kevan (1979) (Canadian Endangered Species Conservation Council 2016) (Table 1).

The significant increase in species known from Canada since 1979 is a result of research concentrated on the taxonomy and faunistics of Canadian species. Most of the research has focused on the most speciose familes (Table 1), the Hemerobiidae (Klimaszewski and Kevan 1985, 1987a, b, 1988, 1989, 1992, Kevan and Klimaszewski 1986, Oswald 1988, 1993, Klimaszewski et al. 2009) and the Chrysopidae (Adams and Garland 1981, Garland 1984, 1985, 2000a, b, Tauber 2003, Penny 2006, Garland and

Kevan 2007). Other significant works include the review of the Mantispidae of Canada by Cannings and Cannings (2006), the Neuroptera of North America by Penny et al. (1997), and the neuropteroid insects of British Columbia by Scudder and Cannings (2009). As of 2017, more than half of Canadian species have been DNA barcoded and have Barcode Identification Numbers (BINs) (Ratnasingham and Hebert 2013) associated with them (Table 1).

Two of the more notable additions to the Canadian fauna are *Nallachius americanus* (McLachlan) (Dilaridae) and *Ululodes quadripuntatus* (Burmeister) (Ascalaphidae) (Garland and Marshall 1980, Prenny and Jones 2017). Each of these species belong to families previously unrecorded in Canada, but were predicted by Kevan (1979) to occur here. The mantidfly, *Dicromantispa sayi* (Banks) (Mantispidae) is another species that was expected by Kevan (1979) and subsequently recorded in southern Ontario (Cannings and Cannings 2006). The chrysopid, *Nineta gravida* (Banks) was rediscovered on Canada's Pacific coast after 90 years (Garland 2000b), while the ithonid, *Polystoechotes punctatus* (Fabricius) appears to be extirpated from the eastern half of North America having not been recorded there since 1952 (Marshall 1996).

Most of the recent increase in species known from Canada has been in the families Coniopterygidae and Hemerobiidae (Table 1). Very little work has been done on the North American Coniopterygidae since Meinander (1974) revised the family (Penny et al. 1997, Meinander et al. 2009). Given their small size and cryptic nature it is likely that research on the Coniopterygidae will yield at least a few new species and distribution records for Canada. BINs for specimens of Coniopterygidae suggest that there may be 20 or more species in this family left to describe. BINs also indicate that there may be several undescribed species of Hemerobiidae, Chrysopidae, and Mymeleontidae.

Hemerobiidae represents a distinctly northern and western group in North America and is the most species-rich family of Neuroptera in Canada with 43 species (70% of the North American hemerobiid fauna) (Table 1). Kevan and Klimaszewski (1986) characterized the Canadian fauna as "boreo-alpine". Several species are transcontinental in Canada, their ranges extending south into the northernmost parts of the eastern US and along the mountain ranges of the western US. Kevan and Klimaszewski (1986) describe five general distribution patterns for the Hemerobiidae: Holarctic, transcontinental Nearctic, western Nearctic, disjunct Nearctic (western with scattered eastern records) and eastern Nearctic. One species, *Wesmaelius longipennis* (Banks), was listed by Kevan and Klimaszewski (1986) as endemic to California. However, specimens of *W. longipennis* in the Canadian National Collection, collected from coastal and interior locations in British Columbia, and one from Quebec, in the 1920s and 1930s, were recently identified (J Klimaszewski pers. comm.). This is a significant extension of the known range and implies that the California records may represent the southern extent of a more widely distributed northern species.

Few Neuroptera in Canada are considered to be exotic species. These introductions include three Coniopterygidae (*Conwentzia psociformis* (Curtis), *Semidalis vicina* (Hagen), *S. pseudouncinata* Meinander), three Hemerobiidae (*Psectra diptera* (Bur-

Table 1. Census of Neuroptera in Canada.

Taxon[1]	No. species reported in Kevan (1979)	No. species currently known from Canada[2]	No. BINs[3] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[4]	Information sources
Coniopterygidae	7	12 (3)	56	>20	all except Arctic	Meinander 1972, Penny et al. 1997, Canadian Endangered Species Conservation Council 2016
Sisyridae	3	3	3	0	all ecozones	Penny et al. 1997, Bowles 2006
Dilaridae	0	1	0	0	Mixedwood Plains	Prenny and Jones 2017
Berothidae	1	1	1	2	Western Interior Basin	Scudder and Cannings 2009
Mantispidae	3	4	4	0	Montane Cordillera, Western Interior Basin, Prairies, Mixedwood Plains	Cannings and Cannings 2006
Hemerobiidae	28	43 (3)	43	15	all ecozones	Kevan and Klimaszewski 1986, Penny et al. 1997, Canadian Endangered Species Conservation Council 2016
Chrysopidae	25	26 (1)	21	6	all except Arctic	Garland and Kevan 2007, Canadian Endangered Species Conservation Council 2016
Ithonidae[5]	1	1	1	0	Montane Cordillera, Western Interior Basin, Prairies, Mixedwood Plains[6]	Penny et al. 1997
Ascalaphidae	0	1	0	0	Mixedwood Plains	Garland and Marshall 1980
Myrmeleontidae	7	9	12	>5	most ecozones south of taiga	Penny et al. 1997, Canadian Endangered Species Conservation Council 2016
Total	**75**	**101 (7)**	**141**	**>48**		

[1]Classification follows the phylogeny indicated in Engel et al. (2018). [2]Numbers in parentheses indicate number of non-native species included in the total. [3]Barcode Index Number, as defined in Ratnasingham and Hebert (2013) [4]See figure 1 in Langor (2019) for a map of ecozones. [5]Ithonidae now includes the Polystoechotidae (Engel et al. 2018). [6]Believed to be extirpated from eastern North America (Marshall 1996).

meister), *Wesmaelius subnebulosus* (Stephens), *Micromus variegatus* (Fabricius), and the chrysopid, *Chrysoperla carnea* (Stephens) (Meinander 1972, Kevan and Klimaszewski 1986, Meinander et al. 2009). *Chrysoperla carnea*, once considered to be of Eurasian origin and introduced to North America (Henry 1983, Brooks 1994) is mass-produced and introduced into agricultural systems as a biocontrol agent (Tauber et al. 2000). *Chrysoperla carnea* was recently divided into a complex of 15 or more species that are reproductively isolated by their mate-attraction songs (Henry et al. 2011) and analysis of commercially produced specimens labeled as *C. carnea* were in fact dominated by *C. plorabunda* (Fitch) (a North American species) and no *C. carnea* were present (Henry and Wells 2007).

Future research on Canadian Neuroptera is likely to yield some new species and range extensions in the more diverse families (Table 1). The Paleobiology Database (http://fossilworks.org) indicates that the fossil record has thus far yielded 15 species from three families for Canada, and 68 species in five families for North America, and research on Canadian fossil deposits may reveal additional species. Other interesting avenues of research include the application of native Neuroptera as control agents in agricultural settings, the mating songs of *Chrysoperla* and the existence of this phenomenon and other mate selection methods in related taxa and systematic revisions of the Myrmeleontidae and Coniopterygidae.

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Megaloptera of Canada

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Abstract

An updated summary on the fauna of Canadian Megaloptera is provided. Currently, 18 species are recorded in Canada, with six species of Corydalidae and 12 species of Sialidae. This is an increase of two species since 1979. An additional seven species are expected to be discovered in Canada. Barcode Index Numbers are available for ten Canadian species.

Keywords

alderflies, biodiversity assessment, Biota of Canada, dobsonflies, fishflies, Megaloptera

The order Megaloptera (dobsonflies, fishflies, and alderflies) is one of the three orders of Neuropterida, and is characterized by the prognathous adult head, the broad anal area of hind wing and the exclusively aquatic larval stages (New and Theischinger 1993). Currently, there are ca. 380 described species of Megaloptera worldwide (Yang and Liu 2010, Oswald 2016). Extant Megaloptera are composed of only two families; Corydalidae, which is divided into Corydalinae (dobsonflies) and Chauliodinae (fishflies), and Sialidae (alderflies). Major species diversity of Megaloptera is confined to the subtropical and warm temperate regions, e.g., the Oriental, Neotropical, and Australian Regions (Yang and Liu 2010, Liu et al. 2012, 2015).

Southern Canada is probably the northern limit of the distribution range of Nearctic Megaloptera. Recent phylogeographic studies suggest that the Canadian population of a fishfly species (i.e., *Nigronia serricornis* (Say)) was formed very rapidly after the Pleistocene glacial period (Heilveil and Berlocher 2006). Thus, the Canadian Megaloptera may play an important part in understanding the evolutionary history of Nearctic Megaloptera.

All known Canadian species of Megaloptera are also found in the United States of America. Kevan (1979) recorded 16 native species of Megaloptera in Canada, including six species of Corydalidae and 10 species of Sialidae. Since then, no more species of Corydalidae have been found in Canada. Evans (1984) reported two new fishflies, *Orohermes crepusculus* (Chandler) and *Protochauliodes cascadius* Evans, from the northwestern USA where they coexist with *Dysmicohermes disjunctus* (Walker) and *Protochauliodes spenceri* Munroe in Oregon (Evans 1972). As the latter two species are known from southwestern British Columbia, *O. crepusculus* and *P. cascadius* may also be found in similar habitats there. Additionally, *Neohermes concolor* (Davis), which is widespread in the eastern USA (Liu et al. 2016), may also occur in adjacent areas of Canada. It should be also noted that in the Species Catalogue of Lacewing Digital Library (LDL), the most comprehensive and frequently updated database of species of Neuropterida (Oswald 2016), *Chauliodes rastricornis* Rambur is not recorded in Canada, although the Canadian record of this species is reported by van der Weele (1910). Herein the distribution of *C. rastricornis* in Canada is confirmed.

For Canadian alderflies, the most important faunal work after Kevan (1979) is that of Whiting (1991) in which *Sialis infumata* Newman and *S. joppa* Ross were newly recorded in Canada. An additional four species of *Sialis* are estimated to be found in Canada, namely *S. aequalis* Banks, *S. driesbachi* Flint, *S. hasta* Ross, and *S. spangleri* Flint, because these species are distributed around the Great Lakes region of northeastern USA that is in close promimity to Canada.

DNA barcodes are available for all but one species of known Canadian Corydalidae, but for less than half of Sialidae (Table 1). Species with DNA barcodes comprise *Chauliodes pectinicornis* (Linnaeus) (BOLD:AAH3593), *C. rastricornis* (BOLD:AAH3594), *D. disjunctus* (BOLD:ACA3660), *N. serricornis* (BOLD:AAA1274), *P. spenceri* (BOLD:ACP8653), *Sialis concava* Banks (BOLD:AAL6477), *S. hamata* Ross (BOLD:ACA3407), *S. joppa* Ross (BOLD:AAG9766), *S. vagans* Ross (BOLD:AAH7456), and *S. velata* Ross (BOLD:AAG9765). Current barcode information does not indicate the presence of cryptic species.

Thirteen of the 18 species of Canadian megalopterans have their larval stage described, and their life history is known (Davis 1903, Cuyler 1958, Neunzig 1966, Azam and Anderson 1969, Evans 1972, Leischner and Pritchard 1973, Lilly et al. 1978); however, most of the information is based on studies of materials or populations from the United States.

Additional surveys of Megaloptera habitats in southern Alberta and British Columbia, especially southwestern British Columbia, are warranted to fill in gaps in distribution and to ascertain whether other species are present. Fresh material of all megalopterans, especially Sialidae, is needed for obtaining DNA barcodes.

Table 1. Census of Megaloptera in Canada.

Taxon[1]	No. species reported in Kevan (1979)	No. species currently known from Canada	Number of BINs[2] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[3]	Information sources
Corydalidae	6	6	5	3	Boreal Shield, Pacific Maritime, Atlantic Maritime, Mixedwood Plains	van der Weele 1910, Evans 1972, Yang and Liu 2010, Oswald 2016, Liu and Winterton 2016
Sialidae	10	12	5	4	Boreal Shield, Boreal Plains, Pacific Maritime, Atlantic Maritime, Montane Cordillera, Mixedwood Plains, Prairies	Whiting 1991, Liu et al. 2015
Total	**16**	**18**	**10**	**7**		

[1]Classification follows that of Yang and Liu (2010). [2]Barcode Index Number, as defined in Ratnasingham and Hebert (2013). [3]See figure 1 in Langor (2019) for a map of ecozones.

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REVIEW ARTICLE

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Diptera of Canada

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Abstract

The Canadian Diptera fauna is updated. Numbers of species currently known from Canada, total Barcode Index Numbers (BINs), and estimated numbers of undescribed or unrecorded species are provided for each family. An overview of recent changes in the systematics and Canadian faunistics of major groups is provided as well as some general information on biology and life history. A total of 116 families and 9620 described species of Canadian Diptera are reported, representing more than a 36% increase in species numbers since the last comparable assessment by JF McAlpine et al. (1979). Almost 30,000 BINs have so far been obtained from flies in Canada. Estimates of additional number of species remaining to be documented in the country range from 5200 to 20,400.

Keywords

biodiversity assessment, Biota of Canada, Diptera, flies, systematics

This paper is dedicated to the memory of Terry A Wheeler, an exceptional Canadian dipterist and long-time contributor to the Biological Survey of Canada, who passed away in the early stages of this project.

The world fauna of Diptera counts almost 160,000 named species (Borkent et al. 2018) divided into approximately 160 extant families (Pape and Thompson 2013). Flies dominate the Canadian insect fauna in numbers of named species and, in many habitats, in overall abundance. That dominance becomes especially apparent in the northern parts of the country where dipterans form a ubiquitous feature of the summer landscape.

Diptera occur in almost all freshwater and terrestrial habitats where they display an impressive range of life histories and feeding habits. From parasites to leafminers, predators and filter feeders (to mention only a few), flies have diversified to exploit almost all organic substrates for their development (see Courtney et al. (2017) and Marshall (2012) for detailed overviews). Canada holds approximately 20% of the world's freshwater reserves so, unsurprisingly, families with aquatic stages are very well represented in the country. In the present survey, the Chironomidae (non-biting midges), whose immature stages are primarily aquatic, account for the most named species (798) in a single family (Table 1).

The diversity of flies in Canada was last reviewed by JF McAlpine et al. (1979) as part of a broader treatment of the terrestrial arthropods (Danks 1979). Subsequently, the three volumes of the *Manual of Nearctic Diptera* (JF McAlpine et al. 1981, 1987, JF McAlpine and Wood 1989) have been major catalysts for dipterological research in Canada and the USA. A detailed overview of these contributions, and the people who made them possible, was provided in Cumming et al. (2011). The identification keys to genus found in Volumes 1 and 2 (JF McAlpine et al. 1981, 1987) paved the way for future taxonomic work on the Nearctic fauna, and for many families they remain the best identification resource. While recent catalogues are now available for a number of Nearctic Diptera families, e.g., Dolichopodidae (Pollet et al. 2004) and Tachinidae (O'Hara and Wood 2004), no comprehensive catalogue has been published for the Canadian fauna of the whole order since Stone et al. (1965). The global online database, Systema Dipterorum (Pape and Thompson 2013), provides extensive information about Diptera names and literature; it is especially useful for resolving issues related to precedence and validity of names during taxonomic revisions.

As with many arthropod groups, the development of DNA-based identification and phylogenetic tools has had a strong impact on Diptera systematics. DNA barcoding using a part of the cytochrome c oxidase 1 (COI) gene (Hebert et al. 2003) has been applied to members of nearly all Diptera families found in Canada, and more specimens of flies have been DNA barcoded than of any other order in the country – 1.14M specimens as of June 2018 in the Barcode of Life Data System (BOLD; www.boldsystems.org). DNA barcoding and the Barcode Index Number (BIN) system (Ratnasingham and Hebert 2013) usually provide good estimates of species limits in taxa with good coverage, e.g., Canadian Muscidae (Renaud et al. 2012b, Hebert et al. 2016) and Simuliidae (Rivera and Currie 2009). However, gaps and errors in existing barcode libraries in some freshwater taxa (Curry et al. 2018), as well as poor correspondence between COI DNA barcodes and morphology for at least one genus found in Canada (*Protocalliphora* Hough; Whitworth et al. 2007) warrant caution when using BINs alone as estimates of true Diptera species diversity. In any case, further investigations will be required to explore the great discrepancies between named species and BINs for some families such as the Cecidomyiidae (243 vs 11,396) or the Sciaridae (129 vs 2863) (Table 1), and to determine the relative contributions of gaps in taxonomic knowledge and discordance with the DNA barcoding and/or BIN approach.

The *Manual of Nearctic Diptera*, especially Volume 3 (McAlpine and Wood 1989), also had a major impact on the field of Diptera phylogenetics. The hypotheses of family-level relationships and the proposed classification presented have served as a basis for future updates (Yeates and Wiegmann 2012) and have since been tested repeatedly using new sources of data and continuously evolving quantitative methods (see Wiegmann and Yeates (2017) for review). It is notable that while the last three decades have generated an impressive body of literature on Diptera phylogenetics, a lack of consensus still remains in many parts of the Diptera phylogeny (Borkent 2018). Consequently, the family concepts used in the present work follow Pape et al. (2011) but the classification reflects a consensus of opinions of co-authors and collaborators who have contributed data to this paper.

When compared to the data provided in JF McAlpine et al. (1979), the results of the present work (Table 1) show an increase from 101 to 116 families (excluding the unranked *Iteaphila* group formerly placed in Empididae). While the Oreoleptidae and the Richardiidae represent new records for the country, most of the additional families represent reclassification of taxa formerly combined with other families (see text below and Table 1 for details). The numbers of recorded and named species have also increased since 1979 for most families, with the exception of those that were split (e.g., Tipulidae and Empididae) or those in which numerous synonymies were uncovered (e.g., Bibionidae). Especially worth noting are the Sphaeroceridae and Anthomyzidae, with five- and nine-fold increases in species numbers since 1979, respectively. In each of these cases, the impressive increase in species numbers can be attributed to decades-long dedication to biosystematics study of particular families by individuals and institutions (S Marshall and colleagues at the University of Guelph, Ontario, for the Sphaeroceridae and K Barber at the Great Lakes Forestry Centre in Sault Ste. Marie, Ontario, for the Anthomyzidae).

JF McAlpine et al. (1979) compiled 7056 species of Diptera in Canada (mistakenly reported as 7058 in table 42) and estimated that an approximately equivalent number remained to be discovered. The 9620 species reported here represents a 36% increase since 1979. Significant advances have been made over the last four decades but some major gaps remain. While few families are known well enough to claim full coverage in Canada, the bulk of undescribed or unrecorded Canadian Diptera diversity is in the nematocerous families, especially those with diminutive and/or delicate adults such as the Chironomidae, Ceratopogonidae, Cecidomyiidae and Mycetophilidae, all of which are in great need of taxonomic attention (Table 1).

Table 1. Census of Diptera in Canada.

Taxon[1]	No. species reported in McAlpine et al. (1979)	No. species[2] currently known from Canada	No. BINs[3] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[3A]	Information sources
Nematocerous Diptera						
Infraorder Tipulomorpha						
Superfamily Tipuloidea						
Tipulidae	520[4]	216	190	30	all ecozones	Oosterbroek 2018
Cylindrotomidae	?[4]	7	6	0	Pacific Maritime, Boreal Plains, Boreal Shield, Newfoundland Boreal, Mixedwood Plains, Atlantic Maritime	Oosterbroek 2018
Limoniidae	?[4]	354	345	186	all ecozones	Oosterbroek 2018
Pediciidae	?[4]	56	52	0	all but Arctic	Oosterbroek 2018
Superfamily unassigned						
Trichoceridae	20	21	34	10	all ecozones	Pratt 1992
Infraorder unassigned						
Deuterophlebiidae	1	3	1	1	Boreal Cordillera, Montane Cordillera	
Nymphomyiidae	2	1	1	0	Boreal Shield, Atlantic Maritime, Mixedwood Plains	Courtney 1994
Infraorder Psychodomorpha						
Blephariceridae	11	7	4	3	all but Prairies	
Psychodidae	30	34	114	10–50	all ecozones	Quate 1955, Young and Perkins 1984
Tanyderidae	2	2	0	1	Montane Cordillera, Atlantic Maritime	
Infraorder Ptychopteromorpha						
Ptychopteridae	7	8	5	8	all but Arctic	Fasbender and Courtney 2017
Infraorder Culicomorpha						
Superfamily Chironomoidea						
Chironomidae	480	798	4266	1000	all ecozones	Ashe and O'Connor 2009, 2012
Superfamily Simulioidea						
Ceratopogonidae	180	263	1341	300	all ecozones	Borkent and Grogan 2009, Borkent 2016

Taxon[1]	No. species reported in McAlpine et al. (1979)	No. species[2] currently known from Canada	No. BINs[3] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[3A]	Information sources
Thaumaleidae	3	13	6	2–5	Pacific Maritime, Boreal Shield, Newfoundland Boreal, Montane Cordillera, Mixedwood Plains, Atlantic Maritime	Pivar et al. 2018
Simuliidae	110	164	153	20	all ecozones	Adler and Crosskey 2018
Superfamily Culicoidea						
Dixidae	21	34	23	10	all ecozones	
Corethrellidae	? [5]	1	1	0	Mixedwood Plains	Borkent 2008, 2014
Chaoboridae	9[5]	11	21	0	all ecozones	Borkent 1979, 1981, 2014
Culicidae	74	82	75	3	all ecozones	Thielman and Hunter 2007, Jackson et al. 2013, Giordano et al. 2015
Infraorder unassigned						
Axymyiidae	1	1	1	2	Mixedwood Plains	
Infraorder Bibionomorpha s. lat.						
Anisopodidae	5	5	15	2–5	all but Arctic	
Superfamily Scatopsoidea						
Scatopsidae	30	30	48	15–20	all ecozones	
Canthyloscelidae	1[6]	1	1	0	all but Arctic	
Infraorder Bibionomorpha s. str.						
Pachyneuridae	1	1	1	0	Pacific Maritime	
Bibionidae	40[7]	26	29	2–3	all ecozones	
Hesperinidae	?[7]	1	1	0	all Boreal ecozones	Papp 2010
Superfamily Sciaroidea						
Ditomyiidae	?[8]	3	9	5–10	all but Arctic	Munroe 1974
Bolitophilidae	? [8]	16	23	5	all ecozones	Bechev and Chandler 2011
Keroplatidae	? [8]	28	95	4	all ecozones	Evenhuis 2006
Mycetophilidae	350[8]	489	1199	500	all ecozones	
Cecidomyiidae	100	243	11,396	1000–16,000	all ecozones	Gagné and Jaschhof 2017
Diadocidiidae	? [8]	2	8	5	all but Arctic	Bechev and Chandler 2011

Taxon[1]	No. species reported in McAlpine et al. (1979)	No. species[2] currently known from Canada	No. BINs[3] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[3A]	Information sources
Sciaridae	30	129	2863	100–200	all ecozones	Mohrig et al. 2013
Suborder Brachycera						
Infraorder Xylophagomorpha						
Superfamily Xylophagoidea						
Xylophagidae	15	14	16	1–2	all but Arctic, Taiga Shield and Taiga Plains	Woodley 2011c
Infraorder Tabanomorpha						
Superfamily Rhagionoidea						
Rhagionidae	35[9]	48	57	10–15	all ecozones	Kerr 2010
Bolbomyiidae	?[9]	3	5	2	Pacific Maritime, Mixedwood Plains	Kerr 2010
Superfamily Tabanoidea						
Pelecorhynchidae	4	5	1	1	Montane Cordillera, Mixedwood Plains	
Oreoleptidae	0	1	2	0–1	Montane Cordillera, Boreal Cordillera	Zloty et al. 2005
Athericidae	3	2	3	0	all but Arctic and Prairies ecozones	
Tabanidae	132	142	90	0	All but Arctic	
Infraorder Stratiomyomorpha						
Superfamily Stratiomyoidea						
Xylomyidae	4	7	8	0	Pacific Maritime, Western Interior Basin, Boreal Shield, Mixedwood Plains, Atlantic Maritime	Woodley 2011a,b
Stratiomyidae	84	114	71	5–10	all but Arctic	Woodley 2001, 2011a
Infraorder unassigned						
Acroceridae	20	20	14	5	all but Arctic	
Nemestrinidae	2	2	0	0	Western Interior Basin	
Infraorder Asilomorpha						
Superfamily Asiloidea						

Taxon[1]	No. species reported in McAlpine et al. (1979)	No. species[2] currently known from Canada	No. BINs[3] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[3A]	Information sources
Bombyliidae	70[10]	105	86	44	all ecozones	
Mythicomyiidae	? [10]	1	2	5	all but Arctic, Taiga Shield, and Taiga Plains	Evenhuis 2002
Hilarimorphidae	7	7	1	1	all but Arctic	Webb 1974, 1975
Asilidae	125	222	141	5–10	all but Arctic	
Mydidae	2	2	1	0	Western Interior Basin, Mixedwood Plains	
Apioceridae	1	1	0	0	Western Interior Basin	
Scenopinidae	8	10	3	1–5	all but Arctic	
Therevidae	30	50	28	0	all ecozones	Webb et al. 2013
Infraorder Eremoneura						
Superfamily Empidoidea						
Iteaphila group	?[11]	17	23	9	all ecozones	
Oreogetonidae	? [11]	7	8	1–2	all but Arctic	
Empididae	300[11,12]	251	497	200	all ecozones	
Brachystomatidae	? [11]	11	11	2	all ecozones	
Hybotidae	? [11]	155	353	200	all ecozones	
Dolichopodidae s.l.	500[12]	508	657	200	all ecozones	Pollet et al. 2004
Lower Cyclorrhapha						
Lonchopteridae	4	7	6	0–1	all ecozones	Klymko and Marshall 2008
Superfamily Platypezoidea						
Platypezidae	21	39	46	12	all ecozones	
Superfamily Phoroidea						
Phoridae	127	135	110	300	all ecozones	
Superfamily Syrphidoidea						
Syrphidae	500	539	359	34	all ecozones	
Pipunculidae	45	85	170	170	all ecozones	
Schizophora: Acalytratae						
Superfamily Diopsidoidea						

