An annual compilation of research enabled by the Canadian Museum of Nature

Canadian Museum of Nature Science Review 2019

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Canada

ABOUT THE CANADIAN MUSEUM OF NATURE

The Canadian Museum of Nature is the national museum of natural sciences for the second-largest country in the world, which is an Arctic nation with the world's largest coastline.

The global vision of the museum is a sustainable, natural future. As current environmental changes such as greenhouse gas emissions, species extinctions, loss of natural spaces, and other causal factors run counter to this vision, the museum's mission is one of inspiring change. The museum's national mission is to create and deliver inspiring and memorable connections with nature. It achieves this through impactful programs of research, collections management, exhibitions and engagement in a 21st-century global context.

The museum is one of many national natural history museums and like-minded organizations in the global scientific community working to provide the foundation that fosters the change required to "save the world." This foundation is built on evidence, knowledge and inspiration.

The Canadian Museum of Nature inspires others through nationally and internationally travelling public exhibitions, as well as galleries and programs based at its Victoria Memorial Museum Building, a National Historic Site of Canada, in Ottawa, Ontario. Social media, online content, and strategic partnerships also contribute to this inspiration theme.

The museum houses and curates Canada's national natural history collection at its Natural Heritage Campus in Gatineau, Quebec. The collection comprises over 14.6 million natural history specimens providing the evidence on which museum scientists, associates, colleagues and other researchers base their studies — resulting in the generation of new knowledge about the natural world.

This authoritative, scientific collection spans the tree of life, including specimens of animals, fossils of plants and animals, and algae, lichens and plants, and geological diversity, including minerals, rocks and gems. The specimens are organized into 3.4 million units or lots, of which some 3 million are accessioned into the permanent collection and the remainder exist as prepared or unprepared backlog material. The museum's National Biodiversity Cryobank of Canada, a biorepository of frozen tissues, samples and specimens from across Canada and abroad, is a source of material for genomic research conducted by staff and the international research community.

Each year, the museum's collection grows by about 20,000 new specimens, which are obtained through staff field research, exchanges with other museums, purchases, and donations from collectors.

The museum also houses vital library and archival references about nature: a large collection of books and periodicals that is particularly strong in the fields of the Canadian Arctic, ornithology, systematics and taxonomy; an archival collection; a nature art collection and a mixed media collection.

Two research centres of excellence are located at the museum's Natural Heritage Campus: the Beaty Centre for Species Discovery and the Centre for Arctic Knowledge and Exploration.

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FOREWORD

Scientific collections are knowledge-based resources and constitute important research infrastructure, enabling scientific research and discovery at local, regional, national and international levels. The collections of natural history museums are central to understanding and advancing knowledge of the past, present and future of biological and geological diversity and the public understanding of science. Documentation of the use and impact of collections raises awareness of their relevance and facilitates their continued support and development.

The national natural history collection at the Canadian Museum of Nature has supported scientific research and public understanding of Canada's natural heritage for over 150 years; this central role of the collection and the people associated with it remains unchanged.

Here, we document the impact of the museum on the generation of new scientific knowledge in 2019. We identify 385 articles published in scientific journals and books in 2019 by museum staff and associates and by other researchers whose work was enabled by the museum's collections. External researchers accessed museum collection information by personal visits to the collections, by requesting information about or borrowing museum specimens, and by retrieving collection data mobilized online.

We also profile a subset of the publications to demonstrate the diverse science that museum researchers are engaged in and the many ways that Canadian Museum of Nature collections are used by others to generate new knowledge about the natural world. The report follows the same format as the museum's inaugural Research Review for 2018[1].

The global science impact of the Canadian Museum of Nature is substantial.

METHODS

Papers published in 2019 by Canadian Museum of Nature staff and associates were identified by internal museum reporting mechanisms and literature searches. Papers published in 2019 that were enabled by Canadian Museum of Nature collections and by authors not affiliated with the museum were discovered through automated and manual literature searches.

Automated literature searches were conducted via a Ruby application developed by David Shorthouse[2] that downloads Gmail messages from Google Scholar search alerts (alert query "Canadian Museum of Nature"), parses alert text for publisher URLs, stores the URLs, and downloads the PDF of the paper when openly available. A secondary process mines PDFs for digital object identifiers (DOIs) and the following Canadian Museum of Nature collection codes: CAN (vascular plant), CANA (alga), CMNAR (amphibian and reptile), CMNA (annelid), CMNAV (bird), CANM (bryophyte), CMNC (crustacean), CMNFI (fish), CMNIF (fossil invertebrate), CMNFV (fossil vertebrate), CMNI (general invertebrate), CMNEN (insect), CANL (lichen), CMNMA (mammal), CMNML (mollusc), CMNPB (palaeobotany), CMNPYM and CMNPYF (palynology), and CMNPA (parasite). Manual literature searches were conducted in Google Scholar by querying the same collection codes as well as CMN and NMC (National Museum of Canada, as the Canadian Museum of Nature was formerly known).

Publications retrieved during automated and manual searches were assessed to determine if they provided evidence that museum collections contributed to the published research. Evidence includes citation of, or reference to, one or more museum specimens in the paper, inclusion of one or more museum specimens in a Global Biodiversity Information Facility (GBIF) dataset cited in the paper, indication that a museum collection was searched for relevant specimens during a study regardless of whether suitable material was found, and indication of significant use of museum collections for consultation and identification of species.

Publications that used museum collection data mobilized by GBIF were compiled using GBIF's literature tracking programme (https://www.gbif.org/literature-tracking). Papers that cite a GBIF dataset including one or more Canadian Museum of Nature specimens are indexed on the GBIF publisher page for the museum (https://www.gbif.org/publisher/a41250f0-7c3e-11d8-a19c-b8a03c50a862).

To characterize the types of research questions to which museum personnel and collections contributed in 2019, we assigned each paper in the list to one of the following four themes: Earth History and Evolution, Environmental Health, Species Discovery, and Endangered Species and Conservation. Although many papers could be placed under more than one category, we chose the single category that best encapsulated each work. For a subset of papers under each theme, we provide a summary of the research reported and explanation of its potential broader impact and contribution to advancing knowledge. We determined the country of origin of the primary author of each publication to assess the museum's contributions to global science. All papers are relevant to the museum's Beaty Centre for Species Discovery, and we identified papers related to Arctic science, one of the museum's research and collections strengths. The complete list of 2019 scientific publications is arranged alphabetically by first author under each research theme.

