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Cover: Shining Clubmoss (*Huperzia lucidula*) near Gunisao Lake, Manitoba, the only extant population of this lycopod in the province. See the article by Staniforth (101–106) that describes its provincial distribution and its significance as the species' northernmost occurrence in North America. This Shining Clubmoss population is also discussed in the article by Staniforth and Brunton (107–121) which presents a synopsis of all lycopod species in Manitoba. Photo: R.J. Staniforth.

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Note

Confirmation of Shining Firmoss (*Huperzia lucidula*; Lycopodiaceae) in Manitoba

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Abstract

The occurrence of Shining Firmoss (*Huperzia lucidula*; Lycopodiaceae) in Manitoba has been suspected since 1943 but unconfirmed. The discovery at the herbarium of the University of Manitoba of a non-accessioned specimen, collected in Riding Mountain National Park (RMNP), Manitoba, confirmed that the species occurred in the province. At about the same time, a thriving colony of Shining Firmoss was discovered at Gunisao Lake, ~380 km to the northeast of the RMNP site. Shining Firmoss is now established as a rare, widely dispersed element in Manitoba's flora.

Key words: Shining Firmoss; *Huperzia lucidula*; Manitoba; new distribution records

Shining Firmoss, *Huperzia lucidula* (Michaux) Trevisan (synonym: *Lycopodium lucidulum* Michaux), so named because of the glossiness of its leaves, is one of about 25 species of *Huperzia* found worldwide (PPG I 2016) and one of three species recorded from Manitoba in VASCAN (Brouillet *et al.* 2010+). It is a perennial, forest-floor, evergreen plant (Figure 1) of hardwood and mixed forests. According to Wagner and Beitel (1993), it is found in Canada from Manitoba east to Newfoundland and in the eastern United States from the Canadian border south to Alabama and Georgia. However, the reports from Manitoba in these sources, as well as in Cody and Britton (1989), are unsupported by specimen citations.

In 2012, D. Sawatsky discovered a previously unknown 1958 herbarium specimen of Shining Firmoss in the University of Manitoba Herbarium (WIN). (Herbarium acronyms follow Thiers [2020].) That specimen (*J.M. Walker* [later, Shay] *213,* WIN 82392) from Riding Mountain National Park (RMNP), Manitoba (Figure 2) confirmed the occurrence of the species in the province. The specimen was unaccessioned and, thus, likely had been overlooked until the time of Sawatsky's discovery.

The collection label reads: "*Lycopodium lucidulum*. Coll. #213. Date: July 19, 1958. Habitat: Damp, shaded hollow beneath woods. Coll. J.M. Walker"

Figure 1. Part of a colony of Shining Firmoss (*Huperzia lucidula*) found near Gunisao Lake, Manitoba (*R.J. Staniforth 849*, RS), in 2013. Photo: R.J. Staniforth.

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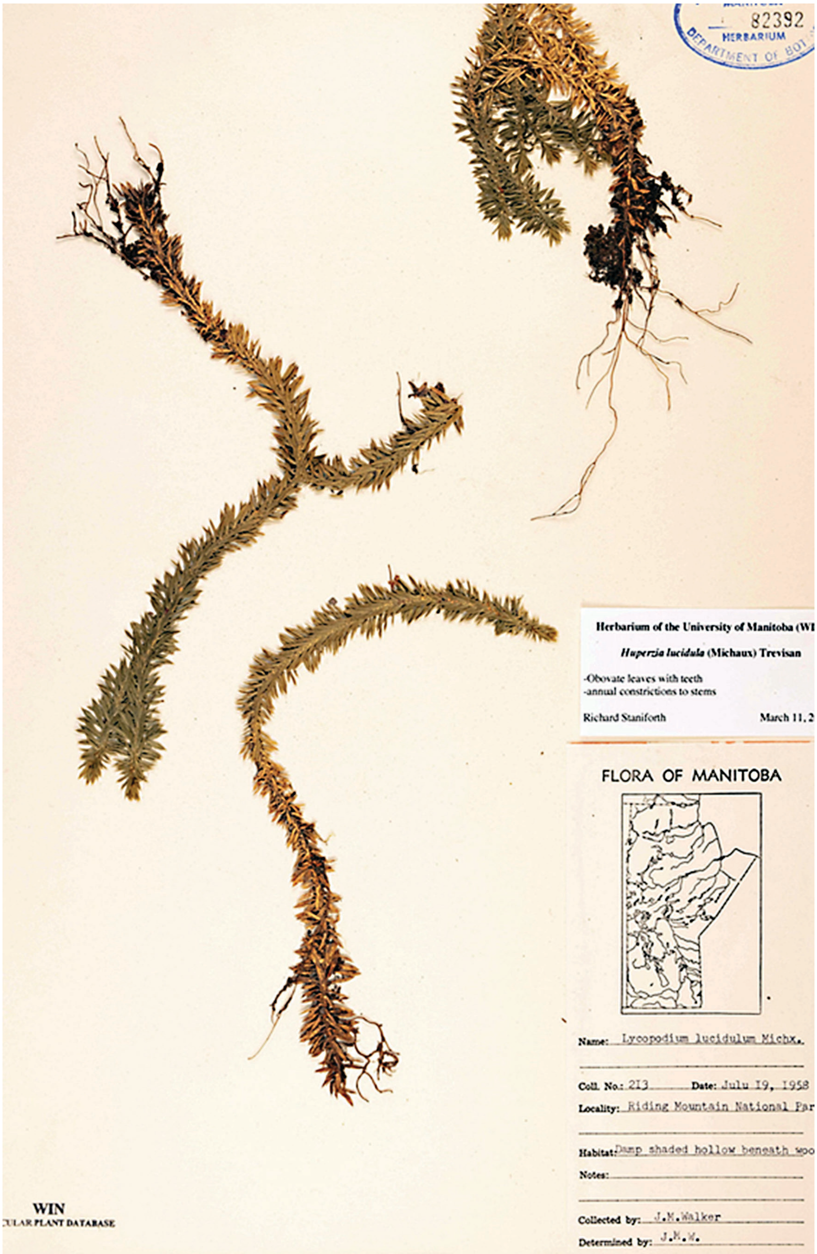

FIGURE 2. Herbarium specimen of Shining Firmoss (*Huperzia lucidula*) recently discovered at the University of Manitoba (WIN). Note the annual constrictions in the stem, the stem width, the long oblanceolate leaves, and the spreading leaf posture. Photo: R.J. Staniforth.

(Figure 2). I revised it to *Huperzia lucidula* (Michaux) Trevisan, a homotypic synonym of the name *L. lucidulum,* based on the attributes noted in Table 1. Further, on 24 June 2013, I discovered a small (1 m × 3 m) colony of the species at Gunisao Lake in central Manitoba (Figure 1) growing along the edge of a granite outcrop in pine–spruce–birch forest (*R.J. Staniforth 849*, RS, the personal collection of R.J.S. to be deposited in a public Manitoba herbarium). This colony consisted of mature trailing plants and numerous immature plants that had clearly developed from gemmae. The RMNP and the Gunisao Lake sites are

TABLE 1. Comparison of morphological features of Shining Firmoss (*Huperzia lucidula*), Northern Firmoss (*Huperzia selago*), and their hybrid Butters' Firmoss (*Huperzia ×buttersii*).

Morphological characteristic	Shining Firmoss	Butters' Firmoss	Northern Firmoss
Annual stem constrictions	Conspicuous	Indistinct	Obscure
Stem thickness	10–20 mm	Intermediate	7–14 mm
Leaf posture	Spreading to reflexed	Intermediate	Spreading-ascending
Leaf shape	Oblanceolate (widest above middle)	Intermediate	Tapered, triangular (widest below middle)
Leaf length	7–11 mm	Intermediate	3.5–7.5 mm
Leaf margin	1–8 teeth per side	Teeth inconspicuous or (rarely) absent	Entire (teeth absent)
Leaf stomata	Undersurface only	A few on upper surface, many below	Both surfaces
Gemma shape	Rounded	Intermediate	Acute
Spore viability	Viable (regular shape and size)	Aborted (irregular shape and variable size)	Viable (regular shape and size)

Sources: modified from Wagner and Beitel (1993), Haines (2003), and Palmer (2018).

~380 km apart (Figure 3). In 2015, firmoss expert W. Testo confirmed vouchers from the 2013 Gunisao Lake collection as *H. lucidula*. On the basis of its irregular gemmae shape and the presence of aborted spores, however, a replicate of *R.J. Staniforth 849* in Daniel Brunton Private Herbarium (DFB; now renumbered *R.J. Staniforth 849b*, for clarification) was determined by D.F. Brunton and confirmed by W. Testo to be the sterile hybrid Butters' Firmoss (*Huperzia ×buttersii* (Abbe) Kartez and Gandhi [*H. lucidula ×Huperizia selago* (L.) Bernhardi]; D. Brunton pers. comm. 13 May 2015). I conclude that all other specimens collected at Gunisao Lake represent *H. lucidula* based on the distinctions of diagnostic characteristics noted for *H. lucidula*, *H. ×buttersii*, and *H. selago* (including *Huperizia appressa* (Desvaux) Löve and Löve, *p.p.* [*pro parte,* in part]) in Table 1.

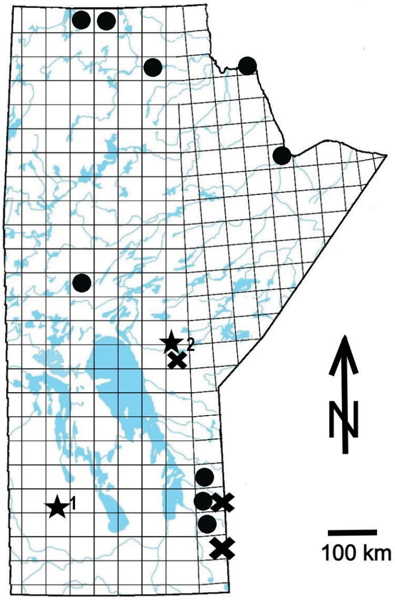

FIGURE 3. Manitoba locations (50 × 50 km grid) of Shining Firmoss (*Huperzia lucidula* ★: 1. Riding Mountain National Park, 2. Gunisao Lake), Butters' Firmoss (*Huperzia ×buttersii* ✖), and Northern Firmoss (*Huperzia selago* ●).

Earlier reports of *H. lucidula* in Manitoba are vague and unsubstantiated. The species was not mentioned in the first provincial floras (Burman 1909; Jackson *et al.* 1922). Lowe (1943: 9) was the first botanist to include the species on a provincial list: "Moist woods. Occasional. Riding Mt. Nat. Park, Victoria Beach and Kenora, Ont.", but no supporting specimens with a collection date prior to 1943 have been located. Scoggan (1957: 51) decided that "in the absence of supporting specimens… it seems best to exclude this species for the present from the flora of Manitoba". However, he later wrote that the species did occur in "SE Man. (Bissett)" (Scoggan 1978: 135), but offered no further explanation. Shortly thereafter, White and Johnson (1980: 29) included *H. lucidula* in their enumeration of the rare vascular flora of Manitoba on the basis of an RMNP collection (perhaps the unaccessioned *J.M. Walker 213* collection found by Sawatsky in 2012), but with no mention of southeastern Manitoba records. My critical examination of all eastern Manitoba specimens of *L. lucidulum* (Appendix S1) found that all of these had been misidentified and either represented the hybrid

Butters' Firmoss (*Huperzia ×buttersii*) or Northern Firmoss (*Huperzia selago*).

Before the discovery of the *J.M. Walker 213* RMNP specimen and the colony at Gunisao Lake, recent Manitoba reports of this species appear to originate from the inclusion of *H. lucidula* in *Plants of Riding Mountain National Park* (Cody 1988). Cody (1988: 19) reported that the species is "Rare on moss-covered shale under birch near the East Gate", but a thorough field exploration by D. Staniforth and R.J.S. (19–21 September 2010) failed to find any plants at that location. A subsequent extensive search in Manitoba herbaria (the Manitoba Museum [MMMN], WIN, the University of Winnipeg [UWPG], and the small plant collection at RMNP [W. Vanderschuit pers. comm. ~ June 2009]) for a voucher specimen to confirm the Cody report was unsuccessful. A voucher was also searched for by G. Mitrow and M. Anions in the National Collection of Vascular Plants – Agriculture and Agri-food Canada (DAO), where Cody had been the curator. Although one was not found, a fuzzy photograph (Figure 4) of the apparently missing collection which had been accessioned in 1982 as DAO 337594, "Ex herb. Manitoba", was discovered (M. Anions pers. comm. 10 November 2010). There are two herbarium labels on this specimen, one in the photograph and the other on the newer sheet (Figure 5). The photograph gives the following information:

FIGURE 4. A photograph of the missing herbarium voucher of Shining Firmoss (*Huperzia lucidula*) at the National Collection of Vascular Plants (DAO), Agriculture and Agri-food Canada, Ottawa, Ontario; *J.C. Ritchie 3325* specimen (DAO 337594). The original specimen was missing, but a photograph of it remained and was made into a herbarium specimen with its own label and accession number. See Figure 5 for the detailed label data. Photo: R.J. Staniforth.

> Flora of Manitoba. *Lycopodium lucidulum* Michx. Coll: #3325. Date: 10-7-58. Locality: Riding Mtn. National Park near E. Gate. Habitat: N.-facing slope near birch on wet moss-covered shale. (Apparently the first authentic record for Manitoba.) Coll: J.C. Ritchie. Det: J.C.R. Stet! [let it stand as written] W.J. Cody 1982.

The photograph of the firmoss lacks fine definition. The possibility that the specimen is incorrectly identified cannot be excluded using the photographic evidence alone. However, given the 1982 W.J. Cody and 1989 D.W. White annotations on the herbarium sheet in support of the original identification by Ritchie, the identification is considered likely to be accurate.

Huperzia lucidula is a widely dispersed and rare taxon in Manitoba (Figure 3). It has not been recorded to the north, west, or southwest of Manitoba; i.e., Saskatchewan (Harms and Leighton 2011) and North Dakota (Shipunov 2019). It is known eastward, where it is considered to be regularly occurring both in adjacent northwest Ontario (Walshe 1980; Cody and Britton 1989) and northeastern Minnesota (Tryon 1954; Chayka and Dziuk 2020). It is possible that additional occurrences will be found in Manitoba, especially beside granite outcroppings within the boreal forests of mid-Manitoba.

The dispersal potential of hybrid *Huperzia ×buttersii* is presumably more limited than that of putative parents *H. lucidula* and *H. selago,* because of its dependence on relatively large dispersal units (the gemmae). This hybrid is known only from several sites in southeastern Manitoba, usually in direct or close association with plants of one or both parents (Figure 3; Staniforth 2012; Staniforth and Brunton 2022).

Acknowledgements

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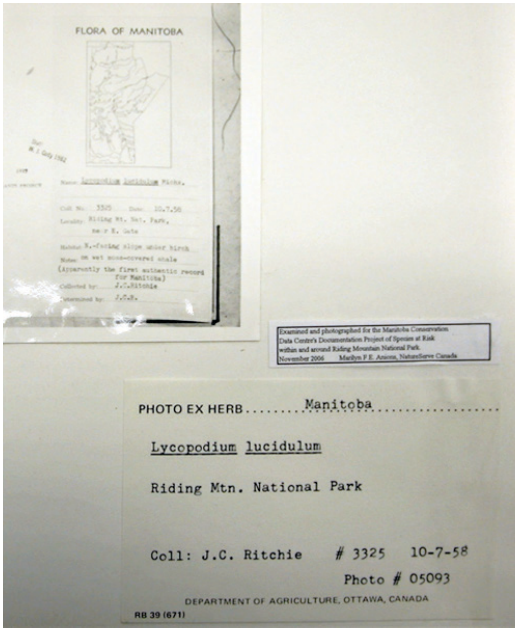

FLORA OF MANITOBA

Name: Lycopodium lucidulum Michx.

Coll. No. 3325 Date 10.7.58

Locality: Riding Mt. Nat. Park, near E. Gate

Habitat: N.-facing slope under birch

Notes: on wet moss-covered shale (Apparently the first authentic record for Manitoba)

Collected by: J.C.Ritchie

Determined by: J.C.R.

Examined and photographed for the Manitoba Conservation Data Centre's Documentation Project of Species at Risk within and around Riding Mountain National Park.
November 2006 Marilyn F.E. Anions, NatureServe Canada

PHOTO EX HERB........Manitoba..................

Lycopodium lucidulum

Riding Mtn. National Park

Coll: J.C. Ritchie # 3325 10-7-58

Photo # 05093

DEPARTMENT OF AGRICULTURE, OTTAWA, CANADA

RB 39 (671)

FIGURE 5. Herbarium label of *J.C. Ritchie 3325* specimen (DAO 337594) of Shining Firmoss (*Huperzia lucidula*). Photo: R.J. Staniforth.

tant, Winnipeg, Manitoba), W. Testo (University of Gothenburg, Sweden), and W. Vanderschuit (Parks Canada, Riding Mountain National Park, Manitoba). I also thank two anonymous reviewers and *The Canadian Field-Naturalist* editorial staff who spent a substantial amount of time on enhancements to the original manuscript.

Note: The author died as the manuscript neared completion. Daniel F. Brunton of Ottawa, Ontario, was invited by Diana Staniforth to complete the final review and publication process and was honoured to do so.

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SUPPLEMENTARY MATERIAL:

APPENDIX S1. Specimens of Shining Firmoss (*Huperzia lucidula*), Butters' Firmoss (*Huperzia ×buttersii*), and Northern Firmoss (*Huperzia selago*) known from Manitoba herbaria.

The Canadian Field-Naturalist

A synopsis of lycophytes in Manitoba, Canada: their status, distribution, abundance, and habitats

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Abstract

A steady increase in the number of lycophyte taxa discovered in Manitoba over the last 20 years prompted a determination of which species should be included in an updated provincial list. Collections made throughout the province since 2008 and a critical examination of over 1000 herbarium specimens enabled a substantive review and update of Manitoba's lycophyte flora. It now comprises 22 taxa: 14 species and two hybrid clubmosses (Lycopodiaceae), three spikemosses (Selaginellaceae), and two species and one hybrid quillwort (Isoetaceae). Thirteen of the 21 species are designated to be of conservation concern, with NatureServe ranks of Critically Imperilled (S1; three), Imperilled (S2; two), or Vulnerable (S3; nine). Based on verified specimens, we describe the abundance and habitats, and summarize recent changes in nomenclature and systematics for all Manitoba lycophyte taxa.

Key words: Status; distribution; abundance; habitat; lycophytes; Lycopodiaceae; Selaginellaceae; Isoetaceae; Manitoba

Introduction

The lycophytes, class Lycopodiopsida (PPG I 2016), are spore-bearing vascular plants (i.e., tracheophytes) represented in Manitoba and in Canada by three families: clubmosses (Lycopodiaceae), spikemosses (Selaginellaceae), and quillworts (Isoetaceae). Lycophytes first appeared about 400 million years ago and are the oldest extant lineage of vascular plants, evolving long before the seed plants (Moran 2004). The class was diverse and abundant 350–300 million years ago, but many of its lineages became extinct at the end of the Carboniferous Period when the climate became drier and coastal swamps became more saline (Moran 2004). Contemporary members of the three living lycophyte families are often overlooked, being small, unobtrusive inhabitants of forest floors, dry grasslands, and tundra, or submerged aquatics (Cody and Britton 1989).

This study was motivated by uncertainty about which lycophyte taxa occur in Manitoba. New species have been discovered in the province intermittently since the publication of the provincial flora (Scoggan 1957) and the most recent review of their diversity (Staniforth 2012). Many long-established taxa have also been redefined based on new research (e.g., Wagner and Beitel 1992, 1993; Haines 2003), providing a more contemporary understanding of the group. The primary purpose of our study was to examine herbarium and recently collected field specimens of Manitoba lycophytes critically to determine the distribution, abundance, and habitats of each verifiable taxon documented in the province.

As was typical of that time, Scoggan (1957) considered clubmosses (Lycopodiaceae) to be taxa within one large genus, *Lycopodium* L. More recently, however, Holub (1975), Wagner and Beitel (1992), and Haines (2003) divided *Lycopodium sensu lato* (*s.l.*, in the broader sense) into several genera. In Manitoba, *Lycopodium* (*s.l.*) is now considered to consist of six genera: tree-clubmosses (*Dendrolycopodium* Haines), ground-cedars (*Diphasiastrum* Holub), firmosses (*Huperzia* Bernhardi), bog clubmosses (*Lycopodiella* Holub), clubmosses (*Lycopodium* L. *sensu stricto* [*s.s.*, in the narrower sense]), and interrupted clubmosses (*Spinulum* Haines). This division has received widespread acceptance (PPG I 2016) and is incorporated into most recent field guides (e.g., Cobb *et al*. 2005; Chadde 2013; Walewski 2016; Palmer 2018). The genera are readily distinguishable in the field, but individual taxa within particular genera can be more challenging to identify, and some have undergone taxonomic revisions.

A contribution towards the cost of this publication has been provided by the Thomas Manning Memorial Fund of the Ottawa Field-Naturalists' Club.

The circumscriptions of the three species of spikemosses listed by Punter (1995) have remained unchanged, but the quillworts have increased from a single species to three (see Annotated Checklist).

Methods

A total of 981 specimens of Manitoba lycophytes in the University of Manitoba (WIN), University of Winnipeg (UWPG), the Manitoba Museum (MMMN) herbaria (acronyms according to Thiers 2020), and the personal collection of R.J.S. were examined and documented by R.J.S. between 2008 and 2020. An additional 61 specimens defied identification, mostly because they were vegetative. Determinations, identification confirmations, and label information for all specimens examined were documented in a spreadsheet (Table S1). Each taxon accepted in the present study is supported by at least one Manitoba specimen verified and annotated by one or more lycophyte specialists (see Acknowledgements).

The herbarium specimen data were supplemented by extensive collecting throughout the province between 2008 and 2020 by R.J.S. and D. Staniforth. This involved many thousands of kilometres of travel through southern Manitoba and as far north as Lynn Lake in the west and Split Lake, Berens River, and Churchill in the east (Figure 1), visiting provincial parks and provincial forest reserves as well as roadside plant communities. Between 2010 and 2014, travel to remote northern communities to gather data for the Manitoba breeding bird atlas (MBBA 2014) enabled access to areas previously poorly or unsurveyed (Figure 1, Table S2). This resulted in a substantial improvement in both the quantity of Manitoba lycophyte records and their geographic distribution. Specimens collected during those trips are deposited in various herbaria, including MMMN, WIN, and

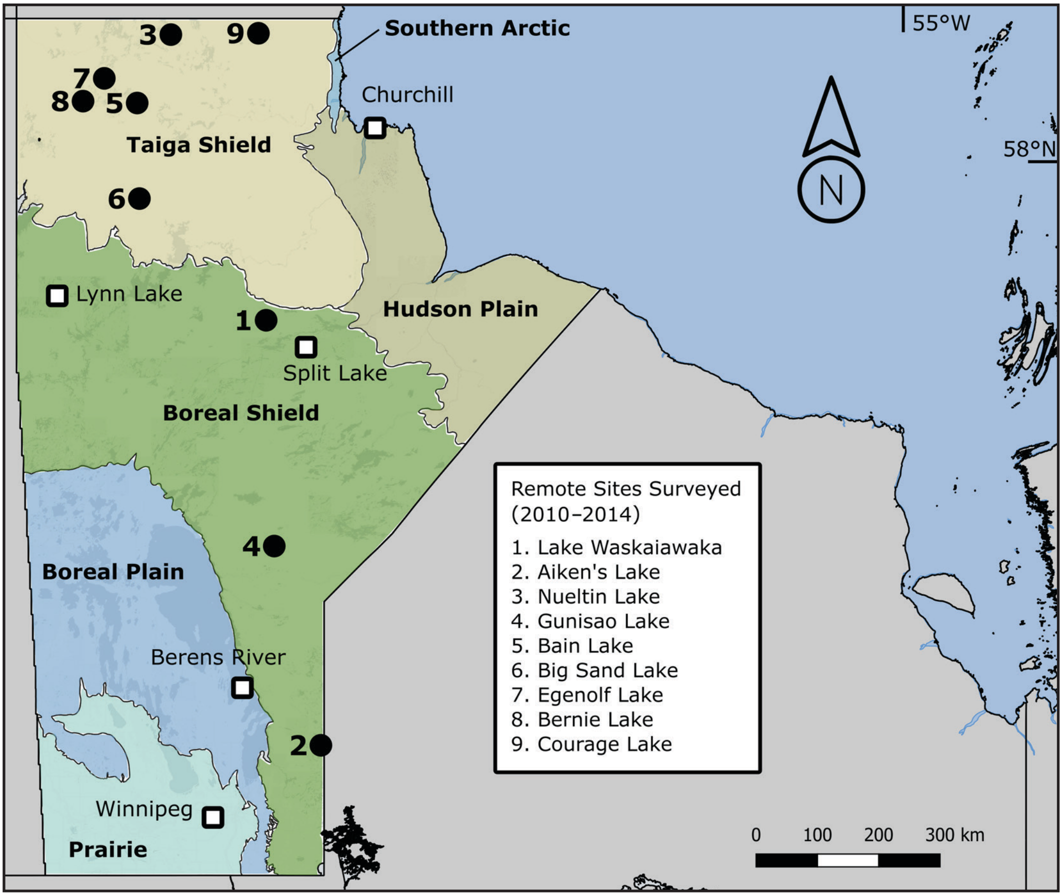

FIGURE 1. Manitoba ecozones and key geographic locations, including recently investigated remote sites (see Table S2). Ecozone delineation adapted (simplified) from Manitoba's Protected Areas Initiative (2013). Basemap from SimpleMappr (Shorthouse 2010).

UWPG. The first set of vouchers from the 2008–2020 surveys is currently in the R.J.S. personal collection (here designated RS), which is to be deposited in a public Manitoba herbarium.

Based on these data, we compiled and summarized the distribution, abundance, and habitat of each lycophyte taxon (see Annotated Checklist).

Results

Twenty-two taxa (19 species and three hybrids) have been documented from the examination of the 981 museum specimens and recent collections with supporting vouchers as occurring (or having occurred) in Manitoba (Annotated Checklist, below; some representatives are shown in Figure 2). We report two species for the first time in the province: Alpine Ground-cedar (*Diphasiastrum alpinum* (L.) Holub; Figure 2c) and Continental Firmoss (*Huperzia continentalis* Testo, Haines and Gilman; Figure 2d). Hickey's Quillwort (*Isoetes ×hickeyi* Taylor and Luebke) is added to the list of Manitoba's flora based on the report in Brunton and Britton (1991). Savin-leaved Ground-cedar (*Diphasiastrum ×sabinifolium* (Willenow) Holub, *pro sp.* [*pro specie* – originally described as a distinct species]) is excluded from the flora.

Annotated Checklist of Manitoba Lycophytes

The list is organized by family then alphabetically by genus and species. VASCAN (Brouillet *et al.* 2010+) is the default authority for nomenclature and taxonomy, unless otherwise stated. For consistency's sake, common names also typically are those recommended by VASCAN. Thus *Dendrolycopodium* spp. are tree-clubmosses, *Diphasiastrum* spp. are ground-cedars, *Huperzia* spp. are firmosses, *Lycopodiella* sp. is bog clubmoss, *Lycopodium* spp. are clubmosses, *Spinulum* spp. are interrupted clubmosses, *Selaginella* spp. are spikemosses, and *Isoetes* spp. are quillworts (Figure 2).

The relative abundance of lycophyte species was measured by the number of specimens examined in Manitoba herbaria (Table 1). For specimens that lack a collection number, the accession number and herbarium acronym of the hosting collection are noted.

This checklist is a complete representation of the Manitoba lycophyte specimen record. Substantial collections preserved in out-of-province herbaria (e.g. Canadian Museum of Nature [CAN]) are almost completely duplicated in Manitoba herbaria.

The Annotated Checklist also cites the current subnational (i.e., Manitoba [MB]) conservation status rank (S-rank) assigned to each of the lycophyte taxa (NatureServe 2022). S-ranks provide information on the conservation evaluation (level of risk) for that species and include the following categories: S1 (Critically Imperilled), S2 (Imperilled), S3 (Vulnerable), S4 (Apparently Secure), and S5 (Secure). Taxa that are yet to be ranked are cited as "unranked"; hybrids are not included in conservation status rankings but recognized as "unranked hybrids" (NatureServe 2022). Only one synonym (syn.) is included for most species.

Species reported for MB for the first time are indicated by an asterisk (*).

Lycopodiaceae, clubmosses

Dendrolycopodium, tree-clubmosses (Figure 2a)

Historically (e.g., Scoggan 1957), the scientific name of the common tree-clubmoss in MB was *Lycopodium obscurum* Michaux. Haines (2003) reclassified the taxon, placing it in the new genus *Dendrolycopodium* as *Dendrolycopodium obscurum* (Michaux) Haines. This has caused confusion in MB and western Canada because *D. obscurum* (*s.s.*) is exclusively an eastern species (Wagner and Beitel 1993). Only Prickly Tree-clubmoss (*Dendrolycopdium dendroideum* (Michaux) Haines) and Hickey's Tree-clubmoss (*Dendrolycopodium hickeyi* (Wagner, Beitel, and Moran) Haines) have been confirmed from MB. *Dendrolycopodium hickeyi* was only recently recognized as occurring here (Staniforth 2012). Putative hybrids between tree-clubmosses have been recorded from New England where they are considered rare (Haines 2011). Such hybrids are not yet known in MB.

Dendrolycopodium dendroideum (syn. *Lycopodium dendroideum* Michaux). Prickly Tree-clubmoss, lycopode dendroide (Figure 2a). Moist, mixed, and coniferous forests throughout MB (Figure 3a). Very common and S4. Number of specimens seen: 141 (Table 1). Northernmost MB record: Big Sand Lake, Sand Lake Provincial Park, 57.614°N, 99.850°W, mixed woodland on clay, 12 June 2011, *R.J. Staniforth 00699* (RS).

Dendrolycopodium hickeyi (syn. *Lycopodium hickeyi* (Wagner, Beitel, and Hickey) Moran; *Lycopodium obscurum* var. *isophyllum* Hickey). Hickey's Tree-clubmoss, lycopode de Hickey. Moist mixed forests and coniferous forests throughout MB (Figure 3b). Uncommon and S3. Number of specimens seen: 42 (Table 1). Northernmost MB record: Nueltin Lake, central area, 59.797°N, 99.782°W, open White Spruce (*Picea glauca* (Moench) Voss) woods, lichen, and birch on sandy gravel, 1 July 2012, *R. Staniforth 00825* (RS).

Diphasiastrum, ground-cedars (Figures 2b,c)

We follow Haines (2003) in recognizing *Diphasiastrum* as a distinct genus within *Lycopodium* (*s.l.*). Zeiller's Ground-cedar (*Diphasiastrum ×zeilleri* (Rouy) Holub), the most frequently encountered *Diphasia-*

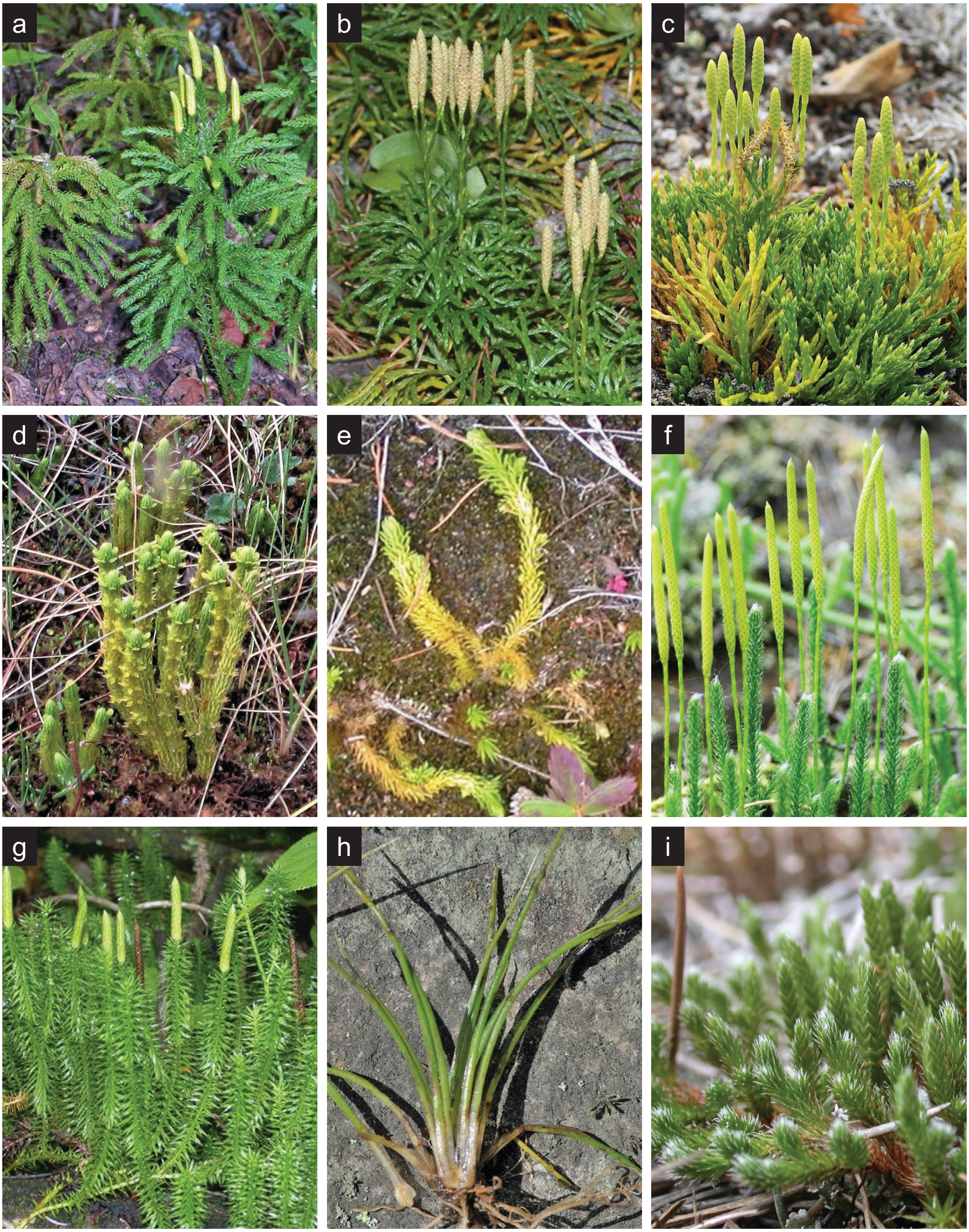

FIGURE 2. Representative lycophytes verified as occurring in Manitoba, Canada. a. Prickly Tree-clubmoss (*Dendrolycopodium dendroideum* (Michaux) Haines), Hecla Provincial Park. b. Zeiller's Ground-cedar (*Diphasiastrum ×zeilleri* (Rouy) Holub), Whiteshell Provincial Park. c. Alpine Ground-cedar (*Diphasiastrum alpinum* (L.) Holub), Bain Lake. d. Continental Firmoss (*Huperzia continentalis* Testo, Haines, and Gilman), Courage Lake. e. Northern Bog Clubmoss (*Lycopodiella inundata* (L.) Holub), Gunisao Lake. f. One-cone Clubmoss (*Lycopodium lagopus* (Laestadius) Zinserling), Black Lake, Nopiming Provincial Park. g. Interrupted Clubmoss (*Spinulum annotinum* (L.) Haines), Hecla Provincial Park. h. Spiny-spored Quillwort (*Isoetes echinospora* Durieu), Hunt Lake, Whiteshell Provincial Park. i. Rock Spikemoss (*Selaginella rupestris* (L.) Spring), Whiteshell Provincial Park. Photos: R.J. Staniforth.

TABLE 1. Numbers of Manitoba lycophyte specimens, based on verified herbarium specimens in Manitoba herbaria up to 2020*, arranged in descending order of NatureServe (2022) subnational conservation rank (status ranks) for Manitoba.

Taxon	No. specimens in Manitoba herbaria (excluding duplicates)	Status rank†
Interrupted Clubmoss (*Spinulum annotinum*)	192	S4
Prickly Tree-clubmoss (*Dendrolycopodium dendroideum*)	141	S4
Zeiller's Ground-cedar (*Diphasiastrum ×zeilleri*)	80	—
Northern Interrupted Clubmoss (*Spinulum canadense*)	58	—
Rock Spikemoss (*Selaginella rupestris*)	93	S4
Prairie Spikemoss (*Selaginella densa*)	18	—
Northern Ground-cedar (*Diphasiastrum complanatum*)	74	S3
Running Clubmoss (*Lycopodium clavatum*)	58	S3
One-cone Clubmoss (*Lycopodium lagopus*)	73	S3
Spiny Quillwort (*Isoetes echinospora*)	20	S3
Hickey's Tree-clubmoss (*Dendrolycopodium hickeyi*)	42	S3
Blue Ground-cedar (*Diphasiastrum tristachyum*)	10	S3
Northern Spikemoss (*Selaginella selaginoides*)	8	S3
Northern Firmoss (*Huperzia selago*)	30	S2
Large-spored Quillwort (*Isoetes macrospora*)	6	S2
Northern Bog Clubmoss (*Lycopodiella inundata*)	5	S1
Butters' Firmoss (*Huperzia ×buttersii*)	3	—
Hickey's Quillwort (*Isoetes ×hickeyi*)	2	—
Shining Firmoss (*Huperzia lucidula*)	3	—
Continental Firmoss (*Huperzia continentalis*)	1	S1
Sika Ground-cedar (*Diphasiastrum sitchense*)	2	S1
Alpine Ground-cedar (*Diphasiastrum alpinum*)	1	S1

*See Table S1.

†S5 = Secure, S4 = Apparently Secure, S3 = Vulnerable, S2 = Imperilled, S1 = Critically Imperilled, — = not ranked.

strum taxon in southeast MB (R.J.S. pers. obs.), has previously been widely misidentified as Northern Ground-cedar (*Diphasiastrum complanatum* (L.) Holub).

**Diphasiastrum alpinum* (syn. *Lycopodium alpinum* L.). Alpine Ground-cedar, lycopode alpin (Figure 2c). Lichen–spruce woodland in northern MB (Figure 3c). Very rare and S1. Single specimen known (Table 1). Photographed on an esker top near Bain Lake, south of Egenolf Lake, 58.92°N, 99.17°W, 9 July 2013. *R.J. Staniforth RS01422.* Herbarium specimens consist of herbarium sheets with photographs, identified by A. Gilman and W. Testo pers. comm. 17 December 2018 (MMMN, RS, UWPG, WIN).

Diphasiastrum complanatum (syn. *Lycopodium complanatum* L.). Northern Ground-cedar, lycopode aplati. Moist, mixed forests, and dry coniferous forests and barrens; throughout MB (Figure 3d). Common and S3. Northern Ground-cedar is morphologically variable in MB. Plants in southern mixed forests are tall (to 30 cm) with long side branches, whereas plants from exposed northern sites are short (<5 cm) and tufted. This variation has led to some MB populations being confused with Savin-leaved Ground-cedar (*Diphasiastrum ×sabinifolium* (Willdenow) Holub, *pro sp.*; Staniforth 2012), but specimens in RS have recently been revised to *D. complanatum* by A. Gilman. Number of specimens seen: 74 (Table 1). Northernmost MB record: Simon's Point Esker, near Nueltin Lake 59.862°N, 100.078°W, lichen-Dwarf Birch [*Betula pumila* L.] community on moist sand and gravel, 3 July 2012. *R. Staniforth* RS00832 (RS).

