The CANADIAN FIELD-NATURALIST

A JOURNAL OF FIELD BIOLOGY AND ECOLOGY

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Dawn singing in Brown Creeper (*Certhia americana*)

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Abstract
The dawn chorus of birds is an impressive display in which many individuals of a variety of species sing concurrently before sunrise. Brown Creeper (*Certhia americana*) is a small passerine bird that has not been well studied and is thought not to sing during the dawn chorus. Here, we used automated recordings to analyze Brown Creeper singing during the 2015–2017 breeding seasons from April through August in order to identify patterns in the timing and quantity of singing. We found that Brown Creepers did sing before sunrise, most often between April and early June and then more sporadically through mid July. We did not find any seasonal changes in song rates before sunrise, but we did find non-linear seasonal trends in both the timing and total duration of dawn singing bouts. Dawn choruses began earlier and lasted longer from April through mid June after which they began later and became shorter. Our results highlight the benefit of using automated recording techniques to study natural history of difficult to study species and add to our understanding of Brown Creeper natural history.

Key words: Dawn chorus; vocal behaviour; Brown Creeper; autonomous recording

Introduction

During the breeding season, territorial males of many bird species participate in daily bouts of extended singing prior to sunrise, in a communication network commonly known as the dawn chorus (Staicer *et al*. 1996; Gil and Gahr 2002; Burt and Vehrencamp 2005). Several hypotheses exist as to why birds sing before sunrise (see Staicer *et al*. 1996), including environmental influences (e.g., low light levels could make for poor foraging; Kacelnik 1979), intrinsic factors (e.g., circadian rhythms or hormones; reviewed in Staicer *et al*. 1996; Greives *et al*. 2015), or social explanations (e.g., territory defence; Amrhein and Erne 2006; or maintaining relationships with neighbours; Foote *et al*. 2008). Song output during the dawn chorus is also often an honest signal of male quality (Gil and Gahr 2002), allowing females to compare the quality of their mate against his neighbours and make decisions about extra-pair copulations (e.g., Otter *et al*. 1997; Suter *et al*. 2009). The characteristics of the dawn chorus (e.g., start time, duration, and song rate) often show seasonal variation and may show distinct patterns. Different characteristics of the dawn chorus may: 1) peak early in the season and gradually decline (e.g., Mace 1987), 2) remain relatively constant across the breeding season (e.g., Kunc *et al*. 2005), 3) build toward a mid-season peak and then decline (e.g., Davis 1958), or 4) peak in particular breeding stages (e.g., Bruni and Foote 2014).

Not all species sing extensively before sunrise, and, for some species, we lack knowledge about their singing habits and behaviours. Brown Creeper (*Certhia americana*) is one such species. A small, cryptically-coloured passerine in the Certhiidae family, Brown Creeper is the only North American species of treecreeper (Poulin *et al*. 2020). Brown Creepers are old forest specialists, and are common across much of North America, preferring to nest in habitats with high densities of large-diameter trees and snags (Poulin *et al*. 2008). While the syllables and song structure of Brown Creeper are fairly well described (e.g., Baptista and Johnson 1982; Baptista and Krebs 2000), there is little previous research on its singing behaviour. Brown Creeper sing a single short song (~ 1.2 s) composed of 4–9 high-frequency notes that is thought to be sung only by males (Poulin *et al*. 2020; Figure 1). Brown Creepers have not been identified singing before sunrise during the dawn chorus. However, there has not been a study of the phenology or daily pattern of singing (Poulin *et al*. 2020) and two congeneric European treecreeper species sing before sunrise (Santema *et al*. 2019). Much of what we do know about the singing behaviour comes from the
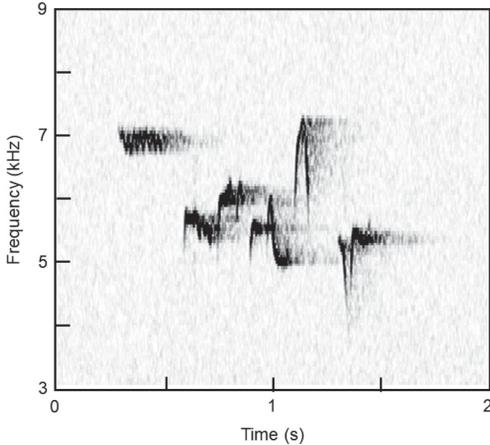
FIGURE 1. Spectrogram of Brown Creeper (*Certhia americana*) song.

1978 nesting study by Davis, in which Brown Creeper nests were monitored and some general observations of vocal behaviour were made. Davis (1978) reports anecdotally that Brown Creepers sang territorially and engaged in counter-singing with neighbours, most often beginning in April through to early June. Singing rates were described as increasing during territory establishment and with increased levels of intraspecific competition. Davis (1978) describes male Brown Creepers as singing one to eight songs per minute, with singing bouts lasting 1–22 minutes. These singing bouts occurred 'sporadically' through the day, with singing documented as early as 0450 and as late as 1917, although there is no specific mention of singing before sunrise. Singing was also documented during nest building; while females collected nesting material, males were noted singing close by (Davis 1978).

Here, we analyzed recordings made with automated recording units to examine the singing behaviour of Brown Creepers (*C. americana americana*) during the breeding season to determine if Brown Creepers sing before sunrise, and if so, to describe and quantify any seasonal changes in timing or patterns of singing behaviour. Automated recording is advantageous when species are either sensitive to intrusions, such as those caused by human observers, or are difficult to locate and observe (Blumstein *et al.* 2011). Previous research did not identify Brown Creepers as being particularly sensitive to human disturbance (Gutzwiller *et al.* 1994); however, they are cryptic and have a soft high-frequency "tinkling" song (Tyler 1948) that may be difficult to hear, thus automated recordings could be an effective technique for recording Brown Creeper singing.

Methods

Study species and site description

We recorded in Hiawatha Highlands Conservation Area, Sault Ste. Marie, Ontario, Canada (46.588°N, 84.292°W) from late March/early April through the end of August, 2015–2017 (see Table S1 for dates by recorder) as part of a project for long-term monitoring of bird community composition and vocal behaviour. This conservation area is comprised primarily of mature Sugar Maple (*Acer saccharum* Marshall), Eastern White Pine (*Pinus strobus* L.), and Balsam Fir (*Abies balsamea* (L.) Miller; Sault Ste. Marie Region Conservation Authority 2015; see Foote *et al.* 2018 for further habitat description). While some populations migrate, many populations of Brown Creeper, including our study population, are year round residents (Poulin *et al.* 2020).

We deployed four song meters in each year (model SM2+ in 2015; Model SM3 in 2016 and 2017; Wildlife Acoustics, Maynard, Massachusetts, USA) for a total of 12 different locations over three years. Recorders were spaced such that they were likely to pick up different birds. Within a year, the nearest-recorder distance averaged 425 ± 28.4 m (± SE) while among years, the nearest recorder distance averaged 211 ± 14.9 m. Nest locations of adjacent pairs ranged from 100 to 200 m and territory size averaged 2.3 to 6.4 ha (Davis 1978) such that locations were independent and were likely several territories apart.

Recorders were programmed to begin recording at astronomical twilight (when the sun is 18° below the horizon), before any species at our site begins their dawn singing bout and only nocturnal singing species are vocally active (Leopold and Eynon 1961; Perrault *et al.* 2014), and continued recording until on average 74.3 ± 2.02 min after sunrise (see mean post-sunrise recording time by recorder in Table S1). Recorders recorded for 59 min followed by a 1 min pause to write files. Recordings were made as wav files at 22 050 Hz (SM2) or 24 000 Hz (SM3) and 16-bit accuracy. The batteries and memory cards in recorders were changed weekly.

Recording analysis

We scanned each recording using Syrinx software (John Burt, Seattle, Washington, USA), and visualized spectrograms with a transformation size of 512 FFT, frequency range of 1000–10 000 Hz, a setting of 10 ms per line, and spectral gain of +5. Recordings from each day at each location were combined using a series list text file that included a 1 min blank sound file between each 59 min recording to account for the pause for file writing and to keep the analysis in real-time. Scanning each recording from beginning to end, we used the time and frequency cursors to annotate

all visible Brown Creeper songs (Figure 1), as well as the sunrise time each morning. Sunrise times were obtained from the National Research Council Canada website (National Research Council Canada 2017). In the event that we detected two Brown Creepers singing simultaneously, we annotated the songs of the loudest male. We added an annotation for the second bird as 'bird2' to keep track of instances of potential counter-singing. Eleven of the 12 recorders had singing Brown Creepers and we assume that a bird at a given site is the same individual. Winter (2020) selected 10 songs from our annotations from seven of these locations and found higher spectrogram cross-correlation scores for within location than among locations supporting that the primary singer at each site was a single individual. Once each file was annotated, we calculated the time of the first song relative to sunrise (min), the total duration of singing before sunrise (dawn bout; time of last − first song before sunrise [min]), song rate before sunrise (number of songs before sunrise/duration of dawn chorus [songs/min]), and song rate after sunrise (number of songs after sunrise/recording length post-sunrise [songs/min]) for each location. Our recording equipment failed on 214 nights across the 11 recorders (see Table S1 for details by recorder). We excluded 41 recordings from analysis (17 due to inclement weather making it impossible to transcribe recordings, and 24 due to premature battery failure causing the recordings to end before sunrise), leaving us with 1335 recordings from 11 locations for analysis.

Statistical analysis

We constructed generalized additive mixed-effects models (GAMMs) to look at the probability of detection of Brown Creepers on the recordings and at the presence/absence of singing before sunrise (dawn bouts). These models included year and recording date (expressed as day of year, where January 1 = 1; 2016 was a leap year hence the requirement to use Julian dates) as covariates, with recorder location as a random effect, with binomial distributions and logit link function. We also constructed GAMMs for singing start time relative to sunrise, total duration of dawn bout minutes), pre-dawn song rate (songs/min). These models also included year, recording date, and male ID as a random effect. An additional model for song rate included period of the day (before or after sunrise) to compare song rates between these two periods.

Best models were selected by backwards stepwise regression based on AIC, and in instances where the estimated degrees of freedom (edf) for the smooth terms were close to 1 (indicating a potential linear relationship), we refit the models as generalized linear mixed-effects models (GLMM). We followed Zuur *et al.* (2014) to build and validate GAMMs, and our smooth terms were constructed using thin plate regression with shrinkage. We identified three males that could be problematic in the analysis (one due to much greater song output and two due to fewer days with singing compared to other locations), however when we re-ran the analyses without these data, most of the resulting top models and significance of terms did not differ. We present the results from models including all data, and in instances where the removal of any/all of these males changed the best model, we present results both with and without these males.

All analyses were done in R (v.3.4.2; R Core Team 2017) using the 'mgcv' package (v.1.8-23; Wood 2018) for GAMMs, with 'lme4' package (v.1.1-15; Bates *et al*. 2015) for GLMMs, and graphics made with 'ggplot2' package (v.2.2.1; Wickham 2016). We used the 'lmerTest' package (v.2.0-36; Kuznetsova *et al*. 2017) to calculate *P*-values for GLMMs via Satterthwaite's degrees of freedom method. The *P*-values obtained for GAMM models are estimates, and as such, values that are marginally significant should be interpreted with caution (Zuur *et al*. 2009). For all results, we report means ± SE.

Results

We identified Brown Creeper songs on 54.4% (726/1335) of recordings, and of these, 64.2% (466/726) of recordings included Brown Creepers singing one or more songs before sunrise (Figure 2). Date had a non-linear relationship with both the probability of detecting a Brown Creeper (smooth term: r^2 = 0.163, $F_{3.11}$ = 26.87, $P < 0.0001$; Table S2, Figure 2a) and the probability of pre-dawn song (smoother term: r^2 = 0.294, $F_{5.42}$= 14.09, $P < 0.0001$; Table S2, Figure 2b).

The average start time of the first singing bout of the morning was 5.61 ± 1.10 min before sunrise (range: 80.6 min before dawn to 129.2 min after dawn, $n = 726$). For mornings with a dawn bout (song beginning before sunrise), the start time of singing averaged 21.75 ± 0.47 min before sunrise (range: 0.50–80.60 min before sunrise, $n = 466$). The start time of dawn bouts relative to sunrise changed through the season, with a strong non-linear relationship with date (smoother term: r^2 = 0.17, $F_{4.70}$ = 5.17, $P < 0.0001$; Table S3, Figure 3). Brown Creepers started singing well before sunrise in the early to mid-breeding season (April–mid June; Julian dates 89–160). By mid June (~Julian day 170), Brown Creepers began to sing closer to sunrise and eventually stopped singing a dawn bout (Figure 3). The latest dawn chorus was recorded on 12 August (Julian 224), however, the mean last chorus date among 11 recorders was 18–19 July (Julian 200). Four males stopped singing a dawn bout for 17–39 days before resuming dawn song for
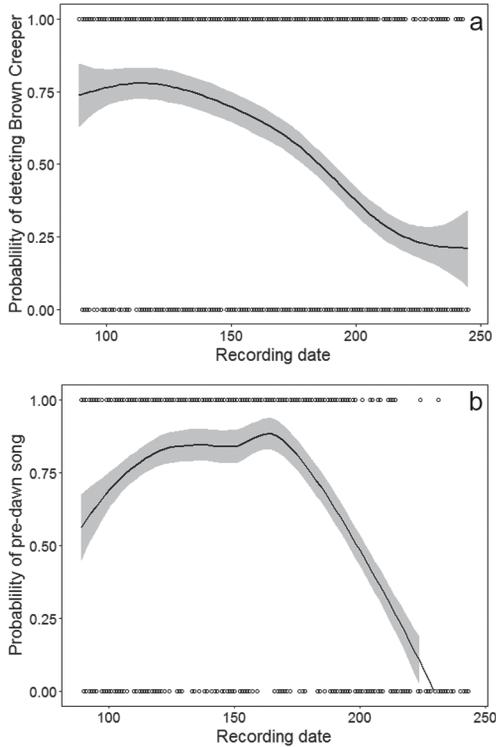
FIGURE 2. Probability of detecting Brown Creeper (*Certhia americana*) song a. at any time of day and b. before dawn by recording date. Open circles are the observed data, and black lines show the relationship between recording date (Julian day) and response variables obtained from GAMMs, with the grey areas representing the 95% CI for the smooth functions.

several days. The mean date of initial chorus cessation excluding these several late choruses was 8–9 July (Julian 180).

The average duration of a Brown Creeper dawn chorus was 13.29 ± 0.45 min (range: 0.25–51.33 min). Our best model for duration of singing included significant terms for recording date and year (smoother term for date: $r^2 = 0.17$, $F_{3.96} = 5.17$, $P < 0.0001$; Table S3). Similar to the pattern we found with start time, the total duration of singing appeared to change around mid June. During the early to mid-breeding season (April through mid June; Julian 89–160) there was a trend of increasing duration, peaking around mid June (~Julian 170), after which the total duration of Brown Creeper dawn singing activity decreased steadily (Figure 4).

As we found no evidence of non-linear relationships between recording date and song rate, we constructed GLMMs to examine dawn chorus song rates. Song rate during the dawn chorus was not significantly related to date (Table S4). We detected Brown Creeper less often after sunrise ($n = 343$ recordings) compared to before sunrise ($n = 466$ recordings). Brown Creeper sang at a significantly higher rate before (3.9 ± 0.15 songs/min) compared to after sunrise (3.6 ± 0.09 songs/min; Table S4).

To determine if the dawn bouts of different Brown Creeper overlapped, we plotted the number of males singing from the beginning to the end of recording for a randomly chosen date (5 May 2017), from among dates when all recorders were working properly (Table S1) and in the period where most birds sing a dawn bout (Figure 2). Before sunrise, 2–3 birds often sang concurrently while after sunrise only one

FIGURE 3. Start time of the dawn chorus of Brown Creeper (*Certhia americana*) relative to sunrise (dashed line indicates sunrise). Open circles are observed data, while the black line represents the non-linear relationship between start time and recording date (Julian day), based on the output of the GAMM; grey regions indicate the 95% CI.

FIGURE 4. The relationship between the duration of pre-dawn singing of Brown Creeper (*Certhia americana*) and recording date (Julian day). Open circles are observed data, while the black line represents the non-linear relationship between duration of the dawn chorus and recording date, based on the output of the GAMM; grey regions indicate the 95% CI.

bird was recorded singing at any given point in time (Figure 5). Additionally, we examined our annotation files to determine when we recorded a second distant Brown Creeper before sunrise. On average 2.4 ± 0.99 % of recordings included two singing Brown Creeper before sunrise (range: 0–4.2%).
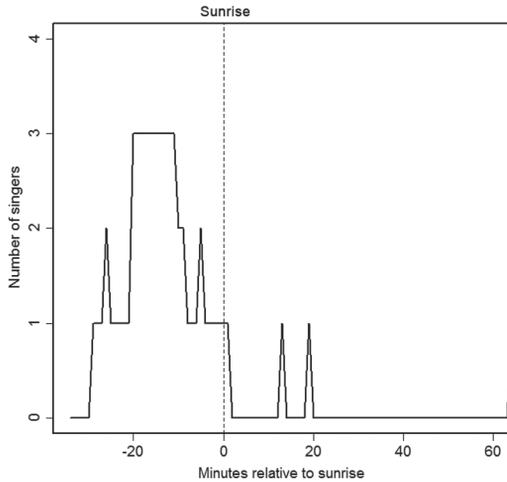
FIGURE 5. Number of Brown Creeper (*Certhia americana*; *n* = 4) singing in each minute of recording from the beginning of singing before sunrise to the end of the recording on 5 May 2017.

Discussion

We show that Brown Creepers sing a pronounced bout before sunrise during the dawn chorus and sing at a rate that exceeds daytime singing. We show that the probability of detecting Brown Creeper singing before sunrise, and both start time and duration of the dawn bout are related to date with a pronounced drop in activity in mid June with birds mostly stopping singing before sunrise by mid July. Our results are similar to Davis' (1978) general description of daytime vocal behaviour from a similar latitude (~140 km south of our site). During the breeding season, song rate remains constant during the dawn bout. Brown Creepers are fairly cryptic and understudied and we provide the first seasonal study of dawn vocal activity in this species.

The average start time of Brown Creeper dawn bouts was nearly 22 min before sunrise and thus begins in the middle to later period of the dawn chorus (Allard 1930; Leopold and Eynon 1961; Staicer *et al.* 1996). Between approximately April 10 (Julian day = 100) and the first week of July (Julian day ≈ 190), males began singing before dawn on most days (Figure 2a). The seasonal pattern of variation in start time of the dawn bout is similar to that observed in other species (e.g., Bruni *et al.* 2014; Zhang *et al.*

2015) including Spotted Towhee (*Pipilo maculatus*), a species that sings earlier relative to sunrise in the peak of the breeding season, which corresponds with males reaching maximum gonadal development (30–60 min; Davis 1958). Other species show a more linear decline in dawn bout start time (e.g., Bruni *et al.* 2014) or show no relationship between start time and date (e.g., Leopold and Eynon 1961; Pérez-Granados *et al.* 2018).

We also found that singing bouts tended to lengthen in the early breeding season, peaking around mid June, before shortening thereafter. While there are fewer studies of dawn bout length in relation to date, our results for Brown Creeper are similar to other species. In Field Sparrow (*Spizella pusilla*), dawn bout length was related to breeding stage, increasing in the fertile stage and then decreasing afterward (Zhang *et al.* 2015). Although not related to date directly, the pattern is similar to our seasonal pattern of longer bouts mid-season. In Collared Flycatcher (*Ficedula albicollis*), dawn bout length declines toward the end of the breeding season, once young have hatched and in Cerulean Warbler (*Setophaga cerulea*), bout length decreased with date (MacDonald and Islam 2019). The patterns in pre-dawn singing of Brown Creeper have an inflection point around early–mid June, which are likely tied to the hatching and fledging of young. Davis' (1978) nesting study showed that young hatch typically in early–late June and all young were fledged by mid June to la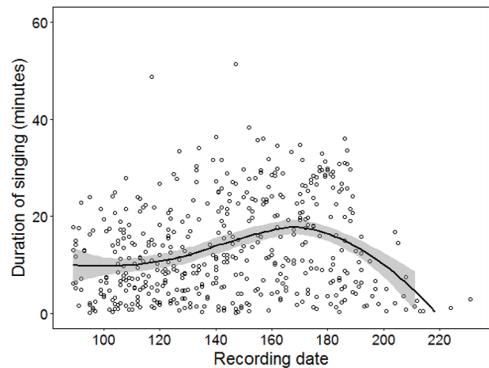te July, which is when we see a significant change in the likelihood of singing (around hatching) and the end of singing (around fledging).

We did not find a seasonal pattern in average dawn song rates. Other studies have found relatively consistent seasonal song rates while other chorus properties have remained constant (e.g., Olinkiewicz and Osiejuk 2003; Kunc *et al.* 2005). Dawn song rate has been linked to male quality and reproductive success (e.g., Otter *et al.* 1997; Poesel *et al.* 2001) and is repeatable (Murphy *et al.* 2008) but also relates to the intensity of response to intruders later in the day (Poesel *et al.* 2004) and the likelihood of intrusion (Naguib *et al.* 2001). Perhaps we see that song rate remains seasonally consistent because it is an indicator of quality to both mates and rivals in Brown Creeper. However, some studies have shown the song rate does also decline with date (e.g., Pärt 1991; Dolan *et al.* 2007) and so the characteristics that remain consistent or change seasonally may vary among species.

The range of Brown Creeper song rate reported by Davis (1978) was 1–8 songs/min, which is consistent with our observed song rates before dawn (range: 0.13–8.32 songs/min). We found that song rates were significantly higher before sunrise than after sunrise

as has been shown in many other passerines (reviewed in Staicer *et al*. 1996). Davis (1978) observed that singing rates increased with increasing intraspecific territorial competition but did not measure song rates or compare them among contexts. Our recorder density was not conducive to examining counter-singing interactions, however, we did detect two individuals singing in just over 2% of recordings. Future studies with more densely spaced arrays of recorders (e.g., Mennill *et al*. 2012) covering mapped territories could be used to study counter-singing in this species.

Brown Creepers had already begun to sing when our study began. However, an earlier description by Tyler (1948) suggests that they begin to sing just as March ends. Some of the variation in the probability of detecting a Brown Creeper on a recording was likely due to individuals moving as our recorders were at fixed locations. A further limitation of our study is that we did not identify or monitor individuals in the field, and thus lack information such as the pairing status or reproductive stage of individuals in the population. Without these, our understanding of the singing behaviour of Brown Creepers is still incomplete, and further research is needed to explore the relationships between breeding stage and singing behaviour. Additional factors such as age (Poesel *et al*. 2006), food availability (Berg *et al*. 2005), condition (Murphy *et al*. 2008), neighbourhood density (Liu 2004), and social status (Otter *et al*. 1997) may also influence singing behaviour and should also be addressed in future research. Although many knowledge gaps remain, the results of this study help increase our understanding of Brown Creeper dawn singing and identify areas of inquiry for future research.

Author Contributions

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

Acknowledgements

Literature Cited

Allard, H.A. 1930. The first morning song of some birds of Washington D.C.; its relation to light. American Naturalist 64: 436–469. https://doi.org/10.1086/280329

Amrhein, V., and N. Erne. 2006. Dawn singing reflects past territorial challenges in the winter wren. Animal Behaviour 71: 1075–1080. https://doi.org/10.1016/j.anbehav.2005.07.023

Baptista, L.F., and R.B. Johnson. 1982. Song variation in insular and mainland California Brown Creepers (*Certhia familiaris*). Journal of Ornithology 123: 131–144. https://doi.org/10.1007/BF01645053

Baptista, L.F., and R. Krebs. 2000. Vocalizations and relationships of Brown Creepers *Certhia americana*: a taxonomic mystery. Ibis 142: 457–465. https://doi.org/10.1111/j.1474-919X.2000.tb04442.x

Bates, D., M. Maechler, B. Bolker, and S. Walker. 2015. Fitting linear mixed-effects models using lme4. Journal of Statistical Software 67: 1–48. https://doi.org/10.18637/jss.v067.i01

Berg, M., N. Beintema, J. Welbergen, and J. Komdeur. 2005. Singing as a handicap: the effects of food availability and weather on song output in the Australian Reed Warbler *Acrocephalus australis*. Journal of Avian Biology 36: 102–109. https://doi.org/10.1111/j.0908-8857.2005.03285.x

Blumstein, D.T., D.J. Mennill, P. Clemins, L. Girod, K. Yaom, G. Patricelli, J.L. Deppe, A.H. Krakauer, C. Clark, K.A. Cortopassi, S.F. Hanser, B. McCowan, A.M. Ali, and A.N.G. Kirschel. 2011. Acoustic monitoring in terrestrial environments using microphone arrays: applications, technological considerations, and prospectus. Journal of Applied Ecology 48: 758–767. https://doi.org/10.1111/j.1365-2664.2011.01993.x

Bruni, A., and J.R. Foote. 2014. Dawn singing of Eastern Phoebes varies with breeding stage and brood number. Wilson Journal of Ornithology 126: 500–507. https://doi.org/10.1676/13-175.1

Bruni, A., D.J. Mennill, and J.R. Foote. 2014. Dawn chorus start time variation in a temperate bird community: relationships with seasonality, weather, and ambient light. Journal of Ornithology 155: 877–890. https://doi.org/10.1007/s10336-014-1071-7

Burt, J.M., and S.L. Vehrencamp. 2005. Dawn chorus as an interactive communication network. Pages 320–343 *in* Animal Communication Networks. *Edited by* P.K. McGregor. Cambridge University Press, Cambridge, United Kingdom. http://doi.org/10.1017/cbo9780511610363.019

Davis, C.M. 1978. A nesting study of the Brown Creeper. Pages 237–263 *in* Living Bird. *Edited by* D.A. Lancaster and J.R. Johnson. The Laboratory of Ornithology, Ithaca, New York, USA.

Davis, J. 1958. Singing behavior and the gonad cycle of the

Rufous-sided Towhee. Condor 60: 308–336. https://doi.org/10.2307/1365157

Dolan, A., K. Sexton, L. Redmond, and M. Murphy. 2007. Dawn song of eastern kingbirds: intrapopulation variability and sociobiological correlates. Behaviour 144: 1273–1295. https://doi.org/10.1163/156853907781890922

Foote, J.R., L.P. Fitzsimmons, D.J. Mennill, and L.M. Ratcliffe. 2008. Male chickadees match neighbors interactively at dawn: support for the social dynamics hypothesis. Behavioral Ecology 19: 1192–1199. https://doi.org/10.1093/beheco/arn087

Foote, J.R., K.L.D. Marini, and H. AL-Ani. 2018. Understanding the function of nocturnal song in ovenbirds: males do not countersing at night. Journal of Avian Biology 49: jav-012511. https://doi.org/10.1111/jav.01729

Gil, D., and M. Gahr. 2002. The honesty of bird song: multiple constraints for multiple traits. Trends in Ecology & Evolution 17: 133–141. https://doi.org/10.1016/S0169-5347(02)02410-2

Greives, T.J., S.A. Kingma, B. Kranstauber, K. Mortega, M. Wikelski, K. van Oers, A.C. Mateman, G.A. Ferguson, G. Beltrami, and M. Hau. 2015. Costs of sleeping in: circadian rhythms influence cuckoldry risk in a songbird. Functional Ecology 29: 1300–1307. https://doi.org/10.1111/1365-2435.12440

Gutzwiller, K.J., R.T. Wiedenmann, K.L. Clements, and S.H. Anderson. 1994. Effects of human intrusion on song occurrence and singing consistency in subalpine birds. Auk 111: 28–37. https://doi.org/10.2307/4088502

Kacelnik, A. 1979. The foraging efficiency of great tits (*Parus major* L.) in relation to light intensity. Animal Behaviour 27: 237–241. https://doi.org/10.1016/0003-3472(79)90143-X

Kunc, H.P., V. Amrhein, and M. Naguib. 2005. Seasonal variation in dawn song characteristics in the common nightingale. Animal Behaviour 70: 1265–1271. https://doi.org/10.1016/j.anbehav.2005.02.010

Kuznetsova, A., P.B. Brockhoff, and R.H.B. Christensen. 2017. lmerTest package: tests in linear mixed effects models. Journal of Statistical Software 82: 1–26. https://doi.org/10.18637/jss.v082.i13

Leopold A., and A.E. Eynon. 1961. Avian daybreak and evening song in relation to time and light intensity. Condor 63: 269–293. https://doi.org/10.2307/1365621

Liu, W.C. 2004. The effect of neighbours and females on dawn and daytime singing behaviours by male chipping sparrows. Animal Behaviour 68: 39–44. https://doi.org/10.1016/j.anbehav.2003.06.022

MacDonald, G.J., and K. Islam. 2019. Do social factors explain seasonal variation in dawn song characteristics of paired male Cerulean Warblers (*Setophaga cerulea*)? Bioacoustics: online. https://doi.org/10.1080/09524622.2019.1682671

Mace, R. 1987. The dawn chorus in the great tit *Paras major* is directly related to female fertility. Nature 330: 745–746. https://doi.org/10.1038/330745a0

Mennill D.J., M. Battiston, D.R. Wilson, J.R. Foote, and S.M. Doucet. 2012. Field test of an affordable, portable wireless microphone array for spatial monitoring of animal ecology and behaviour. Methods in Ecology and Evolution 3: 704–712. https://doi.org/10.1111/j.2041-210X.2012.00209.x

Murphy, M.T., K. Sexton, A.C. Dolan, and L.J. Redmond. 2008. Dawn song of the eastern kingbird: an honest signal of male quality? Animal Behaviour 75: 1075–1084. https://doi.org/10.1016/j.anbehav.2007.08.020

Naguib, M., R. Altenkamp, and B. Griessmann. 2001. Nightingales in space: song and extra-territorial forays of radio tagged song birds. Journal für Ornithologie 142: 306–312. https://doi.org/10.1007/BF01651369

National Research Council Canada. 2017. Sunrise/sunset calculator. Government of Canada. Accessed 25 October 2017. https://www.nrc-cnrc.gc.ca/eng/services/sunrise.

Olinkiewicz, A., and T.S. Osiejuk. 2003. Effect of time of season and neighbours on singing activity in the Corn Bunting *Miliaria calandra*. Acta Ornithologica 38: 117–122. https://doi.org/10.3161/068.038.0208

Osiejuk, T.S., and L. Kuczyński. 2000. Song functions and territoriality in Eurasian Treecreeper *Certhia familiaris* and Short-toed Treecreeper *Certhia brachydactyla*. Acta Ornithologica 35: 109–116.