ACKNOWLEDGEMENTS

Mark Graham, Jean-Marc Gagnon, Ed Hendrycks and Troy McMullin contributed to the final list of publications.

Citation: Saarela, J.M., Anderson, R. & Tudor, S. 2020. Canadian Museum of Nature Science Review 2019. Canadian Museum of Nature, Ottawa.

1. Anderson, R., & Saarela, J. M. (2019). Canadian Museum of Nature Research Review 2018. Canadian Museum of Nature, Ottawa, Ottawa, Ontario, 32 pp. Available from https://nature.ca/en/about-us/museum-corporation/annual-reports-corporate-publications/research-review (accessed 9 April 2020)

2. Shorthouse, D. 2019. Museum-tracker. Software available from https://github.com/mus-nature-ca/museum-tracker (accessed 9 April 2020). © Canadian Museum of Nature, available under the MIT Licence (https://opensource.org/licenses/MIT)

SCIENCE REVIEW 2019

In 2019, 385 scientific papers were enabled by the Canadian Museum of Nature and its national natural history collection. Of these, 70 papers were authored or co-authored by museum staff members including eight papers with a museum research associate co-author, 60 were authored by museum research associates, and museum specimens contributed in some way to research published in 255 papers by authors not affiliated with the museum. Twenty-six papers are relevant to Arctic science: five with museum staff co-authors (two of these with research associate co-authors), eight with museum research associate co-authors, and 13 by non-staff authors whose work was enabled by museum specimens.

Affiliations of first authors of the papers represent 42 countries (Figure 1). Following Canada, with 122 papers, the best-represented country in the dataset is the United States, with 97 papers. China is represented by 15 papers, five countries are represented by 10–14 papers, and the remainder with 1–9 papers.

A total of 320 (83%) publications provide evidence that Canadian Museum of Nature specimens somehow contributed to the research. Of these, 206 publications explicitly cite one or more museum specimens, 108 cite a GBIF dataset that includes museum specimens, three indicate museum collections were searched for material relevant to a study, and one indicates museum collections were consulted to aid in identification of specimens. Of the remaining papers, 66 are authored or co-authored by museum staff members or research associates and do not cite museum specimens, and one (Collella et al. 2019) includes the museum's National Biodiversity Cryobank of Canada in a short list of model cryogenic biorepositories for the expansion of genomic sampling in the Arctic. Although we aimed to be comprehensive, it is certain that some papers that should be included in the list have been missed, given the manual effort required to find and confirm that relevant publications meet our criteria for inclusion and the highly variable way that natural history collection specimens and their repositories are referred to in scientific papers. Omissions should be brought to the attention of the authors.

The list demonstrates the breadth of natural sciences research conducted by Canadian Museum of Nature staff and research associates and the diversity of global research to which museum collections contribute. We assigned 81 publications to the Earth History and Evolution research theme. Sixty-nine of these publications are from the palaeobiology literature and the remainder are from the field of mineralogy. Fifty-one palaeobiological papers cite one or more museum specimens, reflecting the importance

FIGURE 1. GEOGRAPHIC ORIGINS OF PAPERS BY FIRST AUTHOR

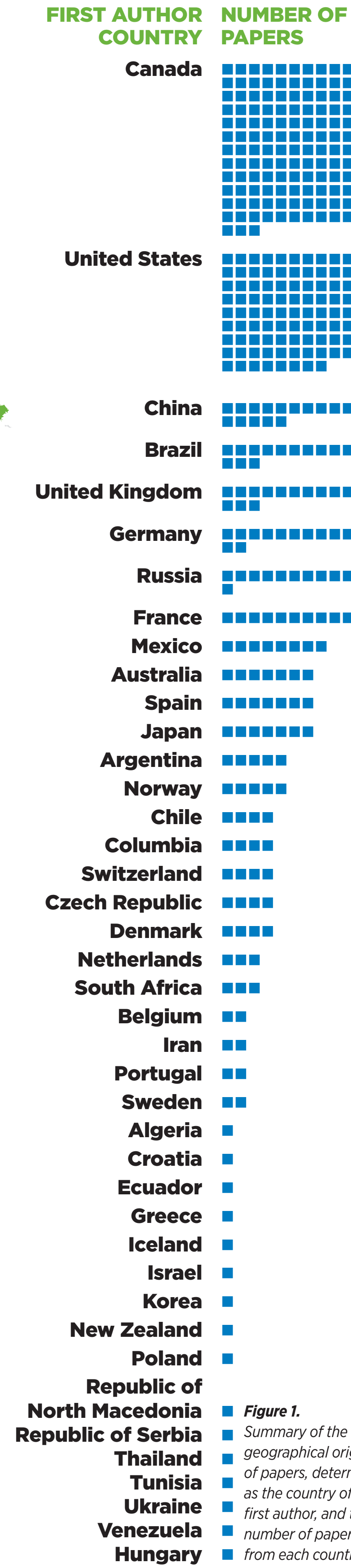

Figure 1. *Summary of the geographical origins of papers, determined as the country of the first author, and the number of papers from each country.*

of the museum's fossil collection to global science. We assigned 16 papers to the Environmental Health research theme and 20 to the Endangered Species and Conservation theme. Most (88%) of the former and over half (55%) of the latter cite one or more museum specimens or one or more GBIF datasets that include museum specimens, demonstrating how natural history collections information contributes to these important research areas.

The research theme to which the Canadian Museum of Nature contributed most substantially in 2019 — with 250 papers— is Species Discovery, which includes papers focused on the taxonomy, systematics and ecology of extant biodiversity. Of these, 140 papers cite museum specimens and 83 cite one or more GBIF datasets that include museum specimens. In general, papers that cite museum specimens comprise descriptions of new species and taxonomic studies of amphipods, beetles, birds, diatoms, fishes, lichens, mosses, polychaetes, shrews, shrimps, sponges, and vascular plants; checklists or summaries of biodiversity of lichens and allied fungi, beetles, sponges and vascular plants of areas such as parks, preserves, major water bodies, and countries; and new records of species in particular areas, including beetles, lichens and allied fungi, a slug, and vascular plants. These results are not unexpected, given the critical role of museum specimens in taxonomic and systematics research aimed at documenting and understanding global biodiversity.