Diphasiastrum sitchense (Ruprecht) Holub (syn. *Lycopodium sitchense* Ruprecht; *Lycopodium sabinaefolium* var. *sitchense* (Ruprecht) Fernald). Sitka Ground-cedar, lycopode de Sitka. Occurs locally among dry lichen and shrubs in northern MB (Figure 3e). Very rare and S1. Collected from two sites (Table 1). Manitoba Hydro North Central Project Site #26, 54°12′N, 94°14′W, mineral dry soil, 11 July 1991, *E. Punter* (WIN52607); north

FIGURE 3. Distribution of Manitoba lycophytes. Maps indicate presence (dots) in 50 × 50 km universal transverse Mercator grid squares as indicated by data in Table S1. a. Prickly Tree-clubmoss (*Dendrolycopodium dendroideum*). b. Hickey's Tree-clubmoss (*Dendrolycopodium hickeyi*). c. Alpine Ground-cedar (*Diphasiastrum alpinum*). d. Northern Ground-cedar (*Diphasiastrum complanatum*). e. Sitka Ground-cedar (*Diphasiastrum sitchense*). f. Blue Ground-cedar (*Diphasiastrum tristachyum*). g. Zeiller's Ground-cedar (*Diphasiastrum ×zeilleri*). h. Continental Firmoss (*Huperzia continentalis*). i. Shining Firmoss (*Huperzia lucidula*). j. Northern Firmoss (*Huperzia selago* (*s.s.*)). k. Butters' Firmoss (*Huperzia ×buttersii*). l. Northern Bog Clubmoss (*Lycopodiella inundata*). m. Running Clubmoss (*Lycopodium clavatum*). n. One-cone Clubmoss (*Lycopodium lagopus*). o. Interrupted Clubmoss (*Spinulum annotinum*). p. Northern Interrupted Clubmoss (*Spinulum canadense*). q. Spiny-spored Quillwort (*Isoetes echinospora*). r. Large-spored Quillwort (*Isoetes macrospora*). s. Hickey's Quillwort (*Isoetes ×hickeyi*). t. Prairie Spikemoss (*Selaginella densa*). u. Rock Spikemoss (*Selaginella rupestris*). v. Northern Spikemoss (*Selaginella selaginoides*).

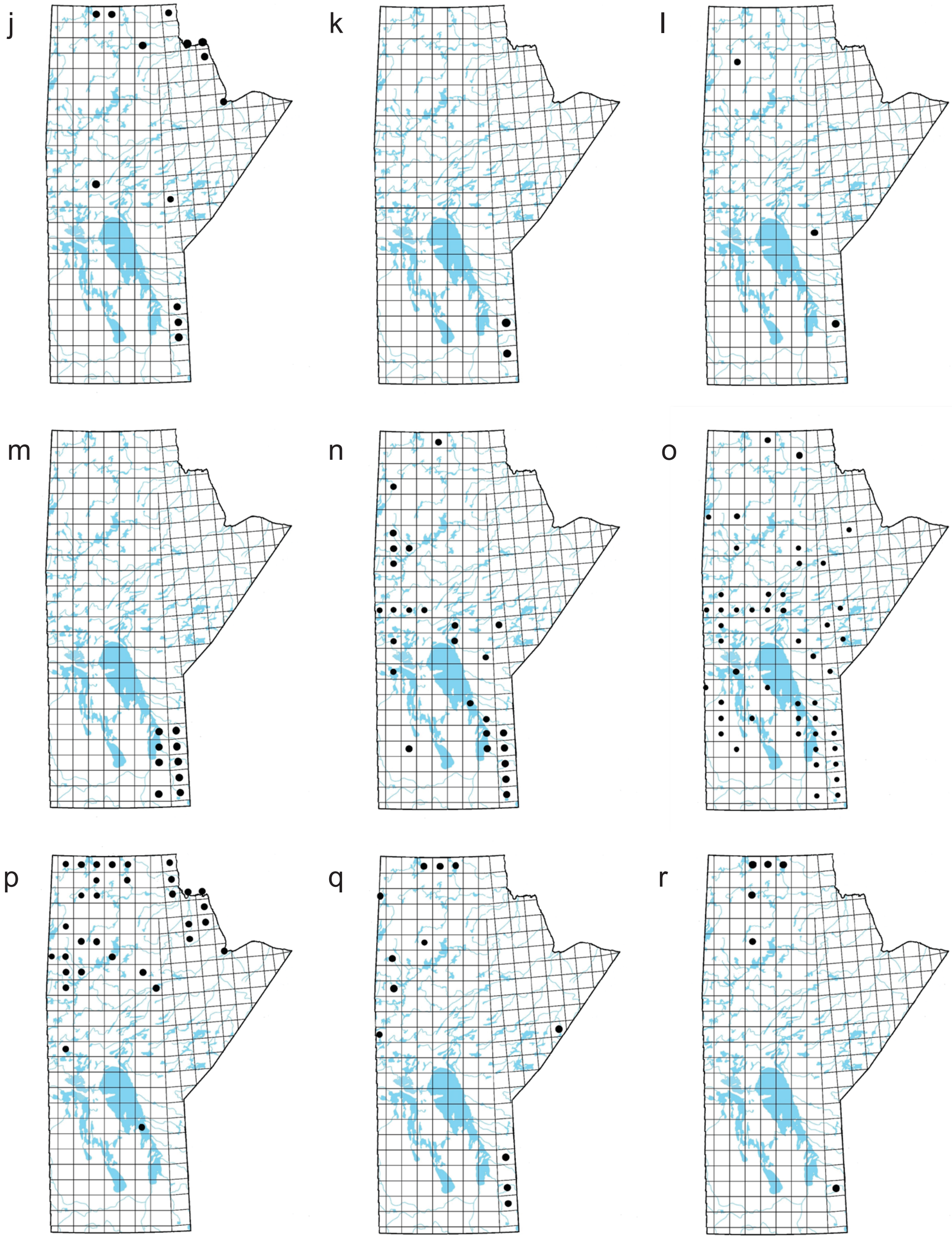

FIGURE 3. *Continued.*

of Courage Lake, near Nunavut border 59.99°N: 98.38°W, regenerating post-burn spruce forest, *R. Staniforth 00895* (RS).

Diphasiastrum tristachyum (Pursh) Holub (syn. *Lycopodium tristachyum* Pursh). Blue Ground-cedar, lycopode à trois épis. Locally on dry sand hills and rock outcrops in southeast to mid-west MB (Figure 3f). Rare and S3. Number of specimens seen: 10 (Table 1). Northernmost MB record: Grass River Provincial Park, 54.642°N, 100.804°W, rock island in Iskwasum Lake, on thin organic layer with Jack Pine (*Pinus banksiana* Lambert)–White Spruce, 26 July 2008, *R.J. Staniforth 00386* (RS).

Diphasiastrum ×zeilleri (*Lycopodium zeilleri* (Rouy)

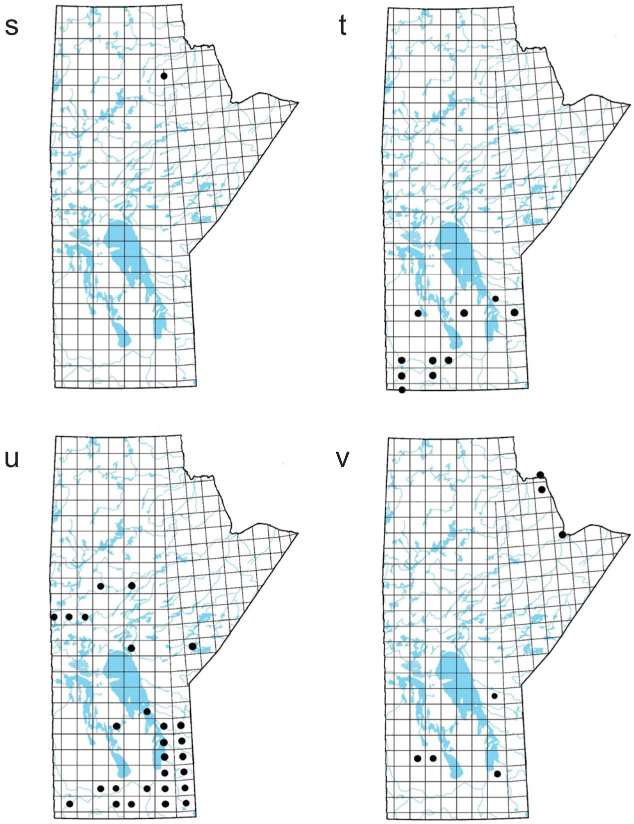

FIGURE 3. *Continued.*

Victorin; *D. complanatum* × *D. tristachyum*). Zeiller's Ground-cedar, lycopode de Zeiller (Figure 2b). Moist mixed and coniferous forests, especially in southeast MB, rarer northwards (Figure 3g). Common. Unranked. Number of specimens seen: 80 (Table 1). This hybrid appears to be self-sustaining in numerous populations in southeast MB (R.J.S. pers. obs.). As is typical of hybrids, the plants have a mixture of morphological features of each putative parent species. The most obvious difference between *D. ×zeilleri* and *D. complanatum* is the deeply buried rhizome found in the former versus the superficial rhizomes in the latter. *Diphasiastrum ×zeilleri* has also been reported in nearby northwestern Minnesota (Chayka and Dziuk 2020) and adjacent northwestern Ontario (D.F.B. pers. obs.). Northernmost MB record: Hwy 391 about 10 km north of Leaf Rapids, 56.518°N, 99.976°W, at edge of conifer-lichen woodland on sand substrate with thin organic layer, 14 July 2011, *R.J. Staniforth 00711* (RS).

Huperzia, firmosses (Figure 2d)

All members of the genus *Huperzia* are scarce in MB. Plants in the Northern Firmoss (*Huperzia selago* (L.) Bernhardi) complex can be difficult to identify in the field and often require microscopic study of their gemmae (Gilman and Testo 2015). Gemmae in firmosses are modified buds (actually, six-leaved plantlets) that separate from parent plants and may develop into new individuals. Their formation in firmosses is unique among the clubmosses (Haines 2003).

**Huperzia continentalis* (syn. *Huperzia selago* (L.) Bernhardi, *p.p.* [*pro parte*, in part]; *Huperzia appressa auct. non* [*auctorum non*, not as the original authors] (Desvaux) Löve & Löve), Continental Firmoss, lycopode du continent (Figure 2d). Tundra heath in northern MB (Figure 3h). Very rare and S1. Known from one specimen (Table S1). All *Huperzia* specimens in RS were critically examined by W. Testo in August 2015 but those from other herbaria need to be critically examined to clarify the range of *Huperzia* species in northern MB. Plants of this recently recognized taxon

(Testo *et al.* 2016) have perhaps been misinterpreted in the field in MB as representing *H. selago* (*s.l.*). Northernmost MB record: north of Courage Lake, 59.995°N, 98.387°W, open lichen tundra in damp depressions on moist organic substrate, 17 July 2014, *R.J. Staniforth 00889* (RS).

Huperzia lucidula (Michaux) Trevisan (syn. *Lycopodium lucidulum* Michaux). Shining Firmoss, lycopode brilliant. Dry outcrops in northern MB (Figure 3i). Very rare. Not ranked. Known from three specimens (Table 1; see also Staniforth 2022). Two records from Riding Mountain National Park, 50.680°N, 99.560°W (*J.C. Ritchie 3325*, DAO337594; *Walker 213*, WIN) and one from Gunisao Lake. Northernmost MB record: Gunisao Lake, near lodge, 53.521°N, 96.371°W, granite outcrop, with Jack Pine, spruce, birch forest, shady, moist peat, 24 June 2013, *R.J. Staniforth 00849* (RS) confirmed by W. Testo (August 2015).

Huperzia selago (L.) Bernhardi (*s.s.*) (syn. *Lycopodium selago* L., *p.p.*). Northern Firmoss, lycopode sélagine. Damp, shady non-calcareous outcrops and boulders in eastern MB, and on damp sedge tundra in northern MB (Figure 3j). Rare and S2. Number of specimens seen: 30 (Table 1). Northernmost MB record: Baralzon Lake, 60.000°N, 98.167°W, hummocky sedge-heath tundra, 10 July 1950, *H.J. Scoggan 8214* (WIN4718).

Huperzia ×buttersii (Abbe) Kartez and Gandhi (*H. lucidula* × *H. selago*). Butters' Firmoss, lycopode de Butters. Mixed and coniferous forests, on non-calcareous outcrops and boulders in southeast MB (Figure 3k). Very rare. Unranked hybrid. Known from three specimens (Table 1). Northernmost MB record: Quesnel (Caribou) Lake, 50.917°N, 95.650°W, rock outcrop with mosses and lichens, 4 August 1974, *G.M. Keleher 74-242* (WIN 28636).

Lycopodiella, bog clubmosses (Figure 2e)

Bog clubmosses are small inconspicuous plants of wet open sites usually within boreal forests. They grow close to the substrate; their strobili are upright and leafy.

Lycopodiella inundata (L.) Holub (syn. *Lycopodium inundatum* L.). Northern Bog Clubmoss, lycopode inondé (Figure 2e). Disturbed, wet, boggy sites in the boreal forest in north and central MB (Figure 3l). Very rare and S1. Known from five specimens (Table 1). Northernmost MB record: Singleton Lake, 58.333°N, 100.079°W, peaty substrate between cobbles, just above the waterline with *Sphagnum*, *Drosera*, and *Juncus*, 6 July 1996, *E. Punter 96-627* (WIN76000).

Lycopodium, clubmosses (Figure 2f)

Both clubmoss species in MB were formerly considered within *Lycopodium clavatum* L. (*s.l.*). They can usually be distinguished by the number of strobili per peduncle and by leaf characteristics. In the few colonies of *L. clavatum* (*s.s.*) in MB that consistently possess single strobili instead of two or more (R.J.S. pers obs.), leaf arrangement, size, and shape facilitate identification.

Lycopodium clavatum L. Running Clubmoss, lycopode claviforme. Mixed and conifer forests in southeastern MB (Figure 3m). Uncommon and S3. Number of specimens seen: 58 (Table 1). Northernmost MB record: Aikens Lake, 35 km northeast of Bissett, 51.201°N, 95.309°W, mixed forest, birch, Trembling Aspen (*Populus tremuloides* Michaux), White Spruce, on sandy loam, 1 June 2012, *R.J. Staniforth 00816* (RS). Westernmost MB record: Manitoba Model Forest, Grindstone Provincial Park, 51.165°N, 96.833°W, Black Spruce (*Picea mariana* (Miller) Britton, Sterns, and Poggenburg) site, 25 July 1994, *W.S. Morgan 94-143* (WIN56750).

Lycopodium lagopus (Laestadius) Zinserling (syn. *Lycopodium clavatum* var. *megastachyon* Fernald; *Lycopodium clavatum* var. *monostachyon* (Hooker and Greville)). One-cone Clubmoss, lycopode patte-de-lapin (Figure 2f). Boreal forest, often close to non-calcareous outcrops and boulders, in a wide band from southeastern to northwestern MB (Figure 3n). In northern MB, it can be found in open sites on the sides and tops of sandy eskers. Uncommon and S3. Number of specimens seen: 73 (Table 1). Northernmost MB record: south of Courage Lake, 59.929°N, 98.353°W, slope between eskers (under) Black Spruce and birch, on moist sandy gravel in shade, 17 July 2014, *R.J. Staniforth 00890* (RS, WIN).

Spinulum, interrupted clubmosses (Figure 2g)

The genus *Spinulum* is the most recent segregate of the former genus *Lycopodium* (Haines 2003) and is represented in MB by two species. At Courage Lake in northern MB in July 2014, plants of both taxa were found growing within 150 m of each other while maintaining their distinct identities (R.J.S. pers. obs.).

Spinulum annotinum (L.) Haines (syn. *Lycopodium annotinum* L., *p.p.*; *Spinulum annotinum* ssp. *alpestre* (Hartman) Uotila). Interrupted Clubmoss, lycopode innovant (Figure 2g). Moist, mixed and coniferous woodlands on organic substrates. The commonest lycophyte in MB. It is found throughout MB except for the agricultural south but is rare in the extreme north (Figure 3o) where it is largely replaced by *Spinulum canadense* (next species). Very common and S4. Number of specimens seen: 192 (Table 1). Northernmost MB record: south of Courage Lake, 59.929°N, 98.353°W, base of esker, under spruce and bushes on moist, well-drained gravel, 17 July 2014, *R.J. Staniforth 00891* (RS).

Spinulum canadense (Nessel) Haines (syn. *Lycopodium annotinum* variety *pungens* (La Pylae) Desvaux). Northern Interrupted Clubmoss, lycopode innovant boreal. Forest-tundra, tundra, and barrens. Throughout the northern half of MB (Figure 3p). Uncommon. Not ranked. Number of specimens seen: 58 (Table 1). Northernmost MB record: Baralzon Lake, 60.000°N, 98.100°W, hummocky sedge tundra, 29 July 1950, *H.J. Scoggan 8217* (WIN4663). Southernmost MB record: Rice River Road, between Princess Harbour and Berens River, 52.131°N, 96.831°W, 18 June 2018, *R.J. Staniforth 01380* (RS).

Isoetaceae, Quillworts

Isoetes, quillworts (Figure 2h)

In MB, the two species of quillworts and their hybrid are aquatic or emergent plants. They resemble tufted graminoid plants but grow submerged in a few centimetres to several metres of water in clear freshwater ponds, lakes, and slow rivers. Their quill-like leaves are made buoyant by large air chambers. Their deciduous nature floats them into the flotsam lines of beaches in late summer and gives an indication of the local presence of deep-water populations. Like spikemosses, quillworts are heterosporous, i.e., they produce both megaspores and microspores. The size and (especially) sculpturing on the megaspores constitute key identification characters for *Isoetes* identification.

Isoetes echinospora Durieu. Spiny-spored Quillwort, isoète à spores épineuses (Figure 2h). A submerged or emergent species of acidic substrate in shallow ponds, lakes, and slow-moving rivers in the boreal region of MB. Rare and S3, although undoubtedly overlooked (Figure 3q). Number of specimens seen: 20 (Table 1). Northernmost MB record: north shore of Courage Lake, 59.990°N, 98.380°W, sandy beach, shallow lake, washed up, 15 July 2014, *R.J. Staniforth 00894* (RS).

Isoetes macrospora Durieu (syn. *Isoetes lacustris auct. non* L.). Large-spored Quillwort, isoète lacustre. A submerged species of acidic substrate in lakes in the boreal forest region of Manitoba (Figure 3r). Very rare and S2; possibly disjunct from a predominately eastern range (Brunton and Britton 1991; Grigoryan *et al.* 2020). Known from six specimens (Table 1). Northernmost MB record: Baralzon Lake, 60.000°N, 98.167°W, shallow water, 30 July 1980, *H.J. Scoggan 8241* (WIN4774).

Isoetes ×hickeyi Taylor and Luebke. Hickey's Hybrid Quillwort, isoète de Hickey. Submerged aquatic in mixed *I. echinospora* and *I. macrospora* population in the Boreal region of MB (Figure 3s). Known currently only from Seal River, west of Great Island. 58.00°N, 96.00°W, 8 July 1956 (Britton and Brunton 1991). Very rare. Unranked hybrid. Two specimens reported (Table 1), suggesting that sterile hybrids are (were) well represented in this population.

Selaginellaceae, spikemosses

Selaginella, spikemoss (Figure 2i)

There are three species of spikemosses in MB, all small, creeping moss-like plants, covered by densely overlapping, tiny leaves. Their upright strobili possess megasporangia and microsporangia in the leaf axils.

Selaginella densa Rydberg (syn. *Selaginella rupestris* var. *densa* (Rydberg) Clute). Prairie Spikemoss, sélaginelle dense. Prairie grassland in southwest MB, in an alvar region in the Interlake, and rare east of Lake Winnipeg on boreal outcrops (Figure 3t), although considered uncommon in adjacent Ontario in Woodland Caribou Park (D.F.B. pers. obs.). Rare. Not ranked. Number of specimens seen: 18 (Table 1). Northernmost MB record: Brokenpipe Lake, 51.283°N, 100.367°W, glacial beach, 5 August 1983, *J.L. Parker 83-11* (MMMN39455).

Selaginella rupestris (L.) Spring (syn. *Lycopodium rupestre* L.). Rock Spikemoss, sélaginelle des rochers (Figure 2i). Non-calcareous outcrops, sandy road edges and dry grassy fields in the lower two thirds of MB (Figure 3u). Common and S4. Number of specimens seen: 93 (Table 1). Northernmost MB record: Hwy 391, about 12 km west of Notigi, 55.833°N, 99.484°W, rock outcrop with Jack Pine, 15 July 2011, *R.J. Staniforth 00717* (RS).

Selaginella selaginoides (L.) Beauvois (syn. *Lycopodium selaginoides* L.). Northern Spikemoss, sélaginelle fausse-sélagine. Wet, mossy stream banks and calcareous fens in the Hudson Bay lowlands, but also in southern MB (Figure 3v). Very rare and S3. Known from eight specimens (Table 1). Northernmost MB record: Churchill area, Spaceport Project, 58.44°N, 93.47°W, streambank through White Spruce forest, 28 July 1994, *G.M. Keleher & E. Punter 94/82* (WIN57178).

Key to Lycophytes of Manitoba

The following key includes all lycophyte taxa confirmed from MB. It is based on the keys in Staniforth (2012) as modified by subsequent literature (e.g., Gilman and Testo 2015; Testo *et al.* 2016; Palmer 2018; Grigoryan *et al.* 2020) and personal experience of D.F.B. Each taxon is individually addressed in the Annotated Checklist (above).

1. Terrestrial, creeping; with above-ground or subterranean rhizomes (horizontal stems); upright shoots covered by numerous small, evergreen leaves **4**
– Submerged aquatic; globose corm topped by a crown of long, quill-like leaves .... (Isoetaceae) **2**

2. Individuals larger than typical plants of the population; megaspores polymorphic, often lens-shaped (aborted); densely congested ornamentation pattern includes both spines and muri (ridges) .... ***Isoetes ×hickeyi***
– Plants uniform in size within the population; megaspores uniformly globose (viable); ornamentation either exclusively echinate or with muri **3**

3. Leaves light green; moderately to strongly reflexed; megaspores small (450–525 µm), ornamentation uniformly, densely echinate (spiny); no equatorial band .... ***Isoetes echinospora***
– Leaves dark green to green-brown; straight to slightly recurved; megaspores large (650–800 µm), broken reticulate pattern ornamentation of thin-walled muri; prominent equatorial band of densely distributed papillae (minute tubercles) .... ***Isoetes macrospora***

4. Sporangia in the axils of specialized leaves (sporophylls) clustered into strobili (cones) at shoot summit; no gemmae (vegetative buds) **5**
– Sporangia in the axils of ordinary stem leaves and not arranged in strobili; gemmae conspicuous on shoots .... (*Huperzia*) **17**

5. Plants tall (>4 cm), resemble large moss plants or miniature coniferous trees; strobili cylindrical, megaspores small (<100 µm) **6**
– Plants short (<4 cm), resemble small (often matted) moss plants; strobili typically four-sided, megaspores large (>300 µm) .... (Selaginellaceae) **20**

6. Plants annual, small; stem prostrate and creeping; strobili "bushy" with green leaves; spores rugulate .... ***Lycopodiella inundata***
– Plants perennial, robust; sprawling or erect; stem upright or low arching, strobili narrow with appressed scales, on thin, erect stems; spores reticulate **7**

7. Leafy shoots (branches) narrow (2–6 mm), flat; leaves 4–5 ranked along stem .... (*Diphasiastrum*) **8**
– Leafy shoots wide (5–12 mm), round; leaves many-ranked along stem **11**

8. Horizontal stems on or near soil surface (often hidden under litter); peduncles with 1–2 strobili **9**
– Horizontal stems deeply buried in soil; peduncles with 2–4 strobili **10**

9. Solitary strobilus sessile; abaxial (underside) leaves arched, trowel-shaped, slightly shorter than other branch leaves .... ***Diphasiastrum alpinum***
– 1–2 strobili peduncled; abaxial leaves appressed, narrowly deltoid, much shorter than other branch leaves .... ***Diaphasiastrum complanatum***

10. Plants short (<10 cm); strobili sessile or stalked <1 cm; leaves divergent, ascending, separate or partially overlapping .... ***Diphasiastrum sitchense***
– Plants short (10–15 cm tall); strobili long stalked (2–10 cm); leaves strongly appressed, overlapping ... **11**

11. Branches narrow (<2 mm), round to square in cross-section; strongly ascending ("popped-umbrella" form); leaves glaucous blue-green colour .... ***Diphasiastrum tristachyum***
– Branches wide (>2 mm), flat; sprawling arrangement; leaves glossy dark-green colour .... ***Diphasiastrum ×zeilleri***

12. Strobili long stalked; leaves densely arranged about stem in groups of 6–10, softly hair-tipped (not prickly) .... (*Lycopodium*) **13**
– Strobili sessile; leaves loosely arranged about stem in groups of 3–5, acute to spine-tipped (prickly) **14**

13. Peduncles typically with solitary strobilus; stems sparsely branched, ascending to erect; leaves 3–5 mm long, appressed .... ***Lycopodium lagopus***

– Peduncles typically with 1–5 strobili; stems frequently branched, sprawling; leaves 4–6 mm long, divergent .... ***Lycopodium clavatum***

14. Leaves about the stem in groupings of 4–5; leafy rhizome superficial .... (*Spinulum*) **15**
– Leaves about the stem in groupings of 3; naked rhizome subterranean .... (*Dendrolycopodium*) **16**

15. Strobili 1.5–4.5 cm long; leaves toothed, 5–10 mm long; those immediately above annual constriction widest at or near mid-length .... ***Spinulum annotinum***
– Strobili <1.7 cm long; leaves entire, 3–6 mm long; those immediately above annual constriction widest at or near base .... ***Spinulum canadense***

16. Leaves along stem strongly appressed (stem smooth); single rank (row) of leaves on abaxial side of branches .... ***Dendrolycopodium hickeyi***
– Leaves along stem strongly divergent (stem prickly); double rank (rows) of leaves on abaxial side of branches .... ***Dendrolycopodium dendroideum***

17. Leaves wide (1.5–2.0 mm), toothed, parallel-sided or widest above middle, dark green; always shiny; annual constrictions on stem conspicuous **18**
– Leaves narrow (1.0–1.25 mm) entire, widest near base; yellow-green to green; dull to somewhat shiny; annual constrictions on stem inconspicuous **19**

18. Leaves coarsely toothed, widest above middle; spore regular in shape (viable) .... ***Huperzia lucidula***
– Leaves entire or with few teeth, parallel sided; spores misshaped (aborted) .... ***Huperzia ×buttersii***

19. Gemmae arranged in single whorl at apex of annual growth segment .... ***Huperzia selago***
– Gemmae scattered along stem or arranged in several whorls at apex of annual growth segment .... ***Huperzia continentalis***

20. Delicate, mat-forming; leaves divergent, flat, narrow, acute-tipped and with numerous coarse marginal cilia .... ***Selaginella selaginoides***
– Dense tufted clumps; leaves strongly appressed, oblong, bristle-tipped, with few fine marginal cilia **21**

21. Leaf tip bristles 1.25–2.0 mm long; dense clumps appearing “frosty”; upper leaves longer than lower .... ***Selaginella densa***
– Leaf tip bristles 0.5–1.0 mm long, loosely arranged to dense clumps green; upper and lower leaves approximately equal in length .... ***Selaginella rupestris***

Discussion

We update and expand on the earlier synopsis of MB lycophytes presented by Staniforth (2012) and report new taxa and provide more precise information about their taxonomy, distribution, abundance, and habitats. Nineteen species and three hybrids of lycophytes are now documented for the province. This is a substantial increase over previous published reports: eight species in Scoggan (1957), 13 species in Punter (1995), and 18 taxa in Staniforth (2012). The circumscriptions of the three lycophyte families have remained unchanged in recent years, although the firmosses have increasingly been treated (e.g., Haines 2003) as a distinct family (Huperziaceae). However, we retain them within Lycopodiaceae for consistency purposes. We also make two exceptions from the scientific nomenclature employed in Brouillet *et al.* (2010+). Following Haines (2003), we treat *S. annotinum* ssp. *alpestre* as *S. canadensis*, and following Grigoryan *et al.* (2020), we treat the North American *I. macrospora* as distinct from *I. lacustris* of Europe.

Most MB lycophytes have North American northern pan-boreal distributions (Cody and Britton 1989). Exceptions to this are *D. tristachyum*, which is primarily eastern boreal (Cody and Britton 1989), *I. macrospora*, which is primarily eastern and central boreal (Britton and Brunton1991), and *S. densa*, which is primarily Great Plains in distribution (Valdespino 1993).

Several MB lycophyte taxa have their most northern, southern, and, in some cases, northwestern continental boundaries within the province. Knowledge of the status and trends of such edge populations is important as changes may reflect large-scale, long-term variations in climate and other environmental factors (Maslovat *et al.* 2021). The tradition of reporting “Northernmost collection” in MB was started by Scoggan (1957), but at that time he probably did not fully appreciate the value of extreme geographic records for informing on potential environmental change. Between 1950 and 1999, the northernmost MB collections for *D. complanatum*, *H. selago*, *S. canadense*, and *I. macrospora* were all from Baralzon Lake (60°00′N) or Nueltin Lake (59˚49′N). Since 2000, additional collections of these species have been made from similar latitudes, indicating their continued persistence in the far north. In 2011, *S. rupestris* was collected over 300 km further to the northwest from its previously known range limit, as identified by Scoggan (1957). In such a sparsely investigated area of the province, however, this range extension more likely reflects a gap in distributional knowledge than a dramatic, short-term phytogeographic change.

Three taxa, *D. tristachyum*, *D. ×zeilleri*, and *S. densa,* have ranges that reach north to mid-Manitoba, while *S. canadensis* is at its known southern boundary in that region. Similarly, both *L. clavatum* and *H. ×buttersii* reach their most northerly known continental limits in southeast MB (see Annotated Checklist). Documenting changes to their ranges could be valuable for evaluating if environmental changes are occurring within the respective habitats of these taxa.

Taxa not recorded from MB but with potential to be found in the province occur in the adjacent provinces (i.e. Saskatchewan and northwest Ontario; Harms and Leighton 2011; Oldham and Brinker 2009, respectively), Nunavut Territory, and the north central United States (i.e., North Dakota, northern Minnesota, or northwest Wisconsin; Chadde 2013; Wagner and Beitel 1993; Palmer 2018, respectively). These include Flat-branched Tree-clubmoss (*Dendrolycopodium obscurum* (L.) Haines (*s.s.*)), Southern Ground-cedar (*Dendrolycopodium digitatum* (Dillenius) Holub), Haberer's Ground-cedar (*Dendrolycopodium ×habereri* (House) Holub), Mountain Firmoss (*Huperzia appressa* (Desvaux) Löve and Löve), and Rock Firmoss (*Huperzia porophila* (Lloyd and Underwood) Holub).

No lycophytes are currently listed under MB's *Endangered Species and Ecosystems Act* (C. Friesen pers. comm. 2021). However, some taxa are documented as regionally rare (Table 1). Thirteen species are formally designated as having NatureServe S1, S2, or S3 ranks while *H. lucidula, S. canadense*, and *S. densa* remained unranked. Based on the findings of our study, the S3 status ranks for *S. selaginoides* underestimates the rarity of that species in MB; conversely the designated S3 rank overestimates the rarity of *D. complanatum, L. lagopus*, and *L. clavatum* (see Annotated Checklist). Accordingly, the S3 ranks of these taxa warrant review. Unranked hybrids *D. ×zeilleri*, *H. ×buttersii*, and *I. ×hickeyi* are noted in Table 1 with a dash.

In 2012, the Manitoba Association of Plant Biologists, the Manitoba Conservation Data Centre, and the Nature Conservancy of Canada developed a plan to identify and map sites of alvars and their plant communities (Neufeld *et al*. 2018). That areal protection initiative indirectly resulted in protection for rare pteridophytes Gastony's Cliffbrake (*Pellaea gastonyi* Windham) and Western Cliffbrake (*P. occidentalis* (Nelson) Rydberg) along with a population of S3 lycophyte *S. densa* (Friesen and Murray 2015). This is an example of how protection of ecosystems can be successful in protecting "non-target" rare species as well. Such incidental protection may also be effective for conservation of *S. selaginoides* (S2) populations near Churchill and York Factory (Table 1). Other rare species, such as *D. alpinum*, *H. continentalis*, and *I. macrospora,* may be secure from at least direct physical impact by their remote locations in extreme northern Manitoba.

Complicating conservation management for *L. inundata* is the possibility that it might be ruderal in Manitoba (R.J.S. pers obs.). Similarly, it is difficult to conceive site protection measures for certain *Huperzia* taxa which appear to be short-lived in their locations (see Annotated Checklist).

Most species of MB lycophytes inhabit various terrestrial and aquatic ecozones within the boreal forest. The variety of plant communities found in the boreal forest in Boreal Shield, Boreal Plain, Hudson Plain, Taiga Shield, and Southern Arctic ecozones (Manitoba's Protected Areas Initiative 2013) provides a diversity of suitable lycophyte habitats. Within these broad ecozones (Figure 1), plant communities range from the tundra–forest transition in the far north to the deciduous–coniferous forest transition in mid- and southeast MB. There are also wide differences within each plant community in terms of moisture, edaphic, and geologic regimes. This ecological variation allows for heterogeneous plant associations, thus expanding the potential diversity of lycophyte representation. Manitoba Provincial Parks and Provincial Forests provide an important diversity of habitats for most of MB's lycophytes, excluding species from the far north or those that are extremely rare.

Author Contributions

Tragically, R.J.S. died as the manuscript was in an advanced stage of review. In January 2022, D.F.B., a reviewer of the original manuscript, was invited by Diana Staniforth to see the manuscript through to completion and was honoured to do so.

Conceptualization: R.J.S.; Data Curation: R.J.S.; Methodology: R.J.S.; Data Analysis: R.J.S.; Investigation: R.J.S.; Writing – Original Draft: R.J.S.; Writing – Key: D.F.B.; Writing – Review & Editing: R.J.S and D.F.B.

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SUPPLEMENTARY MATERIALS:

TABLE S1. Records of examined lycophyte vouchers found in Manitoba, Canada.

TABLE S2. Locations of remote lycophyte collection sites, Manitoba, Canada, 2010–2014.

The Canadian Field-Naturalist

Evidence of successful hatching by introduced Red-eared Slider (*Trachemys scripta elegans*) in British Columbia, Canada

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Abstract

Globally, competition and disease from introduced Red-eared Slider (*Trachemys scripta elegans*) is a threat to co-existing native turtles. Red-eared Slider has been introduced throughout south coastal British Columbia (BC), mainly as pet turtle releases. Urban centres receive the most individuals, particularly in the Lower Mainland area outlying Vancouver, on southern Vancouver Island, and on the Sunshine Coast. The range of Red-eared Sliders in BC overlaps that of the Threatened Pacific Coast population of Western Painted Turtle (*Chrysemys picta bellii*). Herein we report on a survey for both species, noting presence, assessed population sizes, and nesting activity. Across 19 sites in the south coast occupied by both turtle species, we found the median abundance of Red-eared Sliders to be 2.5 times larger than that of Western Painted Turtles (Mann–Whitney $U = 104$, $n_1 = n_2 = 19$, Z-Score = −2.2188, $P = 0.02642$, two-tailed). There had been no evidence of Red-eared Sliders successfully hatching in the wild in BC until our study. We observed complete development, with 19 neonates from three different nesting sites between 2015 and 2017. Thus, Red-eared Slider is indeed established and able to breed in BC and thus competition and disease introduction from the species likely contributes to the decline of the Pacific Coast population of Western Painted Turtle, particularly at sites with low painted turtle numbers. The scale and mechanisms of impact requires further investigation.

Key words: Red-eared Slider; Western Painted Turtle; invasive species; reproduction; population status; northern climates; British Columbia

Introduction

Red-eared Slider (*Trachemys scripta elegans*) is a widely introduced turtle species that negatively impacts native turtles and ecosystems globally but may not necessarily be able to reproduce and spread in northern climates (Ficetola *et al.* 2009). Originally from the Mississippi Valley, USA and Caribbean basin, Red-eared Slider is an aquatic emydid turtle that occupies a variety of lentic habitats. Because of human activity, they now occur on every continent except for Antarctica, making this species the world's most widespread freshwater turtle (Ernst and Lovich 2009).

The International Union for the Conservation of Nature's (IUCN) Invasive Species Specialist Group has assigned Red-eared Sliders a Vertebrate Pest Category rating of Extreme in Australia, where a risk assessment has been conducted (GISD 2018) and has categorized it as one of the world's 100 worst invasive species (Lowe *et al.* 2000). Although introductions of various other emydid turtle species have occurred Canada-wide, Red-eared Sliders are now the most widespread non-native turtle in Canada and the most abundant non-native turtle in British Columbia (BC; Bury and Matsuda 2012).

Like many other introduced species, Red-eared Sliders commonly are associated with human-modified habitats and urban centres, attributable to the more frequent release of pet store turtles into these ecosystems (Bury 2008; Lambert *et al.* 2013). Red-eared Sliders tend to thrive in urban and human-modified habitats due to the species' generalist nature with respect to diet, habitat, and the availability of food in urban waterbodies (Ferronato *et al.* 2009; Thomson *et al.* 2010). This success in urban environments also may be attributed to the species' ability to tolerate

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high levels of radioactive, thermal, chemical, and organic pollution (Gibbons 1990).

Globally within its introduced range, Red-eared Slider is considered invasive only in regions where it is capable of repeated, successful reproduction (Ficetola *et al.* 2009; Thomson *et al.* 2010). For example, introduced Red-eared Sliders reproduce readily in warmer Mediterranean climates where they have been introduced. At higher latitudes, successful embryo development and hatchling survival are limited by temperature and moisture (Ficetola *et al.* 2009). Red-eared Slider reproduction has been observed throughout Europe in both Mediterranean and more continental climates (Lever 2003; Cadi *et al.* 2004; Çiçek and Ayaz 2015; Dordević and Andelković 2015), in California (Spinks *et al.* 2003; Thomson *et al.* 2010), and also in southern Ontario where full details on successful reproduction are being compiled into a manuscript (S. Gillingwater pers. comm. 23 February 2021). A recently emerged hatchling also was reported from Vancouver Island, BC (C. Miller Retzer pers. comm. 6 October 2020).

In their native range, Red-eared Slider nest May through July, laying 1–30 eggs per clutch and commonly two or sometimes three clutches per season (Tucker 1997). They require 60–80 days to hatch in native conditions, but in colder summers incubation can exceed 100 days; hatchlings overwinter in the nest in some areas (Tucker 1997; Ultsch 2006; Costanzo *et al.* 2008), although most hatchlings emerge in autumn (Ernst and Lovich 2009). Unfavourable climate restricts embryo development and hatchling overwintering survival (Packard *et al.* 1997; Tucker and Packard 1998; Kleewein 2015). At the northern limit of its native range in Illinois, Red-eared Sliders do not extend beyond areas where the ground frequently freezes to a depth of 12 cm (Ernst and Lovich 2009). Minimum temperature for complete embryo development is 21°C (viability minimum) with an optimal minimum of 25°C (Greenbaum 2002). Further, this species exhibits a temperature-dependent sex ratio with eggs incubated at temperatures below 27°C producing only males, while those incubated above 30°C produce only females (Ernst and Lovich 2009). Temperature-dependent sex ratios may limit population growth and spread in their introduced range where temperatures do not reach minima needed for successful development (Cadi *et al.* 2004).