Taxon[1]	No. species reported in McAlpine et al. (1979)	No. species[2] currently known from Canada	No. BINs[3] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[3A]	Information sources
Diopsidae	1	2	2	0	Mixedwood Plains	Feijen 1989
Psilidae	25	27	28	3	all but Arctic	
Strongylophthalmyiidae	1	2	2	0	Pacific Maritime, Prairies, Boreal Shield, Mixedwood Plains, Atlantic Maritime	Barber 2006
Tanypezidae	1	1	1	0	Boreal Shield, Mixedwood Plains	Lonsdale 2013
Superfamily Neroidea						
Micropezidae	16	16	11	0	all ecozones	Merritt and Peterson 1976
Superfamily Sciomyzoidea						
Sciomyzidae	85	120	143	15	all ecozones	Knutson et al. 1986
Sepsidae	17	19	27	5–10	all ecozones	Ozerov 2005
Conopidae	30	42	34	2–5	all but arctic ecozones	
Coelopidae	4	4	3	0	Arctic, Pacific Maritime, Taiga Shield, Boreal Shield, Atlantic Maritime	Vockeroth 1965, Mathis and McAlpine 2011
Dryomyzidae	7[13]	8	8	1–5	all but Arctic	Mathis and Sueyoshi 2011
Helcomyzidae	?[13]	1	0	0	Pacific Maritime	
Heterocheilidae	?[13]	1	0	0	Pacific Maritime	
Superfamily Lauxanoidea						
Lauxaniidae	64	78	90	10	all ecozones	
Chamaemyiidae	30	35	94	10	all ecozones	
Superfamily Tephritidoidea						
Tephritidae	40	122	82	21	all but Arctic	Foote et al. 1994
Platystomatidae	10	10	7	5	all but Arctic	
Ulidiidae	35[14]	35	29	20	all but Arctic	
Lonchaeidae	97	99	78	13	all but Arctic	
Pyrgotidae	3	3	1	0	Pacific Maritime, Prairies, Mixedwood Plains	
Richardiidae	0	1	0	0	Mixedwood Plains	
Pallopteridae	9	9	7	9	all but Arctic	

Taxon[1]	No. species reported in McAlpine et al. (1979)	No. species[2] currently known from Canada	No. BINs[3] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[3A]	Information sources
Piophilidae	31	31	35	4	all ecozones	Rochefort and Wheeler 2015
Superfamily Opomyzoidea						
Agromyzidae	305	450	772	76	all ecozones	
Clusiidae	6	22	22	0	all but Arctic	Caloren and Marshall 1998, Lonsdale and Marshall 2007
Asteiidae	5	5	8	3	all Boreal and Maritime ecozones, Montane Cordillera, Prairies, Mixedwood Plains	
Anthomyzidae	4	37	33	3	all but Arctic	Roháček and Barber 2016
Periscelididae	2	3	8	5	all Boreal and Maritime ecozones, Montane Cordillera, Prairies, Mixedwood Plains	Mathis and Rung 2011
Odiniidae	5	6	8	3	all Boreal and Maritime ecozones, Montane Cordillera, Prairies, Mixedwood Plains	Gaimari and Mathis 2011
Opomyzidae	10	11	11	4	all ecozones	Wheeler et al. 1999
Aulacigastridae	3	2	3	1	all but Arctic	Rung and Mathis 2011
Superfamily Carnoidea						
Chloropidae	100	140	361	260	all ecozones	
Milichiidae	11	13	55	20–30	all ecozones	Brake 2009, Brochu and Wheeler 2009
Canacidae	5[15]	10	11	0	all ecozones	Munari and Mathis 2010
Carnidae	8	12	21	5–10	all ecozones	Brake 2011, Stuke 2016
Acartophthalmidae	2	1	1	1	all but Arctic	
Superfamily Ephydroidea						
Drosophilidae	60	79	102	20–25	all ecozones	Brake and Bächli 2008, Miller et al. 2017, Bächli 2018
Ephydridae	150	197	182	10–15	all ecozones	Mathis and Zatwarnicki 1995
Curtonotidae	1	1	1	0	Prairies, Boreal Plains, Mixedwood Plains	Klymko and Marshall 2011
Diastatidae	5	7	11	2–3	all ecozones	Mathis and Barraclough 2011
Camillidae	1	2	1	0	Mixedwood Plains	
Braulidae	1	1	0	0	Prairies	

Taxon[1]	No. species reported in McAlpine et al. (1979)	No. species[2] currently known from Canada	No. BINs[3] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[3A]	Information sources
Superfamily Sphaeroceroidea						
Sphaeroceridae	35	184	190	20	all ecozones	Roháček et al. 2001
Heleomyzidae	74[16]	72	74	38	all ecozones	
Chyromyidae	5	5	10	5	Pacific Maritime, Prairies, Boreal Shield, Mixedwood Plains, Atlantic Maritime	
Schizophora: Calyptratae						
Superfamily Hippoboscoidea						
Hippoboscidae	13[17]	17	1	0	all but Arctic	Graciolli et al. 2007
'Muscoid grade'						
Fanniidae	?[18]	84	85	8–10	all ecozones	
Muscidae	525[18]	440	479	40	all ecozones	
Anthomyiidae	375	515	412	10–30	all ecozones	Griffiths 1982–2004
Scathophagidae	130	126	115	29	all ecozones	
Superfamily Oestroidea						
Calliphoridae	40	62	39	0	all ecozones	
Oestridae	15	17	7	0	all ecozones	
Rhinophoridae	2	2	3	1	Boreal Shield, Newfoundland Boreal, Mixedwood Plains, Atlantic Maritimes	O'Hara et al. 2015
Sarcophagidae	85	135	132	5–15	all ecozones	
Tachinidae	500	736	647	100	all ecozones	O'Hara and Wood 2004
Total	**7056**	**9620**	**29,583**	**5205–20,458**		

[1]Higher classification follows a consensus of opinions of co-authors and collaborators; family limits follow Pape et al (2011). [2]Numbers compiled from published records and collection holdings. [3]Barcode Index Number as defined in Ratnasingham and Hebert (2013). [3A]See figure 1 in Langor (2019) for a map of ecozones. [4]McAlpine et al. (1979) included Cylindrotomidae, Limoniidae and Pediciidae in the Tipulidae.[5]McAlpine et al. (1979) included Corethrellidae in Chaoboridae. [6]McAlpine et al. (1979) included this species in the Synneuridae which has since become a subfamily of the Canthyloscelidae. [7]McAlpine et al. (1979) included Hesperinidae in Bibionidae. [8]McAlpine et al. (1979) included Ditomyiidae, Bolitophilidae, Keroplatidae and Diadocidiidae in the Mycetophilidae. [9]McAlpine et al. (1979) included Bolbomyiidae in Rhagionidae. [10]McAlpine et al. (1979) included Mythicomyiidae in Bombyliidae. [11]McAlpine et al. (1979) included *Iteaphila* group, Oreogetonidae, Brachystomatidae and Hybotidae in Empididae. [12]McAlpine et al. (1979) included the Microphorinae and Parathalassiinae in the Empididae. [13]McAlpine et al. (1979) included the Helcomyzidae and Heterocheilidae in the Dryomyzidae. [14]McAlpine et al. (1979) included these species under Otitidae, now replaced by the senior valid name Ulidiidae. [15]McAlpine et al. (1979) included 4 species in the Tethinidae which has since become a subfamily of Canacidae. [16]McAlpine et al. (1979) included 4 species in the Trixoscelidinae which has since become a subfamily of Heleomyzidae. [17]McAlpine et al. (1979) included 1 species in the Nycteribiidae and 1 in the Streblidae, both of which have since become subfamilies of Hippoboscidae. [18]McAlpine et al. (1979) included Fanniidae in Muscidae.

Nematocerous Diptera

The nematocerous Diptera (Lower Diptera), previously known as Nematocera, include those species of adult flies with elongate antennae composed of at least four flagellomeres. The group includes 36 extant families worldwide, of which 33 occur in Canada. The concepts and names of many families have changed since JF McAlpine et al. (1979) (see below and Table 1).

As adults, nematocerous Diptera tend to be long-legged and, compared to brachyceran Diptera, weaker fliers. Larvae are found in a wide array of habitats and include a large number of aquatic and semiaquatic taxa (see Tipulomorpha and Culicomorpha below), fungal feeders, gall makers, detritus feeders, predators, and even parasites, among others. The biting flies are mostly in the Culicomorpha and include those species that vector important diseases of humans, domestic animals and wildlife.

The nematocerous Diptera are clearly paraphyletic in relation to the Brachycera, although the exact sister group of Brachycera within the nematocerous Diptera is not certain (Woodley et al. 2009). The phylogenetic relationships among families have also been, in part, rather unstable. The phylogenetic analysis by Wood and Borkent (1989) laid groundwork, which was largely supported by Oosterbroek and Courtney (1995). Michelsen (1996) proposed the Neodiptera, a clade including Axymyiidae, Pachyneuridae, Bibionidae, Sciaroidea, Perissommatidae, Scatopsoidea, Anisopodidae, and Brachycera based on characters of the adult prothorax and cervical sclerites. However, a study of the male internal reproductive system by Sinclair et al. (2007) did not support the Neodiptera and indicated instead that the Blephariceridae + Psychodidae + Trichoceridae + Anisopodidae + Brachycera formed a monophyletic assemblage.

Molecular analyses have proposed a wide array of differing relationships that conflict with each other, at least in part, and with most morphological analyses (Pawlowski et al. 1996, Friedrich and Tautz 1997, Miller et al. 1997, Bertone et al. 2008). Wiegmann et al. (2011) and Lambkin et al. (2013) have provided the most recent overall interpretation of family relationships based on both morphological and molecular evidence, but these have major issues of interpretation (Borkent 2018). See below for summaries of the limits and phylogeny of the infraorders.

Infraorder Tipulomorpha (F Brodo)

The major change to this infraorder since JF McAlpine et al. (1979) is the division of the Tipulidae into four families: Tipulidae, Cylindrotomidae, Limoniidae, and Pediciidae. Most European workers had recognized the family status of the first three taxa for decades, as Byers (1992) carefully documented while still favouring the inclusion of all craneflies in a single family. Starý (1992) elevated the pediciines from a tribe of the limoniines to full family status. The recognition of four families of crane flies remains a contentious issue among taxonomists. Molecular analyses (Bertone et al. 2008, Wiegmann et al. 2011) as well as a recent morphological study (Lukashevich and Ribeiro 2018) indicate that Limoniidae are paraphyletic, thereby calling into question the family ranking of these crane fly taxa. In the present work we have decided to follow the four-family concept, mostly to remain aligned with the classification used in the online Catalogue of the Craneflies of the World (Oosterbroek 2018) and BOLD. Tipulomorpha also include Trichoceridae (winter crane flies), a small family now formally recognized as the sister group to the Tipulidae s. lat. (crane flies) (Bertone et al. 2008, Wiegmann et al. 2011, Wiegmann and Yeates 2017).

Most recent taxonomic work in this infraorder has focused on the crane flies, bringing the total number of Canadian species to 633, mainly in the families Limoniidae (354 species in Canada) and Tipulidae (216), representing an increase of 21% since JF McAlpine et al. (1979) (Table 1). Monographs of *Chionea* Dalman (Byers 1983), *Dicranoptycha* Osten Sachen (Young 1987) and *Symplecta* (*Symplecta* Meigen) (Starý and Brodo 2009) in the Limoniidae and of *Nephrotoma* Meigen (Tangelder 1983, Oosterbroek 1984), *Prionocera* Loew (Brodo 1987), and *Tipula* (*Eremotipula* Alexander) (Gelhaus 2005) in the Tipulidae, have added species to our fauna, as did the documentation of crane flies of the Canadian Arctic (Brodo 1990, 2000) and additions to the eastern Canadian aquatic crane flies (LeSage and Harrison 1981, Sinclair 1988, Gathmann and Williams 2006). There are nearly as many BINs as there are recorded species of crane flies in Canada, although not every species has been barcoded, and it is expected that over 200 additional species will eventually be documented, mostly in the Pediciidae (Table 1). The number of Trichoceridae (21) has not changed much since 1979, but 10 more species are expected in Canada (Table 1).

Crane flies are mostly aquatic or semi-aquatic but a few, notably the pest species, are terrestrial and associated with roots of grasses and herbaceous plants. Many larvae are saprophagous, fungivorous, (*Limonia* Meigen and *Metalimnobia* Matsumura species), or carnivorous (some Limoniidae and Pediciidae species), and Cylindrotomidae are phytophagous. *Tipula paludosa* Meigen and *T. oleracea* (Linnaeus) are established pests of dairy lands and golf courses (Gelhaus 2001). The larvae of winter crane flies feed on detritus and fungi and are often associated with small animal burrows or bird's nests (Dahl 1973).

Nymphomyiidae and Deuterophlebiidae (BJ Sinclair)

The placement of these two families remains controversial. Previously, they have both been assigned to the infraorder Blephariceromorpha (Wood and Borkent 1989, Oosterbroek and Courtney 1995), Nymphomyiidae alone as sister to the Culicomorpha (Sæther 2000), and one or both families as sister to all Diptera (Bertone et al. 2008, Wiegmann et al. 2011, Lambkin et al. 2013, Sinclair et al. 2013). Deuterophlebiidae are often considered sister to Blephariceridae (Wood and Borkent 1989, Oosterbroek and Courtney 1995) or possibly sister to Nymphomyiidae (Schneeberg et al. 2011, 2012). With the generally accepted assignment of Blephariceridae to the re-defined Psychodomorpha (see below), we have chosen not to assign these two families to infraorder.

Only one species of minute Nymphomyiidae (<2 mm long) is recorded from Quebec and New Brunswick (Courtney 1994). The second nymphomyiid species listed in JF McAlpine et al. (1979) was re-interpreted and transferred to Chironomidae (Kevan and Cutten 1981). The Deuterophlebiidae were revised by Courtney (1990) and are confined to the mountains of western Canada where three species are known and another expected (Table 1). Both families have aquatic immature stages that are morphologically adapted to fast-flowing waters.

Infraorder Psychodomorpha (G Curler and BJ Sinclair)

The limits of the Psychodomorpha have either been based on adult thoracic features (Hennig 1973, JF McAlpine et al. 1979) or defined by a suite of larval characters (Wood and Borkent 1989). The latter grouping has been viewed as a heterogeneous assemblage of non-Neodiptera (Psychodidae, Trichoceridae) and Neodiptera (Perissommatidae, Anisopodidae and Scatopsoidea) families (Michelsen 1996). Recent analyses support a three-family concept, namely Blephariceridae, Psychodidae and Tanyderidae (Bertone et al. 2008, Wiegmann et al. 2011); however, these families did not form a clade in the analyses in Lambkin et al. (2013). Additional support for a relationship between Psychodidae and Tanyderidae is based on wing venation (Bertone et al. 2008, Borkent and Sinclair 2012). The three family concept of this infraorder is followed here.

The number of species of Blephariceridae known from Canada (7) has decreased from the 1979 estimate, due to several synonymies (Hogue 1987, Courtney 2000), and three more species are expected (Table 1). Two of the four Nearctic species of Tanyderidae occur in Canada and one more may eventually be found here (Table 1). The immatures of blephacerids are conspicuously adapted to fast-flowing waters while those of the Tanyderidae occur in slower moving streams. The larval biology and morphology of western tanyderid species are documented in Wipfler et al. (2012).

The Psychodidae fauna of Canada is known to include three subfamilies, 15 genera and 34 species (Quate 1955, Young and Perkins 1984, G Curler unpubl. data; Table 1). Phlebotominae and Trichomyiinae are represented by three and one species, respectively; all other records are Psychodinae. There are more than three times as many BINs as recorded species in this family indicating that a relatively large number of species (we estimate 10–50) remain to be documented (Table 1). Species of *Lutzomyia* França are hematophagous and mainly tropical or subtropical, with Canadian records representing the northernmost limits in the western Hemisphere for Phlebotominae. Most species of Nearctic Psychodinae are detritivores living among moist decaying plant material or in madicolous habitats along stream margins, headwaters or seeps. In addition, several species of Psychodinae occur in homes and other habitats with anthropogenic influence (e.g., sewage treatment facilities, latrines, farmyards, polluted drainages).

Infraorder Ptychopteromorpha (BJ Sinclair)

Wood and Borkent (1989) proposed the infraorder Ptychopteromorpha for two small families of flies, Ptychopteridae and Tanyderidae. Molecular and morphological evidence supporting the transfer of the Tanyderidae to the Psychodomorpha (Bertone et al. 2008, Borkent and Sinclair 2012), has resulted in this infraorder being represented solely by the family Ptychopteridae. The phylogenetic placement of this infraorder among the nematocerous Diptera remains disputed, although the multi-chambered male accessory glands are similar to those of Bibionomorpha and Culicomorpha (Sinclair et al. 2007). Currently four Canadian species in Bittacomorphinae and four species in Ptychopterinae are known for this entirely aquatic lineage, but an additional eight species are expected to eventually be found in the country (Table 1). The North American species of the subfamily Bittacomorphinae have recently been revised and keys to species provided (Fasbender and Courtney 2017).

Infraorder Culicomorpha (A Borkent and DC Currie)

This infraorder includes eight families, all of which occur in Canada (Table 1). This is one more than recognized in JF McAlpine et al. (1979) due to the subsequent recognition of Corethrellidae as distinct from the Chaoboridae (Wood and Borkent 1989). Phylogenetic relationships among the families of Culicomorpha are well known and have considerable support (Borkent 2012, Kutty et al. 2018) but the position of Chironomidae needs further testing, as either the sister group of all remaining families, or as the sister group of Ceratopogonidae.

With 798 named species, the Chironomidae (non-biting midges) currently stand as the most species-rich family of Diptera in Canada, and at least 1000 additional species are expected to occur in the country (Table 1). The remaining families of non-biting midges, namely Chaoboridae (11 species in Canada), Thaumaleidae (13) and Dixidae (34) are represented by relatively few species (Table 1). Focused collecting at microhabitats of the latter two families has greatly increased the number of Canadian records (Moulton 2017, Pivar et al. 2018) and as many as 15 additional species are expected to occur in the country.

The remaining four families have some or all species with biting females. The Culicidae (82 species in Canada), Simuliidae (164) and Ceratopogonidae (263) are all quite diverse, whereas a single species of Corethrellidae (formerly in Chaoboridae) is known for the country (Table 1). The Culicidae (mosquitoes) and Simuliidae (black flies) are both very well known, but while only three additional mosquito species are estimated to be unrecorded, a further 20 species of black flies are expected to eventually be documented in Canada (Table 1). The Ceratopogonidae (biting midges) are by far the most poorly known of biting flies. There are close to ten times as many BINs as recorded species for the group and it is thought that less than half of the Canadian fauna is known to date (Table 1).

The medical and veterinary significance and dominant presence in aquatic systems of so many Culicomorpha has meant that they are some of the best known of the Diptera, including interpretation of their immatures. Taxa may be identified using the following references: Chaoboridae (Sæther 1972, larvae, pupae, adults), Corethrellidae (Borkent 2008, adults; McKeever and French 1991, larvae, pupae), Culicidae (Mattingly 1971, larvae, pupae, adults to genus; Wood et al. 1979, larvae, adults) Chironomidae (Wiederholm 1986, 1989, pupae, adults to genus; Andersen et al. 2013, larvae to genus), Ceratopogonidae (Downes and Wirth 1981, adults to genus; Borkent 2014, pupae to genus), Simuliidae (Adler et al. 2004, larvae, pupae, adults), and Thaumaleidae (Arnaud and Boussy 1994, Pivar et al. 2018, Sinclair 1996, adults). Dixidae are poorly understood and require fundamental revision (Greenwalt and Moulton 2016).

Immature Culicomorpha are aquatic in both lotic and lentic habitats where they are prey for aquatic organisms, including fish. The Chironomidae are especially common, occupying virtually every aquatic niche, including tree holes, rivers, lakes, and even tidal habitats where their abundant larvae often have a strong influence on aquatic community structure. As adults, the Culicidae are the most prevalent, ubiquitous and persistent blood feeders in Canada, where some species are vectors of arboviruses, including West Nile virus, currently the most common mosquito-borne infection of humans in the country (Roth et al. 2010). Simuliidae are also quite common and sometimes very abundant in large rivers and lake outlets, with the resulting blood feeding activities affecting both humans and livestock. Most Ceratopogonidae are predaceous but the majority of *Culicoides* Latreille species have biting females. One species, *C. sonorensis* Wirth and Jones, is a vector of Bluetongue virus of cattle and other ruminants in south-central British Columbia (Sellers and Maarouf 1991). Female Corethrellidae are known only to bite frogs.

Axymyiidae (BJ Sinclair)

The phylogenetic relationships and systematic assignment of the family remains disputed (Sinclair 2013). It has been variously assigned to a monotypic Axymyiomorpha due to the absence of synapomorphies (Wood and Borkent 1989, Borkent and Sinclair 2012, Ševčík et al. 2016), to a variably defined Bibionomorpha (Oosterbroek and Courtney 1995, Grimaldi and Engel 2005, Pape et al. 2011), to Axymyiomorpha (incl. Axymyiidae, Perissommatidae, *Pachyneura* Zetterstedt) (Amorim 1993), or considered a sister family to Bibionomorpha s. str. (Wiegmann et al. 2011, Sinclair et al. 2013).

Axymyiidae are a small family of Holarctic flies with a single eastern species, *Axymyia furcata* McAtee, recorded from Canada (Ontario, Quebec) but two species from the Pacific Northwest (Sinclair 2013, Fitzgerald and Wood 2014) are expected to occur in British Columbia (Table 1). Detailed descriptions of all life stages and keys to Nearctic species are provided by Wood (1981), Wihlm et al. (2012), and Fitzgerald and Wood (2014). The life history of the eastern Nearctic *A. furcata* is well documented (Wihlm and Courtney 2011) and all known larval stages in Axymyiidae are restricted to burrowing in water-permeated wood.

Infraorder Bibionomorpha s. lat. (BJ Sinclair)

The boundaries of the Bibionomorpha have revolved around the nematocerous families included in the Neodiptera by Michelsen (1996), but there has been little consensus. Hennig (1973) favoured a broad concept that included the Bibionidae, Pachyneuridae, Sciaroidea, Scatopsoidea, Anisopodidae, Axymyiidae, and Perissommatidae (non-Nearctic), whereas Wood and Borkent (1989) restricted the infraorder to Bibionidae, Pachyneuridae, and Sciaroidea. Amorim (1993) included the following groups in the Bibionomorpha: Bibionidae, Pachyneuridae (in part), Sciaroidea, and Anisopodidae. More recently molecular analyses have again supported the broad concept sensu Hennig (1973), exclusive of Perissommatidae (Wiegmann et al. 2011) or exclusive of both Perissommatidae and Axymyiidae (Bertone et al. 2008). Grimaldi and Engel (2005) also recognized a broad concept, although exclusive of Scatopsoidea. Recently Sinclair et al. (2013) showed that the male terminalia of Perissommatidae show derived attributes of the Bibionomorpha s. str. Given these conflicting classifications we have chosen to use both narrow (s. str.) and broad (s. lat.) concepts of the group as followed in Ševčík et al. (2016). The phylogenetic relationships within the Bibionomorpha s. str. have been studied by Wood and Borkent (1989), Amorim and Rindal (2007), and Ševčík et al. (2016).

Three families are excluded from Bibionomorpha s. str. due to the absence of a highly modified and multi-chambered accessory gland and different configuration of the ejaculatory apodeme (Sinclair et al. 2013). Anisopodidae and Canthyloscelidae (= Synneuridae) have low diversity in Canada (six and one species, respectively) but the Scatopsidae are represented by 30 species, with 15–20 more expected (Table 1). Canadian Scatopsidae can be identified using the genus key in Cook (1981) and species keys referred to therein. The Anisopodidae have not received much recent taxonomic attention in the Nearctic, although species of *Sylvicola* Harris were revised by Pratt and Pratt (1980). The larvae of these families are saprophagous and found in moist decaying organic matter.

Infraorder Bibionomorpha s. str. (BJ Sinclair)

Seven of the ten families of Bibionomorpha s. str. found in Canada are species-poor, including Pachyneuridae (1 species in Canada), Bibionidae (26), Hesperinidae (1; formerly in Bibionidae), and the following four families, formerly included in Mycetophilidae by J.F. McAlpine et al. (1979): Ditomyiidae (3), Bolitophilidae (16), Keroplatidae (28) and Diadocidiidae (2) (Table 1). The number of species of Bibionidae known from Canada has decreased by approximately a third from the 1979 estimate (Table 1), primarily due to numerous synonyms discovered subsequently (S Fitzgerald pers. comm.). For all families, a few additional species are eventually expected to be found in Canada.

The remaining three families are much more diverse. The number of Sciaridae (129 species in Canada) has quadrupled since 1979 (Table 1), primarily due to ongoing revisionary studies by Scandinavian and German colleagues (see Mohrig et al. 2013 and subsequent papers by these authors). The numbers of known Cecidomyiidae (243 species in Canada) have more than doubled since 1979 and those of Mycetophilidae now reach 489 species, thereby representing the highest documented diversity of any family in this infraorder (Table 1). Diversity estimates based on BINs are all much higher than the known fauna for these three families, and especially for the Cecidomyiidae, where they suggest that the known species represent only approximately 2% of the Canadian fauna (Table 1). Hebert et al. (2016) estimated 16,000 species of Cecidomyiidae in Canada, a 10-fold increase from the diversity predicted in 1979, a remarkable figure, but one consistent with the newly appreciated diversity of this family in temperate (Jaschhof and Jaschhof 2009, 2013) and tropical (Borkent et al. 2018, Brown et al. 2018) sites. As we are uncertain whether BINs indicate number of species, it is difficult to predict the number of species in Canada and it is possible that anywhere from 1000–16,000 species remain to be documented in the country. The great diversity of this family is in part due to the apparent host specificity of plant-feeding species, with several of economic importance. Hundreds of species of sciarids and mycetophilids also await documentation in Canada (Table 1).