Papers published in 2019 that cite a GBIF dataset including museum specimens address diverse biological questions, including the same types of questions as in the studies that cite museum specimens and questions that require a large amount of reliable biodiversity information from broad geographical areas. Examples of the latter kinds of questions include testing ecological hypotheses of island size and island species richness, characterizing patterns of insect biodiversity at continental scales in the context of climate and vegetation, characterizing gaps in butterfly inventory data and incompleteness of specimen-based inventories of plants in order to prioritize areas for collecting, characterizing plant endemism on islands worldwide, characterizing global distribution patterns of plants that exchange photosynthesized carbohydrates for nutrients obtained from soil fungi (mycoheterotrophy), and understanding how grasses evolved from tropical to temperate climates in response to climate cooling in the Cenozoic.

DATA MOBILIZATION

The Canadian Museum of Nature shares data online for 904,761 (29.4%) of its more than three million accessioned specimens or lots (Table 1).

Of these, 808,667 records are mobilized via the Global Biodiversity Information Facility (GBIF) and 96,094 (algae and mineral collections) via other online databases (Table 1). The completeness of these digital records varies, ranging from a species name and high-level geographical provenance (i.e., country and province/state) ("skeletal" records) to complete collection information including geographical coordinates, which often must be determined secondarily, and one or more images of the specimen. A total of 73.3% of all mobilized museum data has geographical coordinate data and 72.5% of GBIF-mobilized museum data has coordinate data. One or more images are available for 12.4% of museum specimen records mobilized online; more than 87% of records with images are herbarium specimens, primarily vascular plants, which are flat and straightforward to image and have been a museum priority for imaging. Algal collections represent 11.8% of the total records with images. Non-botanical specimens represent less than 1% of all records with images.

The large number of papers identified that cite a GBIF dataset including specimen data from the Canadian Museum of Nature demonstrates how our collections contribute broadly to development of new knowledge. We predict the number of papers that access and use GBIF-mobilized Canadian Museum of Nature data will increase in the coming years. As the global GBIF dataset grows, more and more researchers are likely to use the available information in their work. As more Canadian Museum of Nature specimens are digitized, a greater number of GBIF-mobilized Canadian Museum of Nature data points will be available to the global community. As the proportion of georeferenced Canadian Museum of Nature specimens increases, a greater number of data points will be discoverable using map-based queries in the GBIF portal. As the proportion of images associated with Canadian Museum of Nature specimen records increases and those images are mobilized, we expect usage of those resources to increase, particularly in systematic and related biodiversity studies where an image may be useful or required for a specimen to be considered in a study (even if it is impossible to accurately identify a specimen to species level from an image, as is the case for many groups of organisms).

DATA MOBILIZATION

TABLE 1. SUMMARY OF CANADIAN MUSEUM OF NATURE COLLECTIONS
including number of physical specimens or lots, number of records digitized and mobilized online, number of mobilized records that are georeferenced, and number of mobilized records with an associated image. Digital resources are hosted on an Integrated Publishing Toolkit (http://ipt.nature.ca) and mobilized via the Global Biodiversity Information Facility (GBIF) unless otherwise indicated. GBIF data summarized here were captured on 17 April 2020.

Canadian Museum of Nature Collection	Number of physical specimens or lots[1]	Number (%) of records[2] digitized and mobilized online	Number (%) of mobilized records georeferenced[3]	Number (%) of mobilized digital records with one or more specimen images
Herbarium[4]	1,061,954	291,290[5] (27.3)	209,475 (71.9)	98,777 (33.9)
Algae	161,194	53,539 (33)[6]	40,638 (80.1)[6]	13,244 (13.1)[6]
Bird	119,900	100,970 (84.2)	90,520 (89.7)	207 (0.2)
Crustacea	73,970	68,962 (93.2)	65,265 (94.6)	52 (0.08)
Fish	62,892	62,173 0 (98.9)	58,809 (94.6)	16 (0.02)
Mammal	59,502	59,469 (99.9)	44,468 (74.8)	10 (0.02)
Mollusc	129,260	50,737 (39.2)	37,984 (74.9)	257 (0.5)
Fossil Vertebrate	54,663	50,125 (91.7)	–[8]	47 (0.09)
Amphibian and Reptile	37,858	37,666 (99.5)	31,577 (83.8)	41 (0.1)
Faunal Assemblage	87,016	0	0	0
Insect	1,085,635	19,051 (1.8)	7,764 (40.8)	16 (0.08)
General Invertebrate and Annelid	42,112	30,538 (72.5)	27,480 (89.9)	39 (<0.01)
Parasite	18,710	15,475 (82.7)	13,606 (87.9)	5 (0.03)
Palynology	14,569	14,566 (99.9)	–[8]	2 (0.01)
Palaeobotany	4,593	4,441 (96.7)	–[8]	1 (0.02)
Fossil Invertebrate	4,552	3,204 (70.6)	–[8]	0 (0)
Mineral	48,992	42,555[7] (89.2)	35,7437 (74.9)	0 (0)
TOTAL	**3,067,372**	**904,761 (29.4)**	**663,329 (73.3)**	**112,714 (12.4)**

1. These numbers are estimates and include only accessioned material; unprocessed backlog material is excluded.
2. "Records" means catalogueable units or lots, not total number of specimens (i.e., one jar of fishes, a catalogueable unit, may contain 12 individual specimens).
3. "Georeferenced" means the digital record includes geographical coordinates that allow the record to be mapped and retrieved in map-based queries. The numbers were determined including the GBIF location flag "Include records where coordinates are flagged as suspicious."
4. Including bryophytes, lichens and vascular plants. Algae are treated separately because their data are published in a separate database.
5. This number is lower than the one reported in the 2018 research review (294,562), which included ca. 3000 duplicate records of lichens that were removed from the GBIF-mobilized dataset on 23 July 2019 (http://ipt.nature.ca/resource?r=cmn_herbarium&v=1.91). The correct number for the table in the 2018 research review is 291,632 (http://ipt.nature.ca/resource?r=cmn_herbarium&v=1.79). The number reported for 2019 is slightly lower than the correct 2018 number because of additional corrections to the dataset. Although digitization of herbarium material continued throughout 2019, there were no imports of data into the museum's collection management information system due to technical difficulties and personnel turnover.
6. Mobilized via http://www.nature-cana.ca/databases/index.php
7. Mobilized via http://collections.nature.ca/en/Search/Index
8. Locality information for palaeobiology collections is shared only upon request.