In Europe, where Red-eared Sliders occupy the same wetland as native European Pond Turtle (*Emys orbicularis*), the introduced turtle outcompetes the native species for basking space (Cadi and Joly 2003; Lambert *et al.* 2013). Cadi and Joly (2004) also found that in sites of mixed species, European Pond Turtles showed higher mortality rates and increased weight loss compared to Red-eared Sliders. In the upper Midwest of the United States north of the confluence of the Ohio and Mississippi Rivers where other subspecies of painted turtles occur with Red-eared Sliders and the sliders are native, painted turtles are almost always less abundant than the sliders (Dreslik and Phillips 2005). Disease transmission also is a concern, and this may be the most significant impact of introduced Red-eared Slider on native turtles (Hays *et al.* 1999; Thomson *et al.* 2010).

It has been assumed that Red-eared Sliders do not reproduce successfully in BC water bodies based on numerous incidental field observations from local biologists and naturalists who have found stalled embryo development upon excavating nests. Therefore, it was presumed that populations were being sustained without reproduction through ongoing pet turtle releases (P. Govindarajulu and K. Welstead pers. comm. 4 July 2012). However, in the warmest summers of south coastal BC where the climate is mild, current environmental conditions could allow for successful reproduction in some localities. Further, with predicted climate change, many regions will experience warmer temperatures and changes in precipitation levels that may allow introduced Red-eared Sliders to more readily reproduce. Here we report on the reproductive efforts of introduced Red-eared Sliders sympatric with native Western Painted Turtle (*Chrysemys picta bellii*) along the south coast of BC.

Methods

Study area

Our area of study included the Lower Mainland and Fraser River Valley (LM/FV; in the Greater Vancouver and Fraser Valley Regional Districts), the Sea-to-Sky area (Squamish/Whistler), and the Upper Sunshine Coast (Powell River area) between Saltery Bay and Lund, including Texada Island (collectively south coast north, SCN; Figure 1). Other than differences in geographical location and therefore slight longitudinal and possibly climatic differences, these regions differed with respect to human population density, land use, and the degree of human disturbance. The LM/FV is heavily populated in the Greater Vancouver area with decreasing population density moving east from Vancouver into the Fraser Valley where agriculture is the primary land use. The SCN has similar population density to the Fraser Valley areas but with minimal agriculture. All survey site information including waterbody name, region, global positioning system (GPS) location, and location and species of turtles observed were deposited with the BC Conservation Data Centre.

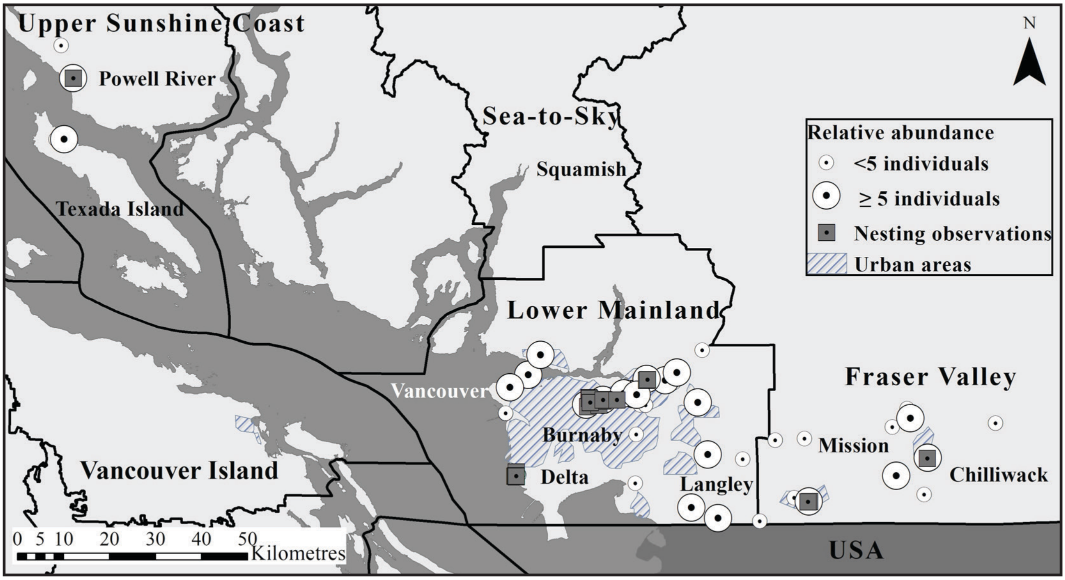

FIGURE 1. Distribution and relative abundance of Red-eared Slider (*Trachemys scripta elegans*) and their nests in south coastal British Columbia, 2008–2018.

Distribution and abundance of turtles

We conducted Western Painted Turtle and Red-eared Slider surveys at waterbodies with historical occurrence records and other waterbodies of unknown occupancy status that met the biophysical features and attributes of suitable turtle habitat. This habitat included lakes, ponds, marshes, river channels, sluggish streams, and sloughs with emergent or floating vegetation, vegetative mats, bottom substrates with organic material, submerged or emergent logs, large woody debris or rocks, and warm shallow water margins (ECCC 2018). Surveys were conducted in April–May and September–October, 2009–2018. We visually searched for basking turtles on logs, rocks, or shoreline areas using binoculars and/or a spotting scope. Because both emydid turtle species have similar ectothermic requirements and basking behaviour, we assumed that there was an equal likelihood of detecting either species if present (Peterman and Ryan 2009).

These surveys were conducted either by foot from vantage points along the shore or by kayak. Unless the presence of Western Painted Turtles was confirmed on the first visit, we attempted at least three surveys at each site deemed suitable over the course of the field season, following BC Ministry of Environment Resource Information Standards Committee (RISC) guidelines (MELP 1994). However, some sites were surveyed only once or twice if on an earlier visit the site was deemed unsuitable for turtles, if access was restricted, or the waterbody condition changed substantially between surveys. We attempted to conduct all surveys between 0900 and 1500 on warm sunny days of zero precipitation early in the breeding season (April and May) when turtles are likely to bask (MELP 1994). We generally avoided surveying on cloudy or rainy days or on hot days (>25°C) in the summer (mid-July through mid-August) when Western Painted Turtles in this region are rarely observed basking (see Lefevre and Brooks 1995; Semproni and Ogilvie 2007; Engelstoft and Ovaska 2008).

We summarized our detection data from the basking surveys as maximum abundance for each site using the maximum number of Red-eared Sliders and Western Painted Turtles observed on any one survey at a site through all survey years to avoid double counting individuals. For data analyses we grouped all sites into three regional categories: LM/FV sites were classified as either LM/FV urban (n = 17) or LM/FV rural (n = 19) depending on whether the site was located within a major city surrounded by residential or commercial infrastructure ("urban") or outside of city limits ("rural"); sites north of LM/FV (Squamish/Whistler, Upper Sunshine Coast, Texada Island; n = 6) were grouped into a third regional category: SCN. Using an online calculator (Social Science Statistics 2018) we performed two-tailed Mann-Whitney U-tests on the maximum abundance of both species with all regions combined where either one or both species were observed (n = 42 sites) and with all regions combined with sites where both species were detected (n = 19 sites). These tests were also conducted within each region where both species were detected with a sufficient sample size of sites ($n = 10$ for rural and $n = 7$ for urban). The tests determined if there was a difference in abundance of the two turtle species.

Red-eared Slider reproduction

Nesting surveys—We conducted nesting surveys for both Western Painted Turtles and Red-eared Sliders at sites where Western Painted Turtles were observed from our detection surveys between mid-May and mid-July, 2009–2018 in the LM/FV, on the Sunshine Coast, and on Texada Island, following a standardized protocol (Coastal Painted Turtle Working Group 2011). However, Red-eared Sliders often deposit eggs later in the summer (into August) compared to Western Painted Turtles (A.M.M. pers. obs. 2009) so we continued to respond to reports of nesting Red-eared Sliders to track nesting observations past the standard nesting monitoring season for Western Painted Turtles. We did all nesting surveys in the late afternoon and evening, as turtle nesting activity is known to peak around 1800 (Bowen *et al.* 2005). We searched suitable potential upland habitat for evidence of nesting activity, which is usually visible as test holes, depredated and emerged nest holes, and eggshell remains from predation (Engelstoft and Ovaska 2008). Potentially suitable nesting habitat consists of exposed, south-facing, sandy soil with little or no vegetation on flat or gentle slopes with limited understorey and canopy cover (Klemens 2000; Semlitsch and Bodie 2003; Marchand and Litvaitis 2004). Although nesting female painted turtles may travel up to 650 m from water to nest, we concentrated our searches within the first 150 m from the water's edge where most nesting activity occurs (Christens and Bider 1986).

During nesting surveys, we recorded data on the survey site (description and GPS coordinates, Universal Transverse Mercator [UTM] Zone 10U), date with start and end times, species of turtles observed, numbers of individuals, nesting substrate, distance of the nest from the water, and numbers of eggs deposited (for actual nesting attempts). Completed nests were marked with exact UTM positions and maps of the nesting sites were created using ArcGIS (ESRI, Redlands, California, USA) Desktop 10.3 to plot their precise location. We installed iButton temperature loggers (Embedded Data Systems, Lawrenceburg, Kentucky, USA) when possible, at nest sites from 2009 to 2013. We placed an iButton in a nylon cover and buried it at the level of the nest chamber (average 25 cm depth). Completed Red-eared Slider nests were protected with hardwire mesh exclosures to prevent predation and allow us to monitor hatching success and prevent escape.

Due to distance between occupied sites, time and labour constraints, lack of nesting evidence at many occupied sites, and access constraints, our nesting surveys and the sites annually monitored changed over time. By the summer of 2018, we had reduced our nesting surveys for Red-eared Sliders and Western Painted Turtles to three sites where we repeatedly saw nesting attempts. Besides summer monitoring, we checked known nests periodically throughout the year for signs of disturbance and predation. In both the fall and the spring, we monitored nests frequently for signs of emergence. We also responded to incidental reports from other biologists working in the region and public reports of Red-eared Sliders depositing eggs, although these nests could not always be located.

Embryonic development monitoring—To determine how quickly Red-eared Slider eggs develop in south coastal BC, we excavated and examined nests from a subsample of sites where dates for egg deposition were known. However, in other cases, eggs and fully developed hatchlings were found via excavation by Sandhill Crane (*Antigone canadensis*) or by incidental observations from previously undetected nests, where the egg deposition date was not known and the period of development could not be determined. All eggs were dissected and embryos preserved in ethanol.

For each embryo, we recorded egg condition, yolk condition (hardened yolks versus unhardened yolks to determine viability), and stage of development by comparing with descriptions and photos in Greenbaum (2002). To determine if there was an increase in the frequency of later developmental stages overtime, we first summarized the number of eggs classified in two developmental range categories: ≤ stage 21 and stage 22–26 (with stage 26 being completed development and hatched). We then calculated a 2×2 χ^2 statistic using two 5-year time periods: 2008–2012 and 2013–2017. Because successful reproduction seemed evident, any known Red-eared Slider nests deposited after 2017 were removed to reduce the likelihood of Red-eared Slider recruitment.

Results

Distribution and abundance of Red-eared Sliders

Red-eared Sliders were present in all regions of our study area, with sites in the LM/FV having higher abundances than in SCN (Figure 1). Median abundance of Red-eared Sliders and Western Painted Turtles were 4.5 and 1 per site, respectively, at the 42 sites (three regional categories combined: LM/FV urban, LM/FV rural, and SCN) where either or both turtle species were observed basking. Overall Red-eared Sliders were significantly more abundant in our study region than Western Painted Turtles ($U = 208.5$, $n_1 = n_2 = 42$, $Z = 3.38263$, $P < 0.001$).

When limited only to sites where both turtle species were observed ($n = 19$), a significantly higher abundance of Red-eared Sliders (median = 5) continued to be found (Western Painted Turtles: median = 2; $U = 104$, $n_1 = n_2 = 19$, $Z = –2.2188$, $P = 0.02642$; Figure 2). No significant difference was found in abundance of the two species in the LM/FV rural sites (median abundance of 5 and 2, Red-eared Slider and Western Painted Turtle, respectively; $U = 24$, $n_1 = n_2 = 10$, $Z = −1.92762$, $P = 0.0536$; Figure 2). Both species were observed at too few sites in the SCN region ($n = 2$) to test for differences in abundance (Figure 2). Significantly more Red-eared Sliders than Western Painted Turtles were found at the urban LM/FV sites that contained both species (median 16 and 3, respectively; $U = 8.5$, $n_1 = n_2 = 17$, $Z = −1.98052$, $P = 0.0477$; Figure 2). Thus, in south coastal BC, the majority of introduced turtles occupy urban sites in the Lower Mainland in close proximity to human populations, becoming scarcer with distance from urban centers (Figures 1 and 2).

Red-eared Slider reproduction

We documented 28 incidental nests in the LM/FV and SCN regions from 2008 to 2018 with 15 nests confirmed and their development tracked (Figure 1). Seven nests (of the 15) were intensively monitored because the egg deposition dates were known (Table 1). We found 93% (14/15) had some portion of eggs that were fertile (vascularized and/or with an embryo present) and 80% ($n = 12$) had eggs with embryos that developed to at least stage 21 of a maximum 26 (Greenbaum 2002). Of these 12 nests that reached a late stage of development, complete embryonic development and hatchling emergence occurred in 33% ($n = 4$ nests) between 2014 and 2017 at three different sites (Table 1).

Of all the eggs that we tracked for development (Table 1), 87% (113/130 eggs) were fertile (vascularized and/or with an embryo present) and of the fertile eggs, 74% (84/113) developed to at least stage 21 (Figure 3). From 2008 to 2012, the majority (75% or 18/24) of viable eggs developed only to a maximum of stage 21, five eggs advanced to stage 22–25, and only one egg had completed development (> stage 26). However, during 2013–2017 more than half the viable eggs (56% or 45/89) advanced to stage 22–25 or completed development (Table 1, Figures 3 and 4). In 2014, we first began to observe complete embryonic development and hatchling emergence, with the first record occurring at Reifel Migratory Bird Sanctuary with six healthy neonates (Table 1, Figure 4). Significantly more of the viable eggs developed to at least stage 22–26 in 2013–2017 than in 2008–2012 ($n = 113$, $\chi^2_1 = 4.98$, $P = 0.0255$).

We recorded hatchlings in nests annually into 2017 at three sites both in the LM/FV (Reifel Migratory Bird Sanctuary and Burnaby Lake), and in the SCN (Cranberry Lake in the Upper Sunshine Coast), for a total of 19 neonates observed between 2014 and 2017 (Table 1). Further, we observed juvenile Red-eared Sliders (>1 year after hatching until breeding age of 4–5 years for males and 8–10 years for

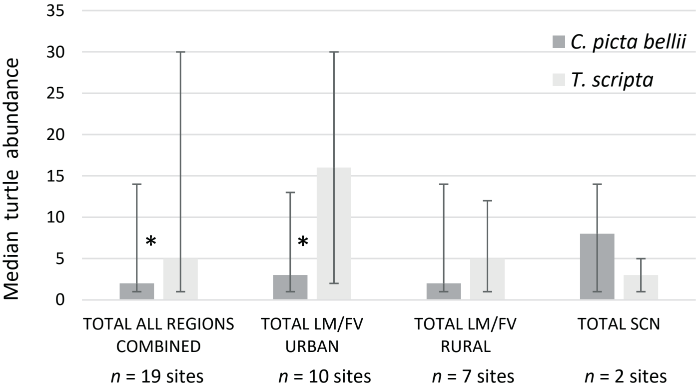

FIGURE 2. Median abundance (bars show maxima and minima) of Western Painted Turtle (*Chrysemys picta bellii*) and Red-eared Slider (*Trachemys scripta elegans*) observed basking at the same waterbody, south coastal British Columbia, 2009–2018. Regions were Lower Mainland/Fraser Valley (LM/FV) in the Greater Vancouver and Fraser Valley Regional Districts ('rural' sites outside of city limits and 'urban' sites within a major city surrounded by residential or commercial infrastructure), and South Coast North (SCN) in the Upper Sunshine Coast (Powell River area) between Saltery Bay and Lund, including Texada Island (see Figure 1). An asterix indicates a significant difference ($P < 0.05$) in abundance between the two turtle species (Mann-Whitney *U*-tests, see text).

TABLE 1. Red-eared Slider (*Trachemys scripta elegans*) nests and egg development in south coastal British Columbia, 2008–2018. N/A = not applicable; N/R = not recorded.

Site	Year	Annual nest number	Cumulative nest number	Date laid	Number of eggs	Number fertilized	Number of embryos	Developed to which embryonic stage* (x number of eggs)
Reifel Island Bird Sanctuary†	2008	1	1	04-Jun	Min. 1	Min. 1	Min. 1	21
Mill Lake	2012	N/A	N/A	N/A	N/A	N/A	N/A	Completed development - Juvenile
Burnaby Lake	2012	1	2	8-Jul	>2	N/R	N/R	N/R
Reifel Island Bird Sanctuary†	2012	2	3	23-May	9	9	3	23 (x3), <12 (x6)
Reifel Island Bird Sanctuary	2012	3	4	08-Jul	N/R	N/R	N/R	N/R
Reifel Island Bird Sanctuary†	2012	4	5	N/R	7	7	7	23 (x1), 22 (x1), 21 (x5)
Reifel Island Bird Sanctuary†	2012	5	6	N/R	6	6	0	<12 (x6)
Burnaby Lake	2012	6	7	12-Jul	>12	N/R	N/R	N/R
Lafarge Lake	2012	7	8	19-Jul	>1	N/R	N/R	N/R
Mill Lake	2012	8	9	16-Jul	N/R	N/R	N/R	N/R
Deer Lake	2012	9	10	N/R	N/R	N/R	N/R	N/R
Reifel Island Bird Sanctuary†	2013	1	11	12-May	10	5	1	22–23 (x1), <12 (x4)
Reifel Island Bird Sanctuary†	2013	2	12	25-May	8	5	2	19–20 (x2), <12 (x3)
Reifel Island Bird Sanctuary†	2013	3	13	22-Jul	13	11	11	19–20 (x7), <12 (x4)
Burnaby Lake†	2013	4	14	N/R	16	16	16	24–25 (x16)
Sardis Pond	2013	5	15	N/R	N/R	N/R	N/R	N/R
Burnaby Lake	2014	1	16	N/R	N/R	N/R	N/R	N/R
Lafarge Lake	2014	2	17	N/R	N/R	N/R	N/R	N/R
Reifel Island Bird Sanctuary	2014	3	18	26-May	9	5	1	25 (x1), <12 (x4)
Reifel Island Bird Sanctuary	2014	4	19	24-Jun	12	11	11	23 (x7), 21 (x4)
Reifel Island Bird Sanctuary‡	2014	5	20	N/R	Min. 6	6	Min. 6	>26 (x6)
Reifel Island Bird Sanctuary†	2015	1	21	N/R	Min. 3	3	Min. 3	>26 (x3)
Burnaby Lake†	2015	2	22	N/R	Min. 4	4	Min. 4	>26 (x4)

TABLE 1. *Continued.*

Site	Year	Annual nest number	Cumulative nest number	Date laid	Number of eggs	Number fertilized	Number of embryos	Developed to which embryonic stage* (x number of eggs)
Lafarge Lake	2017	1	23	N/R	N/R	N/R	N/R	N/R
Cranberry Lake†	2017	2	24	N/R	14	12	10	>26 (x6), 21 (x4), <12 (x2)
Cranberry Lake†	2017	3	25	N/R	12	10	8	21 (x8), <12 (x2)
Reifel Island Bird Sanctuary†	2017	N/A	N/A	N/A	N/A	N/A	N/A	Completed development - Juvenile
Burnaby Lake	2017	4	26	N/R	N/R	N/R	N/R	N/A
Burnaby Lake	2018	5	27	11-Jun	15	15	15	Nest removed
Burnaby Lake	2018	6	28	20-Jun	9	9	9	Nest removed

*Embryonic stage according to Greenbaum (2002).
†Nests monitored for development.
‡First confirmed completed development.

females; ECCC 2018) at two sites: one in 2012 (Mill Lake) and another in 2017 (Reifel Migratory Bird Sanctuary; Table 1).

Summer temperatures (data not shown) within nests at Reifel Migratory Bird Sanctuary and at Burnaby Lake in 2012 reached or exceeded the minimum viability threshold for completed embryonic development of Red-eared Slider (average 23°C) in 51% of the three daily readings ($n = 299$) and 71% of the three daily readings ($n = 260$) throughout the summer period, respectively. In 2013, summer temperatures exceeded those in the previous year at Burnaby Lake and were above the optimal minimum (average 26°C) for the species in 37% of the three daily readings throughout the period ($n = 260$). No temperature readings were taken at nests after 2013.

Discussion

Our survey results show that Red-eared Sliders appear to be more abundant in many sites throughout the LM/FV than the native Western Painted Turtle, particularly in urban areas. Without historical data we cannot determine whether the original Western Painted Turtle populations were always small and disjunct or whether Red-eared Sliders have affected Western Painted Turtle abundance over the last few decades since their introduction. Still, there is sufficient evidence from studies outside of Canada to suggest Red-eared Sliders contribute to population declines in Western Painted Turtles; indeed the threat impact of invasive species, including Red-eared Slider, is listed as high in the final Recovery Strategy for the species (ECCC 2021). While the Committee on the Status of Endangered Wildlife in Canada initially assessed the status of the Pacific Coast population of Western Painted Turtle in 2006 as Endangered, it reassessed this species in 2016 and recommended a downlisting to Threatened, its current legal status (SARA Registry 2021).

Red-eared Sliders are successfully hatching in south coastal BC; coupled with their distribution and relatively high abundance in the region, there is a potential for significant or severe consequences for Western Painted Turtle populations in the LM/FV. Many regions in BC are already experiencing warming temperatures—with direct evidence of increased substrate temperatures at turtle nesting sites in some years over the past decade—and with climate change models predicting an increase of 1–2°C in air temperatures by 2050 (Rodenhuis 2009; PCIC 2010; Carlson 2012; Mitchell 2014). However, we were not able to make any direct correlations between temperature changes observed at nesting sites after 2013, the last year temperature loggers were deployed, and our

FIGURE 3. Red-eared Slider (*Trachemys scripta elegans*) embryonic developmental stages (Greenbaum 2002): a. stage 21, b. stage 23, and c. stage 24–25. Photos: Aimee Mitchell.

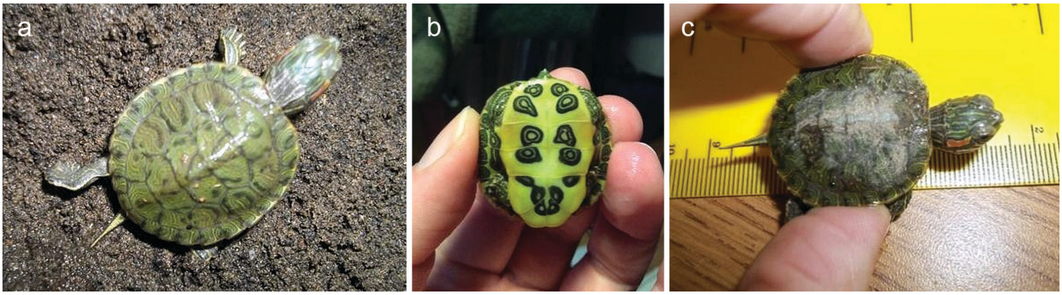

FIGURE 4. Red-eared Slider (*Trachemys scripta elegans*) neonates stage >26, fully developed, and emerged from the egg, Nest 5 laid in 2014 and discovered in early 2015. Photos: Aimee Mitchell.

subsequent observations of increased later stages of development over time.

As the climate shifts towards conditions more favourable for Red-eared Slider reproduction, recruitment to existing populations will also likely increase and distribution expand to areas where conditions are currently less favourable for Red-eared Sliders. This predicted population increase is likely to accelerate as Red-eared Sliders have a large reproductive capacity, commonly producing up to three clutches per season (Tucker 1997). However, reproductive output of Western Painted Turtle may also increase. On occasion, we observed Western Painted Turtles producing three clutches per season in our study area (A.M.M. pers. obs. 15 July 2019); others (Iverson and Smith 1993; St. Clair *et al.* 1994) have reported multiple clutches occur in warmer parts of the species' range.

Red-eared Sliders are known to outcompete native turtles in other areas where they have been introduced (e.g., Cadi and Joly 2003, 2004; Lambert *et al.* 2013). Red-eared Sliders are more aggressive and outcompete smaller native turtles at basking sites (Cadi and Joly 2003; Lambert *et al.* 2013), which often are limited in many of the more urbanized sites where both species coexist in BC. Also, there could be competitive advantage based on the size of juvenile turtles. Red-eared Slider hatchlings are generally larger at nest emergence than Western Painted Turtle hatchlings although there is some size overlap (Ernst *et al.* 1994; Tucker 2000). We also found differences in the size of turtle hatchlings (unpubl. data): average carapace length and weight was 35.1 mm and 6.1 g for Red-eared Slider hatchlings ($n = 6$) and 27.1 mm and 4.7 g for Western Painted Turtle hatchlings ($n = 12$). Thus, compared to Western Painted Turtle hatchlings, Red-eared Slider hatchlings are less likely to be predated upon by aquatic predators with gape size limitations such as herons, fish, and invasive frogs (Ernst *et al.* 1994; Tucker 2000).

Red-eared Sliders bred and raised under unhygienic captive conditions are known to harbour pathogens (Hidalgo-Vila *et al.* 2009) that might transfer to native turtles, as many turtle pathogens are not host-specific (Verneau *et al.* 2011). Thomson *et al.* (2010) and Silbernagel *et al.* (2013) suggest that disease transfer from released pet Red-eared Sliders is a significant threat to native turtles, and disease is implicated in declines of native turtle populations in Europe (Cadi and Joly 2004). Ten Red-eared Sliders captured and euthanized during our study had a bacterial respiratory condition (A. Walton pers. comm. 15 August 2014). In addition, one Western Painted Turtle was rescued from a site dominated 30:1 by Red-eared Sliders in the Lower Mainland and subsequently required treatment for several weeks for a respiratory illness.

Conclusions

We documented the distribution and relative abundance of Red-eared Slider populations across south coastal BC as well as successful reproduction of the species in the wild. Since monitoring began in 2009, we have observed a shift over time from only partially developed Red-eared Slider embryos to successful hatching and emergence (nests laid in 2014 and emerged in 2015). We suspect that with continued climate change, conditions will become more suitable for successful reproduction at more localities and the frequency of successful development and emergence will increase at sites where emergence has already been documented. The predicted increase in abundance and distribution of Red-eared Sliders throughout south coastal British Columbia is a conservation concern and may impact the native federally listed Pacific Coast population of Western Painted Turtle although the exact mechanism remains to be explored. In the interim, we suggest the elimination of both Red-eared Slider adults and their nests to limit further recruitment, as part of a precautionary conservation approach.

Author Contributions

Writing – Original Draft: A.M.M. and R.S.; Writing – Review & Editing: V.L.K. and A.M.M.; Conceptualization: A.M.M.; Investigation: A.M.M., V.L.K., and D.M.; Methodology: A.M.M.; Formal Analysis: A.M.M. and V.L.K.; Funding Acquisition: V.L.K. and A.M.M.

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Note

The intertidal fish collections of Ed Ricketts at Tofino, British Columbia, Canada, 1945 and 1946

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Abstract

Few studies exist on the intertidal fish fauna of the west coast of Vancouver Island, British Columbia. The earliest known regional insights into intertidal fish diversity for the Tofino area were made by iconic marine ecologist Edward Flanders Ricketts. We reviewed his 1945 and 1946 collection cards, now available online. He made 111 collections of 20 species and 294 specimens. Most of these species were cottids (nine species) or pricklebacks (three species), with flatfish, greenlings, poachers, snailfish, gunnels, sand lance, and clingfishes each represented by one or two species. We briefly compare the data with contemporary studies and suggest opportunities for using his museum-curated physical specimens for further analyses.

Key words: Intertidal fishes; Ricketts' historical collections; Vancouver Island

Baseline studies of the intertidal fish communities on the west coast of Vancouver Island (WCVI), British Columbia (BC), Canada are incomplete, but necessary to help understand faunistic changes resulting from climatic shifts (e.g., sea level rise, temperature shifts; Vadeboncoeur 2016) and to help document changes in fish biodiversity in this region. Studies available include the historical surveys by Bean and Weed (1919) at Ucluelet Inlet, tide pool studies by Green (1971) on rocky shores at Botany Beach near Port Renfrew, the autecological work on various species of tide pool cottids at Port Renfrew and Bamfield over the years (e.g., Khoo 1974; Nakamura 1976; Craik 1981; Wuitchik *et al.* 2018), and the recent work by Robinson and Yakimishyn (2013) in eelgrass beds in Pacific Rim National Park near Tofino (Figure 1). Other than the work at Botany Beach, Bamfield, and the recent work in eelgrass beds near Tofino, data describing the intertidal fish along the extensive shorelines (>400 km) of WCVI are not available. Here, we analyze a relatively unknown data set.

The earliest known baseline work was by California-based iconic marine ecologist Edward Flanders Ricketts (1897–1948), co-author of the acclaimed book *Between Pacific Tides* (Ricketts and Calvin 1939), during his 1945 and 1946 collections near Tofino, BC. In addition to operating a marine specimen supply business to service schools and colleges, Ricketts' interests in marine flora and fauna were wide-ranging and he was very knowledgeable about northeast Pacific coastal fishes and their habitats. Observations of intertidal fishes are mentioned on numerous pages in Ricketts and Calvin (1939), which recognized their importance and diversity. For example, before describing a California fish Garibaldi (*Hypsypops rubicundus*) and its habitat, the authors state: "vertebrates have scant place in this account, since an adequate treatment would require a separate book" (Ricketts and Calvin 1939: 153). Ricketts was in contact with noted ichthyologists of the day, such as Rolf Bolin (Hopkins Marine Laboratory at Monterey) and Loren P. Woods (The Field Museum in Chicago), who verified his identifications. Ricketts publicized fisheries conservation and recently has become recognized as an early expert on the population dynamics of Pacific Sardine (*Sardinops sagax*; Tamm 2008).

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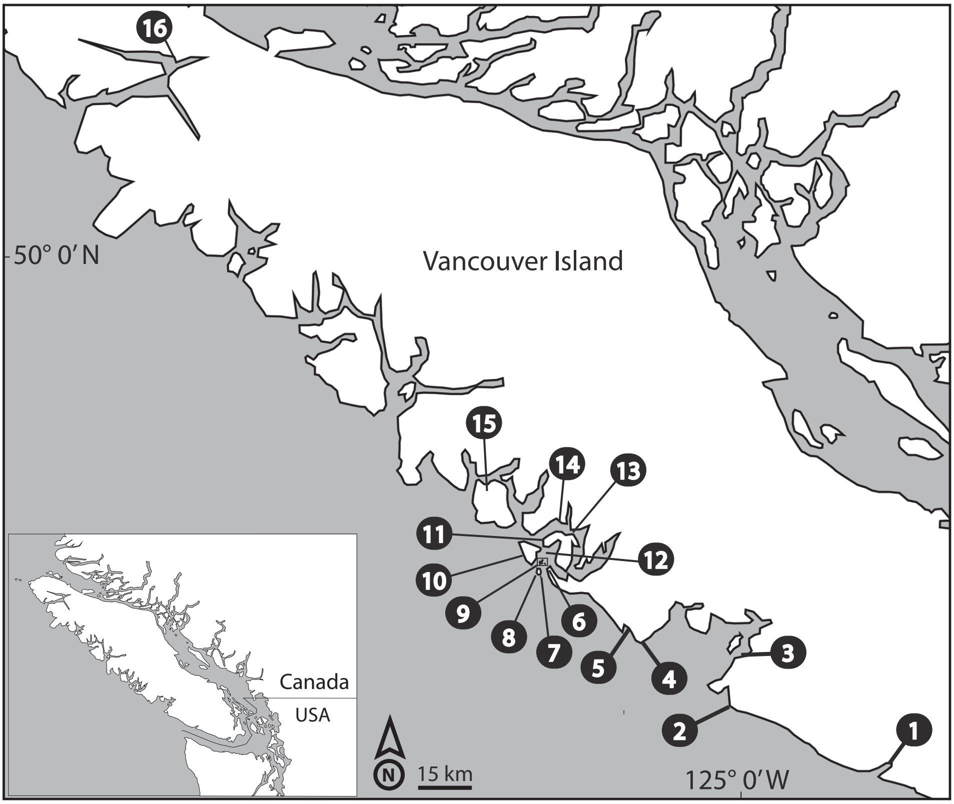

FIGURE 1. The west coast of Vancouver Island, British Columbia, Canada showing general locations of Ricketts' sampling sites in 1945 and 1946: 1. Port Renfrew, 2. Pachena Point, 3. Bamfield, 4. Ucluelet, 5. Florencia Bay, 6. Tofino, 7. Echachis Island, 8. Wickaninnish Island, 9. Clayoquot (Stubbs) and Felice (Round) Islands, Devils Rock (see Figure 2 for detailed view), 10. Vargas Island, 11. Kakawis, 12. Deadmans Island, 13. Tsapee Narrows, 14. Quait Bay, 15. Flores Island, 16. Coal Harbour.

Ricketts' "Pisces" collection of cards is available at Ricketts (1946a) in the system described in detail by Albert and Albert (2014). Each card holds fish data for both Haida Gwaii (formerly Queen Charlotte Islands) and WCVI by species. We used collection data only where species identifications were verified and, therefore, omitted records where identities were listed as "undetermined" or described as juvenile fish too small for identification. In some cases, Ricketts identified species himself in the field, but on most cards, Woods is named. Each of the samples was given a "lot" number, which was recorded on the species card, suggesting all the specimens in a collection were identified by Woods. Ricketts subsequently completed the collection cards, accounting for why both "Queen Charlotte Islands" and WCVI data appear on the cards. There were 26 cards with WCVI collection data. With a few exceptions, each card included typed or handwritten data on collection site, number of fish specimens preserved, habitat, tide level when the specimens were collected, and notes on identification. Wave exposure information was also given frequently.

Ricketts used his experience and powers of observation as a naturalist to collect in conveniently located sites in a variety of intertidal habitats and maximize the diversity of species. It is our interpretation that he most likely did this to obtain a significant number of specimens to offer his clients; build up his own collection of northeast Pacific coastal organisms at his laboratory in Monterey; and collect fish for Woods (e.g., in a letter to Woods in July 1946, he writes: "I hope you get a good representation of Vancouver Island tidepool fish from these collections" [Ricketts 1946b: 386]). Search effort was not quantified on the data cards. Similar to a fisher exploring a new area or a naturalist seeking to document the biodiversity of an unexplored region, he used a variety of methods or protocols (e.g., dipnets, rotenone, hand collection) tailored to maximize his catches in the various locations and habitats he sampled. The utility of such semi-structured sampling is increasing as contemporary citizen science data (e.g., iNaturalist) are increasingly used in mapping species distributions and assessing changes in biodiversity.

Ricketts' collections (5 June–7 July 1945, 17 May–17 July 1946) were made across the WCVI (Figure 1), with most samples concentrated on three islands near the mouth of Clayoquot Sound: "Stubbs Island" (officially Clayoquot Island; 10 sites), "Round Island" (officially Felice Island; two sites), and Wickaninnish Island (two sites; Figure 2). He also collected less frequently from 10 additional sites, some within or near Clayoquot Sound, such as Ucluelet, but others quite distant, such as Coal Harbour on Quatsino Sound, 195 km northwest (location 16 in Figure 1).

Ricketts did not precisely geolocate his sample sites and transit survey methods were difficult to use on wave-swept beaches. We were able to approximate the location of many sites from descriptions on the cards, which were often stated in terms of directions and distances to features that are still present, e.g., major wharves; these sites are identified by letters in Figure 2. However, in three cases, only a general area, such as "Stubbs Island," was provided; for convenience, we show these mid-island (Figure 2). Therefore, we described Ricketts' collection sites at the "island" level, recognizing that some of his cards do give specific locations that are recognizable today. For example, he visited Devils Rock (location "e" on Figure 2), a site well known as habitat for Giant Pacific Octopus (*Enteroctopus dofleini*; often given the common name "devil fish") on the northeast side of Stubbs Island (M. Bartlett pers. comm. 27 November 2020).

Ricketts described 16 habitats at his collection sites, as well as "habitat type not reported". Seven were variations on rocky substrates, one was gravel, four were sand, one was eelgrass, and three were "reef" or "reef pools". In some instances the cards did not record wave exposure as a habitat variable. In these

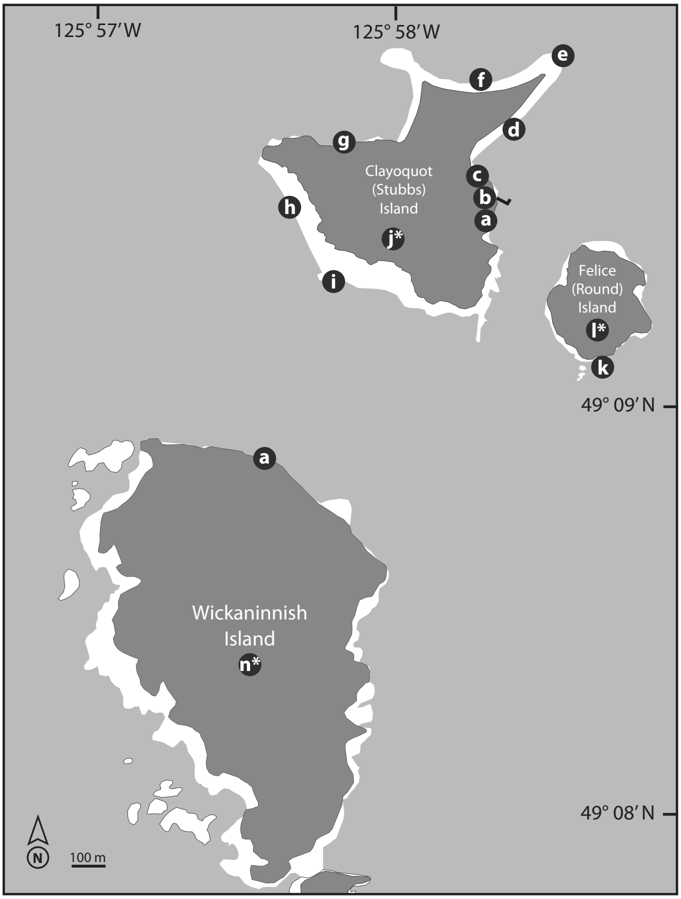

FIGURE 2. Estimated positions of Ricketts' intertidal fish sampling on Clayoquot (Stubbs) Island, Felice (Round) Island, and Wickaninnish Island in 1945 and 1946. Letters with an asterisk indicate a collection site on the island where a specific location was not recorded. White areas around islands represent intertidal and coastal bedrock; dark grey represents forested areas.

cases, we estimated exposure based on assumed location and reference to Howes *et al.* (1994), accessed through BC's provincial spatial data repository. We found that Ricketts sampled in four wave exposure zones, as categorized in Howes *et al.* (1994): exposed or semi-exposed (10 collections), protected (33 collections), semi-protected (51 collections), and 17 collections at sites where exposure was not noted and we could not estimate wave energy.