Otter, K., B. Chruszcz, and L. Ratcliffe. 1997. Honest advertisement and song output during the dawn chorus of black-capped chickadees. Behavioral Ecology 8: 167–173. https://doi.org/10.1093/beheco/8.2.167

Pärt, T. 1991. Is dawn singing related to paternity insurance? The case of the collared flycatcher. Animal Behaviour 41: 451–456. https://doi.org/10.1016/s0003-3472(05)80847-4

Pérez-Granados, C., T.S. Osiejuk, and G.M. López-Iborra. 2018. Dawn chorus interpretation differs when using songs or calls: the Dupont's Lark *Chersophilus duponti* case. Peer J 6: e5241. https://doi.org/10.7717/peerj.5241

Perrault, K., L.M. Lobert, M. Ehnes, and J.R. Foote. 2014. Nocturnal singing in a temperate bird community. Journal of Ornithology 155: 1059–1062. https://doi.org/10.1007/s10336-014-1077-1

Poesel, A., T. Dabelsteen, and S.B. Pedersen. 2004. The dawn song of the Blue Tit *Parus caeruleus* and its role in sexual selection. Ethology 107: 521–531. https://doi.org/10.1046/j.1439-0310.2001.00680.x

Poesel, A., K. Foerster, and B. Kempenaers. 2001. Dawn song of male blue tits as a predictor of competitiveness in midmorning singing interactions. Acta Ethologica 6: 65–71. https://doi.org/10.1007/s10211-004-0086-0

Poesel, A., H.P. Kunc, K. Foerster, A. Johnsen, and B. Kempenaers. 2006. Early birds are sexy: male age, dawn song and extrapair paternity in blue tits, *Cyanistes* (formerly *Parus*) *caeruleus*. Animal Behaviour 72: 531–538. https://doi.org/10.1016/j.anbehav.2005.10.022

Poulin, J.F., E. D'Astous, M. Villard, S.L. Hejl, K.R. Newlon, M.E. McFadzen, J.S. Young, and A. Ghalambor. 2020. Brown Creeper (*Certhia americana*). *In* Birds of the World. *Edited by* A.F. Poole. Cornell Lab of Ornithology, Ithaca, New York, USA. https://doi.org/10.2173/bow.brncre.01

Poulin, J.F., M.-A. Villard, M. Edman, P.J. Goulet, and A.-M. Eriksson. 2008. Thresholds in nesting habitat requirements of an old forest specialist, the Brown Creeper

(*Certhia americana*), as conservation targets. Biological Conservation 141: 1129–1137. https://doi.org/10.1016/j.biocon.2008.02.012

R Core Team. 2017. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Santema, P., M. Valcu, M. Clinchy, L. Zanette, and B. Kempenaers. 2019. Playback of predator calls inhibits and delays dawn singing in a songbird community. Behavioral Ecology 30: 1283–1288. https://doi.org/10.1093/beheco/arz075

Sault Ste. Marie Region Conservation Authority. 2015. Sault Ste. Marie: Hiawatha Highlands Conservation Area. Accessed 2 November 2016. http://ssmrca.ca/conservation-areas/hiawatha-highlands-conservation-area.

Staicer, C.A., D. Spector, and A. Horn. 1996. The dawn chorus and other diel patterns in acoustic signaling. Pages 426–453 *in* Ecology and Evolution of Acoustic Communication in Birds. *Edited by* D.E. Kroodsma and E. Miller. Cornell University Press, Ithaca, New York, USA.

Suter, S.M., D. Ermacora, N. Rieille, and D.R. Meyer. 2009. A distinct reed bunting dawn song and its relation to extrapair paternity. Animal Behaviour 77: 473–480. https://doi.org/10.1016/j.anbehav.2008.11.002

Tyler, W.M. 1948. Brown Creeper. Pages 56–79 *in* Life Histories of North American nuthatches, Wrens, Thrashers and Their Allies. *Edited by* A.C. Bent. Bulletin of the United States National Museum 195. https://doi.org/10.5479/si.03629236.195.1

Wickham, H. 2016. ggplot2: elegant graphics for data analysis. Springer-Verlag, New York, New York, USA. https://doi.org/10.1007/978-0-387-98141-3

Winter, J. 2020. A bioacoustic comparison of song structure in two populations of Brown Creeper *Certhia americana americana*. B.Sc. thesis, Algoma University, Sault Ste. Marie, Ontario, Canada.

Wood, S. 2018. Mixed GAM computation vehicle with automatic smoothness estimation. Accessed 24 August 2018. https://cran.r-project.org/web/packages/mgcv/mgcv.pdf.

Zhang V.Y., A. Celis-Murillo, and M.P. Ward. 2015. Conveying information with one song type: changes in dawn song performance correspond to different female breeding stages. Bioacoustics 25: 19–38. https://doi.org/10.1080/09524622.2015.1076348

Zuur, A.F., E.N. Ieno, N. Walker, A.A. Savilev, and G.M. Smith. 2009. Mixed Effects Models and Extensions in Ecology with R. Springer Science and Business Media, New York, New York, USA. https://doi.org/10.1007/978-0-387-87458-6

Zuur, A.F., A.A. Saveliev, and E.N. Ieno. 2014. A Beginner's Guide to Generalised Additive Mixed Models with R. Highland Statistics Ltd., Newburgh, United Kingdom.

Supplementary Material:

Table S1. Summary of recording dates from 11 autonomous recording units deployed 2015–2017 including recorder failures and the mean (± SE) length of post-sunrise recording.

Table S2. Results of binomial generalized additive mixed models for the presence/absence i) of Brown Creeper (*Certhia americana*) songs ($n = 1335$) and ii) pre-dawn singing ($n = 726$), including the estimated degrees of freedom (edf) for the smooth term, total variance explained (adjusted r^2), SE, and F-, t-, and P-values.

Table S3. Results of generalized additive mixed models for i) start time relative to sunrise and ii) total duration of Brown Creeper (*Certhia americana*) dawn chorus, including the estimated degrees of freedom (edf) for the smooth term, total variance explained (adjusted r^2), SE, and F-, t-, and P-values ($n = 466$).

Table S4. Results of generalized linear mixed models for Brown Creeper (*Certhia americana*) pre-sunrise song rate (songs/min; $n = 466$) and comparison of pre- and post-sunrise song rate (songs/min; $n = 808$).

Boreal Owl (*Aegolius funereus*) and Northern Saw-whet Owl (*Aegolius acadicus*) breeding records in managed boreal forests

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Abstract

During the 2016 breeding season we monitored 169 nest boxes suitable for Boreal Owl (*Aegolius funereus*) and Northern Saw-whet Owl (*Aegolius acadicus*) in high-latitude (>55°N) boreal forests of northwestern Alberta affected by partial logging. Despite the large number of boxes deployed, the number of boxes used by Boreal and Northern Saw-whet Owls was small. Boreal Owls used nest boxes (*n* = 4) in conifer-dominated stands with three being in uncut blocks and the other in a 50% green tree retention cut-block. In contrast, Northern Saw-whet Owls used boxes (*n* = 4) in a broader range of cover types, breeding in boxes placed in stands with at least 20% post-harvest tree retention. Although both species successfully bred in the same landscape, Boreal Owls produced fewer eggs (mean = 2.5) and raised fewer young (mean = 0.5) than Northern Saw-whet Owls (5 and 2.25, respectively). Furthermore, our observed Boreal Owl egg production was lower than has been found for the same species nesting in nest boxes in different regions or forest types. In contrast, breeding parameters of Northern Saw-whet Owls were similar to that found in nest boxes in the eastern boreal region of Canada and in the southern part of its range.

Key words: Nest boxes; breeding records; boreal forest; Boreal Owl; Northern Saw-whet Owl; clutch size; nesting success; partial logging

Introduction

Boreal Owl (*Aegolius funereus*) and Northern Saw-whet Owl (*Aegolius acadicus*) are obligate cavity nesters, occupying tree holes excavated by Pileated Woodpecker (*Dryocopus pileatus*) and Northern Flicker (*Colaptes auratus*; Hayward *et al*. 1993; Johnsgard 2002). Locating natural nest sites for study is difficult as these owls often breed in remote locations where lack of roads and deep snow conditions restrict access (Hayward *et al*. 1993; Korpimaki and Hakkarainen 2012). As a result, most breeding data come from nest box experiments (Hayward *et al*. 1993; Lauff 2009; Korpimaki and Hakkarainen 2012) because boxes provide an efficient (Korpimaki and Hakkarainen 2012) and cost effective (Hayward *et al*. 1992) method to document breeding, examine habitat associations of nesting owls, and provide demographic data.

Forestry activities that reduce cavity availability (Hayward 1997; Korpimaki and Hakkarainen 2012) or eliminate large trees from forest stands (Lopez *et al*. 2010) have been identified as risks to Boreal Owl populations. It is likely that Northern Saw-whet Owls, which have similar nesting habitats, are similarly impacted by logging. More than 35% of the Canadian boreal forest is now managed for forestry resulting in younger trees across the region (Gauthier *et al*. 2015). However, there is a trend to replace traditional clearcutting with management techniques that aim to maintain some old growth forest and to create features of older stands earlier in succession (Burton *et al*. 1999; Lindenmayer *et al*. 2006; Thorpe and Thomas 2007; Etheridge and Kayahara 2013; Fedrowitz *et al*. 2014).

Green tree retention forestry creates a landscape mosaic of old and young forest patches and leaves mature trees after harvest which may preserve cavity nesting communities (Woodley *et al*. 2006; Cooke and Hannon 2011), including cavity nesting owls

(Hayward 1997). But, it is not clear what levels of retention (Lance and Phinney 2001) are most effective for owl conservation or what structures should be retained (Thorpe and Thomas 2007; Cooke and Hannon 2011; Straus *et al.* 2011). Density of primary cavity excavators is reduced in partially harvested stands (Straus *et al.* 2011), resulting in lower cavity density and inherently higher competition among secondary cavity nesters (Bonar 2000). As both Boreal Owls and Saw-whet Owls readily accept nest boxes, these artificial cavities could provide additional nesting opportunities in logged areas.

The northern boundary of the Northern Saw-whet Owl's breeding range is unclear (Buidin *et al.* 2006), and although the Canadian boreal forest represents a considerable part of the ranges of both species, there is little information concerning their population status and breeding ecology. We present results of a nest box experiment initiated to evaluate the responses of Boreal Owl and Northern Saw-whet Owl to variable retention forestry in the western boreal region of Alberta. Our specific objectives were to document owl breeding across three different forest types and a range of retention levels, to describe breeding habitat, and to compare reproductive success of owls breeding in partially logged stands with those from other forest types.

Methods

We conducted our study in the Clear Hills region of Alberta, Canada, an area of ~900 km^2, ranging in elevation from 470 to 920 m above sea level, including the land base of the Ecosystem Management Emulating Natural Disturbance (EMEND) Project located 90 km northwest of Peace River, Alberta (56.7703°N, 118.374°W). This predominantly forested region was historically shaped by fire (Work *et al.* 2004; Bergeron 2012), but the intensification of logging and oil and gas exploration has become a key driver of forest dynamics. The upland mixed wood landscape is comprised of deciduous hardwood patches dominated by Trembling Aspen (*Populus tremuloides* Michaux) and Balsam Poplar (*Populus balsamifera* L.), interspersed with conifer patches that are predominantly White Spruce (*Picea glauca* (Moench) Voss). Forests on poorly drained sites contain open and closed canopies of Black Spruce (*Picea mariana* (Miller) Britton) and Tamarack (*Larix laricina* (Du Roi) K. Koch).

The forest of the EMEND experiment (description of the complete design is available from Spence *et al.* 1999; Work *et al.* 2010) is a patchwork of four main cover types: conifer-dominated (CD, conifers >70% of the canopy), deciduous-dominated (DD, conifers <30% of the canopy), deciduous-dominated with co-

nifer understorey (DU), and mixed (MX, relative equal composition of conifer and deciduous trees). Compartments of ~10 ha of each cover type were subjected to various levels of forest harvesting in winter of 1998–1999. Trees were retained by operators according to prescription and independent of size, status, and species. During August–October 2015 we placed nest boxes in compartments with 20%, 50%, and 75% retention as well as unharvested compartments in three cover types (CD, DD, and MX). A 20% retention means that 20% of the trees in a 10 ha compartment were not cut down. Additional boxes were placed in unharvested CD, DD, and MX stands outside EMEND that were at least 10 ha in size, and in residual trees found in recent (1–5 years) clear-cuts. Boxes were not evenly distributed on the landscape but rather along existing roads and trails to facilitate access. Not all forest cover types were equally available for box placement as many deciduous dominated stands had been previously harvested and the regenerating trees (5–15 years old) were too dense and too small to support boxes.

Nest boxes were built of 2 cm thick rough-cut spruce boards, with an entrance hole of 79 mm, following a box design described by Korpimaki (1985). The bottom 10 cm of each box was filled with aspen chips and shavings to provide insulation and prevent egg breakage. In the field, boxes were hung on live or dead trees at an average height of 5.2 m (range: 2.7–6.2 m), using a sectional Swedish tree climbing ladder (Forestry Suppliers Inc., Jackson, Massachusetts, USA). We did not follow any pattern for box orientation (although orientation was recorded) but ensured that there was a small opening through the vegetation in front of the box to allow a direct flight path to the entrance hole. Two boxes were placed in the three different cover types in the selected 36 EMEND compartments including both harvested and unharvested sites, with boxes set no closer than 200 m (range: 204–647 m) to each other. The average distance between the nest boxes placed outside EMEND was 1274 m (568–2968 m).

Nesting habitat

We monitored 169 nest boxes suitable for both Boreal Owl and Northern Saw-whet Owl at EMEND (72 boxes) or in the surrounding landscape (97 boxes) during the 2016 breeding season. Landscape characteristics at each nest box were tabulated using ArcMap 10.2.2 (2011 ArcGIS Desktop: Release 10, Environmental Systems Research Institute, Redlands, California, USA) at two scales: 1) nest site (NS, 3.14 ha or 100 m radius circle centred on the nest box) and 2) home range (HR, ~100 ha or 564 m radius circle centred on the nest box). We considered the NS scale was an adequate area to describe hab-

itat associations in the immediate vicinity of potential nest sites of owls while maintaining the spatial separation between two neighbouring boxes. Hinam and Cassady St. Clair (2008) reported average home range size of Northern Saw-whet Owls in Alberta as 89.4 ha (range: 11.7–137.0 ha), which is about half the area of Boreal Owl home ranges in Fennoscandia (50–230 ha; Korpimaki and Hakkarainen 2012). Our choice of the HR scale certainly includes the core area for most owls and provides information about breeding habitat across a wider area. Tabulated characteristics included percent composition of the three dominant cover types and percent shrub land, grassland, and agricultural land from the Alberta Biodiversity Monitoring Institute Wall-to-wall Vegetation Layer (Alberta Biodiversity Monitoring Institute 2010). We checked every box at least twice during April–June. Initial visits consisted of a quick glance into the box, using a home-made observation device assembled from an extendable pole, wireless inspection camera (Gardner Bender Wi-Fi inspection Camera, Gardner Bender, Menomonee Falls, Wisconsin, USA), and a cell phone (connected to the inspection camera using the Gardner Bender WiFi Tool app). Occupant species, eggs, cached prey, or any other signs of occupancy (e.g., feathers, additional nest material) were noted and future check dates were scheduled based on the initial findings. Checks were scheduled to document each stage of breeding: number of eggs, hatching success, and fledging success. If a nest was found with a completed clutch, it was checked two more times: about a week after the estimated hatch time and around the estimated fledge time. All boxes were also cleaned in August–September when fledging was confirmed.

Reproductive success

Boxes occupied by owls were monitored until the clutch failed or nestlings were at fledgling age (28–30 days old). Reproductive success was measured as: (1) nesting effort (number of eggs laid), (2) hatching success (% of eggs hatched), and (3) fledging success (% nestlings reaching 28–30 days). The time of nest initiation was calculated based on a two-day egg laying interval (Korpimaki 1981).

Results

Nesting habitat

During the 2016 breeding season, 64 (39%) of 164 nest boxes available for study were used; of the 169 boxes placed, one was destroyed because of forest harvesting, and four boxes could not be accessed after beavers flooded the access trail. Other species were found using the nest boxes (Table 1) but 10 boxes (6%) were used by owls: four by Boreal Owls, four by Northern Saw-whet Owls, and two where the

TABLE 1. Nest box occupancy during the 2016 breeding season at Clear Hills, Alberta. A nest box was marked used if presence of species, or any sign of usage (e.g., cached prey, eggs, feathers) was detected inside the box. Identity of users remained unknown when animal presence was never detected at the box, but signs indicated clear use by either group (owls or squirrels).

Nest box occupancy	Number of boxes (%)
American Kestrel (*Falco sparverius*)	2 (1.2)
Boreal Owl (*Aegolius funereus*)	4 (2.4)
Northern Flicker (*Colaptes auratus*)	5 (3.0)
Northern Flying Squirrel (*Glaucomys sabrinus*)	3 (1.8)
Northern Saw-whet Owl (*Aegolius acadicus*)	4 (2.4)
Red Squirrel (*Tamiasciurus hudsonicus*)	36 (22.0)
Unknown owl (*Aegolius* sp.)	2 (1.2)
Unknown squirrel	8 (4.9)
Empty boxes	100 (61.0)
Total	164

owl species could not be identified. In these latter two cases, the nest boxes contained cached prey, but no owls were detected and there was no sign of laid eggs or hatched young.

The two owl species used the available cover types differently. Boreal Owls used boxes in conifer patches only ($n = 4$; three in unharvested areas and one nest box in a cutblock with 50% tree retention), while Northern Saw-whet Owls used the deciduous dominated ($n = 2$) and mixed ($n = 2$) cover types. For Boreal Owls, conifer cover was high at both scales (NS = 90.2 ± 9.7, HR = 80.1 ± 9.1) and included low levels of mixed forest only at the HR scale (5.7 ± 1.5). Northern Saw-whet Owls nests were in predominantly deciduous cover (93.4 ± 6.4, $n = 4$) at NS scale, although the mixed component cover increased (25.3 ± 10.9, $n = 4$) at the HR scale. Neither of the species used boxes placed in clear-cuts. Northern Saw-whet Owls did not nest in unharvested forests, occupying one box placed in the 50% tree retention compartment, one in 75%, and two in harvested patches with 20% tree retention.

Reproductive success

Both species successfully bred in a boreal landscape affected by partial harvesting, however breeding phenology of Northern Saw-whet Owls was different from that of Boreal Owls (Table 2). The earliest nest initiation for Boreal Owl was 10 April and the latest clutch was started on 31 May. Northern Saw-whet Owls started breeding one month later than Boreal Owls, with the earliest clutch initiated on 10 May and the latest on 15 June. Two Boreal Owl nests failed be-

TABLE 2. Breeding parameters at eight nest boxes where at least one egg had been laid for Boreal Owl (*Aegolius funereus*) and Northern Saw-whet Owl (*Aegolius acadicus*) at Clear Hills, Alberta, 2016.

Species	Nest initiation date	Fledging date	Eggs laid	Hatched young	Fledglings
Boreal Owl	31 May	n/a	2	0	0
Boreal Owl	2 May	28 June	3	2	2
Boreal Owl	10 April	n/a	3	3	0
Boreal Owl	n/a	n/a	2	0	0
Northern Saw-whet Owl	12 June	10 August	5	4	3
Northern Saw-whet Owl	8 June	10 August	6	5	2
Northern Saw-whet Owl	15 June	10 August	4	4	4
Northern Saw-whet Owl	10 May	n/a	5	4	0

fore clutch completion. The first nest contained two eggs and three cached prey items on 17 May; the eggs did not hatch. The second nest was started on 31 May and the female laid two eggs but on 2 July the nest box was empty. Northern Saw-whet Owls breeding in the ~900 km^2 boreal mixed-wood landscape produced more eggs (mean = 5; range: 4–6) than Boreal Owls (mean = 2.5; range: 2–3), and had also a higher hatching success (85%) than Boreal Owls (50%). Boreal Owls raised only 0.5 fledglings/nest while Northern Saw-whet Owls were more successful, producing 2.25 fledglings/nest. Boreal Owl young were ready to fledge on 28 June, while all Northern Saw-whet Owl nestlings were close to fledging on 10 August.

Discussion

Nesting habitat and retention forestry

Boreal Owl nest box occupancy (2.4%) in our partially harvested landscape was lower than in the highly managed boreal forests of Finland (15%; Korpimaki and Hakkarainen 2012), or China, where occupancy varied between 6–10% over five years for boxes placed in selectively logged forests lacking large trees (Fang *et al.* 2009). However, occupancy at our study site is comparable to that observed in uncut forests of the Northern Rocky Mountains, USA (1.7%; Hayward *et al.* 1993) and Yukon, Canada (1%; Mossop 1997).

Northern Saw-whet Owls also nested in four boxes (2.4%) at EMEND; and although Buidin *et al.* (2006) reported range expansion for this species in eastern Canada north of 50°N, we are unaware of any other studies that documented breeding at a similar latitude as ours. The low occupancy is consistent with findings reported at their northern breeding limit in the boreal forests of Quebec, Canada (2.5%; Buidin *et al.* 2006). In contrast, Saw-whet Owls occupied higher proportions of available boxes in the southern part of their breeding range: 3–36% at a hybrid poplar plantation in north-central Oregon, USA (Moser 2002; Marks *et al.* 2015), and 15% at the Custer National

Forest in South Dakota, USA (Drilling 2013). Given the sparse data from the northern limits of the breeding range, it is not clear whether the difference in occupancy rates is due to lower owl densities in the north, cyclical changes in population size, or the relative availability of cavities in these different forest types found further south.

Our study shows for the first time that the breeding ranges of Boreal Owl and Northern Saw-whet Owl overlap in northwestern Alberta at >55°N. Northern Saw-whet Owls nested in relative proximity to conspecifics, with the minimum distance of 659 m between two occupied nest boxes. Similar results were obtained in the commercial poplar plantations in Oregon, where owls nested within 0.5–1.2 km of nest boxes occupied by conspecifics (Marks *et al.* 2015). In contrast, early nesting Boreal Owls at EMEND occupied boxes 11.4 km apart. However, a second clutch was initiated (potentially by the same female) only 330 m from a nest box that contained three Boreal Owl nestlings. It is probable that some home ranges overlapped within species, although substantial local overlap between these two species seems unlikely as the minimum distance between occupied nest boxes of a Boreal and a Northern Saw-whet Owl was 2770 m. Lane and McKeown (1991) reported aggressive interactions of Boreal Owl and Northern Saw-whet Owls and suggested that limited cavities might be a source of interspecific competition; this avenue for future work should be explored.

The nest site choices observed here for Boreal Owls corroborates their use of old conifer forests, which has been well documented elsewhere (Hayward *et al.* 1993; Korpimaki and Hakkarainen 2012). Low retention compartments lack the structural complexity of old forests. Stands with 20% green tree retention were at the time of our research 17 years post-harvest, and covered by dense aspen regeneration, with only a few trees large enough to potentially host a natural cavity created by primary cavity excavators. The absence of Boreal Owls from low retention patches (i.e., patches

with more trees cut), even when nest boxes were provided, is consistent with suggestions that they key on forests with significant structural complexity not just nest sites (Hayward *et al.* 1993).

The pattern of nest box use by Northern Saw-whet Owls at our research site underscores their willingness to breed in a broader range of forest types if cavities are available (Moser 2002; Drilling 2013; Marks *et al.* 2015). Nesting of Northern Saw-whet Owls in younger stands could be explained by their higher maneuverability and lighter wing loading than Boreal Owls, allowing them to hunt in dense vegetation (Hayward and Garton 1988).

Variable retention forestry that creates a mosaic of stands of different cover types and structural complexity, including uncut patches that resemble old forests, seems capable of providing nesting habitat for cavity nesting owls—if nest sites are available. Our findings complement those of other studies showing that on logged landscapes at least 30% retention, with some patches at least 10 ha in size, is needed to maintain most cavity users associated with old boreal forests (Cooke and Hannon 2011). However, our nest box data suggest that further examining how these species react to disturbance by partial logging is warranted.

Timing of nesting

Timing of nest initiation (10 April–31 May) for Boreal Owls at our study site is comparable to laying dates at Chamberlain Basin, Idaho, USA (12 April–24 May; Hayward *et al.* 1993). However, they started breeding earlier in both Nova Scotia, Canada (20 March–1 June; Lauff 2009) and Finland (13 March–2 May; Korpimaki and Hakkarainen 2012). The latest clutch laid at EMEND was probably a replacement nest, or a second clutch initiated by a polyandrous female (see Korpimaki and Hakkarainen 2012 for criteria).

Timing of nest initiation (10 May–15 June) for Northern Saw-whet Owls breeding at EMEND was comparable to birds breeding in the Mignan Region, Quebec, Canada (nest initiation dates range from early-April to mid-June; Buidin *et al.* 2006). Nest initiation dates are seldom reported from Saw-whet Owl nest box experiments; however, birds breeding in nest boxes placed in hybrid poplar plantation in Oregon started laying in early and mid-March (1 March; Marks *et al.* 2015 and 16 March; McCullough and Conway 2017).

Nesting effort and success

Northern Saw-whet Owls in our study laid more eggs (mean = 5; range: 4–6; *n* = 4) than did conspecifics in the boreal forests of Quebec (mean = 3.5, range: 1–6; *n* = 9; Buidin *et al.* 2006). However, conspecif-

ics breeding in a young poplar plantation in Oregon (mean = 5.8, range: 5–7; Marks *et al.* 2015) and in the Custer National Forest, South Dakota, USA (mean = 5.2 eggs/nest, range: 2–8; *n* = 136; Drilling 2013) laid more eggs than we observed.

Boreal Owl egg production (mean = 2.5; range: 2–3; *n* = 4) was lower than reported from Nova Scotia (mean = 3.5, range: 3–4; *n* = 4; Lauff 2009) or central Idaho (mean = 2.95, range: 2–4; *n* = 16; Hayward *et al.* 1993). Owls nesting in Alberta produced fewer eggs than did Finnish owls even in the poorest vole years (mean = 4.75, range: 4–5.4; Korpimaki and Hakkarainen 2012), although year to year variation of clutch size in Fennoscandia was high (mean = 5.71, range: 1–10; Korpimaki 1987).

Boreal Owls hatched only 50% of the eggs, less than birds breeding in spruce-fir forests affected by Spruce Budworm (*Choristoneura fumiferana* Clemens) in Nova Scotia (85.5%; Lauff 2009) or Finnish owls breeding in highly managed boreal forests (86.7%; Korpimaki and Hakkarainen 2012). In contrast, Northern Saw-whet Owls hatched 85% of their eggs, comparable to averages found in a poplar plantation in Oregon (83%; Moser 2002) but were less successful than owls breeding in nest boxes in Custer National Forest in northwestern South Dakota (96%; Drilling 2013).

Boreal Owls at EMEND fledged 0.5 young per nest and fledging success was 35%, lower than documented in both Nova Scotia (62%; Lauff 2009) and Finland (59%; Korpimaki and Hakkarainen 2012). Fledging success for Northern Saw-whet Owls was 52.9% with 2.25 fledglings per nest, comparable to data from the northern limit of their breeding range in the Mignan Region, Quebec (mean = 2.8, range = 1–6; Buidin *et al.* 2006). However, breeding owls at EMEND fledged fewer young than the nine-year average (3.4 fledgling/nest), but well within the range (0.4–4.1 young/nest) recorded for Northern Saw-whet Owls breeding in boxes placed in wooded ravines surrounded by grasslands in northwestern South Dakota (Drilling 2013).

Conclusion

The network of nest boxes established at EMEND provides the starting point for long-term monitoring of these two small owl species. Our early findings suggest that uncut forest patches of sufficient size will be required to conserve populations of Boreal Owl on harvested landscapes. We recommend long-term monitoring of breeding populations of these cavity nesting owls in landscapes affected by partial logging as it is well documented that habitat alteration and low fledging success contributed to negative growth rates (−2.1 to −2.3% per year) of local Boreal Owl populations in Finland, where the species is now con-

sidered near threatened (Korpimaki and Hakkarainen 2012). We also know that reduction of old growth forest cover is a main factor affecting male survival and reproductive success for Boreal Owl (Laaksonen *et al.* 2004; Korpimaki and Hakkarainen 2012), and that reduction of forest patch size and increasing fragmentation decreases reproductive output for Northern Saw-whet Owls (Hinam and Cassady St. Clair 2008). We suggest continuous monitoring of the nest box network established at EMEND as this could support useful conclusions about the effectiveness of nest box provisions in partially logged forests in maintaining cavity nesting owl populations. Additionally, studies for both owl species should focus on landscape characteristics that promote preservation of breeding populations during post-harvest recovery of stands impacted by variable retention logging.

Author Contributions

Acknowledgements

Literature Cited

Alberta Biodiversity Monitoring Institute. 2010. ABMI Wall-to-wall Land Cover Map Version 2.1. Accessed 16 December 2016. https://abmi.ca/home/data-analytics/da-top/da-product-overview/Data-Archive/Land-Cover.html.

Bergeron, C. 2012. Fire history, landscape biodiversity and indicators for sustainable management of the boreal mixedwood forest. Ph.D. thesis, University of Alberta, Edmonton, Alberta, Canada.

Bonar, R.L. 2000. Availability of pileated woodpecker cavities and use by other species. Journal of Wildlife Management 64: 52–59. https://doi.org/10.2307/3802974

Buidin, C., Y. Rochepault, M. Savard, and J.P.L. Savard. 2006. Breeding range extension of the Northern Saw-whet Owl in Quebec. Wilson Journal of Ornithology 118: 411–413. https://doi.org/10.1676/05-092.1

Burton, P.J., D.D. Kneeshaw, and K.D. Coates. 1999. Managing forest harvesting to maintain old growth in boreal and sub-boreal forests. Forestry Chronicle 75: 623–631. https://doi.org/10.5558/tfc75623-4

Cooke, H.A., and S.J. Hannon. 2011. Do aggregated harvests with structural retention conserve the cavity web of old upland forest in the boreal plains? Forest Ecology and Management 261: 662–674. https://doi.org/10.1016/j.foreco.2010.11.023

Drilling, N.E. 2013. Studies of nesting Northern Saw-whet Owls in northwestern South Dakota. Technical Report: M-SDOWLBAND-03. Rocky Mountain Bird Observatory, Brighton, Colorado, USA. Accessed 15 November 2015. https://birdconservancy.org/wp-content/uploads/2013/08/NSWO_2012NestRsrchRpt.pdf.

Etheridge, D.A., and G.J. Kayahara. 2013. Challenges and implications of incorporating multi-cohort management in northeastern Ontario, Canada: a case study. Forestry Chronicle 89: 315–326. https://doi.org/10.5558/tfc2013-062

Fang, Y., S.H. Tang, Y. Gu, and Y.H. Sun. 2009. Conservation of Tengmalm's Owl and Sichuan Wood Owl in Lianhuashan Mountain, Gansu, China. Ardea 97: 649. https://doi.org/10.5253/078.097.0437

Fedrowitz, K., J. Koricheva, S.C. Baker, D.B. Lindenmayer, B. Palik, R. Rosenvald, W. Beese, J.F. Franklin, J. Kouki, E. Macdonald, C. Messier, A. Sverdrup-Thygeson, and L. Gustafsson. 2014. Can retention forestry help conserve biodiversity? A meta-analysis. Journal of Applied Ecology 51: 1669–1679. https://doi.org/10.1111/1365-2664.12289

Gauthier, S., P. Bernier, T. Kuuluvainen, A.Z. Shvidenko, and D.G. Schepaschenko. 2015. Boreal forest health and global change. Science 349: 819–822. https://doi.org/10.1126/science.aaa9092

Hayward, G.D. 1997. Forest management and conservation of Boreal Owls in North America. Journal of Raptor Research 31: 114–124.

Hayward, G.D., and E.O. Garton. 1988. Resource partitioning among forest owls in the River of No Return Wilderness, Idaho. Oecologia 75: 253–265. https://doi.org/10.1007/BF00378606

Hayward, G.D., P.H. Hayward, and E.O. Garton. 1993. Ecology of Boreal Owls in the Northern Rocky Mountains, USA. Wildlife Monographs 124: 1–59.

Hayward, G.D., R.K. Steinhorst, and P.H. Hayward. 1992. Monitoring Boreal Owl populations with nest boxes—sample-size and cost. Journal of Wildlife Management 56: 777–785. https://doi.org/10.2307/3809473

Hinam, H.L., and C. Cassady St. Clair. 2008. High levels of habitat loss and fragmentation limit reproductive success by reducing home range size and provi-

sioning rates of Northern saw-whet owls. Biological Conservation 141: 524–535. https://doi.org/10.1016/j.biocon.2007.11.011

Johnsgard, P.A. 2002. North American Owls: Biology and Natural History. Second Edition. Smithsonian Institution Press, Washington, DC, USA.