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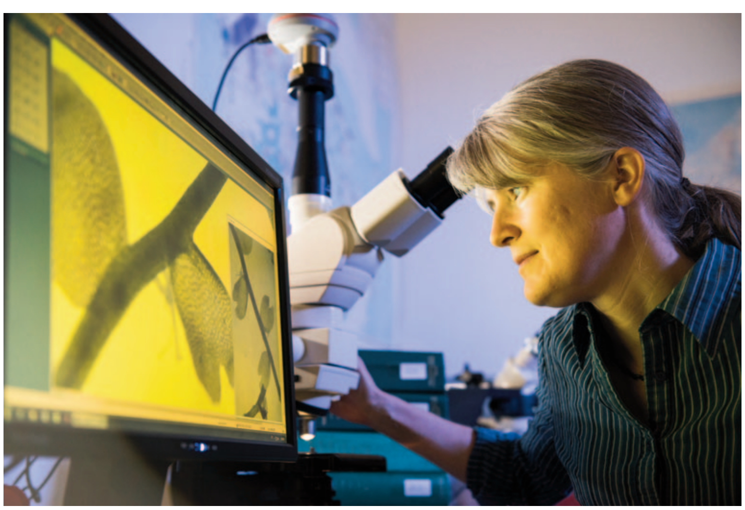


Photo: Martin Lipman

BOOKS

HORVÁTH, L., GAULT, R. A., PFENNINGER-HORVÁTH, E., AND POIRIER, G. 2019

Mont Saint-Hilaire: History, Geology, Mineralogy

**The Canadian Mineralogist, Special Publication 14
Mineralogical Association of Canada,
Quebec, QC, 644 pp.**

This lavishly illustrated book showcases the geology, history and the mineralogy of the world-famous Mount Saint-Hilaire mineral location in Quebec. The book is the result of 20 years of work by the four authors and follows up from a much less comprehensive volume published in 1990. Co-author Robert Gault is a research associate at the Museum and co-author Glenn Poirier is a senior research assistant at the Museum.

Mont Saint-Hilaire is globally important due to its mineralogical richness; no other location on Earth has such an extensive mineral diversity in such a small area. The quarry is home to an astounding 434 mineral species (25% of the known species in Canada). Of these, 66 new mineral species were first described from this site, 32 of which are found nowhere else in the world. Discovery of new minerals is continuing with at least three new minerals described since the book was published. The museum has had a long association with mineral species discovery at Mont Saint-Hilaire; museum research staff were involved in over half of these new mineral discoveries. The museum also curates one of the best collections of minerals from Mont Saint-Hilaire.

Serandite and analcime specimen from Mont Saint-Hilaire, collections of Canadian Museum of Nature (CMNMC 37124). This is the most photographed serandite specimen in the world, called "the Rollerskate.

EARTH HISTORY AND EVOLUTION

The Earth has a long history of change over time. Understanding the past can be key to managing the present and predicting the future. Museum scientists study and classify mineral diversity, work with rocks to understand how the Earth was formed, and study fossils preserved in rocks to understand how species have evolved and what aspects of their morphology may be important in explaining their biology, where they lived and how many of them there are (or were). By looking at why some groups of organisms are successful with lots of species, and others not, we can better understand extinctions and how these might be explained and possibly even prevented. Understanding Earth history is a complex blend of geology and palaeobiology.

MALLON, J. C. (2019)

Competition structured a Late Cretaceous megaherbivorous dinosaur assemblage

Scientific Reports, 9, 15447.
https://doi.org/10.1038/s41598-019-51709-5.

Unlike megaherbivorous (> 1,000 kg) mammal assemblages, the assemblage of megaherbivorous dinosaurs from the Late Cretaceous of North America was especially rich, typically consisting of six species of multi-tonned animals living together at any one time. What accounts for such diversity? Some have suggested that plant resources were not limiting during the Late Cretaceous, either because primary productivity was elevated or because dinosaur food requirements were low. In this study, Canadian Museum of Nature palaeobiologist Dr. Jordan Mallon finds evidence to suggest that plant resources were, in fact, limiting, and that the diversity of large herbivorous dinosaurs was facilitated by dietary niche partitioning (i.e., each species feeding on different types of plants). Thus, despite their different ancestry and physiologies, megaherbivorous mammal and dinosaur assemblages evolved in response to the same evolutionary pressures. Palaeoecological studies like this not only show us how dinosaur ecosystems were different, but also allow us to identify underlying principles that structure all ecosystems in both the past and present, and that will assuredly operate as ecosystems evolve into the future.

Illustration of the large herbivorous dinosaur assemblage during the Late Cretaceous in present-day Alberta .

Photo: Julius Csotonyi, used with permission

PEKOV, I. V., SHCHIPALKINA, N. V., ZUBKOVA, N. V., GURZHIY, V. V., AGAKHANOV, A. A., BELAKOVSKIY, D. I., CHUKANOV, N. V., LYKOVA, I. S., VIGASINA, M. F., KOSHLYAKOVA, N. N., SIDOROV, E. G., & GIESTER, G. (2019)

Alkali sulfates with aphthitalite-like structures from fumaroles of the Tolbachik Volcano, Kamchatka, Russia. I. Metathénardite, a natural high-temperature modification of Na_2SO_4

The Canadian Mineralogist, 57, 885–901.
https://doi.org/10.3749/canmin.1900050

There are 5,000 unique mineral species known to science. However, the diversity of mineral species in the crust of the Earth is oddly discontinuous, with the bulk of the crust being composed of approximately a dozen minerals. That said, certain localities, such as the Tolbachik Volcano in Kamchatka, Russia, contain an astounding diversity of mineral species. Of the nearly 300 minerals observed to occur at Tolbachik, more than 100 of these were first discovered there. This paper adds to this list of new discoveries, with the description of metathénardite, Na2SO4, a mineral predicted to occur by Alfred Lacroix in 1905 as a high-temperature atomic restructuring of a more common mineral, thénardite. Although metathénardite is easily produced in the laboratory, this paper is the first to confirm that this mineral can also be created, and exist stably, in nature.

WU, X.-C., SHI, J.-R., DONG, L.-Y., CARR, T. D., YI, J., & XU, S.-C. (2020)

A new tyrannosauroid from the Upper Cretaceous of Shanxi, China

Cretaceous Research, 108, 104357.
https://doi.org/10.1016/j.cretres.2019.104357
(published online 17 December 2019).