Ricketts made 111 collections yielding 20 species and 294 specimens in 1945 and 1946 (Table 1). Most of his collections and specimens were from Clayoquot (Stubbs) Island (62 collections, 211 specimens), mainly close to the Clayoquot Hotel where he stayed (Tamm 2004; Ricketts 2006). Eighteen species were found on this island. Ricketts made 19 collections on Felice (Round) Island, comprising 27 specimens in nine species. On Wickaninnish Island he made 12 collections with 23 specimens in 12 species. At the 10 additional sites, ranging from Coal Harbour to Ucluelet, he made 18 collections with 33 specimens in six species.

Most of the fish species collected were cottids (Cottidae; nine species) or pricklebacks (Stichaeidae; three species), with flatfish (Pleuronectidae), greenlings (Hexagrammidae), poachers (Agonidae), snailfish (Liparidae), gunnels (Pholidae), sand lance (Ammodytidae), and clingfishes (Gobiesocidae) represented by one or two species. We updated the species nomenclature using Fishbase (Froese and Pauly 2021). Tidepool Sculpin (*Oligocottus maculosus*; 87 specimens), Black Prickleback (*Xiphister atropurpureus*; 37 specimens), High Cockscomb (*Anoplarchus purpurescens*; 28 specimens), and Rosylip Sculpin (*Ascelichthys rhodorus*; 22 specimens) were the most commonly collected species (Table 1).

Although Ricketts' fish collections were not designed as detailed ecological surveys, his species lists are similar to those found by later researchers who conducted specific ecological studies on intertidal fish in the region, with the caveat that Ricketts' data sets are limited and sampling strategies and methods are difficult to compare.

Of the 20 fish species collected by Ricketts, 15 have been caught in recent and extensive Clayoquot Sound eelgrass beach seine surveys (2001–2019; Robinson and Yakimishyn 2013; Robinson pers. comm. 31 December 2020) where 73 species were found, while five species—Rockhead (*Bothragonus swanii*), Calico Sculpin (*Clinocottus embryum*), Mosshead Sculpin (*Clinocottus globiceps*), Fluffy Sculpin (*Oligocottus synderi*), and Rock Prickleback (*Xiphister mucosus*)—were not observed. Ricketts noted that all five of these species were found in low tide pools in rock or reef habitat. If they are still present in the area, they may be living in these specialized habitats not sampled by the eelgrass surveys in Clayoquot Sound. Ten common or occasional species caught in eelgrass were not collected by Ricketts. This was likely because of his sampling methods, as well as his predilection to collect in exposed reefs or semi-protected areas, where common or occasional inshore species such as the sea perches (Embiotocidae), sticklebacks (Gasterosteidae), and some rockfishes (Sebastidae) are not found. These ubiquitous taxa are found in a variety of mainly protected habitats as well as eelgrass. Ricketts did sample in eelgrass, but only at one location on Felice (Round) Island, where he collected a specimen of Red Irish Lord (*Hemilepidotus hemilepidotus*).

There might be opportunities to resample Ricketts' sites to investigate whether the species he inventoried have changed. However, because we do not have exact location data and his sampling effort is not known, it might be difficult to replicate his work. Further investigations of his extensive field notes for the 1945 and 1946 work, recently archived online (Ricketts 1946b), could help to determine his site locations more precisely. Some specific sampling locations, e.g., Devils Rock on Clayoquot (Stubbs) Island, are known and may be worth revisiting. Depending on study parameters, such as sample size, there are also possible opportunities to use Ricketts' 1945 and 1946 physical collections of fishes for analyses of past environmental conditions and genetic analysis, as specimens were archived and available for researchers at the Field Museum in Chicago (C. McMahan pers. comm. 14 November 2019). For example, microplastic fragments in stomachs of archived specimens might be compared with those in present-day fish. A case study on this approach with four species of freshwater fish was recently presented by Lou *et al.* (2021). Ricketts' specimens were fixed in formalin and are stored in ethanol in the Field Museum (C. McMahan pers. comm. 21 January 2022). Although these storage media can make DNA genetic studies problematic, new methods are being developed to improve the use of such archived specimens (Appleyard *et al.* 2021).

Recently, Levings (2020) revealed Ricketts' collections of invertebrates and ecological observations on the inside waters of British Columbia. His inventories of intertidal fishes on the WCVI, which we have summarized here, are another important component of the legacy left by the iconic naturalist.

Author Contributions

Writing – Original Draft: C.D.L. and C.B.; Writing – Review and Editing: C.D.L. and C.B.; Conceptualization: C.D.L. and C.B.; Investigation: C.D.L.

TABLE 1. Number of collections and specimens of the 20 fish species Ricketts inventoried on his 1945 and 1946 trips to Clayoquot (Stubbs) Island, Felice (Round) Island, Wickaninnish Island in Clayoquot Sound, and 10 additional sites on the west coast of Vancouver Island, British Columbia, Canada.

Family/species	Total no. collections/total no. specimens			
	Stubbs Island (n = 62/211)	Round Island (n = 19/27)	Wickaninnish Island (n = 12/23)	Additional sites (n = 18/33)
Agonidae				
Rockhead (*Bothragonus swanii*)	—	—	1/1	—
Ammodytidae				
Pacific Sand Lance (*Ammodytes hexapterus*)	1/1*	—	—	—
Cottidae				
Smoothhead Sculpin (*Artedius lateralis*)	2/4	—	1/3	—
Rosylip Sculpin (*Ascelichthys rhodorus*)	6/19	2/2	1/1	—
Sharpnose Sculpin (*Clinocottus acuticeps*)	2/4	—	—	—
Calico Sculpin (*Clinocottus embryum*)	1/6	—	1/1	1/1
Mosshead Sculpin (*Clinocottus globiceps*)	1/1	—	1/1	—
Red Irish Lord (*Hemilepidotus hemilepidotus*)	2/3	1/1	—	—
Pacific Staghorn Sculpin (*Leptocottus armatus*)	1/6	—	—	—
Tidepool Sculpin (*Oligocottus maculosus*)	7/67	—	—	7/20
Fluffy Sculpin (*Oligocottus synderi*)	4/7	—	1/5	—
Gobiesocidae				
Northern Clingfish (*Gobiesox maeandricus*)	6/12	4/5	1/1	4/6
Hexagrammidae				
Kelp Greenling (*Hexagrammus decagrammus*)	1/1	—	—	—
Liparidae				
Tidepool Snailfish (*Liparis florae*)	3/8	2/3	1/1	—
Pholidae				
Penpoint Gunnel (*Apodichthys flavidus*)	7/13	2/5	1/1	—
Crescent Gunnel (*Pholis laeta*)	—	1/2	—	1/1
Pleuronectidae				
English Sole (*Parophrys vetulus*)	2/8	—	1/5	—
Stichaeidae				
High Cockscomb (*Anoplarchus purpurescens*)	6/20	2/3	1/2	3/3
Black Prickleback (*Xiphister atropurpureus*)	8/29	4/5	1/1	2/2
Rock Prickleback (*Xiphister mucosus*)	2/2	1/1	—	—

*From the stomach of a Coho Salmon (*Oncorhynchus kisutch*).

and C.B.; Methodology: C.D.L. and C.B.; Formal Analysis: C.D.L. and C.B.

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Dispelling myths about the origins of wolf–coyote hybrids and related *Canis* species in Ontario

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Abstract

Long-standing myths exist about the origins of wolf–coyote hybrids and related *Canis* species in Ontario. Specifically, there is a perceived controversy whether they are the product of natural hybridization that occurred between wolves and coyotes in the wild during the last century or the descendants of animals that escaped or were released from captive colonies or controlled breeding experiments. We review the relevant evidence and conclude that captive colonies and controlled breeding experiments were unlikely to have played any role in the origins of wolf–coyote hybrids and related *Canis* species in Ontario.

Key words: Algonquin Wolf; Eastern Coyote; Eastern Wolf; wolf–coyote hybrids; captive colonies; controlled breeding experiments

Introduction

Long-standing myths exist about the origins of wolf–coyote hybrids and related *Canis* species in Ontario, the latter of which include Algonquin Wolf (*Canis* sp.) and Eastern Coyote (*Canis latrans* var.). Specifically, there is a perceived controversy whether they are the product of natural hybridization that occurred between wolves and coyotes in the wild during the last century or the descendants of animals that escaped or were released from captive colonies or controlled breeding experiments. The myths that caused this perceived controversy held by a vocal minority of public stakeholders relate to the Ontario Ministry of Natural Resources and Forestry (OMNRF; formerly the Ontario Department of Lands and Forests and the Ontario Ministry of Natural Resources) and their alleged direct or indirect role in breeding wolves, coyotes, and/or their hybrids for release into the wild; encouraging hybridization or augmentation of canids in Ontario; and releasing hybrid or non-native canids into the wild. Although these myths, propagated decades ago by members of the public, have been debunked by employees of the OMNRF (Kolenosky *et al.* 1964), they persist.

A detailed review of the taxonomy of *Canis* species in Ontario and interbreeding among them is beyond the scope of this article, but interested readers are encouraged to consult available literature reviews for relevant information (Chambers *et al.* 2012; Way and Lynn 2016; vonHoldt and Aardema 2020). Way and Hirten (2019) also provide a pictorial representation of North American *Canis* species that may be helpful. Briefly, Algonquin Wolf (*sensu* COSSARO 2016) derive from Eastern Wolf (*Canis lycaon*) that hybridized with western Coyote (*Canis latrans*) and Gray Wolf (*Canis lupus*; Rutledge *et al.* 2010, 2012); Eastern Coyote (*sensu* Hilton 1978; Parker 1995) derive from western Coyote that hybridized with Eastern Wolf and Domestic Dog (*Canis familiaris*; Wheeldon *et al.* 2010, 2013). Notably, Algonquin Wolf has effectively replaced Eastern Wolf, whereas Eastern Coyote has merely extended the range of western Coyote (albeit in modified form). Hybridization occurs between Algonquin Wolf and Eastern Coyote in central Ontario, including near Algonquin Park, such that wolves, coyotes, and their hybrids occur across the landscape (Benson *et al.* 2012), complicating management of wolves and coyotes (Beacon Environmental Limited and Wildlife 2000 Consulting 2018).

There were contrasting views of the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and the Committee on the Status of Species at Risk in Ontario (COSSARO) regarding the taxon known as both Eastern Wolf and Algonquin Wolf. In 2015, COSEWIC recognized Eastern Wolf as a unique species (defined under the federal *Species at Risk Act* [SARA]), *Canis* sp. cf. *lycaon*, and assessed it as Threatened in Canada, noting that its range included central Ontario and southern Quebec. It was listed as Special Concern under SARA in 2003, a status it retains (SARA Registry 2021). COSEWIC (2015: iv) stated that

> Eastern Wolf is best defined by a combination of genetic distinctiveness, morphological characters, and an ecological role associated with a feeding preference for smaller prey than fed on by Gray Wolf.

COSEWIC (2015: iv) recognized that "the taxonomy of Eastern Wolf is under debate" and that "the Eastern Wolf population has a degree of hybridization with Coyote".

In 2016, COSSARO recognized Algonquin Wolf as a unique species (defined under Ontario's *Endangered Species Act* [ESA]), *Canis* sp., and assessed it as Threatened in Ontario, noting that its occurrence was concentrated in various protected areas of central Ontario. It was listed as Threatened under Ontario's ESA in 2016. COSSARO (2016: 8) stated that "Algonquin Wolf is most appropriately described as a hybrid group that collectively represents a genetically discrete cluster with distinct morphological characteristics". COSSARO (2016: 9) explained that it

> named this taxon Algonquin Wolf to a) differentiate it from other populations that have been [inappropriately] labelled 'Eastern Wolf' (e.g., hybrids in the Great Lakes region, which are genetically distinct from the Algonquin Wolf), and b) acknowledge the hybrid ancestry of this evolutionarily significant unit.

However, although COSEWIC and COSSARO used different names for this taxon (Eastern Wolf versus Algonquin Wolf), COSSARO (2016: 9) clarified that "these two taxa are considered to have the same genetic characteristics". Accordingly, Eastern Wolf and Algonquin Wolf were synonymous in a contemporary context, but the former supplanted the latter in a historical context (i.e., before the wolf–coyote hybridization that occurred during the last century), because only the former was appropriate when referring to this taxon in its original form. Notably, in late 2021, COSSARO adopted a name change for Algonquin Wolf to "better reflect the outcome of discussions regarding genetics", whereby it will be referred to as Eastern Wolf, consistent with COSEWIC (COSSARO 2021). We have used the names Algonquin Wolf and Eastern Wolf for this taxon, where appropriate, based on prior context and for the purpose of differentiating between its contemporary and historical forms, respectively.

The 2016 listing of Algonquin Wolf as Threatened under Ontario's ESA led to additional protection for wolves and coyotes in parts of central Ontario, which elicited criticism from some public stakeholders, some of whom cited the perceived controversy regarding the origin of Algonquin Wolf. Indeed, the aforementioned myths were propagated in response to the 2016 listing of Algonquin Wolf as Threatened and the subsequent posting of the draft recovery strategy (Beacon Environmental Limited and Wildlife 2000 Consulting 2018) on the Environmental Registry. Hence, it is important to resolve the issue.

Here, we review the relevant evidence to resolve the origins of wolf–coyote hybrids and related *Canis* species in Ontario. First, we address the history of captive colonies and controlled breeding experiments. Second, we address the results of morphological and genetic investigations.

Captive Colonies

Between 1956 and 1968, the OMNRF maintained captive colonies of wolves, coyotes, and coyote–dog hybrids for research purposes at the Wildlife Research Station in Algonquin Park. The history of the captive colonies is documented by several sources (e.g., Standfield 1954; Pimlott 1961; Kolenosky *et al.* 1964; Rutter and Pimlott 1968; Pimlott *et al.* 1969).

Standfield (1954) documented that a litter of seven coyote–dog hybrids and a litter of five "brush wolves" (i.e., coyotes) were removed from dens in the Niagara Peninsula and raised to sexual maturity in captivity. He noted that the captive animals were maintained at the Southern Research Station at Maple (they were later transferred to the Wildlife Research Station in Algonquin Park). He also detailed planned breeding experiments, including hybrid brother × sister matings, brush wolf and Domestic Dog matings, and a brush wolf brother × sister mating, which were intended to be completed in 1956. Standfield (1954) indicated that the purpose of the planned breeding experiments among captive animals was to study the inheritance of certain morphological characters noted in hybrids collected in Ontario. He noted that the female parent of the hybrid litter was being used in the breeding program. Standfield (1954: 5) stated that "Two brother × sister matings of hybrid animals have been successful: three young being produced in one litter and four in the other". He indicated that the breeding program would continue until 1956 and that the breeding population would probably continue at a level of 12 animals.

Pimlott (1961) noted that coyote–dog hybrids in the captive colony at one time numbered over 40 animals. He also mentioned obtaining a series of tape recordings of the howls of the captive animals, which were played to elicit replies from wild wolves, a technique applied to locate wolf packs in Algonquin Park (Joslin 1967).

Kolenosky *et al.* (1964: 1, 10) acknowledged that "the purposes and activities of the [OMNRF's] program have been occasionally misrepresented and often misunderstood" and that "[occasionally] some extravagant rumours have circulated about the research program in Algonquin Park". Commenting on the purpose of the captive colonies, Kolenosky *et al.* (1964: 10) clarified that

> These are used for breeding experiments, as a basis for identifying wild-caught hybrids [referring to coyote–dog hybrids] which are presented for bounty, for developing methods to determine ages of wild wolves, for testing the effects of poisons and drugs, for testing new marking devices such as collars and tags and for other experimental purposes as they are required.

They documented that in 1959 and 1960 the program biologist used tame "Eastern Timber Wolves" from the captive colony to travel with him in the bush to locate wild packs, but the animals were returned to captivity at the end of each trip. Kolenosky *et al.* (1964: 10–11) also stated the following:

> Wolves are not being bred for releasing in Algonquin Park … All the timber wolves that have ever been part of this captive colony are either still caged or are now dead. None have been released to augment the wild population. There has never been any research or management program to breed and release wolves in any area of Ontario nor has it ever been contemplated. Wolves are not being imported from Alaska or any other area to be released in Algonquin Park … The importation and release of wolves has never been suggested for any area of Ontario; least of all for Algonquin Park.

Rutter and Pimlott (1968) documented multiple wolves from the captive colony, including two litters of five wolf pups, which were obtained from Moosonee, Ontario, in spring 1960 and Black Donald, Ontario, in spring 1961, and whose fates were explicitly detailed. They documented that the wolf pups from these litters were temporarily placed on an island in Potter Lake in Algonquin Park in the summers of 1960 and 1961 (with a pair of yearling wolves in the latter). They also documented multiple instances of certain wolves from the captive colony temporarily roaming freely (i.e., lost and found).

Pimlott *et al.* (1969) confirmed that captive colonies of wolves, coyotes, and coyote–dog hybrids were maintained at the Wildlife Research Station in Algonquin Park from 1956 to 1968. They also mentioned captive wolves in the context of two studies on wolf howling and captive wolves and coyotes in the context of testing drugs for use in capturing and handling wolves.

Notably, none of these sources mention that any wolves from the captive colonies escaped or were released into the wild permanently, i.e., those that escaped or were released into the wild were later returned to captivity. Similarly, none of these sources mention that any coyotes or coyote–dog hybrids from the captive colonies escaped or were released into the wild permanently or even temporarily. Collectively, these sources indicate that the captive colonies were used for research purposes, not manipulation of wild canid populations.

Controlled Breeding Experiments

Between 1969 and 1983, the OMNRF carried out a series of controlled breeding experiments with Ontario canids for research purposes (Kolenosky 1971; Schmitz and Kolenosky 1985a).

Kolenosky (1971) reported that a female wolf mated with a male coyote and produced two hybrid litters in captivity. The wolf was taken from Lawrence Township, Algonquin Park (captured in the wild on 24 August 1964) and the coyote was taken from East Gwillimbury Township, York County (removed from a den on 23 April 1966). On 14 May 1969, the wolf produced the first hybrid litter of five pups; two pups were killed and consumed by the wolf on 7 July 1969. On 20 May 1970, the wolf produced the second hybrid litter of five pups; one pup was killed and consumed by one of the parents (probably the wolf) ~17 days after birth. Kolenosky (1971: 449) stated that "Further crosses involving the original parents and the two litters of offspring [were] planned". Interestingly, Standfield (1970: 35) stated that "a reciprocal cross was not successful", indicating that an attempt was made to cross a male wolf and a female coyote, which was not reported by Kolenosky (1971).

Schmitz and Kolenosky (1985a) reported further crosses, including sibling crosses of F1 hybrids, which produced F2 hybrids. They also reported the crossing of one F1 hybrid female with the male coyote parent, which produced back-crosses. The numbers of F1 hybrids, F2 hybrids, and back-crosses produced during the controlled breeding experiments were not explicitly detailed. However, carcasses from 28 adults were used for comparison of body morphometrics among the parents, F1 hybrids, F2 hybrids, and back-crosses. Thus, it seems that all the animals involved in the controlled breeding experiments were euthanized for the collection of data or died in captivity.

Neither Kolenosky (1971) nor Schmitz and

Kolenosky (1985a) reported any instances of escape or release of captive wolf–coyote hybrids into the wild. Schmitz and Kolenosky (1985a) indicated that the controlled breeding experiments were carried out to test the wolf–coyote hybrid hypothesis, which was formulated to explain the origins of the "wild canids of questionable identity" (Kolenosky 1971: 446) in eastern North America, specimens of which Silver and Silver (1969) observed in captivity with the objective of establishing their identity. The controlled breeding experiments clarified that wolf–coyote hybridization was possible and that the "wild canids of questionable identity" in eastern North America plausibly originated from wolf–coyote hybridization that had occurred naturally in the wild.

Wolf–Coyote Hybridization in the Wild

Several studies provide evidence that wolf–coyote hybridization had occurred naturally in the wild in Ontario before the controlled breeding experiments.

Schmitz and Kolenosky (1985b) analyzed and compared body morphometrics and skull characters among various *Canis* specimens, including several groups of wolves and coyotes for which data were obtained from carcass samples collected in Ontario by the OMNRF between 1959 and 1969 (i.e., before the controlled breeding experiments), and wolf–coyote hybrids for which data were obtained from specimens raised in captivity (i.e., originating from the controlled breeding experiments). They tentatively concluded that the most parsimonious explanation was that coyotes in southeastern and central Ontario, which resembled wolf–coyote hybrids, descended from coyotes that hybridized with wolves. Their tentative conclusion implicitly suggests that wolf–coyote hybridization had occurred naturally in the wild in Ontario before the controlled breeding experiments.

Rutledge *et al.* (2012) analyzed genetic data of historical (1964–1965) and contemporary (1987–1999; 2002–2007) wolf samples from Algonquin Park. These wolf samples showed evidence of mixed ancestry, including varying levels of autosomal admixture and haplotype introgression from coyotes and other wolves. Rutledge *et al.* (2012) demonstrated that wolves in Algonquin Park (i.e., Algonquin Wolf) descended from Eastern Wolf that hybridized with western Coyote and Gray Wolf, thereby clarifying the evolutionary history of Algonquin Wolf. Their findings indicate that wolf–coyote hybridization had occurred naturally in the wild in Ontario before the controlled breeding experiments. Moreover, genetic data revealed that wolf–coyote admixture and the proportion of coyote-like animals occurring in Algonquin Park increased between 1964–1965 and 1987–1999, a finding seemingly corroborated by morphological data of Algonquin Park wolves that revealed a reduction (although not statistically significant) in the body weight and skull size of females and males, respectively, between those periods (Theberge and Theberge 2004). Rutledge *et al.* (2012) concluded that the wolf culls conducted in Algonquin Park in 1964–1965 as part of the wolf research program transformed the genetic composition of the Algonquin Park wolf population by facilitating coyote introgression. They suggested that extensive wolf culling prompted some of the remaining wolves in Algonquin Park to mate with individuals from the expanding coyote population. However, the culled wolves already showed evidence of coyote introgression, indicating that wolf–coyote hybridization had occurred before the wolf culls, and, thus, implying that the wolf culls merely exacerbated wolf–coyote hybridization in Algonquin Park.

Wheeldon *et al.* (2013) analyzed genetic data of historical (1974–1984) and contemporary (2005–2010) coyote samples from southeastern Ontario. These coyote samples showed evidence of mixed ancestry, including varying levels of autosomal admixture and haplotype introgression from wolves and dogs. Wheeldon *et al.* (2013) demonstrated that coyotes in southeastern Ontario (i.e., Eastern Coyote) descended from western Coyote that hybridized with Eastern Wolf and Domestic Dog, thereby clarifying the evolutionary history of Eastern Coyote. Their findings indicate that wolf–coyote (and coyote–dog) hybridization had occurred naturally in the wild in Ontario not only at the time of the controlled breeding experiments, but also earlier, because the contrasting levels of autosomal admixture and haplotype introgression from wolves (and dogs) observed in the coyote samples imply that backcrossing of wolf–coyote (and coyote–dog) hybrids with coyotes had occurred naturally in the wild in Ontario then, which implies that initial hybridization must have occurred earlier. The coyote–dog hybrids from the captive colony predated the coyote samples, but this seems irrelevant, because suspected coyote–dog hybrids occurred in the wild in Ontario before development of the captive colony (Standfield 1954).

Conclusions

The findings of these studies collectively support the origins of wolf–coyote hybrids and related *Canis* species in Ontario via natural hybridization that occurred in the wild. Indeed, the haplotype diversity of Algonquin Wolves (Rutledge *et al.* 2010, 2012) and Eastern Coyotes (Wheeldon *et al.* 2010, 2013) does not support either originating from the descendants of a relatively small number of animals from captive colonies or controlled breeding experiments. Land clearing associated with logging and agriculture, as well as the decline of larger predators, such as wolves, likely facilitated the eastward expansion of coyotes (Young and Jackson 1951; Moore and Parker 1992; Hody and Kays 2018), which brought them into contact with declining wolves in Ontario and resulted in wolf–coyote hybridization (Schmitz and Kolenosky 1985b; Rutledge *et al.* 2012; Wheeldon *et al.* 2013). Coincident with the beginning of the controlled breeding experiments, Standfield (1970) described the species and types of canids that occurred in Ontario, including wolves (two types), coyotes, wolf–coyote hybrids, wolf–dog hybrids (infrequent), and coyote–dog hybrids. Standfield (1970: 36) stated that "To the best of our knowledge the present occurrence and distribution of these species and types has been in response to habitat changes and natural movements", which reflects our current understanding of their past and present occurrence and distribution. Standfield (1970: 36) also stated that "There has been no intentional manipulation of populations by man", which, to the best of our knowledge, was true then and remains true at the time of this writing.

In summary, there is no evidence that animals from the captive colonies or controlled breeding experiments escaped or were released into the wild permanently or even temporarily (except certain wolves from the captive colony) in Ontario. The captive colonies were used for research purposes, and the controlled breeding experiments were carried out to test the wolf–coyote hybrid hypothesis. The results of morphological and genetic investigations indicate that wolf–coyote hybridization had occurred naturally in the wild in Ontario before the controlled breeding experiments. We conclude that captive colonies and controlled breeding experiments were unlikely to have played any role in the origins of wolf–coyote hybrids and related *Canis* species in Ontario.

Author Contributions

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Please also see the comment by John Theberge in News and Comment, whose work on Ontario canids began during the late 1950s and was present in the early days.

The Canadian Field-Naturalist

Do turtle roadkill hotspots shift from year to year?

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Abstract

Freshwater turtles face many threats but roadkill is one of the most serious for many species. Roadkill of turtles is not uniformly distributed across roads but aggregated in certain areas, termed hotspots. A key question in identifying hotspots is whether they are fixed locations or if they shift from year to year because of changes in movement patterns. We compared how one, two, and three years of road survey data compared with the pooled data from four years of surveys. We found 254 turtles during 73 surveys during four years along a 15.5 km road section in Ottawa, Ontario, Canada. The four years of pooled data produced four hotspots ("pooled hotspots") while each year or combination of years produced from three to five hotspots, four of which approximately corresponded to the pooled hotspots. The average percentage overlap of hotspots between one, two, or three years of survey data and the pooled hotspots ranged from 58.7% to 88.9%. Just one year of surveys sometimes missed one of the pooled hotspots, underestimated the spatial extent of the pooled hotspots, and also sometimes produced an additional "temporary" hotspot. Two years of surveys generally produced better approximations of the pooled hotspots and better identified the spatial extent of those hotspots.

Key words: Mitigation; reptiles; road ecology; survey methods; turtles

Introduction

Turtles are one of the most endangered groups of species in the world, with more than half of the 360 species threatened with extinction (Stanford *et al.* 2020). While turtles face many threats, roadkill is a major cause of mortality for many species (Gibbs and Shriver 2002; Steen and Gibbs 2004; Aresco 2005; Dupuis-Désormeaux *et al.* 2017). Turtle life history strategies are typified by high rates of egg and hatchling mortality offset by extremely low rates of adult mortality (Congdon *et al.* 1993, 1994; Heppell *et al.* 1996). Even a small increase in adult mortality rates can lead to population declines (Congdon *et al.* 1993, 1994; Steen and Robinson 2017). Turtle populations are also extremely slow to rebound from declines (Keevil *et al.* 2018). Roadkill, which affects adults moving among wetlands, dispersing juveniles, and adult females seeking nesting locations, can lead to population declines (Gibbs and Shriver 2002; Piczak *et al.* 2019; Nicholson *et al.* 2020) or extinctions (Howell and Seigel 2019).

Roadkill affects a wide range of freshwater turtle species (Ashley and Robinson 1996; Langen *et al.* 2012; Carstairs *et al.* 2018). Turtles are found on roads throughout the active season, however, peak mortality tends to occur during the nesting season (Beaudry *et al.* 2010; Cureton and Deaton 2012; Carstairs *et al.* 2018). In areas with high road density, turtle populations have been found to be strongly male biased (Steen and Gibbs 2004; Piczak *et al.* 2019) and this could be a result of females being more prone to roadkill during nesting forays. While adult females are more apt to be hit by cars during the nesting season, male turtles have been found on roads throughout the active season, and overall there was no significant difference in the sex ratio of most turtle species found on roads in Ontario (Carstairs *et al.* 2018). Some species that rarely leave the water except for nesting do show strong female bias in road mortality (Crawford *et al.* 2014a).

Roadkill of turtles is not uniformly distributed across roads but often aggregated in certain areas, termed hotspots (Langen *et al.* 2007; Crawford *et al.* 2014b). Turtle hotspots often occur along road segments with wetland habitat on both sides of the road, have relatively high traffic volumes, and high forest cover (Haxton 2000; Aresco 2005; Langen *et al.* 2012). Determining hotspot locations is typically

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accomplished by conducting multiple surveys of the road or roads of interest (Choquette *et al.* 2016; Boyle *et al.* 2017). Collecting such data is labour intensive as it requires multiple surveys (weekly or more frequently) and driving potentially thousands of kilometres (Langen *et al.* 2012; Santos *et al.* 2017).

Once hotspots have been identified, road mitigation in the form of wildlife fencing and some form of crossing structure under the road can be installed. Such mitigation structures have demonstrated reduced turtle mortality when properly installed (Aresco 2005; Baxter-Gilbert *et al.* 2015; Read and Thompson 2021). Effective road mitigation can reduce road mortalities of freshwater turtles by more than 90% (Heaven *et al.* 2019) although mortalities at fence ends can remain a problem (Markle *et al.* 2017; Read and Thompson 2021).

A central question in any survey work is how many surveys are sufficient? Are surveys from one year sufficient to determine the location of roadkill hotspots or do the hotspots shift from one year to the next as a result of differences in weather, wildlife movement patterns, or other factors? The location of bat roadkill hotspots varied from one year to the next but appeared to be correlated with yearly variation in plant productivity (Medinas *et al.* 2021). In contrast, turtle hotspots may be more spatially consistent, as previous turtle studies have found major roadkill hotspots to occur in the same location over time (e.g., Aresco 2005). However, many studies have been for only short periods or have pooled two years of survey data to determine a more robust measure of hotspot locations (e.g., Cureton and Deaton 2012; Langen *et al.* 2012). One four-year study found that turtle hotspots often re-occurred in subsequent years but none of the hotspots occurred in all years (Garrah *et al.* 2015). Given the expense of road mitigation, it is important to know how to identify the location and spatial extent of major hotspots where roadkill most commonly occurs. To help assess these issues, we conducted four years of surveys along a road with known high levels of turtle mortality to determine how hotspots varied from year to year when compared with hotspots determined from pooling four years of surveys ("pooled hotspots"). We focussed on turtles because all species in our study area are listed as species at risk by the federal government (Government of Canada 2022) and listed species are more likely to be the focus of road mitigation projects. We hypothesized that one year of surveys would not be sufficient to confidently determine the locations and extent of pooled hotspots but that two or more years would be required.

Methods

We selected a 15.5 km section of Roger Stevens Drive in rural Ottawa, Ontario (45.0728°N, 75.8192°W) because it was known as an area of high turtle mortality based on previous surveys by D.C.S. The surveyed section was a paved, two-lane road with a posted speed limit of 80 km/h. The road is technically within the City of Ottawa but is in an area of few houses and adjacent to a large, city-owned, natural area with extensive forest and wetland habitat. Over 4000 vehicles per day were reported along this road in 2019 (City of Ottawa 2021). Road surveys were conducted for four consecutive years starting in 2016. Surveys started in mid- to late-May and finished from August to October depending on the year (Table 1). Surveys after August were typically less productive. For example, only 16% of observations in 2016 were made after August in the year when the most surveys were conducted in September and October. Surveys were conducted by car travelling at ~30–50 km/h, typically with at least two people in the vehicle, and usually between 0900 and 1600. Roadside walking surveys in wetland areas were also occasionally undertaken, in association with finding a dead turtle. This introduced a bias in data collection of sometimes finding additional dead turtles near where a turtle was found from driving surveys. Some of these turtles would likely have not been detected through just driving surveys, which can underestimate total roadkill (Langen *et al.* 2007). Walking surveys were generally spatially restricted and did not produce a large number of dead turtles, so the overall bias to our data is likely limited.

During surveys, the road surface and road shoulders were scanned for live and dead turtles. For the first three years (2016–2018), the location of turtle observations was recorded with a handheld global positioning system (GPS) unit (various models, Garmin Ltd., Olathe, Kansas, USA). Starting in 2019, most observations were recorded using the iNaturalist app for mobile phones (https://iNaturalist.ca),

TABLE 1. Number of road surveys and number of turtles found per month along a 15.5 km survey route along Roger Stevens Drive, Ottawa, Ontario conducted from 2016 to 2019.

	Number of surveys (number of turtles)			
	2016	2017	2018	2019
May	1 (1)	6 (32)	2 (8)	3 (10)
June	4 (34)	6 (30)	6 (20)	5 (11)
July	4 (14)	6 (23)	6 (11)	2 (6)
August	5 (18)	4 (11)	3 (6)	1 (1)
September	4 (10)	1 (2)	1 (1)	0
October	1 (1)	2 (4)	0	0

using the phone's internal GPS. Most observations had a spatial accuracy of 5–10 m. All turtles were removed from the road or road shoulder to prevent double counting of carcasses on a subsequent survey or to ensure the safety of the animal if alive. We included both live and dead turtles (excluding hatchlings) in the analyses as live turtles would frequently have been killed if we had not removed them from the road and our goal was to determine the main crossing areas along the road, information that is independent of whether the turtle was found alive or dead. Road surveys were conducted approximately weekly or more often during spring and summer.

We used Siriema 2.0 software (Coelho *et al.* 2014) to analyze the spatial pattern of hotspots as it has been widely used in road ecology (e.g., Gunson and Teixeira 2015; Choquette *et al.* 2016; Boyle *et al.* 2017; Arango-Lozano and Patiño-Siro 2020). The data were analyzed as single years, as two- and three-year combinations, and as all four years pooled together, for a total of 15 datasets. All species were given equal weight in the analyses. To determine if there were significant spatial aggregations, a Linear Ripley's K test was performed using a 250 m initial radius, a 200 m radius step, 100 simulations, and a CL of 95%. This was then followed by a Linear Hotspot Analysis using a radius of 200 m, 1000 simulations, 500 road divisions, and a CL of 95%. The radius lengths selected for the Ripley's K test and the Linear Hotspot Analysis were chosen based on the length of the surveyed road (15 km), the fact that turtles can move hundreds or thousands of metres (Obbard and Brooks 1980; Grgurovic and Sievert 2005), and that typical road mitigation fencing for turtles will be in the hundreds of metres (e.g., Aresco 2005; Baxter-Gilbert *et al.* 2015; Markle *et al.* 2017; Boyle *et al.* 2021). Shorter radius lengths typically produce more and shorter hotspots than longer lengths (Spanowicz *et al.* 2020). Mitigation fencing limited to these shorter hotspot locations increases the risk of mortality at fence ends and hence longer radius lengths should produce more effective guidance for mitigation locations and lengths.

The process was repeated for each turtle dataset. Hotspots were identified as locations where observed values fell above the upper 95% CL. If there were sections within hotspots where observed values equalled but did not dip below the upper CL, then the hotspot was considered continuous. To determine how well each dataset matched the four-year pooled data, we calculated the percentage overlap:

$$\%\ \text{overlap} = O / (L1 + L2 - O) \times 100$$

where O = length of sample hotspots that overlaps with pooled hotspot length, $L1$ = total length of sample hotspots, and $L2$ = total length of pooled hotspots.

Differences in hotspot overlap of one, two, and three years of data with the four years of pooled data were compared using the non-parametric Kruskal-Wallis H test. No *post-hoc* comparison test was performed given the small sample sizes of each group.

Results

We found 254 turtles during 73 surveys from 2016 to 2019. We conducted an average of 18.25 surveys per year (range 11–25) and the number of turtles observed in a given year (mean = 63.5, range 28–102) was positively correlated with the number of surveys ($r^2 = 0.88$). Painted Turtle (*Chrysemys picta*) made up 55.5% of all observations, Blanding's Turtle (*Emydoidea blandingii*) 24.8% of observations, Snapping Turtle (*Chelydra serpentina*) 13.0% of observations, and 6.7% of turtle carcasses could not be identified because of their poor condition.

The Linear Ripley's K test indicated that the data for each year and each combination of years were significantly aggregated at all spatial scales from 0 to 11 km. The pooled data from all four years of road surveys resulted in four well-defined hotspots along the first 8 km of the road (Figure 1). The hotspots averaged 0.6 km in length (range 0.4–1.2 km) for a total length of 2.8 km. We found 198 of the 254 turtles (78%) in these four hotspots (Figure 2). Hotspot 3 consistently had a large number of turtles, being ranked first or second in three of the four years, and five out of six two-year datasets.

The number of hotspots in each year or combination of years ranged from three to five, with all but one of those hotspots approximately corresponding to the four pooled hotspots (Figures 1, 3, 4). Most years or combination of years resulted in four hotspots (11 of 15, 73.3%). All years or combination of years that yielded only three hotspots involved the year 2017 (2017, 2016/2017, 2017/2019; Figures 1, 3, 4).

The average percentage hotspot overlap between individual years or combination of years and the pooled hotspots ranged from 58.7% to 88.9% (Figure 5) and the overlap varied significantly among one, two, and three years of data ($H = 9.257$, $P < 0.01$). Even with two years of survey data, the percentage overlap with the pooled hotspots was as low as 56.9%. Considering just the major hotspot (hotspot 3; Figure 2), results from single years of surveys resulted in an average overlap with the four years of pooled data of only 58.7%, while two years of surveys produced a mean overlap of 78.5%, and three years of surveys produced a mean overlap of 91.5%.

Discussion

The number and location of the hotspots varied from year to year (Figure 1). Considering results

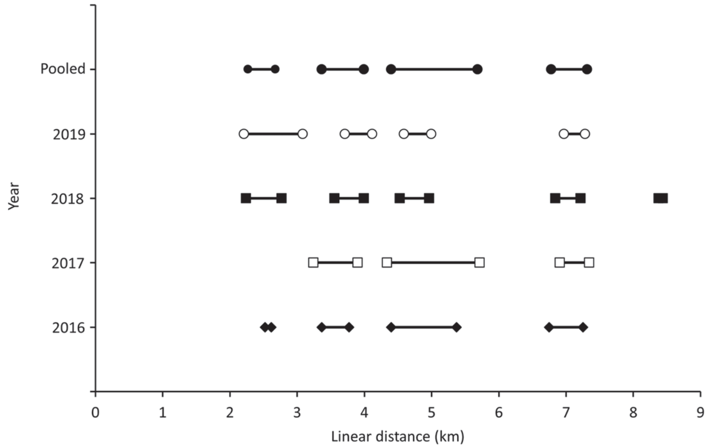

FIGURE 1. Hotspot locations along a 15.5 km survey route along Roger Stevens Drive, Ottawa, determined from survey results from 2016 to 2019, along with hotspots determined from all four years of data pooled together. Hotspots are arranged from west to east and no hotspots were found beyond km 9.