Korpimaki, E. 1981. On the ecology and biology of Tengmalm's Owl (*Aegolius funereus*) in southern Ostrobothnia and Suomenselkä, Western Finland. Acta Universitatis Ouluensis, A 118, Biol 13. University of Oulu, Oulu, Finland.

Korpimaki, E. 1985. Clutch size and breeding success in relation to nest-box size in Tengmalm's owl *Aegolius funereus*. Holarctic Ecology 8: 175–180. https://doi.org/10.1111/j.1600-0587.1985.tb01168.x

Korpimaki, E. 1987. Clutch size, breeding success and brood size experiments in Tengmalm's owl *Aegolius funereus*: a test of hypotheses. Ornis Scandinavica 18: 277–284. https://doi.org/10.2307/3676896

Korpimaki, E., and H. Hakkarainen. 2012. The Boreal Owl: Ecology, Behaviour and Conservation of a Forest-Dwelling Predator. Cambridge University Press, New York, New York, USA. https://doi.org/10.1017/CBO9780511844164

Laaksonen, T., H. Hakkarainen, and E. Korpimaki. 2004. Lifetime reproduction of a forest-dwelling owl increases with age and area of forests. Proceedings of the Royal Society B: Biological Sciences 271: S461–S464. https://doi.org/10.1098/rsbl.2004.0221

Lance, A.N., and M. Phinney. 2001. Bird responses to partial retention timber harvesting in central interior British Columbia. Forest Ecology and Management 142: 267–280. https://doi.org/10.1016/S0378-1127(00)00356-X

Lane, B., and S. McKeown. 1991. Physical interaction between a male Boreal Owl and male Northern Saw-whet Owl. Loon 63: 74–75.

Lauff, R.F. 2009. First nest records of the Boreal Owl *Aegolius funereus* in Nova Scotia, Canada. Ardea 97: 497–502.

Lindenmayer, D.B., J.F. Franklin, and J. Fischer. 2006. General management principles and a checklist of strategies to guide forest biodiversity conservation. Biological Conservation 131: 433–445. https://doi.org/10.1016/j.biocon.2006.02.019

Lopez, B.C., D. Potrony, A. Lopez, E. Badosa, A. Bonada, and R. Salo. 2010. Nest-box use by Boreal Owls (*Aegolius funereus*) in the Pyrenees Mountains in Spain. Journal of Raptor Research 44: 40–49. https://doi.org/10.3356/JRR-09-32.1

Marks, J.S., A. Nightingale, and J.M. McCullough. 2015. On the breeding biology of Northern Saw-whet Owls (*Aegolius acadicus*). Journal of Raptor Research 49:

486–497. https://doi.org/10.3356/rapt-49-04-486-497.1

McCullough, J.M., and C.J. Conway. 2017. Breeding behavior of Northern Saw-whet Owls in Oregon. Northwest Science 91: 222–227. https://doi.org/10.3955/046.091.0211

Moser, B.W. 2002. Reproductive success of Northern Saw-whet Owls nesting in hybrid poplar plantations. Northwest Science 76: 353–355.

Mossop, D.H. 1997. The importance of old growth refugia in the Yukon boreal forest to cavity-nesting owls. 584–586 *in* Biology and Conservation of Owls of the Northern Hemisphere: 2nd International Symposium. *Edited by* J.R. Duncan, D.H. Johnson, and T.H. Nicholls. General Technical Report NC-190. U.S. Dept. of Agriculture, Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota, USA.

Spence, J.R., W.J.A. Volney, V.J. Lieffers, M.G. Weber, S.A. Luchkow, and T.W. Vinge. 1999. The Alberta EMEND project: recipe and cooks' argument. Pages 583–590 *in* Science and Practice: Sustaining the Boreal Forest. SFM Network, 14–17 February 1999. Edmonton, Alberta, Canada.

Straus, M.A., K. Bavrlic, E. Nol, D.M. Burke, and K.A. Elliott. 2011. Reproductive success of cavity-nesting birds in partially harvested woodlots. Canadian Journal of Forest Research 41: 1004–1017. https://doi.org/10.1139/x11-012

Thorpe, H.C., and S.C. Thomas. 2007. Partial harvesting in the Canadian boreal: success will depend on stand dynamic responses. Forestry Chronicle 83: 319–325. https://doi.org/10.5558/tfc83319-3

Woodley, S.J., G. Johnson, B. Freedman, and D.A. Kirk. 2006. Effects of timber harvesting and plantation development on cavity-nesting birds in New Brunswick. Canadian Field-Naturalist 120: 298–306. https://doi.org/10.22621/cfn.v120i3.319

Work, T.T., J.M. Jacobs, J.R. Spence, and W.J. Volney. 2010. High levels of green-tree retention are required to preserve ground beetle biodiversity in boreal mixedwood forests. Ecological Applications 20: 741–751. https://doi.org/10.1890/08-1463.1

Work, T.T., D.P. Shorthouse, J.R. Spence, W.J.A. Volney, and D. Langor. 2004. Stand composition and structure of the boreal mixedwood and epigaeic arthropods of the Ecosystem Management Emulating Natural Disturbance (EMEND) landbase in northwestern Alberta. Canadian Journal of Forest Research 34: 417–430. https://doi.org/10.1139/x03-238

Note

Interactions between Elk (*Cervus canadensis*) and invasive Feral Swine (*Sus scrofa*) on the Canadian Prairies

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Abstract
Elk (*Cervus canadensis*), a native species on the Canadian Prairies, makes extensive use of agro-ecosystems. Feral Swine
(*Sus scrofa*) is a highly invasive species introduced to western Canada in the late 1980s; it is now endemic and rapidly
expanding its range across the Canadian Prairies. Here we consider a series of 14 trail camera photos obtained near St.
Breiux, Saskatchewan on 18 November 2018. Taken at night over 67 minutes, they document close, non-aggressive encoun-
ters between Elk and Feral Swine. We believe that these are the first documented observations of close (<5 m) interactions
between free-ranging Elk and Feral Swine in North America that include no indications of fear response or displacement of
one species by the other. These types of indirect interactions among species have important implications in terms of potential
risk of disease transmission and interpreting potential ecological impacts of invasive Feral Swine on native large mammals.

Key words: Behaviour; *Cervus canadensis*; Elk; Eurasian Wild Boar; indirect contact; invasive species; *Sus scrofa*; Feral
  Swine

Feral Swine (*Sus scrofa*), also known as feral pig
or wild hog, is not native to North America and is a
complex hybrid of Eurasian Wild Boar and domes-
tic pigs (Keiter *et al.* 2017; Michel *et al.* 2017). Over
the last 35 years, the species has been imported from
Europe and Asia to all ten Canadian provinces and
Yukon as domestic livestock for meat production and
penned shoot operations in Alberta, Saskatchewan,
and Quebec (Michel *et al.* 2017). Escapes and pur-
poseful releases of domestic animals have resulted in
endemic populations of free-ranging Feral Swine in
all provinces except Atlantic Canada (Brook and van
Beest 2014; Michel *et al.* 2017; Aschim and Brook
2019). Currently, most Feral Swine in Canada are in
Saskatchewan, where they continue to spread rap-
idly (Aschim and Brook 2019). Ecological impacts of
Feral Swine on large mammals have been well doc-
umented through habitat damage, predation, and ag-
gressive interactions that displace native mammals
(Barrios-Garcia and Ballari 2012).

Trail camera photos of large mammals in central
Saskatchewan have confirmed the presence of both
Elk (*Cervus canadensis*) and Feral Swine on the land-
scape, but show that Elk avoid Feral Swine at the scale
of the individual trail camera location (O'Brien 2019).
Contrary to these findings, herein we report an obser-
vation of a prolonged, non-aggressive close interac-
tion (<5 m) between a young male Elk and a sounder
group of Feral Swine in the same study area as that
of O'Brien (2019). A sounder group typically com-
prises a mature female along with several generations
of her mature female offspring and one or two litters
of young born that year. Adult males visit sounders
regularly and mate with any receptive females. On the
Canadian Prairies, observed sounder size ranges from
three to 36 animals (R.K.B. unpubl. data).

We obtained a set of trail camera photos (Figure 1)
from a landowner living near the town of St. Breiux
(52°37′N, 104°51′W) in central Saskatchewan, Can-
ada, that included Elk and Feral Swine in the same
images. The study area is an agro-ecosystem that in-
cludes extensive annual and perennial agricultural
cropland mixed with patches of deciduous forest and
wetland (Stolle *et al.* 2015; O'Brien *et al.* 2019). On
18 November 2018, 14 images were collected from
an unbaited trail camera (Moultrie, Calera, Alabama,
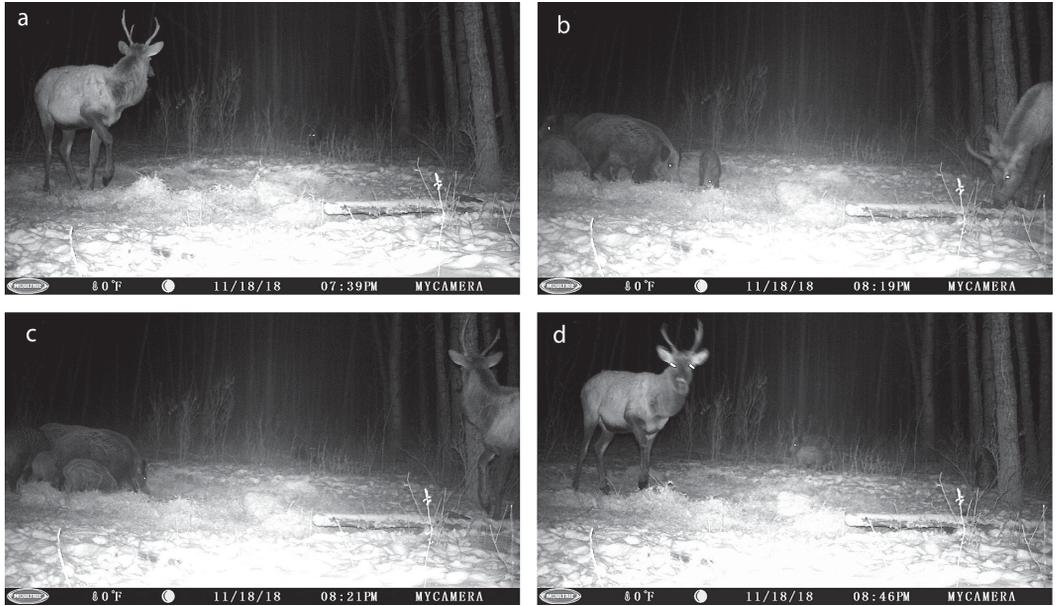
FIGURE 1. A subset of trail camera photos of a juvenile yearling male Elk (*Cervus canadensis*) interacting with a group of five invasive Feral Swine (*Sus scrofa*) from 14 images taken near St. Brieux, Saskatchewan on 18 November 2018. a. Elk looking at a Feral Swine moving into the site (1939). b. Elk feeding near Feral Swine (2219). c. Elk looking up at another Feral Swine moving into the site (2021). d. Elk looking at the trail camera with three Feral Swine in the background. Piglets (<6 months of age) are distinguished by their smaller size and horizontal lighter coloured stripes.

USA) over 67 minutes from 1939 to 2046 (Figure 1). At the time the images were taken, there was a thin ground cover of snow and the temperature recorded by the camera was −18°C. Each image includes a yearling "spike" bull Elk. A spike bull is defined as an antlered juvenile male with no branching of either antler (Slabach *et al.* 2018). The same images also included one to five Feral Swine that were part of the sounder group described above and were in the general area, sometimes within the range of the camera and sometimes not. In the images, the animals are standing or feeding on vegetation (Figure 1). To our knowledge, this is the first published photographic evidence of fine-scale, non-aggressive interactions between Elk and Feral Swine in North America.

Trail camera photographs of wildlife interactions provide important insights into their complex behaviour and ecology in the absence of human observers (Caravaggi *et al.* 2018). Feral Swine are highly invasive in Canada and are spreading rapidly, especially on the Canadian Prairies (Aschim and Brook 2019). They can be extremely aggressive toward other animals and will predate a range of species (Desbiez *et al.* 2009; Barrios-Garcia and Ballari 2012). Feral Swine are opportunistic, generalist feeders and have been found to eat various vertebrate species (Ballari and Barrios-Garcia 2013). In a comprehensive world-wide review of diets of introduced Feral Swine in North America (hybrids of Wild Boar and domestic pigs) and native Wild Boar in Europe and Asia, Ballari and Barrios-Garcia (2013) concluded that, in their native ranges, Wild Boar populations generally consume fewer vertebrate prey than those where Feral Swine have been introduced. The increased consumption of vertebrates in areas where Feral Swine were introduced is likely a result of the evolution of native vertebrates without Feral Swine as predators (Ballari and Barrios-Garcia 2013). Because Feral Swine are opportunistic, generalist feeders, they are able to switch to a local, seasonally abundant, vertebrate prey, such as Elk calves or deer fawns (Wilcox 2015). Habitat damage by Feral Swine may also displace native mammals (Singer *et al.* 1981; Barrios-Garcia and Ballari 2012).

Contrary to past evidence, our trail camera photos document a prolonged (>1 h) interaction between a juvenile male Elk and a sounder group of Feral Swine. Observations of the Elk feeding and lying <5 m from actively foraging Feral Swine, and in some cases much closer, indicate a lack of aggressive response by the Feral Swine and a corresponding lack of detectable fear response or displacement of one species by the other. These observations indicate that not all interactions between Elk and Feral Swine are

aggressive. In contrast, Pellerin (1993) found that Roe Deer (*Capreolus capreolus*) avoided Wild Boar feeding areas. Indeed, Feral Swine are more recognized as competitors with and predators on other large mammals such as White-tailed Deer (*Odocoileus virginianus*; Seward *et al.* 2004).

Indirect interactions among species through shared feeding sites that are close together in time and space are an important concern in terms of disease transmission, as vegetation and soil can act as fomites, carrying pathogens. Elk and Feral Swine share food sources, and this may function as an indirect route of disease transmission (Richomme *et al.* 2005). Both Elk and Feral Swine are effective hosts of bovine tuberculosis, and the *Mycobacterium bovis* bacterium can be spread via saliva on feed, especially in winter when cold temperatures allow it to survive for up to six months in the environment (Phillips *et al.* 2003). Similarly, chronic wasting disease (CWD) prions can be spread through the environment among many species including Elk, Feral Swine, Mule Deer (*Odocoileus hemionus*), White-tailed Deer, and Moose (*Alces americanus*), which are all found in this study area (O'Brien *et al.* 2019). CWD prions can survive in the environment for years, likely resulting in a very high risk of indirect disease transmission among species (Zabel and Ortega 2017). The potential for disease transmission will likely increase in species that show tolerance toward Feral Swine and remain in close proximity. If an individual Feral Swine becomes infected with CWD, transmission will be much more frequent within its group than between different groups of Feral Swine, potentially imposing social constraints on disease transmission and limiting spread (Podgorski *et al.* 2018). Further research using global positioning system (GPS) collars, trail cameras, habitat analysis, and disease testing is required to better understand the impacts and risks of invasive Feral Swine to Elk and other native large mammals on the Canadian Prairies.

Author Contributions

Writing – Original Draft: R.K.B.; Writing – Review and Editing: R.K.B. and M.J.C.; Conceptualization R.K.B. and M.J.C.; Funding Acquisition: R.K.B.

Acknowledgements

Literature Cited

Aschim, R.A., and R.K. Brook. 2019. Evaluating cost-effective methods for rapid and repeatable national scale detection and mapping of invasive species spread. Scientific Reports 9: 7254. https://doi.org/10.1038/s41598-019-43729-y

Ballari, S.A., and M.N. Barrios-Garcia. 2013. A review of wild boar *Sus scrofa* diet and factors affecting selection in native and introduced ranges. Mammal Review 43: 124–134. https://doi.org/10.1111/mam.12015

Barrios-Garcia, M.N., and S.A. Ballari. 2012. Impact of wild boar (*Sus scrofa*) in its introduced and native range: a review. Biological Invasions 14: 2283–2300. https://doi.org/10.1007/s10530-012-0229-6

Brook, R.K., and F.M. van Beest. 2014. Feral wild boar distribution and perceptions of risk on the central Canadian prairies. Wildlife Society Bulletin 38: 486–494. https://doi.org/10.1002/wsb.424

Caravaggi, A., M. Gatta, M.C. Vallely, K. Hogg, M. Freeman, E. Fadaei, J.T.A. Dick, W.I. Montgomery, N. Reid, and D.G. Tosh. 2018. Seasonal and predator-prey effects on circadian activity of free-ranging mammals revealed by camera traps. PeerJ 6: e5827. https://doi.org/10.7717/peerj.5827

Desbiez, A.L.J., S.A. Santos, A. Keuroghlian, and R.E. Bodmer. 2009. Niche partitioning among White-lipped Peccaries (*Tayassu pecari*), Collared Peccaries (*Pecari tajacu*), and Feral Swine (*Sus scrofa*). Journal of Mammalogy 90: 119–128. https://doi.org/10.1644/08-mamm-a-038.1

Keiter, D.A., J.C. Kilgo, M.A. Vukovich, F.L. Cunningham, and J.C. Beasley. 2017. Development of known-fate survival monitoring techniques for juvenile wild pigs (*Sus scrofa*). Wildlife Research 44: 165–173. https://doi.org/10.1071/WR16204

Michel, N.L., M.P. LaForge, F.M. Van Beest, and R.K. Brook. 2017. Spatiotemporal trends in Canadian domestic wild boar production and habitat predict wild pig distribution. Landscape and Urban Planning 165: 30–38. https://doi.org/10.1016/j.landurbplan.2017.05.003

O'Brien, P., E. Vander Wal, E.L. Koen, C.D. Brown, J. Guy, F.M. van Beest, and R.K. Brook. 2019. Understanding habitat co-occurrence and the potential for competition between native mammals and invasive wild pigs at the northern edge of their range. Canadian Journal of Zoology 97: 537–546. https://doi.org/10.1139/cjz-2018-0156

Pellerin, J.-C. 1993. Relations interspécifiques entre le chevreuil (*Capreolus capreolus* L.) et le sanglier (*Sus scrofa* L.). Bulletin d'écologie 24: 179–189.

Phillips, C.J.C., C.R.W. Foster, P.A. Morris, and R. Teverson. 2003. The transmission of *Mycobacterium bovis* infection to cattle. Research in Veterinary Science 74: 1–15. https://doi.org/10.1016/s0034-5288(02)00145-5

Podgorski, T., M. Apollonio, and O. Keuling. 2018. Contact rates in wild boar populations: implications for disease transmission. Journal of Wildlife Management 82: 1210–1218. https://doi.org/10.1002/jwmg.21480

Richomme, C., D. Gauthier, and E. Fromont. 2005. Contact rates and exposure to inter-species disease transmission in mountain ungulates. Epidemiology and

Infection 134: 21–30. https://doi.org/10.1017/S0950268805004693

Seward, N.W., K.C. VerCauteren, G.W. Witmer, and R. Engeman. 2004. Feral swine impacts on agriculture and the environment. Sheep & Goat Research Journal 19: 34–40.

Singer, F.J., D.K. Otto, A.R. Tipton, and C.P. Hable. 1981. Home ranges, movements, and habitat use of European wild boar in Tennessee. Journal of Wildlife Management 45: 343–353. https://doi.org/10.2307/3807917

Singer, F.J., W.T. Swank, and E.E.C. Clebsch. 1984. Effects of wild pig rooting in a deciduous forest. Journal of Wildlife Management 48: 464–473. https://doi.org/10.2307/3801179

Slabach, B.L. J.T. Hast, S.M. Murphy, W.E. Bowling, R.D. Crank, G. Jenkins, K.L. Johannsen, and J.J. Cox. 2018. Survival and cause-specific mortality of elk *Cervus canadensis* in Kentucky, USA. Wildlife Biology 2018(1): (2018). https://doi.org/10.2981/wlb.00459

Stolle, K., F.M. van Beest, E. Vander Wal, and R.K. Brook. 2015. Diurnal and nocturnal activity patterns of invasive Wild Boar (*Sus scrofa*) in Saskatchewan, Canada. Canadian Field-Naturalist 129: 76–79. https://doi.org/10.22621/cfn.v129i1.1670

Wilcox, J.T. 2015. Implications of predation by wild pigs on native vertebrates: a case study. California Fish and Game 101: 72–77.

Zabel M., and A. Ortega. 2017. The ecology of prions. Microbiology and Molecular Biology Reviews 81: e00001-17. https://doi.org/10.1128/MMBR.00001-17

No relationship between gastrointestinal parasite intensities or mercury burdens on fluctuating asymmetry in Common Eider (*Somateria mollissima*) mandibles

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Abstract
Mercury (Hg) emissions have increased since 1950 and biomagnification in Arctic ecosystems can affect animals, particularly at higher trophic levels. Exposure to Hg can negatively affect young developing animals, resulting in altered morphology and ultimately, lower fitness. We examined the relationship of mandible fluctuating asymmetry (FA) with gastrointestinal helminth intensity and breast muscle Hg concentration in Common Eider (*Somateria mollissima borealis*). Procrustes analysis of variance indicated significant FA but relatively high measurement error. Based on multiple linear regression modelling, there was no significant relationship between FA and Hg concentration or parasite burden. There may be a mismatch in trying to relate amount of Hg and parasite intensity in adults to FA that would have occurred early in life during skeletal development.

Key words: Mercury; parasite; Common Eider; fluctuating asymmetry; skeletal asymmetry; *Somateria mollissima*

Introduction

Mercury (Hg) emissions have increased since 1950, primarily due to coal combustion (Streets *et al.* 2011). In the atmosphere, emitted Hg may undergo reactions that result in the deposition of Hg onto the land and oceans (Krabbenhoft and Sunderland 2013). Deposited Hg is then methylated and converted into methylmercury (MeHg), which may accumulate across trophic levels, particularly in aquatic food webs (AMAP 2011; Krabbenhoft and Sunderland 2013). Methylmercury is the most toxic form of mercury to animals. In the Arctic, it is estimated that 74.2–94.4% of Hg in animals originates from an anthropogenic source (Dietz *et al.* 2009).

Like other contaminants, Hg can affect biological processes such as function of the central nervous system, hormonal regulation, and reproduction in animals. Mercury toxicity in birds often results in lower reproductive output, detrimental nesting behaviour, reduction in feeding rates, and thereby reduced juvenile survival (Scheuhammer *et al.* 2007). Compiled experimental and correlational studies also reveal Hg's adverse impacts on avian reproduction, behaviour, endocrine system, and immunocompetence (Whitney and Cristol 2018).

In general, reduced immune function caused by contaminants may increase host susceptibility to parasites (Sures 2006) and several studies have linked increased parasite load with higher Hg exposure. For instance, Glaucous Gulls (*Larus hyperboreus*) show higher acanthocephalan parasite intensities with higher Hg levels (Sagerup *et al.* 2009). Zebra Finches (*Taeniopygia guttata*) provided with MeHg in their diet showed greater coccidian parasite intensities instead of lower parasite intensities during the anticipated parasite expulsion timeframe (Smith *et al.* 2018).

Fluctuating asymmetry (FA; Klingenberg 2015) is a biological assessment that has been used to de-

termine contaminant and parasite impacts on animals (Møller 1992; Jenssen et al. 2010; Rodríguez-González et al. 2020). FA refers to the structural discrepancies in left-right sides of a structure and its divergence from the expected ideal phenotype during an organism's development (Klingenberg 2003; Nijhout and Davidowitz 2003). FA studies focus on the idea that environmental stress lowers the individual's ability to mitigate the developmental variations on each side of the organism, resulting in higher asymmetry between the two sides of an organism's structure (Klingenberg 2015). For instance, studies on small mammals reported higher levels of skull FA with increased exposure to environmental contaminants (Oleksyk et al. 2004; Sánchez-Chardi et al. 2013; Yalkovskaya et al. 2016).

In this study, we evaluated the relationship between individual FA values, Hg content, and parasite intensity in Common Eider (Somateria mollissima borealis). Common Eiders are sea ducks found in coastal regions in the Arctic and subarctic zones (Goudie et al. 2000). Bivalves, gastropods, and crustaceans comprise the majority of prey items that eiders consume (Waltho and Coulson 2015). Common Eiders often become infected with endoparasitic helminths such as acanthocephalans and cestodes through their consumption of intermediate crustacean hosts such as amphipods (Friend and Franson 1999; McLaughlin 2008; Nikolov et al. 2008). The endoparasites harboured by eiders include different species of digeneans, cestodes, acanthocephalans, and nematodes (Bishop and Threlfall 1971; Borgsteede et al. 2005). Wayland et al. (2001a) showed that in the Canadian Arctic, nematode numbers increase with higher Hg levels in Common Eiders. Parasite stress in Common Eider ducklings are also known to reduce nutrient availability and cause inflammation of the intestinal mucosa (Hollmén et al. 1999). Parasites may impede the intake of necessary nutrients by inducing mucosa layer damage in the gastrointestinal tract (Hollmén et al. 1999).

Overall, the stresses induced by Hg contamination and the resulting parasite intensity during development in young Common Eiders might reduce the ability of individuals to alleviate developmental variations on the skull, leading to higher observable FA in adults. Therefore, we predicted greater FA in the skulls of adult Common Eiders with higher levels of Hg and greater gastrointestinal parasite intensity. In this study, we assumed that the Hg concentration and parasite intensity in adults reflects Hg exposure and parasites during development.

Methods

Eiders were collected in Cape Dorset, Nunavut in May 2011 as part of the annual Indigenous hunt. We used the skulls from 39 adult male Common Eiders, along with the corresponding wing chord (cm), total Hg (dry weight) in pectoral muscle tissue, and genus level helminth parasite intensity for each individual (see Provencher et al. [2016] for additional details of methods used to determine amount of mercury and parasite intensity; the parasite intensity parameter Provencher et al. [2016] used included non-infected birds that both Margolis et al. [1982] and Rózsa et al. [2000] consider to be parasite abundance, not intensity). The skin was removed from the cranium and lower mandible of each specimen, which were then cleaned by Dermestid Beetles (Dermestes maculatus) and bleached with 3% hydrogen peroxide.

Landmarks (distinct locations for three dimensional measurements) chosen for FA analysis for vertebrate skulls often try to capture the whole shape of the skull (Oleksyk et al. 2004; Urošević et al. 2015; del Castillo et al. 2016). Mandibles were chosen for digitization rather than the whole skull because past FA studies show that the greatest potential effects of contaminants are on mandible FA (Sánchez-Chardi et al. 2013; Yalkovskaya et al. 2016). As mentioned in Klingenberg (2015), structures that have object symmetry, like skulls, should possess single landmarks on the midline of the structure and paired landmarks on the left and right side of the structure to ensure the required data are gathered for the analyses. Based on these criteria, we chose dorsal, lateral, and ventral landmarks that reflected the overall mandible shape. Measurement errors that can affect FA analysis are often associated with difficulty in finding and distinguishing the landmarks on the structure (Klingenberg 2015). To reduce the likelihood of measurement errors, the locations of the landmarks in this study were chosen because they were easily distinguished and past studies have found them to be repeatable.

In total, 20 landmarks were digitized on 39 mandibles (Figures 1 and 2; Table 1) using a MicroScribe 3D Digitizer (Solution Technologies Inc., Oella, Maryland, USA). Ten mandibles (26%) were digitized twice to calculate measurement error. Mandibles were secured in modelling clay on a raised wooden platform (11.0 cm tall × 4.5 cm wide × 9.7 cm long) clamped to a steady table. An elastic further secured the mandible by holding it between landmarks 5 and 9, 15 and the platform. All landmark digitization occurred from October 2017 to August 2018 and was performed by J.G.P.

Procrustes fit and Procrustes ANOVA (analysis of variance) in program MorphoJ (Klingenberg 2011) was used to acquire FA scores. The Procrustes fit removes configurational size, position and orientation differences, and determines shape differences among individuals (Klingenberg 2015). A Procrustes

FIGURE 1. Landmarks on the dorsal surface of a Common Eider (*Somateria mollissima*) mandible. Photo: C.A. Scobie.
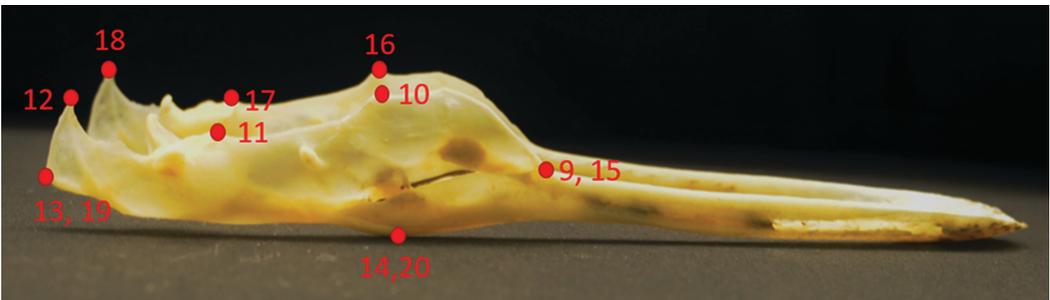
FIGURE 2. Landmarks on the lateral surface of a Common Eider (*Somateria mollissima*) mandible. Landmarks with two numbers associated with it are replicated in the same area on the opposite lateral surface of the mandible. Photo: C.A. Scobie.

TABLE 1. Landmark definitions on the lateral and dorsal surfaces of the Common Eider (*Somateria mollissima*) mandible.

No.	Definition
Dorsal	
1	Tip of dentary (adjacent to the very anterior point where dentary splits into two)
2, 3	Supra-angular
3, 7	Very posterior tip of the protruding process towards the inside of the mandible in the angular/articular region
4, 6	Most anterior tip of the protruding process towards the inside of the mandible in the angular/articular region
5	Most posterior point where the dentary splits into two (adjacent with dentary tip)
Lateral	
9, 15	Point where the dentary articulates with the other bones. Point directly adjacent to the vacuity, occurs at the bottom of the curved bone
10, 16	Uppermost point of the protruding process before the supra-angular
11, 17	Pointed edge in the articular/angular region the lies just before articular surface
12, 18	Uppermost pointed tip of the articular
13, 19	Most posterior point of the curve at the bottom of the articular
14, 20	Most posterior point in the articulation between dentary and the latter half of the mandible (or the vacuity)

fit was selected with alignment with the principal axes. A Procrustes ANOVA was then used to acquire FA values for each individual, with the assumption that isotropic variation at all landmarks was identical. Procrustes ANOVA uses the total variation derived from the differences between each individual config-

uration and the average configuration and allocates it into individual, reflection (comparison of sides of symmetrical object), and the interaction between individuals and reflection variation, as well as measurement error (Klingenberg *et al.* 2002). MorphoJ provides individual FA values as Procrustes FA values or Mahalanobis distances (Klingenberg and Monteiro 2005; Klingenberg 2011).

Total Hg was measured from muscle tissue from the left pectoral muscle of each eider. Most of the total Hg found in aquatic birds is comprised of the toxic form (MeHg; Houserova *et al.* 2007), so we used total Hg in our analyses with the assumption that most was likely MeHg. The intestines of each eider were examined thoroughly and all helminths found were identified to genus. Initial dataset exploration showed right-skewed counts for *Lateriporus* (cestode or tape worm), *Microsomacanthus* (cestode), and *Profilicollis* (acanthocephalan or spiny-headed worm) data. These data were log-transformed to remove non-normality. Program STATA 11 (StataCorp 2009) was used to perform a multiple linear regression analysis involving Hg concentration (Hg/g of dry weight) and parasite intensity for log-*Lateriporus*, log-*Microsomacanthus*, and log-*Profilicollis* and categorical variables *Fimbriarioides* (a cestode), unidentified cestode, in relation to Mahalanobis distances measuring FA, while controlling for wing length.