Xiao-Chun Wu, a palaeobiologist with the Canadian Museum of Nature, and collaborators from China and USA have named *Jinbeisaurus wangi*, a new Late Cretaceous genus and species of tyrannosauroid dinosaur from China. The specific epithet *wangi* honours Mr. Wang of the Shanxi Museum of Geology, who discovered the dinosaur from a locality in northern ('bei') Shanxi Province ('Jin') of China; the genus name *Jinbeisaurus* is based on the locality. Since 1980, there have been many remains of plant-eating dinosaurs discovered in Shanxi Province, but only a few isolated teeth of meat-eating dinosaurs were recovered. Shanxi Province has been anxious to find meat-eating dinosaurs in their province since building a new geological museum in the early 2000s, but they failed to find any significant evidence until their discovery of *Jinbeisaurus wangi*. This study is significant because it confirms a medium-sized stage during the size transition of tyrannosauroids from the early smaller-body group to the later large-body group represented by such giants as *Tyrannosaurus rex*. Even though they have been extinct for millions of years, dinosaurs, especially the large carnivores, continue to fascinate kids and adults alike.

The fossil locality of Jinbeisaurus wangi in Yangjiayao, Tianzhen County, Datong City, Shanxi Province, China. The arrow indicates the stratigraphic horizon of the Upper Cretaceous where the dinosaur came from.

Photo: Xiao-chun Wu, Canadian Museum of Nature

PUBLICATION PROFILES

ENVIRONMENTAL HEALTH

With increasing human population, our natural world is changing. Understanding human-induced impacts, such as those related to climate change, introduction of invasive species, and loss of habitats, is key to ensuring a sustainable future. In many instances, knowledge about plants and animals can be used to measure and assess the general health of today's ecosystems. These indicator species may be indicative of good and bad changes and are often a simple and fast way to detect change. Border security and the prevention of introduced species is also a concern as invasive species can often have profound impacts on the ecosystems to which they are newly adapting.

CORNWELL, W. K., PEARSE, W. D., DALRYMPLE, R. L., & ZANNE, A. E. (2019)

What we (don't) know about global plant diversity

Ecography, 42(11), 1819–1831.
https://doi.org/10.1111/ecog.04481.

With development of biological databases at global scales, we are now in an era of big biodiversity data. Availability of such massive amounts of information has facilitated numerous advances in theoretical and applied biology, ecology and conservation. However, gaps and biases in these datasets may reduce their utility for addressing issues of global concern. In this study, the authors analysed three genetic, geographic and trait databases to identify gaps and biases in sampling of global plant biodiversity. The geographic data studied comprise over 200 million plant occurrence records originating from museums and herbaria and mobilized via the Global Biodiversity Information Facility, including tens of thousands of records from the Canadian Museum of Nature. The authors found that less than 18% of global land plant diversity is represented in each of the three databases, and some 93,000 land plant species were not represented in the geographic dataset by even a single specimen with location information. The authors argue the current lack of intersection among databases critically affects conservation and biodiversity science. There is an urgent need to increase availability of museum collections data — developed over decades of careful study and curation — through accelerated programs of digitization while simultaneously sampling all plant species for trait and genetic data.

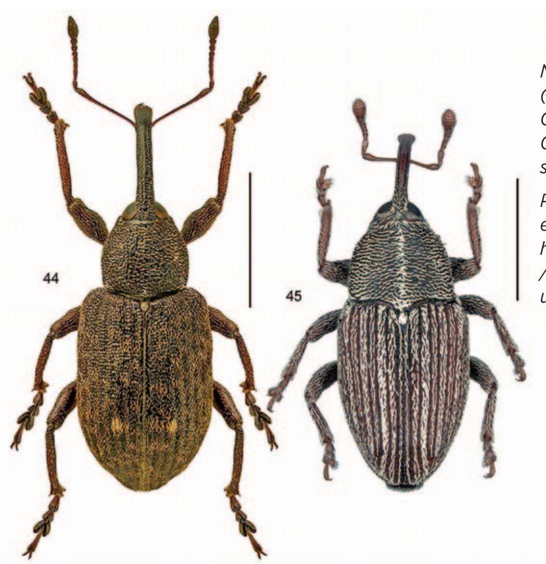
Papaver lapponicum
Photo: Paul Sokoloff

PENTINSAARI, M., ANDERSON, R. S., BOROWEIC, L., BOUCHARD, P. B., BRUNKE, A., DOUGLAS, H., SMITH, A. B. T., & HEBERT, P. D. N. (2019)

DNA barcodes reveal 63 overlooked species of Canadian beetles (Insecta, Coleoptera)

Zookeys, 894, 53–150.
https://doi.org/10.3897/zookeys.894.37862.

Museum collections are often consulted to determine what species are and where they occur. Using DNA barcoding species identification methods developed at the University of Guelph, this collaborative paper, involving eight authors from a variety of Canadian biodiversity science institutions, including the Canadian Museum of Nature, records 63 species of beetles that had been overlooked using traditional means of identification using morphology. This includes the first Canadian records published for 60 species. Recognizing species new to Canada is important in protecting national natural resource-based activities such as agriculture and forestry against potential exotic invasive species.



Notaris scirpi (Fabricius), and Centrinopus helvinus Casey, two weevil species new to Canada.

Photo: Pentinsaari et al. 2019, CC0, https://doi.org/10.3897/zookeys.894.37862.figures44-45

ST. LOUIS, E., STASTNY, M., & SARGENT, R. D. (2020)

The impacts of biological control on the performance of *Lythrum salicaria* 20 years post-release

Biological Control, 140, 104123.
https://doi.org/10.1016/j.biocontrol.2019.104123
(published online 3 October 2019) (3,†).

The wetland plant species purple loosestrife (*Lythrum salicaria*) was introduced from Europe and Asia to North America in the 19th century and has since become a serious invader that out-competes many native wetland species. In the 1990s, two beetle species that feed on purple loosestrife in its native range were introduced to sites in Ontario as biological control agents. In this study, biologists from the University of Ottawa assessed the impact of the release of beetles on the performance of purple loosestrife populations in Ontario that varied according to their history of beetle colonization. The authors used literature information to identify populations known to have been exposed to beetles, and they used herbarium records, including records from the Canadian Museum of Nature, to identify populations not known to have been exposed to the beetles and that have existed for at least 20 years. Purple loosestrife plants at sites with long histories of beetle colonization had higher levels of herbivore damage and fewer inflorescences than plants at sites that have not been colonized or have been colonized more recently by beetles. The study is an example of how information from museum collections gathered decades ago can contribute to understanding an invasive species with serious ecological impacts.