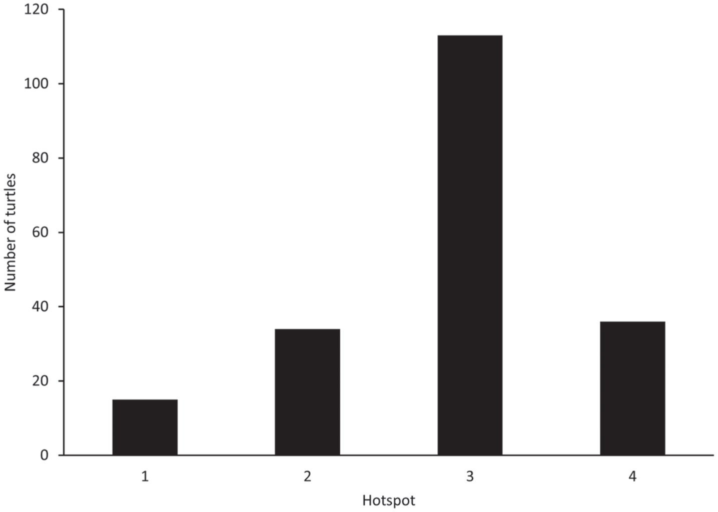

FIGURE 2. Number of turtles found in each of four pooled hotspots from road surveys conducted along Roger Stevens Drive, Ottawa, from 2016 to 2019. Hotspots are arranged from west to east, corresponding to pooled hotspots in Figure 1.

from individual years, each of the four survey years resulted in hotspots that approximately corresponded to the pooled hotspots (Figure 1). Only one of the four years (2018) produced a hotspot that did not correspond to one of the pooled hotspots, and only one year (2017) missed any of the pooled hotspots. This also means that half of all years produced either a "temporary" hotspot, or missed a pooled hotspot.

Considering results from two years of combined data, all of the datasets produced three or four hotspots, which approximately corresponded with the pooled hotspots (Figure 3). Two of the datasets missed one pooled hotspot, but there were no "temporary" hotspots produced. Datasets from three years of pooled data all produced four hotspots that approximately corresponded to the pooled hotspots (Figure 4). By definition, the three-year datasets contain most of the data in the four years of pooled data. However, if hotspot location was highly variable from year to year, even three years of data might be insufficient to identify the approximate locations of the pooled hotspots.

Hotspot 1 was the only hotspot that was not always identified by a single year of data or two years of combined data (Figure 1, 3). This hotspot also had the fewest total number of turtles (Figure 2). Overall, the results from each individual year produced hotspots that approximately corresponded with three of the four pooled hotspots.

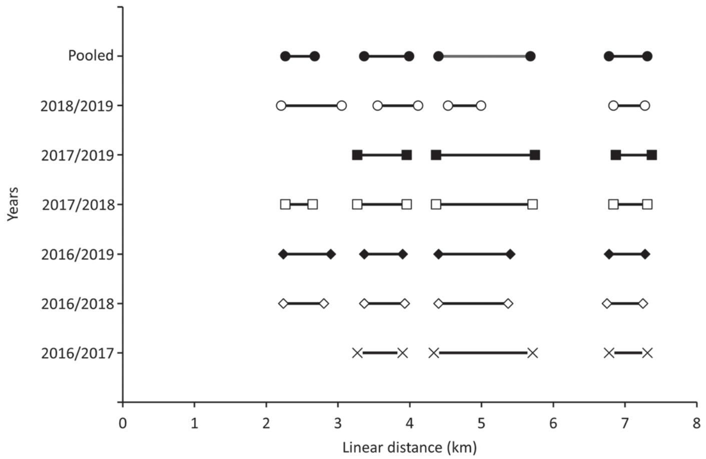

FIGURE 3. Hotspot locations along Roger Stevens Drive, Ottawa, determined from pooling two years of survey results using data from 2016 to 2019, along with hotspots determined from all four years of data pooled together. Hotspots are arranged from west to east and no hotspots were found beyond km 8.

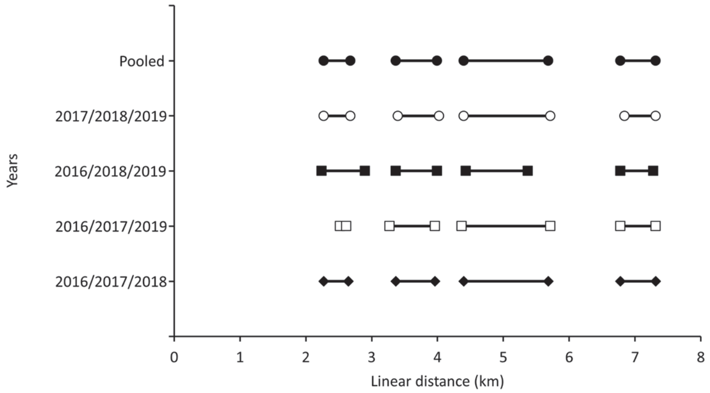

FIGURE 4. Hotspot locations along Roger Stevens Drive, Ottawa, determined from pooling three years of survey results using data from 2016 to 2019, along with hotspots determined from all four years of data pooled together. Hotspots are arranged from west to east and no hotspots were found beyond km 8.

The question of how much turtle hotspots shift from one year to another has not been explored in great detail. Amphibian and reptile hotspots were found to be generally consistent over a two-year period in New York state (Langen *et al.* 2007). Similarly, Diamondback Terrapin (*Malaclemys terrapin*) hotspots during nesting season were spatially consistent between two years in Georgia, USA (Crawford *et al.* 2014b). In contrast, a four-year survey along a 37 km road in eastern Ontario found that while many turtle hotspots were consistent across some years, none were consistent across all years (Garrah *et al.* 2015).

Hotspot mitigation typically focusses not just on those hotspots that are statistically significant, but on those with the greatest number of turtles, as road mitigation is expensive and budgets are limited. Is one year of data collection sufficient to identify which are the major hotspots? From our data, in three of the four years, the hotspot with the most turtles overall (hotspot 3; Figure 2), was also identified as the road section with the most or second-most turtles. The year with the fewest surveys (2019) also produced no clear major hotspot. Considering our data with two years of pooled surveys, five of the six datasets agreed that hotspot 3 had the most turtles, and in the sixth dataset hotspot 3 tied for first place. Hotspot 3 was also the longest in length indicating an above average number of turtles over a sustained length of road. The hotspot corresponded with large wetland on both sides of the road suggesting turtles were crossing the road at multiple locations in that section of road.

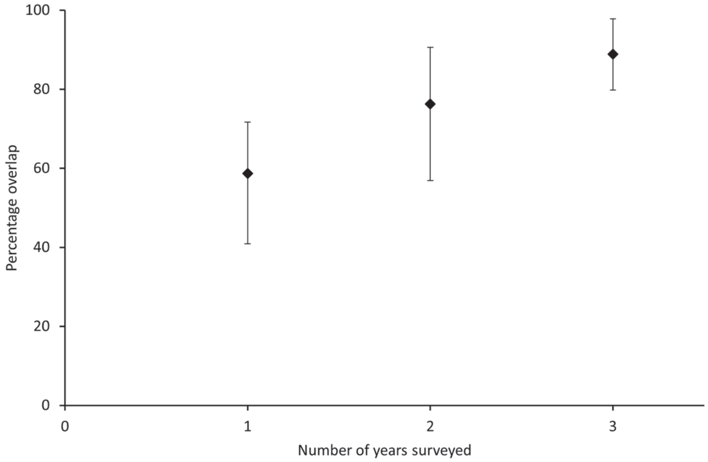

FIGURE 5. Mean percentage overlap of turtle hotspots by number of years of combined data compared with the hotspots from the four years of pooled data. Hotspots are from turtles found along Roger Stevens Drive, Ottawa, from 2016 to 2019. The mean percentage overlap is graphed along with the minimum and maximum overlap from each dataset.

Our data have limitations, beginning with the assumption that four years of surveys are adequate to determine the location and spatial extent of the hotspots. Given that hotspots defined by three or four years of surveys showed great similarity, it is unlikely that more years of surveys would greatly change the location or spatial extent of the hotspots. Although the number of surveys we conducted varied from year to year, even the year with the fewest surveys (with surveys ending in August), and fewest turtles (2019) produced hotspots in general agreement with the pooled hotspots (Figure 1). Our surveys were also conducted over a fairly short distance (15.5 km) and longer road sections may result in greater hotspot variation across time (e.g., Garrah *et al.* 2015). Overall, our results suggest that one year of intensive survey effort can identify the approximate location of major hotspots with reasonable confidence. Small variations in hotspot locations should be considered of minor importance as wildlife fencing must span a longer distance than the hotspot, as increased roadkill at fence-ends (i.e., where mitigation barrier structures terminate) is a common issue in road mitigation projects (e.g., Huijser *et al.* 2016; Markle *et al.* 2017). A more important problem would be if the hotspot from a single year's data greatly underestimated the spatial extent of the pooled hotspot. In our single year survey results, the length of the major hotspot (hotspot 3) averaged less than 60% of the length of the pooled hotspot. Fencing based on one survey year would likely have been inadequate. In contrast, the length of hotspot 3 based on two years of survey results was almost 80% of the pooled hotspot length. In this case, if wildlife fencing was installed based on the two-year hotspot results and the fencing included a generous extension beyond each end of the hotspot, then the fencing would likely be adequate to reduce or eliminate roadkill. We suggest that road surveys to identify turtle hotspots be conducted across a minimum of two years to reduce the risk of misidentifying the location and spatial extent of hotspots. Considering the expense of permanent wildlife fencing, two years of data collection is not a substantial cost and additional survey years ahead of mitigation planning and installation will only increase the accuracy of where these actions are needed.

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Note

Mallard (*Anas platyrhynchos*) drake observed consuming an adult Western Tiger Salamander (*Ambystoma mavortium*)

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Abstract

We observed a Mallard (*Anas platyrhynchos*) drake consuming an adult Western Tiger Salamander (*Ambystoma mavortium*) in the southern interior of British Columbia, Canada. To our knowledge, this is the first published report of this predator–prey interaction. We outline the events of the short observation, briefly discuss natural history of the predator and prey relevant to the observed interaction, and provide chronological photographs of the event.

Key words: Mallard; *Anas platyrhynchos*; Western Tiger Salamander; *Ambystoma mavortium*; predator–prey interaction; Species-at-Risk; White Lake Grassland Protected Area

On 11 May 2019, we observed and photographed a Mallard (*Anas platyrhynchos*) drake feeding on an adult Western Tiger Salamander (*Ambystoma mavortium*) near the middle of White Lake (49.309°N, 119.633°W) in the southern interior of British Columbia, Canada (Figure 1). We estimate that the salamander was 15–20 cm long. The Mallard appeared to have difficulty handling the large amphibian, as we observed the bird diving to retrieve it twice after dropping it dead into the water. Adult *Ambystoma* have dorsal serous glands that produce toxins distasteful to predators (Roofe 1961; Brodie and Gibson 1969; Hopkins and Migabo 2010). We speculate that the Mallard's apparent struggle handling the salamander was an attempt to "wash off" these toxins before consuming it.

On manoeuvring its prey into a position suitable for ingestion, the Mallard began tossing its head back and using the salamander's momentum to force it, head first, down its throat (Figure 1). Over the course of this 2–3 minute event, we noted a Mallard hen associating with the drake, and she too was diving periodically. Mallards eat invertebrates and plants primarily (Drilling *et al*. 2020). In winter, they eat mostly plant matter (Munro 1936; Jorde *et al*. 1983), but are known to increase their protein diet during the breeding season (Swanson *et al*. 1979). To our knowledge, no published record of Mallards feeding on Western Tiger Salamanders exists (Cook 1987); however, Mallards have been observed consuming vertebrates, such as American Toad (*Anaxyrus americanus*; Mueller 1980), fish (Harrison 1962; Harris 2005), and birds (Petrovan and Lue 2017).

White Lake, the namesake of the White Lake Grassland Protected Area, is a shallow, alkaline lake in sagebrush grasslands that is known to dry out completely late in dry summers (Richardson *et al*. 2000). The shallow depth of the lake may provide access to the Endangered Southern Mountain population of Western Tiger Salamander (SARA Registry 2021) for unlikely, opportunistic predators, such as Mallards.

Author Contributions

Writing – Original Draft: N.G.E.; Writing – Review & Editing: N.G.E., I.R.W., and J.G.W.; Conceptualization: N.G.E., I.R.W., and J.G.W.; Observation: N.G.E., I.R.W., and J.G.W.

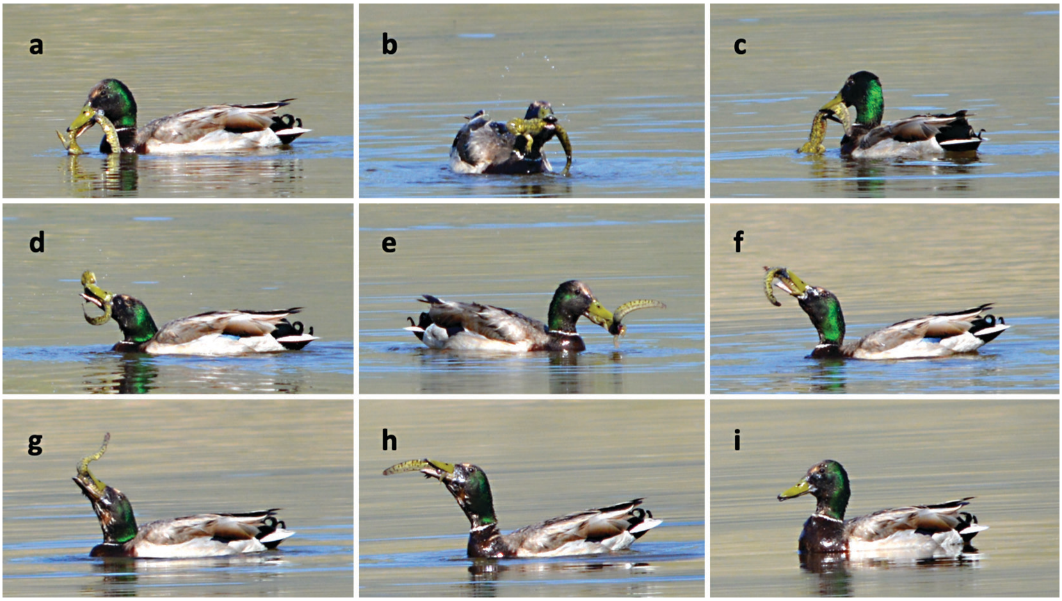

FIGURE 1. Chronological images of a Mallard (*Anas platyrhynchos*) drake consuming a Western Tiger Salamander (*Ambystoma mavortium*). a. Mallard holding the salamander in its bill; b–d. attempting to swallow the adult salamander tail first while thrashing the salamander through the water; e. manoeuvring the salamander so that its head is in the Mallard's bill; f–h. swallowing the salamander head first using its momentum to force it down the Mallard's throat; i. after successfully swallowing the salamander. Photos: I.R. Walker.

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Note

A disjunct population of American Hazelnut (*Corylus americana*): a new plant species for the Ottawa district

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Abstract

A previously unknown population of American Hazelnut (*Corylus americana*), a native shrub species, has been discovered in the Ottawa district. This location is disjunct from the species' nearest known populations. Although American Hazelnut is not a particularly conspicuous species, it was found in a relatively well documented area. The location includes remnant vegetation from the Constance Bay Sandhills, a former savannah habitat, including other species whose occurrence in the region is disjunct. American Hazelnut is strongly affiliated with savannahs and related habitats across Ontario and the upper midwest of the United States.

Key words: American Hazelnut; *Corylus americana*; Constance Bay; Ottawa; savannah; sand barren; plant distribution; plant dispersal

On 15 September 2019, A.L.B., O.J.C., and J.D.M. were exploring the inaccurately but recently named "Torbolton Forest" in the northwestern corner of the City of Ottawa, historically known as the Constance Bay Sand Hills. The Ottawa Field-Naturalists' Club Conservation Committee has an ongoing focus on the biodiversity of the Constance Bay area, which is home to a disproportionally large number of the Ottawa district's rare and unusual species. J.D.M. noted jagged leaf margins and hairy petioles on a large shrub along an informal trail. On further examination, the leaves, twigs, buds, petioles, and fruit (Figure 1) were all found to be consistent with American Hazelnut (*Corylus americana* Walter). On 22 September 2019, O.J.C., A.L.B., and Elsa Clarkin located numerous individual plants of American Hazelnut in an ovoid area ~300 m by 200 m. Records of all individual plants along with photo vouchers were added to iNaturalist (2021) and two specimens were deposited in the herbarium of the Canadian Museum of Nature (CAN 11014722 and CAN 11014723). On 28 September 2019, O.J.C. and J.D.M. conducted a further survey, locating additional individuals in the same general area. On 19 April 2020, A.L.B. documented a shrub with spring catkins, further confirming the identification (Figure 1c). Overall, several dozen individuals were found; however, only a small number of these had attained a large enough size to flower or fruit. Many individuals were short with evidence of deer grazing (Figure 1d); the closed canopy of the pine plantation likely contributes to their suppression.

American Hazelnut has not been reported previously from Constance Bay in various inventories (e.g., Porsild 1941; White 1979). In Ontario, American Hazelnut is known primarily from southern Ontario, where it is found from southern Lake Huron across to and along the north shore of Lake Ontario, and at a few sites along the St. Lawrence River valley as far as Cornwall; it is also found around the shores of Lake of the Woods in northwestern Ontario (Soper and Heimburber 1982). Soper and Heimburger (1982) show no occurrences closer to Ottawa than Cornwall, and no occurrences outside the Great Lakes–St. Lawrence watershed (Figure 2). The only records from Quebec are south of Montreal (Sabourin 2009). The shrub has not appeared in more recent regional inventories, such as Brunton's (2005) extensive flora, and this occurrence has not previously been reported to iNaturalist. More widely, American

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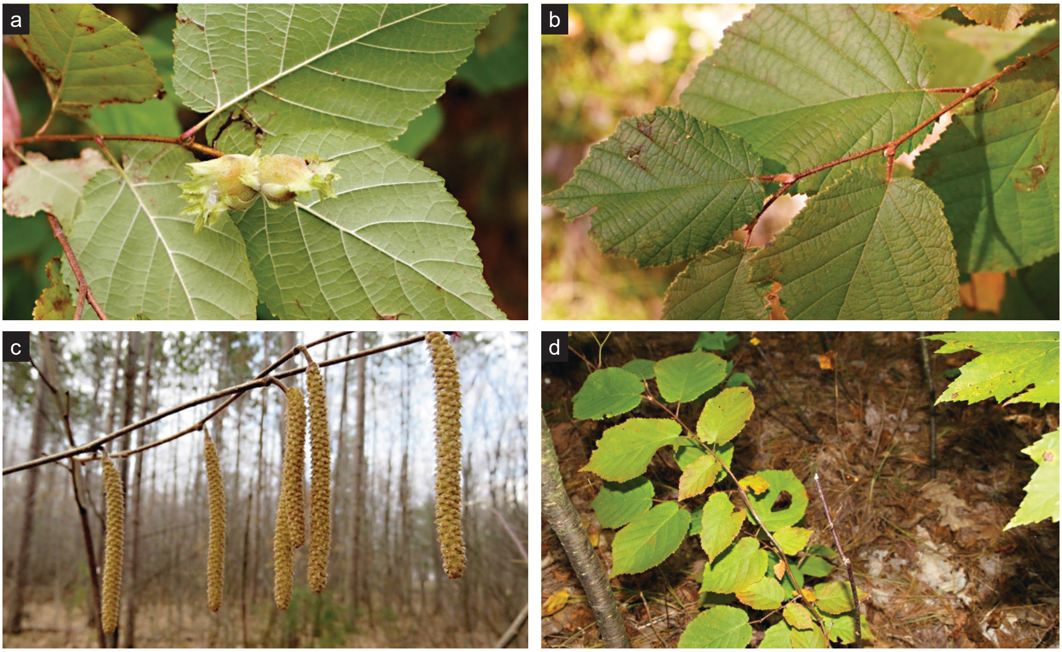

FIGURE 1. American Hazelnut (*Corylus americana*). a. Fruit and leaves, b. hairy twigs and petioles, and c. catkins, Constance Bay, Ottawa District, 15 September 2019, 26 September 2020, and 19 April 2020, respectively. The hairy twigs, petioles, and catkins of American Hazelnut distinguish it from the common and widespread Beaked Hazel (*Corylus cornuta*). d. Most of the individual American Hazelnut plants were found to be short, with evidence of browsing (26 September 2020). Photos: a. b, d. J. Mueller. Photo: c. A. Bélair.

Hazelnut is found across much of the eastern and midwestern United States (Catling and Small 2000).

American Hazelnut occurs in many situations, but is typically in upland areas that are dry and well drained, in habitats that are open or have a partial tree canopy (Soper and Heimburger 1982; Hilty 2018). This is in contrast to the typical habitat of its more familiar relative, Beaked Hazelnut (*Corylus cornuta* Marshall), which is common in the Ottawa district in moist forest understories. Among other differences, Beaked Hazelnut has glabrous leaves and twigs (Soper and Heimburger 1982). The ubiquity and familiarity of Beaked Hazelnut to local naturalists and, conversely, the lack of local familiarity with American Hazelnut, may have played a role in the lack of documentation of American Hazelnut until now.

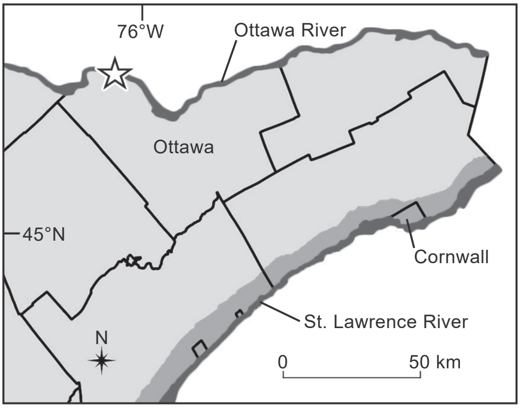

FIGURE 2. American Hazelnut is considered to be a native plant in a narrow band (dark grey) along the north shore of Lake Ontario (not shown) and the St. Lawrence River, from west of Kingston (not shown) to east of Cornwall (modified from Soper and Heimburger 1982). The new population at the Constance Bay Sandhills described here (indicated by the star) is disjunct and local.

Given the location of the shrubs, American Hazelnut is presumably native to the site as a relic of the original habitat. Today's "Torbolton Forest" is a plantation on the site of the Constance Bay Sandhills, a complex of savannah and sand barren vegetation that has been documented as having many regionally rare or unique plant species (e.g., Porsild 1941; White 1979). However, the establishment of extensive pine plantations, combined with development and sand extraction, have reduced the extent of the savannah habitat to 1% of its original area (Catling *et al*. 2010). The fraction that persists is largely the result of a single, experimentally restored clearing in the plantation, while other vegetation persists in narrow openings created by roads and trails (Catling and Kostiuk 2010). Because of the extent of habitat destruction, there has been speculation that species may have disappeared from the sandhills before being documented (Catling and Brunton 2010). One species, Beach Heather (*Hudsonia tomentosa* Nuttall), is presumed extirpated (Catling *et al.* 2010).

The discovery of a disjunct population of a southern, savannah-associated species at Constance Bay is not without precedent. While there are other sand barrens in the middle Ottawa valley that share some characteristics with the Constance Bay Sandhills, the sandhills have a distinct, southern floristic component (Carbyn and Catling 1995). Other southern species with a disjunct occurrence at Constance Bay include Butterfly Milkweed (*Asclepias tuberosa* L.), which is next encountered on granite barrens in the Frontenac Axis (Catling and Brownell 1999), and Hairy Puccoon (*Lithospermum caroliniense* (J.F. Gmelin) MacMillan), where the next-closest known locality is Sandbanks Provincial Park (Crowder *et al.* 1997). In addition to American Hazelnut, there are 13 "regionally significant" plant species found on the Constance Bay peninsula, but nowhere else in the City of Ottawa (Brunton 2005). Of these, all are associated with dry sandy habitats, and one is the extirpated Beach Heather (see Tables 1 and 2).

The presence of American Hazelnut in this area of former savannah habitat is, thus, not unexpected. American Hazelnut is known as a historically significant component of oak savannahs and as a component of thickets in tallgrass prairies (Packard 1997). In one analysis, American Hazelnut was present 79% of the time among dry sand savannah sites in the Great Lakes region (Will-Wolf and Stearns 1999) and in another, it was present in 77% of Jack Pine (*Pinus banksiana* Lambert) barrens in the northern Great Lakes region (Pregitzer and Saunders 1999), both habitats with which the Constance Bay Sandhills have some affinity (i.e., habitats share origins, structure, and ecological processes; Carbyn and Catling 1995). American Hazelnut's occurrences to the south of Ottawa include its presence in savannah remnants of the Rice Lake Plains (Catling 2008) and along the Trent River (Catling and Catling 1993). In the Ojibway Prairie Provincial Nature Reserve in Windsor, Ontario (one of the few large remaining examples of this habitat in Ontario), three shrub species resist periodic burns to form small thickets: Gray Dogwood (*Cornus racemosa* Lamarck), Sassafras (*Sassafras albidum* (Nuttall) Nees), and American Hazelnut. Of these, the hazelnut is the most frequent and most prominent (J.D.M. pers. obs.).

The dispersal of American Hazelnut to the Constance Bay Sandhills could have occurred in a number of ways. In general, the extent of prairie and savannah vegetation is believed to have expanded substantially during the hypsithermal period, c. 8000–5000 BCE (before current era i.e., before Christ; Rodger 1998). American Hazelnut may have advanced with the rest of this plant community at that time. If the shrub arrived after the savannah at Constance Bay was established, its dispersal may have been facilitated by Indigenous peoples (Reznicek 1983; MacDougall 2003). In general, savannah communities in Ontario were often occupied or used by Indigenous peoples for various purposes (Bakowski and Riley 1994). This site is near the Ottawa River, a known trade route. Although many of the disjunct species found at Constance Bay (Table 1) are not noted for their use

TABLE 1. Regionally significant plant species recorded from the Constance Bay peninsula, but not recorded from elsewhere in the Ottawa area, based on Brunton (2005).

Scientific name	Common name
Asclepias tuberosa L.	Butterfly Milkweed
Carex siccata Dewey	Dry-spike Sedge
Cyperus houghtonii Torrey	Houghton's Flatsedge
Cyperus lupulinus (Sprengel) Marcks	Hop Flatsedge
Epigaea repens L.	Trailing Arbutus
Helianthemum canadense (L.) Britton	Canada Frostweed
Hudsonia tomentosa Nuttall	Beach Heather
Lechea intermedia Leggett ex Britton	Large-pod Pinweed
Lithospermum caroliniense (J.F. Gmelin) MacMillan	Golden Puccoon
Oenothera oakesiana (A. Gray) J.W. Robbins ex S. Watson	Oakes' Evening-primrose
Polygonnum articulatum L.	Northern Jointweed
Prunus pumila var. *susquehanae* (Wildenow) H. Jaeger	Susquehanna Sand Cherry
Viola sagittata Aiton	Arrow-leaved Violet

TABLE 2. Plant species considered characteristic of tallgrass prairie and/or savannah* that are recorded from Constance Bay. Species also considered "regionally significant" or "regionally uncommon"† are highlighted in bold. A number of species overlap with Table 1.

Scientific name	Common name
Andropogon gerardi Vitman	**Big Bluestem**
Anemone cylindrica A. Gray	Tall Thimbleweed
Asclepias tuberosa L.	**Butterfly Milkweed**
Bromus kalmii A. Gray	**Kalm's Brome Grass**
Carex richardsonii R. Brown	**Richardson's Sedge**
Carex siccata Dewey	**Dry-spike Sedge**
Ceanothus americanus L.	**New Jersey Tea**
Ceanothus herbaceus Rafinesque	Prairie Redroot
Comandra umbellata (L.) Nuttall	Bastard Toadflax
Cyperus lupulinus (Sprengel) Marcks	**Hop Flatsedge**
Desmodium canadense (L.) de Candolle	Canada Tick-trefoil
Elymus canadensis L.	**Canada Wild Rye**
Helianthemum canadense (L.) Britton	**Canada Frostweed**
Helianthus divaricatus L.	Woodland Sunflower
Lechea intermedia Leggett ex Britton	**Large-pod Pinweed**
Lysimachia quadrifolia L.	**Whorled Yellow Loosestrife**
Monarda fistulosa L.	Wild Bergamot
Polygala polygama Walter	**Racemed Milkwort**
Prunus pumila L. *s.l.* ‡	**Sand Cherry**
Rhus aromatica Aiton	**Fragrant Sumac**
Schizachyrium scoparium (Michaux) Nash	**Little Bluestem**
Sorghastrum nutans (L.) Nash	**Indian Grass**
Spartina pectinata Link§	Prairie Cord Grass
Viola sagittata Aiton‖	**Arrow-leaved Violet**

*Species listed by Rodger (1998) in "Appendix 1: NHIC list of *rare and characteristic* [emphasis added] vascular plants associated with tallgrass prairie and savanna in Ontario"; as none of these species is provincially rare, all are presumed to be listed as *characteristic*.

†Brunton (2005).

‡*Prunus pumila* L. is listed by Rodger (1998) as *sensu lato*, which would include *Prunus susquehanae* Wildenow, listed by Brunton (2005) as "regionally significant".

§*Spartina pectinata* Link is strongly associated with Ottawa River shorelines in the Ottawa district, and tends to prefer a moister habitat than the other species listed here. It is unknown whether it would have occurred inland at Constance Bay where moisture allowed, but it certainly would have intermingled with the other characteristic species where the savannah habitat interfaced with the beach.

‖*Viola sagittata* Aiton is only listed by Brunton (2005) as var. *ovata* (Nuttall) Torrey & A. Gray, (formerly *Viola fimbriatula* Smith), whereas Rodger (1998) lists only the species and neither refers to a variety nor to *sensu lato* or *stricto*.

by Indigenous peoples, Hairy Puccoon was traditionally used to make a dye and body paint (Densmore 1928). However, it is conversely worth noting that American Hazelnut has not been documented at any other site along the Ottawa River corridor (Soper and Heimburger 1982; Sabourin 2009; iNaturalist 2021). Also, it is very difficult to separate the possibility that Indigenous use of the habitat is responsible for the presence of certain species from the possibility that the presence of those species is what prompted Indigenous use of the habitat (Bakowski and Riley 1994; MacDougall 2003).

Alternatively, certain bird species may have facilitated the dispersal of American Hazelnut. Blue Jays (*Cyanotta cristata*) are known to be prolific dispersers of nuts, and have cheek pouches to allow multiple nuts to be carried (Darley-Hill and Johnson 1981; Johnson and Adkisson 1985). Similarly, the Extinct Passenger Pigeon (*Ectopistes migratorius*), once considered to be the most abundant bird in North America, frequented (and was perhaps an important ecological component of) savannah habitats (Ellsworth and McComb 2003). Like Blue Jays, Passenger Pigeons are believed to have played a significant role in the dispersal of nut-bearing plant species (Webb 1986).

The pattern of occurrence of American Hazelnut at Constance Bay suggests that it is not a recent arrival. Most of the documented individual plants are suppressed by a combination of grazing and shading by planted pines (Figure 1d). The only individuals large enough to fruit are those that have been "released" into canopy gaps by a combination of tree mortality and informal trail construction. That numerous suppressed individuals are established suggests that the population was present before the conversion of the habitat to pine plantation. Like American Hazelnut, most of the other rare and unusual species of Constance Bay (Tables 1 and 2) do not occur throughout the site and are restricted to small pockets. This is readily explained by the documented extensive loss of habitat (Catling and Brunton 2010), and it is possible that additional subpopulations of American Hazelnut have been lost. Furthermore, this species is not widely available in garden centres at major retailers. Although a determined plant enthusiast could acquire one, cross-pollination is required to set seed, making it unlikely to spread from a single ornamental planting (Kock *et al.* 2008).

Although some may find it surprising that a large and relatively conspicuous plant has until now gone unrecorded in a well-botanized area, it is not surprising to include it among the flora of Constance Bay, given the ecological history of the Constance Bay Sandhills and the distribution patterns of other locally rare species at the site. This discovery shows that there remains much to be found in well-studied protected areas, especially those known to harbour significant biodiversity. Additional surveys of both Constance Bay and other sandy sites along the Ottawa River are warranted.

Voucher specimens

CANADA, ONTARIO: Ottawa, Constance Bay Sandhills (Torbolton Forest), northeast area north of the recreation centre, 45.5060°N, 76.0940°W, 22 September 2021, *A. Bélair, O. Clarkin, E. Clarkin* (CAN 11014722).

CANADA, ONTARIO: Ottawa, Constance Bay Sandhills (Torbolton Forest), northeast area north of the recreation centre, 45.5060°N, 76.0940°W, 22 September 2021, *A. Bélair, O. Clarkin, E. Clarkin* (CAN 11014723).

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A resurvey of a Wood Turtle (*Glyptemys insculpta*) population in northern New Hampshire, USA, after 13 years

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Abstract

Populations of Wood Turtle (*Glyptemys insculpta*) have declined across the species' range. We surveyed a protected Wood Turtle population in northern New Hampshire in 2007 and again in 2020 to determine whether the size of the population had changed and the average annual survival rate between the two periods. We used closed-population loglinear models to estimate the adult population size in 2007 and 2020 and, for the subset of turtles captured in both years, to estimate the rate of survival. Based on these models, we found an adult population of 56 (95% CI 33–126) in 2007 and 46 (95% CI 31–85) in 2020; we did not detect a statistically significant difference between the two population estimates. In addition, we estimated a 96% average annual adult survival rate and determined this rate could be no lower than 92%. This information provides useful baseline data and will help inform future monitoring and threat mitigation work for this population.

Key words: Wood Turtle; *Glyptemys insculpta*; mark–recapture; population estimates; loglinear models; survival; New Hampshire

Introduction

Wood Turtle (*Glyptemys insculpta*) populations have undergone well-documented declines across the species' range (Garber and Burger 1995; Daigle and Jutras 2005; Saumure *et al.* 2007; Jones and Willey 2015; COSEWIC 2018; Jones *et al.* 2018; Lapin *et al.* 2019). Threats to their population persistence include habitat loss, degradation, and fragmentation; elevated mortality associated with automobiles and agricultural machinery; and poaching and collection (Saumure *et al.* 2007; Erb and Jones 2011; Jones *et al.* 2018). Severe flooding events may also negatively affect Wood Turtle populations, especially in mountainous areas (Jones and Sievert 2009).

Regular losses of even small numbers of adults from a population of this long-lived, slow-to-mature species with high natural mortality rates during early life stages can result in chronic population declines. Compton (1999) estimated that the annual removal of only three adult Wood Turtles from a population of 100 would result in the extirpation of that population in 50 years. We studied a Wood Turtle population in New Hampshire using comparable methods 13 years apart to evaluate the species' probability of persistence in this portion of its range.

Methods

Our study area consisted of a stream and adjacent shrubby wetlands, forested uplands, and light residential development in northern New Hampshire, USA, on primarily publicly owned land managed by the United States Forest Service. Information that would help determine the exact location of the study area has been purposely withheld. Although the habitat is protected from development, threats to this population are numerous: it is adjacent to a high-traffic roadway; the habitat is popular with recreationists; it is effectively isolated from other populations; and it experienced substantial flooding during Tropical Storm Irene in August 2011. As such, the population is threatened by many of the same factors impacting other Wood Turtle populations across the species' range.

In 2007, M.T.J. conducted weekly mark–recapture surveys from May through October. A total of approximately 63 person-hours was spread across 28 surveys

(Jones 2009). M.T.J. searched for turtles in herbaceous and scrub–shrub clearings along the stream and on islets in the stream and by walking upstream toward submerged structural features, such as stumps, logs, and coarse woody debris. Captured turtles were individually marked by filing the marginal scutes with a steel triangular file following the numbering scheme developed by Ernst *et al.* (1974). Turtle age was estimated by counting growth lines, and the sex of each adult turtle was determined by observing the concavity of the plastron and the location of the cloacal opening. A telemetry study was also conducted on a subset of 10 adults; these turtles were only counted as recaptures if they were captured incidentally during surveys. In 2020, we employed a similar survey protocol as outlined in Jones *et al.* (2018) and searched the same stream reach and marked and aged turtles in the same manner as in 2007. We conducted 36 surveys from April through November (excluding August) for a total of 68 person-hours. Telemetry was not a component of the 2020 effort.

We estimated the size of the population in 2007 and 2020 using closed-population loglinear models (Otis *et al.* 1978; Rivest and Lévesque 2001) and conducted all analyses in the "Rcapture" package version 1.4-3 (Baillargeon and Rivest 2007) in the programming language R version 4.2.1 (R Core Team 2020). We considered models that account for different capture probabilities between capture events (M_t), varying capture probabilities between individual turtles (M_h), and behavioural changes resulting from the initial capture (M_b), in addition to the simplest model that assumes an equal capture probability across capture events and individual turtles (M_0). Others have used these closed-population models to estimate the population size of Wood Turtles (Daigle and Jutras 2005; Walde *et al.* 2007; Jones 2009).

Because juvenile Wood Turtles are typically less detectable than adults during visual surveys, combining juvenile detections with adult detections in population calculations can bias results (Daigle and Jutras 2005; Jones 2009). Therefore, juveniles (defined here as turtles of indeterminant sex under nine years of age; see Jones 2009) were excluded from the analysis. To address the problem of serial autocorrelation that can result from observing the same individuals during consecutive survey visits, we grouped survey results into biweekly blocks.

We selected models based on AICc (Burnham and Anderson 2004). We looked closely at the M_t model because there was a two-week period in June 2020 when many more turtles were captured compared with other capture periods. We estimated the survival rate of adult Wood Turtles captured and marked in 2007 by building a separate 2020 population estimate only for those turtles. To develop an estimate for the average annual survival rate, we took the 13th root (to account for the 13 years between surveys) of the estimated survival rate between the two periods. We ultimately used Cormack's (1992) multinomial profile likelihood approach for our population estimates and CI for all three datasets. We compared CI from the 2007 and 2020 population estimates to determine whether there was a significant difference at an alpha level of 0.05 in the adult population between the two years.

Results

In 2007, M.T.J. made 32 captures (including recaptures) of 26 individual turtles (12 males, 10 females, and four juveniles of indeterminant sex). In 2020, we made 48 captures of 28 individual turtles (10 males, 15 females, and three juveniles). Our total catch per unit effort was 0.51 turtles/person-hour in 2007 and 0.71 turtles/person-hour in 2020.

The M_0 model proved to be the best fit in 2007 and in 2020 as well as for the separate dataset used to estimate survival (Table 1); therefore, we selected it for our population estimates. We estimated a population size of 56 adults (95% CI 33–126) in 2007 and 46 adults (95% CI 31–85) in 2020. The 2020 estimate is 17% lower than the 2007 estimate, although we did not detect a significant difference in abundance of the study population between the two sampling periods because of the large and overlapping CI for both estimates, particularly in 2007.

Of the 26 turtles captured in 2007, nine (35%) were recaptured in 2020. Based on this dataset, an estimated 16 turtles captured in 2007 remained in the population in 2020, giving an estimated 96% average annual survival rate and a minimal average annual survival rate (assuming all turtles not captured have died) of 92% (Table 2). Note that the upper bound 95% CI would not exclude 100% survival.

Discussion

We did not detect a statistically significant difference in the population size of adult Wood Turtles between 2007 and 2020. Although it is possible that the study population has declined between the two sampling periods, the large CI for the population estimates prevents us from drawing any conclusions about a population trend. In a similar study involving two surveys conducted seven years apart, Daigle and Jutras (2005) were able to demonstrate a statistically significant 50% decline of a Wood Turtle population in Quebec. They captured far more turtles per survey and had more recaptures, factors that minimized their SE. Although Daigle and Jutras' (2005) 50% population decline was a total rate of decline between 1995

TABLE 1. Comparison of AICc values and other model selection metrics of several closed-population loglinear models for three sets of data for Wood Turtle (*Glyptemys insculpta*) population estimates for two years of surveys, northern New Hampshire, USA.