Although knowledge of the species diversity of Cecidomyiidae appears sparse, general information and identification to genera of the subfamily Cecidomyiinae are provided by Gagné (1989, 2018). The genera of Mycetophilidae can be keyed in Vockeroth (1981), but some subfamilies are now recognized as families (see above). Several genera of Mycetophilidae have been revised since 1979, including: *Acomoptera* Vockeroth (Kerr 2011), *Leptomorphus* Curtis (Borkent and Wheeler 2012), *Mycomya* Rondani (Väisänen 1984), *Phthinia* Winnertz (Fitzgerald and Kerr 2014), *Sciophila* Meigen (Zaitzev 1982) and *Trichonta* Winnertz (Gagné 1981).

Members of the Bibionomorpha s. str. are most abundant in moist woodlands, with many larvae found in fungi, in dead wood and other decaying plant material, beneath bark, and in a variety of other microhabitats. The majority of Cecidomyiidae are associated with plants, forming galls or developing in flowers and leaf rolls, whereas others are inquilines on plant hosts damaged by other gall midges. Some are also associated with fungi, or free-living predators. A number of species of Cecidomyiidae are serious pests of cereals, Brassicaceae, conifers, apple trees, etc., and a zoophagous species is used in the biocontrol of aphids (Darvas et al. 2000).

Suborder Brachycera: Lower Brachycera

Brachycera are a monophyletic suborder traditionally defined by a short antenna with a modified flagellum (third antennal segment) made up of 3–8 fused flagellomeres. The group is very diverse with 83 families occurring in Canada (Table 1). The Brachycera are usually divided into the paraphyletic Lower Brachycera and the monophyletic Eremoneura, which contains both the monophyletic Empidoidea and Cyclorrhapha.

The Lower Brachycera are a large and undoubtedly unnatural assemblage of mostly large and conspicuous flies. Until recently, this group was widely referred to as the Orthorrhapha, but morphological and molecular evidence indicate that it is paraphyletic, at least with respect to the Cyclorrhapha (Woodley 1989). With the assignment of the Empidoidea to the Eremoneura (which includes both Cyclorrhapha and Empidoidea) (Griffiths 1972), the term Lower Brachycera is now used to refer to the non-Eremoneuran Brachycera. Considerable research globally has focused on this group, especially among the therevoid clade (e.g., Woodley 1989, Sinclair et al. 1994, Yeates 1994, 2002, Wiegmann et al. 2000, 2011, Winterton et al. 2007, Trautwein et al. 2010, Shin et al. 2017). Division of the Lower Brachycera is largely stable, with well supported Xylophagomorpha (Woodley 1989), Tabanomorpha (Sinclair et al. 1994, Wiegmann et al. 2000, 2011, Kerr 2010), Stratiomyomorpha (Sinclair et al. 1994, Wiegmann et al. 2011) and Asilomorpha (Woodley 1989, Wiegmann et al. 2011). Several families remain difficult to assign phylogenetically and continue to float between infraorders, i.e., Acroceridae, Hilarimorphidae, Nemestrinidae. Major changes since JF McAlpine et al. (1979) include the recognition of a new family Oreoleptidae (Zloty et al. 2005) and elevation of the Bolbomyiidae (Kerr 2010) and Mythicomyiidae (Evenhuis 2002) from Rhagionidae and Bombyliidae, respectively.

Infraorder Xylophagomorpha (BJ Sinclair)

This infraorder is represented by the single family Xylophagidae, although some authors have divided it into smaller family units (Woodley 1989). The Xylophagomorpha are considered the sister group to the Tabanomorpha in most analyses (Wiegmann et al. 2000, 2011, Sinclair et al. 2013, Shin et al. 2017). Five genera and 14 species are recorded from Canada (Woodley 2011c), similar to numbers recorded in 1979, and another one or two species are expected (Table 1). Current knowledge of the group, generic diagnoses, a key to world genera and catalogue of species have been compiled by Woodley (2011c). Xylophagids are found primarily in wooded and forest regions where the larvae are predators of wood inhabiting insects.

Infraorder Tabanomorpha (BJ Sinclair)

Woodley (1989) and Sinclair et al. (1994) summarized the morphological evidence for relationships of the Tabanomorpha. Much of the uncertainty of higher level phylogeny of the Tabanomorpha is due to doubts concerning the limits and monophyly of the Rhagionidae. Through combined morphological and molecular analyses, Kerr (2010) redefined the family Rhagionidae, establishing its monophyly and recognizing the families Austroleptidae (Australia and Chile) and Bolbomyiidae. The classification of Kerr (2010) is followed here.

Six families of Tabanomorpha occur in Canada and these are organized in two superfamilies. In Rhagionoidea, Bolbomyiidae include three known species in Canada and two more are expected (Table 1). Rhagionidae include 48 species, a substantial increase from 1979, and 10–15 additional species are expected (Table 1). No modern species keys are available for the large genera in the Rhagionidae and most of the family is in need of revision. Adults are common in forested regions, where most larvae occur in damp forest litter and beneath mats of mosses. The immature stages of the Bolbomyiidae are unknown.

In Tabanoidea, three families have low diversity: Pelecorhynchidae (5 species in Canada), Athericidae (2), and the recently erected monotypic family Oreoleptidae (1) (Zloty et al. 2005; Table 1). In part due to their large size and the biting habits of most females, the Tabanidae (horse flies and deer flies) are much better known than most insects in Canada, with keys and illustrations known for all 142 species (Teskey 1990, Thomas and Marshall 2009, Thomas 2011) as well as a complete catalogue (Burger 1995). With the slight increase in species richness since 1979, this family is now considered to be very well known and no additional species are expected in Canada. The larvae of Athericidae and Oreoleptidae occur in riffle zones and/or vegetation of cool streams and flowing rivers. Those of Pelecorhynchidae and Tabanidae are predators of invertebrates found mostly in wetland soils.

Infraorder Stratiomyomorpha (M Hauser)

The infraorder Stratiomyomorpha includes three families, of which the Stratiomyidae and the Xylomyidae occur in Canada while the Pantophthalmidae are restricted to the Neotropics. The sister-group relationship of Stratiomyidae and Xylomyidae is strongly supported, especially by larval characters (Woodley 1989).

The Stratiomyidae are represented by 114 species in Canada, a substantial increase from 1979 (Table 1), and 5–10 more are expected (Table 1). At least five species of Stratiomyidae have been introduced from Europe, Australia and the USA (Swann et al. 2006, Marshall et al. 2015). The fauna is rather well known, although revisions are needed especially for groups with aquatic larvae (*Caloparyphus* James, *Stratiomys* Geoffroy, *Odontomyia* Meigen, *Nemotelus* Geoffroy), which could reveal a few undescribed species as well as some synonyms. Only two genera and seven species of Xylomyidae are known from Canada (Woodley 2011b) but numbers have nearly doubled since 1979 (Table 1); a key to the Canadian species is provided by Webb (1984).

Stratiomyids are usually found in humid and forested areas where their larvae are terrestrial or aquatic, feeding mostly on decaying plant and animal materials (Woodley 2001). The larvae of Xylomyidae are found under the bark of trees but little is known of the biology of these uncommon flies.

Acroceridae and Nemestrinidae (BJ Sinclair)

Both families have been assigned to the Nemestrinoidea based on the parasitic larvae with hypermetamorphosis (Woodley 1989), but this infraorder (including Bombyliidae) is now generally considered polyphyletic with the three parasitic families considered to be distantly related (Yeates 1994, 2002, Winterton et al. 2007, Wiegmann et al. 2011, but see Shin et al. (2017) for a divergent opinion). Only two species of Nemestrinidae are found in Canada (Table 1), the same as in 1979, and these are confined to the central arid regions of British Columbia. Twenty species of Acroceridae are recorded from Canada; a key to New World genera is available in Schlinger et al. (2013), but only one recent revision has included Canadian records (Borkent et al. 2016). A few more acrocerid species are therefore expected in the country. The larvae of Acroceridae are internal parasites of spiders, whereas those of Nemestrinidae are parasitic on grasshoppers and beetles.

Infraorder Asilomorpha (BJ Sinclair)

The higher classification and phylogeny of the Asilomorpha (containing one superfamily – Asiloidea) has received a great deal of focus over the past decades (e.g., Woodley 1989, Winterton et al. 2007, Trautwein et al. 2010, Winterton and Ware 2015). Discussion of the limits of the Asilomorpha, which appear paraphyletic in relation to Eremoneura (Sinclair et al. 1994, Trautwein et al. 2010), has primarily revolved around the placement of the genus *Hilarimorpha* Schiner, which has previously been assigned to the Bombyliidae, Therevidae, or its own separate family considered sister to the Bombyliidae, Asiloidea or Eremoneura (Trautwein et al. 2010).

Eight families of generally large and showy Asilomorpha occur in Canada, five of which are relatively species-poor, including Apioceridae (1 species in Canada), Mydidae (2), Mythicomyiidae (1), Hilarimorphidae (7), and Scenopinidae (10) (Table 1). The diversity of Apioceridae and Mydidae in the southern interior of British Columbia was documented by Cannings (2006), whereas the Mythicomyiidae, Hilarimorphidae and Scenopinidae are poorly documented and more species are expected in Canada (Table 1).

The Canadian fauna of the larger families of Asilomorpha has received much attention since JF McAlpine et al. (1979). The number of Asilidae (222 species in Canada) has nearly doubled, primarily through the recent publications of Cannings (1994, 1997, 2002), and a few additional species may eventually be added (Table 1). The diversity of the Bombyliidae in Canada is outlined in a world catalogue (Evenhuis and Greathead 1999), but the Canadian fauna had largely been ignored for decades until the publication of an illustrated key to eastern Canadian species (Kits et al. 2008). The 105 species of Bombyliidae currently documented represent a 50% increase since 1979 and more than 40 additional species are expected in Canada (Table 1). A world catalogue of Therevidae outlines the Canadian diversity of this family (Webb et al. 2013). With 50 species now recorded from Canada, this family is very well known and no additional species are expected (Table 1).

The Asilomorpha display a wide range of habitats and life histories. The Scenopinidae have predaceous larvae associated with wood-boring larvae, bird's nests, and carpet beetle larvae. The larvae of Hilarimorphidae are unknown and adults are sporadically collected, with verified records indicating that they frequent riverbanks. Adult Mythicomyiidae are flower visitors, feeding on pollen and nectar, whereas the few larval observations suggest egg pod predators of grasshoppers and inquilines in ant nests. Adult Asilidae are efficient predators with highly modified mouthparts; the larvae live in soils and rotting wood. Larvae of Therevidae are often found burrowing through sandy soils (Irwin and Lyneborg 1981). The larvae of Mydidae and Apioceridae are predaceous in sandy soils and adults are flower feeders. The Bombyliidae are generally parasitic on various Holometabola or predaceous on egg pods of grasshoppers (Hall 1981), with adults visiting flowers.

Suborder Brachycera: Eremoneura

The monophyly of Eremoneura is strongly supported and the group comprises the monophyletic Empidoidea and Cyclorrhapha (Cumming et al. 1995, Sinclair and Cumming 2006, Wiegmann et al. 2011, Lambkin et al. 2013). The Eremoneura now also include the monotypic Nearctic family Apystomyiidae (not in Canada), which is considered to be either the sister group of Cyclorrhapha (Trautwein et al. 2010, Wiegmann et al. 2011), or the sister group of the entire Eremoneura (Sinclair et al. 2013). The Eremoneura as a group was not recognized in JF McAlpine et al. (1979).

Superfamily Empidoidea (JM Cumming and BJ Sinclair)

The Empidoidea are a monophyletic lineage comprising five main families, namely Atelestidae, Brachystomatidae, Empididae, Hybotidae, Dolichopodidae s. lat. (including Microphorinae and Parathalassiinae) (Sinclair and Cumming 2006) and three previously unassigned genus-groups. Some authors have treated two of these genus-groups as separate families (i.e., Homalocnemidae (non-Nearctic) and Oreogetonidae), because of the availability of family-group names (Thompson 2009, Pape et al. 2011, Marshall 2012). The *Iteaphila* group has recently been elevated to subfamily rank within yet another newly recognized Empidoidea family, Ragadidae (Wahlberg and Johanson 2018). Recognition of this family is controversial and generally not accepted by the empidoid community, nor is it accepted herein.

Five families of this primarily predaceous group occur in Canada (Table 1): Oreogetonidae (7 species), Empididae (251), Brachystomatidae (11), Hybotidae (155), and Dolichopodidae s. lat. (508), plus the *Iteaphila* genus-group (17). Apart from the Dolichopodidae (exclusive of Microphorinae and Parathalassiinae), the remaining groups were lumped into the Empididae in JF McAlpine et al. (1979). The current total of 949 Canadian species of Empidoidea is a moderate increase over the 800 species recorded by JF McAlpine et al. (1979). Many empidoid genera still require study and recent Nearctic revisions (e.g., Sinclair et al. 2011, Sinclair and MacDonald 2012, Brooks and Cumming 2017) have resulted in numerous new species descriptions. The key to the Nearctic genera of Empididae in Steyskal and Knutson (1981) follows the family concept used by JF McAlpine et al. (1979) and is now out-of-date. Hundreds of additional empidoid species are expected to be eventually documented in Canada (Table 1).

The Oreogetonidae and two subfamilies of Empididae (Clinocerinae and Hemerodromiinae) include species with aquatic larvae. The remaining Empididae are mainly terrestrial and many species are important pollinators (Rader et al. 2016), especially in alpine and arctic regions (Lefebvre et al. 2014). The Hybotidae are common predators in forests, grasslands and agricultural fields (Sinclair and Cumming 2017), whereas the Dolichopodidae are significant predators in various aquatic, semi-aquatic and terrestrial habitats (Grichanov and Brooks 2017).

Suborder Brachycera: Eremoneura: Cyclorrhapha

The Cyclorrhapha constitute the most diverse lineage of Brachycera and include the numerous families of higher flies that pupate inside the last larval exuviae (i.e., puparium). The group is divided into the basal Lower Cyclorrhapha (“Aschiza”) and the monophyletic Schizophora (i.e., flies with a protrusible ptilinum for exiting the puparium). Schizophora are further divided into the paraphyletic Acalyptratae and the monophyletic Calyptratae.

Lower Cyclorrhapha (“Aschiza”)

No recent hypotheses support the monophyly of the Aschiza, which traditionally included the cyclorrhaphan families exclusive of Schizophora (or those flies without a ptilinum for exiting the puparium). Only Brown (1992, 1995) and Disney (1994) have supported the monophyletic Aschiza concept proposed by McAlpine (1989). All other morphological and molecular analyses have shown that the “Aschiza” are a grade and should be referred to as the Lower Cyclorrhapha (Griffiths 1972, Cumming et al. 1995, Zatwarnicki 1996, Collins and Wiegmann 2002, Moulton and Wiegmann 2004, Wiegmann et al. 2011, Pauli et al. 2018). This is an important lineage to understand phylogenetically as it sets the stage for the massive radiation of Schizophora. Unfortunately, there has been a profound lack of agreement about relationships within this grade.

Lonchopteridae (J Skevington and JM Cumming)

Placement of Lonchopteridae has been one of the most intractable problems within Diptera phylogenetics. The family has floated around in different analyses, in some cases being proposed as sister to the rest of Cyclorrhapha (Griffiths 1972), as sister to the Phoroidea (Brown 1992, Cumming et al. 1995), or as sister to (or within) the Platypezoidea + Phoroidea (Collins and Wiegmann 2002, Moulton and Wiegmann 2003, Wiegmann et al. 2011). Seven species of lonchopterids are known from Canada (Klymko and Marshall 2008) and another could eventually be discovered. Larvae are found in wet, decaying organic matter where they feed on bacteria and fungi. Two species occur in aquatic environments such as springs, seeps and shorelines (Valliant 2002). Adults feed on fungi, nectar, pollen and dead insects (Klymko and Marshall 2008).

Superfamily Platypezoidea (J Skevington and JM Cumming)

The status of this superfamily is contentious and its use should probably be abandoned. In the strict sense it appears to include Platypezidae (including *Microsania* Zetterstedt and *Melanderomyia* Kessel) and Opetiidae (non-Nearctic) (Tkoč et al. 2017), but even this is controversial, as Opetiidae has also been placed outside the superfamily in numerous positions in various phylogenies. There are 39 named platypezid species known from Canada and while a few more species are still expected (Table 1), some recent synonymies were established (e.g., Cumming and Wheeler 2016) and more are likely to occur as previous revisionary work, primarily by EL Kessel and associates (e.g., Kessel and Buegler 1972), routinely described males and females as separate species. Immature platypezids are fungivorous and the males of many species form large swarms.

Superfamily Phoroidea (J Skevington and JM Cumming)

Phylogenetic analyses that include the relevant taxa support the relationship of Phoridae (including Sciadocerinae sensu Brown et al 2015, Disney 2001) and Ironomyiidae (non-Nearctic) in this superfamily (Wiegmann et al. 2011, Young 2018). There are 135 named species of Phoridae known from Canada with the diversity estimated to be much greater, with perhaps 300 additional species (B Brown pers. comm.; Table 1). Phorids likely have the widest diversity of larval lifestyles of any insect family. Although some of the most common species are decomposers (including carrion feeders), others are fungivorous, phytophagous (including leaf miners), inquilines in social insect nests, predators, or parasitoids.

Superfamily Syrphoidea (J Skevington)

This is another higher grouping that should likely be abandoned. Pipunculidae and Syrphidae have been proposed as sister taxa in all published morphological phylogenetic hypotheses (Sinclair et al. 2013 and references therein), but most molecular analyses refute this relationship and place Pipunculidae as sister to Schizophora and Syrphidae as sister to Pipunculidae + Schizophora (Wiegmann et al. 2011, Pauli et al. 2018). Only Moulton and Wiegmann (2004) have proposed that Syrphidae are sister to Schizophora and that Pipunculidae are sister to Syrphidae + Schizophora. Recently discovered morphological evidence based on metapleural characters (Tachi 2014) supports the sister-group relationship of Pipunculidae and Schizophora.

There are currently 539 described species of Syrphidae recorded in Canada, a modest increase since 1979, and another 34 species are thought to occur (Table 1). The number of Pipunculidae species in Canada has almost doubled since 1979 and currently totals 85 species, but much of the fauna remains to be discovered and at least another 170 species are expected to occur. Most adult syrphids are pollinators, but larvae range from predators of aphids and other soft-bodied insects, predators and parasitoids of ants, to saprophages in rotting wood, slime fluxes, and sewage. Most pipunculids are parasitoids of Auchenorrhyncha (Skevington and Marshall 1997) and *Nephrocerus* Zetterstedt are parasitoids of Tipulidae (Koenig and Young 2007).

Schizophora: Acalyptratae

The Schizophora are a large monophyletic subgroup of Cyclorrhapha characterized by an inflatable sac-like ptilinum that temporarily extrudes from the head of the adult fly to allow emergence from the puparium. This exceedingly successful lineage contains 54 families in Canada, which are traditionally divided into the paraphyletic Acalyptratae and the monophyletic Calyptratae.

Acalyptratae are a large and heterogeneous assemblage of families circumscribed by the absence of characters used to define the Calyptratae. Many families are readily characterized by appearance or habit, but support for relationships amongst them has been elusive, likely because several lineages originated in a short period as part of an explosive radiation following the K-T extinction event 65mya (Wiegmann et al. 2011). As such, support for family-level relationships is often weak, with the exception of a few groups within Ephydroidea, Nerioidea, and Tephritoidea. Evolutionary reconstruction and superfamily composition has therefore been contentious and varied historically (JF McAlpine 1989, Yeates et al. 2007). Nine superfamilies are currently recognized, all of which occur in Canada, and the number of families in the country totals 44 (Table 1). The Canadian acalyptrate fauna is relatively well known, although it is likely that many species remain undescribed, especially amongst taxa with diminutive species.

Superfamily Diopsoidea (O Lonsdale)

Diopsoidea, historically called Nothyboidea by some, are a weakly supported cluster of families of low-to-medium species richness. Current superfamily definitions largely stem from a classification developed by Hennig (1958), refined in subsequent studies (Hennig 1965, 1973), and later elaborated upon by JF McAlpine (1989) and DK McAlpine (1997a, b), who suggested alternate superfamily placement for some families. The classification of JF McAlpine (1989) is followed here, although phylogenetic studies testing this system are ongoing and classification is expected to change. Strongylophthalmyiidae were once considered a subfamily of Tanypezidae by some, but Lonsdale (2013) found that these sister-taxa are best represented by a two-family system.

The superfamily includes nine families, four of which occur in Canada (Table 1): Psilidae (27 species), Diopsidae (2), Strongylophthalmyiidae (2), and Tanypezidae (1). The Canadian fauna of these families appears to be relatively well-known and only a few species have been added in recent decades, but work on Psilidae is still required. Revisions and keys to Nearctic genera and species are available for Diopsidae (Feijen 1989), Strongylophthalmyiidae (Barber 2006) and Tanypezidae (Lonsdale 2013, Knab and Shannon 1916). Nearctic Psilidae were treated in Melander (1920) and subsequent revisions treating species of Nearctic *Loxocera* Meigen are available in Capelle (1953) and Buck and Marshall (2006b). Buck and Marshall (2006a) partially revised *Psila* Meigen. Little is known of the life histories of non-pest species. Most taxa for which information is known appear to be saprophagous in damaged or decaying plant material, but some are primary invaders of plants, and a few of these are occasional crop pests.

Superfamily Nerioidea (O Lonsdale)

The Micropezidae are the only nerioid family known in Canada. Some authors, including Hennig (1958), treated a number of micropezid subfamilies as full families under the assumption that the stilt-legged flies (Neriidae) rendered them paraphyletic, but most contemporary authors now follow DK McAlpine (1975, 1998) in recognizing a broad monophyletic Micropezidae.

Only sixteen of the approximately 700 described species of Micropezidae occur in Canada, one of which is a recently introduced European *Micropeza* Meigen (Hoebeke and Wheeler 1994). Species numbers have otherwise remained unchanged since 1979 and no additional species are anticipated (Table 1). Adult Micropezidae generally display distinctive stilt-like mid and hind legs, and most of the relatively few species for which oviposition or larval habitats are known occur in rotting wood (Marshall 2012) and a variety of other decomposing materials.

Superfamily Sciomyzoidea (JF Gibson)

The families presently composing Sciomyzoidea were treated separately as Conopoidea and Sciomyzoidea by JF McAlpine et al. (1979) and JF McAlpine (1989). The inclusion of the orphaned family Conopidae within the Sciomyzoidea was supported by Wiegmann et al. (2011) and has been generally accepted since (e.g., Marshall 2012). Other taxonomic changes within the superfamily since 1979 include the recognition of the Helcomyzidae (1 species in Canada) and Heterocheilidae (1) as families distinct from Dryomyzidae (Malloch 1933, DK McAlpine 1991a, b), bringing the total number of families found in Canada to seven (Table 1). Members of the Sciomyzoidea are some of the largest acalyptrates, but species diversity is relatively low with fewer than 200 species in Canada. Current numbers of species have not changed much since JF McAlpine et al. (1979) for Coelopidae (4 species), Dryomyzidae (8), and Sepsidae (19). For Sciomyzidae (120) and Conopidae (42), species numbers in Canada have increased by approximately 40% since 1979 (Table 1). A few additional species are expected to eventually be documented in four of the seven families.

Knutson et al. (1986) produced a catalogue of North American Sciomyzidae. Most other recent faunistic and taxonomic work on sciomyzoid families has been global in nature but with relevance to the Canadian fauna: Coelopidae (Mathis and McAlpine 2011); Conopidae (Gibson and Skevington 2013); Dryomyzidae (Mathis and Sueyoshi 2011); Helcomyzidae (Mathis 2011a); Heterocheilidae (Mathis 2011b); Sciomyzidae (Knutson and Vala 2011). As well, western Canadian Conopidae were treated by Gibson (2017). There has been no work on Canadian Sepsidae. Complete life history and range are not known for most species, but some taxa (Conopidae, Sciomyzidae) are parasitoids. Restriction to marine coasts is also common within the group (Coelopidae, Helcomyzidae, Heterocheilidae, Dryomyzidae – *Oedoparena*).

Superfamily Lauxanioidea (JF Gibson)

The recent molecular analysis of Wiegmann et al. (2011) supported a monophyletic Lauxanioidea, including two families found in Canada, Lauxaniidae and Chamaemyiidae. The current number of reported species in Canada for Lauxaniidae (78) and Chamaemyiidae (35) represent modest increases since 1979, but a few more species of each family are likely to be recorded in the future (Table 1). Most of the Canadian Lauxanioidea fauna has not been revised since JF McAlpine et al. (1979). A notable exception is the revision of *Pseudodinia* Coquillet (Chamaemyiidae) by Barber (1985), which added ten species to the Canadian list and detailed much of the life history known for the group. Species of Lauxaniidae are suspected to be saprophagous as immatures while those of Chamaemyiidae are parasitoids of aphids and other Sternorrhyncha.

Superfamily Tephritidoidea (O Lonsdale)

The superfamily was divided by Korneyev (2000a) into a monophyletic "higher Tephritidoidea" and a paraphyletic "lower Tephritidoidea", all eight families of which are represented in Canada (Table 1). Korneyev (2000b) provided analysis and discussion of the family-level and genus groupings within Tephritidae, but admitted that much remains to be investigated. The "higher" families are Ulidiidae (35 species in Canada), Platystomatidae (10), Pyrgotidae (3), and Tephritidae (122). The "lower" families are Piophilidae (31), Pallopteridae (9), Lonchaeidae (99) and Richardiidae (1). Recently, a phylogeny by Han and Ro (2016), based on molecular data, questioned this system, supporting Tephritidae as paraphyletic, finding Richardiidae to belong to the "higher" group of families and a sister-group relationship to the remaining families. The numbers of known species have been relatively constant since 1979, with the exception of the family Tephritidae, which has tripled (Table 1). A few more species are expected to be discovered in Canada for most families, especially for Lonchaeidae, Ulidiidae and Tephritidae.