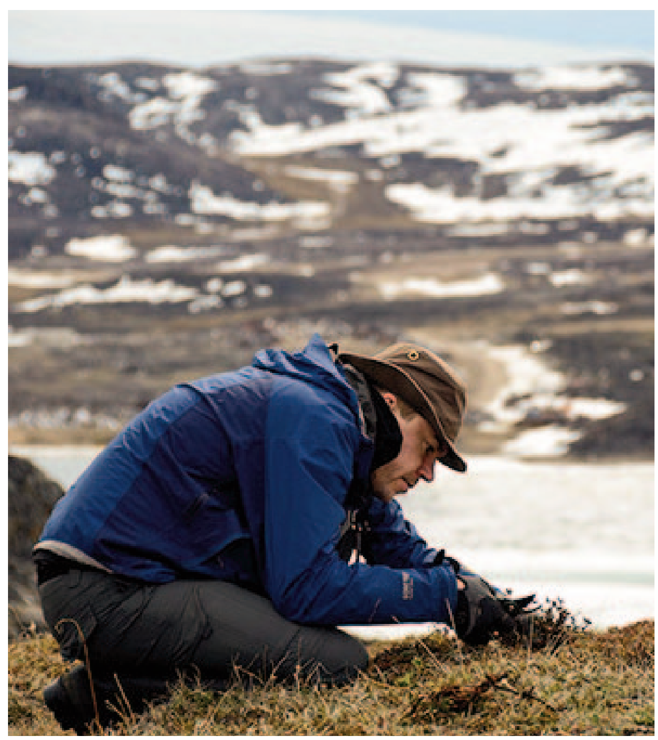
WASOWICZ, P., SENNIKOV, A. N., WESTERGAARD, K. B., SPELLMAN, K., CARLSON, M., GILLESPIE, L. J., SAARELA, J. M., SEEFELDT, S. S., BENNETT, B., BAY, C., ICKERT-BOND, S., & VARE, H. (2020)

Non-native vascular flora of the Arctic: Taxonomic richness, distribution and pathways

Ambio, 49, 693–703. https://doi.org/10.1007/s13280-019-01296-6 (published online 2 December 2019).

The Arctic is one of a few areas globally where non-native species have not substantially affected ecosystems — at least not yet. In this study, authors representing multiple Arctic nations, including Canadian Museum of Nature botanists Drs. Lynn Gillespie and Jeff Saarela, compiled a list of non-native vascular plants known from the Arctic and explored their geographic distributions and pathways of introductions. Plant specimens in the herbarium of the Canadian Museum of Nature were a key source of information for non-native plant species documented from the Canadian Arctic, including specimens collected by Gillespie and Saarela during Arctic research expeditions.

The authors documented 341 non-native vascular plant species known from the Arctic. Of those, 188 are naturalized in at least one of 23 Arctic subregions, in several subregions there are no non-native plant species known, and in most regions there are few naturalized species. Museum collections anchor the findings, and future generations of scientists will be able to review the primary collections-based evidence. The study represents a new baseline that will allow better understanding of future changes in the composition and distribution of the non-native flora of the Arctic expected in response to climate change and increasing human-caused disturbance.



Jeff Saarela collecting plant specimens in the Canadian Arctic. Photo: Roger D. Bull, Canadian Museum of Nature

PUBLICATION PROFILES

SPECIES DISCOVERY

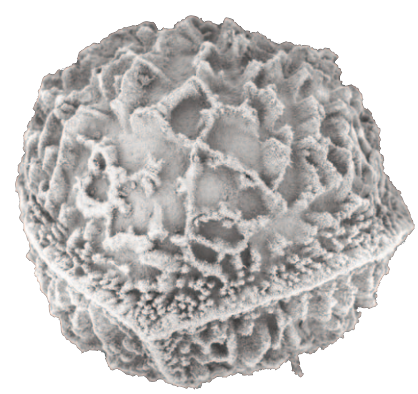
Knowledge about the diversity of life on our planet and its geological underpinnings continues to grow with numerous new species of plants, animals and minerals being discovered, named and classified every year by scientists around the globe. Identifying species and their inter-relationships is also an important part of understanding the process and impact of environmental change. Museums play a central but underappreciated role in developing this knowledge by acquiring, studying and sharing scientific specimens in their collections. Through programs of off-site loans, visiting scientists and online data mobilization, museum collections are mined for previously unstudied or 'lost' specimens, which often represent new additions to the tree of life. Museum scientists also use evidence from DNA from extant species to reconstruct the evolutionary history of life on Earth.

BRUNTON, D. F., SOKOLOFF, P. C., BOLIN, J. F., & FRASER, D. F. (2019)

Isoetes laurentiana, sp. nov. (Isoetaceae) endemic to freshwater tidal marshes in eastern Quebec, Canada

Botany, 97(11), 571–583.
https://doi.org/10.1139/cjb-2019-0037.

Sometimes you don't need to travel far at all to find a species new to science. Museum research associate Dan Brunton, an expert on Quillworts (members of the genus *Isoetes*), has studied these predominantly aquatic plants across the planet for over 30 years. While botanizing in the St. Lawrence River estuary he noticed that some populations of *Isoetes tuckermannii*, a provincially rare species in Quebec, didn't look quite right. Morphological examination of herbarium specimens from 68 populations sampled across the St. Lawrence estuary, together with flow cytometry data from collaborators at Catawba College and detailed scanning electron microscope (SEM) imagery taken at the Canadian Museum of Nature, revealed these populations to be an undescribed species endemic to these freshwater tidal marshes. The species was named *Isoetes laurentiana*. This study has not only added a new species to the impressive suite of endemic vascular plants found in the St. Lawrence estuary, but highlights the potential for species discovery in well-explored places and well-known taxonomic groups through continued systematic work, even close to home. In fact, the species was discovered while the first author was casually strolling along the Ile d'Orleans river shore with colleagues from a Committee on the Status of Endangered Wildlife in Canada (COSEWIC) meeting, waiting for a dinner reservation at a nearby restaurant. Discovery can come at the most unexpected times — even as an aperitif!



Examining the megaspores of Isoetes laurentiana using the museum's scanning electron microscope revealed fine structures important to defining this new species.

Photo: Paul Sokoloff / Dan Brunton, Canadian Museum of Nature

Lepanus pecki, a new species of dung beetle named for CMN Research Associate Dr. Stewart Peck.

Photo: Nicole Gunter, Cleveland Museum of Natural History

GIRÓN, J. C., & HOWDEN, A. T. (2019)

Five new species of *Pandeleteius* Schönherr, 1834 (Coleoptera: Curculionidae: Entiminae: Tanymecini) from South America

The Coleopterists Bulletin, 73(4), 831–845.
https://doi.org/10.1649/0010-065x-73.4.831.