Model	Estimated population*	AICc	ΔAICc	*w*	*K*
2007					
M_0	56	72.693	0.000	0.696	2
M_b	36	74.673	1.980	0.259	3
M_h†	60	78.129	5.436	0.046	4
M_t	54	93.566	20.873	<0.001	10
2020					
M_0	46	105.681	0.000	0.678	2
M_b	34	107.531	1.849	0.269	3
M_h†	46	111.136	5.455	0.044	4
M_t	42	114.361	8.679	0.009	11
2007 recaptures‡					
M_0	16	47.075	0.000	0.864	2
M_b	11	50.865	3.790	0.130	3
M_h†	22	56.855	9.780	0.006	4

*Estimates for M_0, M_h, and M_t are derived from Cormack's (1992) multinomial profile likelihood approach and calculated by the closedpCI function in Rcapture. Because this approach does not work for M_b, the estimate reported in the table for this model is from the closedp function.

†Estimates from the M_h model are derived from Chao's (1987) moment estimator.

‡The sample size for this dataset ($n = 9$) was too small for us to consider M_t ($K = 9$).

TABLE 2. Estimated survival rate of Wood Turtles (*Glyptemys insculpta*) captured in 2007 and recaptured in 2020, northern New Hampshire, USA.

	Estimated	Minimum
No. surviving turtles (of 26)	16	9
Survival rate, %	62	35
Average annual survival rate, %	96	92

and 2002, we extrapolated their estimated total survival rate between those seven years into annual rates (Table 3). With an average annual survival rate of just over 80% (Table 3), their population declined by 50% in seven years. A more intensive survey effort would likely be required to detect statistically significant changes in our study population.

Despite the lack of statistical significance, it is important to note the biological significance of a 17% decline in 13 years. Removing one or two adults annually from a small population can lead to extirpation of that population within a century (Compton 1999). If the population truly has declined by 17% between 2007 and 2020, it may disappear within a matter of decades.

Others have estimated average annual rates of adult Wood Turtle survival ranging from 83% to 97%,

TABLE 3. Estimated rates of adult survival in various Wood Turtle (*Glyptemys insculpta*) populations.

Estimated annual survival rate, %	Location	Period	Study
97	Michigan	1998–2015	Schneider *et al.* (2018)
96	New Hampshire	2007–2020	Current study
93	New Hampshire	2005–2013	B. Wicklow (unpubl. data)
93	Ontario	1991–2007	Mullin *et al.* (2020)
89	Ontario	1991–2007	Mullin *et al.* (2020)
89	Minnesota	2015–2016	Lapin *et al.* (2019)
87–90	Quebec*	1998–1999	Saumure *et al.* (2007)
87	Wisconsin	2014–2015	Lapin *et al.* (2019)
86	Iowa	2012–2015	Lapin *et al.* (2019)
83.4 or 84.6	Quebec*	1995–2002	Daigle and Jutras (2005)

*Same population.

compared with our 96% (Table 3). Schneider *et al.* (2018) determined a significant population increase over the course of their study with an estimated annual rate of survival of 97%, whereas Saumure *et al.* (2007) and Daigle and Jutras (2005) noted a significant decline when survival dropped below 90% annually. These determinations agree with Compton (1999), who estimated that an annual adult survival rate of 96% would result in a stable Wood Turtle population, but that populations would decline if survival dipped below 94% annually. Lapin *et al.* (2019) posited that a minimum annual survival rate of 95% is required to maintain stable numbers over time. Therefore, the estimated 96% annual adult survival rate of our study population may indicate a stable adult population between 2007 and 2020. In light of the large CIs associated with our estimates, a survival rate that points to a stable adult population may indicate that the population size has remained relatively constant across sampling periods. Alternatively, if future monitoring confirms that the population is in decline despite this high adult survival rate, it may suggest that recruitment of hatchlings or juveniles is low and would warrant investigation. Recruitment failure has been noted in other populations and can be attributed to a variety of factors, including increased recreational use, agricultural practices, and predation (Brooks *et al.* 1992; Garber and Burger 1995; Daigle and Jutras 2005). A small proportion of captured young turtles can be attributed to poor recruitment (Daigle and Jutras 2005). It can also be a result of juveniles simply being harder to find: only 10% of Wood Turtles captured by Schneider *et al.* (2018) were juveniles and yet that population increased significantly over the course of their study.

If the nine turtles that were captured in both years represent the only surviving individuals, the corresponding average annual survival rate (92%) would not be indicative of a stable population. If this was the case, the adult population would likely be declining and poor recruitment may or may not be playing a role in a long-term population decline. More intensive survey efforts are needed to determine how adult survival and survivorship during earlier life stages are influencing population trends.

Turtles may also be removed from a population through illegal collecting and by dispersal. Although we do not know if collection plays a role in the dynamics of our study population, the collection and removal of an individual from the wild has the same effect on the population as if that turtle died; therefore, there is no need to differentiate between the two fates. However, dispersal may play a role. Jones and Willey (2020) have documented cross-watershed, overland, and long-distance (greater than 16 km of straight-line distance) movements by Wood Turtles, although such events are rare. Other Wood Turtle populations exist within 16 km, although development and other factors may isolate our study population from others. No exchange of turtles between our population and others has been observed. For these reasons, we believe the effects of dispersal on the survivorship rates described above are negligible.

Although crucial to the conservation of rare turtles, protecting habitat may not always be enough to sustain populations (Howell *et al.* 2019). The key habitat features of our study population are on lands owned by the United States Forest Service and are, therefore, protected from development, but threats to turtles remain. Recreation likely poses the biggest challenge. The simple act of encouraging the public to visit occupied Wood Turtle habitat can lead to devastating impacts: Garber and Burger (1995) determined that two separate Wood Turtle populations were extirpated within 10 years after their protected habitat was opened to recreation. The proximity of a high-traffic roadway also threatens our study population, as Wood Turtles have been documented crossing this road, and even low levels of road mortality could result in significant population decline. More research is needed to determine the risk and severity of road mortality and where crossing structures could be constructed to allow for safe turtle passage. Flooding from intense storms is also a concern. Had Tropical Storm Irene arrived later in the season when Wood Turtles were concentrated in streams instead of uplands, it may have had a far greater impact on our population.

Given the potential severity of these threats, we recommend more intensive monitoring at five-year intervals and, with increased search effort, documenting any statistically significant changes to the population and taking necessary conservation action. We also recommend nesting surveys and nest monitoring to help determine whether recruitment is an issue. In the meantime, we are working on management actions to further protect this population, because protection of existing populations should be prioritized over recovery after declines have already occurred (Keevil *et al.* 2018).

Author Contributions

Writing – Original Draft: B.H.; Writing – Review & Editing: B.H. and M.T.J.; Conceptualization: B.H. and M.T.J.; Investigation: B.H. and M.T.J.; Methodology: B.H. and M.T.J.; Formal Analysis: B.H. and M.T.J.

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Notes on the nomenclature, characteristics, status, and biology of Field Thesium, Thésium des Champs (*Thesium ramosum* Hayne; Thesiaceae/Santalaceae), a potentially serious invasive plant in Alberta

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Macdonald, I.D., and S. Visser. 2022. Notes on the nomenclature, characteristics, status, and biology of Field Thesium, Thésium des Champs (*Thesium ramosum* Hayne; Thesiaceae/Santalaceae), a potentially serious invasive plant in Alberta. Canadian Field-Naturalist 136(2): 167–177. https://doi.org/10.22621/cfn.v136i2.2819

Abstract

Field Thesium (*Thesium ramosum* Hayne; Thesiaceae/Santalaceae) is an alien species in Canada, previously misidentified as *Thesium arvense* Horvátovszky or Flaxleaf (*Thesium linophyllon* L.). It is a hemiparasitic herb characterized by its many 25–50 cm long aerial stems that grow indeterminately from a caudex. Its narrow leaves extend along each aerial stem from their base into the paniculate inflorescence. The flowers are white, 4–5 mm wide, with five corolla lobes; they are perfect and occur singly, subtended by a three-parted bract at the tip of a narrow pedicel, with 60–90 such flowers along each inflorescence. Its roots develop profuse haustoria that attach to host plant roots. *Thesium ramosum* is compared to the related native genera, *Comandra* and *Geocaulon* (placed in Comandraceae or Santalaceae), which share features but differ by having determinate growth and being unbranched. *Thesium ramosum* is widespread from western Europe to western China, but in North America it is known from only three western states and Alberta, where it has established in Fish Creek Provincial Park and elsewhere in Calgary. Worldwide, many species in the genus *Thesium* are notable invasives and *T. ramosum* has the potential to be a high risk invasive in North America. Observations in the park show that it can spread rapidly and parasitize many host species. It does not have federal or provincial control status in Canada, but because it is parasitic and has potential to become widespread, it is regulated in the USA by the United States Department of Agriculture.

Key words: *Thesium ramosum*; *Thesium arvense*; Thesiaceae; Santalaceae; vascular plant; invasive hemiparasite; Alberta; Calgary; Fish Creek Provincial Park; identification; distribution

Introduction

Field Thesium (*Thesium ramosum* Hayne [J. Bot. (Schrader) 3(1): 30, t.7 (1800)]) in Thesiaceae (or Santalaceae), formerly *Thesium arvense* Horvátovsky, is a potentially invasive vascular plant species for Canada. It was first observed in 2001 by G.J. Yaki where it grew along trails in Fish Creek Provincial Park, Calgary, Alberta. He collected specimens for identification in 2003 and 2004, and the earlier collection (University of Calgary [UAC] 81466) was identified as *T. arvense* by S.V. in June 2005 using the keys for the genera and species in Santalaceae that were available in the *Flora of China* (Xia and Gilbert 2003). Specimens collected by S.V. also were submitted to the Agriculture and Agri-Food Canada National Collection of Vascular Plants in Ottawa, Ontario (DAO 806480 and DAO 806481), where S.J. Darbyshire confirmed their identification as *T. arvense*. Consultation with NatureServe (2005) at the time of identification revealed that *T. arvense* had been reported from North Dakota and Montana, but not from Canada. Hence this was the first record of this species in Canada. Since its initial observation two decades ago, the plant has spread throughout Fish Creek Provincial Park and to other locales in the City of Calgary. Considering the potential for this species to become a serious invasive plant (PPQ 2019), we here provide detailed information on the nomenclature, characteristics, occurrence, and biology that may be relevant to its control.

Species Name

A classification of Santalales was published, first as clades based on molecular phylogenetic as well as morphological data (Der and Nickrent 2008), then

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as families by Nickrent *et al.* (2010). While the Santalaceae *sensu lato* has been retained by VASCAN (Brouillet *et al.* 2010+) and other sources (The Plant List 2013; BONAP 2015; IPNI 2015; Missouri Botanical Garden 2021), it was divided into six families (Nickrent and Musselman 2004), which include in the *Flora of North America* – Volume 12 Thesiaceae Vest (Nickrent 2016a), and Comandraceae (Nickrent 2016b). Thesiaceae has two genera in North America: *Buckleya* Torrey and *Thesium* L. Comandraceae also has two genera in North America: *Comandra* and *Geocaulon*. The name *Thesium arvense* Horvátovszky [Fl. Tyrnav. Indig. 1:27. 1774] was recognized as being illegitimate by Gutermann (2009), who reported that the proper name should be *Thesium ramosum* Hayne [J. Bot. (Schrader) 3(1): 30, plate 7 (left). 1800] (IPNI 2015). Other synonyms for the species are *Linosyris ramosa* (Hayne) Kuntze, *Thesium brevibracteatum* P.C. Tam, and *Thesium parnasi* A. DC. (Czerepanov 1981; The Plant List 2013; Missouri Botanical Garden 2021; Plants of the World 2022).

Thesium has been regarded as being a most diverse and taxonomically complex genus (Musselman and Haynes 1996). The genus has 350 species worldwide, and with 190 species, it is most diverse in southern Africa and has over 90 species in the rest of Africa. Elsewhere it has 26 species in Europe, over 40 in Asia, three in South America, and one in each of Australia and North America (D.L. Nickrent and M.A. García pers. comm. 23 March 2022).

Species Description

Thesium ramosum is a perennial, hemiparasitic herb that develops from a caudex and presents many aerial stems with a rather bushy growth habit (Figure 1).

The following description and discussion of the physical features of the species and its behaviour are intended to be an expansion of the concise description of the species in the *Flora of North America* (Nickrent 2016a). It is based on observations between 2012 and 2021, and an examination of well over 50 representative and vigorous specimens from Fish Creek Provincial Park and vicinity, and from Teton County, Montana. Terminology used conforms to Nickrent (2016a) and Harris and Harris (2000).

The **caudex** is a subterranean stem with an off-white, cylindric body that is 4–9 cm long and 4–15 mm in diameter with several 0.7–1.5 cm long lobes around its base, from which 2–7 (10) cm long, spreading roots develop. These produce many fine rootlets that envelop the roots of its parasitized host and produce bell-shaped, white **haustoria** that attach to the surface of the host roots where they appear to digest the epidermis to gain access to the root sap. Typically, the root cluster is comparatively small and shallow, given the size of the mature plants.

The apex of the caudex extends only 0.6–1.5 cm above the ground, and has many **growth buds** over its surface that begin to develop by late July and persist over the winter. By mid-April of the following year these buds start to extend as medium green **aerial stems**. About 5–10 of the aerial stems grow to about 5 cm long by mid-April to early May, and to 10–12 cm by mid-May as more of the buds on the caudex develop. By mid-June they are 20 cm long, and typically by early July they are well beyond 30 cm with an average of 37 aerial branches. In more vigorous, older plants, the aerial branches may have over 100 stems that can be up to 50 cm long. At maturity the aerial stems are 1.5–1.9 mm in diameter, somewhat woody, and have about seven blunt, finely scabrid, low longitudinal ridges. Also, some of the aerial branch bases may remain green over the winter and in the spring may produce buds and aerial branch shoots. Of interest, during the major flood of June 2013 in Calgary, aerial stems that were pushed over and buried by the flood deposits along their length produced clusters of additional normal aerial stems that emerged through the sediments (E. Harder pers. comm. 22 July 2015).

The **leaves** begin to develop as the aerial stems extend. They are alternate, medium green, simple, narrowly linear, straight to slightly falcate, acute at both ends, 3.5–4.5 (9.1) cm long, and 0.9–2.9 mm wide. They have minutely serrulate margins, a finely scabrid surface, and a single midvein that is often paralleled along each side by faint side veins that extend to half the midvein's length. The leaves are sessile, or with a petiole only 1.0–4.5 mm long, and lack stipules. Young plants have leaves that extend only (3) 4–6 (8) cm into the inflorescence, but as the plants mature they develop well into the axils of the panicle branches, often as very long blades.

The **inflorescence** develops beyond the leafy portion of the young aerial stem by early June with indeterminate paniculate growth. Initially there are only single flowers on bracted pedicels along its axis, but by late June or later secondary branches develop along the axis in the lower to middle portions of the inflorescence, each with several pedicels having bracts and flowers along their length. By mid-July the inflorescence is about 20–35 cm long, and by August it becomes notably bushy and may continue growing well into October to become over 50 cm long. Occasionally in late season, the inflorescence apices become fasciated and the flowers become congested.

A narrow, (3) 10–20 mm long, thin **pedicel** supports a single three-parted bract above which is a single flower. The **bracts** are medium green, acute, 7–12 (25) mm long, 0.6–1.1 mm wide, with minutely

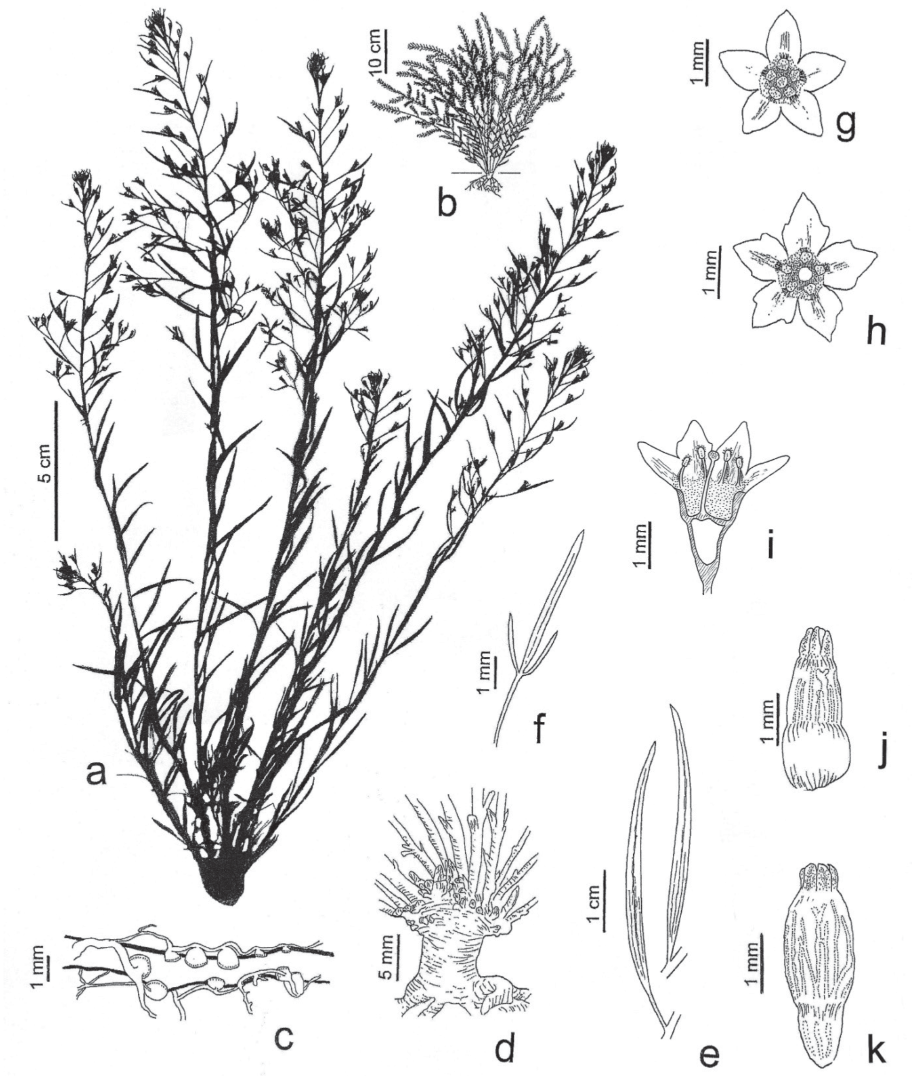

FIGURE 1. Field Thesium (*Thesium ramosum* Hayne). a. whole plant (STMU 4846: Ian D. Macdonald 140705a1), b. growth habit, c. haustoria attached to host root, d. caudex with aerial branches and buds, e. aerial branch leaves, f. bract and bracteoles, g. typical flower with smooth margins on corolla lobes, note anthers with supporting post-staminal hairs, h. flower with toothed margins on corolla lobes, i. longitudinal section of flower showing hypanthium, pistil, and anther arrangement, j. young fruit with fleshy elaiosome, k. mature fruit with firm elaiosome. Illustration by I.D. Macdonald from specimen microscope photos.

serrulate, clear margins and a finely scabrid surface with a single midvein. Two veinless bracteoles on either side of the bract's base are about (1/5) 1/3–1/2 (3/5) of its length.

The **flowers** in the Alberta sites begin to develop by late May with notable numbers by mid-June, and may continue to develop through to early October. Generally only 1–3 flowers are open at the apex of each inflorescence branch at any one time. The corollas are perfect, 4–5 mm in diameter, with a single whorl of 5 (4),1–1.3 mm long, petal-like **corolla lobes**, which Der and Nickrent (2008: 107) interpreted as a perianth where "the calyx is reduced and fused to the wall of the inferior ovary", with the sepals present only as small glands (Nickrent 2016a). The corolla lobes are triangular, only occasionally with a single tooth along each margin, and bright white with a green base adaxially and a single broad green midvein abaxially. The ovary is inferior with a single clear, pale white, erect style and a finely textured, capitate stigma that at anthesis is exserted barely above the anthers. The capitate anthers and pollen are yellow and the filaments are pale white. The five stamens originate from the green hypanthium ring at the base of the green corolla lobes and initially lie along one-half to two-thirds of the corolla lobe's length. Multiple threads (**post-staminal hairs**) attach the stamen's filaments to the corolla lobe, and as the flowers open over several hours in the mid-morning, these hairs extend to push the filaments to a vertical position so that the anthers are then held surrounding, but away from, the stigma. The flowers close by late afternoon or early evening by the swelling of the abaxial broad green midvein that pushes the corolla lobes to close around the stamens causing the corolla tips to refold back over the anthers to cover them. The flowers do not reopen again. Hence, the open corolla is available for pollination for about nine hours, and the refolded corolla lobe tips appear to prevent the anthers from touching the stigma. The refolded corolla lobes wither to a length of 0.7–0.9 mm and persist on the apex of the mature fruit. No information as to whether the plants are cross- or self-pollinated is available for our population.

The **fruit** is a nutlet-like pseudodrupe that is medium green, linear, cylindric-ovate, with an overall length of 4.1–4.4 mm, and presents three sections. At the base is the persistent pedicel that becomes the lipid-rich **elaiosome**, which is 1.0–1.3 (1.8) mm long and about half the main fruit body length. It is ivory-white and fleshy when young, but due to drying, becomes amber, firm, and longitudinally wrinkled when mature. Above this is the 2.0–2.8 mm long and 1.4–1.6 (1.8) mm wide, inferior ovary. Its surface is fluted with 12 to 16 longitudinal, parallel, finely textured veins with occasional cross veinlets. It contains a single white, oval seed that essentially fills the fruit body. At the top are the persisting, withered corolla lobes. The fruits mature over 6–10 days, start to abscise by late June or early July, and are continually produced over the growing season, often well into early October. Typical plants average over 30 aerial stems, and by late September, each inflorescence axis will have 30–50 fruits, and an additional 30–40 along the branchlets. As a result, potentially over 2250 fruits per plant may be produced.

Seedlings from the previous year's fruits develop by mid-June, and those that survive the summer's droughts can grow to about 15 cm long by the autumn. The more vigorous of these seedlings will produce flowers and fruits and have growth buds at their bases on their developing caudices at the end of the growing season. Unlike the 'tumbleweeds' of the prairies, *T. ramosum* does not separate from the ground and roll with the wind at the end of the season; rather, its dead aerial stems remain attached to the caudex, or occasionally break off, and allow their inflorescences to simply fall with minimal dispersion of any persisting fruits.

Comparison to *Comandra* and *Geocaulon*

Two related species, formerly in Santalaceae but both placed in Comandraceae (Nickrent *et al.* 2010) in *Flora of North America* (Nickrent 2016b), share similar floral characteristics in having the five-merous corollas, post-staminal hairs and fruits that are pseudodrupes, but differ in several important and readily recognizable ways. The first species is Bastard Toadflax (*Comandra umbellata* (L.) Nuttall) with three subspecies in Canada: Eastern Bastard Toadflax (*Comandra umbellata* (L.) Nuttall subsp. *umbellata*) that occurs across Canada and the eastern half of the USA, Pale Bastard Toadflax (*Comandra umbellata* subsp. *pallida* (A. de Candolle) Piehl) that occurs across the western half of the continent, and California Bastard Toadflax (*Comandra umbellata* subsp. *californica* (Eastwood ex Rydberg) Piehl) that is restricted to Vancouver Island, British Columbia. This species has dull white, narrow petals with pinnately branching abaxial midveins that neither swell nor significantly fold the petals inward after pollination, and has a fruit that is a brown, spherical, hard pseudodrupe. The subspecies differ in glaucescence, leaf thickness, and leaf blade lateral vein presentation (Flora of North America Committee 1993+; Nickrent 2016b).

The second species, Northern Comandra (*Geocaulon lividum* (Richardson) Fernald), occurs across Canada and the northern tier of states. Its petals are green and become maroon with maturity; they have reticulate abaxial veins that greatly swell and become rugose after pollination. The drying petals fold upwards and are persistent, but unlike *T. ramosum*, their tips do not enclose the stamens. Its anthers and post-staminal hairs are very short, and its fruit is a red, ovoid, fleshy pseudodrupe. However, neither species has the indeterminate growth nor the profuse branching of *T. ramosum* and neither is invasive. *Comandra umbellata* subsp. *pallida* has the synonym *Thesium umbellatum* L. [Sp. Pl. 208. 1753] (Fosberg 1940).

Occurrence in Alberta, Elsewhere in North America, and Eurasia

In Canada, *T. ramosum* currently is known from only eight locations within and near Calgary, Alberta, in the province's Grassland Natural Region, Foothills Fescue Natural Subregion (Alberta Sustainable Resource Development 2006). The most extensive population occurs along the 17.8 km length of Fish Creek Provincial Park (centrum 50.9259°N, 114.0572°W, elevation range 993–1112 m; Figure 2). Since its discovery, it has been reported from seven additional locations in Calgary and one area outside the city (see below for location descriptions).

While several of the Field Thesium sites along the Fish Creek and Bow River floodplains were inundated by the major Calgary flood of early June 2013, the plants had not yet set fruit, and it is unlikely that propagules were distributed downstream along the Bow River after this event. However, only recently it has been reported from three locations along the river south of the park (K.L. Hull pers. comm. 1 December 2021). It has not yet been reported from elsewhere in Alberta (ACIMS 2018), or the adjacent provinces: British Columbia (Douglas *et al.* 2000; BCCDC 2021); Saskatchewan (Harms 2006; SCDC 2021); Manitoba (Burchill 2016; Manitoba Environment and Biodiversity 2021), or elsewhere in Canada (Brouillet *et al.* 2010+).

Elsewhere in North America, the first collection was in 1943 from northeastern North Dakota in Towner County (Stevens 1944) from roadside and pasture sites, and was originally identified as Flaxleaf (*Thesium linophyllon* L.) by O.A. Stevens and W. Wieland (Stevens 1944). Their 1943 specimen is now at the Missouri Botanical Garden (MO 971578; van Bruggen 1986), along with a more recent 1974 specimen (MO 971576). As well, Musselman and Haynes (1996) reported *T. arvense* from Eddy County (North Dakota) based on a collection by C. Slaughter, now at the herbarium of Old Dominion University, Norfolk, Virginia (ODU *sine numero*), and included a photo illustration of a specimen with the species' characteristic corolla and cylindric-ovate fruit shape. No additional county locations in North Dakota have been reported (A.S. Shipunov pers. comm. 19 March 2022).

The species was first recorded as *T. arvense* from southwestern Montana in Madison County in 1992 by P. Lesica; his collections are now at the University of Montana (MONTU 118539). It has since been reported in that state from seven counties of the Rocky Mountains and western foothills at elevations between 1676 and 2286 m in a variety of habitats, including dry roadside rights-of-way, meadows, native and improved grasslands, riparian zone, native slope, moist grassland, and river-side hummocks in calcareous meadows (Lesica 2012; Mincemoyer 2013; Consortium of Pacific Northwest Herbaria 2016a). Indeed, just in the western portion of Teton County it is now known to be well-established in over 15 locations, including along river courses and in native grasslands (M. Korte pers. comm. 28 August 2017).

In southeastern Idaho the species, originally identified as *T. arvense*, was collected in 1993 by E.F.

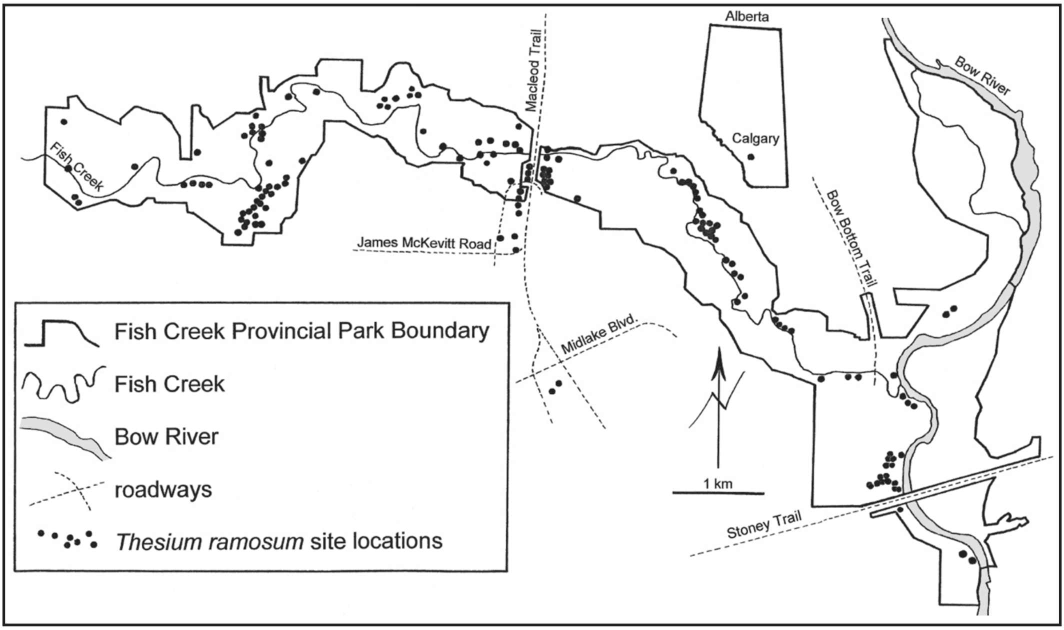

FIGURE 2. Locations of Field Thesium (*Thesium ramosum* Hayne) in Fish Creek Provincial Park and vicinity, Calgary, Alberta (to 2018).

Evert (University of Wyoming [RM] 907040) from a montane riparian meadow at an elevation of 1807 m in Teton County (BONAP 2015; Consortium of Pacific Northwest Herbaria 2016b).

There are no records from elsewhere in the United States (BONAP 2015; Nickrent 2016a), although Haynes and Musselman (1994) indicated that the genus *Thesium* had been introduced into the United States on several occasions and was reported as a minor weed in the Great Plains several decades ago, but had since been extirpated. There is only one species of *Thesium* currently known to occur in North America: *T. ramosum*. The confusion of the species with *T. linophyllon* in the original North Dakota and Montana specimen identifications probably derived from the lack of available reference floras and descriptions. *Thesium linophyllon* differs from *T. ramosum* in having rhizomes, a dichasium inflorescence, and comparatively short bracts (Gudžinskas and Žalnervičius 2017). All of the North American occurrences have been mapped in the United States Department of Agriculture weed risk assessment (PPQ 2019) and in the United States on a county level, by the Biota of North America Program (BONAP 2015).

Hendrych (1961) indicated that, of all the species of the genus *Thesium*, *T. ramosum* had the largest distribution in Eurasia. Its native distribution in southern Europe, as cited by Plants of the World (2022) and Ukranian Biodiversity Information Network (2018), extends from Italy to the Czech Republic to southwestern Russia to Ukraine to Greece; its western Asian distribution extends from Turkey to Iraq to Iran, and its central Asian distribution extends east of the Caspian Sea from Afghanistan to Turkmenistan to Kazakhstan to the Tan-Shan Mountains of western China. It also is introduced in northern European and the southeastern Baltic countries (PPQ 2019), but has not been reported from the western European and northern Baltic countries.

Invasive Potential

Around the world, the genus *Thesium* includes many species that are regarded as being invasive and weedy in agricultural situations. The Global Compendium of Weeds (Thomas 2011), which listed over 28 000 species from around the world that have been cited as having potential for being weedy, included 11 references for species of *Thesium*, *T. ramosum* (sub *T. arvense*) being listed as a 'casual alien', naturalized, or an agricultural weed in various European countries. Randall (2017) also listed invasive plant species from around the world, including five references for *T. arvense*, and at least two other species in the genus that are toxic. Other sources that cited various species of *Thesium* as being invasive include Clement and Foster (1994) for Great Britain, Haynes and Musselman (1994) for the Middle East, and Randall (2012) for Australia. Of the at least 18 species of *Thesium* occurring in Europe (Hendrych 1980), Dostálek and Münzbergová (2010) indicated that some were well-known agricultural weeds, while some species, including *T. arvense*, were considered to be endangered in some parts of Europe. For example, in the Czech Republic, they indicated that *T. linophyllon* was quite common and was capable of using a wide range of angiosperms as hosts, listing the genera *Themeda* (red grass), *Poa* (bluegrass), *Galium* (bedstraw), *Hordeum* (barley), *Allium* (onion), and *Vitis* (grape). They also found of three species studied that, while *T. linophyllon* showed some degree of host preference, two other species, *Thesium ebracteatum* Hayne and *Thesium bavarum* Schrank, showed none; however, all three had an extremely wide host range. In Jordan, Qasem (2006) indicated that *Thesium chinese* Turczanionow was a problematic species that posed high concern to farmers and was a potential threat to agriculture and forestry. In Japan, Suetsugu *et al.* (2008) reported that *T. chinese* had 22 species from 11 families as hosts, including members of their preferred hosts in the Poaceae, as well as species in the Caryophyllaceae, Rosaceae, Cyperaceae, Oxalidaceae, Violaceae, and Rubiaceae.

In North America, The Animal and Plant Health Inspection Service (PPQ 2019) produced a weed risk assessment report that dealt with the potential for *T. ramosum* to become a problem species in the USA. Their analysis considered four major topics: Establishment and Spread Potential, possibly by contamination in seed, grain, hay, etc., or in soil from foot or vehicle traffic or construction; Impact Potential on natural and agricultural environments; Geographic Potential, based on several climatic, edaphic, and habitat criteria; and Entry Potential that considered its possible spread to other jurisdictions. Despite the authors' cautions about very high uncertainty and insufficient documentation, they concluded that *T. ramosum*, with its ability to parasitize a wide variety of species, has a "High Risk invasive potential" to become weedy or invasive in the extensive range of geographic, climatic, and diverse habitat conditions which occur through much of the USA. Indeed, their Figure 2 encompasses virtually all of the lower 48 states and extends into the lower third of all Canada's provinces, including in Alberta, a corridor that reaches up to its northern boundary.

In Montana, Musselman and Haynes (1996) reported that *Thesium* plants formed haustoria on a diversity of hosts (* indicates non-native species): Timber Milk-vetch (*Astragalus miser* Douglas), *Smooth Brome (*Bromus inermis* Leysser), horsetail (*Equise-*

tum spp.), Prairie Junegrass (*Koeleria macrantha* (Ledebour) Schultes), *Kentucky Bluegrass (*Poa pratensis* L.), Sandberg's Bluegrass (*Poa secunda* J. Presl), Prickly Rose (*Rosa acicularis* Lindley), willow (*Salix* sp.), snowberry (*Symphoricarpos* sp.), Mountain Golden Banner (*Thermopsis montana* Nuttall), *Yellow Goatsbeard (*Tragopogon dubius* Scopoli), and *Red Clover (*Trifolium pratense* L.). Musselman and Haynes (1996) also noted that for Montana, it was remarkable that so few introductions of *Thesium* had occurred, considering how widespread the genus was, and how many comparable habitats were present. However, M. Korte (pers. comm. 28 August 2017) reported that *T. ramosum* is invading, not only disturbed habitats, but also native fescue grasslands, and given its spread in Teton County, it probably actually is far more widespread now than presently known in Montana.

In Alberta, *T. ramosum* presently is localized, the most widespread population being within the boundaries and immediate vicinity of the valley of Fish Creek Provincial Park (Figure 2), with small populations currently known from seven other locations within and near the city of Calgary (see below). Within the park, it has spread from a single location in 2001 to many locations along 11 km within the park by 2005, with subpopulations of only several plants to hundreds. At one location in the park (Marshall Springs), where a slope was cleared of vegetation for the construction of a storm pond and planted in rehabilitation species, *T. ramosum* initially was recorded the following year as having only an incidental occurrence, but within two years the population had exploded to over 650 vigorous plants in a 25 m × 60 m area. At another site in the park (Glennfield) that had compacted soil from former disturbance, there were 518 plants in a 5 m × 20 m area.

A survey of 102, 0.5 m radius circular plots in the park that were centred around plants of *T. ramosum* recorded 153 species. Those which occurred in more than 20% of the plots were the following (* indicates non-native species): **B. inermis* (76.5%), **P. pratensis* (64.7%), Western Snowberry (*Symphoricarpos occidentalis* Hooker; 56.9%), *Canada Thistle (*Cirsium arvense* L. (Scopoli); 50.0%), *Common Dandelion (*Taraxacum officinale* F.H. Wiggers; 35.3%), Northern Bedstraw (*Galium boreale* L.; 34.3%), *Black Medick (*Medicago lupulina* L.; 34.3%), Smooth Aster (*Symphyotrichum laeve* (L.) Á. Löve & D. Löve; 28.4%), Wood's Rose (*Rosa woodsii* Lindley; 22.5%), American Vetch (*Vicia americana* Muhlenberg ex Willdenow; 20.6%), and *Leafy Spurge (*Euphorbia virgata* Waldstein & Kitabel; 20.6%). The remaining 142 additional associated species with less than 20% frequency included three tree species, 16 shrub species, 15 native grassland grasses, 75 native grassland forbs, three wetland species, 16 local crop species, and 14 other non-native species. The habitats for these sites included successional open sites with recent or past disturbance, open low thickets, aspen grove margins, and pathway verges. The success of this species probably is due to its high production of seeds and the ability of its haustoria to tap the roots of a variety of associated host plants.

Conclusion

By the definition of Randall (2017), *T. ramosum* in Alberta at this time would be a "sleeper weed", i.e., a species that has been identified as being present and posing a future threat. In the United States, while the weed risk assessment for *T. ramosum* (PPQ 2019) has designated it as having High Risk of becoming weedy or invasive across the nation, it has not been proposed for federal listing (PPQ 2019). None of the three states where it is reported have active control measures in place (G.D. Adams pers. comm. 10 January 2018). Nevertheless, all *Thesium* species are parasitic and are regulated by the United States Department of Agriculture (USDA 2018). In Canada, the species is not listed as a regulated invasive plant species (Government of Canada 2021a,b). Also, in Alberta, *T. ramosum* has not been designated by the government (Alberta Queen's Printer 2017; Wheatland County 2017), although the Alberta Invasive Species Council (2014) has identified this species as an invasive weed for legislative consideration by the Alberta government and has recommended that it be listed as a Prohibited Noxious Weed (McClay 2012).

Selected Voucher Specimens

Specimens of *T. ramosum* from Fish Creek Provincial Park and elsewhere in Calgary have been deposited at the following herbaria (acronyms follow Thiers 2017+): University of Alberta (ALTA), Canadian Museum of Nature (CAN), Canadian Food Inspection Agency/Genotyping/Botany (CFIA-BOT), Agriculture and Agri-Food Canada (DAO), Minot State University (MISU), University of Montana (MONTU), Royal Alberta Museum (PMAE), Queen's University, Kingston (QK), St. Mary's University, Calgary (STMU), University of Calgary (UAC), University of Regina (USAS), Royal British Columbia Museum (V), and University of Manitoba (WIN). These species are listed chronologically by collection date, and present location, latitude/longitude, habitat, collection date, collector and number, and housing herbarium and accession number.