Revisions of the Nearctic fauna are available for Pallopteridae (Malloch and McAtee 1924), Pyrgotidae (Steyskal 1978) and Tephritidae (Foote et al. 1994). The global Piophilidae were revised by JF McAlpine (1977), and Rochefort and Wheeler (2015) reviewed the Piophilidae of northern Canada. The *Manual of Nearctic Diptera*, including references therein, is the best recent resources for identification of Lonchaeidae (JF McAlpine 1987), Platystomatidae (Steyskal 1987b) and Ulidiidae (Steyskal 1987a). Most Canadian Platystomatidae belong to *Rivellia* Robineau-Desvoidy and are keyed in Namba (1956), and most eastern Canadian Tephritidae species are easily identified using Jackson et al. 2011.

Species of most families are very conspicuously patterned, especially on the wings, and are behaviourally fascinating with elaborate courtship rituals. Lonchaeidae and Piophilidae are darker and less "charismatic", and much remains to be discovered of their biology. Many taxa are saprophagous as larvae, but less commonly predaceous in damaged or decaying plant vegetation, e.g., Pallopteridae (Teskey (1976); a few are primary invaders of plants and may be pestiferous, especially Tephritidae (DK McAlpine 1973, Norrbom and Korytkowski 2010, Marshall 2012). Piophilidae prefer animal matter in advanced states of decay (JF McAlpine 1977). A minority of Tephritidae are saprophages, parasitoids, inquilines or predators, and Pyrgotidae are parasitoids of scarab larvae (Korneyev 2000b, Marshall 2012).

Superfamily Opomyzoidea (O Lonsdale)

JF McAlpine's (1989) superfamily Opomyzoidea is largely derived from Hennig's (1971) concept of Anthomyzoidea, but it is a highly problematic and likely polyphyletic entity that remains in use mostly as a convenient grouping for numerous families and genera of uncertain placement. Winkler et al. (2010) used molecular data to show that the superfamily is non-monophyletic. The boundaries of Aulacigastridae and Periscelididae have undergone considerable permutation, resulting in some stability and recognition of the new family Neminidae (discussion in Rung and Mathis (2011)), but placement and status of the genera allied to *Stenomicra* Coquillet are still uncertain (Winkler et al. 2010, Marshall 2012).

With 450 species, the Agromyzidae are by far the most diverse opomyzoid family in Canada. More than a hundred species have been added since 1979 but the large number of BINs (772) (Table 1) suggest that much taxonomic work remains to be done, especially in the large genus *Phytomyza* Fallén, which contains many undescribed species. The remaining families are relatively species-poor and often uncommon in Canada. These consist of the Asteiidae (5 species in Canada), Aulacigastridae (2), Periscelididae (3), Odiniidae (6), Opomyzidae (11), Anthomyzidae (37) and Clusiidae

(22). Numbers of Canadian species for these small families have remained relatively constant since 1979 with the exception of the Anthomyzidae, which increased nine-fold through the revisionary work of Roháček and Barber (2016), and the Clusiidae, which were fully revised over the past 20 years (e.g., Lonsdale et al. 2011, Lonsdale 2017b; Table 1). A few additional Canadian species are expected for each family except the Clusiidae (Table 1).

The Canadian Agromyzidae were revised by Spencer (1969), but since that time generic concepts have been extensively reconsidered, especially in Winkler et al. (2009) and Lonsdale (2014), and several genera have been revised: *Amauromyza* Hendel (Boucher 2012b); *Cerodontha* Rondani (Boucher 2002, 2003, 2008, 2012a); *Liriomyza* Mik (Lonsdale 2017a); *Pseudonapomyza* Hendel (Boucher 2004). Many north temperate species of *Phytomyza* (sometimes as "*Chromatomyia* Hardy") were treated in a long series of papers by GCD Griffiths. Apart for the Anthomyzidae and the Clusiidae (see above), little has been published about the remaining families since 1979. Rung and Mathis (2011) globally revised *Aulacigaster* Macquart (the only Aulacigastridae occurring in Canada) and a new invasive Opomyzidae was recorded by Wheeler et al. (1999).

Winkler et al. (2009) summarized known biologies, which often includes phytophagy with a number of Agromyzidae being highly pestiferous, but there are also associations with fungi, sap fluxes, frass, and insect galleries in trees. Some taxa are predaceous and a few have larvae that are aquatic to semi-aquatic; Rotheray and Horsfield (2013) found Clusiidae to feed on biofilm in decaying wood.

Superfamily Carnoidea (JF Gibson)

The families currently in Carnoidea (Marshall 2012) were divided amongst the superfamilies Anthomyzoidea and Drosophiloidea in JF McAlpine et al. (1979). Another recent change to the classification of the group involves the inclusion of the family formerly known as the Tethinidae in the Canacidae (DK McAlpine 2007a). JF McAlpine (1989) determined "Carnites" Newman (1834) as the oldest family-level name in the group, thus making Carnoidea the proper superfamily name rather than Chloropoidea.

Of the five Carnoidea families in Canada (Table 1), three have few species and only minor changes have occurred since 1979: Acartophthalmidae (1 species in Canada), Carnidae (12), and Milichiidae (13). Canacidae were globally catalogued recently (Munari and Mathis 2010) and the number of reported Canadian species has doubled since 1979 to a current total of 10. More carnids and milichiids remain to be discovered in Canada and species numbers are expected to at least double for these families (Table 1). Much recent work has been completed on Chloropidae, both globally (e.g., Nartshuk 2012) and within Canada only (e.g., Grégoire Taillefer and Wheeler 2011, Barrie and Wheeler 2016). These publications have resulted in 40 more species of Chloropidae reported here compared to JF McAlpine et al. (1979), but many more species of this family are suspected to be undescribed or unreported based on BIN numbers and field observations. Members of Carnoidea display a wide range of life histories including saprophagous larvae, coprophagous larvae, kleptoparasitism (Milichiidae), crop pests (some Chloropidae), and parasites in bird's nests (Carnidae).

Superfamily Ephydroidea (JF Gibson)

The families currently in Ephydroidea (Marshall 2012) were divided amongst the superfamilies Anthomyzoidea and Drosophiloidea in JF McAlpine et al. (1979). The present configuration reflects the most recent phylogenetic hypotheses and correctly identifies Ephydridae as the oldest valid family-group name in the taxon (JF McAlpine 1989, Grimaldi 1990). The recent molecular analysis of Wiegmann et al. (2011) supported a monophyletic Ephydroidea.

Of the six families in Canada (Table 1), four have few species recorded from the country and have not seen a marked change in species numbers since JF McAlpine et al. (1979): Braulidae (1 species in Canada), Diastatidae (7), Curtonotidae (1), and Camillidae (2). A few additional species of Diastatidae are expected (Table 1). Both Drosophilidae and Ephydridae have seen numbers of species reported in Canada increase by approximately 30% since JF McAlpine et al. (1979), to 79 and 197 species, respectively, and more unreported and undescribed species are likely to be found (Table 1). Nearctic Drosophilidae have been the subject of considerable phylogenetic, taxonomic, and faunistic research (e.g., Remsen and O'Grady 2002, Brake and Bächli 2008, Miller et al. 2017) and many of the genera and subgroups of Nearctic Ephydridae have been revised recently (e.g., Mathis and Zatwarnicki 1995, Costa et al. 2016). Most species of Ephydroidea are suspected to be saprophagous as larvae, although there have been records of leaf-mining and predaceous species. Some species of Ephydridae are noteworthy as extremophiles, including hot spring, salt water, and petroleum-inhabiting species. Some Drosophilidae are important model species in genetic research and the family also includes a number of agricultural pests.

Superfamily Sphaeroceroidea (SA Marshall and O Lonsdale)

In Canada, this superfamily contains three families (Table 1). While detailed study is required, consensus thus far is that the family Heleomyzidae is rendered paraphyletic by the Sphaeroceridae (Roháček et al. 2001). While some authors have suggested that Sphaeroceridae and Heleomyzidae should be combined (DK McAlpine 2007b), others have suggested dividing the Heleomyzidae into multiple families, as discussed in JF McAlpine (1989), DK McAlpine (1985, 2007b), and Papp (1998). It appears most likely that the Heleomyzidae will be broken up once the phylogeny of the group is better resolved.

The infrequently encountered Chyromyidae include five recorded species in Canada with perhaps as many more awaiting discovery (Table 1). The more heterogeneous

Heleomyzidae currently have 72 recorded species in Canada, including four species previously treated as Trixoscelidae by JF McAlpine et al. (1979), and as many as 38 additional species are expected (Table 1). Most species in the superfamily belong to the well-defined family Sphaeroceridae, which include thousands of species worldwide (catalogued by Roháček et al. 2001). The Canadian Sphaeroceridae have been fully revised since 1979, resulting in a five-fold increase in species numbers (from 35 to 184); relatively few additions are expected as further collecting is carried out (Table 1).

Canadian Sphaeroceridae can be identified to genus using the keys in Marshall and Richards (1987) and in Marshall and Buck (2010); almost all Canadian species can be identified with keys cited in the latter work. The Canadian Chyromyidae can be keyed using Malloch (1914) and Wheeler (1961), but the fauna should be re-examined as it is probable that undescribed species remain to be discovered. The Canadian Heleomyzidae were remarkably well covered by Gill (1962, 1965); there have been few changes since then but new synonymies and additional taxa are to be expected, especially once the genus *Suillia* Robineau-Desvoidy is revised.

Sphaeroceridae develop as microbial grazers in a wide variety of moist microhabitats, including dung, carrion, fungi and many kinds of decaying plant material. Many inhabit mammal nests or burrows, and several species are associated with caves. Heleomyzidae have similar habits and also occur in caves, mammal nests, bird's nests, fungi, and dung. Some Chyromyidae have also been reared from bird's nests. Immature stages of Sphaeroceroidea are poorly known with the exception of the specialized coastal species found in decomposing seaweed (Marshall 1982).

Schizophora: Calyptratae

This large monophyletic subgroup of Schizophora has received much systematic attention over the last three decades (e.g., McAlpine 1989, Nirmala et al. 2001, Kutty et al. 2008, 2010, Zhang et al. 2016). Whereby JF McAlpine et al. (1979) grouped all calyptrates into a single superfamily (Muscoidea), most recent published works (Kutty et al. 2010, Wiegmann et al. 2011, Lambkin et al. 2013, Cerretti et al. 2017) have supported a division of the group into the Hippoboscoidea, the paraphyletic 'muscoid grade', and the Oestroidea (nested in the muscoid grade) proposed by Kutty et al. (2008). The composition of the Calyptratae has remained mostly unchanged since Roback (1951), and ten of the approximately 15 recognized calyptrate families worldwide (Cerretti et al. 2017) occur in Canada.

Superfamily Hippoboscoidea (J Savage)

The Hippoboscoidea are presently considered the sister-group to the remaining calyptrates (Kutty et al. 2008, 2010). It includes the Glossinidae (tsetse flies) and the Hippoboscidae (louse flies and batflies) with only the latter family found in Canada. JF McAlpine et al. (1979) recognized the families Nycteribiidae and Streblidae, which are now included as subfamilies of the Hippoboscidae (Kutty et al. 2010, Pape et al. 2011). The Canadian batflies, represented by two species of wingless spider-like nycteribiines and one small hairy strebline are only known from western provinces (British Columbia and Saskatchewan) (Wenzel 1965, Graciolli et al. 2007). With the exception of the Nycteribiinae (Graciolli et al. 2007), there has been little work done on the Canadian Hippoboscidae fauna since 1979. While 17 species are currently recorded from Canada, DNA barcodes from Canadian hippoboscid specimens are few and all placed in a single BIN, further emphasizing the need for additional field collecting and taxonomic work on this group.

All Hippoboscidae are larviparous and deposit mature larvae that are ready to pupate. The adults have a striking appearance that reflects their ectoparasitic habits and many species have limited or no flying abilities. The stocky, dorsoventrally flattened Hippoboscinae will feed on the blood of many birds and mammal species while the Streblinae and Nycteribiinae are restricted to bats.

"Muscoid Grade" (J Savage)

While we acknowledge the paraphyly of the muscoid grade, the group is used here for convenience as no alternative classification scheme has yet been proposed to assign the muscoid families to higher taxa. Members of this assemblage can be recognized mostly by the absence of diagnostic features found in the Hippoboscoidea (e.g., adaptations to ectoparasitic habits) and the Oestroidea (e.g., meron with a row of strong setae). The most important change relating to the Canadian fauna since JF McAlpine et al. (1979) is the recognition of the Fanniidae as distinct from the Muscidae (Griffiths 1972, McAlpine 1989)

All four muscoid families are found in Canada. In his census of Canadian Diptera, JF McAlpine et al. (1979) reported more muscid than anthomyiid species (525 vs 375) but the subsequent recognition of the Fanniidae as a separate family (84 species in Canada) and numerous synonymies have reduced the number of Canadian muscids to 440. The publication of more than a hundred new anthomyiid species and records (Griffiths 1982–2004) have resulted in a total of 515 documented species of Anthomyiidae and the group has supplanted the muscids as the most species-rich muscoid family in Canada. The Scathophagidae currently have 126 recorded species in Canada but have received less taxonomic attention than the other taxa. BINs are close to the numbers of described species for all families in this group and an increase in species numbers of only 10–20% is expected in the future (Table 1).

The Anthomyiidae are the only muscoid family to have been recently revised for Canada (Griffiths 1982–2004, excluding *Botanophila* Lioy and *Fucellia* Robineau-Desvoidy). A few generic and type revisions (e.g., Cuny 1980, Pont 1984, 2011, Savage 2003, Moores and Savage 2005) as well as some faunistic contributions (e.g., Renaud et al. 2012a, b) have nonetheless improved our knowledge of the taxonomy and distribution of Canadian Muscidae and Fanniidae. The Scathophagidae, unfortunately, have remained mostly unstudied.

In Canada, muscoid flies are especially well represented in northern and alpine habitats (Huckett 1965, Griffiths 1982–2004). The saprophagous housefly (*Musca domestica* Linnaeus) is the best known member of the group, but immature and adult muscoids exhibit a range of ecological habits so broad that it almost spans the complete spectrum displayed at the order level (see Marshall (2012) and Courtney et al. (2017) for general overview).

Superfamily Oestroidea (JE O'Hara)

This large lineage of nearly 15,000 species worldwide (Pape et al. 2011) has long been recognized as monophyletic based on morphology (Griffiths 1972, McAlpine 1989) and this view has since been corroborated by molecular analyses (Kutty et al. 2010, Wiegmann et al. 2011, Marinho et al. 2012). Some major family-level changes have been recently implemented in the Oestroidea (see Ceretti et al. 2017), but the same five families recognized by JF McAlpine et al. (1979) are still recognized today (Table 1).

With 736 known species, the Tachinidae have a large presence in Canada (O'Hara and Wood 2004, J O'Hara and M Wood unpubl. data), placing them second behind the Chironomidae as the most speciose family of Diptera in the country based on numbers of described species (Table 1). More than 200 species have been added to the Canadian fauna since 1979, mostly as a result of tribal (Wood 1985, O'Hara 1989, 2002) and generic revisions (e.g., O'Hara 1983, 1994, 2012, Sun and Marshall 2003). Despite these advances, dozens of undescribed Canadian species are still awaiting description in collections. Much recent attention has also been dedicated to the Sarcophagidae (135 species in Canada) and the Calliphoridae (62) and their species numbers have increased by over 50% since 1979 (Table 1). Catalogues and revisions that account for most of the increase in Canadian numbers of sarcophagid species include Pape (1996), Dahlem and Naczi (2006), and Giroux and Wheeler (2009, 2010). A few additional species of sarcophagids are expected in the country. The Canadian calliphorid fauna is very well known and recent taxonomic tools to identify it include Sabrosky et al. (1989), Rognes (1991), Whitworth (2006), Marshall et al. (2011), Jewiss-Gaines et al. (2012), and Tantawi et al. (2017). No additional species are expected in Canada. The Oestridae (17 species in Canada) and introduced Rhinophoridae (2) have not undergone any significant changes since JF McAlpine et al. (1979) (Table 1). The correspondence between BINs and known species numbers is generally good in this superfamily except for the Oestridae and, to a lesser extent, the Calliphoridae (Table 1).

The Oestroidea are generally large robust flies that display a wide range of life histories and ecological habits. The Tachinidae and Rhinophoridae are all parasitoids of terrestrial arthropods and the larvae of Oestridae are internal parasites of wild or domestic mammals. The calliphorids include a few parasitoid species in the *Pollenia* Robineau-Desvoidy complex, all presumably introduced from Europe with their earthworm hosts (Rognes 1991), and some ectoparasites of birds (*Protocalliphora* Hough) but most are saprophagous and associated with decaying animal matter. The Sarcophagidae have the most diverse larval habits of the superfamily; some are kleptoparasites in the nests of solitary bees and wasps, some feed on carrion or dung, and others are associated with living animals as parasitoids (particularly arthropods) or predators. Several parasitic species of Oestridae, Sarcophagidae and Calliphoridae are also known to cause myiasis in humans and other vertebrates (Marshall 2012).

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Mecoptera of Canada

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Abstract

The Mecoptera are represented in Canada by 25 extant species in four families, an increase of three species since the prior assessment in 1979. An additional 18 or more species and one family are expected to occur in Canada based on distributional records, recent collections and DNA analyses. The Barcode of Life Data System currently lists 24 Barcode Index Numbers for Canadian Mecoptera. There are nine species of fossil Mecoptera known from Canada.

Keywords

biodiversity assessment, Biota of Canada, Mecoptera, scorpionfly

Mecoptera, commonly known as scorpionflies or hangingflies, is one of the smaller insect orders with about 600 extant species in nine families worldwide (Penny 1997). The order is represented in the fossil record dating back to the Permian about 200 million years ago (Webb et al. 1975). The paleobiology database (https://fossilworks.org) currently lists a total of 686 species in 40 families globally, 30 species from North America and nine of those found in Canada. Several early Eocene fossil species were recently discovered in British Columbia (Archibald 2005, 2009, 2010, Archibald et al. 2013).

Table 1. Census of Mecoptera in Canada.

Taxon[1]	No. species reported in Downes (1979)	No. species currently known from Canada	No. BINs[2] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[3]	Information sources
Boreidae	7	9[4]	6	>4	Montane Cordillera, Pacific Maritime, Western Interior Basin, Mixedwood Plains, Atlantic Maritime	Penny 1997, GBIF 2017
Panorpidae	10	12	16	11	Mixedwood Plains, Atlantic Maritime, Boreal Shield, Prairies	Penny 1997, Cheung et al. 2006, GBIF 2017
Bittacidae	4	3	1	1	Mixedwood Plains, Prairies	Penny 1997, Cheung et al. 2006, GBIF 2017
Meropeidae	1	1	1	0	Mixedwood Plains	Penny 1997, Cheung et al. 2006, GBIF 2017
Panorpodidae	0	0	0	2	Pacific Maritime, Montane Cordillera	Penny 1997, GBIF 2017
Total	**22**	**25**	**24**	**>18**		

[1]Classification follows that indicated in Downes (1979). [2]Barcode Index Number, as defined in Ratnasingham and Hebert (2013). [3]See figure 1 in Langor (2019) for a map of ecozones. [4]Count of known Boreidae includes one species of *Caurinus* as this genus has been collected at several locations in coastal British Columbia (DCA Blades and C Wood unpubl. data).

The extant fauna of Canada and the USA consists of 87 species in five families (Penny 1997, Blades 2016) with 25 species currently known from Canada (Table 1). The greatest diversity of Mecoptera in Canada occurs in the Mixedwood Plains ecozone of southern Ontario, totaling 19 species in four families. Some of those species range westward to southeastern Manitoba and eastward to the Maritimes (Cheung et al. 2006). Boreidae (snow scorpionflies) is the only family represented from the Rocky Mountains westward in Canada. The family Panorpodidae, which includes two species, *Brachypanorpa sacajawea* Byers and *B. oregonensis* (MacLachlan), found in the bordering states of Washington, Idaho and Montana, may also occur in southern British Columbia (Byers 1997).

The number of extant species known from Canada has increased by three (14%) since the previous assessment by Downes (1979). One new species of Boreidae has been described and at least four more species are expected to occur in British Columbia (Blades 2002, Canada Endangered Species Conservation Council 2016; DCA Blades and C Wood unpubl. data). Other changes in the known fauna include the addition of two Panorpidae species and the removal of one Bittacidae species that was included in the 1979 assessment. There are no known endemic or non-native species in the Canadian fauna.

The Mecoptera of Canada are relatively well known compared with many insect orders. Undescribed extant species for Canada are expected for Boreidae and Panorpidae. Barcode Index Numbers (BINs) for *Panorpa* suggest that a number of species are likely to be species complexes. Areas of research on Canadian Mecoptera that are currently lacking include basic biology, such as the life histories, biogeography and species in the fossil record.

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REVIEW ARTICLE

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Siphonaptera of Canada

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Abstract
There are currently 154 species of fleas recorded in Canada, in four superfamilies and seven families. Only two species have been added to the list since the previous summary by Holland (1979), one of which is unlikely to be established in Canada. There have been a number of significant nomenclatural changes since then, most notable of which is the split of the Hystrichopsyllidae into two families, Hystrichopsyllidae and Ctenophthalmidae. An additional 23 species may eventually be recorded based on presence of suitable hosts and proximity to known distributions. Six species are introduced and one species is adventive. Although total diversity is reasonably well known, there are numerous gaps in distribution of fleas throughout the country. Barcode Index Numbers are available for only 22 species of fleas collected in Canada.

Keywords
biodiversity assessment, Biota of Canada, fleas, Siphonaptera

Fleas are a relatively small group, with more than 2200 species known worldwide. Species in Canada range in size from <2 mm (the introduced sticktight flea, *Echidnophaga gallinacea* (Westwood)) to >9 mm (*Hystrichopsylla schefferi* Chapin, likely the largest flea in the world). Fleas have profound medical and veterinary significance, and are best known for their role as vectors for the bacterial agent of bubonic plague. Their consequent historic impact on humans and society has been immeasurable. Flea vectors and bubonic plague have been recorded in Canada, and although known to occur in humans, have not been of major concern in recent years. However, the fear of plague epidemics was the stimulus for some of the early work on fleas in western Canada. As a result, our knowledge of the flea fauna of Canada is very good, largely through the efforts of George P. Holland. He produced two monographs (Holland 1949, 1985), the most recent of which included nearly all species recorded for Canada, as well as those for Alaska and Greenland. Today, fleas are mostly regarded as a source of annoyance to humans and to their pets. For example, the introduced cat flea is widespread, and a primary target for pest control in the home.

The following account is for the 154 species known to occur in Canada (Table 1). There have been some nomenclatural changes since Holland (1979, 1985), but only two species, *E. gallinacea* and *Myodopsylla borealis* Lewis, have been added to our fauna since that time (Chilton et al. 2000, Galloway et al. 2000). With these exceptions in mind, it is possible to identify the majority of taxa in Canada using Holland's more recent monograph (Holland 1985). The number of species recorded in Canada represents about 51% of the 303 species found in North America (Lewis and Eckerlin, in press). By far the greatest diversity of species occurs in British Columbia, and more than two thirds of species in Canada are found only in the provinces west of Ontario. There are six species of fleas introduced into North America north of Mexico that have been recorded in Canada (Pulicidae, 3; Leptopsyllidae, 1; Ceratophyllidae, 2), mostly ectoparasites of synanthropic rodents, poultry, and pets. One species of Pulicidae, *E. gallinacea*, is adventive on migratory birds from the United States and unlikely to become established in Canada.

The higher classification of Lewis (1993a, 1998, 2000) is adopted here. Because of his recognition of the Ctenophthalmidae at the family level, including the Stenoponiinae, Neopsyllinae, Rhadinopsyllinae, Ctenophthalminae, Doratopsyllinae, and Anomiopsyllinae, compared to Holland's Ctenophthalminae (as part of the Hystrichopsyllidae), the tables here and in Holland (1979) do not compare readily. As well, Holland (1979) cited all taxa, including subspecies, known for Canada as well as for Alaska and Greenland, further complicating comparison of numbers of taxa from 1979 to now. Taxonomic and nomenclatural changes introduced by Smit (1983) in his treatment of the Ceratophyllidae were published too late for Holland to consider and make changes to his 1985 monograph, though these changes were mostly at the generic level and have no effect on numbers of taxa in Holland (1985). There are recent monographs and regional lists of fleas in biogeographic areas outside Canada, where flea species not yet recorded for Canada occur. These include Traub et al. (1983), Lewis et al. (1988), Haas et al. (1989), Lewis (1990), Larson (1997), and Lewis (1998). The papers of RE Lewis (1972, 1973, 1974, 1975, 1993b, Lewis and Lewis 1985) on distribution and host preferences in fleas and on classification of the Siphonaptera are valuable references. As well, Lewis and colleagues published several recent reviews of genera of fleas in North America (Lewis 2000, 2002, 2003, 2008a, b, 2009, Lewis and Galloway 2001, Lewis and Haas 2001, Lewis and Jameson 2002, Lewis and Wilson 2006) wherein there are relevant nomenclatural changes from taxa cited by Holland (1985). In addition, volumes I-V of the Illustrated Catalogue of the Rothschild Collection of Fleas (Hopkins and Rothschild 1953–1971) are essential companions for anyone studying fleas in Canada.

Table 1. Census of Siphonaptera in Canada.