Results

The analysis indicated highly significant variation in symmetry among individuals ($F_{1026,988} = 6.72$, $P < 0.0001$; Table 2). Similarly, directional asymmetry or the variation among reflections was significant ($F_{26,988} = 47.80$, $P < 0.0001$; Table 2), which means there was variation among averages of the two sides of the left and right side of the mandibles. The analysis also showed significant FA or reflection variations among individuals ($F_{988,477} = 2.43$, $P < 0.0001$; Table 2), indicating a difference between the average of all left sides and all right sides of the mandibles. The *F*-value for the interaction between individual and reflection (Table 2) indicates the magnitude of FA relative to the measurement error (Klingenberg 2015). Our *F*-ratio indicates that measurement error was relatively high, but twice as much variation was explained by FA than measurement error (Table 2).

Mercury was detected in the muscle tissue of all eiders and they had an average concentration of 0.7 µg/g dry weight (Table 3). Parasite intensity and Hg concentration did not significantly predict variation in Mahalanobis distances ($R^2 = 0.17$, $F_{7,31} = 0.90$, $P = 0.51$; Table 3). An apparent positive relationship between mercury and FA (Figure 3; Table 3) was not significant ($t_{38} = 1.81$, $P = 0.08$).

Discussion

We did not find a significant relationship between

TABLE 2. Procrustes ANOVA results for adult male Common Eider (*Somateria mollissima*) mandibles assuming identical isotropic variation for all landmarks. Results include analyses of digitized left and right sides of 39 mandibles, each with nine paired landmarks and two median landmarks.

Variables	SS	MS	df	F	P
Individual	0.140	0.00014	1026	6.72	<0.0001
Reflection	0.025	0.00097	26	47.80	<0.0001
Ind × Reflection	0.020	0.00002	988	2.43	<0.0001
Error	0.004	0.00001	477		

TABLE 3. Results of multiple linear regression analysis looking at Mahalanobis fluctuating asymmetry values of 39 adult male Common Eider (*Somateria mollissima*) mandibles from Cape Dorset, Nunavut, Canada in relation to mercury content and parasite intensity. Descriptive statistics are also provided for variables included in the model: average (median for parasite intensity), range of variables, and prevalence of each type of parasite.

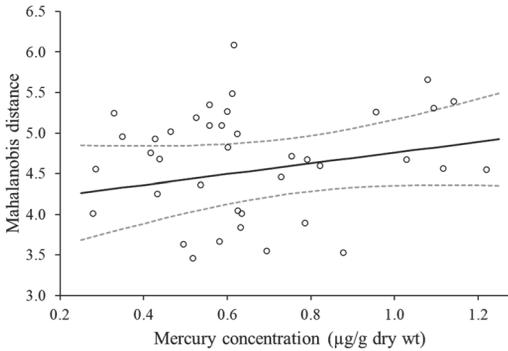| Variable	β	SE	P	Average (range)	Prevalence (%)
Wing	−0.14	0.10	0.18	29.5 cm (27.5–31.1)	—
Mercury	0.67	0.37	0.08	0.7 µg/g (0.3–1.2)	—
Lateriporus (cestode)	−0.07	0.07	0.36	9 (0–191)	90
Profilicollis (acanthocephalan)	0.01	0.06	0.87	4.5 (0–144)	69
Fimbriarioides (cestode)	−0.22	0.74	0.11	0 (0–1)	3
Unidentified cestode	−0.10	0.54	0.85	0 (0–2)	5
Microsomocanthus (cestode)	−0.02	0.05	0.75	100 (0–1000)	87
Intercept	7.07	3.02	0.03		

FIGURE 3. Predicted Mahalanobis fluctuating asymmetry values of 39 adult male Common Eider (*Somateria mollissima*) mandibles from Cape Dorset, Nunavut, Canada in relation to mercury concentration. The predictive model used median values of *Lateriporus*, *Profilicollis*, and *Microsomacanthus* and reference categorical values for *Fimbriarioides* and unidentified cestodes. Open circles are the raw data used in the model. Dashed lines represent 95% confidence interval.

FA in Common Eider mandibles and Hg concentration or parasite intensity. Our results do not support our initial hypothesis of higher FA with increasing muscle tissue Hg levels and parasite burden.

Unfortunately, Hg concentration in adult eider tissues does not necessarily reflect the amount of mercury birds are exposed to during skeletal development. Because birds have several ways of reducing their Hg load, we are unable to determine the amount of Hg to which eiders were exposed during development using Hg levels in the tissues of adult eiders. For instance, adult Cory's Shearwater (*Calonectris borealis*) deposit dietary Hg into their feathers (Monteiro and Furness 2001). Reduced brain, muscle, and liver Hg levels were also found after molting and Hg excretion in European Starling (*Sturnus vulgaris*; Whitney and Cristol 2017). The different Hg elimination processes throughout the avian body could have decreased the Hg load in the eiders in our study, making adult Hg levels a poor reflection of Hg levels experienced during development.

An antagonistic interaction between consumed Hg and Selenium (Se) during development may have also reduced any impact of Hg on mandible symmetry. Selenium is found in relatively high levels in Arctic waterfowl (Stout *et al.* 2002; Braune and Malone 2005), including Common Eiders (Wayland *et al.* 2001b). Methylmercury is converted to inorganic Hg in animal tissues, where it may bind to Se and prevent further damage in the animal's body (Eagles-Smith *et al.* 2009; Scheuhammer *et al.* 2015). In Japanese Quail (*Coturnix japonica*) chicks, continuous exposure to Hg and Se diets led to dramatic

mortality declines while exposure to Hg-only diets led to high mortality (Stoewsand *et al.* 1974). Studies on Mallard (*Anas platyrhynchos*; Hoffman and Heinz 1998) and Shaoxing Duck (*Anas platyrhynchos domesticus*; Ji *et al.* 2006) also attributed Se exposure and diet to the increases in antioxidant enzymes such as glutathione peroxidase, glutathione, and superoxide dismutase which reduces tissue and neurological damage and promotes MeHg removal from the body. For our study, Hg and Se intake during development possibly reduced the negative impacts of MeHg in Common Eiders through increased protection from oxidative stress.

In comparison to other studies, Common Loon (*Gavia immer*) with higher Hg burdens (>40 µg/g) showed greater feather weight asymmetry compared to adults with smaller Hg loads (<10 µg/g; Evers *et al.* 2008). These Hg levels are much greater than the maximum found in our study (1.2 µg/g). Herring *et al.* (2017) found inconsistent relationships between overall FA and tissue Hg levels in various water birds. They found no relationships between the overall FA and total blood and feather Hg levels for American Avocet (*Recurvirostra americana*), Black-necked Stilt (*Himantopus mexicanus*), and Caspian Tern (*Hydroprogne caspia*), but overall FA increased with higher Hg levels in breast feathers and blood for Forster's Tern (*Sterna forsteri*; Herring *et al.* 2017). Herring *et al.* (2017) concluded that different avian structures may exhibit different relationships with Hg levels in different tissues and that some species may not show relationships with FA and Hg. Further comprehensive studies should determine which species exhibit Hg-related FA by examining multiple structures at once and pinpointing the most affected structure due to contaminant exposure. Although prevalence was high, the amount of mercury found in Common Eiders in our study was quite low compared to other studies (0.83 µg/g blood Hg; Meattey *et al.* 2014) that also did not find adverse effects related to mercury.

We also did not find any relationship between FA and any of the helminth intensities in our study. Camphuysen *et al.* (2002) compiled levels of infection with *Profilicollis botulus* in Common Eider and found prevalence ranged from 76.7 to 100% with mean abundance ranging from 30 to 271 worms with a maximum of 1270 parasites in a single bird. Kats *et al.* (2007) also found *P. botulus* infection levels in Common Eider (prevalence = 83.8%; mean number = 109, range = 1–2938) far above what we observed, but infection did not contribute significantly to negative effects on body condition, regardless of age. The natural infection rates found in healthy juvenile and

adult eiders suggest that helminths may not severely impact juvenile growth and development.

The Procrustes ANOVA results indicate moderate measurement error during mandible digitization, which could have contributed to our non-significant results. Van Dongen (2015) showed that high measurement error in FA studies weakens the relationship between the true and estimated individual FA values and leads to biased FA estimates. It is possible that the measurement error in our study resulted in underestimated or overestimated individual FA values, which possibly prevented us from finding significant relationships. Variation among individuals for some of the landmarks potentially led to inconsistencies in landmark digitization for the whole group of individuals, which resulted in higher measurement error. Future studies should focus on increasing sample size, choosing better and more pronounced landmarks, and allocating time to practice digitization before each session to reduce measurement error. If feasible, an alternate method could be used where the mandibles are scanned three-dimensionally and digital techniques used to measure symmetry. Checking all the samples with a pilot study may also be beneficial for determining problematic or appropriate landmarks to use and whether replicates are needed for the main study (Klingenberg 2015).

Author Contributions

Writing – Original Draft: J.G.P.; Writing – Review & Editing: C.S. and E.B.; Conceptualization: C.S.; Investigation: J.F.P. and J.G.P.; Methodology: G.G., J.F.P., and C.S.; Resources: G.G., J.F.P., C.S., and E.B.; Formal Analysis: J.F.P., C.S., and E.B.; Funding Acquisition: G.G. and J.F.P.; Visualization: J.G.P.

Acknowledgements

Literature Cited

AMAP (Arctic Monitoring and Assessment Programme). 2011. AMAP Assessment 2011. Oslo, Norway.

Bishop, C.A., and W. Threlfall. 1971. Helminth parasites of the common eider duck, *Somateria mollissima* (L.), in Newfoundland and Labrador. Proceedings of the Helminthological Society of Washington 41: 25–35.

Borgsteede, F.H.M., A. Okulewicz, P.E.F. Zoun, and J. Okulewicz. 2005. The gastro-intestinal helminth fauna of the eider duck (*Somateria mollissima* L.) in The Netherlands. Helminthologia 42: 83–87.

Braune, B.M., and B.J. Malone. 2006. Mercury and selenium in livers of waterfowl harvested in northern Canada. Archives of Environmental Contamination and Toxicology 50: 284–289. https://doi.org/10.1007/s00244-005-7093-7

Camphuysen, C.J., C.M. Berrevoets, H.J.W.M. Cremers, A. Dekinga, R. Dekker, B.J. Ens, T.M. Van der Have, R.K.H. Kats, T. Kuiken, M.F. Leopold, and J. Van der Meer. 2002. Mass mortality of common eiders (*Somateria mollissima*) in the Dutch Wadden Sea, winter 1999/2000: starvation in a commercially exploited wetland of international importance. Biological Conservation 106: 303–317. https://doi.org/10.1016/S0006-3207(01)00256-7

del Castillo, D.L., V. Segura, D.A. Flores, and H.L. Cappozo. 2016. Cranial development and directional asymmetry in Commerson's dolphin, *Cephalorhynchus commersonii commersonii*: 3D geometric morphometric approach. Journal of Mammalogy 97: 1345–1354. https://doi.org/10.1093/jmammal/gyw101

Dietz, R., P.M. Outridge, and K.A. Hobson. 2009. Anthropogenic contributions to Hg levels in present-day Arctic animals—a review. Science of the Total Environment 407: 6120–6131. https://doi.org/10.1016/j.scitotenv.2009.08.036

Eagles-Smith, C.A., J.T. Ackerman, J. Yee, and T.L. Adelsbach. 2009. Mercury demethylation in waterbird livers: dose-response thresholds and differences among species. Environmental Toxicology and Chemistry 28: 568–577. https://doi.org/10.1897/08-245.1

Evers, D.C., L.J. Savoy, C.R. DeSorbo, D.E. Yates, W. Hanson, K.M. Taylor, L.S. Siegel, J.H. Cooley, M.S. Bank, A. Major, and K. Munney. 2008. Adverse effects from environmental Hg loads on breeding common loons. Ecotoxicology 17: 69–81. https://doi.org/10.1007/s10646-007-0168-7

Friend, M., and J.C. Franson. 1999. Field manual of wildlife diseases. General field procedures and diseases of birds (No. ITR-1999-001). Geological Survey, Biological Resources Division, Madison, Wisconsin, USA.

Goudie, R.I., G.J. Robertson, and A. Reed. 2000. Common Eider (*Somateria mollissima*). *In* The Birds of North America. *Edited by* A.F. Poole and F.B. Gill. Cornell Lab of Ornithology, Ithaca, New York, USA. https://doi.org/10.2173/bna.546

Herring, G., C.A. Eagles-Smith, and J.T. Ackerman. 2017. Mercury exposure may influence fluctuating asymmetry in waterbirds. Environmental Toxicology and Chemistry 36: 1599–1605. https://doi.org/10.1002/etc.3688

Hoffman, D.J., and G.H. Heinz. 1998. Effects of mercury and selenium on glutathione metabolism and oxidative stress in mallard ducks. Environmental Toxicology and Chemistry 17: 161–166. https://doi.org/10.1002/etc.5620170204

Hollmén, T., J.T. Lehtonen, S. Sankari, T. Soveri, and M. Hario. 1999. An experimental study on the effects

of polymorphiasis in common eider ducklings. Journal of Wildlife Diseases 35: 466–473. https://doi.org/10.7589/0090-3558-35.3.466

Houserova, P., V. Kubáň, S. Kráčmar, and J. Sitko. 2007. Total mercury and mercury species in birds and fish in an aquatic ecosystem in the Czech Republic. Environmental Pollution 145: 185–194. https://doi.org/10.1016/j.envpol.2006.03.027

Jenssen, B.M., J.B. Aarnes, K.M. Murvoll, D. Herzke, and T. Nygård. 2010. Fluctuating wing asymmetry and hepatic concentrations of persistent organic pollutants are associated in European shag (*Phalacrocorax aristotelis*) chicks. Science of The Total Environment 408: 578–585. https://doi.org/10.1016/j.scitotenv.2009.10.036

Ji, X., W. Hu, J. Cheng, T. Yuan, F. Xu, L. Qu, and W. Wang. 2006. Oxidative stress on domestic ducks (Shaoxing duck) chronically exposed in a mercury-selenium coexisting mining area in China. Ecotoxicology and Environmental Safety 64: 171–177. https://doi.org/10.1016/j.ecoenv.2005.03.009

Kats, R.K.H., T.K. Christensen, H. Bækgaard, F.H.M. Borgsteede, B.J. Ens, C.J. Camphuysen, E.H.W.G. Meesters, M.F. Leopold, and R.H. Drent. 2007. On the role of gastrointestinal helminths (*Amidostomum acutum* and *Profilicollis botulus*) in recent mass mortalities among common eider *Somateria mollissima* wintering in the Netherlands: a comparison between beached and shot birds. Pages 111–136 *in* Common Eiders *Somateria Mollissima* in the Netherlands—the rise and fall of breeding and wintering populations in relation to the stocks of shellfish. Ph.D. thesis, University of Groningen, Groningen, Netherlands.

Klingenberg, C.P. 2003. A developmental perspective on developmental instability: theory, models and mechanisms. Pages 12–34 *in* Developmental Instability: Causes and Consequences. *Edited by* M. Polak. Oxford University Press, New York, New York, USA.

Klingenberg, C.P. 2011. MorphoJ: an integrated software package for geometric morphometrics. Molecular Ecology Resources 11: 353–357. https://doi.org/10.1111/j.1755-0998.2010.02924.x

Klingenberg, C.P. 2015. Analyzing fluctuating asymmetry with geometric morphometrics: concepts, methods, and applications. Symmetry 7: 843–934. https://doi.org/10.3390/sym7020843

Klingenberg, C.P., M. Barluenga, and A. Meyer. 2002. Shape analysis of symmetric structures: quantifying variation among individuals and asymmetry. Evolution 56: 1909–1920. https://doi.org/10.1111/j.0014-3820.2002.tb00117.x

Klingenberg, C.P., and L.R. Monteiro. 2005. Distances and directions in multidimensional shape spaces: implications for morphometric applications. Systematic Biology 54: 678–688. https://doi.org/10.1080/10635150590947258

Krabbenhoft, D.P., and E.M. Sunderland. 2013. Global change and mercury. Science 341: 1457–1458. https://doi.org/10.1126/science.1242838

Margolis, L., G.W. Esch, J.C. Holmes, A.M. Kuris, and G.A. Schad. 1982. The use of ecological terms in parasitology (report of an ad hoc committee of the American Society of Parasitologists). Journal of Parasitology 68:

131–133. https://doi.org/10.2307/3281335

McLaughlin, J.D. 2008. Cestodes. Pages 261–276 *in* Parasitic Diseases of Wild Birds. *Edited by* C.T. Atkinson, N.J. Thomas, and D.B. Hunter. Wiley-Blackwell, Ames, Iowa, USA. https://doi.org/10.1002/9780813804620.ch14

Meattey, D.E., L. Savoy, J. Beuth, N. Pau, K. O'Brien, J. Osenkowski, K. Regan, B. Lasorsa, and I. Johnson. 2014. Elevated mercury levels in a wintering population of common eiders (*Somateria mollissima*) in the northeastern United States. Marine Pollution Bulletin 86: 229–237. https://doi.org/10.1016/j.marpolbul.2014.07.015

Møller, A.P. 1992. Parasites differentially increase the degree of fluctuating asymmetry in secondary sexual characters. Journal of Evolutionary Biology 5: 691–699. https://doi.org/10.1046/j.1420-9101.1992.5040691.x

Monteiro, L.R., and R.W. Furness. 2001. Kinetics, dose-response, excretion, and toxicity of methylmercury in free-living Cory's shearwater chicks. Environmental Toxicology and Chemistry 20: 1816–1823. https://doi.org/10.1002/etc.5620200827

Nijhout, H.F., and G. Davidowitz. 2003. Developmental perspectives on phenotypic variation, canalization, and fluctuating asymmetry. Pages 3–113 *in* Developmental Instability: Causes and Consequences. *Edited by* M. Polak. Oxford University Press, New York, New York, USA.

Nikolov, P.N., B.B. Georgiev, and B.S. Dezfuli. 2008. Cyclophyllidean cysticercoids from *Echinogammarus tibaldii* (Amphipoda, Gammaridae) from Lake Piediluco, Italy. Acta Parasitologica 53: 215–218. https://doi.org/10.2478/s11686-008-0017-8

Oleksyk, T.K., J.M. Novak, J.R. Purdue, S.P. Gashchak, and M.H. Smith. 2004. High levels of fluctuating asymmetry in populations of *Apodemus flavicollis* from the most contaminated areas in Chornobyl. Journal of Environmental Radioactivity 73: 1–20. https://doi.org/10.1016/j.jenvrad.2003.07.001

Provencher, J.F., H.G. Gilchrist, M.L. Mallory, G.W. Mitchell, and M.R. Forbes. 2016. Direct and indirect causes of sex differences in mercury concentrations and parasitic infections in a marine bird. Science of the Total Environment 551: 506–512. https://doi.org/10.1016/j.scitotenv.2016.02.055

Rodríguez-González, A., A.L. May-Tec, J. Herrera-Silveira, C. Puch-Hau, M. Quintanilla-Mena, J. Villafuerte, I. Velázquez-Abunader, M.L. Aguirre-Macedo, and V.M. Vidal-Martínez. 2020. Fluctuating asymmetry of sclerotized structures of *Haliotrematoides* spp. (Monogenea: Dactylogyridae) as bioindicators of aquatic contamination. Ecological Indicators 117: 1–10. https://doi.org/10.1016/j.ecolind.2020.106548

Rózsa, L., J. Reiczigel, and G. Majoros. 2000. Quantifying parasites in samples of hosts. Journal of Parasitology 86: 228–232. https://doi.org/10.1645/0022-3395(2000)086[0228:qpisoh]2.0.co;2

Sagerup, K., V. Savinov, T. Savinova, V. Kuklin, D.C. Muir, and G.W. Gabrielsen. 2009. Persistent organic pollutants, heavy metals and parasites in the glaucous gull (*Larus hyperboreus*) on Spitsbergen. Environmental Pollution 157: 2282–2290. https://doi.org/10.1016/j.envpol.2009.03.031

Sánchez-Chardi, A., M. García-Pando, and M.J. López-Fuster. 2013. Chronic exposure to environmental stressors induces fluctuating asymmetry in shrews inhabiting protected Mediterranean sites. Chemosphere 93: 916–923. https://doi.org/10.1016/j.chemosphere.2013.05.056

Scheuhammer, A., B. Braune, H.M. Chan, H. Frouin, A. Krey, R. Letcher, L. Loseto, M. Noël, S. Ostertag, P. Ross, and M. Wayland. 2015. Recent progress on our understanding of the biological effects of mercury in fish and wildlife in the Canadian Arctic. Science of the Total Environment 509: 91–103. https://doi.org/10.1016/j.scitotenv.2014.05.142

Scheuhammer, A.M., M.W. Meyer, M.B. Sandheinrich, and M.W. Murray. 2007. Effects of environmental methylmercury on the health of wild birds, mammals, and fish. Ambio 36: 12–19. https://doi.org/10.1579/0044-7447(2007)36[12:eoemot]2.0.co;2

Smith, J.H.E., D.A. Cristol, and J.P. Swaddle. 2018. Experimental infection and clearance of coccidian parasites in mercury-exposed zebra finches. Bulletin of Environmental Contamination and Toxicology 100: 89–94. https://doi.org/10.1007/s00128-017-2246-8

StataCorp. 2009. Stata Statistical Software: Release 11. StataCorp LP, College Station, Texas, USA.

Stoewsand, G.S., C.A. Bache, and D.J. Lisk. 1974. Dietary selenium protection of methylmercury intoxication of Japanese quail. Bulletin of Environmental Contamination and Toxicology 11: 152–156. https://doi.org/10.1007/bf01684595

Stout, J.H., K.A. Trust, J.F. Cochrane, R.S. Suydam, and L.T. Quakenbush. 2002. Environmental contaminants in four eider species from Alaska and arctic Russia. Environmental Pollution 119: 215–226. https://doi.org/10.1016/S0269-7491(01)00336-0

Streets, D.G., M.K. Devane, Z. Lu, T.C. Bond, E.M. Sunderland, and D.J. Jacob. 2011. All-time releases of mercury to the atmosphere from human activities. Environmental Science & Technology 45: 10485–10491. https://doi.org/10.1021/es202765m

Sures, B. 2006. How parasitism and pollution affect the physiological homeostasis of aquatic hosts. Journal of Helminthology 80: 151–157. https://doi.org/10.1079/joh2006346

Urošević, A., K. Ljubisavljević, and A. Ivanović. 2015. Fluctuating asymmetry and individual variation in the skull shape of the common wall lizard (*Podarcis muralis* Laurenti, 1768) estimated by geometric morphometrics. Herpetological Journal 25: 177–186.

Van Dongen, S. 2015. Variation in measurement error in asymmetry studies: a new model, simulations and application. Symmetry 7: 284–293. https://doi.org/10.3390/sym7020284

Waltho, C., and J. Coulson. 2015. Food and feeding. Pages 99–130 *in* The Common Eider. Poyser Monographs, London, United Kingdom.

Wayland, M., A.J. Garcia-Fernandez, E. Neugebauer, and H.G. Gilchrist. 2001a. Concentrations of cadmium, mercury and selenium in blood, liver and kidney of common eider ducks from the Canadian Arctic. Environmental Monitoring and Assessment 71: 255–267. https://doi.org/10.1023/A:1011850000360

Wayland, M., H.G. Gilchrist, D.L. Dickson, T. Bollinger, C. James, R.A. Carreno, and J. Keating. 2001b. Trace elements in king eiders and common eiders in the Canadian Arctic. Archives of Environmental Contamination and Toxicology 41: 491–500. https://doi.org/10.1007/s002440010276

Whitney, M., and D. Cristol. 2017. Rapid depuration of mercury in songbirds accelerated by feather molt. Environmental Toxicology and Chemistry 36: 3120–3126. https://doi.org/10.1002/etc.3888

Whitney, M.C., and D.A. Cristol. 2018. Impacts of sublethal mercury exposure on birds: a detailed review. Pages 113–163 *in* Reviews of Environmental Contamination and Toxicology, Volume 244. *Edited by* R. de Voogt. Springer International, Cham, Switzerland. https://doi.org/10.1007/398_2017_4

Yalkovskaya, L.E., M.A. Fominykh, S.V. Mukhacheva, Y.A. Davydova, and A.V. Borodin. 2016. Fluctuating asymmetry of rodent cranial structures in an industrial pollution gradient. Russian Journal of Ecology 47: 281–288. https://doi.org/10.1134/S1067413616030176

Note

Red Fox (*Vulpes vulpes*) scavenging on the spring sea ice: potential implications for Arctic food webs

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Abstract
Red Fox (*Vulpes vulpes*) has been increasingly observed in the Arctic. However, few observations of Red Foxes occupying and using resources on the sea ice have been reported. We observed a Red Fox scavenging on a Polar Bear (*Ursus maritimus*) carcass on the Beaufort Sea, Northwest Territories, Canada. The fox was in a jumble of ice (i.e., rubble ice) approximately 4.5 km from shore. Local Inuvialuit hunters had also previously observed Red Foxes on the sea ice. Our observation, coupled with those of Inuvialuit hunters, is of interest because it provides additional information on the adaptability of Red Foxes to local environments and their ability to use a wide range of habitats and food sources. Moreover, it points to encroachment by Red Foxes into the offshore habitat of Arctic Foxes (*Vulpes lagopus*) and potential competition with them for scarce resources, which may impact trophic food webs.

Key words: Beaufort Sea; Red Fox; range expansion; scavenging; sea ice; *Vulpes vulpes*

Red Fox (*Vulpes vulpes*) is among the most cosmopolitan terrestrial mammals, occupying a wide variety of biomes and habitats globally (Larivière and Pasitschniak-Arts 1996). In the past half century, Red Foxes have expanded their range onto Arctic tundra (Smits *et al*. 1989; Killengreen *et al*. 2011), including several islands in the Arctic Ocean (Gallant *et al*. 2012). As a generalist that can use a wide variety of items as food, such as eggs, small mammals, and carrion (Larivière and Pasitschniak-Arts 1996; Dalén *et al*. 2004), the occurrence of Red Foxes in the Arctic may have consequences for trophic food webs and faunal community dynamics. Concern regarding range expansion of Red Fox into the Arctic has largely focussed on potential interference or exploitative competition with resident Arctic Fox (*Vulpes lagopus*; e.g., Frafjord *et al*. 1989; Hersteinsson and

MacDonald 1992; Dalén *et al*. 2004; Pamperin *et al*. 2006; Killengreen *et al*. 2007; Henden *et al*. 2010; Gallant *et al*. 2012).

Almost all observations of Red Foxes in the Arctic have been in terrestrial (tundra) habitats; few have reported Red Foxes occupying and using resources on the sea ice. Sea ice is the domain of the congeneric Arctic Fox (Smith 1976; Pamperin *et al*. 2008), although Inuvialuit hunters (as reported to the coauthors) and others (e.g., Richardson and Andriashek 2006; Watts *et al*. 2010) have also occasionally observed Gray Wolves (*Canis lupus*) hunting on the frozen Arctic Ocean. On the Labrador Sea, Red Foxes have been reported as somewhat common on the sea ice, along with Arctic Foxes and Gray Wolves (Andriashek *et al*. 1985). However, in the Beaufort Sea, only a single Red Fox was observed offshore during

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>10 000 km of survey effort (Andriashek and Spencer 1989). We are not aware of any other published reports of Red Foxes on sea ice. Here, we report an observation of a Red Fox scavenging offshore on the frozen Beaufort Sea, and we place it in the context of local and Traditional Ecological Knowledge in the vicinity of Tuktoyaktuk and Aklavik, Northwest Territories (NT).

On 30 March 2019, while searching for Polar Bear (*Ursus maritimus*) from a helicopter as part of a mark–recapture population census, we observed the carcass of a hunter-killed Polar Bear on the spring sea ice ~70 km northeast of Tuktoyaktuk, NT. The carcass was skinned but otherwise intact. Fox tracks surrounded it, and we observed a Red Fox running from the carcass while we circled at low elevation (~30 m above ground level). We have ample experience observing both Arctic Foxes and Red Foxes, and identified the individual as the latter based on pelage colour (cross fox colour morph), comparatively large body size, long legs, ears, and muzzle. Regrettably, we took no photographs. The Red Fox was observed 4.5 km from land, in an area of landfast jumbled ice.

During >6600 km of aerial surveys in the Canadian portion of the Beaufort Sea in spring 2019, from the Alaska–Yukon border to Cape Bathurst, NT, we did not observe any additional Red Foxes on the sea ice. However, fox tracks and Arctic Foxes were commonly seen offshore, and Red Foxes were commonly observed on islands and the coastal mainland during our aerial survey.

Some Inuvialuit hunters have regularly observed Red Foxes on the spring sea ice in the southern Beaufort Sea (D.C.G. and Lennie Emaghok unpubl. data). As such, it is important to note that our observation of Red Foxes on the sea ice is not unique, but well known among local Inuvialuit hunters, as told by the four Inuvialuit coauthors. However, the occurrence of Red Foxes on the frozen ocean— and their foraging there—has not been commonly reported in the scientific literature.

Although Red Foxes have previously been observed on the sea ice during similar aerial surveys, there is only a single published observation outside of the Labrador Sea (Andriashek and Spencer 1989). Red Foxes likely disperse across relatively short stretches of sea ice to colonize offshore islands (Andriashek *et al*. 1985), and many such instances likely occur but are unreported. On the Labrador Sea, for example, the numerous small offshore islands are important areas for nesting birds, which may represent a seasonal food source for Red Foxes. Similar habitats and resources are present across Arctic North America, including within our study area. However, only one published observation is of a Red Fox forag-

ing on the sea ice: in the Beaufort Sea, a Red Fox was observed apparently killing and feeding on a Ringed Seal (*Phoca hispidus*) pup (Andriashek and Spencer 1989), a main prey item of Arctic Foxes in spring (Smith 1976). Curiously, this observation was made close to our observation site (near Tuktoyaktuk), albeit 32 years earlier. This is consistent with local Inuvialuit knowledge that Red Foxes are occasionally seen on the sea ice near the coast. Taken together, this information suggests that Red Foxes may have learned to hunt on the spring sea ice in this region. This relationship may be more common, but unreported, across the Arctic.

Our observation is of interest because it points to the adaptability of Red Foxes to use an increasingly wide range of novel habitats and food sources. More important, it points to encroachment by Red Foxes on the habitat of Arctic Foxes with the potential for aggressively displacing or killing them (Frafjord *et al*. 1989; Bailey 1992; Pamperin *et al*. 2006) or competing for scarce resources (Hersteinsson and MacDonald 1992; Dalén *et al*. 2004; Henden *et al*. 2010; Killengreen *et al*. 2011; Gallant *et al*. 2012), not only on land but also on the spring sea ice. In nearby Alaska, Pamperin *et al*. (2006) reported a Red Fox killing an Arctic Fox on land, where they are sympatric. Moreover, Red Foxes have been used by wildlife managers to control Arctic Fox abundance in Alaska's Aleutian Islands (Bailey 1992), attesting to their ability to potentially displace Arctic Foxes. We suggest further investigation of the extent of Red Fox occurrence and foraging on the sea ice, through scientific surveys and reference to the local knowledge of Inuvialuit, Inupiat, Inuit, and Cree hunters.