CANADA, ALBERTA: Calgary, Fish Creek Provincial Park: Marshall Springs: *ca* 50.923°N, 114.109°W, meadow, 1 July 2003, *G.J. Yaki* s.n. (UAC 81466); Glennfield, east of Macleod Trail, south of Fish Creek; along paved pathway, 50.9288°N, 114.0688°W, Fish

Creek valley basin, successional meadow of *Symphoricarpos occidentalis, Rosa woodsii / Bromus inermis, Euphorbia esula* (now *E. virgata*)*, Poa pratensis, Cirsium arvense, Galium boreale, Tragopogon dubius, Taraxacum officinale*, 20 July 2009, *I.D Macdonald 090720a1* (ALTA 123602); Glennfield: north of entrance, 50.9289°N, 114.0685°W, Fish Creek valley basin, fringe and opening of floodplain mesic mid-aged deciduous forest of *Populus balsamifera*, with *Bromus inermis, Symphoricarpos occidentalis, Poa pratensis, Monarda fistulosa, Cirsium arvense, Agrostis stolonifera, Equisetum arvense, Zigadenus elegans* (now *Anticlea elegans*)*, Anemone canadensis* (now *Anemonastrum canadensis*)*, Trifolium hybridum, Hesperostipa curtiseta*, 30 Oct. 2009, *I.D. Macdonald 091030a1* (UAC 84126); south of Bebo Grove: 50.9266°N, 114.1163°W, along pathway through successional opening in aspen forest cover, associated with *Symphoricarpos occidentalis, Bromus inermis, Poa pratensis, Plantago major, Taraxacum officinale, Solidago gigantea, Cirsium arvense*, 12 Sept. 2013, *I.D. Macdonald 130912a7* and 130912a6iii (CAN 606617 and V 239272); Marshall Springs: engineered wetlands, 50.9230°N, 114.1113°W, Fish Creek valley basin south side slope, associated with *Elymus repens, Festuca trachyphylla, Cirsium arvense, Medicago lupulina, Melilotus officinalis*, 20 Sept. 2013, *I.D. Macdonald 130920a5* (USAS *sine numero*); Marshall Springs: western portion of park south of Fish Creek, engineered wetland, 50.9236°N, 114.1091°W, Fish Creek valley basin, south side of upper slope, population of 660 plants in 25 × 60 m area, in large submesic meadow of *Elymus repens, Festuca trachyphylla, Melilotus officinalis, Medicago lupulina, Cirsium arvense, Sonchus uliginosus* (now *Sonchus arvensis* L. subsp. *uliginosus* (M. Bieberstein) Nyman)*, Thesium arvense* (now *T. ramosum*)*, Euphorbia esula* (now *E. virgata*)*, Trifolium hybridum*—Note: 43 branches, longest 51 cm, actively budding at branch bases, 28 Sept. 2013, *I.D. Macdonald 130928a1* (WIN 76458 and STMU 3495); Marshall Springs: engineered wetland pond berm south of Fish Creek, 50.9238°N, 114.1094°W, Fish Creek valley basin south side slope terrace, associated with successional meadow of *Elymus repens, Cirsium arvense, Medicago lupulina, Thesium arvense* (now *T. ramosum*)*, Melilotus officinalis*, 11 Oct. 2013, *I.D. Macdonald* 131011a1 (MONTU 159781); Marshall Springs: engineered wetland pond berm south of Fish Creek, 50.9238°N, 114.1094°W, Fish Creek valley basin south side slope terrace, associated with successional meadow of *Elymus repens, Bromus inermis, Cirsium arvense, Medicago lupulina, Thesium arvense* (now *T. ramosum*)*, Melilotus officinalis*, July 7, 2014, *I.D. Macdonald 140707a1* (MISU 0-29002); Parkside: 50.922230°N, 114.043340°W, Fish Creek valley basin, above floodplain, associated with successional meadow of *Poa pratensis, Elymus repens, Cirsium arvense, Medicago lupulina, Bromus inermis, Galium boreale, Melilotus officinalis*, 14 July 2014, *I.D. Macdonald 140714a1* (CFIA-BOT 6033 and 6034); Shawnessy: southwest corner of Macleod Trail and Shawnessy Boulevard SW intersection, 50.9118°N, 114.0682°W, urban disturbed refuse site in unkempt rough meadow, with *Symphoricarpos occidentalis, Poa pratensis, Euphorbia esula* (now *E. virgata*), 25 July 2013, *I.D. Macdonald 130725a1* (STMU 3967); Greengate Nursery: between company eastern fence and west side roadbed slope of Macleod Trail SW, south of Fish Creek Provincial Park boundary, 50.9272°N, 114.0711°W, highway roadbed berm, west-facing, successional meadow of *Bromus inermis, Poa pratense, Melilotus officinalis, Medicago lupulina, Medicago sativa, Festuca trachyphylla, Thesium arvense* (now *T. ramosum*)*, Elymus repens, Euphorbia esula (*now *E. virgata*), 28 July 2013, *I.D. Macdonald 130728a3–5* (PMAE B13.2.2., QK 18310997 and SASK *sine numero*); Bowmont Park: south of Silver Springs Road NW, 51.0975°N, 114.1797°W, Bow River valley basin, crest and slope of the northern valley promontory, associated with native grassland species *Hesperostipa comata, Calamovilfa longifolia* (now *Sporobolus rigidus* (Buckley) P.M. Peterson var. *rigidus*)*, Bouteloua gracilis, Muhlenbergia cuspidata, Carex filifolia, Symphoricarpos occidentalis, Rosa acicularis, Symphyotrichum ericoides, Symphyotrichum laeve, Solidago missouriensis, Artemisia frigida, Maianthemum stellatum, Linum lewisii, Linum rigidum, Heterotheca villosa*, 29 Sept. 2016, *I.D. Macdonald & Jenna Cross 160929a1* (UAC 93189); Beaverdam Flats Park: central portion of park, northwest corner of Ogden Community, 50.9971°N, 114.0246°W, Bow River Valley Basin floodplain, sandy opening in Balsam Poplar (*Populus balsamifera* L.) grove, associated with *Amelanchier alnifolia, Tanacetum vulgare, Rosa woodsii, Betula occidentalis, Juncus alpinus* var. *balticus, Melilotus alba, Bromus inermis, Medicago sativa,* elev. 1026 m, 9 August 2018, *I.D. Macdonald & Gustave J. Yaki 180809a1* (STMU 5800).

Additional Reported Calgary and Vicinity Locations with respect to Fish Creek Provincial Park

Ann and Sandy Cross Conservation Area: about 8 km to its southwest, but outside the boundary of the city, 51.8763°N, 114.2344°W; elev. 1262 m, 2006 (*fide* G.J. Yaki pers. comm. August 2010); McHugh Bluff Park in Sunnyside, 14 km to its north, 50.0614°N, 114.0748°W, elev. 1077 m, 2019 (K.L. Hull pers. comm. 12 July 2019); Arbour Lake: in northwestern Calgary, 23 km to its north northwest, 51.1309°N, 114.2174°W, elev. 1244 m, 2019 (B.M. Smith pers. comm. 20 August

2019); also, three sites along the Bow River south of the Park within the city with no available locations (K.L. Hull pers. comm. 1 December 2021).

Author Contributions

Investigation: I.D.M. and S.V.; Writing – Original Draft: I.D.M. and S.V.; Writing – Review & Editing: I.D.M. and S.V.; Visualization: I.D.M.

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Book Reviews

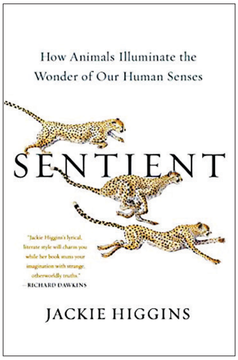
Book Review Editor's Note: *The Canadian Field-Naturalist* is a peer-reviewed scientific journal publishing papers on ecology, behaviour, taxonomy, conservation, and other topics relevant to Canadian natural history. In line with this mandate, we review books with a Canadian connection, including those on any species (native or non-native) that inhabits Canada, as well as books covering topics of global relevance, including climate change, biodiversity, species extinction, habitat loss, evolution, and field research experiences.

Currency Codes: CAD Canadian Dollars, USD United States Dollars, EUR Euros, AUD Australian Dollars, GBP British Pounds.

Biology

Sentient: How Animals Illuminate the Wonder of our Human Senses

By Jackie Higgins. 2021. Atria Books. 320 pages and 13 black and white illustrations, 37.00 CAD, Hardcover, 17.99 CAD, E-book.



This book is about sentience and the senses that comprise it. The author, Jackie Higgins, spins a wonderful tapestry of all the senses you have heard of and several more that you may not have thought about. Each sense, of the twelve listed, is expounded in a chapter that uses as its gateway the sentience of a particular species. Perhaps unsurprisingly, owls exemplify hearing and bloodhounds smell, while a sense of direction (ability to navigate) is demonstrated by Bar-tailed Godwit (*Limosa lapponica*), the amazing endurance of which allows it to navigate non-stop from Alaska to New Zealand. Others, however, are much less obvious: sense of colour is exemplified not by the peacock but by Peacock Mantis Shrimp (*Odontodactylus scyllarus*), an animal that I had not even heard of until Higgins brought it to my attention, but which I recently encountered on a coral reef off Sulawesi, Indonesia, much to my delight. Apart from an amazing colour perception, based on not three (as in humans) but 12 different colour receptors, the mantis shrimp also has the distinction of having the fastest strike of any animal (according to *Guinness World Records 2020*; 2019, Guinness World Records Limited), and they are known to smash the glass of their aquaria on occasion. I kept a respectful distance from the one I found in Indonesia.

Another mind-jolting exemplar, in this case for "pleasure and pain", is Common Vampire Bat (*Desmodus rotundus*)—hardly a species that you would associate with pleasure. But vampire bats will gladly share a blood meal among adults in exchange for the comfort of another's touch. This touch comes in the form of allogrooming, the licking, nibbling, and nuzzling that one bat performs on another. In addition to describing this fact of nature, Higgins uses it as a springboard for discussion of the importance of touch to humans, noting that we use the phrase "it touched me" to denote the arousal of any emotion, and highlighting the importance of touch among our array of senses—something that became excruciatingly clear during the distancing phase of the recent COVID-19 pandemic.

Other species used as exemplars are the four-eyed Brownsnout Spookfish (*Dolichopteryx longipes*) for 'dark vision', Star-nosed Mole (*Condylura cristata*) for 'touch', goliath catfishes for 'taste', Giant Peacock Moth (*Saturnia pyri*) for 'desire', Cheetah (*Acinonyx jubatus*) for 'balance', trashline orb-weaver spiders (*Cyclosa* spp.) for 'time', and Common Octopus (*Octopus vulgaris*) for 'body'. The book incorporates a strong human element by telling the story of each example species through the history of its discovery and the research conducted on its senses. Higgins has interviewed many of the researchers she writes about and has visited their research facilities to see, not only the animals concerned, but also the ways in which their senses have been tested and described. This element of the book makes it clear how much serendipity is involved in scientific discovery, as well as what prolonged and tedious hard work is sometimes necessary to tease out answers to simple questions we may pose about the acuity of the senses.

This is possibly the best popular science book I have read since David Quammen's *The Song of the Dodo* (1997, Touchstone)—and I read plenty of popular science! It is beautifully written, contains a plethora of information on every aspect of sentience, and is bang up-to-date in terms of the scholarship on show. It is hard to see where popular science can go to improve on this.

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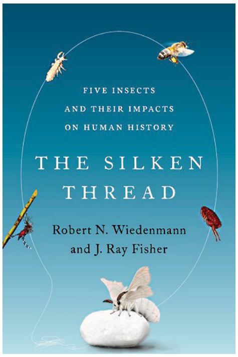
ENTOMOLOGY

The Silken Thread: Five Insects and their Impacts on Human History

By Robert N. Wiedenmann and J. Ray Fisher. 2021. Oxford University Press. 268 pages and 54 figures, 43.95 CAD, Hardcover, 26.99 CAD, E-book.



How do you choose five insects, out of an estimated five million insect species in the world, to write a book about? While other authors might have balked at the challenge, Wiedenmann and Fisher felt that there were five species that shaped human history, linked together by the Silk Roads (either directly through trade routes and diseases, or through indirect paths) … thus the main part of the title, *The Silken Thread*. While common usage refers to the Silk Road, it is really plural, as these were a vast web of trade routes, on land and sea, used for more than 1500 years, extending from Turkey to eastern China and into Greece, Italy, northern Europe, Russia, India, and North Africa. The species the authors chose were Domestic Silk Moth (*Bombyx mori*), Oriental Rat Flea (*Xenopsylla cheopis*), Body Louse (*Pediculus humanus humanus*), Yellow Fever Mosquito (*Aedes aegypti*), and Western Honey Bee (*Apis mellifera*).

Wiedenmann and Fisher divide the book into five sections—one for each species—with each section comprised of one to four chapters. Then there is a final concluding section linking the 'silken threads' together. Each section starts with a timeline related to events in that section. There are 54 figures, footnotes following some chapters, a bibliography by section, and an index. I noticed errors in the first three figures of Chapter 9: photos and captions were mixed up; one photo was used twice; and one photo was missing. This was in the e-book, and I don't know if the hard copy has the same problems. This is one of the few non-fiction e-books that I have read, and I would have preferred it in hard copy, where I could have flipped back and forth more easily to check on some historical fact or attach a sticky note … perhaps this just shows my ignorance of such features in e-books! At times the authors' writing is like a 'faux' mystery, setting up false themes or scenarios as to how or why certain events happened, then debunking each—I found this to be irritating after a while.

Domestication of Wild Silk Moth (*Bombyx mandarina*) began in about 7000 before current era (BCE i.e., before Christ) in northern China, and it has produced a species that is now unable to fly and is totally reliant on humans to reproduce effectively. Moth pupae secrete proteins for their cocoons, and this creates silk fibre, a textile with many amazing properties: high tensile strength but soft; hypoallergenic; moisture facilitating; lustrous; and impervious to growth of damaging fungi, bacteria, and clothes moths. Silk has always been a luxury product, at one time only worn by the emperor and his family, its demanding production a closely guarded secret. It has been used for clothing, as a surface for painting, as a measure of currency, and even exchanged for military aid. The trade routes used to transport silk were opened by the Han Dynasty in China around 130 BCE and became known as the Silk Roads.

All fleas are obligate parasites of mammals and birds, and Oriental Rat Flea is no exception. It hitched its fortunes to Brown Rats (*Rattus norvegicus*) and Black Rats (*Rattus rattus*), which hitched their fortunes to humans. These fleas carry the bacterium *Yersinia pestis* that causes the plague, of which there are three forms—one is the famous bubonic plague. There have been three major plague pandemics: the first, in the year 540 concentrated around Egypt and the Mediterranean; in 1331, the second originated in Mongolia and moved to Europe (becoming the Black Death); and, in 1855, the third plague pandemic erupted in China, Hong Kong, and India and spread to the rest of the world.

While fleas started the slow spread of the plague, Body Louse continued the rapid spread through Europe, where about 25 million people (one third of the estimated population at the time) died during the Black Death; a similar number died in Asia and Africa. Body lice live in clothing but feed on our bodies. We scratch the itchy bites and the lice faeces (frass) are rubbed into the bite or scratch wound … transmitting the typhus-carrying bacterium *Rickettsia prowazekii*. The first typhus epidemic may have been in 430 BCE in Greece; it also killed many of the Irish fleeing the potato famine in the late 1840s. But the highest casualties came during World War I, when typhus killed some 2.5 million Russian soldiers and civilians, and another 5 million in the five years following the end of the war.

Yellow Fever Mosquito is native to Madagascar and nearby islands off the southeast coast of Africa. It was eventually transferred to the Western Hemisphere through the transatlantic slave trade, first to Brazil, then throughout the Americas. These mosquitoes carry the yellow fever virus (a flavivirus, the family that includes dengue, Zika, chikungunya, West Nile, and Japanese encephalitis) and transmit it to humans. Of infected adults, 50–75% die because there is no cure, only palliative care. In the last half of the 19th century, yellow fever had a huge impact in the southern USA, shutting down railways and severely disrupting trade as people fled the population centres. It also affected the building of the Panama Canal (started in 1880, but completed between 1904 and 1914), killing thousands of workers, until a major campaign to eradicate mosquitos was undertaken. A yellow fever vaccine was developed in 1937.

The last of the five insects explored in *The Silken Thread* is Western Honey Bee. Ninety percent of our food is produced from 100 crops, and 70 of these are pollinated by bees, mostly honeybees. Keeping bees in hives had occurred by at least 4500 BCE in Egypt, and Europeans brought honeybees to North America in 1622 to pollinate the crops they brought with them. Wiedenmann and Fisher include a discussion of the honeybee's history as well as its current challenges, such as crowding in commercial hives that raises the risk of disease, infection, and parasites. Honeybees are also hit hard by land cover changes and insecticides, but they, in turn, are often associated with declines of native solitary bees through competition for nectar.

Wiedenmann and Fisher cover a lot of human history from the last 2500 years or so, all through the lens of these five insects (a single timeline linking all of the events would have been helpful). The sections on each of the insects could easily be expanded into separate books, which would allow for more detail on their natural history and associated human history. However, by weaving them together, the authors successfully make their case that, "The Silk Roads advanced science, mathematics, literature, art, languages, and religions, and became a singular force that shaped the diversity of societies and cultures across the continent and beyond" (p. 41). These impacts are still felt today, albeit in different forms. It will probably take more than one read of this book to absorb all of the connections.

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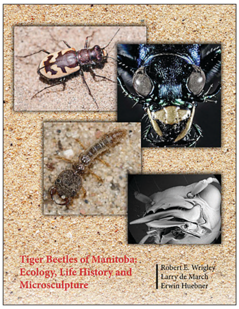
Tiger Beetles of Manitoba: Life History, Ecology and Microsculpture

By Robert E. Wrigley, Larry de March, and Erwin Huebner. 2022. Self-published. 106 pages and 80 images, 20.00 CAD, Paper.



A distinct connection to a particular taxon is sometimes an unspoken and deeply personal justification for a particular scientific pursuit. It is not uncommon for a biologist to identify themselves or others by their taxon of choice. "Oh, they are a nematode person" or "I am the fly guy around here" are familiar turns of phrase for anyone in the biodiversity world. These labels need not be problematic. They are usually self-appointed and are born of a choice of a taxon for esoteric reasons. We end up with "our taxon" because of undergraduate and grad school research projects, necessity within a work placement, or a series of direct involvements with a group of species that one cannot shake. However he got there, Dr. Robert Wrigley, lead author of *Tiger Beetles of Manitoba: Life History, Ecology and Microsculpture*, ended up as a "tiger beetle guy".

Wrigley's employment has been within natural history collections and zoos, but always in the vertebrate section. This book demonstrates that a considerable amount of his interest and passion has been with tiger beetles (Coleoptera: Cicindelidae), regardless of his official titles. He has pulled together a considerable amount of scholarship, field research, collections research, and photographic expertise from his co-authors to generate a comprehensive guide to the tiger beetles of his home province.

The book is laid out in a very user-friendly way. The opening 40 pages lays out a detailed, but highly readable, background on the Cicindelidae. This includes a history of cicindelology in Manitoba, current knowledge of the ecology of tiger beetle adults and larvae, and physical characteristics of the group. I particularly enjoyed the discussion of the tiger beetle's historical biogeography. I feel that some explanation of how the various species got there and why they are where they are is essential for a book focussed on the beetle family in a defined geographical region.

Following this introduction is a species-by-species account of the 19 species of tiger beetles found in Manitoba. In a typical field guide approach, diagnostic characteristics and excellent photos are included rather than a dichotomous key. This is entirely appropriate given the number and distinct appearance of the species listed. With these pages in hand, a reader could identify any tiger beetle that they are skilled enough to catch or photograph. Furthermore, they could learn more about the ecology of the species and possibly seek out unseen species in unique habitats within the province.

A series of scanning electron micrographs of tiger beetle structures is also included in the book. These photos bring equal parts morphological examination and aesthetic appreciation. Rather than a biophysics treatise, the photographs are presented as an expression of nature's microscope-scaled sculpture. Along with the breathtaking photographs of all 19 species alive and in the field, humourous cartoons and the occasional poem are included. Such is the freedom of self-publishing that these can be included at will.

A deep love of wondrous little predators is at the core of this book. The patience required to track down and study what are often considered the most agonizingly elusive of insects is beyond comprehension. The reward for such patience and dedication is this book. It may turn you into a tiger beetle person yourself.

A copy of *Tiger Beetles of Manitoba* may be purchased for 20.00 CAD by contacting robertwrigley@mymts.net. (Please note there is a 19.00 CAD shipping cost within Canada.) The book is also available for viewing on the Nature North website (http://naturenorth.com/Tiger%20Beetle/Tiger_Beetles.html).

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HERPETOLOGY

Biology and Conservation of the Wood Turtle

Edited by Michael T. Jones and Lisabeth L. Willey. 2021. Northeast Association of Fish and Wildlife Agencies. 235 pages, available online at no charge at https://www.northeastturtles.org/biology-and-conservation-of-the-wood-turtle.html.

The conservation of wildlife requires research followed by enough societal and political will to apply this knowledge towards conserving the species. But, getting to the level of understanding required to effectively manage a species (and convince decision makers that the knowledge has merit) takes years of research, typically by many people, and across the spatial extent of a species' range. This buildup in research effort, at least in wildlife studies, often results in certain species becoming 'flavours of the day', wherein much of the funding and energy of jurisdictions and academics focusses on doing a good job for an obvious management need. For example, in the 1990s, extensive research undertaken from British Columbia to Newfoundland and Labrador established the use of American Marten (*Martes americana*) as an indicator and proxy for the amount of mature forest that could be maintained. Within forest wildlife management, there then followed a focus on salamanders and coarse woody debris, salmon and forest nutrients, and, lately, the response to disturbance by the boreal population of Woodland Caribou (*Rangifer tarandus caribou*). In the management of wildlife in agricultural lands, much effort has gone into insectivorous birds, the timing of harvest, and the pollination ecology of bees. Wood Turtle (*Glyptemys insculpta*) is a relatively recent focus for research, with most research conducted in the last 10 years; as a resident of forest and field, Wood Turtle's habitat straddles both forestry and agriculture, and, as a species listed as either Threatened or Endangered across all jurisdictions in Canada and the United States, jurisdictions and landowners are searching for information on how to conserve the species. Thus, the timing of *Biology and Conservation of the Wood Turtle* is ideal.

The book is a compilation of the state of knowledge on Wood Turtles. Twenty-four authors contributed to 10 chapters, covering a range of topics from Evolution, Distribution, and Habitat Use, and finishing with management aspects, such as Threats and Predators, Restoration, and a Conservation Vision. The authors are an experienced group of mainly government biologists and academics, many of whom have spent decades working on turtle ecology. The editors, Michael Jones and Lisabeth Willey, also have years of research experience, with Jones, in particular, involved with most turtle-related initiatives in the American northeast. The book caters to managers and scientists but is an easy read, and will also be of use to students, the general public, and landowners. The book contains over a hundred quality colour photos, often of different Wood Turtle habitats from Minnesota to Cape Breton. As evidence of Wood Turtle's importance, the publisher is actually a collective of 13 state and provincial government departments from the northeastern United States, and from Ontario to Newfoundland and Labrador; the association has published several monographs on managed species of shared relevance, such as American Black Bear (*Ursus americanus*) and White-tailed Deer (*Odocoileus virginianus*).

As a listed species, jurisdictions and, depending on the location, some landowners, are expected to conserve Wood Turtle and its habitat. To this end, the book's latter three chapters focus on why the species is in trouble and document strategies used to improve Wood Turtle's chances of persistence. The main threats to the species are unsustainable mortality rates for adults due to roadkill and farm machinery, the illegal pet trade, and, for juveniles, mortality from egg and hatchling depredation. Options for mitigation include buffer strips with less machinery, nest protection, predator removal, and, in extreme situations, captive breeding and release. Given the rate of decline in much of Wood Turtle's range, and thus the need for more management, I would suggest that the mitigation section of the book could have been expanded, with more detail, more examples of implementation, and corresponding evidence of successes and failures. However, the coverage of spatial ecology (i.e., habitat use, movement) is very well done, and the chapters on evolution and historical biology are most welcome, as these topics are often omitted in conservation-oriented products. All in all, the *Biology and Conservation of the Wood Turtle* is an excellent compilation of the decades of research and management conducted on a species whose protection will require considerable effort. The book is another good example of the level of effort required by researchers and managers in order to conserve a species.

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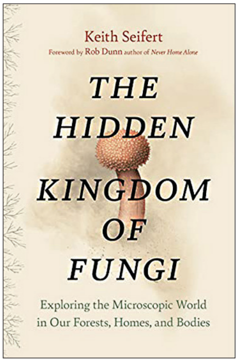
OTHER

The Hidden Kingdom of Fungi: Exploring the Microscopic World in our Forests, Homes, and Bodies

By Keith Seifert. 2022. Greystone Books. 280 pages, 34.95 CAD, Hardcover.



Most people think of fungi as toadstools or mushrooms seen in gardens or forests and perhaps the moulds growing in showers or bathtubs. Occasionally, someone will opt out of having mushrooms as a pizza topping, but little additional thought is given to these strange organisms. Personally, I've had a long-standing interest in fungi, spanning back to my childhood when I would scour the countryside with my *Non-Flowering Plants* field guide (Shuttleworth and Zim 1967) in hand, trying to figure out the various mushrooms I encountered. Keith Seifert has written an impressive book to broaden our perception of fungi and foster a new level of appreciation for them.

Seifert's *The Hidden Kingdom of Fungi* is divided into three major parts. Part 1, The Hidden Kingdom, includes two chapters, Life in the Colonies: Fungal Evolution and Life on the Commons: from Mutualism to Parasitism to Biological Invasion. Part 2, The Fungal Planet, has five chapters, Forests: Seeing the Fungi for the Trees; Farming: the Seventh-Oldest Profession; Fermentation: Food, Drink, and Compost; The Secret House: Fungi and the Built Environment; and Holobiont: the Mycobiome and the Human Body. Part 3, The Mycelial Revolution, has two final chapters, Mycotechnology: Fungi for the People and Thirty Thousand Feet: Fungi and the Sustainable Planet. Also included is a foreword by Rob Dunn (a writer and biologist whose work has included studying fungi and bacteria in houses), a note about names, an introduction, acknowledgements, an appendix of fungal classification including the kingdoms of

Mycota and fungal-like Stramenopiles, notes, literature cited, and an index.

The book communicates well that fungi are everywhere—we breathe in fungal spores constantly, our bodies are breeding grounds for yeasts, and the global environment supports a vast microbiome where fungi play a critical role. Some of my favourite chapters were in Part 2. Fungi play a daily role in our lives, from farming to fermentation. In Chapter 5, the author states that generally towns and cities originated with the invention of agriculture, which provided a steady source of food. However, an alternative point of view is that cities arose to guarantee a reliable source of alcohol. Humans stumbled on the fermentation process—likely from eating fermented fruit on shrubs and trees—and wanted to mass-produce it. In fact, alcohol production using Brewer's Yeast (*Saccharomyces cerevisiae*) appears to have occurred before using this same yeast species to bake bread. The use of fungi in food production is everywhere, from cheese and soy sauce to chocolate, tea, and coffee.

Chapter 6, The Secret House, was an eye-opener. Our houses harbour more species of fungi than once assumed. Fungal spores float in the air, make up most of the dust on our furniture, collect in the carpet, and slowly decompose the two-by-fours in our walls. Moist environments, like kitchens, bathrooms, basements, and crawl spaces, support hundreds of fungal species. Living in homes with high concentrations of fungal spores may lead to a variety of health issues, including allergies and asthma. The author tested a central vacuum system sample from his house and discovered that the sample contained over 600 fungal species! Most of the species arrived indoors from the yard, but others originated from spoiling food, soil fungi tracked in on shoes, and the expected dust fungi. The presence of conifer endophytes was a puzzle until the author recalled the annual festivities involving a Christmas tree.

Humans are in constant contact with fungi; our bodies may be home to more fungal species than we will ever realize. We are essentially walking ecosystems. Some of the more commonly known signs of fungi living on our bodies include dandruff (caused by a yeast-like fungus called *Malassezia*), and athlete's foot, jock itch, and ringworm, which can all be caused by up to 40 different types of fungal species, but most often by just one, *Trichophyton rubrum*. We buy creams and other medications to treat these fungal ailments only to have the irritations return. Humans and fungi are closely related, so typically what is toxic to fungi is also toxic to us. Hence, most fungal infections return after a couple weeks post-treatment because not all the fungal cells are eradicated, which allows them to grow and spread again.

Fungi, however, have proven to be incredibly helpful. One of the best examples of scientific serendipity involved Alexander Fleming and his breakthrough while studying enzymes and bacterial infections in his laboratory (see Fleming 1929). After returning from a family holiday, he examined an old culture of the pathogenic skin bacterium *Staphylococcus aureus* that had been accidentally contaminated with a green mould colony. He noticed that the interface between the mould and the cream-coloured bacterium was now clear agar on the gel plate. The clear (rather than green) agar meant that something was killing the bacterium. Fleming named the bacterium-killing substance penicillin. Since then, various fungal species have been used to treat bacterial infections, launching the age of antibiotics.

With the good comes the bad, unfortunately. Since 1980, about 100 species of frogs, toads, and salamanders have gone extinct, largely due to chytridiomycosis, an infectious disease caused by the fungus *Batrachochytrium dendrobatidis*, or Bd. The disease is about 90% fatal and may lead to an "amphibian apocalypse" (p. 207). In addition to Bd, another fungal species, *Batrachochytrium salamandrivorans*, or Bsal, was found in Europe infecting European Fire Salamander (*Salamandra salamandra*). Apparently, the disease originated in southeastern Asia. It has not yet spread to North America, where 40% of the world's salamander species occur. Our understanding of Bd and Bsal has only just begun, and hopefully we can curb the spread of these deadly fungal diseases and an eventual "apocalypse".

In the last chapter, the author provides a summary (p. 218) worth repeating as we bear witness to the extraordinary biodiversity fungi provide:

> Reconsidering our attitude towards fungi is an important part of modifying our actions. I hope more people will become curious about our microscopic neighbors—or at least less suspicious or fearful of them. Fungi are among our closest relatives, and we are already deeply embedded with them. We should work with them a lot more than we do now. The future is fungal. It is also bacterial, algal, protistan, viral, buggy, wormy—full of all sorts of creatures, the big and beautiful, the small and ugly. Most of the life forms around us were here long before we arrived and will remain long after we are gone. Let's learn what we can from them and hope for a long, rich journey together.

With the author's hopeful words, I recommend *The Hidden Kingdom of Fungi* as an inspiring vehicle of exploration and intrigue. Understanding that we share this planet with millions of incredibly fascinating life forms is the first step in becoming thoughtful stewards of the planet.

Acknowledgements: I thank Susan I. Hagen and Rebecca S. Wang for providing feedback and improving the manuscript.

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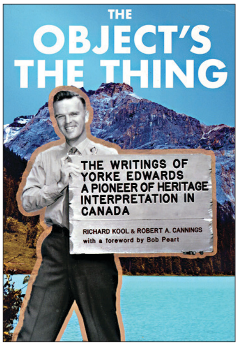
The Object's the Thing: the Writings of Yorke Edwards, a Pioneer of Heritage Interpretation in Canada

By Richard Kool and Robert A. Cannings. 2021. Royal BC Museum. 336 pages, 24.95 CAD, Paper.



As the title suggests, this volume introduces a prominent figure in the 'Golden Age' (1960s and 1970s) of Canadian natural environment interpretation. Simply put, particularly in regards to parks, interpretation programs are springboards for visitors' understanding and appreciation of the landscape. Done well, they not only enhance visitor experiences but greatly assist in the conservation and management of the natural environment. I began my own career in park interpretation in the late 1960s and worked in various capacities in interpretive programming, planning, and facility design both in Ontario and Alberta parks over the following decade and a half. I looked forward to reading this book both for its potential documentary value and as a trip down memory lane.

The Object's the Thing extolls the achievements and writings of Roger Yorke Edwards (1924–2011). It was coauthored by one of the authors of the comprehensive obituary (and bibliography) that appeared in this publication (Canning *et al.* 2020). The book's intention is to show why Edwards was, in the view of the foreword's author Bob Peart, "widely accepted as 'the father of nature interpretation in Canada'" (p. xvii). Edwards himself would disagree with this assessment, noting that "There is really nothing new about interpretation" (p. 192). He was correct—it was over a century old in Canada when he started his interpretive career in 1957. The foreword statement is but the first of a series of startling exaggerations (further discussed below) that undermine this otherwise thorough documentation of Edwards's long and productive career.

Edwards initiated the British Columbia (BC) park interpretive program in 1959 and was its senior administrator for almost a decade. Subsequently with the Canadian Wildlife Service (CWS) in Ottawa for five years (until 1972), he oversaw the development of several regional interpretive centres before moving back to BC, where he served for over a decade as assistant director and then director of the Royal British Columbia Museum. *The Object's the Thing* (a phrase taken from a speech [pp. 264–275] on the importance and use of artefacts in interpretation) chronicles his thoughts and activities during his career, mostly through extracts from his speeches, annual reports, and popular articles.

One of the best parts of *The Object's the Thing* is the biographical first chapter. It describes Edwards's naturalist beginnings and biological-interpretive career, commencing at the University of Toronto where he studied forestry. The chapter is full of solid information and context, although I would have liked to see more about his time (1945–1947) in Ontario's Algonquin Park associating with the biologists who were developing the interpretive program there. That surely is where Edwards's first thoughts on park interpretation developed.

The following chapter describing Edwards's interpretive insights as being exceptional, if not nationally unique, is less successful. The chapter's overall impact is lessened by overly-grand claims or simply incorrect assertions, including that his work in BC parks "conceptualized and created park interpretation in Canada" (p. 27). Such a program had been running in Ontario's Algonquin Park for 15 years before the first fledgling BC effort began. Indeed, Edwards acknowledged that fact himself (p. 285). Simply put, Algonquin Park is the birthplace of park interpretation in Canada. Virtually every insight presented in this chapter as representing new interpretive thinking by Edwards was, in fact, already in practice elsewhere in Canada (in the Ontario parks program, at least).

Similarly, the assertion in the first chapter that by the late 1960s the BC program was considered "a standard for park education across the country" (p. 10) is dubious. We in the Algonquin Park interpretive naturalist program at that time (the largest such program in Canada) knew nothing of the BC program. In the mid-1970s, the rapidly expanding and comparable Alberta park program also did not recognize the previously established BC program as being especially significant either (pers. obs.). That's not to say that the BC program was not excellent, but that's far from it being a recognized national standard.

The rest of the book—over 250 pages—consists of short essays, speeches, and reports arranged in chronological order and detailing (rather repetitively) Edwards's thinking and activities concerning park and museum interpretation and natural environment conservation. The essays are typically well-expressed summations of established interpretive theory and practice from that time. It's almost entirely familiar and well-established 'how-to-do-it' stuff, with few or no new guiding principles for Canadian park interpretation being offered.

Oddly, there is not a word by either the authors or Edwards concerning the rich and diverse origins of natural history interpretation in Canada. Nothing is said, for example, of the groundbreaking and innovative work by Philip Henry Gosse, who wrote the first Canadian interpretive publication (*The Canadian Naturalist: a Series of Conversations on the Natural History of Lower Canada*) in 1840. Similarly, no mention is made of the contribution to 19th- and early 20th-century interpretive literature by Catharine Parr Traill and Ernest Thompson Seton. Nor is there recognition of the interpretive value or suitable parks application of the eloquently crafted early to mid-20th-century environmental and conservational insights of people like Grey Owl (Archie Belaney) and Farley Mowat. For a reader looking for an overview of how the BC parks or the short-lived CWS interpretive programs developed, or an understanding of Edwards's important roles in shaping them, however, *The Object's the Thing* is informative.

While Edwards was indeed an important interpretive pioneer in BC, his perspective on natural environment conservation was more passive than many of his naturalist contemporaries, particularly during the environmentally turbulent late 1960s and 1970s. During his brief term (1969) on the Ottawa Field Naturalists' Club's (OFNC) Board of Directors and as Chairman of the OFNC Natural Areas Committee, for example, he argued that naturalists' clubs should primarily study nature, gather data, and encourage established authorities to improve ecological management of natural lands under their control (e.g., the federal government regarding Gatineau Park in the National Capital Region), but should not forcefully advocate for conservation action (Edwards 1970). Also, the philosophical perspectives he expressed concerning BC's controversial 1960s hydroelectric dam construction and forestry practices (pp. 171 and 179–182, respectively) seem to condone those massively impactful resource exploitation initiatives. We are all creatures of our times, of course. Just the same, some of these expositions seem shocking not just looking back from today, but probably in his day as well.

There are few interpretive revelations to be had in *The Object's the Thing* for those who have read widely on the subject. Or, like this reviewer, are old enough (!) to have directly participated in that aptly described 'Golden Age' of Canadian park interpretation. Still, this is a useful review and compilation of achievement for any readers interested in how environmental messaging developed in Canada (especially western Canada) in the mid to later part of the 20th century. Accordingly, Yorke Edwards deserves the accolades he has received (including election as an Honorary Member of the OFNC in 1980) for his promotion of natural environment interpretation in Canada, especially in British Columbia.

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NEW TITLES

Prepared by Jessica Sims

If you are interested in reviewing a book on this list, please contact Jessica Sims (bookrevieweditor@canadianfieldnaturalist.ca). This list covers a range of upcoming and new releases in field biology, ecology, and natural history. We also welcome your suggestions for new titles and offers to review unlisted books with a Canadian connection, including those on any species (native or non-native) that inhabits Canada, or books covering topics of global relevance, including climate change, biodiversity, species extinction, habitat loss, evolution, and field research experiences.

Please note: Books marked with a * have already been assigned to a *Canadian Field-Naturalist* reviewer. All other books are available for review, and review copies of books marked with a † have been explicitly offered by publishers.

Currency Codes: CAD Canadian Dollars, AUD Australian Dollars, USD United States Dollars, EUR Euros, GBP British Pounds.

BIOLOGY

Ancestors in Evolutionary Biology: Linear Thinking about Branching Trees. By Ronald A. Jenner. 2022. Cambridge University Press. 385 pages, 79.95 CAD, Hardcover.

†The Cosmic Oasis: the Remarkable Story of Earth's Biosphere. By Mark Williams and Jan Zalasiewicz. 2022. Oxford University Press. 288 pages, 27.95 USD, Hardcover. Also available as an E-book.

Cryptic Species: Morphological Stasis, Circumscription, and Hidden Diversity. Edited by Alexandre K. Monro and Simon J. Mayo. 2022. Cambridge University Press. 350 pages and 75 black and white illustrations, 102.95 CAD, Hardcover.

Dancing Cockatoos and the Dead Man Test: How Behaviour Evolves and Why it Matters. By Marlene Zuk. 2022. W.W. Norton. 352 pages, 38.95 CAD, Hardcover.

The Earth: a Biography of Life: the Story of Life on our Planet through 47 Incredible Organisms. By Elsa Panciroli. 2022. Greenfinch. 256 pages, 44.00 CAD, Hardcover, 20.99 CAD, E-book.

The Evolution of Agency: Behavioral Organization from Lizards to Humans. By Michael Tomasello. 2022. MIT Press. 176 pages, 30.00 USD, Hardcover, 24.90 USD, E-book.

Evolution of Learning and Memory Mechanisms. Edited by Mark A. Krause, Karen L. Hollis, and Mauricio R. Papini. 2022. Cambridge University Press. 400 pages, 137.95 CAD, Hardcover, 49.95 CAD, Paper.

The Hidden Universe: Adventures in Biodiversity. By Alexandre Antonelli. Illustrations by Lizzie Harper. 2022. University of Chicago Press. 256 pages and 26 halftones. 22.00 USD, Hardcover. Also available as an E-book.

An Immense World: How Animal Senses Reveal the Hidden Realms Around Us. By Ed Yong. 2022. Knopf Canada. 464 pages, 38.00 CAD, Hardcover, 16.99 CAD, E-book.

Much Like Us: What Science Reveals about the Thoughts, Feelings, and Behaviour of Animals. By Norbert Sachser. Translated by Ruby Bilger. 2022. Cambridge University Press. 166 pages, 27.95 CAD, Hardcover.