Taxon[1]	Adjusted no. species reported in Holland (1979)[2]	No. species currently known from Canada[3]	No. BINs[4] available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[5] and host range	Information sources
Superfamily Pulicoidea						
Pulicidae	7[6]	8 (3)	1	2	potentially all ecozones; wide variety of mammals and birds	Holland 1949, 1985, Galloway et al. 2000, 2002; WRME[7]
Superfamily Vermipsylloidea						
Vermipsyllidae	3	3	0	2	Western Interior Basin, Boreal Plains, Mixedwood Plains, Pacific Maritime, Montane Cordillera, Prairies, Atlantic Maritime; mostly carnivores	Holland 1949, 1985; WRME
Superfamily Hystrichopsylloidea						
Hystrichopsyllidae[8]	6	6	0	0	all ecozones south of taiga; insectivores, small rodents	Holland 1949, 1985; WRME
Ctenophthalmidae[8]	50	51[9]	3	3	all except Arctic ecozones; insectivores, rodents	Holland 1949, 1985, Lewis and Haas 2001, Morrone and Acosta 2006; WRME
Superfamily Ceratophylloidea						
Ischnopsyllidae	4	5	0	0	transcontinental exclusive of Arctic and alpine areas; specific to bats	Holland 1949, 1985, Chilton et al. 2000; WRME
Leptopsyllidae	14	14 (1)	0	3	all except Arctic; rodents, lagomorphs, birds	Holland 1949, 1985; WRME
Ceratophyllidae	67	67 (2)	18	13	all ecozones; mainly small mammals and birds	Holland 1949, 1985, Lewis 1990, 1993a, b, 2000, 2002, 2003, 2007, 2008a, b, 2009, Lewis and Galloway 2001, Lewis and Haas 2001, Lewis and Jameson 2002, Lewis and Wilson 2006, Lewis and Eckerlin 2013; WRME
Total	**151**	**154 (6)**	**22**	**23**		

[1]Classification follows Lewis (2000). [2]Holland (1979) included subspecies in the numbers he reported, many of which have since been suppressed. Holland also included species recorded in Alaska and Greenland, but not in Canada. Numbers of species in this column have been adjusted to include only species Holland (1985) recorded as occurring in Canada. [3]Numbers in parentheses represent the numbers of introduced species included in the total for each family, exclusive of the non-native, *E. gallinacea*, which may disperse into Canada on birds from the USA. [4]Barcode Index Number, as defined in Ratnasingham and Hebert (2013). [5]See figure 1 in Langor (2019) for a map of ecozones. [6]Holland (1979) reported eight species of Pulicidae, but it appears he included *Actenopsylla suavis* Jordan & Rothschild in that total; he reported no specimens that had actually been collected in Canada or Alaska. Only those seven species for which there are Canadian records are included here. [7]J.B. Wallis/R.E. Roughley Museum of Entomology, Department of Entomology, University of Manitoba, Winnipeg, MB. [8]Holland (1979) treated this group of fleas as one family, Hystrichopsyllidae, though it is currently separated into two families, Hystrichopsyllidae and Ctenophthalmidae. Numbers of species in each family in 1979 are based on those reported by Holland (1985). [9]Totals adjusted to accommodate nomenclatural changes to the genera, *Catallagia* (Lewis and Haas 2001) and *Corrodopsylla* (Morrone and Acosta 2006).

The flea fauna of Canada is relatively well known; it is expected that at least another 23 species may be discovered, more than half of these in the family Ceratophyllidae. These estimates were generated by considering the fauna of adjacent jurisdictions (northern United States, including Alaska) that include species with ranges in close proximity and for which known hosts occur in Canada. I know of no undescribed species of fleas in Canada.

There are enormous gaps in the known ranges of various species across the country. For example, *Tarsopsylla octodecimdentatus coloradensis* (Baker) is a nest flea of red squirrel, *Tamiasciurus hudsonicus* (Erxleben), and *Kueichenlipsylla atrox* (Jordan) is a winter-active flea that infests mustelids. Known records are few and widely scattered. They no doubt occur in many other parts of Canada, but apparent rarity and gaps in distribution are probably the result of insufficient targeted collecting effort. There is also scant information on the seasonal dynamics and life histories of fleas, though there are some recent studies on important aspects of ecology and flea/host interactions (e.g., Reichardt and Galloway 1994, Lindsay and Galloway 1997, 1998, Thomas and Shutler 2001, Perez-Orella and Schulte-Hostedde 2005, Shutler and Campbell 2007, Gorrell and Schulte-Hostedde 2008, Guderham and Schulte-Hostedde 2011, Waterman et al. 2014, Raveh et al. 2015). Larval taxonomy is in its infancy in Canada (but see Elbel 1991, Pilgrim and Galloway 2000, 2007, Galloway and Pilgrim 2001, Harriman et al. 2011). There are extensive or partial larval descriptions for only 16 of the taxa found in Canada, seven of which are for introduced and adventive species.

The Canadian fauna has been poorly characterised using DNA barcodes; there are only about 14% as many BINs as there are described species in Canada, most of which (18 of 22) are from Ceratophyllidae (Table 1). Recent and current studies are focussed on a small number of flea taxa, and there are few broad surveys being undertaken where additional taxa for DNA barcoding could be collected. This represents a significant gap in our knowledge of the fleas of Canada. There are certainly taxonomic problems that could benefit from careful research in which DNA barcoding is a component. For example, there are four species of *Ceratophyllus* that infest cliff swallows (*Petrochelidon pyrrhonota* Veillot) in Canada: *Ceratophyllus celsus celsus* Jordan, *C. scopulorum* Holland, *C. calderwoodi* Holland, *C. arcuegens* Holland. Although their geographic distributions are largely allopatric, there are critical areas of overlap (Galloway 1988). DNA barcoding might be a valuable tool to examine species status among these taxa. It is important that people continue to collect adult fleas and larvae from identified hosts and their nests throughout the country to add to our understanding of this important group of ectoparasites.

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Lepidoptera of Canada

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Abstract

The known Lepidoptera (moths and butterflies) of the provinces and territories of Canada are summarised, and current knowledge is compared to the state of knowledge in 1979. A total of 5405 species are known to occur in Canada in 81 families, and a further 50 species have been reported but are unconfirmed. This represents an increase of 1348 species since 1979. The DNA barcodes available for Canadian Lepidoptera are also tabulated, based on a dataset of 148,314 specimens corresponding to 5842 distinct clusters. A further yet-undiscovered 1400 species of Lepidoptera are estimated to occur in Canada. The Gelechioidea are the most poorly known major lineage of Lepidoptera in Canada. Nunavut, Prince Edward Island, and British Columbia are thought to show the greatest deficit in our knowledge of Lepidoptera. The unglaciated portions of the Yukon (Beringia), and the Pacific Maritime, Montane Cordillera, and Western Interior Basin ecozones of British Columbia are also identified as hotbeds of undescribed biodiversity.

Keywords

biodiversity assessment, Biota of Canada, moths, butterflies

Introduction

The order Lepidoptera (moths and butterflies) comprises the fourth-largest insect order in terms of global diversity, with approximately 158,000 described species (van Nieukerken et al. 2011), and an estimated total global diversity of 300,000 to 400,000 species (Kristensen et al. 2007). Butterflies are much better known than moths, but moth species outnumber butterfly species by at least 10 to one.

The higher classification of Lepidoptera is reasonably well known, thanks in large part to recent genetic work (Regier et al. 2012, Sohn et al. 2013, Heikkilä et al. 2014, Regier et al. 2015a, b, Sohn et al. 2016, Kawahara et al. 2017). An excellent summary of the higher classification of the order was presented by Aarvik et al. (2017). Presently 127 families of Lepidoptera are recognised globally (van Nieukerken et al. 2011). There is no comprehensive catalogue of the order, although catalogues of some constituent taxa exist, as well as regional works.

There has been considerable taxonomic work on Lepidoptera in Canada, but it has been scattered among hundreds of published works. Munroe (1979) provided an overview of major work up to that point, presented a rough count of 4692 known Canadian species, and included a prediction of 2042 undiscovered species, for a total fauna estimated to be 6734 species. Specific numbers were given for each family, which suggests that a precise count of species had been done. At that time, there was no comprehensive list of Lepidoptera of Canada, so Munroe probably relied on major taxonomic works and specimens in the Canadian National Collection of Insects, Arachnids and Nematodes (CNC).

Since Munroe (1979), we have learned a great deal about Canadian Lepidoptera. Dombroskie (2011) released a matrix key to families, subfamilies, and tribes of Lepidoptera of Canada, and Layberry et al. (1998) treated the butterflies of Canada in detail. The websites BugGuide (2018), Moth Photographers Group (2018), and Pacific Northwest Moths (Crabo et al. 2013) provide a wealth of records and information pertinent to Canada. The "Macromoths of Canada" website (Troubridge and Lafontaine 2003) has excellent images but is a little dated as it follows a previous classification scheme. Since Munroe (1979), checklists have been published for Yukon Territory (Lafontaine and Wood 1997), British Columbia (Pohl et al. 2015), Alberta (Pohl et al. 2010), Saskatchewan macromoths (Hooper 1987-2007), Ontario butterflies and macromoths (Riotte 1992), Quebec butterflies and macromoths (Handfield 1999; revised in 2011), Quebec and Labrador combined (Handfield et al. 1997), Newfoundland and Labrador butterflies and macromoths (Morris 1980), and New Brunswick butterflies and macromoths (Webster et al. 2006).

Pohl et al. (2018) published a comprehensive checklist of the Lepidoptera of Canada and Alaska, which captures information from all the above sources and others. It lists 5405 species known to occur in Canada, and an additional 50 unconfirmed records, for a total reported fauna of 5455 species in 81 families (Table 1). In total, 207 of these species (3.8%) are non-native, and 262 (4.8%) are Holarctic. Pohl et al. (2018) provides a detailed review of historical literature, as well as an extensive list of taxonomic works relevant to the Canadian fauna and a list of collections with Canadian holdings. Thus, our knowledge of the distribution of Lepidoptera in Canada has been comprehensively detailed there, and the present paper essentially compares Munroe (1979) to Pohl et al. (2018).

At the time of Munroe (1979), the most recent North American checklist would have been McDunnough (1938, 1939), but it is clear from Munroe's text that he had a working copy of the forthcoming North American list, of which he was a co-author (Hodges et al. 1983; the checklist was essentially complete in 1978 and took five years to publish). Thus, the classification and placement of most species in Munroe's scheme can be deduced from Hodges et al. (1983). Furthermore, using the data compiled by Pohl et al. (2018), which includes hundreds of literature sources as well as collection data, we have determined what would have been known about current taxonomic groupings in Munroe's time. We have used that information to reassess Munroe's family-level counts in terms of the classification in use today (Table 1). His species counts for most of the families are reasonably accurate, given the classification in use at the time. However, his numbers for the Gelechiidae and Noctuidae are far off the mark, and it is clear from Munroe's text that they were only estimates, see further discussion of those groups below. Additional small errors were made in Incurvariidae and Drepanidae. Consequently, once errors are taken into account, we estimate that rather than Munroe's report of 4692 species, only 4107 Lepidoptera species were known in Canada in 1979.

For the DNA barcode data, all available Canadian Lepidoptera records were extracted from the Barcode of Life Datasystems (BOLD) database (Ratnasingham and Hebert 2007) on 30 September 2017. A total of 148,314 barcoded Canadian specimens belonging to 5842 distinct clusters, hereafter referred to as Barcode Index Numbers (BINs) (Ratnasingham and Hebert 2013), were found. Of those records, 145 specimens were not identified beyond "Lepidoptera", but most of those matched BINs that had some level of identification based on other specimens in the dataset. Only 38 specimens, belonging to 28 BINs, could not be identified to family level and were excluded from further analysis. The resulting dataset thus contained 148,276 specimens, belonging to 5814 BINs, all identified at least to family level (Table 1). The numbers of undiscovered species for each family presented in Table 1 were estimated based on barcode data, augmented by the authors' collective knowledge of existing undescribed species, the extent of sampling, and the rate of discovery of new species in the various families.

Overview of Canadian Lepidoptera superfamilies

Superfamily Micropterigoidea

The sole family, Micropterigidae, includes primitive moths with functional mandibles. They were revised recently for North America, and one new species was described from western Canada (Davis and Landry 2012). The new species was known at the time of

Table 1. Census of Lepidoptera in Canada. Source for currently known and introduced species is Pohl et al. (2018).

Taxon[1]	No. species reported in Munroe (1979) [2]	No. species currently known in Canada[3]	No. BINs available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[3A]
Superfamily Micropterigoidea					
Micropterigidae	2	2	4	0	south of taiga ecozones
Superfamily Eriocranioidea					
Eriocraniidae	2	2	6	2	south of taiga ecozones
Superfamily Hepialoidea					
Hepialidae	10	13 (1)	11	1	south of taiga ecozones
Superfamily Neopseustoidea					
Acanthopteroctetidae	0[4]	2	2	1	south of taiga ecozones
Superfamily Nepticuloidea					
Nepticulidae	38	69 (9)	110	50	all except Arctic
Opostegidae	4	4	14	10	south of taiga ecozones
Superfamily Adeloidea					
Prodoxidae	1 (16)[5]	22 (1)	23	2	all ecozones
Tridentaformidae	0[6]	1	0	0	Pacific Maritime, Prairies
Incurvariidae	33 (2)[7]	2	6	4	south of taiga ecozones
Heliozelidae	15	17	23	5	south of taiga ecozones
Adelidae	0 (10)[8]	10	14	4	all ecozones
Superfamily Tischerioidea					
Tischeriidae	8	14	18	5	south of taiga ecozones
Superfamily Tineoidea					
Meessiidae	0	1	1	1	Mixedwood Plains
Psychidae	6	11 (4)	13	3	south of taiga ecozones
Dryadaulidae	0 (1)[9]	1	5	4	Mixedwood Plains, Atlantic Maritime
Tineidae	23 (22)[10]	62 (9)	106	50	all except Arctic
Superfamily Gracillarioidea					
Bucculatricidae	0 (30)[11]	39	69	30	all except Arctic
Gracillariidae	115[12]	165 (5)	237	90	all except Arctic
Superfamily Yponomeutoidea					
Yponomeutidae	21 (19)[13]	19 (7)	22	5	all except Arctic
Ypsolophidae	0 (12)[14]	15 (2)	20	5	south of taiga ecozones
Plutellidae	18 (6)[15]	11	13	5	all ecozones
Glyphipterigidae	3[16]	15 (1)	13	5	south of taiga ecozones
Argyresthiidae	23	33 (2)	42	10	all ecozones
Lyonetiidae	40 (9)[17]	11 (2)	14	5	south of taiga ecozones
Attevidae	0 (1)[18]	1	1	0	Mixedwood Plains, Atlantic Maritime
Praydidae	0 (1)[19]	2 (1)	2	0	Montaine Cordillera, Mixedwood Plains, Newfoundland Boreal
Heliodinidae	5 (3)[20]	4	3	1	Montaine Cordillera, Prairies, Mixedwood Plains
Bedelliidae	0 (1)[21]	1	1	0	south of taiga ecozones
unassigned superfamily					
unassigned Apoditrysia	0[22]	1	0	0	Mixedwood Plains
Superfamily Douglasioidea					
Douglasiidae	4	5	7	3	all except Arctic
Superfamily Gelechioidea					
Autostichidae	0 (5)[23]	7 (1)	10	5	south of taiga ecozones
Lecithoceridae	0	1	0	0	Mixedwood Plains
Oecophoridae	79 (14)[24]	20 (5)	25	10	all except Arctic

Taxon[1]	No. species reported in Munroe (1979) [2]	No. species currently known in Canada[3]	No. BINs available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[3A]
Depressariidae	0 (64)[25]	87 (9)	88	5	all except Arctic
Cosmopterigidae	10	29	48	20	south of taiga ecozones
Gelechiidae	525 (200)[26]	370 (14)	604	350	all ecozones
Elachistidae	28[27]	66 (2)	95	50	all ecozones
Coleophoridae	55 (51)[28]	109 (10)	210	150	all except Arctic
Batrachedridae	0 (4)[28]	6 (1)	8	2	south of taiga ecozones
Scythrididae	15	14 (1)	28	15	all except Arctic
Blastobasidae	20 (17)[29]	19	41	30	south of taiga ecozones
Stathmopodidae	0	1	1	1	Boreal Shield, Newfoundland Boreal, Mixedwood Plains, Atlantic Maritime
Momphidae	10	24 (3)	54	30	all except Arctic
Pterolonchidae	0	2 (1)	1	0	Pacific Maritime, Boreal Cordillera
Lypusidae	0 (1)[30]	1 (1)	1	0	Pacific Maritime
Superfamily Alucitoidea					
Alucitidae	1	3	4	0	all except Arctic
Superfamily Pterophoroidea					
Pterophoridae	50	82 (1)	85	15	all ecozones
Superfamily Carposinoidea					
Copromorphidae	1	2	2	0	Montane Cordillera
Carposinidae	4	4	8	1	south of taiga ecozones
Superfamily Schreckensteinioidea					
Schreckensteiniidae	0 (2)[31]	3	5	0	all except Arctic
Superfamily Epermenioidea					
Epermeniidae	4	8	12	2	south of taiga ecozones
Superfamily Urodoidea					
Urodidae	0	1	1	0	south of taiga ecozones
Superfamily Choreutoidea					
Choreutidae	7	19 (1)	23	10	all except Arctic
Superfamily Galacticoidea					
Galacticidae	0	1 (1)	0	0	Mixedwood Plains
Superfamily Tortricoidea					
Tortricidae	556[32]	835 (41)	791	100	all ecozones
Superfamily Cossoidea					
Cossidae	5	6 (1)	6	0	all except Arctic
Sesiidae	44	62 (4)	50	14	all except Arctic
Superfamily Zygaenoidea					
Limacodidae	14	18	13	0	south of taiga ecozones
Zygaenidae	1	3	2	0	Atlantic Maritime, Mixedwood Plains, Boreal Plains
Superfamily Thyridoidea					
Thyrididae	3	2	1	1	south of taiga ecozones
Superfamily Papilionoidea					
Hesperiidae	64	74 (1)	55	5	all ecozones
Papilionidae	18	18	14	0	all ecozones
Pieridae	37	42 (1)	20	1	all ecozones
Lycaenidae	58	66 (1)	55	1	all ecozones
Riodinidae	1	1	2	1	Montane Cordillera, Prairies
Nymphalidae	94[33]	105 (1)	93	4	all ecozones

Taxon[1]	No. species reported in Munroe (1979) [2]	No. species currently known in Canada[3]	No. BINs available for Canadian species	Est. no. undescribed or unrecorded species in Canada	General distribution by ecozone[3A]
Superfamily Pyraloidea					
Pyralidae	400 (175)[34]	243 (15)	203	30	all ecozones
Crambidae	0 (225)[34]	295 (7)	295	40	all ecozones
Superfamily Mimallonoidea					
Mimallonidae	2	2	1	0	Mixedwood Plains
Superfamily Drepanoidea					
Drepanidae	18 (12)[35]	12	12	1	south of taiga ecozones
Superfamily Lasiocampoidea					
Lasiocampidae	10	8	18	2	all except Arctic
Superfamily Bombycoidea[36]					
Apatelodidae	2	2	1	0	Mixedwood Plains
Saturniidae	23	24 (1)	12	0	south of taiga ecozones
Sphingidae	54	60 (3)	47	3	all ecozones
Superfamily Geometroidea					
Uraniidae	2	2	5	0	all except Arctic
Geometridae	450	534 (9)	559	50	all ecozones
Superfamily Noctuoidea					
Notodontidae	50	57	64	10	all except Arctic
Erebidae	86 (286)[37]	342 (7)	318	40	all ecozones
Euteliidae	0 (5)[38]	8	6	0	Montane Cordillera, Prairies, Mixedwood Plains, Atlantic Maritime
Nolidae	0 (15)[39]	18 (2)	19	0	all except Arctic
Noctuidae	1520 (1050)[40]	1182 (18)	998	100	all ecozones
[unknown Lepidoptera]			28		
Total	**4692 (4107)[41]**	**5455 (207)**	**5842**	**1400**	

[1]Classification follows Pohl et al. (2018). [2]Numbers in brackets are corrections for tabulation errors and taxonomic changes, detailed in the footnotes below. [3]Numbers in brackets are non-native species. [3A] See figure 1 in Langor (2019) for a map of ecozones. [4]Munroe treated this family as part of Eriocraniidae. No Canadian species were known at that time, although one was listed as expected. [5]Munroe reported only the Yucca Moth (*Tegeticula yuccasella* Riley) from Canada for this family, but we have added 15 known species transferred from the Incurvariidae. [6]Munroe predicted that the sole described species, *Tridentaforma fuscoleuca* (Braun), would be found in Canada, but it was placed in the Incurvariidae at that time. [7]Munroe erred in his count of this family; only 27 described species were known in Canada at the time, in what then comprised the Incurvariidae, so we have reduced the count by six. As well, we have removed 10 species that are now placed in Adelidae, and 15 species now placed in Prodoxidae, leaving only two species remaining in Incurvariidae, that were known in 1979. [8]This family was treated as a subfamily of the Incurvariidae by Munroe, although the genus *Cauchas* (now in Adelidae) was placed in the Incurvariinae at that time. Munroe specifically mentions six "Adelinae" species in Canada but we have also transferred four species of *Cauchas* that were known from Canada at that time. [9]One species of Dryadaulidae, *Dryadaula visaliella* (Chambers), has been known in Canada at least as long ago as Forbes (1923). It would have been counted in Tineidae by Munroe (1979). [10]Munroe treated the subfamily Acrolophinae (excluding *Amydria*) as a separate family; he listed no known Canadian species and ten expected "Acrolophidae" species. One species of "Tineidae" sensu Munroe has been transferred to Dryadaulidae. [11]Munroe treated this group as part of the Lyonetiidae. He specifically mentioned 30 known Canadian species of *Bucculatrix*, the sole genus in the family Bucculatricidae. [12]Munroe listed five "Phyllocnistidae", as a separate family. They are now considered a subfamily within the Gracillariidae. [13]Munroe treated the Ochsenheimeriinae as a separate family, in the Tineoidea, but listed no known Canadian species. The sole species he listed as "expected", *Ochsenheimeria vacculella* von Röslerstamm, was confirmed for Canada as the manuscript went to press, and was added as a footnote; we have included it in his species tally here. He treated the Attevidae and Praydidae as part of the Yponomeutidae; we have removed the sole known Canadian species of Attevidae, *Atteva aurea* (Fitch), which Munroe specifically mentioned in the text. We have also removed one species of Praydidae, *Prays atomocella* (Dyar), which Munroe is assumed to have been aware of, as specimens from 1927 are in the CNC where he worked. [14]Munroe treated this family as part of the Plutellidae; we have transferred 12 species here that we estimate would have been known from Canada at the time. [15]An estimated six species of Plutellidae, as currently defined (excluding 12 species now placed in Ypsolophidae), would have been known in Canada at the time. [16]Munroe treated Acrolepiinae as a separate family and listed one known Canadian species. [17]Munroe included the Bucculatricidae and Bedelliidae within this family. We have removed the 30 Canadian species of *Bucculatrix*

and sole Canadian species of *Bedellia* that were specifically mentioned by Munroe in the text. [18]This family was not recognised at the time of Munroe. However, he specifically mentioned the sole known Canadian species, *Atteva aurea* (Fitch), which was placed in the Yponomeutidae at the time. [19]This family was placed within the Yponomeutidae at the time of Munroe. He did not specifically mention any species currently placed in Praydidae, but one of them, the Hop-tree Borer (*Prays atomocella* (Dyar)), is represented by Canadian specimens in the Canadian National Collection where Munroe worked, so we assume it was known to him and we have transferred it here. [20]Munroe included the Schreckensteiniidae within this family; we have removed two *Schreckensteinia* species that were well known in Canada at the time (reported by ESBC 1906 and Prentice 1965). [21]Members of this recently recognized family were placed in the Lyonetiidae at the time of Munroe. He specifically mentions the sole known Canadian species, *Bedellia somnulentella* (Zeller), and we have transferred it here. [22]This unnamed group is a holding place for the genus *Cycloplasis*. It has historically been placed in the Heliodinidae, but was excluded from that group by Hsu and Powell (2004), and was further excluded from the Yponomeutoidea by Sohn et al. (2013). No Canadian species were known at the time of Munroe (1979). [23]Munroe placed most of the current members of this family in the subfamily Symmocinae in the Blastobasidae. Three species then placed in Symmocinae would have been known from Canada at that time: *Oegoconia deauratella* (Herrich-Schäffer) was listed from Alberta by Bowman (1951); *Gerdana caritella* Busck was reported from British Columbia by Clarke (1941); and *Glyphidocera septentrionella* Busck was described from British Columbia in 1904. Thus, we have transferred three species from Blastobasidae to Autostichidae here. Additionally, two species of the genus *Taygete* are represented in the Canadian National Collection and would have been available to Munroe; they have been transferred here from the Gelechiidae, following a recent taxonomic move of this genus (B Landry 2002). [24]Historically this was a much more diverse group, but most subfamilies have been removed recently. Munroe (1979) reported 52 Depressariinae, seven Ethmiinae, and four Stenomatinae (=”Stenominae” of Munroe) species, all of which have since been transferred to the Depressariidae. The species *Carcina quercana* (Fabricius), formerly in the Oecophorinae, was also transferred to the Depressariidae. The presence of that introduced species in Victoria, British Columbia, was well known at that time (Hodges 1974). Thus we have transferred 64 species from Oecophoridae to Depressariidae. Additionally, the Chimabachinae (one species reported by Munroe) was moved to the Lypusidae. Thus from Munroe's count, only 14 species remain in the Oecophoridae as currently constituted. [25]This family was not recognized at the time of Munroe; it was erected recently for groups that were previously placed in the Oecophoridae; see footnote under that family. [26]Munroe's counts of 525 known and 525 expected species of Gelechiidae is wildly inaccurate. After detailed examination of literature and collections, we estimate that approximately 200 Gelechiidae species would have been known in Canada at the time, see discussion in the text. [27]Munroe treated the subfamily Parametriotinae as the separate family Agonoxenidae, and listed two known Canadian species. [28]The Batrachedridae have recently been removed from Coleophoridae, and recognised as a distinct family. Munroe (1979) specifically mentioned four known Canadian species. [29]We have removed the three species of Autostichidae, which Munroe treated within the subfamily Symmocinae in the Blastobasidae. [30]This family was not recognised in North America at the time of Munroe. The subfamily Chimabachinae (=”Cheimbachinae” [sic] Munroe) was transferred from the Oecophoridae to this family recently. The sole North American species, *Dasystoma* (=”*Cheimophila*”) *salicella* (Hübner), was specifically mentioned as occurring in Canada by Munroe. [31]Munroe treated the members of this family within the Heliodinidae. We have transferred the two species that were known in Canada at that time. [32]Munroe treated the tribe Cochylini as a separate family, with 46 species. [33]Munroe treated the Libytheinae (one species), Danainae (one species), and Satyrinae (30 species) as separate families. [34]Munroe combined the Pyralidae and Crambidae in his count, and gave no specific numbers for Canadian species known among the various subfamilies recognized at that time. We have estimated the numbers in these families as presently constituted. [35]Munroe made an error here; the 12 Canadian species have been well known for many decades and have not been reclassified in more than 100 years. [36]Munroe listed the Bombycidae species *Bombyx mori* (Linnaeus), the Silkworm Moth, known only in captivity. We have excluded it from his tabulation and our count here. [37]Munroe listed 16 Lymantriidae and 70 Arctiidae; both are now subfamilies of Erebidae. All other Erebidae (as currently recognized) were placed in Noctuidae at the time. We estimate that approximately 200 Erebidae other than Lymantriinae and Arctiinae would have been known in 1979, for a total of 286 species of Erebidae. [38]The Euteliidae were considered a subfamily of Noctuidae at the time of Munroe. He gave no details at the subfamily level within the “Noctuidae”, but our data indicates that five species now placed in Euteliidae were known in Canada at the time. [39]The Nolidae were considered a subfamily of Noctuidae at the time of Munroe. He gave no details at the subfamily level within the “Noctuidae”, but our data indicates that 15 species now placed in Nolidae were known in Canada at the time. [40]Munroe made a significant error here, but it is obscured by changes in taxonomy. We estimate that in 1979, approximately 1270 “Noctuidae” (sensu Munroe) were known from Canada, 250 fewer than he reported; see discussion in the text. Additionally, following the current classification, we have transferred an estimated 200 “Noctuidae” species to the Erebidae, five species to Euteliidae, and 15 species to Nolidae, leaving an estimated 1050 Noctuidae (as currently constituted) known in Canada at the time. [41]This corrected total number of Lepidoptera species known in Canada in 1979 takes into account Munroe's errors noted above: -6 Incurvariidae, -323 Gelechiidae, -6 Drepanidae, and -250 “Noctuidae”, for a total that is 585 fewer than Munroe reported. As well, we have included the Yponomeutidae species *Ochsenheimeria vacculella*, which Munroe added in a footnote, and we have excluded the Bombycidae species *Bombyx mori*, known only in captivity.