Acknowledgements

Literature Cited

Andriashek, D., H.P. Kiliaan, and M.K. Taylor. 1985. Observations on foxes, *Alopex lagopus* and *Vulpes vul-*

pes, and wolves, *Canis lupus*, on the off-shore sea ice of northern Labrador. Canadian Field-Naturalist 99: 86–89. Accessed 1 April 2019. https://www.biodiversitylibrary. org/page/28065099.

Andriashek, D., and C. Spencer. 1989. Predation on a Ringed Seal, *Phoca hispida*, pup by a Red Fox, *Vulpes vulpes*. Canadian Field-Naturalist 103: 600. Accessed 1 April 2019. https://www.biodiversitylibrary.org/page/34 348436.

Bailey, E.P. 1992. Red foxes, *Vulpes vulpes*, as biological control agents for introduced Arctic Foxes, *Alopex lagopus*, on Alaskan islands. Canadian Field-Naturalist 106: 200–205. Accessed 1 April 2019. https://www.bio diversitylibrary.org/page/34347420.

Dalén, L., B. Elmhagen, and A. Angerbjörn. 2004. DNA analysis on fox faeces and competition induced niche shifts. Molecular Ecology 13: 2389–2392. https://doi. org/10.1111/j.1365-294X.2004.02249.x

Frafjord, K., D. Becker, and A. Angerbjörn. 1989. Interactions between arctic and red foxes in Scandinavia —predation and aggression. Arctic 42: 354–356. https:// doi.org/10.14430/arctic1677

Gallant, D., B.G. Slough, D.G. Reid, and D. Berteaux. 2012. Arctic fox versus red fox in the warming Arctic: four decades of den surveys in north Yukon. Polar Biology 35: 1421–1431. https://doi.org/10.1007/s00300-012-1181-8

Henden, J.-A., R.A. Ims, N.G. Yoccoz, P. Hellström, and A. Angerbjörn. 2010. Strength of asymmetric competition between predators in food webs ruled by fluctuating prey: the case of foxes in tundra. Oikos 119: 27–34. https://doi.org/10.1111/j.1600-0706.2009.17604.x

Hersteinsson, P., and D.W. MacDonald. 1992. Interspecific competition and the geographical distribution of red and arctic foxes *Vulpes vulpes* and *Alopex lagopus*. Oikos 64: 505–515. https://doi.org/10.2307/3545168

Killengreen, S.T., R.A. Ims, N.G. Yoccoz, K.A. Bråthen, J.-A. Henden, and T. Schott. 2007. Structural characteristics of a low Arctic tundra ecosystem and the retreat of the Arctic fox. Biological Conservation 135: 459–472. https://doi.org/10.1016/j.biocon.2006.10.039

Killengreen, S.T., N. Lecomte, D. Ehrich, T. Schott, N.G. Yoccoz, and R.A. Ims. 2011. The importance of marine vs. human-induced subsidies in the maintenance of an expanding mesocarnivore in the arctic tundra. Journal of Animal Ecology 80: 1049–1060. https://doi. org/10.1111/j.1365-2656.2011.01840.x

Larivière, S., and M. Pasitschniak-Arts. 1996. *Vulpes vulpes*. Mammalian Species 537: 1–11. https://doi.org/ 10.2307/3504236

Pamperin, N.J., E.H. Follmann, and B.T. Petersen. 2006. Interspecific killing of an arctic fox by a red fox at Prudhoe Bay, Alaska. Arctic 59: 361–364. https://doi. org/10.14430/arctic284

Pamperin, N.J., E.H. Follmann, and B.T. Petersen. 2008. Sea-ice use by arctic foxes in northern Alaska. Polar Biology 31: 1421–1426. https://doi.org/10.1007/ s00300-008-0481-5

Richardson, E.S., and D. Andriashek. 2006. Wolf (*Canis lupus*) predation of a polar bear (*Ursus maritimus*) cub on the sea ice off northwestern Banks Island, Northwest Territories, Canada. Arctic 59: 322–324.

Smith, T.G. 1976. Predation of ringed seal pups (*Phoca hispida*) by the arctic fox (*Alopex lagopus*). Canadian Journal of Zoology 54: 1610–1616. https://doi.org/10.11 39/z76-188

Smits, C.M.M., B.G. Slough, and C.A. Yasui. 1989. Summer food habits of sympatric Arctic Foxes, *Alopex lagopus*, and Red Foxes, *Vulpes vulpes*, in the northern Yukon Territory. Canadian Field-Naturalist 103: 363–367. Accessed 14 July 2020. https://www.biodiversity library.org/page/34348195.

Watts, D.E., L.G. Butler, B.W. Dale, and R.D. Cox. 2010. The Ilnik wolf *Canis lupus* pack: use of marine mammals and offshore sea ice. Wildlife Biology 16: 144–149. https://doi.org/10.2981/09-040

Note

An assessment of historical records of Wolverine (*Gulo gulo*) from New Brunswick

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Abstract
We assessed selected historical reports and original archival records of Wolverine (*Gulo gulo*) in New Brunswick. Wolverine range in the Maritimes region of Canada is based on a widely accepted 1904 report of extant museum skulls from Canterbury Station, New Brunswick, which is discounted here. However, we report at least 15 pelt export records from the 18th century and conclude that Wolverines appear to have been uncommon, but present, over much of New Brunswick until at least 1794, and seem to have been extirpated from the province by the middle of the 19th century.

Key words: Wolverine; *Gulo gulo*; New Brunswick; historical record

Proper documentation of the past distribution of species will assist in recovery efforts and the assessment of wildlife response to human-associated threats, including climate change (Monsarrat *et al*. 2019). Numerous species of large mammals were extirpated from regions colonized during the 17th to 19th centuries (Krohn and Hoving 2010; Naughton 2012), but data on these events are often sparse because documentation was coarse and requires interpretation, and surviving archival material is limited (Boshoff and Kerley 2010).

The historical distribution of Wolverine (*Gulo gulo*) in the Maritime provinces of Canada is not well understood. Much of the evidence for Wolverine occurrence in New Brunswick is based on 17th century written accounts of French priests and seigneurs (e.g., Denys 1672; LeClerq 1692), combined with Indigenous Traditional Knowledge (see Squires 1946). van Zyll de Jong (1975) located the species along the northern New Brunswick border with the Gaspé Peninsula, while Dilworth (1984) does not include Wolverine in *Mammals of New Brunswick*. Hall and Kelson (1959), Peterson (1966), and Banfield (1974) all place the southern historical limit of Wolverine in eastern Canada along the Maine–New Brunswick border, mainly on the basis of specimens

reputed to have been collected at Canterbury Station, New Brunswick, in 1904. Banfield (1974) states that Wolverine was extirpated from New Brunswick and southeastern Quebec around 1850, while Anderson (1946) suggests that it was still sporadically present in eastern Canada until the 1940s.

Most authors have suggested that Wolverine was historically absent from Nova Scotia, Prince Edward Island, and the Gaspé Peninsula, Quebec, although more recently, Gallant *et al*. (2016) reviewed online historical documents and concluded that Wolverine occurred throughout the region, with the apparent exception of Prince Edward Island. However, most of these historical observations lack physical proof, such as a skull or pelt. Denys (1672) for example, accurately described a Wolverine, until he added that it possessed a long, rope-like tail, which Wolverines lack. The most satisfactory evidence of Wolverines in New Brunswick is records of pelts (Raymond 1899a,b) being exported by sea in the mid-1700s from Saint John to Massachusetts or Halifax, Nova Scotia (Squires 1946; Forbes *et al*. 2010; Gallant *et al*. 2016). However, the records are few and details have not been published. Likewise, there is much uncertainty surrounding the early 20th century report from Canterbury Station. The objective of this note is to

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build on the work of Gallant *et al*. (2016) and to better assess records and historical status of Wolverine in New Brunswick.

We searched for written accounts of Wolverines in the Maritime provinces and attempted to locate original documentation, such as exports of pelts from New Brunswick ports. The first published account of Wolverine pelts from New Brunswick is in an export consignment document for a shipment to England in 1781 (Raymond 1899a: 34; with original spelling, but notes in brackets are added by G.J.F. and D.F.M.):

> Shipt by Messrs. Hazen and White, on Board the Ship Recovery… and goes consigned to the Hon'ble Michael Francklin, Esq'r, at Halifax, viz., to be shipt for England for sale: 571 Moose skins, 11 Cariboo do. ["do" = ditto, for skins], 11 Deer do., 3621 Musquash [Muskrat] Skins, 61 Otter do., 77 Mink do., 152 Sable [Marten] do., 40 Fishers do., 6 Catts, 11 Lucervers [Lynx] do., 17 Red Foxes do., 6 Cross Fox do., 9 Bear do. Fort Howe, River St. John, 21 Nov'r, 1781. James Proud, for Messrs Francklin, Hazen and White.

The "6 Catts" was changed to "6 Wolverene" in a separate publication by the same author later that year (Raymond 1899b). We examined the original export document (James White Paper; Ship Accounts B3-2, New Brunswick Museum Archives & Research Library [NBM ARL]), as well as a rewritten receipt by the ship's staff (B3-5). There are two additional copies of the receipt (B3-3, B3-4) but they simply list cervids and only refer to other "small furs". All documents are in cursive script but a comparison of letters allows for deciphering the word "Catts" or "Catty" in the export document, and the term Catts is very clear in the ship's receipt.

Raymond (1899a,b) does not indicate why he changed Catts to Wolverine, and except for one reference to Cougar (*Puma concolor*) as Catts in early 17th century Massachusetts (Morton 1637), we could not find the use of Catts in similar accounts from the period, nor in a contemporary summary of early French and English names for wildlife in Atlantic Canada (Ganong 1910). Terms for Wolverine in early French records are carcajou, quincajou, and blereaux (Ganong 1910). The term Wolverine, or various spellings of carcajou (Table 1), were used in export documents from the same trading post that was responsible for the 1781 account; thus, the use of a new word for Wolverine is unlikely. Catts might indicate Lynx (*Lynx canadensis*) but Lynx are consistently referred to as lucivee or lucervers in the same export documents, including the 1781 document, which listed 11 Lucervers (Raymond 1899a,b). Catts may refer to Bobcat (*Lynx rufus*), but there is no definitive record of Bobcats in other export documents for the time period, either because they were not separated from Lynx pelts or not abundant enough to be harvested. There is one "cat" record from 1774 (F81-32) but the species is uncertain. Another suggestion for Catts is Cougar (Morton 1637), which is also called "catamount" (Parker 1998), but there is no mention of Cougars in export documents of the period, and exporting six Cougars in one shipment, therefore, seems unlikely. In summary, there is enough uncertainty about the "6 Catts" reported by Raymond (1899a,b) that we recommend these not be cited as evidence of Wolverines in New Brunswick.

Raymond (1898), repeated in Squires (1946), noted that he had access to other export documents of

TABLE 1. Records of Wolverine (*Gulo gulo*) exported from Saint John Harbour, New Brunswick, 1764–1794.

New Brunswick Museum Reference no.	Date	Name of ship	Destination	Record*	Value†
Hazen F79-7	3 July 1764	*Speedwell*	Newbury, Mass.‡	2 Wolverine	12
Hazen F79-18	28 May 1765	*Wilmot*	Newbury, Mass.	2 Wolverin	12
Hazen F79-21	June 1765	?	? (Boston, Mass.)§	1 Wolverin	4
Hazen F79-20	July 1765	*Wilmot*	Newbury, Mass.	2 Wolverin	12
Hazen F79-19	15 June 1766	*Peggy*	Newbury, Mass.	3 Caurkajuaq¶	12
Hazen F79-8	20 August 1767	*Woodbridge*	Newbury, Mass.	1 Rackajeau	4
Hazen F79-3	23 June 1768	*St. Johns Paquet*	Newbury, Mass.	2 Carkajeaux	8
Hazen F79-16	3 June 1794	*Speedwell*	?	2 Wolveren	12

*Spelling as in original document.
†Value is in shillings. Prior to 1783 currency is "Lawful Money of Massachusetts" set at approximately 1.6£ 8 shilling per 1£ sterling (Raymond 1898). After 1783, value is in British sterling.
‡Written as Newbury but refers to Newburyport, Massachusetts, 60 km north of Boston.
§No destination given, but this shipment was to a new partner, based in Boston, Massachusetts (Raymond 1898).
¶Also spelled Caurkajian in a second copy of export record (F79-22).

the same trading company, from which he tallied "8 Woolverene" over a 10-year period, 1764–1774. We located these export records in the NBM ARL, as well as additional records apparently not used by Raymond. They detail shipments from Saint John by Simonds and White to their partners, Hazen, Jarvis, and Blodgett in Newburyport, Massachusetts, the home base of the company; around 1775, pelts were then shipped to Halifax before export to Britain because of the American War of Independence (Raymond 1898, 1899c; Gwyn 2003). Furs were acquired as part of a bartering system with First Nations trappers and settlers in the Saint John River watershed, including at a trading post in Fredericton, New Brunswick. Another company post was at Maugerville, 20 km down river (Raymond 1898). The NBM ARL contains data for 15 years in a 30-year period (1764–1794), often with multiple exports in each of the 15 years, for a total of 52 export records. Each export document is an itemized list of the number of skins by species, and, except for the occasional combining of Marten (*Martes americana*) and Mink (*Neovison vison*) into one tally, each line represents a single species. Other mustelid species that potentially could be confused with Wolverine, such as Fisher (*Martes pennanti*) and Marten (often termed "sable") are separate line items whenever Wolverines are listed. It is also unlikely that there is misidentification of Wolverines at the time of handling because of their distinctive pelage.

If we discount the "6 Catts" exported in 1781, a minimum of 15 Wolverine pelts were exported from Saint John (Table 1). Wolverine records were regular, from the first year of operation of the trading company (1764) to the last available record (1794), with most (87%) in the earliest five-year period, from 1764 to 1768. During 1769–1775, no Wolverines are mentioned in 24 shipments. After 1775, there are data on only five shipments of any species over three years (1781, 1792, and 1794) and trends in the abundance of Wolverine pelts cannot be assessed. However, even in this smaller data set, excluding the 1781 Catts record, Wolverines were exported in 1794.

The Saint John River extends northward to Quebec, where Wolverines were likely more abundant than in New Brunswick (Banfield 1974; van Zyll de Jong 1975), and there is some concern that these pelts originated far upstream and were not from the province (Forbes *et al.* 2010). The ledgers of the company trading posts indicate extensive trade with local settlers who were involved in trapping. Trade among First Nations was extensive and long-standing, with items moving up and down the seaboard over thousands of kilometres (Bourque 1994). However, most of the pelts in the watershed were supplied by the Wolastoqiyik (Raymond 1898), whose territory is non-coastal and covers much of the Saint John River (Wolastoq) watershed (Raymond 1910), a large (>55 000 km^2) area of central New Brunswick and northern Maine. The section of the watershed in New Brunswick covers nearly half the province. We are not aware of movement of furs from the St. Lawrence River Valley, likely because numerous trading posts already existed there (Biggar 1901; Lee 1984), and it is unlikely pelts would be exported further than necessary. Posts also existed in coastal northeast New Brunswick and are associated with the only other Wolverine pelts reported for New Brunswick; the Robin Pipon Company of Caraquet acquired two Wolverine pelts from coastal New Brunswick in 1767 and one pelt at Caraquet in 1768 (Gallant *et al.* 2016).

Anderson (1946) stated that Wolverines were still present from Cape Breton, Nova Scotia, westward into the 1940s, but no evidence is provided. Hall and Kelson (1959) and Peterson (1966) reported that Wolverines ranged into eastern New Brunswick until the turn of the 20th century, apparently on the basis of skins and skulls collected at Canterbury Station in 1904 and since housed in the Field Museum, Chicago, Illinois, USA. Field Museum records list three New Brunswick Wolverine specimens (catalogue numbers 14020, 14021, and 14022). Although Elliot (1909) appears to suggest that there are four specimens, Peterson (in litt. to W.A. Squires, 26 January 1967) reports he could locate only two Wolverine skulls in the Field Museum, identified as items 14020 and 14021 and ascribed to Canterbury Station, New Brunswick (Adam Ferguson pers. comm. 23 May 2018). Peterson (in litt.) addressed New Brunswick Museum curator W.A Squires' doubt about the veracity of the data associated with these specimens. He reported that D.G. Elliot (1905), curator of the Field Museum's mammal collection, had a particular interest in *Gulo* and would have been confident in the data when citing these specimens in describing an apparent Alaskan species (*Gulo hylaeus*) that is no longer recognized as a separate species. Although, Elliot (1909) lists C.F. Periolat (C.F. Periolat Fur Company, Chicago, Illinois, USA) as the source for the New Brunswick specimens, Field Museum data identify H.W. Grant as the collector. Periolat was a fur buyer who sold specimens to the Field Museum (A. Esai pers. comm. 24 May 2018). Among the 86 mammal specimens in the Field Museum ascribed to C.F. Periolat, 81 are of Alaskan or British Columbian origin and three are from Labrador. The only items listed from New Brunswick are the two Wolverine skulls. It may be significant that Canterbury Station was a stop on the New Brunswick and Canada Railway and that specimens, particularly as many as four at a time, may have arrived from elsewhere. We have not been

able to locate any information on the collector H.W. Grant. It is also noteworthy that the taxonomic review by Rausch (1953) found *G. hylaeus* inseparable from *G. gulo luscus*, the nominate subspecies and the form now deemed present across Canada and most of Alaska. Therefore, the reputed New Brunswick specimens that Elliot believed were morphologically different from those from Alaska could have originated from western North America.

Finally, members of the Natural History Society of New Brunswick (NHSNB), most notably W.F. Ganong and M. Chamberlain, had written about New Brunswick mammals (Chamberlain 1884; Ganong 1903, 1908) and were very active in the province in the late 19th and early 20th centuries. It is inconceivable that any number of Wolverines could have been taken during this period without it coming to the attention of NHSNB members or being commented on in the society bulletin. In a review of accounts of rare wildlife in Maine and surrounding areas, Krohn and Hoving (2010) do not record Wolverines in the region after 1865 (Allen 1904), and an account of the professional trapper, Rufus Philbrook, who trapped extensively in the same region as Canterbury from 1859 to 1862 makes no mention of Wolverines (Palmer 1949). Gesner (1847) reports Wolverines as seldom killed in New Brunswick, while Adams (1873) omits Wolverines entirely from his list of New Brunswick mammals. The last mention of Wolverines in New Brunswick is from the 1850s (Chamberlain 1884). We conclude that W.A. Squires was correct in discounting the Canterbury specimens as originating in New Brunswick and that Wolverines were extirpated from the Maritimes by the 1850s.

Excluding the 1781 record and the Canterbury skulls, the information above suggests that at least 18 Wolverine pelts can definitely be ascribed to New Brunswick. Data on exports during the >100 years of French-controlled fur trade in the Saint John River watershed before 1763 are unknown, but it can be assumed that Wolverines would be at least as abundant during this period of lower human density (Raymond 1910). With the three pelts from northeastern New Brunswick added to the 15 from the Saint John River region, Wolverines appear to have been uncommon, but present, over much of New Brunswick, at least until 1794. Although these results support the assessment of Gallant *et al*. (2016), only 18 Wolverines were exported over 30 years; thus, it would seem that Naughton's (2012) judgement that Wolverines were scarce at the time of European contact is correct. With the Canterbury Wolverine records discounted, and with contemporary reports suggesting that Wolverine was essentially extirpated from the province after the middle of the 19th century (Gesner 1847; Adams

1873; Chamberlain 1884), Banfield's (1974) assessment that Wolverines were no longer present in New Brunswick by around 1850 would seem to be correct. Finally, although the data-mining approach advocated by Gallant *et al*. (2016) is powerful, the information presented here emphasizes the value of verifying results through original source documents in archives, given that much remains to be made accessible online.

Acknowledgements

Literature Cited

Adams, A.L. 1873. Field and Forest Rambles with Notes and Observations on the Natural History of Eastern Canada. Henry S. King and Co., London, United Kingdom. Accessed 7 September 2019. https://www.biodiversitylibrary.org/page/41492128.

Allen, G.M. 1904. Fauna of New England. Occasional Paper 7. Boston Society of Natural History, Boston, Massachusetts, USA. Accessed 8 September 2019. https://babel.hathitrust.org/cgi/pt?id=hvd.32044107326209&view=1up&seq=3.

Anderson, R.M. 1946. Catalogue of Canadian Recent Mammals. Bulletin 102. National Museum of Canada, Ottawa, Ontario, Canada.

Banfield, A.W.F. 1974. The Mammals of Canada. University of Toronto Press, Toronto, Ontario, Canada.

Biggar, H.P. 1901. The Early Trading Companies of New France: a Contribution to the History of Commerce and Discovery in North America. University of Toronto Library, Toronto, Ontario, Canada. Accessed 8 September 2019. https://babel.hathitrust.org/cgi/pt?id=uc2.ark:/13960/t6737243c&view=1up&seq=9.

Boshoff A.F., and G.I.H. Kerley. 2010. Historical mammal distribution data: how reliable are written records? South African Journal of Science 106:1–8. https://doi.org/10.4102/sajs.v106i1/2.116

Bourque, B.J. 1994. Evidence for prehistoric exchange on the Maritime peninsula. Pages 23–46 *in* Prehistoric Exchange Systems in North America. *Edited by* T.G. Baugh and J.E. Ericson. Interdisciplinary Contributions to Archaeology. Springer, Boston, Massachusetts, USA.

Chamberlain, M. 1884. Mammals of New Brunswick. Bulletin of the Natural History Society of New Brunswick 3: 37–41. Accessed 8 September 2019. https://babel.hathitrust.org/cgi/pt?id=hvd.32044043125749&view=1up&seq=5.

Denys, N. 1672. Description géographique et historique des costes de l'Amérique septentrionale, avec l'histoire naturelle du païs. Chez Claude Barbin, Paris, France. [Re-

published 1908 as The Description and Natural History of the Coasts of North America (Acadia). *Translated and edited by* W.F Ganong. Champlain Society, Toronto, Ontario, Canada.]

Dilworth, T. 1984. Land Mammals of New Brunswick. Tim Dilworth, Fredericton, New Brunswick, Canada.

Elliot, D.G. 1905. Descriptions of three apparently new species of mammals. Proceedings of the Biological Society of Washington 18: 79–82. Accessed 8 September 2019. https://babel.hathitrust.org/cgi/pt?id=hvd.32044106436108&view=1up&seq=101.

Elliot, D.G. 1909. A catalogue of the collection of mammals in the Field Columbian Museum. Publication 115, zoological series, volume 8. Field Columbian Museum, Chicago, Illinois, USA. Accessed 9 September 2019. https://www.biodiversitylibrary.org/page/36208629.

Forbes, G.J., D.F. McAlpine, and F.W. Scott. 2010. Mammals of the Atlantic Maritime Ecozone. Pages 693–718 *in* Assessment of Species Diversity in the Atlantic Maritime Ecozone. *Edited by* D.F. McAlpine and I.M. Smith. NRC Research, Ottawa, Ontario, Canada.

Gallant, D., L.Y. Gauvin, D. Berteaux, and N. Lecomte. 2016. The importance of data mining for conservation science: a case study on the wolverine. Biodiversity Conservation 25: 2629–2639. https://doi.org/10.1007/s10531-016-1188-5

Ganong, W.F. 1903. On reported occurrences of the panther (*Felis concolor*) in New Brunswick. Bulletin of the Natural History Society of New Brunswick 21: 82–86.

Ganong, W.F. 1908. On the occurrence of the wolf in New Brunswick. Bulletin of the Natural History Society of New Brunswick 26: 30–35. Accessed 9 September 2019. https://www.biodiversitylibrary.org/page/49580777.

Ganong, W.F. 1910. The identity of the animals and plants mentioned by the early voyagers to eastern Canada and Newfoundland. Proceedings and Transactions of the Royal Society of Canada 3: 197–242. Accessed 22 July 2020. Available at https://archive.org/stream/identityofanimal00ganouoft.

Gesner, A. 1847. New Brunswick; with notes for Emigrants. Simonds and Ward, London, England. Accessed 9 September 2019. https://babel.hathitrust.org/cgi/pt?id=mdp.39015027949166.

Gwyn, J. 2003. The Mi'kmaq, poor settlers, and the Nova Scotia fur trade, 1783–1853. Journal of the Canadian Historical Association 14: 65–91. Accessed 7 September 2019. https://www.erudit.org/en/journals/jcha/2003-v14-n1-jcha849/010320ar.pdf.

Hall, E.R., and K.R. Kelson. 1959. The Mammals of North America. Ronald Press, New York, New York, USA.

Krohn, W.B., and C.L. Hoving. 2010. Early Maine Wildlife. University of Maine Press, Orono, Maine, USA.

LeClerq, C. 1692. Nouvelle relation de la Gaspésie, qui contient les moeurs et la religion des sauvages gaspesiens porte-croix, adorateurs du soleil & d'autres peoples de l'Amérique septentrionale, dit le Canada. Chez Amable Auroy, Paris, France. [Re-published 1910 as New Relations of Gaspesia. *Translated and edited by* W.F Ganong. Champlain Society, Toronto, Ontario, Canada.] Accessed 8 September 2019. https://archive.org/details/

newrelationofgas05lecl/page/n10.

Lee, D. 1984. The Robins in Gaspé, 1766 to 1925. Fitzhenry and Whiteside, Toronto, Ontario, Canada.

Monsarrat, S., P. Novellie, I. Rushworth, and G. Kerley. 2019. Shifted distribution baselines: neglecting long-term biodiversity records risks overlooking potentially suitable habitat for conservation management. Philosophical Transactions of the Royal Society B: Biological Sciences 374: 20190215. https://doi.org/10.1098/rstb.2019.0215

Morton, T. 1637. New English Canaan or New Canaan. Charles Green, London, United Kingdom. [Reprinted in 1883 as The New English Canaan of Thomas Morton with Introductory Matter and Notes. *Edited by* C.F Adams, Jr. Prince Society, Boston, Massachusetts, USA.] Accessed 7 September 2019. https://www.gutenberg.org/files/54162/54162-h/54162-h.htm#Page_179.

Naughton, D. 2012. The Natural History of Canadian Mammals. University of Toronto Press, Toronto, Ontario, Canada.

Palmer, R.S. 1949. Rufus Philbrook, trapper. New England Quarterly 22: 452–474. https://doi.org/10.2307/361944

Parker, G. 1998. The Eastern Panther: Mystery Cat of the Appalachians. Nimbus Publishing, Halifax, Nova Scotia, Canada.

Peterson, R.L. 1966. The Mammals of Eastern Canada. Oxford University Press, Toronto, Ontario, Canada.

Rausch, R. 1953. On the status of some Arctic mammals. Arctic 6: 91–148. https://doi.org/10.14430/arctic3870

Raymond, W.O. 1898. At Portland Point: the first English settlement of St. John. New Brunswick Magazine 1: 6–20. Accessed 22 July 2020. https://www.canadiana.ca/view/oocihm.8_06717_1/1?r=0&s=1.

Raymond, W.O. 1899a. The James White papers, continued: A.D. 1781–1788. Collections of the New Brunswick Historical Society 4: 30–72. Accessed 8 September 2019. https://tinyurl.com/y9gk9cux.

Raymond, W.O. 1899b. At Portland Point: eleventh paper. New Brunswick Magazine 2: 249–263. Accessed 7 September 2019. http://www.canadiana.ca/view/oocihm.8_06717_11/1?r=0&s=1.

Raymond, W.O. 1899c. At Portland Point: supplementary paper no. 1. New Brunswick Magazine 3: 164–178. Accessed 7 September 2019. http://www.canadiana.ca/view/oocihm.8_06717_16/1?r=0&s=1.

Raymond, W.O. 1910. The River St. John: Its Physical Features, Legends and History from 1604 to 1784. John A. Bowes, Saint John, New Brunswick, Canada. [Reprint 1943. *Edited by* J. Webster, Sackville Press, United Kingdom.]

Squires, W.A. 1946. Changes in mammal population in New Brunswick. Acadian Naturalist 2: 26–44.

van Zyll de Jong, C.G. 1975. The distribution and abundance of the Wolverine (*Gulo gulo*) in Canada. Canadian Field-Naturalist 89: 431–437. Accessed 7 September 2019. https://www.biodiversitylibrary.org/page/28033165.

Note

First confirmed nest of Long-billed Curlew (*Numenius americanus*) in roadside brush stubble

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Abstract
Long-billed Curlew (*Numenius americanus*) typically nests in open grass habitat, such as native grassland, hayfields, or cow pasture. In May 2019, we discovered a Long-billed Curlew nest in the dense roadside shrub stubble near Prince George, British Columbia. The shrub stubble substrate for this nest appeared to be taller and denser than adjacent hayfields, which reduced the visibility of the nest site. The eggs in this nest were the first to hatch of the 11 curlew nests we monitored in the area.

Key words: Concealment; Long-billed Curlew; nesting; *Numenius americanus*

Long-billed Curlew (*Numenius americanus*) typically nests in open grassland habitats, from native grassland to agricultural lands, such as hay fields and cattle pastures. Long-billed Curlew nests are often found in areas of variable vegetation density and height (Dugger and Dugger 2020), and are often constructed close to cow pies and other mounds or objects (Cochrane and Anderson 1987; Coates *et al.* 2019). In general, the surrounding vegetation to nests is below 10 cm high at nest initiation (Dugger and Dugger 2020) and nesting success has been found to be higher when forb cover is lower (Gregory *et al.* 2011). In Utah, vegetation surrounding Long-billed Curlew nests (within 15 m) was significantly shorter than random sites (Paton and Dalton 1994), meaning curlews typically prefer shorter vegetation. The Birds of British Columbia (1990) documents curlew nest site preference of dry grasslands and avoidance of dense grass and shrubs (Campbell *et al.* 1990). In rare cases, curlews are known to nest in cropland (Devries *et al.* 2010).

During May to June 2019, we studied Long-billed Curlews around Prince George, British Columbia in the most northerly breeding latitude documented for this species (Davidson and Mahony 2015). On 9 May at 1000 we found a Long-billed Curlew nest in mowed roadside stubble, within 4 m of both the road edge and the adjacent hay field fence.

This nest, along Wright Creek Pit Road, Prince George, British Columbia (54.13846°N, 122.77565°W), was 3.31 m from the gravel road edge, and 3.78 m from the fence line of the adjacent hay field (Figure 1). The vegetation within 1 m of the nest was made up of a variety of shrub, tree, and wildflower species (percent cover within 1 m: spirea [*Spiraea* sp.] 60%, Trembling Aspen [*Populus tremuloides* Michaux] 20%, Giant Red Paintbrush [*Castilleja miniata* Douglas ex Hooker] 5%, Arctic Lupine [*Lupinus arcticus* S. Watson] 5%, peas [family Fabacea] 5%, and buttercups [*Ranunculus* sp.] 5%). There were also three or four small forb species under the larger and woodier species. Besides estimated percentage cover, vegetation measurements were not made. The nest (Figure 1) had a diameter of 14–18 cm and a depth of 3.5 cm.

The day after finding the nest, we flushed the female from the nest in order to float the eggs. Based on the egg floating (Hays and Lecroy 1971; Stocking *et al.* 2010), we estimated the incubation of the nest to have started 7–10 days earlier, or about 30 April–2 May.