This paper highlights a unique collaboration between a recent visiting scientist awardee (Dr. Girón, Texas Tech University) and a deceased Research Associate (Howden) of the Canadian Museum of Nature. Using specimens identified and dissected by Anne Howden along with notes, illustrations and descriptions she drafted before her death, Dr. Girón put together this publication by finishing the descriptions of five new species in the weevil genus Pandeleteius, a group for which Anne Howden was the world specialist. The museum was a beneficiary of the Howden collection comprising over half a million specimens of beetles, and today, as a part of the museum's collection, it serves as one of the primary resources in the world for the study of beetles and the discovery and description of new species.

Visiting scientist Jennifer Giron in the insect collection at the CMN's Natural Heritage Campus.

Photo: Jennifer Giron, with permission.

GUNTER, N. L., & WEIR, T. A. (2019)

Revision of Australian species of the dung beetle genus *Lepanus* (Coleoptera: Scarabaeidae: Scarabaeinae): key to species groups and description of 14 new species from the *L. pygmaeus* species group

Zootaxa, 4564, 41–80.
http://doi.org/10.11646/zootaxa.4564.1.2.

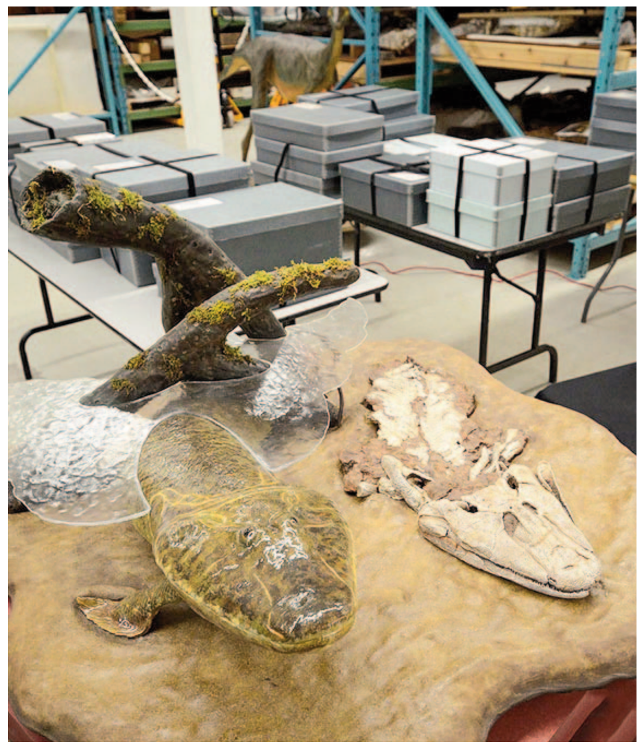
Thousands of new species are described every year, and 2019 was no different. Systematists often don't have to go far on their journey of species discovery as most new species are already housed within museum collections. This is especially true for insects, which are well represented in collections, comprise most undescribed animal life, and require specialized taxonomic expertise to diagnose the most cryptic species. Gunter & Weir's revision of the Australian dung beetle genus *Lepanus* highlights the importance of museum collections for taxonomy and the uniqueness of the world-class scarab collection housed at the Canadian Museum of Nature. The authors report approximately 75% of species in the genus are unnamed with 61 undescribed species known from global collections. This paper describes 14 new species similar to *Lepanus pygmaeus*, a species with a broad distribution across northern Australia, with CMN specimens representing six of the new species.

STEWART, T. A., LEMBERG, J. B., TAFT, N. K., YOO, I., DAESCHLER, E. B., & SHUBIN, N. H. (2020)

Fin ray patterns at the fin-to-limb transition

Proceedings of the National Academy of Sciences of the United States of America, 117(3), 1612–1620.
https://doi.org/10.1073/pnas.1915983117
(available online 30 December 2019).

The evolutionary transition from life in the water to life on land is one of the most significant in the history of vertebrate life. This process involved the evolution of limbs from fins. Most research into this transformation has focussed on the evolution of the internal skeleton, in the fossil record of fishes. In this study, researchers from the United States focus instead on the dermal skeletons of fins. They constructed digital 3D models of the fins of three species of fishes with primitive features of tetrapods that lived during the late Devonian period some 375 million years ago. They then characterize how fins were adapted for interacting with the substrate before digits evolved. One of the species studied was *Tiktaalik roseae*, based on remarkable fossils that are part of the Nunavut Vertebrate Fossil Collection housed at the Canadian Museum of Nature. This Devonian fish, with tetrapod features that show the transition between swimming fish and their four-legged vertebrate descendants, was discovered in 2004 on Ellesmere Island in Nunavut, Canada.



Foreground: a model and cast of Tiktaalik roseae in the fossil collection at the Canadian Museum of Nature. Background: Boxes containing the fossils of Tiktaalik roseae and two other species of lobe-finned fish.

Photo: Roger D. Bull, Canadian Museum of Nature

PUBLICATION PROFILES

ENDANGERED SPECIES AND CONSERVATION

Over the last few decades, natural habitats are being lost, species diversity on Earth is declining and we may be entering the next great period of extinction. Museum collections represent huge databases of relevant information about species presence in space and time. By studying collections, scientists can identify centres of diversity (hotspots), areas of endemism and ecosystems undergoing change. Through partnerships with organizations concerned with conservation, museums are irreplaceable sources of information in assessing species for their endangered status.

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ALLEN, J. L., MCMULLIN, R. T., TRIPP, E. A., & LENDEMER, J. C. (2019)

Lichen conservation in North America: a review of current practices and research in Canada and the United States

Biodiversity and Conservation, 28(12), 3103–3138. https://doi.org/10.1007/s10531-019-01827-3.

Historically, lichens have been under-represented in conservation assessments and implementation compared to other groups of organisms, such as plants and vertebrates, but some progress has been made in recent decades. In this paper, the authors — all lichenologists, including Canadian Museum of Nature lichenologist Dr. R. Troy McMullin — review the status of lichen conservation in Canada and the United States. They present detailed case studies to demonstrate the threats to and declines in lichen diversity, and they discuss the legal framework that exists to protect lichens at different scales in both countries. The authors also highlight the effective use of museum collections and databases to inform conservation strategies, and they propose clear actions that must be taken to accelerate lichen conservation.