Munroe (1979), but had been misidentified, so the number of known Canadian species has not changed since then (Table 1). The DNA barcode data indicate three BINs with >2% difference within *Epimartyria auricrinella* Walsingham, but this was examined in detail by Davis and Landry (2012) and they found no morphological evidence for cryptic species, and concluded this was simply high intraspecific variation. These moths are inconspicuous and are not attracted to lights, so they are poorly collected, and their distribution in Canada is incompletely known.

Superfamily Eriocranioidea

The sole family is the Eriocraniidae, and since Munroe (1979) the Acanthopteroctetidae have been removed from it (see below). At least two more eriocraniid species are expected in Canada, which may account for some of the additional BINs (Table 1).

Superfamily Hepialoidea

The sole family Hepialidae (ghost moths) are medium-sized to large moths whose larvae bore into stems or roots. Currently 13 species are known from Canada, compared to 10 reported by Munroe (1979), and it is expected that one additional species will eventually be found (Table 1). The group remains in need of modern taxonomic treatment. A global catalogue with a bibliography was published by Nielsen et al. (2000).

Superfamily Neopseustoidea

The sole Nearctic family Acanthopteroctetidae was recently recognised as distinct from the Eriocraniidae. At the time of Munroe (1979), no species were known in Canada, but two species have since been collected, one of which was described as new by Davis (1984). One additional species of *Acanthopteroctetes*, known from Glacier National Park, Montana, is expected in Canada (Table 1). Two BINs are reported for Canada (Table 1). These moths are not attracted to light and are rarely collected so Canadian distribution is incompletely known.

Superfamily Nepticuloidea

The Nepticulidae and Opostegidae belong to this superfamily. Our knowledge of Nepticulidae has improved substantially in recent years. Munroe reported 38 species for Canada, based on Wilkinson and Scoble (1979), which was in press at the time, but the total has now nearly doubled to 69 species (Table 1). The number of BINs is much higher than the number of known species, which signals that many more species remain to be documented in Canada – we estimate 50 (Table 1). A world catalogue was published recently by van Nieukerken et al. (2016), which presents a revised higher classification scheme for the group. Due to their minute size, these moths are rarely collected and much remains to be learned about this family in Canada.

Davis and Stonis (2007) published a monograph of the New World Opostegidae, but very little Canadian material was available for that work. The four species currently known in Canada were documented by Munroe (1979). No additional described species are known adjacent to Canada, but the high number of BINs (14) indicates significant undocumented diversity, and several more species (we estimate 10) are expected to be discovered here (Table 1).

Superfamily Adeloidea

This superfamily has undergone significant reorganisation since Munroe (1979), with the Adelidae and Tridentaformidae raised to family level, separate from the Incurvariidae. As well, the Lamproniinae have been moved from the Incurvariidae to the Prodoxidae. The five families in Canada include 52 species and 66 BINs, and 15 additional species are expected (Table 1).

The family Prodoxidae is now well documented for Canada thanks to several recent revisions (e.g., Davis et al. 1992, Pellmyr 1999, Pellmyr et al. 2005) which have increased the Canadian species count to 22. Few additional species are expected to be found in the country. Two *Tegeticula* species (yucca moths) are known in Canada, and are of conservation concern because they are restricted to a few patches of native yucca (*Yucca glauca* Nutt.; Asparagaceae) in southern Alberta.

Globally there is only one described species of Tridentaformidae, *Tridentaforma fuscoleuca* (Braun). It was placed in the Incurvariidae at the time of Munroe (1979). It was unknown in Canada at that time, but was discovered since then, in British Columbia and Alberta. No BINs are available and no additional species are expected in Canada.

Munroe (1979) reported 33 species of Incurvariidae in Canada, but this was erroneous; only 27 species would have been known from Canada as the family was constituted at the time. Most of the known species have since been moved to Adelidae (10 species) and Prodoxidae (15 species). As currently constituted, only two Incurvariidae species are recorded from Canada, both of which were known in 1979. Four more species are expected, based on DNA barcode data.

There has been no recent research on Heliozelidae in Canada; several more BINs than described species are known, and five more species are expected here.

The Adelidae were recognised as a distinct family recently, since Munroe (1979). A few undescribed species are known to occur in Canada, but there has been no taxonomic work on the group since Powell (1969).

Superfamily Tischerioidea

Tischeriidae is the sole family in this group. Munroe (1979) reported eight species for Canada and this has now increased to 14 through recent collecting efforts (Table 1). Puplesis and Diškus (2003) published a world catalogue, erecting one new genus that occurs in Canada. These moths are rarely collected and poorly known, and it is expected that a few additional species will eventually be found in Canada, in part based on the fact that there are more BINs than documented species in the country (Table 1).

Superfamily Tineoidea

This superfamily has undergone reorganisation recently, with Acrolophinae relegated to subfamily status in Tineidae, and Meessiidae and Dryadaulidae newly recognised as families distinct from Tineidae. The four families in Canada total 75 species and 125 BINS, and an additional 58 species are expected (Table 1).

No species now placed in Meessiidae were known from Canada at the time of Munroe (1979), but since then one has been discovered and one more, which occurs close to the Canadian border in Maine, is expected in eastern Canada. A BIN has been assigned to the single Canadian species.

The number of Psychidae species known in Canada has nearly doubled since Munroe (1979), from six to 11. This group contains a relatively high proportion of non-native species, presumably due to parthenogenetic reproduction in some taxa which enhances their colonising abilities (Davis 1964). Two of the newly recorded taxa are non-native European species, bringing the total number of non-native species to four for Canada. It is expected that three additional species will be found in Canada. Sobczyk (2011) published a world catalogue that included many new synonyms, status changes, and new combinations. The higher classification proposed therein applied only to European taxa, so the placement of many Nearctic genera remains uncertain.

Two described species of Dryadaulidae occur in the Nearctic region, one of which, *Dryadaula visaliella* (Chambers), is known from eastern Canada; it was counted among the Tineidae by Munroe (1979). This species exhibits significant genetic variation, based on DNA barcoding, and likely represents three taxa. As well, DNA barcode data suggests that two additional species likely occur in Canada, probably undescribed.

The Tineidae, now including Acrolophinae, are much more diverse than was known at the time of Munroe (1979), now with 62 known species and approximately 50 more expected. The family includes nine non-native species, some of which are stored product pests. Little taxonomic work has been done on the family in the past 100 years, other than the higher-level work of Regier et al. (2015a). The family is in need of modern taxonomic treatment.

Superfamily Gracillarioidea

This superfamily was recently recognised as distinct, and includes groups previously placed in the Tineoidea. Bucculatricidae were treated by Munroe (1979) within the family Lyonetiidae, and comprised 30 of the 40 Canadian "Lyonetiidae" species reported therein. Little taxonomic work has occurred on this family in North America since Braun (1963); however, an additional nine species have been added to the Canadian fauna since 1979 (Table 1). This group remains poorly known. As indicated by DNA barcode data, at least 30 more species remain undiscovered in Canada (Table 1).

Gracillariidae is the largest family in the Gracillarioidea. Munroe (1979) treated Phyllocnistinae as a separate family with five species. As constituted today, 165 species of Gracillariidae are known with an estimated 90 more species yet to be discovered (Table 1). Currently, 237 BINs are available for this family in Canada (Table 1), which supports the high estimate of undocumented species. Although a few gracillariid groups were revised recently, and some life history information has been published (e.g., Eiseman 2018), the family remains relatively poorly known. De Prins and De Prins (2005) published a world catalogue, which has been updated and made available online (De Prins and De Prins 2016). A higher-level phylogenetic analysis was published by Kawahara et al. (2017).

Superfamily Yponomeutoidea

This superfamily was redefined recently by Sohn et al. (2013), based on molecular analyses, and currently contains 10 named families in Canada. Based on that analysis, Ochsenheimeriinae has been relegated to subfamily status within Yponomeutidae, and Attevidae and Praydidae – formerly recognised as subfamilies of Yponomeutidae – are now recognised as distinct families. As well, Ypsolophidae was separated from the Plutellidae, Acrolepiinae was added to Glyphipterigidae, and Lyonetiidae (after removal of several other groups) was moved here from Tineoidea. As well, Bedelliidae was recognised as distinct from the Lyonetiidae. Despite these major changes, we have been able to reconcile Munroe's (1979) species tallies with the current classification (Table 1), thanks to his detailed synopses of each subfamily in the text. The yponomeutoid families Yponomeutidae, Ypsolophidae, Argyresthiidae, Lyonetiidae, and Bedelliidae have not been examined at the species level for many decades, and are in need of modern treatment. The lack of identification tools has impeded our accrual of knowledge about them, although a few species have been added to these families since 1979 (Table 1).

Our understanding of Glyphipterigidae has improved tremendously since 1979; Heppner (1985) revised the North American Glyphipteriginae, and Landry (2007) revised the genus *Acrolepiopsis*, which includes all Canadian members of the subfamily Acrolepiinae. As a consequence of that recent taxonomic research, the number of species (three) reported by Munroe (1979) has increased five-fold to 15, and it is expected that five more species will eventually be documented (Table 1). A world catalogue of the Acrolepiinae was published by Gaedike (1997).

The number of recorded species of Plutellidae, as currently defined, has almost doubled in Canada since 1979, increasing from six to 11 species (Table 1). A few more species remain to be discovered, including apparently undescribed species collected in arctic and alpine habitats.

The sole Canadian Attevidae species, *Atteva aurea* (Fitch), is native to southern Texas but it has adapted to feed on the non-native Tree-of-Heaven (*Ailanthus altissima* (Mill.) Swingle; Simaroubaceae) that has become naturalised in temperate North America, and the moth has now spread as far north as eastern Canada where adults have been regularly trapped in recent years. A BIN is available for this species, and no additional species are expected in Canada (Table 1).

The sole Canadian Praydidae species is the Hop-tree Borer, *Prays atomocella* (Dyar), which was known in Canada in 1979 and would have been tabulated by Munroe among the Yponomeutidae. That species has since been listed as "Endangered" in Canada (COSEWIC 2015). A second, non-native species was reported in Canada (in British Columbia and Newfoundland) by deWaard et al. (2009). Each species has been assigned one BIN, and no additional species of this family are expected to currently occur in Canada (Table 1).

The Heliodinidae are well known, thanks to the revision by Hsu and Powell (2004) for North America. The Schreckensteiniidae have been removed from the group, to their own superfamily, since Munroe (1979).

Unassigned Apoditrysia

The genus *Cycloplasis* is currently not assigned to any superfamily or family. It was provisionally placed immediately following the Yponomeutoidea by Pohl et al. (2016, 2018). The genus contains five species worldwide, two of which occur in North America. One of these, *C. panicifoliella* Clemens, was unknown to Munroe (1979), but it has been discovered recently in southern Ontario (Pohl et al. 2018). No other species are expected in Canada.

Superfamily Douglasioidea

The sole family Douglasiidae was removed from the Yponomeutoidea and assigned to its own superfamily since Munroe (1979). The group was revised by Gaedike (1990), in German, but that paper does not adequately delimit the species and they remain difficult to identify. Gaedike (1990) did not add any new Canadian records, but since then a species previously known only from Europe was found in Yukon Territory (Pohl et al. 2018).

Superfamily Gelechioidea

This superfamily has undergone significant reorganisation based on recent morphological and molecular work (Heikkilä et al. 2014, Sohn et al. 2016) and 15 families containing 756 species are currently known from Canada, with an additional 668 species anticipated (Table 1). The taxonomic definition of every family other than Gelechiidae has changed considerably in the past 20 years, and some questions remain concerning the higher level classification of this group. Although a few groups have been revised in recent years, this superfamily is the most poorly known major lineage of Lepidoptera in North America, and undescribed species probably outnumber the described species in some families.

As currently defined (Heikkilä et al. 2014), Autostichidae comprises a diverse family of several subfamilies that had previously been placed in their own families (Glyphidocerinae, Deocloninae) or in the Elachistidae, Oecophoridae, and Blastobasidae. At the time of Munroe (1979), this family was not recognised, but five species now contained within it were known in Canada. Currently seven Canadian species are known and five more species are estimated to be undocumented in the country.

Lecithoceridae is restricted to the southern Palaearctic, Africa, and Australia, except for the Nearctic genus *Martyringa* (two species) which was tentatively included in the family by Heikkilä et al. (2014). At the time of Munroe (1979), the genus was placed in the subfamily Depressariinae, in the family Oecophoridae, but neither species was known from Canada. One species has since been found in Canada (Handfield et al. 1997). No BIN is available for this species, and no additional species are expected to occur in Canada.

Since Munroe (1979), many groups have been moved out of the Oecophoridae to other families in the Gelechioidea, including to the Lypusidae and Depressariidae. As currently defined, 14 species of oecophorids were known from Canada in 1979. There are now 20 species known in Canada and it is estimated that 10 undocumented species occur in the country.

Until recently, Depressariidae was considered a subfamily of Elachistidae, but Munroe (1979) reported these species in Oecophoridae and listed 64 known Canadian species. There are currently 87 documented species in Canada. Although the family is better known than most gelechioids, some taxonomic problems remain, and five more species are expected to be discovered and described in Canada.

Munroe (1979) reported 10 species of Cosmopterigidae. Currently 29 species are known from Canada, with 20 more expected to occur, based in large part on the fact that many more BINs are known than are documented species. This group is relatively well known taxonomically but is poorly collected in Canada.

Gelechiidae is a large family of small, cryptically coloured moths. Significant taxonomic works have been published recently on the Dichomeridinae (Hodges 1986) and on the genus *Chionodes* (Hodges 1999), and a few smaller groups have been treated as well. Overall, however, the family is still poorly known with many genera poorly delimited and many species that cannot be identified without examination of type material. Hundreds of species likely await discovery in Canada. A checklist of North American species was published by Lee et al. (2009).

Munroe (1979) made a significant error in his report of 525 known plus 525 undiscovered Canadian Gelechiidae species. Based on examinations of hundreds of publications and almost all the significant Lepidoptera collections in Canada, Pohl et al. (2018) could only locate records of 370 gelechiid species. Only 287 of those had been described by 1979, and many of those have been identified in collections only within the past 20 years. We estimate that only about 200 species of gelechiids would have been known in Canada in 1979. It appears that Munroe's value of 525 species was only a very rough guess, rather than a formal tabulation. In the text section (p. 453) he writes: *"Even an estimate of species can be based on only the roughest of guesses... much of the group is awaiting arrangement or is on loan to specialists. There are certainly several hundred species in Canada..."*. His value of 525 species was probably meant to be a rough estimate of the total (known plus expected) fauna, rather than separate counts of 525 known and 525 expected species. Note that Munroe based his Gelechioidea classification on Hodges (1978), which placed all the currently recognised families other than Gelechiidae as subfamilies or tribes within the lesser families of Gelechioidea, not within Gelechiidae (the only exception being two species of Autostichidae (genus *Taygete*) which were placed in Gelechiidae in 1979). Thus, the taxonomic composition of the family Gelechiidae has changed very little since then, and Munroe's error cannot be attributed to subsequent taxonomic changes. Currently, 370 Gelechiidae species are known from Canada. The high number of BINs (604) indicates that there are many undescribed and unreported species, and we estimate that 350 species remain undocumented, underscoring that much work awaits before this family is well known in Canada.

The concept of the family Elachistidae has changed considerably since Munroe (1979). He treated the subfamily Parametriotinae as a separate family, under the name Agonoxenidae. Our knowledge of the Elachistinae has improved greatly in the past two decades, thanks to revisions of most groups by Kaila (1995, 1996, 1997, 1999a, b). The subfamily Parametriotinae is less well known with new species awaiting description. There have been significant advances in knowledge of the fauna, and the number of species documented in Canada increased from 28 in 1979 to 66 currently (Table 1). Nonetheless, this family is poorly collected in Canada and many new species and records remain to be discovered: we estimate 50. The fact that the number of BINs greatly exceeds the number of documented species further supports our estimate of high undocumented diversity in Canada.

A few works have been published recently on Canadian Coleophoridae, including Landry (1998b) and Landry and Wright (1993). The known species diversity in Canada has more than doubled, from 51 to 109 species since 1979; however, the group remains poorly known, and many more species await description and discovery (we estimate 150 species). Baldizzone et al. (2006) published a world catalogue of the family.

The species currently in Batrachedridae were included in the Coleophoridae by Munroe (1979). The New World species were revised by Hodges (1966) and very little work has been done on them since. Munroe (1979) specifically mentioned four known Canadian species but two more have been recorded since then.

Scythrididae was not well known at the time of Munroe (1979), who reported 15 Canadian species. The family was revised for North America by Landry (1991). Currently, 14 species are known from Canada, a reduction of one species since 1979 due to synonymy. However, it is estimated that half of the Canadian fauna remains undocumented.

The composition of the Blastobasidae has changed considerably since Munroe (1979), most notably with removal of the Autostichidae as a separate family. The last comprehensive work on Blastobasidae was by Dietz (1910), so it is in need of modern treatment. Adamski and Hodges (1996) published a nomenclature review and a checklist of the known North American species. This group is reasonably well collected, but most Canadian specimens sit unidentified in collections due to the difficulties identifying them. Currently, 19 species are known from Canada (up from 17 in 1979), but the number of BINs is twice as high as the number of known species, so many – we estimate 30 species – remain to be documented.

Until recently, Stathmopodidae was placed within the Oecophoridae, but the group was elevated to family status by Heikkilä et al. (2014). No Canadian species were known at the time of Munroe (1979). This small group is relatively well known in North America, although the sole Canadian species, *Stathmopoda aenea* (Braun), was overlooked in the North American checklist of Hodges et al. (1983). It was first reported from Canada by Handfield et al. (1997). A second species is expected in Canada as well.

Momphidae was recognised as a distinct family by Munroe (1979) and he reported ten species. This has now increased to 24. The family is poorly known and in need of revision. There are more than twice as many BINs as documented species in Canada, indicating that many more species – we estimate 30 – remain to be documented.

Pterolonchidae is a small family that was treated as a subfamily within the Coleophoridae at the time of Munroe (1979), but it had no known representatives in Canada. Since then, *Coelopoeta maiadella* Kaila was described and *Pterolonche inspersa* Staudinger was introduced for biocontrol of knapweed (*Centaurea* spp.; Asteraceae). Only one BIN for Canadian species is available and no undocumented species are expected to occur in Canada.

Lypusidae was not recognised as a family in 1979 and the one species recorded from Canada at that time, *Dasystoma salicella* (Hübner), was placed in Oecophoridae (Munroe 1979). This non-native species is still the only representative of the family in Canada and no undocumented species are expected.

Superfamily Alucitoidea

At the time of Munroe (1979), all Nearctic Alucitidae were thought to be a single species, *Alucita hexadactyla* Linnaeus, but Landry and Landry (2004) revised the Nearctic species and recognised three valid species, none of which is the Palaearctic *A. hexadac-*

tyla. All three Nearctic species occur in Canada. Barcode data indicates a fourth BIN, based on a single specimen from western Canada that requires further research. Gielis (2003) published a world catalogue of Alucitoidea.

Superfamily Pterophoroidea

There has been no comprehensive taxonomic work on the sole family Pterophoridae since Barnes and Lindsey (1921), so it is in need of modern treatment. It is particularly diverse in Cordilleran areas. Munroe (1979) reported 50 species in Canada and this has now increased to 82, with an estimated 15 species remaining to be documented (Table 1). Gielis (2003) published a world catalogue of Pterophoroidea.

Superfamily Carposinoidea

Copromorphidae is a small family that is weakly defined; its present make-up may not stand up to future taxonomic study. The Nearctic genera have all been revised recently by Heppner (1984, 1986) and Sohn (2016), so the species are reasonably well known. Since 1979, documented Canadian diversity increased from one to two species, and no undocumented species are expected to occur in the country (Table 1).

Our knowledge of Canadian Carposinidae has not advanced significantly since Davis (1968) although Diakonoff (1989) clarified the identity of one of our species. The number of known species in Canada remains at four, the number reported by Munroe (1979). DNA barcode data indicates that one more species occurs in Canada, but the specimen has not been examined for verification. Multiple BINs occur in two species but this may refer to intraspecific variation.

Superfamily Schreckensteinioidea

The family Schreckensteiniidae contains only eight species globally. Munroe (1979) treated the two Canadian species known at the time within the family Heliodinidae. One more species has since been discovered in Canada. The group has not been revised for many decades but all three Canadian species were treated by Forbes (1923) and are reasonably well known. However, it was only fairly recently that one of our species was recognized as Holarctic rather than non-native, based on a remote collection locality in northern Alberta (Pohl et al. 2005). Although there are more BINs available than there are documented species, it is thought that this represents intraspecific variation, and no undocumented species are expected (Table 1).

Superfamily Epermenioidea

Epermeniidae species are rarely encountered and poorly known. The North American members of the family were revised by Gaedike (1977), in German, with an updated key by Gaedike (2008). Munroe (1979) recorded four species; currently eight species are known from Canada (Table 1). There may be cryptic species yet undiscovered in Canada, as indicated by DNA barcode data. Gaedike (1996) published a world catalogue of the family.

Superfamily Urodoidea

The family Urodidae was unknown in Canada at the time of Munroe (1979), but Landry (1998a) presented the first Canadian records. The sole Canadian species, *Wockia asperipunctella* (Bruand), is rarely attracted to light and consequently poorly collected, so it may be more abundant than the paucity of records suggests. No more species are expected in Canada.

Superfamily Choreutoidea

Choreutidae is poorly known and in need of modern work. The family was treated in the Sesioidea by Munroe (1979). Manuscript names were assigned decades ago by J. Heppner to Canadian specimens in collections, but most of these are still unpublished. Rota (2011) and Rota and Wahlberg (2012) revised the higher classification of the group. Seven species were recorded by Munroe (1979) and this has since nearly tripled to 19 recorded species, with an additional 10 expected in the country (Table 1).

Superfamily Galacticoidea

The recently recognized family Galacticidae is in need of work and its composition has not been settled. The sole Nearctic species, *Homadaula anisocentra* Meyrick, was placed in the Plutellidae at the time of Munroe (1979). It was introduced to the USA from China in the 1940s and was reported from Canada for the first time by Pohl et al. (2018).

Superfamily Tortricoidea

The family Tortricidae is large with about 10,900 named species worldwide (Gilligan et al. 2018). Despite the importance of many species as agricultural and forest pests, many groups within the family are not well known. The tribe Cochylini was treated by Munroe (1979) as a separate family ("Cochylidae"), but has since been recognized as a subtribe within the Tortricidae. Our knowledge of North American and Canadian Tortricidae has improved substantially in recent years, with the publication of major works on Sparganothini and Atteriini (Powell and Brown 2012), and the large eucosmine genera *Eucosma* (Wright and Gilligan 2015) and *Pelochrista* (Wright and Gilligan 2017). Other significant regional works are Miller (1987) and Gilligan et al. (2008). The Canadian fauna is now known to be significantly larger than was expected by Munroe (1979) who reported 556 species and estimated 250 undocumented species. Currently, 835 species are known and another 100 undocumented species are estimated (Table 1). Brown (2005) recently published a world catalogue, which is kept current online (Gilligan et al. 2018).