This nest was the third nest (hereafter N3) we found in the 2019 season, of 11 discovered nests within a 325 ha study area. Including N3, we found

FIGURE 1. Long-billed Curlew (*Numenius americanus*) nest N3 along rural road in Prince George, British Columbia (May 2019) showing four eggs. Photo: G.H. Sorenson.

seven nests that were successful (fledged), two due to hatch after our field season (still incubating), and two nests that failed during laying and incubation (Figure 2). Within 300 m of N3, we found three other curlew nests, all in relatively uniform hayfield (Figure 2). At the time we discovered N3, the adjacent hay fields all had grass heights <10 cm, making nesting curlews visible at a distance. At the same time, N3 was very well concealed in ~20–30 cm tall, previously-mowed shrubby vegetation. Photos of N3 taken within a day of other nearby nests demonstrate the increased concealment of N3 (Figure 3a,b) relative to N2 (Figure 3c).

We monitored all of the nests found in the Wright Creek Pit Road area to determine hatching date, fledging success, and survival. N3 was the first to hatch, fledging four chicks on 27 May. One nest, about 60 km south, hatched on 26 May, while six of the nests we monitored hatched between 28 May and 13 June (and two nests were still being incubated when we left the field site on June 14). All but one of the 11 monitored nests at Wright Creek were likely first attempts (four eggs in nest, one possible second attempt with three eggs). N3 hatched one day earlier than nearby nests and successfully fledged all four chicks. Not only was the nest better concealed, but the brown cryptic colouring of Long-billed Curlew appeared to better match the brown shrub stubble than the tan and green hayfields, suggesting better camouflage as well as concealment (Figure 3).

Stevens *et al.* (2017) suggested that ground-nesting birds can choose the backgrounds in which they nest to provide better camouflage. Indeed, Coates *et al.* (2019) suggested camouflage was a possible reason Long-billed Curlews placed their nests near cow pies. Stevens *et al.* (2017) documented two strategies of camouflage in ground nesting species: those which flee at the approach of a predator and rely on their egg's camouflage and those which remain on the nest, thus relying on the camouflage of the adult plumage. Long-billed Curlews fit in this latter group, relying on their cryptic plumage and lack of movement to protect them from predators (Dugger and Dugger 2020). Upon our approach of nests, curlews often remained still on the nest even when we stood within 1–2 m of the nest for several minutes. Long-billed Curlew eggs are rarely left unattended (Dugger and Dugger 2020), but are also cryptically coloured (Allen 1980). The eggs in the roadside stubble nest did not appear to have any camouflage differences from those in the hay field nests we observed.

Further monitoring and study is required to determine if the Long-billed Curlews nesting in denser vegetation that we observed may have allowed earlier nesting and contributed to nesting success. The nesting substrate of N3 was quite different from the other nearby Long-billed Curlew nests we monitored and from those observed in other nest description studies (Gregory *et al.* 2011; Dugger and Dugger 2020).
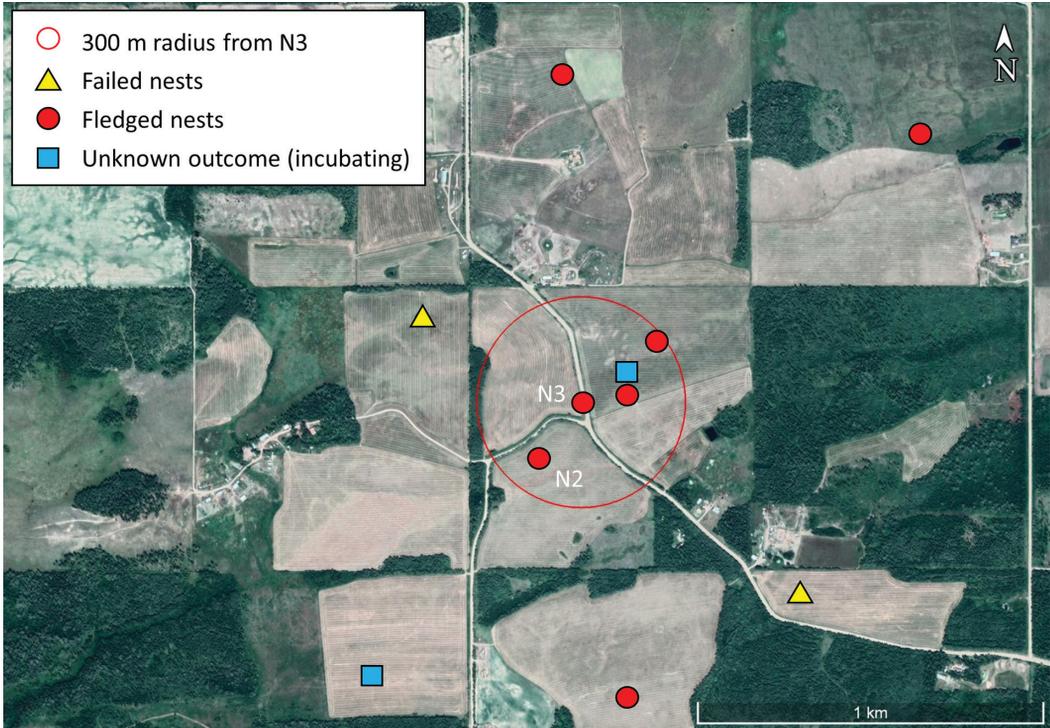
FIGURE 2. Map of nesting locations of Long-billed Curlew (*Numenius americanus*) in Wright Creek Pit Road area (Prince George, British Columbia, 2019) centred on nest N3. Eleven nests were found and monitored within the local study area. Google Earth Imagery date: 29 July 2018. Data providers: Maxar Technologies 2020. Accessed July 2020.

Author Contributions

Writing – Original Draft: G.H.S.; Writing – Review & Editing: G.H.S., D.W.B., and A.L.H.; Conceptualization: G.H.S., D.W.B., and A.L.H.; Investigation: G.H.S. and A.L.H.; Funding Acquisition: D.W.B.

Literature Cited

Allen, J.N. 1980. The ecology and behavior of the Long-Billed Curlew in southeastern Washington. Wildlife Monographs 73: 3–67.

Campbell, R.W., N.K. Dawe, I. McTaggart-Cowan, J.M. Cooper, G.W. Kaiser, and M.C.E. McNall. 1990. The Birds of British Columbia, Volume 2. Diurnal Birds of Prey through Woodpeckers. Royal British Columbia Museum, Victoria, British Columbia, Canada.

Coates, S.E., B.W. Wright, and J.D. Carlisle. 2019. Long-billed curlew nest site selection and success in the Intermountain West. Journal of Wildlife Management 83: 1197–1213. https://doi.org/10.1002/jwmg.21661

Cochrane, J.F., and S.H. Anderson. 1987. Comparison of habitat attributes at sites of stable and declining Long-billed Curlew populations. Great Basin Naturalist 47: 459–466.

Davidson, P.J.A., and N. Mahony. 2015. Long-billed Curlew (*Numenius americanus*). *In* The Atlas of the Breeding Birds of British Columbia, 2008–2012. *Edited by* P.J.A. Davidson, R.J. Cannings, A.R. Couturier, D. Lepage, and C.M. Di Corrado. Bird Studies Canada. Delta, British Columbia, Canada. Accessed 14 May 2020. http://www.birdatlas.bc.ca/accounts/speciesaccount.jsp?sp=LBCU&lang=en.

Devries, J.H., S.O. Rimer, and E.M. Walsh. 2010. Cropland nesting by Long-billed curlews in southern Alberta. Prairie Naturalist 42: 123–129.

Dugger, B.D., and K.M. Dugger. 2020. Long-billed Curlew (*Numenius americanus*), Version 1.0. *In* The Birds of the World. *Edited by* A.F. Poole and F.B. Gill. Cornell Lab of Ornithology, Ithaca, New York, USA. https://doi.org/10.2173/bow.lobcur.01

Hays, H., and M. LeCroy. 1971. Field criteria for determining incubation stage in eggs of the Common Tern. Wilson Bulletin 83: 425–429.

Gregory, C.J., S.J. Dinsmore, L.A. Powell, and J.G. Jor-

Figure 3. Long-billed Curlew (*Numenius americanus*) nest N3 and nearby nest N2 taken within 24 h: a. N3 with female on nest from level of bird in early morning sunlight, 10 May 2019, 0602; b. N3 with female on nest from another angle, 10 May 10, 1026; c. nearby nest (N2) with female on nest, 9 May 2019, 0950. Photos: G.H. Sorenson.

gensen. 2011. Nest survival of Long-billed Curlew in Nebraska. Wader Study Group Bulletin 118: 109–113.

Paton, P., and J. Dalton. 1994. Breeding ecology of Long-billed Curlews at Great Salt Lake, Utah. Great Basin Naturalist 54: 79–85.

Stevens, M., J. Troscianko, J.K. Wilson-Aggarwal, and C.N. Spottiswoode. 2017. Improvement of individual camouflage through background choice in ground-nesting birds. Nature Ecology & Evolution 1: 1325–1333. https://doi.org/10.1038/s41559-017-0256-x

Stocking, J., E. Elliott-Smith, N. Holcomb, and S.M. Haig. 2010. Long-billed Curlew breeding success on Mid-Columbia River National Wildlife Refuges, south-central Washington and north-central Oregon, 2007–08. Open-file report 2010-1089. United States Geological Survey, Reston, Virginia, USA. https://doi.org/10.3133/ofr20101089

Reductions in foliar Hemiptera in portions of a fescue grassland invaded by Smooth Brome (*Bromus inermis*)

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Abstract

Fescue grassland in Canadian prairie is characterized by Plains Rough Fescue (*Festuca hallii*), but the introduced exotic grass, Smooth Brome (*Bromus inermis*), is expanding therein. Hemiptera play an important role as herbivores in vegetation. In an invaded fescue grassland in Manitoba, 52 plant species had a combined average cover of 216%. Kentucky Bluegrass (*Poa pratensis*), another exotic grass, was most abundant at 64%, followed by *B. inermis* at 21% and the native grass *F. hallii* at 18%. Across 47 random sample points, *B. inermis* cover ranged from 0% to 180%. At these points, 2445 specimens of Hemiptera were collected by sweep net and divided into 99 morphologically distinct species. *Bromus inermis* cover had negative correlations with Hemiptera species richness and diversity, but not with abundance and biomass of Hemiptera. However, *B. inermis* cover was negatively correlated with abundance of two individual species of Hemipteran leafhoppers in the family Cicadellidae: *Doratura stylata* and *Diplocolenus configuratus*. Total graminoid cover had no significant correlation with any of the above Hemiptera variables. We conclude that feeding requirements deter some phytophagous Hemiptera from entering sections of fescue grassland invaded by *B. inermis*. In this way, invasion by *B. inermis* can be expected to modify ecosystem function by increasing feeding pressure on neighbouring natural vegetation and other introduced species.

Key words: Invasive species; Smooth Brome; *Bromus inermis*; foliage cover; Hemiptera; Cicadellidae; insect diversity; fescue grassland

Introduction

Smooth Brome *(Bromus inermis* Leysser) is an invasive grass in North America, forming persistent stands in disturbed areas and next to trails, and reducing plant diversity in prairie by 70% (Otfinowski *et al.* 2007). Plant invasion changes the primary base of available food, thereby potentially changing ecosystem function via the activities of arthropods that consume vegetation, carry out pollination, and decompose litter (Litt *et al.* 2014). However, the response of arthropods to invasive plant species is variable. In 87 published articles, 48% of cases reported a decrease in the abundance of herbivorous arthropods after invasion, but 17% reported an increase; corresponding values for arthropod richness were 48% and 13% (Litt *et al*. 2014).

Smooth Brome invasion of natural grasslands has an impact on arthropods (Chu and Knutson 1970; Jonas *et al.* 2002). More specifically, the response of plant-feeding Hemiptera to Smooth Brome in-troduction was reported as negative at 12 Montana sites (Bess *et al.* 2004). In that study, Smooth Brome was absent from nine sites but varied from 20% to 57% cover at another three locations. Compared with non-infested control locations, the sites with Smooth Brome showed reduced diversity of Hemiptera.

Given the potential for Smooth Brome to modify Hemiptera populations and, thereby, modify prairie function in terms of herbivory, our aim was to evaluate the response of Hemiptera to Smooth Brome invasion of fescue prairie. The approach taken was to collect Hemiptera across a Smooth Brome-invaded fescue grassland in Manitoba, Canada. The grassland studied was expected to exhibit a considerable range in Smooth Brome cover because of the patchiness of local invasion.

Methods

In 2015, vegetation cover was scored and Hemiptera collected under permit at Grasshopper Valley in Riding Mountain National Park, Manitoba,

Canada (Figure 1). The northwest corner of the 9780-m^2 trapezoid-shaped study area was at 50.7561°N, 100.2767°W. Spatial variability associated with the invasion of Smooth Brome at Grasshopper Valley presented an opportunity for a natural experiment (Gurevitch *et al.* 2006) to test the impact of this grass on attendant Hemiptera.

Sample points were based on randomly selected latitudes and longitudes. At each point, vegetation scores and arthropod samples were taken across a 2-m by 2-m plot. Sampling was undertaken at all 28 plots that contained Smooth Brome and the first 19 plots that did not contain Smooth Brome, for a total of 47 plots. To focus sampling effort on areas with the invasive grass, 53 additional sets of coordinates without Smooth Brome were omitted. On 15 and 16 June 2015, vegetation cover by species was determined using a pin-frame system and 80 pins for each 2-m by 2-m plot. With one exception, plant identification followed Scoggan (1957), with names as given in Flora of North America Editorial Committee (1993+). Plains Rough Fescue (*Festuca hallii* (Vasey) Piper) was not listed in Scoggan (1957); thus, the description in Flora of North America Editorial Committee (1993+) was used for identification of this taxon.

Following Martin (1977), sweep-nets were used to collect foliar feeders. Plots were sampled weekly for five consecutive weeks between 15 June and 24 July. Samples were not taken when wind speed exceeded 15 km/h. Each sweep-net sample comprised 12 sweeps across each 2-m by 2-m plot. Sweeps were conducted in six horizontal rows, involving one low sweep followed by one high sweep in the same row. To focus effort on a manageable number of specimens, a single sample date was selected for counting. Based on inspection of all samples for specimen abundance and quality, we selected the fourth round of sweep net samples from 13–17 July. Hemiptera were sorted into morphologically distinct species and counted. No evaluation of cryptic species was attempted.

Biomass estimates for Hemiptera followed Sample *et al.* (1993), using relationships for Auchenorrhyncha, Sternorrhyncha, and Heteroptera. Insect length and width were measured separately by species to the nearest 0.01 mm using an eyepiece micrometer in a dissecting microscope. Based on preliminary measurements to determine SD stabilization as sample size increased, a sample size of ten insects per taxon was used where possible. Biomass per taxon was then combined with abundance data to calculate biomass per sample for all Hemiptera combined.

Shannon-Wiener diversity (Gurevitch *et al.* 2006) was calculated as

$$H' = -\sum P_i \ln(P_i)$$

for relative abundance (*P*) of Hemiptera species in each plot. In addition, minimum and maximum theoretical diversity values for a plot were calculated based on the species count and total Hemiptera abundance. The Shannon-Wiener diversity values were rescaled proportionally across this possible range from a minimum of 0% to a maximum of 100%, enabling comparison among plots.

A linear regression approach was taken, as used previously (Tadey 2016). Linear regression was used to relate percentage cover of Smooth Brome to Hemiptera abundance, biomass, species richness, and species diversity. Similar regression tests were run separately for abundance of common Hemiptera as individual species. All regression tests were also run substituting percentage of total graminoid cover for cover of Smooth Brome. Linear relationships were evaluated by regression analysis of variance using Statistix 8.0 (2003). Given the sample size of *n* = 47, each regression analysis of variance calculated the test statistic $F_{1,45}$ to determine if the relationship was significant at the 0.05 probability level.

Species of Hemiptera with abundance responding significantly to cover of Smooth Brome were determined by K.G. Andrew Hamilton and deposited as voucher specimens at the Manitoba Museum, 190 Rupert Street, Winnipeg, Manitoba R3B 0N2, Canada. Ten *Doratura stylata* Boheman and 15 *Diplocolenus configuratus* Uheler were deposited as voucher specimens MM66800 to MM66809 and MM66810 to MM66824, respectively. There are no common names for these insects.
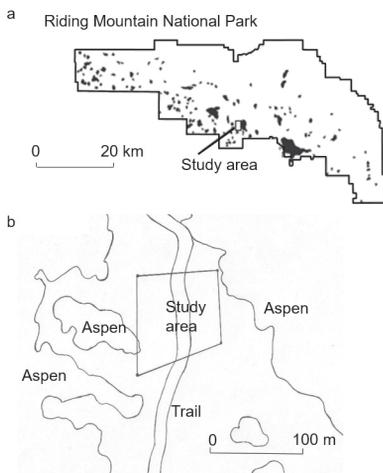
FIGURE 1. a. Location of Grasshopper Valley, the study area, in Riding Mountain National Park, Manitoba. In the map of the study area (b), the width of the access trail is exaggerated, but the trapezoid and stands of Trembling Aspen (*Populus tremuloides*) are drawn to scale.

Results

Fifty-two plant species, including ten grasses, were recorded from the plots. The most abundant plant was Kentucky Bluegrass (*Poa pratensis* L.), with the percentage cover for Smooth Brome similar to that of the naturally occurring Plains Rough Fescue (Table 1). Across plots, Smooth Brome cover ranged from 0% to 180%, and total graminoid cover (grasses and sedges) ranged from 51% to 189%. Mean cover was 216% for all vegetation across all plots.

For the samples collected 13–17 July, 2445 Hemiptera in 99 species were recovered, with a mean per-plot abundance of 52.0 ± 31.6 (SD) and a corresponding median of 50 for the 47 plots. The Hemiptera collected were 58 species and 1932 individuals of suborder Auchenorrhyncha; 30 species and 433 individuals of suborder Sternorrhyncha; and 11 species and 80 individuals of suborder Heteroptera.

Although numerical reductions in both abundance and biomass of Hemiptera fell short of significance when related to Smooth Brome cover (Table 2), species richness (Figure 2) and species diversity (Table 2) both decreased significantly with increasing Smooth Brome cover. *Doratura stylata* and *D. configuratus*, two common species of suborder Auchenorrhyncha in the family Cicadellidae, had significant negative responses in terms of abundance (Table 2) to increasing cover of Smooth Brome. Cover of all graminoid vegetation combined had no significant relation to any of

the above measures of Hemiptera (Table 2).

Discussion

Plant-feeding Hemiptera are often specialized consumers (Scudder 2014), and the negative effect of increased Smooth Brome cover on Hemiptera richness and diversity likely follows from a reduction in acceptable foliage for feeding. Vegetation architectural diversity can also influence insect species occurrence (Browne 1982). However, the lack of any discernible response of Hemiptera species to variation in overall graminoid cover across the study site indicates that responses to Smooth Brome invasion were related to feeding preference rather than any change in vegetation type from forb to grass.

The large number of Hemiptera species (99) recorded in our study is a reasonable representation of the marked diversity of this order. For example, of the Heteropteran family Miridae alone, 314 species occur in the Canadian prairies (Kelton 1980).

The leafhopper *D. stylata* prefers grasses in the subfamily Pooideae over other subfamilies (Whitcomb *et al.* 1987), and all ten grass species recorded in our study, including Smooth Brome, are in this subfamily. Thus, the impact of Smooth Brome invasion on *D. stylata* at our study site is not related to a change in grass subfamily available for feeding.

Our results differ from those of Bess *et al.* (2004), who found that both *D. stylata* and *D. configuratus*

TABLE 1. Vegetation cover by rank for plant species with average cover exceeding 10% across 47 plots in Grasshopper Valley, Riding Mountain National Park, Manitoba. The remaining 46 plant species found varied in cover from 9.1% to 0.05%.

Rank	Species	Mean cover, %
1	Kentucky Blue Grass (*Poa pratensis* L.)	63.6
2	Smooth Brome (*Bromus inermis* Leysser)	20.5
3	Plains Rough Fescue (*Festuca hallii* (Vasey) Piper)	18.3
4	Western Snowberry (*Symphoricarpos occidentalis* Hooker)	17.8
5	Northern Bedstraw (*Galium boreale* L.)	12.1
6	Smooth Blue Aster (*Symphyotrichum laeve* (L.) A. Löve and D. Löve)	11.6

TABLE 2. Probabilities of the test statistic $F_{1,45}$ for analyses of variance for linear regressions with percentage cover of Smooth Brome (*Bromus inermis*) or all graminoids as independent variable, with dependent variable as listed, in 47 plots in Grasshopper Valley, Riding Mountain National Park, Manitoba. Where regressions are significant, the equations relating y (measure of Hemiptera presence) to x (Smooth Brome cover) are given.

| Measure of Hemiptera presence	Probability of $F_{1,45}$ value for Smooth Brome cover	Equation for Smooth Brome cover	Probability of $F_{1,45}$ value for Graminoid cover
Hemiptera abundance	0.066	Not significant	0.96
Hemiptera biomass	0.190	Not significant	0.63
Hemiptera species richness	<0.001	$y = 14.8 - 0.05x$	0.62
Hemiptera diversity index	0.002	$y = 66.4 - 0.10x$	0.76
Doratura stylata abundance	0.011	$y = 9.7 - 0.06x$	0.24
Diplocolenus configuratus abundance	0.001	$y = 3.3 - 0.03x$	0.87
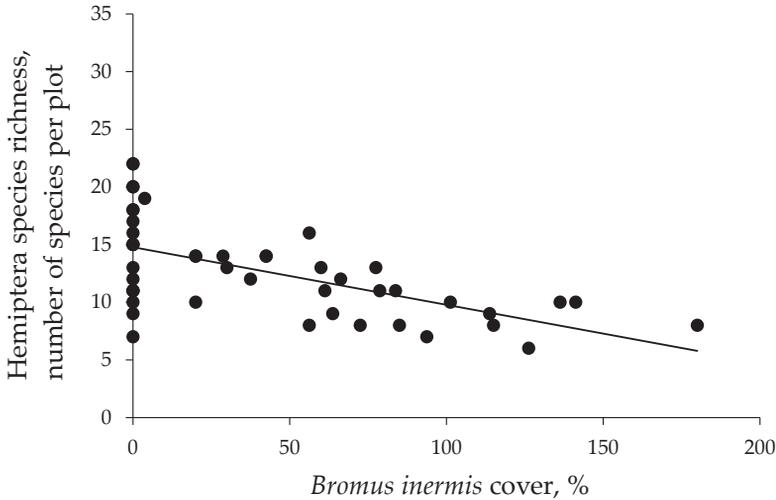
Figure 2. Relation between Hemiptera species richness and Smooth Brome (*Bromus inermis*) cover in 47 study plots in Grasshopper Valley, Riding Mountain National Park, Manitoba. The regression line is $y = 14.8 - 0.05x$.

were associated positively with Smooth Brome sites, compared with sites with Idaho Fescue (*Festuca idahoensis* Elmer) and without Smooth Brome. However, in that study, the Idaho Fescue sites contained only half the total grass cover seen at Smooth Brome sites, the shortfall being made up by forbs. In contrast, the sites with Smooth Brome also included abundant Kentucky Bluegrass. From our study, both *D. stylata* and *D. configuratus* seem to avoid Smooth Brome at the plot level in a grassland dominated by Kentucky Bluegrass.

The changes in Hemiptera occurrence that we observed in response to Smooth Brome invasion might vary with different environmental conditions in other seasons or years. For example, arthropod abundance at a semi-arid site sown with a native plant mix was greater than in monospecific grass-sown plots when irrigation was provided, but not under ambient rainfall (Wenninger and Inouye 2008). The palatability of foliage relates to its quality, which in turn changes with season. As production among grassland plant species varies through spring and summer, relationships evaluated here for Hemiptera collected in July might be different in other months. Notably, Smooth Brome grows mainly in spring (Dibbern 1947). Seasonal variation in feeding may also occur via direct effects on the insects, not just the foliage (Stiegel *et al.* 2017).

Management of Smooth Brome invasion employs cutting and fire (Otfinowski *et al.* 2014) rather than biological control. Thus, reduced Hemiptera in association with increasing Smooth Brome cover does not affect management of this invasive grass. However, knowledge of the impact of Smooth Brome invasion, including effects on arthropods, such as Hemiptera, contributes to our understanding of how the functioning of fescue prairie is modified by this persistent introduced plant species. Avoidance of Smooth Brome infestation by Hemiptera presumably increases feeding pressure on neighbouring plants, including not just native species, but also the dominant and introduced Kentucky Bluegrass.

In summary, Hemiptera appear to select regions in a grassland for feeding. Field areas more heavily invaded by Smooth Brome in fescue grassland ecosystems of the Canadian prairies show a reduction in Hemiptera in terms of both species richness and diversity, with corresponding decreases in abundance of two common species, *D. stylata* and *D. configuratus*. Loss of Hemiptera in Smooth Brome invaded grassland seems to relate to the feeding requirements of these phytophagous insects.

Author Contributions

Writing – Original Draft: V.E.R.; Writing – Reviewing & Editing: T.P.M.; Conceptualization: V.E.R. and T.P.M.; Investigation: V.E.R.; Formal Analysis: V.E.R.; Visualization: V.E.R. and T.P.M.; Supervision: T.P.M.

Acknowledgements

Literature Cited

Bess, J.A., K.M. O'Neill, and W.P. Kemp. 2004. Leafhopper assemblages on native and reseeded grasslands in southwestern Montana. Western North American Naturalist 64: 518–531.

Browne, V. 1982. Size and shape as ecological discriminants in successional communities of Heteroptera. Biological Journal of Linnean Society of London 18: 279–290. https://doi.org/10.1111/j.1095-8312.1982.tb02040.x

Chu, I.W., and H. Knutson. 1970. Preferences of eight grasshopper species among eleven species of cultivated grasses. Journal of the Kansas Entomological Society 43: 20–31.

Dibbern, J.C. 1947. Vegetative responses of *Bromus inermis* to certain variations in environment. Botanical Gazette 109: 44–58. https://doi.org/10.1086/335455

Flora of North America Editorial Committee. 1993+. Flora of North America North of Mexico. Oxford University Press, New York, New York, USA.

Gurevitch, J., S.M. Scheiner, and G.A. Fox. 2006. The Ecology of Plants. Sinauer Associates, Sunderland, Massachusetts, USA.

Jonas, J.L., M.R. Whiles, and R.E. Charlton. 2002. Aboveground invertebrate responses to land management differences in a central Kansas grassland. Environmental Entomology 31: 1142–1152. https://doi.org/10.1603/0046-225X-31.6.1142

Kelton, L.A. 1980. The Insects and Arachnids of Canada. Part 8: the Plant Bugs of the Prairie Provinces of Canada. Heteroptera: Miridae. Publication 1703. Biosystematics Research Institute, Ottawa, Ontario, Canada. Accessed 23 January 2020. http://biblio.uqar.ca/archives/30246389.pdf.

Litt, A.R., E.E. Cord, T.E. Fulbright, and G.L. Schuster. 2014. Effects of invasive plants on arthropods. Conservation Biology 28: 1532–1549. https://doi.org/10.1111/cobi.12350

Martin, J.E.H. 1977. The Insects and Arachnids of Canada. Part 1: Collecting, Preparing, and Preserving Insects, Mites, and Spiders. Publication 1643. Biosystematics Research Institute, Ottawa, Ontario, Canada. Accessed 8 May 2020. http://esc-sec.ca/wp/wp-content/uploads/2017/03/AAFC_insects_and_arachnids_part_1_eng.pdf.

Otfinowski, R., N.C. Kenkel, and P.M. Catling. 2007. The biology of Canadian weeds. 134. *Bromus inermis* Leyss. Canadian Journal of Plant Science 87: 183–198. https://doi.org/10.4141/P06-071

Sample, B.E., R.J. Cooper, R.D. Greer, and R.C. Whitmore. 1993. Estimation of insect biomass by length and width. American Midland Naturalist 129: 234–240. https://doi.org/10.2307/2426503

Scoggan, H.J. 1957. Flora of Manitoba. Bulletin 140. Biological series 47. National Museum of Canada, Ottawa, Ontario, Canada.

Scudder, G. 2014. The Heteroptera (Hemiptera) of the Prairie Ecozone of Canada. Pages 283–309 *in* Arthropods of Canadian Grasslands. Volume 3: Biodiversity and Systematics. Part I. *Edited by* H.A. Cárcamo and D.J. Giberson. Biological Survey of Canada, Ottawa, Ontario, Canada.

Statistix 8.0. 2003. User's manual. Analytical Software, Tallahassee, Florida, USA.

Stiegel, S., M.H. Entling, and J. Mantilla-Contreras. 2017. Reading the leaves' palm: leaf traits and palatability along the microclimatic gradient of forest layers. PLoS ONE 12: e0169741. https://doi.org/10.1371/journal.pone.0169741

Tadey, M. 2016. Variation in insect assemblage and functional groups along a grazing gradient in an arid environment. Entomology, Ornithology and Herpetology: Current Research 5: 179. https://doi.org/10.4172/2161-0983.1000179

Wenninger, E.J., and R.S. Inouye. 2008. Insect community response to plant diversity and productivity in a sagebrush–steppe ecosystem. Journal of Arid Environments 72: 24–33. https://doi.org/10.1016/j.jaridenv.2007.04.005

Whitcomb, R., J. Kramer, M. Coan, and A. Hicks. 1987. Ecology and evolution of leafhopper-grass host relationships in North American grasslands. Pages 121–169 *in* Current Topics in Vector Research, Volume 4. *Edited by* K.F. Harris. Praeger, New York, New York, USA.

Note

Bison (*Bison bison*) activity fragments subnivean tunnels of small mammals

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Abstract
Ecological interactions between ungulates and small mammals are generally not well understood. Here, we report an observation of unusually extensive small mammal (likely Meadow Vole [*Microtus pennsylvanicus*] or Tundra Vole [*Microtus oeconomus*]) tracks above the snow, exiting from trails and bed sites created by Bison (*Bison bison*) in northern Canada. We believe that weather and snow conditions were optimal for this observation. Although alteration of above-snow activity of small mammals in response to snow compaction by ungulates is probably not a rare event, it is not often reported. The effect on voles of exiting their subnivean tunnels as a result of Bison activity is unclear, but may be detrimental to their overwinter survival. Ungulate activity compacts snow, fragmenting small mammal tunnels resulting in loss of their insulative value for voles, and making it harder for them to dig new tunnels. Clearly, determining the effect of snow disturbance by gregarious ungulates on voles or other microtines, particularly regarding their overwinter survival, requires detailed investigation. Nevertheless, this observation provides new information on the ecological interactions between ungulates and small mammals, particularly from the boreal forest, where such information is largely lacking.

Key words: Bison; *Bison bison*; *Microtus*; subnivean; snow; voles; winter ecology; Yukon

Ecological interactions between ungulates and small mammals are generally not well understood. Such interactions undoubtedly occur frequently, with unknown consequences to the interacting species. Most of the few studies investigating these relations have focussed on the impact of ungulate grazing on the size of small mammal populations (e.g., Hayward *et al.* 1997; Keesing 1998; Matlack *et al.* 2001; Weickert *et al.* 2001; Torre *et al.* 2007) or the composition of small mammal communities (e.g., Muck and Zeller 2006; Saetnan and Skarpe 2006; Parsons *et al.* 2013). Other ecological interactions between ungulates and small mammals and those from biomes other than grassland, savannah, or temperate forests are less known (but see Keesing and Crawford 2001; McCauley *et al.* 2008; Jung *et al.* 2010, 2019; Navarro-Castilla *et al.* 2017).