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MCMULLIN, R. T., DROTOS, K., IRELAND, D., & DORVAL, H. (2018 [2019])

Diversity and conservation status of lichens and allied fungi in the Greater Toronto Area: results from four years of the Ontario BioBlitz

The Canadian Field-Naturalist, 132(4), 394–406. http://doi.org/10.22621/cfn.v132i4.1997.

This article highlights the importance of citizen science in species discovery. Between 2013 and 2016, four bioblitzes took place in different regions of the greater Toronto area (GTA). Professional taxonomists teamed up with citizen scientists to record as much biodiversity as possible. In this study, led by Canadian Museum of Nature lichenologist Dr. R. Troy McMullin, the lichen results are presented, which show that even taxonomically difficult groups can be included in bioblitzes. Dozens of lichen species new to the GTA were discovered, including 13 species that are provincially ranked as S1 (critically imperilled), S2 (imperilled), or S3 (vulnerable), and one of which, *Lecanora carpinea*, is new to Ontario. Lichens are particularly sensitive to air quality and disturbance and, as a result, are not typically studied in cities. However, this article demonstrates that there is plenty of biodiversity yet to be discovered in urban areas, even sensitive species in Canada's most populous city.

BOYLE, J. H., DALGLEISH, H. J., & PUZEY, J. R. (2019)

Monarch butterfly and milkweed declines substantially predate the use of genetically modified crops

Proceedings of the National Academy of Sciences, 116(8), 3006–3011.
https://doi.org/10.1073/pnas.1811437116.

The recent decline of monarch butterflies has attracted much attention. One of the leading hypotheses blames the impact of genetically modified (GM) crop-related herbicide use on milkweeds, the food plants of monarchs. In this publication, museum specimen records, including Canadian Museum of Nature specimen records accessed via the Global Biodiversity Information Facility (GBIF), are used to chart monarch and milkweed occurrence over 116 years (1900 to 2016). Monarchs and milkweeds began to decline around 1950 and continue to do so to the present day. Given that milkweeds and monarchs were declining prior to the introduction of GM crops, blaming GM crop-related herbicide use does not appear to be supported by the data.

Monarch Butterfly Sanctuary in El Rosario, Mexico. Photo: (c) Jean Lauriault

DONALDSON, L. A., RYTWINSKI, T., TAYLOR, J. J., BENNETT, J. R., DRAKE, D. A. R., MARTEL, A., & COOKE, S. J. (2019)

Can conservation targets for imperilled freshwater fishes and mussels be achieved by captive breeding and release programs? A systematic map protocol to determine available evidence

Environmental Evidence, 8(1), 16.
https://doi.org/10.1186/s13750-019-0158-2.

Freshwater fishes and mussels are among the most threatened groups of animals and their decline relates to habitat destruction, pollution, dams, harvesting and invasive species. Freshwater fishes and mussels are closely linked because mussels require the presence of fish for spreading their larval stage within the watershed. Captive breeding programs are one of the tools used by conservation practitioners to conserve, support and supplement populations of imperilled freshwater species. This study is the first one to systematically analyse the effectiveness of captive breeding programs for achieving conservation targets for imperilled freshwater fishes and mussels in the wild. The authors, including Canadian Museum of Nature malacologist Dr. André Martel, have generated a 'systematic map' that will inform conservation managers and policy makers responsible for protecting imperilled freshwater species by identifying existing information and highlighting gaps for captive breeding programs operating in temperate regions, including in Canada.

PRENTICE, M. B., BOWMAN, J., MURRAY, D. L., KLÜTSCH, C. F. C., KHIDAS, K., & WILSON, P. J. (2019)

Evaluating evolutionary history and adaptive differentiation to identify conservation units of Canada lynx (*Lynx canadensis*)

Global Ecology and Conservation, 20, e00708.
https://doi.org/10.1016/j.gecco.2019.e00708.

This paper is the result of a collaboration between Trent University and the Canadian Museum of Nature (co-author Dr. Kamal Khidas is the curator of the vertebrate zoology collections at the museum) on genetic characterisation of Canada lynx populations such that any significant evolutionary units can be recognized for conservation or management purposes. Previous studies have shown that three populations of Canada lynx differ in their skull morphology, with geographic isolation being the crucial factor in accounting for these differences. This current paper reports on variation across Canada lynx populations in eastern Canada and provides evidence that there are actually four distinct populations of Canada lynx—with one to the south of the St. Lawrence River counting as the fourth. Ultimately, these findings should help in refining conservation strategies for Canada lynx, and also underline the importance of keeping and developing natural history collections.

PUBLICATIONS

Scoring of all papers, using the following scheme (see Methods), is summarized in square brackets following each listing.

Authorship:
1 — CMN staff author/co-author; 2 — CMN research associate author/co-author; 3 — no CMN-affiliated author/coauthor

Evidence of use of CMN collections/collection data:
† — publication cites one or more CMN specimens; * — publication cites one or more GBIF datasets that includes CMN collections; ‡ — publication indicates CMN collections were searched for material relevant to a study; # — publication indicates CMN collections were consulted to aid identification of species.

Arctic — paper relevant to Arctic research.

CMN staff and associates are in boldface.

Publications with a 2020 date were first available online in 2019.

Earth History and Evolution

Adams, G. R., Mann, A., & **Maddin, H. C.** (2019). New embolomerous tetrapod material and a faunal overview of the Mississippian-aged Point Edward locality, Nova Scotia, Canada. Canadian Journal of Earth Sciences, 57, 407–417. https://doi.org/10.1139/cjes-2018-0326 [2, †]

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Arbour, V. M., & Evans, D. C. (2019). A new leptoceratopsid dinosaur from Maastrichtian-aged deposits of the Sustut Basin, northern British Columbia, Canada. PeerJ, 7, e7926. https://doi.org/10.7717/peerj.7926 [3, †]

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Buckley, M., Lawless, C., & **Rybczynski, N.** (2019). Collagen sequence analysis of fossil camels, *Camelops* and cf *Paracamelus*, from the Arctic and sub-Arctic of Plio-Pleistocene North America. Journal of Proteomics, 194, 218–225. https://doi.org/10.1016/j.jprot.2018.11.014 [2, †, Arctic]

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Clack, J. A., Challands, T. J., Smithson, T. R., & Smithson, K. Z. (2019). Newly recognized Famennian lungfishes from East Greenland reveal tooth plate diversity and blur the Devonian–Carboniferous boundary. Papers in Palaeontology, 5, 261–279. https://doi.org/10.1002/spp2.1242 [3, †]

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