Superfamily Cossoidea

Little taxonomic work has been done on Cossidae in North America in the past century, but the species are well known and only one has been added to the Canadian fauna since Munroe (1979). His estimate of a total expected fauna of 10 species is now thought to be too high. The current number of six species in Canada matches the number of BINs, and no other undocumented species are expected (Table 1).

Members of Sesiidae were poorly collected and not very well known at the time of Munroe (1979). The family is now much better known in Canada due to a recent revision (Eichlin and Duckworth 1988), and the identification and synthesis of sex pheromones, which have been used as attractants for collecting many species. Munroe (1979) reported 44 species and the current known fauna is 62 species (Table 1). DNA barcode data indicate that several species are likely species complexes, and will require taxonomic work before the Canadian fauna is fully understood. Thus it is expected that the Canadian fauna contains about 14 undocumented species. A world checklist was published by Pühringer and Kallies (2004) and is maintained online by Pühringer and Kallies (2015).

Superfamily Zygaenoidea

This superfamily is highly diverse in the tropics, but only a few species in two families reach into the temperate regions of Canada. No additional species of this superfamily are expected to be found in Canada. Limacodidae has not been revised in many years but the species in North America are reasonably well known. Munroe (1979) reported 14 species and four more have been subsequently recorded in Canada (Table 1). The Nearctic genera of Zygaenidae were revised by Tarmann (1984; in German) but the species have not been revised in many years. The number of species known from Canada has increased from one in 1979 to three currently (Table 1). Munroe (1979) listed one species of Megalopygidae as expected in Canada: *Megalopyge crispata* (Packard). It occurs only as far north as southern Ohio and southern New York state, and we do not expect it to be found here.

Superfamily Thyridoidea

Little research has been done on Thyrididae in the past century. Munroe (1979) reported three species from Canada. Two of these, *Thyris maculata* Harris and *Pseudothyris sepulchralis* (Boisduval), are fairly well known. However, the third species, *Dysodia oculatana* Clemens, was reported by Munroe (1979) as "a southeastern species that enters southern Ontario", but no specimens or observation records could be located and there are no other reports of it in the Canadian literature so the record remains unverified. The mention of that species by Munroe was overlooked by Pohl et al. (2018). Thus, currently we record two species from Canada with the possibility that an additional species may eventually be found.

Superfamily Papilionoidea

The butterflies have been treated extensively in scientific and popular literature, including a comprehensive treatment of Canadian species by Layberry et al. (1998). Butterflies are relatively well understood taxonomically, but some uncertainties exist at the species level and new species and subspecies continue to be described. There are six families in Canada for which 306 species are recorded and an additional 12 species are expected (Table 1). The relationships among butterfly families were not well understood until relatively recently, and all families are now placed in a single superfamily (Heikkilä et al. 2012). Pelham (2008) published a comprehensive catalogue, which is kept up to date online (Pelham 2016).

Hesperiidae is the most poorly known family of butterflies in Canada, as they are less often sampled or studied owing to their small size and often challenging identification. Ten species have been added since Munroe (1979), raising the national total to 74 species. Five more species are expected to be described or discovered in Canada.

Taxonomic changes in the Papilionidae have resulted in a few changed species concepts, but there are few Canadian species and the group is well-studied so there has been no change in number of species (18) since 1979. Five new species of Pieridae and eight of Lycaenidae have been recognized in the Canadian fauna since Munroe (1979), raising the totals to 42 and 66, respectively. These two families include some of the taxonomically most difficult groups, and DNA barcode diagnostic performance is especially poor for sulphurs (genus *Colias*) and blues (Lycaenidae: Polyommatinae). It is expected that one additional species of each family may occur in Canada.

There is currently a single species of Riodinidae in Canada, *Apodemia mormo* (Felder and Felder), but molecular data indicate that the British Columbia and Saskatchewan populations may in fact represent two species (Proshek et al. 2015), and this accounts for the additional expected species. Both populations are of conservation concern. Munroe (1979) listed three more species expected in Canada, possibly based on the occurrence of *Calephelis* species in northeastern USA, but the probability that any of these occur in Canada is low.

Nymphalidae is the largest butterfly family in Canada (and worldwide). Several subfamilies (Libytheinae, Danainae, and Satyrinae) were historically treated as separate families, and were listed as such by Munroe (1979). Munroe reported 94 species combined; since then, 11 more species have been discovered or recognized in Canada. One additional described species is expected to be found here, and taxonomic work may lead to a few more species being recognized here as well.

Superfamily Pyraloidea

Munroe (1979) treated the Crambidae and Pyralidae together as the Pyralidae, and did not give details on the numbers of each subfamily (which is surprising since this was his group of expertise), so the numbers reported in 1979 for each of these families as currently constituted could only be estimated. The majority of Canadian Pyralidae species are in the subfamily Phycitinae, which are fairly well known thanks to revisions by Neunzig (1986, 1990, 1997, 2003) that cover most species in the group. However, some taxonomic issues remain, and the ranges and life histories of many species are not well known. All the other subfamilies that occur in Canada (Galleriinae, Chrysauginae, Pyralinae, and Epipaschiinae) are in need of taxonomic work. Currently, the known species richness of Canada stands at 243, and we estimate that 30 undocumented species await discovery (Table 1).

Currently, 295 species of Crambidae are recorded from Canada and we estimate that 40 more species may eventually be documented in the country (Table 1). Very little taxonomic information has been published about Canadian Crambidae since 1979, and the family remains incompletely known. The Crambinae in particular are in need of modern revision; B. Landry (1995) provided an analysis and classification of North American genera. Scholtens and Solis (2015) provided an updated checklist of North American Pyraloidea.

Superfamily Mimallonoidea

Mimallonidae is primarily a Neotropical family, with two species that have ranges extending into southeastern Canada. No more species are expected in Canada.

Superfamily Drepanoidea

Munroe (1979) treated Drepaninae and Thyatirinae as separate families, but these are both now in Drepanidae. He listed 14 species of Thyatirinae which is erroneous. As of 2018, there are eight known species and seven subspecies of Thyatirinae in Canada. This is a very well known group; all eight Canadian species have not changed in status for decades, and all were known in Canada in 1979. The reason for Munroe's extra species count is not known, but a possibility is that he accidentally included subspecies names. The four Canadian species of Drepaninae have also been well known to lepidopterists for decades. Consequently, the number of species in this family remains at 12 for Canada, but one more species may eventually be recorded (Table 1).

Superfamily Lasiocampoidea

Munroe (1979) listed 10 species of Lasiocampidae, two more than currently known; however, his count was based on a classification that considered *Malacosoma pluvialis* (Dyar) and *M. lutescens* (Neumögen and Dyar) as separate species, rather than as subspecies of *M. californica* (Packard) as they are treated today. The taxonomic status of those taxa remains uncertain, and DNA barcode data indicates significant divisions within *M. californica*, contributing to the 18 BINs in total for the family. Future work may prove Munroe correct in his depiction of this group. We expect that two additional species will eventually be recognized or documented in Canada.

Superfamily Bombycoidea

There are three families of Bombycoidea in the wild in Canada. A fourth, Bombycidae, is an Old World group, known in North America only by the domesticated silkworm moth *Bombyx mori* (Linnaeus), which is cultured in captivity. Munroe (1979) and Pohl et al. (2018) included it in their counts, but we have excluded it here.

Apatelodidae is primarily a Neotropical group, with two species that have ranges extending into southeastern Canada, and no additional species are expected to be found.

Saturniidae is a very well-known family in North America. Tuskes et al. (1996) added much to our knowledge of the biology of the group, but did not add any new Canadian records. Munroe (1979) reported 23 species in Canada, but Pohl et al. (2018) list one more species: an old record of *Coloradia pandora* Blake from Victoria, British Columbia, that is treated therein as a naturally-occurring stray.

Sphingidae are very well known in Canada, based on detailed treatments of the North American fauna (e.g., Tuttle 2007). Six species have been added to the known Canadian fauna in recent years, so the current number of known species is 60, but three more species may yet be discovered in the country (Table 1). Kitching and Cadiou (2000) provided a complete world catalogue.

Superfamily Geometroidea

Of the two families of Geometroidea in Canada, Uraniidae is primarily a tropical group with only two species in Canada. No additional species are expected; additional

BINs in one species appear to represent intraspecific variation. There is no modern taxonomic revision for either genus present in Canada.

Geometridae is a huge group, containing about 23,000 species globally (van Nieukerken et al. 2011). Most Canadian species are fairly well known, but undescribed Canadian species are known in several genera. Authoritative taxonomic works are Bolte (1990) and Ferguson (1985, 2008); diagnostic references by McGuffin (1967, 1972, 1977, 1981, 1987, 1988) are useful as well. Many Canadian species were described or otherwise added to our known fauna in the works published since Munroe (1979), and the current total diversity is 534 species, an increase of 84 species since 1979 (Table 1). We expect 50 more species to eventually be documented from Canada. A global catalogue of the Geometridae was published by Scoble (1999), and an updated checklist derived from it is available online (Scoble and Hausmann 2007).

Superfamily Noctuoidea

Five families of Noctuoidea are recorded from Canada. The world catalogue of "Noctuidae" by Poole (1989) includes most species of Noctuoidea, but excludes the Notodontidae, Lymantriinae and Arctiinae. Lafontaine and Schmidt (2010, 2011, 2013, 2015) published a more recent checklist (plus errata and additions) of valid North American Noctuoidea species. Noctuoidea are particularly well-sampled for DNA barcodes in North America; Zahiri et al. (2017) report that barcodes are known for over 97% of known North American species, with far more species sharing barcodes (255) than species not sampled for barcodes (99).

Notodontidae is the most basal North American noctuoid family. Most Canadian notodontid species are fairly well-known, but the group has not been revised in many decades. A few species have been added by collectors since Munroe (1979), so the number of species has increased to 57 from the 50 reported in 1979 (Table 1). A world catalogue was published by Schintlemeister (2013).

The remainder of the Noctuoidea have undergone considerable reorganization in the past few decades. Munroe recognized "Lymantriidae" and "Arctiidae", and placed all remaining species in the "Noctuidae". More recently, a series of papers examining Noctuoidea phylogeny using genetic and morphological data (Zahiri et al. 2011, 2013, and references therein) has resulted in a stable classification where the family Erebidae includes the Lymantriinae and Arctiinae as well as all the "noctuid" species that exhibit primitive "quadrifine" hindwing venation. Two smaller families Euteliidae and Nolidae are also now recognized, and the rest of the more derived groups of noctuoids are placed in a more restricted concept of the family Noctuidae.

Taking into account the aforementioned classification changes, Munroe's (1979) report of 1520 known Canadian "Noctuidae" is still incorrect. Currently, based on Pohl et al. (2018), there are only 1439 known Canadian species that would have been placed in "Noctuidae" sensu Munroe (1979). Of those 1439 currently recognized species, only 1335 had been described by 1979, and many of those had not yet been discovered in Canada. We estimate that in 1979, approximately 1270 "Noctuidae" (sensu Munroe 1979) were known from Canada. Thus Munroe's value of 1520 is too high by approximately 250. Munroe states in the text section (pp. 279): "*There are perhaps 1500 species of Noctuidae known from Canada...*"; suggesting that his value was only a rough guess rather than based on a tabulation of species. Another possibility is that he may have inadvertently included subspecies in his counts, as 250 is approximately equal to the known Canadian subspecies of "Noctuidae" (sensu Munroe 1979) recognized at that time. Of the estimated 1270 species of "Noctuidae" (sensu Munroe 1979) that were known in 1979, five were eutelliids, 15 were nolids, approximately 200 were erebids other than Lymantriinae and Arctiinae, and approximately 1050 were Noctuidae in the modern sense.

Erebidae is the most speciose Lepidoptera family in the world, with almost 25,000 described species (van Nieukerken et al. 2011). There are no recent comprehensive revisions, but many species are covered and illustrated in field guides and other popular works. Currently, 342 species are recorded from Canada, an increase from approximately 286 species known in 1979 (Table 1). Forty more species of Erebidae are expected in Canada. A catalogue of North American Arctiinae was published by Schmidt and Opler (2008).

The Euteliidae and Nolidae are small families that are relatively well known in Canada. At the time of Munroe (1979), five species of euteliids and 15 of nolids were known from Canada. The current numbers of species are now eight and 18, respectively (Table 1). No additional species are expected for either family.

Noctuidae is the most speciose Lepidoptera family in Canada (Table 1), and the number of species has grown from approximately 1050 to 1182 species since 1979. Many works have been published on Noctuidae in recent years, increasing our understanding of the group significantly. Numerous Noctuoidea generic revisions are available in the ongoing series "Contributions to the Systematics of New World Macro-moths" (Schmidt and Lafontaine 2015). Comprehensive works include Lafontaine and Poole (1991; Plusiinae), Poole (1995; Cuculliinae), Hardwick (1996; Heliothinae), and Lafontaine (1987, 1998, 2004; Noctuinae). A further 100 species are expected in Canada.

Faunal analysis

DNA barcode information

The use of mitochondrial cytochrome *c* oxidase subunit I as a "DNA barcode" for diagnostic and taxonomic work was developed in 2003 (Hebert et al. 2003). Since then, a vast library of DNA barcodes has been assembled (Ratnasingham and Hebert 2007, 2013), including many Lepidoptera species. In previous studies, deWaard et al. (2011)

found 93.2% congruence between BINs and named species in a study of 339 of the 349 geometrid species then known from British Columbia. Zahiri et al. (2017) found 92.8% congruence between BINs and species of Noctuoidea in North America, covering 3565 of 3664 species. They found a total of 3816 BINs, representing a BINs: species ratio of 1.07. In both studies, some of the incongruence was attributed to groups in need of modern taxonomic revision and which contained cryptic species. However, both studies revealed species that exhibited intraspecific variation of the barcode region, and/or shared barcodes with other species, indicating that there are cases where barcodes are not diagnostic. Nonetheless, they have greater than 90% efficacy in North American Lepidoptera.

To date, 5842 BINs have been identified among Canadian Lepidoptera. Many of the barcoded specimens were not identified to species, so a measure of efficacy cannot be calculated. However, if the ratio of BINs to species is similar to that found by Zahiri et al. (2017), this would correspond to 5461 species. Although this is extremely close to the 5455 reported species in Canada, that is merely coincidence, since some named species have not been barcoded and some barcoded species have not been named. The estimate of 5461 barcoded species represents approximately 80% of the estimated 6855 species thought to occur in Canada. Thus, we extrapolate that approximately 80% of Canadian Lepidoptera have been barcoded, although not all have named species-level determinations yet.

In several superfamilies, the number of BINs is significantly greater than the known species (Nepticuloidea, Tineoidea, Gracillarioidea, Gelechioidea), reflecting our lack of knowledge in those groups (see discussion of undescribed species below). Most butterfly families are very well sampled genetically, and are very well known; the lower numbers of BINs than described butterfly species indicates cases where BINs are not diagnostic at the species level. This is most notable in the Pieridae, particularly in the genus *Colias* in which 15 species share five BINs in Canada (Ratnasingham and Hebert 2007).

Current state of knowledge

The checklist by Pohl et al. (2018) lists 5455 species of Lepidoptera reported from Canada, making it the fourth-largest insect order in the country in terms of diversity. A total of 207 species is known to be non-native to North America, 63 of which arrived or were detected after 1979. A further 65 species (not detailed here) are of unknown origin, either non-native or Holarctic.

Our knowledge of Lepidoptera in Canada is generally good, but it is unevenly spread geographically and taxonomically. The composition and distribution of many micromoth families are relatively poorly known, while butterflies and most macromoths are relatively well known. As reported by Munroe (1979), biological and ecological information remains mostly concentrated on a few important pest species.

However, the recent expansion of interest in invertebrate conservation has improved our knowledge of some species.

Munroe (1979) reported 4692 Lepidoptera species known from Canada, and estimated an additional 2042 species that likely occurred here but had yet to be discovered, for a total of 6734 species. However, after taking into account the aforementioned errors in his counts of Incurvariidae, Gelechiidae, Drepanidae, and Noctuidae, only 4107 species were known from Canada at that time, representing 67% of an estimated total fauna of 6149 species. As of 2018, 5455 species are reported from the country and a further 1400 are expected to be discovered, for an estimated total fauna of 6855 species. Since 1979, 1348 more species of Lepidoptera have been documented in Canada, representing 66% of the additional species Munroe predicted would be found here, for an increase in the known fauna of about 33%. Munroe predicted a higher number of Adeloidea than we do, and his estimates for Tineoidea, Gelechioidea, Tortricoidea, and Pyraloidea are significantly lower than ours. Currently, it is estimated that about 80% of the total Canadian species are known, a much higher proportion than in 1979. The approximately 1400 species thought to comprise Canada's unknown Lepidoptera fauna include both species unknown to science and described species with a core range outside of Canada that have not yet been documented here. The undocumented fauna for micromoths is likely to contain a higher proportion of undescribed species than for the taxonomically better-studied macromoths. Species additions among the butterflies will likely be the result of taxonomic changes.

There have been two drivers of the increase in our knowledge of Canadian Lepidoptera. First has been the slow and steady accumulation of new knowledge – the new records, new species descriptions, and revisions, augmented with new character sets and tools such as genetic information and the analytical techniques to derive value from it. The development of DNA barcoding by the Barcode of Life Data Systems group (Ratnasingham and Hebert 2007, 2013) has helped immensely in making sense of species-level genetic variation, and it is a testament to Canadian ingenuity that such an internationally important organization was built in our country. The second driver has been a revolution in how we access existing knowledge. The modern computer and the internet age have put almost the entire written word at our fingertips, easily accessible to anyone with a computer and an internet connection. Tasks that took weeks in Munroe's day, such as obtaining an obscure paper, or getting the opinions of colleagues across the world, now take minutes to hours. Today's curious naturalist can post a photo of a moth online, and trigger a real-time discussion about its identity among the world's top authorities. That was unthinkable in Munroe's time. As well, the simple ability to organize and electronically search vast amounts of information has improved the life of the biologist immeasurably. It was simply not possible to compile a definitive checklist of the Lepidoptera of Canada before modern computers existed. Going forward, the steady accumulation of new information, and enhanced ability to access and organize vast amounts of data will continue to drive our knowledge of Canadian Lepidoptera.

Gaps and opportunities

Undersampled regions

Historic and modern sampling effort for Lepidoptera has not been equal across Canada's vast landscape. Urban centres and adjacent areas with a long history of lepidopterists accordingly have the best-known Lepidoptera fauna; other regions have only a limited history of Lepidoptera surveying or are still relatively unknown. These knowledge gaps can be evaluated through the lens of either political or ecological geography at different spatial scales. Comparison of Lepidoptera diversity patterns to other well-sampled fauna and flora at the provincial/territorial scale provides a good starting point for addressing future research efforts.

As nearly all Lepidoptera depend on plants, comparison of their species richness to that of vascular plants provides a meaningful comparative metric of discrepancies in actual or observed diversity across jurisdictions. The ratio of native Lepidoptera to native vascular plant species richness is remarkably consistent across most of southern Canada, ranging from 1.42–1.60 for the Prairie Provinces, Ontario, Quebec and New Brunswick (Table 2); these regions are generally regarded as being well-known entomologically and botanically. British Columbia has a lower ratio of 1.21, and given that it has the greatest plant diversity in Canada, many more Lepidoptera likely remain to be documented there. As discussed below, British Columbia also has a high incidence of Lepidoptera species new to science. Ratios for the Maritime Provinces are more variable; New Brunswick has a well-known Lepidoptera fauna with a ratio comparable to the rest of southern Canada, while that for Nova Scotia indicates slightly greater Lepidoptera numbers (or possibly a more poorly known flora). Prince Edward Island has the lowest ratio among non-northern Canadian jurisdictions; more Lepidoptera species are expected (but not yet documented) there than in any other province (Pohl et al. 2018). A value of 0.97 for Newfoundland (excluding Labrador) is intermediate between that of southern Canada and the North, as might be predicted given its ecozonal affinities (primarily boreal with some subarctic elements), and the fact that it is well removed from the mainland and therefore largely lacking southern and Atlantic Maritime Lepidoptera. The Lepidoptera of Newfoundland has historically been relatively well studied, although even macromoth species continue to be added to the island's fauna (B Landry and Schmidt 2018). Lepidoptera-to-plant diversity ratios are considerably lower for the North (Yukon Territory, Northwest Territories, Nunavut, Labrador) compared to southern Canada, undoubtedly reflecting different latitudinal patterns in diversity gradients between insects and plants. Nevertheless, comparisons among northern jurisdictions indicate a considerably lower value for Nunavut. The bulk of Nunavut's Lepidoptera faunistics information is based on the Northern Insect Survey work carried out decades ago (Danks 1981), and very limited additional Lepidoptera collecting has occurred there, in large part due to the remoteness and inaccessibility of the region. The southeastern-most extent of Nunavut comprising numerous islands in Hudson Bay and James Bay (e.g., Belcher Islands, Akimiski Island) will certainly reveal species new for the territory, as virtually

Table 2. Comparison of number of native Canadian Lepidoptera species (Pohl et al. 2018) and native vascular plant species (Canadian Endangered Species Conservation Council 2016).

	YT	NT	NU	BC	AB	SK	MB	ON	QC	LB	NF	NB	NS	PE
No. Lepidoptera species	739	601	139	2633	2467	1880	2111	3058	2772	484	853	1593	1745	776
No. plant species	1056	1046	668	2176	1602	1230	1349	2038	1736	682	877	1125	1069	713
Lepidoptera : plant ratio	0.70	0.57	0.21	1.21	1.54	1.53	1.56	1.50	1.60	0.71	0.97	1.42	1.63	1.09

no sampling has occurred there. As well, the mainland portion of Nunavut that lies north of Manitoba, which contains significant areas of boreal forest, has been poorly sampled and will likely yield many new records.

From an ecological perspective, data on the Lepidoptera fauna by ecozone is more limited. Of Canada's 15 terrestrial ecozones (Federal, Provincial and Territorial Governments of Canada 2010), the boreal region is the most expansive (here defined to include the Boreal Shield, Newfoundland Boreal, Boreal Plains, Taiga Shield, Taiga Plains and Hudson Plains ecozones) and it has a relatively well-sampled, taxonomically well-known, homogeneous Lepidoptera fauna where many local faunal inventories have been carried out (see Pohl et al. 2010, Pohl et al. 2018). The exception is the northern reaches of this region where lack of road access has meant that much of the region is unexplored entomologically. The Atlantic Maritime ecozone is relatively well documented (Lafontaine et al. 2001), and the Prairies ecozone moderately so (Pohl et al. 2014). Most recent discoveries, including species new to science and new additions to the Canadian fauna, have come from the Mixedwood Plains (southern Ontario) and Montane Cordillera (southern British Columbia and western Alberta) ecozones, and also Taiga Cordillera and Boreal Cordillera (northern British Columbia, Yukon, and western Northwest Territories). The Pacific Maritime ecozone is most diverse and best known around its southernmost reaches (i.e., Vancouver Island and the Lower Mainland of British Columbia), while the central and northern portions have had little survey effort, and virtually none at higher elevations. Similarly, sampling density across Canada's Arctic ecozone remains sparse. Renewed micromoth collecting efforts in southwestern Ontario near Lake Huron by one collector (K. Stead) in recent years has resulted in a surprising number of new Canadian records for species previously known only from the central USA (south of the Great Lakes and east of the Mississippi valley). Most regions of Canada are expected to yield numerous micromoth discoveries with proper sampling. Rearing and day-time collecting with sweep nets, especially in open habitats, would likely bring many discoveries.

In summary, the jurisdictions that show the greatest deficit in Lepidoptera faunal knowledge include Nunavut, Prince Edward Island, and British Columbia. The Lepidoptera fauna has not been delineated for all ecozones, but most recent discoveries stem from the southern ecozones that also include Canada's diversity hotspots, with the important exception of the northern cordilleran ecozones that encompass parts of Beringia. Directing future sampling effort to targeted areas will provide a more complete picture of jurisdictional and ecozonal faunal inventories that will, in turn, aid decisions in managing the future of Canada's biologically rich heritage, particularly those species of importance to humankind and those in need of conservation.

Undescribed species

As in other insect groups, the state of taxonomic knowledge of Canada's Lepidoptera fauna varies according to group. Butterflies are the best-known insect group taxonomically, and the few recent discoveries involve previously overlooked cryptic species (e.g., Verhulst 2009, Warren et al. 2016). Most faunal additions result from better resolution of species-groups that have traditionally been difficult to delineate, such as *Coenonympha nipisiquit* McDunnough (Sei and Porter 2007). In contrast, a moderate number of new species of macromoths continue to be discovered. Two regions stand out as recently yielding relatively high numbers of new macromoth species: unglaciated parts of the Yukon (Beringia), and the Pacific Maritime, Montane Cordillera, and Western Interior Basin of British Columbia (Fig. 1). Although few of the recently discovered species are endemic to Canada, most often occurring in neighbouring parts of the United Sates, these discoveries do highlight the importance of continued sampling and surveying of Lepidoptera, particularly in diversity hotspots such as southern British Columbia. Approximately 50 species of Canadian macromoths are currently known to be unnamed or unrecognized, primarily in the superfamily Noctuoidea but also including Geometridae (C Schmidt unpubl. data).