Knowledge of such interactions in northern biomes, particularly during winter when snow cover is persistent, is especially scant. Yet, winter is a de-fining season for survival of northern small mammals that remain active, such as voles (*Microtus* spp., *Myodes* spp.; Hansson and Henttonen 1985; Korslund and Steen 2005; Boonstra and Krebs 2012; Haapakoski and Ylönen 2013; Johnsen *et al.* 2017). In the north, winter-active small mammals typically rely on snow cover and subnivean tunnels to survive (Hannson 1986; Courtin *et al.* 1991; Hansen *et al.* 1999; Bilodeau *et al.* 2013a,b; Soininen *et al.* 2015). Subnivean tunnels provide shelter from most predators and insulate small mammals from frigid ambient temperatures; hence, alteration or destruction of such tunnels might affect overwinter survival. Here, we report an observation of unusually extensive small mammal activity above the snow, coincident with trails created by reintroduced Bison (*Bison bison*) in the boreal forest of northern Canada.

On 22 January 2020, while conducting field studies on Bison, we observed a group of ~20–30 Bison in a large sedge meadow adjacent to Sceptre Lake

(61.12710°N, 136.40598°W), Yukon, Canada. There was abundant disturbance (compaction) of the snow cover from Bison walking, bedding, and feeding in the meadow. Within the meadow, we also observed several dozen sets of small mammal tracks emerging from areas of snow disturbed by Bison. The size and characteristics of the tracks were similar to those described for voles (*Microtus* spp.; Elbroch 2003). Although we did not measure trails made by these small mammals, many of them extended ≥25 m across the top of the snow. Snow depth was ~30–40 cm. We do not know the number of voles that made the trails we observed.

Our interpretation of these observations was that a population of voles—likely Meadow Vole (*Microtus pennsylvanicus*) or Tundra Vole (*Microtus oeconomus*)—inhabited the meadow and had established a network of subnivean tunnels beneath the snow. Bison had subsequently occupied the meadow, likely because it provided good foraging habitat, with abundant sedge (*Carex* spp.), a preferred winter food item for Bison in the region (Jung 2015; Jung *et al.* 2015). Bison activity compacted the snow, however, and likely disconnected the voles' tunnel systems. Voles travelling in the tunnels abruptly came out on a Bison trail or bed and travelled above the snow—sometimes for considerable distances—before returning under the snow. A similar observation was made in relation to Field Voles (*Microtus agrestis*) exiting their tunnels where they intersected with human trails in the snow (Hansson 1986). In hindsight, over the years we have made many similar observations of small mammal tracks above the snow in areas of concentrated activity or trails of Bison, Caribou (*Rangifer tarandus*), Moose (*Alces americanus*), or Elk (*Cervus canadensis*; T.S.J. pers. obs.), but not nearly to the same extent as this observation.

For more than two weeks before this observation, there was virtually no wind or new snow in the region, and the existing snow was dry, which likely provided optimal conditions for an accumulation of observable small mammal tracks. This allowed us to see the abundance of tracks made by voles exiting their subnivean tunnels where they intersected with areas of Bison activity. Our observation would likely have been difficult under different weather and snow conditions. Indeed, Hansson (1986) noted that snow conditions affect the density and distribution of snow tracks made by Field Voles in Finland.

If our interpretation of this observation is correct, then Bison (and other gregarious ungulates, e.g., Caribou or Elk) could detrimentally influence overwinter survival of voles where they co-occur. Voles travelling on top of the snow in open habitats are quite detectable and susceptible to predation by birds of prey (e.g., various owls) as well as mammalian carnivores. Moreover, in particularly cold temperatures, voles are susceptible to freezing (Courtin *et al.* 1991). Fragmentation of their tunnels because of snow compaction by Bison could result in some voles being caught above the snow or cold air infiltrating their tunnel system, both of which would subject voles to ambient temperatures. Temperatures in the region for 16 days before our observation were −30° to −45°C. Although we did not observe any signs of predation or find frozen voles, as our time at the remote site was unfortunately limited to <45 min, and we did not actively search for evidence of either. Alternatively, compacted snow created by ungulate trails may be beneficial for voles. Accumulated CO_2 in vole tunnels is a concern when the snow becomes deep (≥30 cm; Penny and Pruitt 1984); however, fragmentation of tunnels by ungulate trails may provide ventilation to the surface and release CO_2 (Hansson 1986).

Our observation provides further insight into the ecological interactions between ungulates and small mammals in the boreal forest, where such information is lacking. Although not previously reported, ungulate compaction of small mammal tunnels undoubtedly occurs wherever these species co-occur during winter. Compaction of snow by ungulates changes the subnivean environment for small mammals, likely by affecting the insulative value of snow, as well as fragmenting existing tunnels and making it more difficult to dig new tunnels. Clearly, targeted research is needed to assess the effects of ungulate disturbance of snow cover on small mammals. Our observation, in addition to others (e.g., Soper 1941; Matlack *et al.* 2001; Weickert *et al.* 2001; Jung *et al.* 2010, 2019), increases understanding of interactions between Bison and small mammals. This observation illustrates ecological interactions that may result from restoring Bison to their native range (Sanderson *et al.* 2008).

Acknowledgements

Literature Cited

Bilodeau, F., G. Gauthier, and D. Berteaux. 2013a. The effect of snow cover on lemming population cycles in the Canadian High Arctic. Oecologia 172: 1007–1016. https://doi.org/10.1007/s00442-012-2549-8

Bilodeau, F., G. Gauthier, and D. Berteaux. 2013b. Effect of snow cover on the vulnerability of lemmings to mammalian predators in the Canadian Arctic. Journal of Mammalogy 94: 813–819. https://doi.org/10.1644/12-MAMM-A-260.1

Boonstra, R., and C.J. Krebs. 2012. Population dynamics of red-backed voles (*Myodes*) in North America. Oecologia 168: 601–620. https://doi.org/10.1007/s00442-011-2120-z

Courtin, G.M., N.M. Kalliomaki, T. Hillis, and R.L. Robitaille. 1991. Effect of abiotic factors on the overwintering success in the meadow vole, *Microtus pennsylvanicus*: winter redefined. Arctic and Alpine Research 23: 45–52.

Elbroch, M. 2003. Mammal Tracks and Sign: a Guide to North American Species. Stackpole Books, Mechanicsburg, Pennsylvania, USA.

Haapakoski, M., and H. Ylönen. 2013. Snow evens fragmentation effects and food determines overwintering success in ground-dwelling voles. Ecological Research 28: 307–315. https://doi.org/10.1007/s11284-012-1020-y

Hansen, T.F., N.C. Stenseth, and H. Henttonen. 1999. Multiannual vole cycles and population regulation during long winters: an analysis of seasonal density dependence. American Naturalist 154:129–139. https://doi.org/10.1086/303229

Hansson, L. 1986. Vole snow trails and tunnels as density indicators. Acta Theriologica 31: 401–408.

Hansson, L., and H. Henttonen. 1985. Gradients in density variations of small rodents: the importance of latitude and snow cover. Oecologia 67: 394–402. https://doi.org/10.1007/BF00384946

Hayward, B., E.J. Heske, and C.W. Painter. 1997. Effects of livestock grazing on small mammals at a desert cienaga. Journal of Wildlife Management 61: 123–129. https://doi.org/10.2307/3802421

Johnsen, K., R. Boonstra, S. Boutin, O. Devineau, C.J. Krebs, and H.P. Andreassen. 2017. Surviving winter: food, but not habitat structure, prevents crashes in cyclic vole populations. Ecology and Evolution 7: 115–124. https://doi.org/10.1002/ece3.2635

Jung, T.S. 2015. Winter diets of reintroduced bison (*Bison bison*) in northwestern Canada. Mammal Research 60: 385–391. https://doi.org/10.1007/s13364-015-0240-2

Jung, T.S., P.M. Kukka, and A. Milani. 2010. Bison (*Bison bison*) fur used as drey material by red squirrels (*Tamiasciurus hudsonicus*): an indication of ecological restoration. Northwestern Naturalist 91: 220–222. https://doi.org/10.1898/NWN09-14.1

Jung, T.S., S.A. Stotyn, and S.M. Czetwertynski. 2015. Dietary overlap and potential competition in a dynamic ungulate community in northwestern Canada. Journal of Wildlife Management 79: 1277–1285. https://doi.org/10.1002/jwmg.946

Jung, T.S., S.A. Stotyn, and N.C. Larter. 2019. Freezer meals: comparative value of muskrat (*Ondatra zibethicus*) push-ups as late-winter forage for a northern ungulate. European Journal of Wildlife Research 65: 61. https://doi.org/10.1007/s10344-019-1301-7

Keesing, F. 1998. Impacts of ungulates on the demography and diversity of small mammals in central Kenya.

Oecologia 116: 381–389. https://doi.org/10.1007/s004420050601

Keesing, F., and T. Crawford. 2001. Impacts of density and large mammals on space use by the pouched mouse (*Saccostomus mearnsi*) in central Kenya. Journal of Tropical Ecology 17: 465–472. https://doi.org/10.1017/S0266467401001328

Korslund, L., and H. Steen. 2006. Small rodent winter survival: snow conditions limit access to food resources. Journal of Animal Ecology 75: 156–166. https://doi.org/10.1111/j.1365-2656.2005.01031.x

Matlack, R.S., D.W. Kaufman, and G.A. Kaufman. 2001. Influence of grazing by bison and cattle on deer mice in burned tallgrass prairie. American Midland Naturalist 146: 361–368.

McCauley, D.J., F. Keesing, T. Young, and K. Dittmar. 2008. Effects of the removal of large herbivores on fleas of small mammals. Journal of Vector Ecology 33: 263–269. https://doi.org/10.3376/1081-1710-33.2.263

Muck, C., and U. Zeller. 2006. Small mammal communities on cattle and game grazing areas in Namibia. African Zoology 41: 215–223. https://doi.org/10.1080/15627020.2006.11407357

Navarro-Castilla, Á., M. Díaz, and I. Barja. 2017. Does ungulate disturbance mediate behavioural and physiological stress response in Algerian mice (*Mus spretus*)? A wild exclosure experiment. Hystrix 28: 165–172. https://doi.org/10.4404/hystrix-28.2-12332

Parsons, E.W.R., J.L. Maron, and T.E. Martin. 2013. Elk herbivory alters small mammal assemblages in high-elevation drainages. Journal of Animal Ecology 82: 459–467. https://doi.org/10.1111/1365-2656.12009

Penny, C.E., and W.O. Pruitt, Jr. 1984. Subnivean accumulation of CO_2 and its effects on winter distribution of small mammals. Pages 373–380 *in* Winter Ecology of Small Mammals. *Edited by* J.F. Merritt. Special publication 10. Carnegie Museum of Natural History, Pittsburgh, Pennsylvania, USA.

Saetnan, E.R., and C. Skarpe. 2006. The effect of ungulate grazing on a small mammal community in southeastern Botswana. African Zoology 41: 9–16. https://doi.org/10.1080/15627020.2006.11407331

Sanderson, E.W., K.H. Redford, B. Weber, K. Aune, D. Baldes, J. Berger, D. Carter, C. Curtin, J. Derr, S. Dobrott, E. Fearn, C. Fleener, S. Forrest, C. Gerlach, C.C. Gates, J.E. Gross, P. Gogan, S. Grassel, J.A. Hilty, M. Jensen, K. Kunkel, D. Lammers, R. List, K. Minkowski, T. Olson, C. Pague, P.B. Robertson, and B. Stephenson. 2008. The ecological future of the North American bison: conceiving long-term, large-scale conservation of wildlife. Conservation Biology 22: 252–266. https://doi.org/10.1111/j.1523-1739.2008.00899.x

Soininen, E.M., I. Jensvoll, S.T. Killengreen, and R.A. Ims. 2015. Under the snow: a new camera trap opens the white box of subnivean ecology. Remote Sensing in Ecology and Conservation 1: 29–38. https://doi.org/10.1002/rse2.2

Soper, J.D. 1941. History, range, and home life of the northern bison. Ecological Monographs 11: 347–412. https://doi.org/10.2307/1943298

Torre, I., M. Díaz, J. Martínez-Padilla, R. Bonal, J. Viñuela, and J.A. Fagallo. 2007. Cattle grazing, raptor abundance and small mammal communities in Mediterranean grasslands. Basic and Applied Ecology 8: 565–575. https://doi.org/10.1016/j.baae.2006.09.016

Weickert, C.C., J.C. Whitaker, and G.A. Feldhamer. 2001. Effects of enclosed large ungulates on small mammals at Land Between the Lakes, Kentucky. Canadian Field-Naturalist 115: 247–250. Accessed 7 July 2020. https://www.biodiversitylibrary.org/page/34995321.

Range extension of two deep-sea nudibranchs, *Tritonia newfoundlandica* and *Doridoxa ingolfiana* (Mollusca: Gastropoda: Heterobranchia), in eastern Canada

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Abstract

Deep-sea nudibranchs (Mollusca: Gastropoda: Heterobranchia) have rarely been reported from eastern Canada. Here we describe range extensions for two species found in the northwest Atlantic Ocean. *Tritonia newfoundlandica* Valdés, Murillo, McCarthy & Yedinak, 2017 was originally collected on the Flemish Cap off Newfoundland, Canada, and *Doridoxa ingolfiana* Bergh, 1899 was originally found off western Greenland with further records in Iceland, northern Norway, and southeastern Canada. We extend the northern range of *T. newfoundlandica* 1067 km along the eastern coast of North America and add occurrences of *D. ingolfiana* in the Labrador Sea, bridging a 2044 km gap between previous records in Greenland and southern Newfoundland. The latter species thus exhibits a continuous distribution from Svalbard, the Faroe Islands, Greenland, down to the southern tip of the Grand Banks in eastern Canada. *Tritonia newfoundlandica* was collected in its known depth range, whereas the depth distribution of *D. ingolfiana* was extended by 30 m to a maximum depth of 1375 m. Both species were collected with numerous nephtheid corals, suggesting that there may be a functional relationship, where the nudibranchs find refuge or food on them.

Key words: North Atlantic Ocean; Newfoundland and Labrador; sea slug; Tritoniidae; Doridoxidae; biodiversity; taxonomy; *Tritonia newfoundlandica*; *Doridoxa ingolfiana*

Introduction

Members of the dendronotid nudibranch family Tritoniidae (Menke, 1828) are grouped into 11 genera and over 80 species, many occurring worldwide. One of the most recently described species, *Tritonia newfoundlandica* Valdés, Murillo, McCarthy & Yedinak, 2017 (no common name) was found off the southern coast of Newfoundland (eastern Canada) and is represented by 62 records to date. Most of the records (*n* = 57) were reported by Valdés *et al.* (2017), and the rest are from Svalbard, Norway (Zakharov and Jørgensen 2017).

Doridoxid nudibranchs are rare: the family Doridoxidae (Bergh, 1899) comprises a single genus and only three species: *Doridoxa benthalis* Barnard, 1963, *Doridoxa ingolfiana* Bergh, 1899, and *Doridoxa walteri* (Krause, 1892) (MolluscaBase 2020; no common names). Before our study, 25 individuals had

been documented, 15 of which were *D. ingolfiana*. Individuals of *D. benthalis* were collected in deep waters (~2300 m) of the southern Atlantic Ocean off South Africa (Barnard 1963). The two original specimens of *D. ingolfiana* were collected off western Greenland in the North Atlantic Ocean during the Danish Ingolf Expedition over a century ago (Bergh 1900). Bergh named the larger specimen *D. ingolfiana* and considered the smaller one a "variant". In 1970, another specimen was collected south of Greenland (Just *et al.* 1985). The third species, *D. walteri*, occurs in Norwegian, Russian, and adjacent waters. It was originally placed in the genus *Dermatobranchus,* but was recently moved to *Doridoxa* (Kantor and Syzoev 2006). Very little is known about its biology.

We add new records of *T. newfoundlandica* and *D. ingolfiana* from the continental slope of Labrador and the Grand Banks of Newfoundland (eastern Canada).

Methods

During scientific expeditions led by Fisheries and Oceans Canada, multispecies surveys were conducted annually on CCGS *Teleost* between September and December, 2006–2015 (see Power *et al.* 2016 and references therein). Surveys followed a random stratified sampling design, where each set deployed a Campelen 1800 trawl that was towed for 15 min (~1.4 km), with the net opening and closing at depth (~500–1500 m). Although the trawl was not designed to target small benthic organisms, several from a variety of phyla, including gastropod molluscs, were collected as bycatch. Species collected in the same trawls (e.g., sponges, corals) were also noted. Some of the nudibranchs collected in these surveys (*n* = 5) were preserved in 4% formalin, whereas samples from 2011 and 2013 were frozen at −20°C. Three other individuals were kept alive for study.

The preserved specimens were examined under a dissecting microscope (M205A, Leica Microsystems, Singapore) and photographed (microscope camera DFC7000T, Leica Microsystems, Wetzlar, Germany). Identification was based on colour, size, general appearance, and more specific external morphological characteristics in preserved specimens (including the penis, secondary gills, rhinophores, renal and anal pores, and dorsum), as well as on some internal characters, mainly the radula, using descriptions from Valdés *et al.* (2017) for *T. newfoundlandica* and from Schrödl *et al.* (2001) and Valdés *et al.* (2017) for *D. ingolfiana*. Voucher specimens of *T. newfoundlandica* (*n* = 1) and *D. ingolfiana* (*n* = 1) were deposited at the Canadian Museum of Nature, Ottawa (catalog numbers CMNML 2020-0001 and CMNML 2020-0002, respectively). The remaining preserved specimens were kept and stored in the Mercier Lab collection, Ocean Sciences Centre, Memorial University (Newfoundland and Labrador, Canada).

A literature search was conducted to locate all records of *T. newfoundlandica* and *D. ingolfiana*. Data on geographic distributions and depth ranges were summarized. Records were mapped using ggplot2 in R (v. 4.0.2; R Development Core Team 2015).

Results and Discussion

Of the 231 deep-sea trawls conducted between the northern Labrador coast and the southern section of the Grand Banks, 10 sets contained nudibranchs (from depths ranging between 930 and 1375 m; Table 1). Several of the nudibranch specimens were collected on or together with bathyal nephtheid corals, i.e., *Duva florida* (Flowery Carnation Coral), *Gersemia fruticosa* (Hedge Carnation Coral), and *Drifa glomerata* (Orb Carnation Coral). García-Matucheski and Muniain (2011) showed evidence of *Tritonia* species

feeding on nephtheid corals (including *G. fruticosa*), which could support the hypothesis that *T. newfoundlandica* and *D. ingolfiana* also feed on them.

Specimens of *T. newfoundlandica* (*n* = 5) were black (Figure 1a–e) with 10 pairs of reddish-brown (on live specimens) secondary gills on the fringes of the dorsal body wall (Figure 1a,b), which faded to yellowish brown after preservation. Preserved specimens had an elongate body, a rounded anterior end, and a pointed posterior end (Figure 1a) as described by Valdés *et al.* (2017). Specimens had perfoliated rhinophores with six branched vertical lamellae and rhinophoral sheaths (Figure 1a,c,d), and an undivided oral veil bearing 10 simple, tentacular processes (Figure 1d). The right, lateral side of the body had a renal and anal pore, as well as the genital opening with a penis (finishing like an arrow or looking short and straight) visible in some specimens (Figure 1a,c). The penis features provided key support for the identification of this species, as mentioned by Valdés *et al.* (2017). The dorsum was smooth and lacking tubercles (Figure 1a). Total body lengths (mean 37 mm, range 26–45 mm) were within the previously documented range (20–60 mm; Valdés *et al.* 2017). One specimen of *T. newfoundlandica* possessed a well-developed whitish female gland complex, which was visible through the body wall (Figure 1e).

Doridoxa ingolfiana (*n* = 7) were ovate with a broader anterior end (Figure 1f,g). They had perfoliated rhinophores with sheaths (Figure 1f), and the genital openings, anal pore, and renal pore were exclusively on the right side of the body (Figure 1h). The penis was large, wide, smooth, had a general mushroom-like appearance at the tip, and was the same colour as the rest of the body (Figure 1g,h). This species did not exhibit oral veil papillae or secondary gills, consistent with descriptions by Schrödl *et al.* (2001) and Valdés *et al.* (2017). Although most of the specimens had papillae on the dorsum, one did not (Figure 1f); this is perhaps an artifact of long-term preservation. Schrödl *et al.* (2001) noted that papillae were occasionally lacking. The anal and renal pores were located posteriorly on the right side of the body (Figure 1h), as mentioned by Valdés *et al.* (2017). One specimen, at 39 mm total length, exceeded the previously reported maximum of 30 mm for all other specimens (Table 1). The colours of the current individuals were also lighter (beige, yellowish, or light pink) than the deep reddish brown described in Valdés *et al.* (2017). Likewise, the specimens found in Norway (Ringvold 2008; Evertsen and Bakken 2013) showed similar light-yellow colours. This suggests that this species displays colour variations that may be genetic or phenotypically plastic, based on environment or diet.

These new records extend the geographic distri-

Table 1. Specimen and observational reports of *Tritonia newfoundlandica* and *Doridoxa ingolfiana.*

Report	Date	Location	Latitude, °N	Longitude, °	Depth, m	n	Total length, mm	Source
T. newfoundlandica								
Existing	26 June 2007	Off NFL	46.4487	44.2460 W	492–538	1	38	Valdés *et al.* 2017
	29 June 2007	Off NFL	46.7468	43.8828 W	480–471	2	45–60	Valdés *et al.* 2017
	3 July 2007	Off NFL	48.0260	43.2692 W	596–599	1	51	Valdés *et al.* 2017
	17 July 2007	Off NFL	46.8870	42.6087 W	1242–1245	3	30–49	Valdés *et al.* 2017
	17 July 2007	Off NFL	46.8873	42.5118 W	1083–1094	6	26–39	Valdés *et al.* 2017
	17 July 2007	Off NFL	47.0463	42.3430 W	759–764	1	47	Valdés *et al.* 2017
	5 Aug. 2008	Off NFL	46.7150	45.0680 W	1232	2	26–27	Valdés *et al.* 2017
	5 June 2009	Off NFL	48.0005	42.2393 W	1554–1607	1	50	Valdés *et al.* 2017
	14 June 2009	Off NFL	47.1643	42.5331 W	1132–1137	4	34–42	Valdés *et al.* 2017
	15 June 2009	Off NFL	47.0722	42.5509 W	1113–1122	11	30–37	Valdés *et al.* 2017
	16 June 2009	Off NFL	46.8461	42.2824 W	870–871	2	26–35	Valdés *et al.* 2017
	17 June 2009	Off NFL	46.8400	42.3596 W	856–943	2	34–40	Valdés *et al.* 2017
	18 June 2009	Off NFL	46.7749	42.1349 W	1108–1127	18	23–38	Valdés *et al.* 2017
	19 June 2009	Off NFL	46.6942	42.0314 W	1104–1112	3	30–35	Valdés *et al.* 2017
	11 Aug. 2011	Svalbard	78.5672	9.0692 E	578	2	20–30	Zakharov and Jørgensen 2017
	1 Sept. 2014	Svalbard	78.5853	9.1353 E	510–521	3	20–30	Zakharov and Jørgensen 2017
New	Oct. 2007	East of NFL	45.9005	56.3620 W	930	1	45	Our study*
	Nov. 2008	Off Labrador	51.6141	50.7598 W	1324	1	35	Our study
	Nov. 2009	Off Labrador	56.4581	55.8019 W	1212	1	26	Our study
	Sept. 2010	Off Labrador	52.7167	52.2333 W	1111	1	38	Our study
	Dec. 2014	Off Labrador	57.6240	56.6186 W	1198	1	41	Our study
D. ingolfiana								
Existing	12 June 2006	Off NFL	43.0807	50.9988 W	290–300	1	26	Valdés *et al.* 2017
	19 June 2007	Off NFL	45.8137	47.7428 W	119–120	1	23	Valdés *et al.* 2017
	29 June 2007	Off NFL	46.7468	43.8828 W	471–480	2	25–27	Valdés *et al.* 2017
	17 July 2007	Off NFL	46.8873	42.5118 W	1083–1094	2	15–27	Valdés *et al.* 2017
	9 Aug. 2007	Off NFL	46.0690	45.0008 W	1357–1358	2	28–30	Valdés *et al.* 2017
	10 Aug. 2008	Off NFL	46.1588	47.9140 W	110–114	1	18	Valdés *et al.* 2017
	18 June 2009	Off NFL	46.7749	42.1349 W	1108–1127	2	11–23	Valdés *et al.* 2017
	N/A	Faroe Islands	62.4987	7.3869 W	603	1	N/A	Sneli *et al.* 2005
	N/A	W. Greenland	65.2833	53.7167 W	100	1	12	Bergh 1899
	21 Oct. 2005	N. Norway	69.3762	15.7306 E	881–907	1	11	Evertsen and Bakken 2013
	5 Oct. 2005	N. Norway	70.1183	17.1138 E	493–503	1	7	Evertsen and Bakken 2013
New	Nov. 2006	South of NFL	51.2500	41.1167 W	1250	1	22	Our study†
	Dec. 2006	South of NFL	51.0167	41.2667 W	1375	2	31–39	Our study
	Nov. 2009	Off Labrador	56.4581	55.8019 W	1212	1	19	Our study
	Nov. 2012	Off Labrador	54.9745	54.6517 W	960	2	18–24	Our study
	Nov. 2015	Off Labrador	52.3791	52.4372 W	1002	1	30	Our study

Note: N/A = not available, NFL = Newfoundland, Canada.
*Voucher specimen at Canadian Museum of Nature: CMNML 2020-0001.
†Voucher specimen at Canadian Museum of Nature: CMNML 2020-0002.

butions of *T. newfoundlandica* (Figure 2a) and *D. in-golfiana* (Figure 2b). The North American range of *T. newfoundlandica* is extended by 9.6° (1067 km north) into the Labrador Sea. *Doridoxa ingolfiana* has historically been reported south of Newfoundland (Valdés *et al.* 2017) and off western Greenland (Schrödl *et al.*
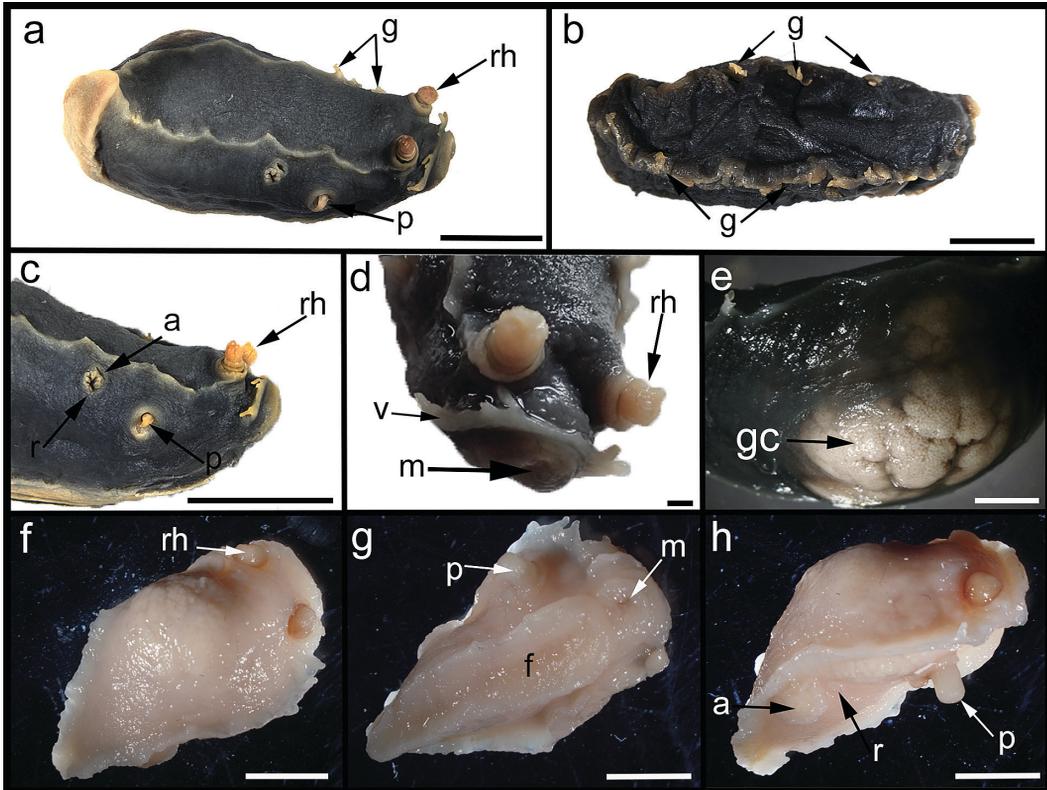
FIGURE 1. The nudibranchs, *Tritonia newfoundlandica* (a–e) and *Doridoxa ingolfiana* (f–h), collected near Newfoundland, Canada. a. General view; b. Dorsal view; c. Lateral view of anterior end; d. Head; e. Lateral view, showing mid-body with whitish female gland complex; f. Dorsal view; g. Ventral view; and h. Lateral view. Scale bars represent 1 cm, except for panel c (1 mm) and panel e (5 mm). Labels: a = anal pore, f = foot, g = secondary gill, gc = gland complex, m = mouth, p = penis, r = renal pore, rh = rhinophore, v = velar appendages. Photos a–d: H.D. Penney. Photos e–h: J.-F. Hamel.

2001), regions separated by 18.4° (2044 km north–south). The current samples demonstrate that the range of *D. ingolfiana* is likely continuous from at least Greenland to southern Newfoundland and extend the species maximum depth to 1375 m.

Recent work on other Cladobranchia nudibranchs in the genera *Coryphella*, *Flabellina* (Korshunova *et al.* 2017a), and *Zeusia* (Korshunova *et al.* 2017b) has revealed cryptic species in each genus. Our study suggests that the distribution of both species is extensive. Consequently, future work should examine genetic differences across latitudes for both *T. newfoundlandica* and *D. ingolfiana* to determine population structure, connectivity, and perhaps assess whether colour and morphological differences may reflect the presence of cryptic species, as already suggested in the *Tritonia* genus by Valdés *et al.* (2018).

Author Contributions

Writing – Original Draft: H.D.P. and J.-F.H.; Writing – Review & Editing: H.D.P., J.-F.H., and A.M.; Conceptualization: J.-F.H. and A.M.; Investigation: H.D.P. and J.-F.H.; Methodology: H.D.P. and J.-F.H.; Formal Analysis: H.D.P. and J.-F.H.; Funding Acquisition: A.M.