Power in the Wild: the Subtle and Not-So-Subtle Ways Animals Strive for Control over Others. By Lee Alan Dugatkin. 2022. University of Chicago Press. 208 pages, 32.50 CAD, Hardcover, 24.99 CAD, E-book.

Sexus Animalis: There is Nothing Unnatural in Nature. By Emmanuelle Pouydebat. Translated by Erik Butler. 2022. MIT Press. 184 pages, 65 colour illustrations, and 14 black and white illustrations, 39.95 CAD, Hardcover.

What Is Regeneration? By Jane Maienschein and Kate MacCord. 2022. University of Chicago Press. 184 pages and 18 halftones, 20.00 USD, Paper. Also available as an E-book.

Women in Field Biology: a Journey into Nature. By Martha L. Crump and Michael J. Lannoo. 2022. CRC Press. 316 pages and 116 black and white illustrations, 104.00 USD, Hardcover, 39.96 USD, Paper. Also available as an E-book.

BOTANY

Chasing Plants: Journeys with a Botanist through Rainforests, Swamps, and Mountains. By Chris Thorogood. 2022. University of Chicago Press. 224 pages, 40 colour plates, and 76 halftones, 27.50 USD, Hardcover. Also available as an E-book.

Dead Wood: the Afterlife of Trees. By Ellen Wohl. 2022. Oregon State University Press. 176 pages and 51 black and white photos, 28.95 CAD, Paper.

Napoleon's Garden Island: Lost and Old Gardens of St Helena, South Atlantic Ocean. By Donal P. McCracken. 2022. University of Chicago Press. 392 pages, 38 colour plates, and 70 halftones, 50.00 USD, Hardcover. Also available as an E-book.

†Rare Vascular Plants of Alberta. Second Edition. By Gina Fryer, Jane Lancaster, Kimberly Ottenbreit, Christina Metke, Donna Cherniawsky, Amy Griffiths, Kristen Foreman, and Jenalee Mischkolz. 2022. Alberta Native Plant Council. Distributed in Canada by UBC Press. 664 pages, 548 colour photos, 508 illustrations, and 934 maps, 47.95 CAD, Paper.

The World Atlas of Trees and Forests: Exploring Earth's Forest Ecosystems. By Herman Shugart, Peter White, and Sassan Saatchi. 2022. Princeton University Press. 400 pages and 250+ colour photos, colour illustrations, and colour maps, 74.99 CAD, Hardcover, 54.99 CAD, E-book.

CONSERVATION AND CLIMATE CHANGE

Climate Change Adaptation: an Earth Institute Sustainability Primer. By Lisa Dale. 2022. Columbia University Press. 216 pages, 26.00 CAD, Paper.

†Conservation and the Genomics of Populations. Third Edition. By Fred W. Allendorf, W. Chris Funk, Sally N. Aitken, Margaret Byrne, and Gordon Luikart. Illustrations by Agostinho Antunes. 2022. Oxford University Press. 784 pages and 321 colour line figures and illustrations, 152.03 CAD, Hardcover, 88.11 CAD, Paper, 77.07 CAD, E-book.

Fen, Bog, and Swamp: a Short History of Peatland Destruction and its Role in the Climate Crisis. By Annie Proulx. 2022. Scribner. 208 pages, 32.00 CAD, Hardcover, 15.99 CAD, E-book.

An Introduction to Conservation Biology. Third Edition. By Anna A. Sher. 2022. Sinauer Associates. 528 pages, 104.99 USD, Paper. Also available as an E-book.

Negative Ecologies: Fossil Fuels and the Discovery of the Environment. By David Bond. 2022. University of California Press. 262 pages, 85.00 USD, Hardcover, 29.95 USD, Paper. Also available as an E-book.

Nowhere Left to Go: How Climate Change is Driving Species to the Ends of the Earth. By Benjamin Von Brackel. Translated by Ayça Türkoğlu. 2022. The Experiment. 288 pages, 34.95 CAD, Hardcover, 24.99 CAD, E-book.

Requiem for America's Best Idea: National Parks in the Era of Climate Change. By Michael J. Yochim. 2022. High Road Books. 288 pages and 32 colour plates, 34.95 USD, Hardcover. Also available as an E-book.

Rewilding the Sea: How to Save our Oceans. By Charles Clover. Illustrations by Emily Faccini. 2022. Witness Books. 288 pages, 21.99 GBP, Hardcover.

Ripple Effects: How We're Loving our Lakes to Death. By Ted J. Rulseh. 2022. University of Wisconsin Press. 288 pages and 32 black and white illustrations, 26.95 USD, Hardcover.

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ORNITHOLOGY

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ZOOLOGY

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The Conchological Albums: Terrestrial Molluscs. Volume 10: Camaenidae (6). By Guido T. Poppe, Sheila P. Tagaro, and Philippe Poppe. 2022. ConchBooks. 203 pages and 95 plates, 58.00 EUR, Hardcover.

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Fascinating Shells: an Introduction to 121 of the World's Most Wonderful Mollusks. By Andreia Salvador. 2022. University of Chicago Press. 256 pages and 123 colour plates, 29.50 CAD, Hardcover, 21.99 CAD, E-book.

From the Seashore to the Seafloor: an Illustrated Tour of Sandy Beaches, Kelp Forests, Coral Reefs, and Life in the Ocean's Depths. By Janet Voight. Illustrations by Peggy Macnamara. Foreword by David Quammen. 2022. University of Chicago Press. 144 pages and 76 colour plates, 32.50 CAD, Hardcover.

A Guide to the Deer of the World. By Charles Smith-Jones. Foreword by Susana González and Noam Werner. 2022. Stackpole Books. 320 pages, 97.00 CAD, Hardcover.

†**Planktonia: the Nightly Migration of the Ocean's Smallest Creatures.** By Erich Hoyt. 2022. Firefly Books. 176 pages and 150 colour photos, 35.00 CAD, Hardcover.

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Polar Bears: Beloved and Betrayed. By Morten Jørgensen. 2022. Self-published. 208 pages, 100+ colour illustrations, and black and white photos, and colour illustrations, 40.00 EUR, Paper.

Small Carnivores: Evolution, Ecology, Behaviour and Conservation. Edited by Emmanuel Do Linh San, Jun J. Sato, Jerrold L. Belant, and Michael J. Somers. Foreword by Anne Rasa. 2022. Wiley. 602 pages, 120.00 CAD, Hardcover, 96.99 CAD, E-book.

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OTHER

Audubon at Sea: the Coastal and Transatlantic Adventures of John James Audubon. Edited by Christoph Irmscher and Richard J. King. Foreword by Subhankar Banerjee. 2022. University of Chicago Press. 352 pages, 20 colour plates, and 38 halftones, 30.00 USD, Hardcover, 29.99 USD, E-book.

Biotic Borders: Transpacific Plant and Insect Migration and the Rise of Anti-Asian Racism in America, 1890–1950. By Jeannie N. Shinozuka. 2022. University of Chicago Press. 296 pages and 17 halftones, 123.50 CAD, Hardcover, 39.00 CAD, Paper, 29.99 CAD, E-book.

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The Correspondence of Charles Darwin. Volume 29 (1881). Edited by Frederick Burkhardt, James A. Secord, and the editors of the Darwin Correspondence Project. 2022. Cambridge University Press. 1022 pages, 143.95 CAD, Hardcover.

I Never Met a Rattlesnake I Didn't Like: a Memoir. By David Carpenter. 2022. Thistledown Press. 232 pages, 24.95 CAD, Paper.

The Inland Island: a Year in Nature. By Josephine Johnson. 2022. Scribner. 192 pages, 25.00 CAD, Paper, 13.99 CAD, E-book. First published in 1969.

Killing Bugs for Business and Beauty: Canada's Aerial War against Forest Pests, 1913–1930. By Mark Kuhlberg. 2022. University of Toronto Press. 284 pages and 36 black and white illustrations, 95.00 CAD, Hardcover, 42.95 CAD, Paper. Also available as an E-book.

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Lookout: Love, Solitude, and Searching for Wildfire in the Boreal Forest. By Trina Moyles. 2022. Random House of Canada. 328 pages, 21.00 CAD, Paper, 13.99 CAD, E-book.

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Mushrooms of the Pacific Northwest. Edition, Revised and Updated. By Steve Trudell. 2022. Timber Press. 416 pages, 29.99 USD, Paper. Also available as an E-book.

Salmon Wars: the Dark Underbelly of Our Favorite Fish. By Douglas Frantz and Catherine Collins. 2022. Henry Holt and Co. 368 pages, 39.99 CAD, Hardcover, 15.99 CAD, E-book.

Screening Nature and Nation: the Environmental Documentaries of the National Film Board, 1939–1974. By Michael D. Clemens. 2022. AU Press. 232 pages, 29.99 CAD, Paper. Also available as an E-book.

The Sloth Lemur's Song: Madagascar from the Deep Past to the Uncertain Present. By Alison Richard. 2022. University of Chicago Press. 352 pages, 12 colour plates, and 50 halftones, 27.00 USD, Hardcover. Also available as an E-book.

Soundings: Journeys in the Company of Whales: a Memoir. By Doreen Cunningham. 2022. Scribner. 320 pages, 36.99 CAD, Hardcover, 17.99 CAD, E-book.

Traces of the Animal Past: Methodological Challenges in Animal History. Edited by Jennifer Bonnell and Sean Kheraj. 2022. University of Calgary Press. 284 pages and 65 illustrations, 74.99 CAD, Hardcover, 42.99 CAD, Paper.

When Animals Dream: the Hidden World of Animal Consciousness. By David M. Peña-Guzmán. 2022. Princeton University Press. 272 pages, 24.95 USD, Hardcover. Also available as an E-book.

The Canadian Field-Naturalist

News and Comment

Compiled by Amanda E. Martin

Upcoming Meetings and Workshops

Wildlife Society Conference

The 29th annual conference of the Wildlife Society to be held 6–10 November 2022 at the Spokane Convention Center, Spokane, Washington. Registration is currently open. More information is available at https://twsconference.org/.

Joint Annual Meeting of the Entomological Society of America, Entomological Society of Canada, and Entomological Society of British Columbia

The joint annual meeting of the Entomological Society of America, Entomological Society of Canada, and Entomological Society of British Columbia to be held 13–16 November 2022 as a hybrid event, with online content and an in-person meeting at the Vancouver Convention Centre, Vancouver, British Columbia. The theme of the conference is: 'Entomology as Inspiration: Insects through Art, Science, and Culture'. Registration is currently open. More information is available at https://www.entsoc.org/events/annual-meeting.

In Memoriam: Richard Staniforth (2 October 1946–12 January 2022)

Dr. Richard Staniforth, a pre-eminent Manitoba naturalist, died during the final revisions of two manuscripts published in this issue of *The Canadian Field-Naturalist*: his Note "Confirmation of Shining Firmoss (*Huperzia lucidula*; Lycopodiaceae) in Manitoba" https://doi.org/10.22621/cfn.v136i2.2665 and his Article, co-authored by Dan Brunton, "A synopsis of lycophytes in Manitoba, Canada: their status, distribution, abundance, and habitats" https://doi.org/10.22621/cfn.v136i2.2669. Dan stepped in to ensure publication of his last two contributions on Manitoba's lycophytes. Richard's numerous plant collections, deposited in the University of Winnipeg herbarium, resulted in the naming of that herbarium in his honour. He was an expert on "primitive plants" as well as birds. A full tribute (Taylor *et al.* 2022) has been published.

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D.A.W. Lepitzki
CFN Editor-in-Chief

Comments on: Tyler Wheeldon and Brent Patterson. 2022. Dispelling myths about the origins of wolf–coyote hybrids and related *Canis* species in Ontario. Canadian Field-Naturalist 136: 139–144. https://doi.org/10.22621/cfn.v136i2.2853

Wheeldon and Patterson presented evidence that extant wolf–coyote hybrids in Ontario are the result of natural events and not descendants of escapees or releases from captive breeding experiments. They quoted supporting statements by two of the three early-day directors of Ontario wolf research programs——Rod Standfield and George Kolensoky. I can add that permanent releases did not occur during Douglas Pimlott's 1958 to 1962 tenure. All wolves he temporarily freed for behavioural studies were either returned to captivity or were known to be killed. I was closely associated with both Pimlott and the captive wolves in Algonquin Park between 1959 and 1965, first as a student assistant and then a graduate student with Pimlott as co-supervisor, studying howling by members of that captive population. There was never any discussion of permanent, deliberate, or accidental releases.

Pimlott's research objective was "to determine the influence of wolves on wildlife populations in Ontario and to provide a factual background for a judicious and efficient program of predator management" (Pimlott *et al.* 1969: 5). Neither wolf taxonomy nor population augmentation was a part of that. Pimlott was hired partly to ascertain wolf population response to bounty removal, following such recent removal by western provinces. Any augmentation of the population would have been self-defeating.

Mary Theberge and I followed Pimlott's Algonquin wolf research with our own between 1986 and 2000. By then, genetics had entered the arsenal of research tools, and we were completely surprised when our geneticist partners, Brad White, Paul Wilson, and Sonya Grewal of Trent University, found a low level of Coyote genes in many Algonquin wolves. However, we were able to attribute that to annual winter wolf migration into broken farmlands outside the park that resulted in excessive wolf mortality, close association with Coyotes during the breeding season, and some coyote movement into vacant park wolf territories. These findings were reported in our 2004 monograph cited by Wheeldon and Patterson and our 1998 book *Wolf Country: Eleven Years Tracking Algonquin Wolves* (McClelland & Stewart).

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Cowichan Bay, BC

Without an over-arching biodiversity protection act, what protections exist for biodiversity in British Columbia? A case study of Oldgrowth Specklebelly Lichen (*Pseudocyphellaria rainierensis*)

As scientists with backgrounds in monitoring and assessment of plant and animal populations in Canada, we are concerned with the biodiversity implications of declines in old-growth forests on Vancouver Island. Our experience recounted here illustrates the practical roadblocks that scientists and the public interested in protecting biodiversity in British Columbia (BC) face, and the lack of effective mechanisms for protection of at-risk species through legislation, regulatory bodies, "ecolabel" certification, or public pressure. We conclude with some thoughts on how conservation objectives can be better met, as Canada moves towards new models for land stewardship and reconciliation.

When considering the highly-publicized potential cut of old-growth forests in the upper Fairy Creek watershed and immediately adjacent areas (Tree Farm License [TFL] 46; Figure 1), we assumed that there must have been careful biological inventories made prior to harvesting, and the results of those surveys would be freely available. Tree Farm License 46 was created in 1983 and includes Pacheedaht and Ditidaht First Nations Territories. The tenure has been under the control of Teal Cedar working with the Pacheedaht First Nation. After conducting a literature search and contacting many of our professional colleagues, we concluded that we were mistaken in our assumption that comprehensive biological surveys were made. As we document later, the Minister responsible has confirmed that comprehensive biodiversity and species surveys are not required prior to clearcutting, road-building, and other forestry operations.

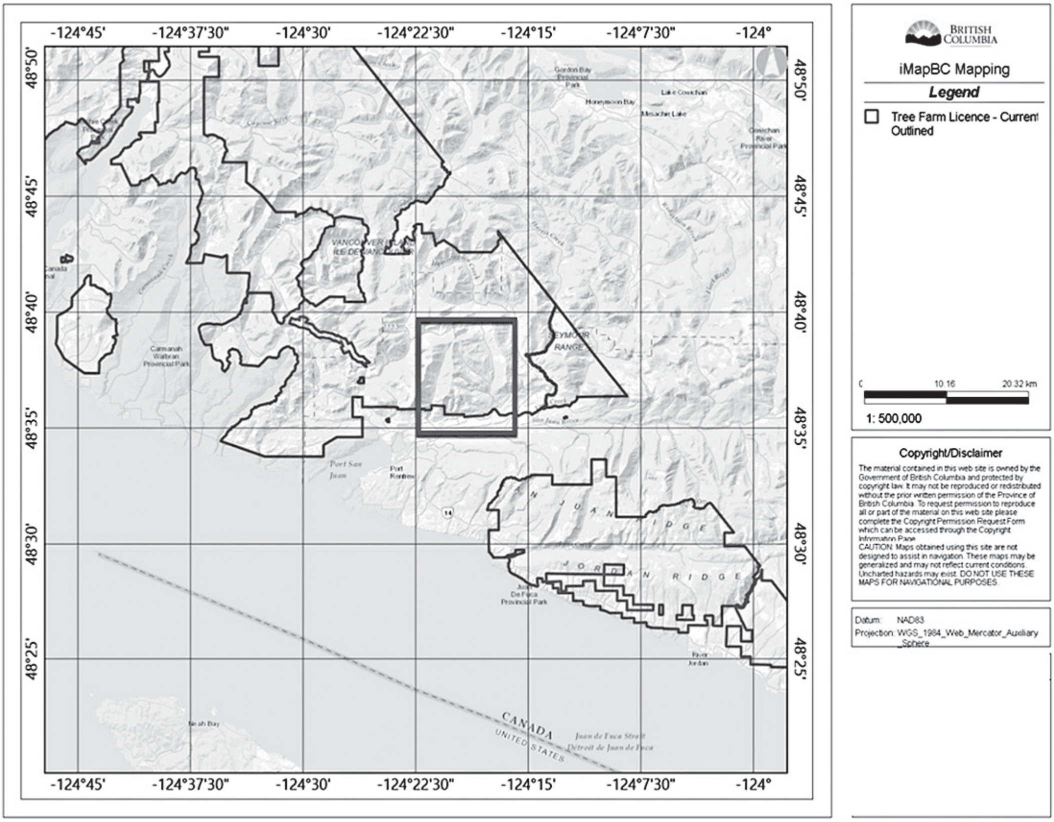

FIGURE 1. South-west Vancouver Island, British Columbia, Canada. The irregular boundaries show Tree Farm License Administrative Boundaries, and the rectangle encompasses the Fairy/Granite Creeks watersheds. Created using publicly available mapping tool: Imap BC, https://maps.gov.bc.ca/ess/hm/imap4m/.

In the absence of government or industry surveys, we initiated our own surveys with colleagues in the Fairy Creek area using iNaturalist. In May 2021, we established a project page (Fairy Creek iNaturalist). Despite access issues, 326 species have been documented by the end of 2021, including 70 observations of 16 species that are considered vulnerable using the iNaturalist convention (listed in the International Union for the Conservation of Nature Red lists or national/regional at-risk species lists).

Of those rare species that were documented, Oldgrowth Specklebelly Lichen (*Pseudocyphellaria rainierensis*) was of particular interest. Considered rare by lichenologists, it is highly correlated with host trees within conifer stands older than about 200 to 300 years old (COSEWIC 2010). Coastal forests that contain host trees have existed in BC for about 4000–7000 years (Hebda 2007). In Canada, Oldgrowth Specklebelly Lichen was assessed as Special Concern by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC; COSEWIC 2010) and is listed as Special Concern under the Canadian *Species at Risk Act* (SARA; SARA Registry 2021a). Canada and BC have prepared a joint management plan for Oldgrowth Specklebelly Lichen that is publicly available (BC Ministry of Environment 2015). The key threat identified in the joint management plan was forest harvesting operations. Through our surveys conducted in 2021 and 2022, numerous occurrences of this unusual lichen (identifications confirmed by lichenologists) were documented in the upper Granite Creek area (immediately adjacent to Fairy Creek; Figure 2), making this newly-discovered population the largest in Canada, based on thalli counts of 670+ compared with a maximum of 524 reported in COSEWIC (2010).

During our site visits in the summer of 2021, we noted that some host trees in upper Granite Creek had been felled and damaged by new logging roads and the remaining host trees were in a planned cut block. We filed a complaint to the designated regulatory body for forestry operations in BC, the Forest Practices Board (FPB), in late July. We were informed that because the species in question was not one of a short list of documented species of interest that the FPB recognizes in southern Vancouver Island, the Board had no basis for intervention. We also received an acknowledgement of our complaint from the company doing the logging, Teal Cedar, which noted in an email communication to us dated 5 August 2021 that:

FIGURE 2. Oldgrowth Specklebelly Lichen (*Pseudocyphellaria rainierensis*) on a host tree in the Granite Creek area, southern Vancouver Island, British Columbia. Felled trees in the background were associated with logging road construction. Photo: T. Lavdovsky.

> It has been brought to our attention by the Forest Practices Board (FPB) that you have reported sightings of Specklbelly (sic) Lichen *Pseudocyphellaria rainierensis* in TFL 46. The information you provided to the FPB, including locations of the sightings has been forwarded to us and we would like to thank you for providing this important information.

We wrote to Teal Cedar requesting clarification of what their plans were now that they knew of the location of the rare lichens, but received no response. Based on photographs of felled host trees in the Upper Granite Creek area obtained after the logging company was notified of the presence of the lichen, operations were unabated (Figure 3). We also informed Pacheedaht Nation Council of the concern for a listed species and have to date received no acknowledgement.

During the late summer and fall of 2021, we continued to highlight the concerns with habitat loss and impacts on previously undocumented animal and plant populations with politicians and the public at large. For example, in September 2021, we worked with the Wilderness Committee to place at our expense a half page advertisement in *The Province* illustrating the issues of logging without having prior knowledge of the species occurring there (Figure 4). In that example, we highlighted our iNaturalist findings as well as the occurrence of the SARA Threatened Western Screech Owl (*Megascops kennicottii kennicottii*; SARA Registry 2021b). However, it is difficult to determine if this approach had an impact with decision-makers and the general public and we are unaware of any positive response to protect the owl or its habitat.

Teal Cedar's products carry an "ecolabel" that is meant to certify that the production of their products is compliant with the Canadian Standards Association (CSA SFM Z809; https://www.csasfmforests.ca). We obtained a copy of the CSA Standard, and challenged the upcoming recertification of Teal Cedar's products from TFL-46 on the grounds that Teal Cedar was not respecting the SFM Criterion 1 (Biodiversity) by not conserving biological diversity (Element 1.2) and failing to respect areas of special biological interest within the area of certification (Element 1.4). The response by the certifying body was in an email (S. Ellsworth, Director, Risk Assurance Services, Pricewaterhouse-Coopers LLP pers. comm. 28 January 2021) which stated:

> Based on the current B.C. Conservation Data Centre listing status of the Oldgrowth Specklebelly Lichen and the requirements under the CAN/CSA Z809-16 Sustainable Forest Management Standard, this issue does not fall within our scope as a certification body, and as a result we have closed the matter.

It appears that this species, being "only" Special Concern in the COSEWIC assessment or SARA listing, or being Blue-listed by the BC Conservation Data Centre, means that the species does not warrant attention from those issuing certification for the forest industry. Hardly a precautionary approach.

FIGURE 3. Examples of felled host trees with Oldgrowth Specklebelly Lichen (*Pseudocyphellaria rainierensis*) in the Granite Creek area, southern Vancouver Island, British Columbia. Photo: T. Lavdovsky.

PREVIOUSLY UNDOCUMENTED VULNERABLE SPECIES LIVE IN THE ANCIENT FORESTS OF SOUTHERN VANCOUVER ISLAND

… YET, CHAINSAWS CONTINUE AND IRREPLACEABLE ECOSYSTEMS ARE LOST

Western Screech-Owl - Threatened

This summer over 320 species (16 vulnerable) have been documented in the Fairy Creek area, take action for them today:

Tell John Horgan to implement a ban on old-growth logging: 1-250-387-1715

OR take action here: https://www.wildernesscommittee.org/SaveOldGrowth

Scan the QR code

FIGURE 4. Advertisement appearing in *The Province*, September 2021.

Finally, after failing to gain the attention of decision-makers at the provincial and federal level through direct communications, we collaborated with a Member of the BC legislature (Mr. Adam Olsen, Saanich North—The Islands) to ask the following questions of the responsible Minister (Ms. Katrine Conroy):

1. Were comprehensive biodiversity surveys done prior to allowing road construction and logging in TFL 46 and are comprehensive species surveys ever carried out prior to clearcutting, road-building and other forestry operations?
2. Given the published commitment to protect the species and its habitat, will you immediately protect these rare lichens and host trees?
3. How do the proposed amendments to FRPA (*Forests and Ranges Protection Act*) ensure that endangered species are identified and protected prior to logging or road construction—and, if at-risk species or ecosystems are found during these surveys, will logging or road-building be halted in the relevant areas?

Minister Conroy's responses to the above questions to A. Olsen (via a pers. comm. 28 January 2021 to us) were revealing and confirmed our suspicion that comprehensive biodiversity and species surveys are not required before clear-cutting, road-building, and other forestry operations. Surprisingly, Minister Conroy further noted that recently adopted amendments to the FRPA do not speak directly to species at risk and stated "the Province manages species at risk by designating Identified Wildlife Management Areas, parks and ecological areas to conserve species and support biodiversity". By extension, this seems to imply that the province has no interest in species-at-risk occurring in areas outside of parks or ecological reserves, unless these are on the very truncated list of species of interest in limited geographical locations under the BC *Wildlife Act* or the FRPA.

During the course of our work, we followed due process and exhausted all the options available to us to provide some measure of protection for this rare lichen species. Returning to the question framed in our title, we can only conclude that the current protections available for at-risk species are inadequate and protect only a small number of the species considered at risk in BC.

How can we do better? What is needed is an overarching Biodiversity Protection Act mandating that sites must be professionally surveyed before resource extraction takes place, and that management protocols must be adhered to for listed species identified, including those species considered to be Special Concern, such as Oldgrowth Specklebelly Lichen. The need for comprehensive surveys in advance of resource extraction is well-demonstrated by our iNaturalist Fairy Creek Project Page. Oldgrowth Specklebelly Lichen is only one of 16 species identified that are of conservation concern.

We envisage a new approach to biodiversity protection that fully integrates both traditional Indigenous knowledge and western science and provide accountability (Gagnon and Berteaux 2009; Jones *et al*. 2010; Artelle *et al*. 2021). This new approach would be consistent with the views of Grand Chief Stewart Phillip (President of the Union of B.C. Indian Chiefs). During a December 2021 Press Conference (Anon. 2021), Grand Chief Phillip noted that a complete inventory of forest lands in BC is needed, including water systems, and fisheries and wildlife. Policy and legislation would then be developed in an informed manner. Chief Phillip's approach is both sensible and urgently needed. If we are serious about addressing climate change and biodiversity for future generations, then science and traditional knowledge must guide new approaches that value and reward biodiversity conservation and not just resource extraction.

Acknowledgements: We thank the lichen experts on the COSEWIC Mosses and Lichens specialist subcommittee for reviewing an earlier draft.

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The Canadian Field-Naturalist

Editors' Report for Volume 135 (2021)

Mailing dates for the four issues in volume 135 were: 22 July 2021, 15 November 2021, 18 February 2022, and 25 May 2022; online posting dates were 23 June, 5 October, 22 January, and 29 April, respectively. In contrast, the mailing and online posting dates of the four issues in volume 134 ranged from 12 August 2020 through 5 May 2021 and 16 July 2020 through 2 April 2021, respectively. Summaries of the distribution of paid subscribers to *The Canadian Field-Naturalist* (CFN) for 2021 are shown in Table 1, and are compared to volume 134. This list does not include free copies distributed to Honorary Ottawa Field-Naturalist' Club (OFNC) members or online access, which is included in OFNC membership dues and provided to *Associate Editors* (AE). Institutional subscribers potentially represent many thousands of users. The total number of paid subscribers decreased by 12.

The number of articles published in volume 135 increased by three relative to the number published in volume 134 while the number of notes decreased by 10, resulting in seven fewer manuscripts published in 2021 ($n = 34$; Table 2). Mammals and birds were the most popular subjects followed by plants (Table 2). Fewer book reviews ($n = 6$) and new titles (37) were published in volume 135 in comparison to volume 134 (Table 3). Barry Cottam, our *Book Review Editor*, stepped down after 135(2) resulting in a small drop ($n = 8$) in the number of pages for the book reviews and new titles beginning with issue 3 (Table 4). Amanda Martin and Bill Halliday assumed duties for the book reviews and new titles, respectively, while the search for a new *Book Review Editor* continued. The total number of pages published increased by eight for volume 135 over volume 134 (Table 4) with more pages of articles ($n = 89$) but fewer pages of notes (38) and tributes (37) published. Once again, there were no thematic collections (editor-selected compilations of previously published contributions in both CFN and the regional OFNC publication, *Trail & Landscape*, on a central theme with internet links to each article) nor additional articles on Great Canadian Field-Naturalists, the latter of which were included in News and Comment in volume 131.

Nearly the same number of manuscripts or enquires about potential submissions were received in 2021 ($n = 46$) as in 2019 (47), but down from the 63 for 2020. Two of the three enquiries have not yet resulted in subsequent submissions with the other being declined following discussion with the assigned

Table 1. The 2021 (2020) circulation of *The Canadian Field-Naturalist*. Compiled by Eleanor Zurbrigg from the subscription list for 135(4). This list does not include copies distributed to Honorary Members or online access which is included in Ottawa Field-Naturalists' Club (OFNC) membership dues.

Subscriber Type	Canada	USA	Other	Total
OFNC Members	42 (47)	6 (2)	0 (0)	48 (49)
Subscriptions:				
Individual	28 (31)	9 (12)	0 (0)	37 (43)
Institutional	58 (61)	79 (82)	12 (11)	149 (154)
Total	128 (139)	94 (96)	12 (11)	234 (246)

Table 2. Number of research articles and notes published in *The Canadian Field-Naturalist*, volume 135 (volume 134), by major field of study.

Subject	Articles	Notes	Total
Mammals	3 (6)	6 (9)	9 (15)
Birds	9 (6)	0 (1)	9 (7)
Amphibians and reptiles	2 (1)	2 (3)	4 (4)
Fishes	1 (2)	0 (0)	1 (2)
Plants	6 (2)	0 (1)	6 (3)
Insects	2 (2)	1 (3)	3 (5)
Non-insect invertebrates	2 (3)	0 (2)	2 (5)
Other	0 (0)	0 (0)	0 (0)
Total	25 (22)	9 (19)	34 (41)

Table 3. Number of reviews and new titles published in the Book Review section of *The Canadian Field-Naturalist*, volume 135 (volume 134), by topic.

	Reviews	New Titles
Zoology	12 (13)	70 (110)
Botany	3 (2)	29 (31)
Miscellaneous	4 (10)	137 (132)
Total	19 (25*)	236 (273)

*Not including six "Books in Brief".

TABLE 4. Number of pages per section published in *The Canadian Field-Naturalist*, volume 135 (134), by issue.

	Issue				
	1	2	3	4	Total
Editorials/Editors' Report	0 (0)	4 (4)	0 (0)	0 (0)	4 (4)
Articles	58 (55)	74 (44)	91 (37)	65 (63)	288 (199)
Notes	9 (15)	12 (28)	5 (28)	16 (9)	42 (80)
Thematic Collections	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Tributes	10 (14)	0 (0)	0 (25)	0 (8)	10 (47)
Book Reviews and New Titles	20 (16)	12 (11)	9 (11)	5 (16)	46 (54)
News and Comment*	3 (2)	2 (1)	2 (1)	2 (3)	9 (7)
Reports†	16 (13)	0 (0)	0 (0)	0 (0)	16 (13)
Erratum	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Blank page‡	0 (1)	0 (0)	1 (0)	0 (0)	1 (1)
Index	— (—)	— (—)	— (—)	6 (9)	6 (9)
Total	116 (116)	104 (88)	108 (102)	94 (108)	422 (414)

*Includes the James Fletcher Award for best paper published in the volume.
†Includes Annual Business Meeting Minutes, Annual Committee Reports, and OFNC Awards; Financial Statements are only available online beginning with volume 132.
‡Necessary to begin each issue with an odd numbered page.

AE prior to it being sent for formal review. Another manuscript was not sent for formal review because it was not suitable for publication in CFN as determined upon initial examination by the *Editor-in-Chief* (EiC) while another was declined following advice from the assigned AE. One manuscript was declined after the initial round of formal review. In total, only four of the 44 manuscripts submitted in 2021 were not accepted for publication and one was subsequently withdrawn by the authors given the magnitude of required revisions. As a result, 89% of submissions were accepted or are undergoing revision and additional review. In 2020, 2019, 2018, and 2017, 80%, 85%, 83%, and 90%, respectively, of the submissions were accepted for publication and either published or underwent further revision and review.

Dwayne Lepitzki, EiC, initially reviewed the appropriateness of a submission and assigned an AE after William Halliday, *Online Journal Manager and Webmaster*, determined the completeness of the submission. Dwayne then reviewed the recommendation from the AE and reviewers and decided if and when the revised manuscript was accepted for publication. A *Copy Editor* (Sandra Garland or John Wilmshurst) was then assigned and once their work was reviewed by Dwayne and the authors, the manuscript was sent for layout and typesetting. *Assistant Editor* Amanda Martin edited content, proofread galleys (as did Dwayne), and sent and received author order and transfer of copyright forms; she also prepared the News and Comment. Robert Forsyth typeset galleys, provided corrections for page proofs, and created pdfs for online posting and printing. Barry Cottam, *Book Review Editor*, requested books for review, selected reviewers, edited submitted reviews, and prepared the new titles listings until 135(3). Ken Young sent page charge invoices to authors and tracked the budget while Eleanor Zurbrigg managed subscriptions and mailed printed copies. William Halliday provided digital content to subscribers, posted tables of contents, abstracts, and pdfs on the CFN website, and prepared the Index. Our AEs managed manuscripts, provided reviews and recommendations, and guided authors through the revisions process. Dave Seburn, our *Map Editor*, reviewed and provided suggestions for all the maps. The Publication Committee, chaired by Jeff Saarela and consisting of Annie Bélair, Dan Brunton, Carolyn Callaghan, Paul Catling, Barry Cottam, William Halliday, Diane Kitching, Dwayne Lepitzki, Amanda Martin, Karen McLachlan Hamilton, Dave Seburn, Ken Young, and Eleanor Zurbrigg effectively guided the operation of the journal. Dan, Barry, and Dave all stepped down from the Publications Committee in 2021. We are indebted to our very dedicated team.

The following AEs managed, assessed, and reviewed manuscripts published in volume 135: R. Brooks, University of Guelph, emeritus, Weymouth NS (2 manuscripts published); P.M. Catling, Agriculture and Agri-Food Canada, retired, Ottawa ON (4 + 1 not accepted for publication); F. Chapleau, University of Ottawa, Ottawa ON (1 – stepped down as AE); J. Foote, Algoma University, Sault St. Marie ON (5 + 1); G. Forbes, University of New Brunswick, Fredericton NB (1); W. Halliday, Wildlife Conservation Society Canada, Whitehorse YT and University of Victoria,

Victoria BC (4); T. Jung, Yukon Government, Whitehorse YT (3); D. Lepitzki, Banff AB (1); G. Mowat, Government of British Columbia, Nelson BC (1); M. Obbard, Ontario Ministry of Natural Resources and Forestry, retired, Peterborough ON (2 – stepped down as AE); J.M. Saarela, Canadian Museum of Nature, Ottawa ON (5 + 1); J. Skevington, Agriculture and Agri-food Canada, Ottawa ON (1); and D. Tozer, Birds Canada, Port Rowan ON (4). C. Callaghan, Canadian Wildlife Federation, Ottawa ON, previous EiC, stepped down as an AE in 2021 while K. Ilves, Canadian Musuem of Nature, Ottawa ON joined as an AE with expertise in fishes.

As with many other journals, AEs are at times having difficulty finding suitable reviewers; without dedicated AEs and reviewers there would be no journal. As such, a heart-felt thanks and gratitude is extended to the following who reviewed manuscripts published in volume 135 (number of manuscripts reviewed >1 in parentheses) or submitted in 2021: Peter Achuff, Canmore AB; Jason Addison, University of New Brunswick; Noel Alfonso, Canadian Museum of Nature; Max Allen, University of Illinois; Jess Alston, University of Wyoming; Michael Anderson, Ducks Unlimited; Lori Biederman, Iowa State University; Maegwin Bonar, Trent University; Rodney Brook, Ontario Ministry of Natural Resources and Forestry; Rob Butler, Pacific Wildlife Foundation; Erin Cameron, St. Mary's University; James Carpenter, American Museum of Natural History; Paul Catling, Ottawa ON; Robert Clark, Canadian Wildlife Service; William Crins, Peterborough ON (2); Christopher Edge, Natural Resources Canada; Dominique Fauteux, Canadian Museum of Nature (2); Robert Forsyth, Kamloops BC; Tony Gaston, Ottawa ON; Carina Gjerdrum, Canadian Wildlife Service; Purnima Govindarajulu, BC Ministry of Environment and Climate Change Strategy; Trevor Goward, University of British Columbia; Diana Hamilton, Mount Allison University; Leanne Heisler, Saskatchewan Ministry of Environment; Jared Hobbs, Victoria BC; Thomas Hossie, Trent University; Altaf Hussain, University of Alberta; John Klymko, Atlantic Canada Conservation Data Centre; Kristin Kovach, Biodiversity Research Institute; Claude Lavoie, Université Laval; James Lendemer, New York Botanical Garden; Steve Lewis, US Fish and Wildlife Service; Jay Mager, Ohio Northern University; Nicholas Mandrak, University of Toronto – Scarborough; Ken Marr, Royal British Columbia Museum; Brent Matsuda, Vancouver BC; Ashley McLaren, Ontario Ministry of Natural Resources and Forestry; Patrick Moldowan, University of Toronto (2); Keith Munro, Ontario Federation of Anglers and Hunters; David Nagorsen, Royal British Columbia Museum; Annegret Nicolai, Université Rennes; Erica Nol, Trent University; Mark O'Donoghue, Government of Yukon; Michael Oldham, Ontario Natural Heritage Information Centre; Laurence Packer, York University; Zoe Panchen, University of British Columbia; James Paterson, Trent University; Brent Patterson, Ontario Ministry of Natural Resources and Forestry; Steven Patterson, St. Mary's University; Michael Peers, Memorial University of Newfoundland; Stéphanie Pellerin, Montreal Botanical Garden; Jodie Pongracz, Government of Yukon; John Reynolds, Kitchener ON; Gregory Robertson, Environment and Climate Change Canada; Fred Schueler, Fragile Inheritance Natural History; Cory Sheffield, Royal Saskatchewan Museum; Diana Six, University of Montana; Graham Sorenson, Birds Canada; Emily Studd, University of Alberta; Julie Thomas, Government of Yukon; Darroch Whitaker, Parks Canada; Douglas Wilcox, State University of New York; Sabrina Wilhelm, Canadian Wildlife Service; Dave Wilson, Memorial University of Newfoundland; Lydia Wong, University of Ottawa; Steve Varga, Ontario Ministry of Natural Resources and Forestry.

The journal was printed at Gilmore Printers, Ottawa. Thanks to Guylaine Duval of Gilmore Printers for overseeing production and printing. The COVID-19 pandemic resulted in supply chain issues with the coated paper stock normally used for printing in short supply and most likely at an increased cost if even available. Due to potential problems of ink bleeding into the alternative uncoated stock, we moved to a digital press beginning with issue four of volume 135 and will continue to explore the use of the digital press for printing subsequent issues and volumes. We are grateful to the OFNC President Jakob Mueller and the Club's Board of Directors for their support of the journal. We are also grateful to all of the individual subscribers and authors who support our team as we strive to provide a high-quality scientific journal on natural history, field biology, and ecology. Finally, we thank our families/partners for their patience and support throughout many long days, evenings, and weekends of working on the journal.

DWAYNE A.W. LEPITZKI, *Editor-in-Chief*
AMANDA E. MARTIN, *Assistant Editor*

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Mailing date of the previous issue 136(1): 8 September 2022