The micromoths are generally much less well known. As a rule, the smaller the moths, the fewer the records and the poorer the taxonomic knowledge of families. Small to minute size coupled with fragility and difficulties in specimen preparation translates

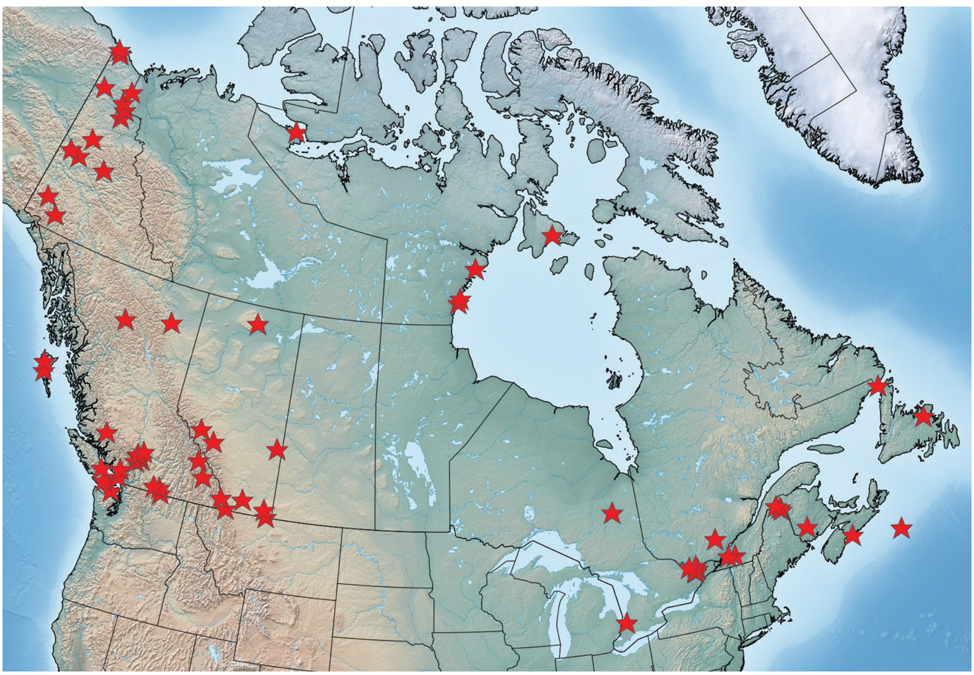

Figure 1. Map of all Canadian macrolepidopteran type localities for species described since 1978.

into fewer, lesser-quality specimens available for study, which hinders taxonomy. Many of the smaller moths are easily missed, particularly if sampled with the usual method of light traps. Many micromoths have diurnal or crepuscular habits (e.g., Micropterigidae, Acanthopteroctetidae, Scythrididae, Epermeniidae) and are rarely collected at lights, so they are often under-represented in collections. Recent insect barcode surveys conducted across Canada with Malaise traps (Gleason and Williams 2012) yielded numerous micromoths, such as Nepticulidae, Tineidae, etc., otherwise rarely collected unless reared from larvae. In general, the proportion of undescribed species in North America exceeds 25% in many micromoth families, compared to less than 10% for the majority of macromoth groups. The superfamily Gelechioidea includes the greatest number of undescribed or unrecognized species (>650), with several families in which that portion equals or exceeds the named species (Blastobasidae 150%, Coleophoridae 138%, Gelechiidae 95%, Momphidae 125%, Scythrididae 100%; see Table 1). A similar though less extreme situation prevails in other superfamilies, notably in the Nepticuloidea, Tineoidea, and Gracillarioidea. In these taxa, the taxonomic impediment is not restricted to Canada but extends to the entire Nearctic Region.

Distribution changes

A few species are known to have expanded their distributions since Munroe's (1979) account. The most dramatic examples include non-native species such as *Noctua pronuba* (Linnaeus), which has spread across the continent in the past two decades after an initial introduction to Atlantic Canada (Copley and Cannings 2005, and references therein). *Lymantria dispar* (Linnaeus), the most notorious non-native lepidopteran, has not expanded into the boreal forest region, but is now widespread throughout the eastern deciduous forest. Although it is not always possible to discern whether new distribution records of native species represent range expansion or simply greater collecting effort, the detection of several conspicuous species in historically well-collected regions clearly indicate range shifts. The best-documented cases involve westward range expansions of eastern species into Alberta, such as *Actias luna* (Linnaeus), *Acronicta mansueta* (Smith), *Harrisimemna trisignata* (Walker), *Ctenucha virginica* (Esper), *Diachrysia balluca* (Geyer) and *Lethe anthedon* (Clarke). There are few cases of western species expanding eastward, although the western bean cutworm (*Striacosta albicosta* (Smith)) is now regularly present in Ontario and has been found as far east as New Brunswick, but was historically restricted to the Great Plains. Northward expansions are best documented in Ontario butterflies, where *Papilio cresphontes* Cramer, *Erynnis baptisiae* (Forbes) and *Anatrytone logan* (Edwards) have moved north and east into the eastern part of the province in the past few decades (Larrivée and Kerr 2012). Conversely, several boreal butterfly species seem to be disappearing from some southern parts of their range. In eastern Ontario, *Colias interior* Scudder, *Oeneis chryxus* (Doubleday), *Icaricia saepiolus* (Boisduval) and *Boloria freija* (Thunberg) have disappeared to varying extents from historic localities. A few Canadian species have become extirpated due to habitat loss from already localized populations, such as *Plebejus samuelis* (Nabokov), *Callophrys irus* (Godart), and *Erynnis persius persius* (Scudder). Despite the above examples, for the most part our species-level knowledge has not been sufficient to detect and measure trends in range changes. We have not yet seen large range changes that can unequivocally be attributed to climate change, but they will undoubtedly occur. For some Lepidoptera groups such as butterflies and macromoths, we are well positioned to detect such changes; for other lesser known groups, it will be difficult to distinguish new immigrants from undetected indigenous species.

Lepidoptera of conservation concern

A total of 26 species and an additional eight subspecies of Lepidoptera are currently ranked by COSEWIC as being of conservation concern based on detailed assessments (COSEWIC 2017). An additional 157 species have been flagged as being of potential conservation concern (ranked as “N3” or lower) at the national level by the National General Status Working Group of the Canadian Wildlife Service (CESCC 2016). A significant impediment to assigning conservation ranks to Lepidoptera is lack of knowledge about the geographic extent of occurrence and area of occupancy, both being metrics based on occurrence (or more rarely absence) records of a given species. For example, *Melaporphyria immortua* Grote was assessed as “data deficient” (COSEWIC 2017) since lack of knowledge about host plants and habitat requirements prevent targeted surveys for this species. Identifying common knowledge gaps among Lepidoptera of potential conservation concern would help in targeting specific regions and/or habitats for future Lepidoptera survey efforts.

Biological knowledge

Lack of knowledge about hostplant or larval requirements can hamper our understanding of Canada’s Lepidoptera fauna, and in some cases impact management decisions, from both a conservation and pest management perspective. Lack of knowledge of basic natural history information is still a considerable data gap among Canadian Lepidoptera. Perhaps as many as half of micromoth species have completely unknown immature stages and host plant requirements. Macromoths fare somewhat better, with an estimated 30% of species that have unknown life histories. Immature stages and life histories are much better known for eastern than for western species, as the eastern fauna has been studied intensively in the past two decades (e.g., Wagner 2005, Wagner et al. 2011). The historic focus on tree and shrub insects has provided for a better understanding of the immature stages of moths that feed on such plants; for example, the Forest Insect and Disease program of the Canadian Forest Service (McGugan 1958, Prentice 1962, 1963, 1965) provided a considerable knowledge base on forest

Lepidoptera biology. The least-known Lepidoptera are those that feed on rare, habitat-specialized or economically unimportant plants.

Lepidoptera is the second-most diverse group (after Hymenoptera) of flowering plant pollinators. They are closely associated with flowering plants and most Lepidopterans that imbibe nectar are potential or actual pollinators. The greatest diversity of nectarivore Lepidoptera is in the Obtectomera clade (van Nieukerken et al. 2011), notably the butterflies and skippers (superfamily Papilionoidea), owlet moths and relatives (Noctuoidea), spanworms (Geometroidea), snout moths (Pyraloidea), and hawk moths (Bombycoidea: Sphingidae). Most micromoths (non-obtectomeran Ditrysia; van Nieukerken et al. 2011) appear to play only a minor role as potential pollinators, although exceptions include the Prodoxidae, some of which are well known for their mutualisms with yucca plants.

Despite the recent focus on the importance of insect pollinators in natural and agro-ecosystems, basic data on Lepidopteran nectar-feeding ecology is so scant that it is uncertain just which Lepidoptera are pollinators, and clearly this is a research priority before the pollinator fauna can be understood. An assessment of which moth groups and which plant taxa are likely the most important players in Lepidopteran pollinator interactions in Canada is an important first step that is sorely needed.

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Trichoptera of Canada

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Abstract

Trichoptera, or caddisflies, are common members of freshwater ecosystems as larvae and are important indicators of aquatic system health. As such, the species are relatively well studied, with keys available for larvae and adults of many of the taxa occurring in Canada. The number of species recorded from Canada since 1979 (Wiggins 1979) has increased from 546 to 636, an increase of 16.4%. Of those species newly recorded, 17 represent newly described taxa since 1979. Taking into consideration the species likely to be subsequently found in Canada based on records in adjacent parts of the United States and results from DNA barcoding, an estimated 129–181 species remain to be documented in Canada.

Keywords

biodiversity assessment, Biota of Canada, caddisflies, Trichoptera

Trichoptera, or caddisflies, is a species-rich group of holometabolous insects with more than 16,000 extant species worldwide (Morse 2018 and see http://entweb.sites.clemson.edu/database/trichopt/), the seventh largest order of insects (Adler and Foottit 2017). The order originated approximately 234 Mya (Malm et al. 2013), and is considered the sister group to Lepidoptera (butterflies and moths) (Morse 1997, Wiggins

1998, Misof et al. 2014). Trichoptera have larvae and pupae that are almost exclusively aquatic (Morse 2017); *Philocasca demita* Ross (Limnephilidae) and *Manophylax* (*Madeophylax*) spp. are some exceptions (Schmid 1998, Chuluunbat et al. 2010). Mackay and Wiggins (1979) suggest that the high trichopteran diversity was driven by the larval secretion of silk, which provided opportunities to exploit different ecological niches. Wiggins (1998) further speculated that the diversification of Trichoptera has taken place entirely within aquatic habitats, due to larvae being able to exploit food resources in new ways thanks to their diverse case/retreat/filter-net construction. The legs of pupal Trichoptera are modified for the water to land transition, allowing pharate adults to swim to the water surface and sometimes to land, with specialized claws used for crawling on stones or plants (Friedrich and Kubiak 2018).

Caddisfly larvae are well known for their underwater architecture, with some taxa constructing elaborate cases out of a range of materials. The behaviours, type of materials used, and the shape of the case often being diagnostic for trichopteran identification (Weaver and Morse 1986, Wiggins 1996, 2004). Some workers (Wiggins and Wichard 1989, Frania and Wiggins 1997, Wiggins 1998, Kjer et al. 2001, Holzenthal et al. 2007, Malm et al. 2013) have recognized three suborders of Trichoptera corresponding to larval construction behaviours (and see Morse 1997, 2017). Annulipalpia (or "fixed-retreat-makers") attach themselves to substrates using silk which often also acts to gather food items from the passing water currents. Integripalpia contain species with "portable-case-making" larvae, constructing tubular cases of various materials (e.g., leaves, wood, small pebbles) held together with silk. "Spicipalpia", consist of larvae that construct closed, semi permeable cocoons for pupation, but which exhibit a wide range of larval behaviours, including some free-living predatory larvae and herbivorous forms that build portable enclosures to provide shelter while they graze, but do not build traditional tube cases or filtering nets like the majority of caddisfly taxa (Malm et al. 2013). Morse (1997, 2017) provided more specific details on the taxa historically included within "Spicipalpia" (i.e., Rhyacophiloidea, Glossosomatoidea, Hydroptiloidea), but the most recent phylogenies (e.g., Kjer et al. 2016, Morse et al. in preparation) consider these families to be basal lineages of Integripalpia. For this faunistic summary, we structure Table 1 to reflect the recent summary of trichopteran higher classification provided by Holzenthal et al. (2011), modified for taxa found in Canada.

Trichoptera continue to be the subjects of much taxonomic work largely because this insect order is among the most important and diverse of all aquatic taxa (Holzenthal et al. 2007), exceeded in number in freshwater habitats only by Coleoptera (16,000+ species) and Diptera (51,000+ species) (Morse 2017), and are key elements of freshwater ecosystems for biological assessment and water quality monitoring. Especially because of their importance in freshwater biomonitoring, Trichoptera is one of the few insect orders in which keys exist for both the larvae (e.g., Wiggins 1996, 1998, Morse and Holzenthal 2008) and adults (e.g., Cooper and Morse 1998, Schmid 1998, Wiggins and Currie 2008), though Wiggins (1979) and Morse (2017) indicated that there is a major deficiency in our ability to identify the immature stages.

Trichoptera taxonomy has a rich history in Canada, with workers such Glenn B. Wiggins, Andrew P. Nimmo, and Fernand Schmid laying a solid foundation for ongoing and future work. Many other North America workers continue to contribute to knowledge of the Canadian trichopteran fauna (see Table 1). Since Wiggins' (1979) summary of the Canadian fauna, Morse (1993) published a checklist of 1653 North American species, which included the fauna of Mexico and Greenland, but did not partition these by country. Schmid (1998) published keys to the genera occurring in Canada and the adjacent United States, which included estimates of numbers of species in each. Unfortunately, precise numbers for species richness in Canada were not provided, though he did provide estimates for Canada and adjacent areas. Most of the data supporting the current assessment (Table 1) are based on an online list of Nearctic Trichoptera (Rasmussen and Morse 2018). Since the time of Wiggins' (1979) summary, the number of Trichoptera species recorded from Canada has increased from 546 to 636, representing an increase of 16.4%. Of the newly recorded species, 17 were described since 1979.

In his overview of Canadian caddisflies, Wiggins (1979) recognized 18 families of Trichoptera within three superfamilies: Rhyacophiloidea (four families), Hydropsychoidea (three families), and Limnephiloidea (11 families), these corresponding to the suborders 'Spicipalpia', Annulipalpia, and Intergripalpia, respectively, and tallied 546 species (Table 1). Since that time, different higher level classification schemes based on phylogenetic analyses have been applied to Trichoptera, both in North America (e.g., Wiggins 1996, Schmid 1998) and globally (Holzenthal et al. 2007, 2011).

The Canadian fauna includes ten superfamilies and 25 families (Table 1; after Holzenthal et al. 2011). Rhyacophiloidea (= Spicipalpia of other authors), as recognized by Wiggins (1979), is now partitioned into three superfamilies: Glossosomatoidea (Glossosomatidae); Hydroptiloidea (Hydroptilidae, Ptilocolepidae [= Hydroptilidae, subfamily Ptilocolepinae of Schmid (1998) and likely Wiggins 1979, so not included in the 1979 work]); and Rhyacophiloidea (Rhyacophilidae). By contrast, Hydropsychoidea is currently applied in a much narrower sense than by Wiggins (1979); it is now represented by a single family, Hydropsychidae, which includes Arctopsychidae of Schmid (1998). Of the other three families included in Hydropsychoidea in Wiggins (1979), Philopotamidae has been placed in Philopotamoidea and Psychomyiidae and Polycentropodidae are now in Psychomyioidea. One additional family within Psychomyioidea is newly recorded in Canada since 1979, Dipseudopsidae [treated as Hyalopsychidae by Schmid (1998)]. An additional five families have been newly recorded from Canada (Wiggins 1996, Schmid 1998, Rasmussen and Morse 2018) based on changes in classification, all within superfamily Limnephiloidea: Apataniidae, Goeridae, Thremmatidae, Uenoidae, and Rossianidae. The latter three families were considered part of Limnephilidae by Wiggins (1979), and Rossianidae was previously recognized as the subfamily Dicosmoecinae of Limnephilidae by Schmid (1998), and likely also by Wiggins (1979). Of the eleven families placed in the Limnephiloidea by Wiggins (1989), ten now reside in different superfamilies: Brachycentridae, Lepidostomatidae, and Phryganeidae have been placed in Phryganeoidea; Calamoceratidae, Molannidae, Leptoceridae, and Odontoceridae placed in Leptoceroidea; and Beraeidae, Helicopsychidae, and Sericostomatidae placed in Sericostomatoidea. These additions and reclassifications account for ca. 40 of the additional species within Canada (Table 1).

Table 1. Census of Trichoptera in Canada[1].

Taxon[1]	No. species reported by Wiggins (1979)	No. species currently known from Canada[2]	No. BINs[3] available for Canadian species	Est. no. undescribed or unrecorded species in Canada[4]	General distribution by ecozone[5]	Information sources[6]
Suborder Annulipalpia						
Superfamily Philopotamoidea						
Philopotamidae	13	14	20	1–13	most ecozones	Schmid 1982, Armitage 1991
Superfamily Psychomyioidea						
Dipseudopsidae[7]	0	3	4	1–2	Atlantic Maritime, Mixedwood Plains, Prairies	Schmid 1983, Schuster and Hamilton 1984, Sturkie and Morse 1998
Polycentropodidae	36	37	32	6	most ecozones	Nimmo 1986, Armitage and Hamilton 1990, Neboiss 1993, Chamorro and Holzenthal 2010
Psychomyiidae	2	4	2	1–4	Atlantic Maritime, Mixedwood Plains, Prairies	Schmid 1983, Armitage and Hamilton 1990
Superfamily Hydropsychoidea						
Hydropsychidae[8]	48	56	62	10–15	most ecozones	Schmid 1968, Gordon 1974, Nimmo 1987, Geraci et al. 2010, Burington 2011
Suborder Integripalpia – "Spicipalpia"						
Superfamily Glossosomatoidea						
Glossosomatidae	21	26	22	8–15	most ecozones	Ross 1956, Nimmo 1974, 1977, Schmid 1982, Wymer and Morse 2000, Etnier et al. 2010, Robertson and Holzenthal 2013, Genco and Morse 2017
Superfamily Hydroptiloidea						
Hydroptilidae	52	75	78	10	most ecozones	Kingsolver and Ross 1961, Denning and Blickle 1972, Ito et al. 2014, Harris and Flint 2016
Ptilocolepidae[9]	?	2	1	0	Pacific Maritime, Newfoundland Boreal; possibly Mixedwood Plains, Boreal Shield, Atlantic Maritime	Ito et al. 2014
Superfamily Rhyacophioidea						
Rhyacophilidae	57	65	36	15	most ecozones	Schmid 1966, 1970, 1981, Nimmo 1971, Prather and Morse 2001
Suborder Integripalpia – Brevitentoria						
Superfamily Leptoceroidea						
Calamoceratidae	2	2	1	0	Pacific Maritime, Western Interior Basin, Montane Cordillera, Mixedwood Plains	Bowles and Flint 1997, Schmid 1998
Molannidae[10]	7	6	3	0	most ecozones, except Atlantic Maritime and Arctic	Roy and Harper 1980, Schmid 1983, 1998
Leptoceridae	56	68	118	30–50	most ecozones	Yamamoto and Wiggins 1964, Holzenthal 1982, Floyd 1995, Glover 1996, Manuel 2010

Taxon[1]	No. species reported by Wiggins (1979)	No. species currently known from Canada[2]	No. BINs[3] available for Canadian species	Est. no. undescribed or unrecorded species in Canada[4]	General distribution by ecozone[5]	Information sources[6]
Odontoceridae	4	5	3	0	Mixedwood Plains, Atlantic Maritime	Schmid 1983, Parker and Wiggins 1987
Superfamily Sericostomatoidea						
Beraeidae	1	1	0	1	Mixedwood Plains	Wiggins 1954, Schmid 1998
Helicopsychidae	1	1	5	3	most ecozones	Moulton and Stewart 1996, Johanson 2002
Sericostomatidae	2	2	2	2	Mixedwood Plains	Ross and Wallace 1974, Schmid 1998, Keth and Harris 2008
Suborder Integripalpia – Plenitentoria						
Superfamily Limnephiloidea						
Apataniidae	?	16	8	0	most ecozones, except Atlantic Maritime	Schmid 1953, Chen 1992, Flint 2007
Goeridae	?	5	4	2	Atlantic Maritime, Mixedwood Plains, Montane Cordillera, Western Interior Basin, Pacific Maritime	Schmid 1983, 1998
Limnephilidae	179	157	128	30	most ecozones	Parker and Wiggins 1985, Ruiter 1995
Rossianidae	?	1	0	0	Montane Cordillera, Western Interior Basin, Pacific Maritime	Schmid 1998
Thremmatidae	?	16	9	3	Newfoundland Boreal and south of boreal on mainland	Vineyard et al. 2005, Hoemsen et al. 2015
Uenoidae	?	2	1	0	widespread in Canada	Wiggins et al. 1985
Superfamily Phryganeoidea						
Brachycentridae	15	16	16	2	most ecozones	Wiggins 1965, Schmid 1983, Flint 1984
Lepidostomatidae	26	30	27	2–3	most ecozones	Weaver 1984, 1988
Phryganeidae	24	26	28	2–5	most ecozones	Wiggins 1956, 1960, 1998
Total	**546**	**637**	**611**	**129–181**		

[1]Modified from Holzenthal et al. (2011) and Ito et al. (2014). [2]Data extracted from Rasmussen and Morse (2018) [3]Barcode Index Numbers (BINs), as defined by Ratnasingham and Hebert (2013). [4]Estimates based on data in Schmid (1998) and Rasmussen and Morse (2018) and from BINs. [5]See figure 1 in Langor (2019) for a map of ecozones. [6]The references cited do not necessarily represent a comprehensive list for each family but rather some of the most significant contributions. See Schmid (1998) for major taxonomic works for Canada to that time and, more importantly, Rasmussen and Morse (2018) provide the most complete species level account of relevant literature with distributional data. BOLD refers to DNA barcode data from the Barcode of Life Data System (www.boldsystems.org). [7]Dipseudopsidae = Hyalopsychidae of Schmid (1998). [8]Includes Arctopsychidae of Nimmo (1987) and Schmid (1998). [9]Records of this family outside of the Pacific Maritime and Newfoundland Boreal are based on single specimen accounts from the literature with no collection information (Ito et al. 2014). [10]The decrease of one species since 1979 is due to the fact that *Molanna cinerea* Hagen, 1861 is now considered nomen dubium.

DNA barcoding (sensu Hebert et al. 2003) has been applied extensively to the Trichoptera fauna of Canada, especially in northern areas (Zhou et al. 2009, Ruiter et al. 2013) and elsewhere, with a comprehensive global library containing more than 16,000 unique haplotypes already well established (Zhou et al. 2016). The 610 Barcode Index Numbers (BINs; Ratnasingham and Hebert 2013) assigned to the Canadian Trichoptera in the Barcode of Life Data System (BOLD; Ratnasingham and Hebert 2007), seemingly represent 96% of the number of described species known from Canada (Table 1). However, many BINs are not yet associated with described species and, in several cases, the ratio of species to BINs is low. For instance, the families Hydropsychidae, Philopotamidae, Hydroptilidae, Phryganeidae, Helicopsychidae, and especially Leptoceridae all have more BINs than known Canadian species suggesting that there are many additional species in Canada remaining to be documented and highlighting that there is still much opportunity for research on Trichoptera in Canada. However, this may also mean that there is enough variation in the barcode region of COI of some Canadian Trichoptera that multiple BINs exist for an individual species, as has been demonstrated in other insect groups (Gibbs 2018). As stressed by Zhou et al. (2016), BINs are not synonymous with species (although there is typically high congruence) and should not be treated as such.

Estimates of the number of undocumented (undescribed or unreported) species in Canada were made by first considering species that are known from adjacent parts of the USA but not yet recorded from Canada. Such species are likely to occur there based on habitat and climate. Furthermore, we took into consideration the number of BINs reported for each family and the likelihood that some of these represent undocumented species. We conservatively estimate that 129–181 additional species will eventually be found in Canada, meaning that the total Canadian fauna could be >800 species (Table 1). The families with the highest numbers of undocumented species are expected to be Leptoceridae (30–50 species) and Limnephilidae (30).

Almost all Canadian jurisdictions (except Prince Edward Island and Labrador) have checklists or at least some faunistics work. Examples include: Yukon (Nimmo and Wickstrom 1984, Wiggins and Parker 1997), Northwest Territories/Nunavut (Nimmo 1984, Winchester 1984, Cordero et al. 2017), British Columbia (Nimmo and Scudder 1978, 1983, Cannings and Roberts 2007, Cannings 2007, Erasmus et al. 2018), Alberta (Nimmo 2001, Hinchliffe 2010), Saskatchewan (Smith 1975, 1984, Hoemsen et al. 2015), Manitoba (Zhou et al 2009, Ruiter et al. 2013), Quebec (Nimmo 1966, Roy and Harper 1979, 1981), New Brunswick and Nova Scotia (Banks 1930, Peterson and van Eeckhaute 1990, 1992), and the island of Newfoundland (Banks 1908, Marshall and Larson 1982). In addition, an up-to-date online global species list (Morse 2018) is available as is an online Endnote-based literature database with more than 12,000 records (Holzenthal et al. 2012), both highly valuable for study of Trichoptera in Canada. Despite the very good taxonomic foundation and state of knowledge concerning faunal composition, there is still plentiful effort needed in Canada before the fauna is fully known. In particular, there are still major challenges to identify the immature stages of Trichoptera (Wiggins 1979), and DNA barcoding offers a means of associating identifiable adults (male and female) to unidentifiable immature stages (Zhou et al. 2007). Barcode data will also help with understanding phylogenetic relationships (Frandsen et al 2016). There are many areas of Canada that need additional caddisfly sampling, particularly northern areas and remote areas in the south. Increased sampling in areas close to the southern border with the USA is also likely to add new Canadian records. With a comprehensive DNA barcode library for Trichoptera well underway (Zhou et al. 2016), the future for Trichoptera studies globally, and within Canada, looks promising.

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