Literature Cited

Barnard, K.H. 1963. Deep sea Mollusca from west of Cape Point, South Africa. Annals of the South African Museum 46: 407–452. Accessed 30 July 2020. https://www.biodiversitylibrary.org/item/127021.
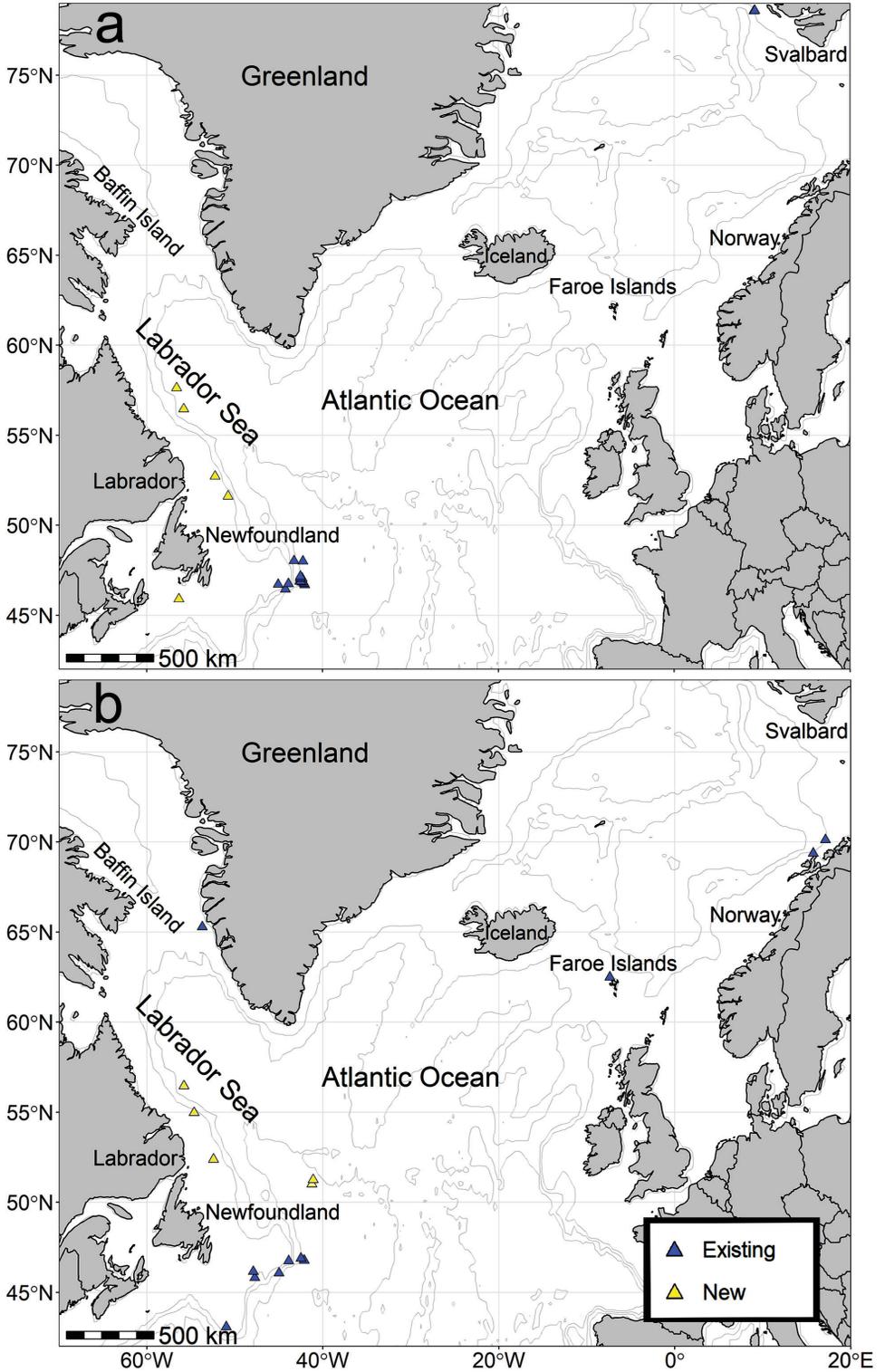
FIGURE 2. Map of existing and new records of a. *Tritonia newfoundlandica* and b. *Doridoxa ingolfiana.*

Bergh, R. 1900. Nudibranchiate Gasteropoda. Volume 2, part 3 *in* The Danish Ingolf-Expedition. Bianco Luno, Copenhagen, Denmark. Accessed 30 July 2020. https://www.biodiversitylibrary.org/item/18830.

Evertsen, J., and T. Bakken. 2013. Diversity of Norwegian sea slugs (Nudibranchia): new species to Norwegian coastal waters and new data on distribution of rare species. Fauna Norvegica 32: 45–52.

García-Matucheski, S., and C. Muniain. 2011. Predation by the nudibranch *Tritonia odhneri* (Opisthobranchia: Tritoniidae) on octocorals from the South Atlantic Ocean. Marine Biodiversity 41: 287–297. https://doi.org/10.1007/s12526-010-0063-y

Just, H., M. Edmunds, and E. Platts. 1985. North Atlantic nudibranchs (Mollusca) seen by Henning Lemche with additional species from the Mediterranean and the North East Pacific. Appendix: an annotated list of the North Atlantic Opisthobranchia. Ophelia Supplement 2: 1–170. Accessed 30 July 2020. http://www.vliz.be/en/imis?refid=75536.

Kantor, Y.I., and A.V. Syzoev. 2006. Marine and Brackish Water Gastropoda of Russia and Adjacent Countries: an Illustrated Catalogue. KMK Scientific Press, Moscow, Russia.

Korshunova, T., A. Martynov, T. Bakken, J. Evertsen, K. Fletcher, I.W. Mudianta, H. Saito, K. Lundin, M. Schrödl, and B. Picton. 2017a. Polyphyly of the traditional family Flabellinidae affects a major group of Nudibranchia: aeolidacean taxonomic reassessment with descriptions of several new families, genera, and species (Mollusca, Gastropoda). ZooKeys 717: 1–139. https://doi.org/10.3897/zookeys.717.21885

Korshunova, T., O. Zimina, and A. Martynov. 2017b. Unique pleuroproctic taxa of the nudibranch family Aeolidiidae from the Atlantic and Pacific Oceans, with description of a new genus and species. Journal of Molluscan Studies 83: 409–421. https://doi.org/10.1093/mollus/eyx036

MolluscaBase. 2020. *Doridoxa* Bergh, 1899. World Register of Marine Species, Ostend, Belgium. Accessed 30 July 2020. http://www.marinespecies.org/aphiaphp?p=taxdetails&id=370548.

Power, D., D. Ings, R. Rideout, and B.P. Healey. 2016. Performance and description of Canadian multi-species bottom trawl surveys in NAFO subarea 2 + divisions 3KLMNO, with emphasis on 2014–2015. Document 16/28. Northwest Atlantic Fisheries Organization, Dartmouth, Nova Scotia, Canada.

R Development Core Team. 2015. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna.

Ringvold, H. 2008. Ny nakensnegl funnet langs norskekysten. Mareano, Norway. Accessed 30 July 2020. https://www.mareano.no/nyheter/nyheter_2008/nakensnegl.

Schrödl, M., H. Wägele, and R.C. Willan. 2001. Taxonomic redescription of the Doridoxidae (Gastropoda: Opisthobranchia), an enigmatic family of deep water nudibranchs, with discussion of basal nudibranch phylogeny. Zoologischer Anzeiger 240: 83–97. https://doi.org/10.1078/0044-5231-00008

Sneli, J.-A., T. Schiøtte, K. Jensen, P.B. Wikander, Ø. Stokland, and J. Sorensen. 2005. The marine Mollusca of the Faroes. Annales societatis scientiarium Færoensis. 42(suppl.): 1–190.

Valdés, Á., L. Lundsten, and N.G. Wilson. 2018. Five new deep-sea species of nudibranchs (Gastropoda: Heterobranchia: Cladobranchia) from the Northeast Pacific. Zootaxa 4526: 401–433. https://doi.org/10.11646/zootaxa.4526.4.1

Valdés, Á., F.J. Murillo, J.B. McCarthy, and N. Yedinak. 2017. New deep-water records and species of North Atlantic nudibranchs (Mollusca, Gastropoda: Heterobranchia) with the description of a new species. Journal of the Marine Biological Association of the United Kingdom 97: 303–319. https://doi.org/10.1017/S0025315416000394

Zakharov, D.V., and L.L. Jørgensen. 2017. New species of the gastropods in the Barents Sea and adjacent waters. Russian Journal of Biological Invasions 8: 226–231. https://doi.org/10.1134/S2075111717030146

Note

An update to the distribution of the Endangered False Hop Sedge (*Carex lupuliformis* Sartwell ex Dewey; Cyperaceae) in Ontario

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Abstract
We provide an update to the Ontario distribution of False Hop Sedge (*Carex lupuliformis*), prompted by the first documented report of the species in the Niagara region, which represents a noteworthy eastern range extension in the province.

Key words: False Hop Sedge; *Carex lupuliformis*; *Lupulinae*; Cyperaceae; Niagara Region; Ontario; endangered species; range extension

False Hop Sedge (*Carex lupuliformis* Sartwell ex Dewey), which occurs in Canada in the southernmost portions of Ontario and Quebec, is federally listed as Endangered (SARA Registry 2019). In Quebec, False Hop Sedge is provincially listed as Threatened, with 14 extant populations as of 2010 (Environment Canada 2014). The species is also listed as Endangered in Ontario (OMNRF 2017) and was described as one of the province's rarest sedges in the Atlas of the Rare Vascular Plants of Ontario (Argus *et al*. 1982–1987). In the most recent edition of Rare Vascular Plants of Ontario (Oldham and Brinker 2009), False Hop Sedge was listed with a subnational rank (SRank) of S1, Critically Imperilled, which remains its current provincial rank. In the last decade, this species has been recorded in two new counties in southwestern Ontario (Lambton and Niagara), extending its known range in the province to six counties, including extant and extirpated populations. Neither of these new locations was mapped in the most recent Committee on the Status of Endangered Wildlife in Canada (COSEWIC) status report (COSEWIC 2011: Figure 7). The Niagara location, reported here, is a significant eastward range extension.

Of the genus *Carex*, the section *Lupulinae* comprises six species and is endemic to central and east-ern North America (Reznicek and Ball 1974). This section is characterized by the largest perigynia of all *Carex* species, as well as inflated perigynia with three stigmas and trigonous (three-sided) achenes (Jones and Hatch 1990). In Ontario, section *Lupulinae* is represented by four species: Gray's Sedge (*Carex grayi* J. Carey), False Hop Sedge, Hop Sedge (*Carex lupulina* Muhlenberg ex Willdenow), and Bladder Sedge (*Carex intumescens* Rudge). Hop Sedge may be challenging to differentiate from False Hop Sedge; however, significant differences in the shape of the achene make this distinction possible, as does the overall larger size of False Hop Sedge. In Ontario, mature achenes are present from early July to late October (Leslie 2018).

The achenes of Hop Sedge are rhomboid, often longer than wide and trigonous with faces flat to slightly concave, enclosed in inflated perigynia and ascending on the culm (Ball and Reznicek 2003). In contrast, the achenes of False Hop Sedge are rhombic, often as long as wide and trigonous with faces strongly concave and angles thickened with prominent nipple-like knobs (Figure 1); they are enclosed in inflated perigynia and held ascending to spreading on the culm (Ball and Reznicek 2003).

The habitat of False Hop Sedge has generally been

FIGURE 1. Mature False Hop Sedge (*Carex lupuliformis*) achene, from plant material collected in Niagara Region. Photo: Jessica Consiglio.

described as wet forests, where it prefers canopy openings, as well as riverine wetlands, marshes, and wet thickets on calcareous soil (Thompson and Paris 2004). Ontario sites are typically treed swamps with extensive vernal pooling, characterized by Red Maple (*Acer rubrum* L.), Silver Maple (*Acer saccharinum* L.), or Green Ash (*Fraxinus pennsylvanica* Marshall) growing on clay loam (OMNRF 2017). In Quebec, False Hop Sedge is predominantly found growing in canopy openings of Silver Maple swamps (Environment Canada 2014; Langlois and Pellerin 2016). Further south, common associates at sites in Connecticut and Massachusetts include Red Maple, Black Gum (*Nyssa sylvatica* Marshall), Green Ash, Swamp White Oak (*Quercus bicolor* Willdenow), and Pin Oak (*Quercus palustris* Münchhausen) in areas with extensive vernal pooling (Thompson and Paris 2004).

False Hop Sedge was first discovered in Ontario by W. Herriot who collected a specimen in 1902 from Waterloo region, although this population has not been seen again despite several attempts to relocate it (Oldham *et al*. 1993). As reported by Oldham and Crins (1988), A.A. Reznicek, M.J.O., and W. Botham rediscovered the species in Ontario in 1985 at a site near Amherstburg, Essex County, where ~15 plants were growing with Eastern Buttonbush (*Cephalanthus occidentalis* L.) and Hop Sedge in a wet willow floodplain woods. Oldham *et al*. (1993) reported a new population discovered in 1992 growing in a small depression at the edge of a deciduous woods in the City of London, Middlesex County, and two additional new sites in Aldborough Township, Elgin County, discovered in 1993. At all three sites, False Hop Sedge was observed growing in the open or at the edges of treed areas that held water in the spring (Oldham *et al*. 1993). The following year, another population was discovered in Middlesex County, near Mount Brydges, by Ron Vanderjeugd (Natural Heritage Information Centre [NHIC] files).

Over a decade later, a new population was documented several kilometres west of West Lorne, Elgin County, by staff from various agencies conducting targetted searches for the species in 2005 (NHIC files). Several years later, Ministry of Natural Resources (MNR) staff documented the species in Ailsa Craig, Middlesex County, growing in a Silver Maple swamp with associated species, such as Blue Beech (*Carpinus caroliniana* Walter), poison ivy (*Toxicodendron* Miller spp.), Wild Geranium (*Geranium maculatum* L.), jewelweed (*Impatiens* L. spp.), and Fowl Manna Grass (*Glyceria striata* Lamarck; NHIC files). In 2009, a new population was discovered by Charles Cecile in London, consisting of a few plants growing in an open, moist Silver Maple woodland located between two small wetlands (NHIC files). In addition, MNR staff observed a new False Hop Sedge population in 2011 in Southwold Township, Elgin County, growing in a treed swamp. In 2015, Brian Miller discovered two new False Hop Sedge populations: one growing in woods north of Dresden, Lambton County, which was the first record of this species in the county, and a third new population found in a wooded swamp in London (NHIC files).

The newest recorded Ontario population of False Hop Sedge was discovered in early September 2019 by J.A.C. during a field trip with the Field Botanists of Ontario (Figure 2), led by Albert Garofalo and Nate Torenvliet in Niagara Falls. Approximately 50 clumps were found growing at the edge of extensive vernal pools; associated species included Red Maple, hickory (*Carya* Nuttall spp.), Black Gum, Pin Oak, and Highbush Blueberry (*Vaccinium corymbosum* L.). Three additional patches, containing similar numbers of clumps, were subsequently found by Andrew Dean, Nadia Cavallin, and Lisa Riederer during the course of the field trip within a few kilometres of the first patch. These represent the first recorded populations of False Hop Sedge in the Niagara region and a significant eastward range extension for the species in Ontario, as it is ~200 km from the nearest presumed extant population.

With a recent increase in the known range of the species in Ontario, it is worth discussing what may have led to False Hop Sedge being historically over-
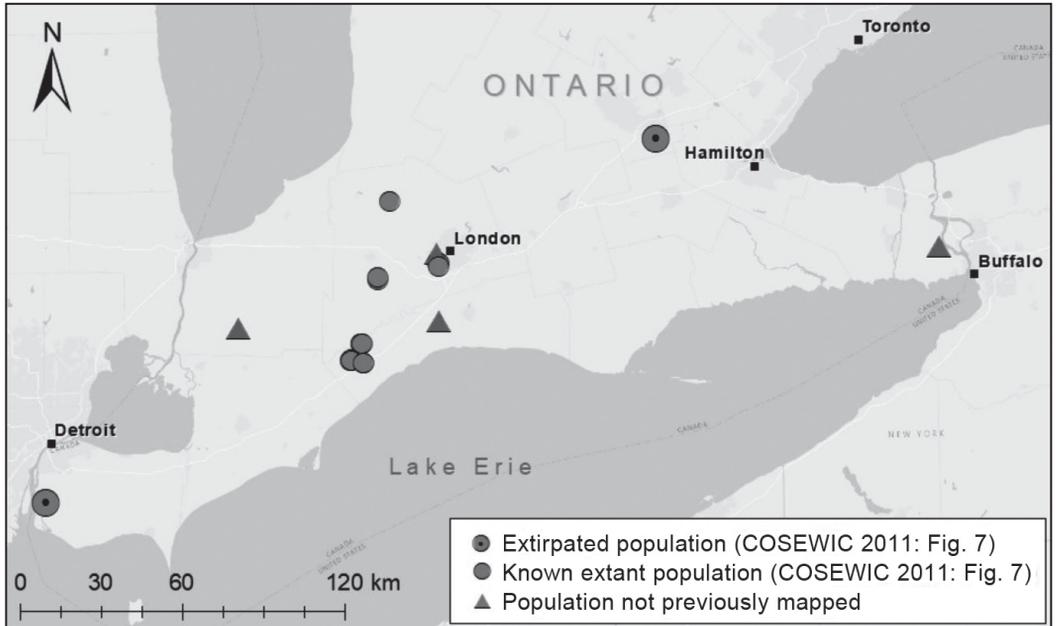
FIGURE 2. Range map of all known Ontario False Hop Sedge (*Carex lupuliformis*) populations (extirpated and known populations; COSEWIC 2011: Figure 7). On the far right is the newly discovered population in Niagara. Map: Jessica Consiglio. Basemap sources: Esri, HERE, Garmin, ©OpenStreetMap contributors and the GIS user community.

looked. For instance, the visually similar Hop Sedge has been reported growing together with False Hop Sedge at most Ontario sites, which could make detection more challenging if botanists are not aware of the subtle differences mentioned above. However, it is not simply a lack of awareness of the species, as a search of major Ontario herbaria by A.A. Reznicek (1973) during his M.Sc. thesis research on the taxonomy of *Carex* series *Lupulinae* in Canada, did not reveal any misidentified material of False Hop Sedge filed with other members of the section (Oldham *et al.* 1993). This is the case outside Ontario as well, with many North American herbarium records suggesting that False Hop Sedge has never been common or abundant, and populations throughout its range generally consist of ~15 individuals (NatureServe 2019).

Despite possible challenges to detection, or perhaps because of them, field botanists in Ontario and Quebec should remain on the lookout for this rare species, especially from July to October when the mature achenes allow for identification.

Voucher specimens

In accordance with guidance given under the *Endangered Species Act*, 2007 (ESA) the specimen was donated to the Ontario NHIC herbarium.

CANADA, ONTARIO: Lambton County, near Dresden, 10–20 small plants in low depression in woods, 2 September 2015, *M.J. Oldham and B. Miller 43139*

(MICH, NHIC 12029).

CANADA, ONTARIO: Niagara Region, Niagara Falls. Black Gum–Red Maple deciduous swamp, associated with *Acer rubrum*, *Nyssa sylvatica*, *Quercus palustris*, *Vaccinium corymbosum*. 7 September 2019, *J.A. Consiglio* (NHIC 09600).

Literature Cited

Argus, G.W., K.M. Pryer, D.J. White, and C.J. Keddy. 1982–1987. Atlas of the Rare Vascular Plants of Ontario. 4 parts. National Museum of Natural Sciences, Ottawa, Ontario, Canada.

Ball, P.W., and A.A. Reznicek. 2003. *Carex*. Pages 252–258 *in* Flora of North America North of Mexico (Vol. 23). *Edited by* Flora of North America Editorial Committee.

Flora of North America Editorial Committee, New York, USA, and Oxford, United Kingdom. Accessed 5 June 2020. http://www.efloras.org/florataxon.aspx?flora_id=1&taxon_id=105644.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2011. COSEWIC assessment and status report on the False Hop Sedge *Carex lupuliformis* in Canada. COSEWIC, Ottawa, Ontario, Canada.

Environment Canada. 2014. Action plan for the False Hop Sedge (*Carex lupuliformis*) in Quebec. *Species at Risk Act* action plan series. Environment Canada, Ottawa, Ontario, Canada. Accessed 9 May 2020. https://tinyurl.com/yaol5gjy.

Jones, S.D., and S.L. Hatch. 1990. Synopsis of *Carex* section *Lupulinae* (Cyperaceae) in Texas. Sida 14: 87–99.

Langlois, A., and S. Pellerin. 2016. Recovery of the endangered False Hop Sedge: a ten-year study. Global Ecology and Conservation 7: 214–224. https://doi.org/10.1016/j.gecco.2016.07.003

Leslie, J. 2018. Vascular Plants at Risk in Ontario. Accessed 7 January 2019. https://tinyurl.com/y6quh2jc.

NatureServe. 2019. NatureServe Explorer: an online encyclopedia of life [web application]. Version 7.1. NatureServe, Arlington, Virginia, USA. Accessed 18 February 2020. http://explorer.natureserve.org.

Oldham, M.J., and S.R. Brinker. 2009. Rare vascular plants of Ontario. Fourth edition. Natural Heritage Information Centre, Ontario Ministry of Natural Resources, Peterborough, Ontario, Canada. Accessed 17 December 2019. https://tinyurl.com/y4v7chjm.

Oldham, M.J., and W.J. Crins. 1988. New and significant records of Ontario sedges (Cyperaceae). Canadian Field-Naturalist 102: 500–507. Accessed 17 December 2019. https://www.biodiversitylibrary.org/page/28243320.

Oldham, M.J., D. McLeod, and R. Vanderjeugd. 1993. *Carex lupuliformis* (Cyperaceae) new to Elgin and Middlesex Counties, Ontario. Field Botanists of Ontario Newsletter 6(3): 17–18.

OMNRF (Ontario Ministry of Natural Resources and Forestry). 2017. Recovery strategy for the False Hop Sedge (*Carex lupuliformis*) in Ontario. Ontario recovery strategy series. Ontario Ministry of Natural Resources and Forestry, Peterborough, Ontario, Canada. Accessed 17 December 2019. https://www.ontario.ca/page/false-hop-sedge-recovery-strategy.

Reznicek, A.A. 1973. The taxonomy of *Carex* series *Lupulinae* in Canada. M.Sc. thesis, University of Toronto, Toronto, Ontario, Canada.

Reznicek, A.A., and P.W. Ball. 1974. The taxonomy of *Carex* series *Lupulinae* in Canada. Canadian Journal of Botany 52: 2387–2399. https://doi.org/10.1139/b74-310

SARA (*Species at Risk Act*) Registry. 2019. Species profile: False Hop Sedge (*Carex lupuliformis*). Accessed 5 June 2020. https://species-registry.canada.ca/index-en.html#/species/2-13.

Thompson, E., and C.A. Paris. 2004. *Carex lupuliformis* Sartwell ex Dewey: False Hop Sedge. Conservation and research plan for New England. New England Wild Flower Society, Framingham, Massachusetts, USA. Accessed 17 December 2019. https://tinyurl.com/y9y7c9tt.

Note

A report of unusual aggregation behaviour in Bullsnakes (*Pituophis catenifer sayi*) near a nest site in Saskatchewan

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Abstract

We describe an unusual aggregation of Bullsnakes (*Pituophis catenifer sayi*) near a nest site in Saskatchewan. Bullsnake is a wide-ranging oviparous colubrid that reaches the northern tip of its continental range on the prairies and badlands of Canada. At that location, it is considered a species of Special Concern, but, until recently, has been the subject of relatively few natural history reports. This is significant, because, at the northern edge of their range, Bullsnakes may behave differently than elsewhere due to thermal limitations experienced at high latitudes. On 29 June 2019, we observed a mass of five adult Bullsnakes in a Silver Sagebrush (*Artemisia cana*) shrub on a slope in southwestern Saskatchewan. Aggregations of Bullsnakes are known to occur at hibernacula, during mating, and inside nest chambers before and after oviposition. However, we are unaware of the occurrence of surface aggregations in any other situation. We suggest that these Bullsnakes may have been exhibiting communal gestation, a behaviour thought to be rare in oviparous snakes whereby gravid females congregate before parturition or oviposition for thermal stability or protection from predators.

Key words: Bullsnake; *Pituophis catenifer sayi*; aggregation behaviour; nesting; herpetology

Bullsnake (*Pituophis catenifer sayi*) is a large oviparous colubrid whose range stretches across the great plains of North America, from the prairies and badlands of southern Alberta and Saskatchewan in Canada to northern Mexico (Ernst and Ernst 2003). In Canada, Bullsnake has been assessed as a species of Special Concern, in part because of habitat loss and suspected population declines across much of its range (COSEWIC 2017).

Bullsnakes have been well studied outside of their Canadian range (e.g., Fitch 1982; Moriarty and Linck 1998; Kapfer *et al.* 2008a,b,c, 2010; Iverson *et al.* 2012), and knowledge of Bullsnake ecology in Canada has expanded greatly in recent years (e.g., Didiuk 2003; Kissner and Nicholson 2003; Wright 2008, 2016; Martinson 2009; Fortney *et al.* 2012; Martino *et al.* 2012; Gardiner *et al.* 2013; COSEWIC 2017; Somers *et al.* 2017; Edkins *et al.* 2018; Powell *et al.* 2018). However, there are still important knowledge gaps in terms of whether they behave differently at the northern periphery of their range relative to areas further south. At the edge of their northern range, certain aspects of Bullsnake behaviour may be unique because of thermal limitations (Edkins *et al.* 2018).

During radio tracking of snakes along Gap Creek in southwestern Saskatchewan, Canada (~2 km south of 49.873°N, 109.573°W), N.B.J. and J.L.V.P. observed an aggregation of five adult Bullsnakes in a Silver Sagebrush (*Artemisia cana* Pursh) shrub (Figure 1). The area, which lies on the boundary between Cypress Upland and Mixed Grassland ecoregions, is composed of prairie grasslands interspersed with shrubs (SCDC 2019). It includes large tracts of native prairie used for grazing cattle. We observed snakes on an exposed south-facing slope at 1045 on 29 June 2019. The sky was clear, ambient air temperature was 24.6°C, and wind speed was 4.9 km/h. The five Bullsnakes were touching each other in a coiled mass. Two of the five snakes had previously been captured, processed, and implanted with radio transmitters, which alerted us to their presence before our arrival. Both implanted snakes were females

FIGURE 1. An aggregation of five Bullsnakes (*Pituophis catenifer sayi*) in a Silver Sagebrush (*Artemisia cana*) shrub observed on an exposed south-facing slope at 1045 on 29 June 2019. The observation was made in a grazing pasture adjacent to Gap Creek (~2 km south of 49.873°N, 109.573°W) in southwestern Saskatchewan, Canada, during a radiotelemetric study. Photo: Noah Johnson.

as determined by a cloacal probe (Fitch 1960). All five snakes were more than 1 m in total length. The two known females had been previously measured with a flexible string (1470 mm and 1290 mm snout-vent length). We were unable to process the remaining three snakes to determine sex or exact length. The approximate size of the unprocessed snakes became visually apparent when they uncoiled and moved away from the shrub. None of the snakes showed any signs of defensive behaviour, such as hissing or striking. This lack of aggression was not unusual because snakes often have the tendency to remain motionless when approached if under cover (N.B.J. and J.L.V.P. pers. obs.). We were able to count the individual snakes when they eventually separated from each other and entered nearby burrows, likely because of our presence. Bullsnake eggshells from previous seasons were found nearby among numerous mammal

burrows and patches of loose soil, suggesting that the slope was an actively used Bullsnake nest site.

In Canada, Bullsnakes often nest communally (Wright 2008). Communal nesting is apparently widespread among reptiles (Graves and Duvall 1995) and is also found among close relatives of Bullsnake, such as Pinesnake (*Pituophis melanoleucus*; Burger and Zappalorti 1986) and Gophersnake (*Pituophis catenifer deserticola*; Williams *et al.* 2015). Communal nesting enhances thermal and hydric stability for eggs and may be especially important when suitable nesting sites are limited (Graves and Duvall 1995). Female Bullsnakes have been observed aggregating inside underground nest chambers before oviposition, and several days following oviposition (Wright 2008). However, coiled masses of female Bullsnakes outside nest chambers are apparently unusual or have gone unreported in the literature. While tracking

Bullsnakes at Gap Creek during the summer of 2019, it was not uncommon to observe two snakes sharing the same burrow or hollow tree; however, this is our first observation of a coiled mass of five snakes.

Graves and Duvall (1995) reviewed communal aggregation behaviour associated with parturition in reptiles. Communal gestation is the aggregation of gravid females before parturition. This behaviour is thought to be especially important for females at high latitudes and altitudes. However, Graves and Duvall (1995) note that communal gestation appears mainly in viviparous species and is thought to be rare in egg laying snakes. The mass of Bullsnakes may have consisted of gravid females that formed an aggregation for thermoregulatory advantages before oviposition. Indeed, the date of observation coincides with the typical timing of oviposition (Wright 2008; Iverson *et al.* 2012). One of the known females in the mass had recently migrated to the nest site from its normal home range roughly 1.2 km away and was presumed gravid for this reason. Gravid *Pituophis* females maintain elevated body temperature (Kapfer *et al.* 2008c) and control over altered body temperature is important for promoting the development of embryos in other snakes (Lourdais *et al.* 2008). Graves and Duvall (1995) suggested that aggregation might help females retain heat because a group of snakes in physical contact would have increased thermal inertia because of their greater mass and reduced surface area. In addition, an aggregation might deter avian predators because several snakes would be harder to pick up than a single snake (Graves and Duvall 1995).

The aggregation we observed was likely not associated with other events where aggregation is observed in Bullsnakes, i.e., mating, and egress or ingress at hibernacula. In southwestern Saskatchewan, Bullsnakes emerge in spring (late April to May) and mate immediately after (Gardiner *et al.* 2013; R.G.P. unpubl. data). Congregation at communal hibernacula typically occurs in late September or early October (Gardiner *et al.* 2013; R.G.P. unpubl. data). It is also unlikely that the Bullsnakes were aggregating to share a limited resource, because there were many similar shrubs in the immediate vicinity.

Our observation reinforces previous studies that have quantified the importance of shrubs as structural features on the landscape (Martino *et al.* 2012; Edkins *et al.* 2018). If communal gestation occurs in Bullsnakes, shrubs may facilitate this behaviour and should be preserved. Likewise, if suitable nesting sites are limited, these sites should also be located so they can be protected.

We note that this observation is not proof of communal gestation; some of the unprocessed snakes may have been males, and we did not collect data on ovi-

position. Our conclusion would have been strengthened if we had determined the sex of all five snakes and if they contained eggs. Future research might confirm the presence of this aggregation behaviour in other populations, its possible significance to reproduction, and whether both sexes aggregate for thermoregulatory advantages.

Author Contributions

Acknowledgements

Literature Cited

Burger, J., and R.T. Zappalorti. 1986. Nest site selection by Pine Snakes, *Pituophis melanoleucus*, in the New Jersey Pine Barrens. Copeia 1986: 116–121. https://doi.org/10.2307/1444896

COSEWIC (Committee on The Status of Endangered Wildlife in Canada). 2017. COSEWIC assessment and status report on the Bullsnake *Pituophis catenifer sayi* in Canada. COSEWIC, Ottawa, Ontario, Canada.

Didiuk, A.B. 2003. CFB Suffield and Suffield National Wildlife Area: cooperative reptile and amphibian studies: snake conservation research and management 2002. Canadian Wildlife Service, Prairie and Northern Region, Edmonton, Alberta, Canada. Accessed 26 May 2020. https://aeic-iaac.gc.ca/050/documents/29548/29548F.PDF.

Edkins, T.L., C.M. Somers, M.C. Vanderwel, M.J. Sadar, and R.G. Poulin. 2018. Variable habitat selection and movement patterns among Bullsnake (*Pituophis catenifer sayi*) populations in Saskatchewan. Canadian Field-

Naturalist 132: 126–139. https://doi.org/10.22621/cfn.v 132i2.2041

Ernst, C.H., and E.M Ernst. 2003. Snakes of the United States and Canada. Smithsonian Books, Washington, DC, USA.

Fitch, H.S. 1960. Criteria for determining sex and breeding maturity in snakes. Herpetologica 16: 49–51.

Fitch, H.S. 1982. Resources of a snake community in prairie–woodland habitat of northeastern Kansas. Pages 83–97 in Herpetological Communities: a Symposium of the Society for the Study of Amphibians and Reptiles and the Herpetologists' League, August 1977. Research report 13. Edited by N.J. Scott, Jr. Fish and Wildlife Service, United States Department of the Interior, Washington, DC, USA. Accessed 26 May 2020. https://biosurvey. ku.edu/sites/biosurvey.ku.edu/files/publishedworks/ pdfs/Fitch_1982.pdf.

Fortney, A.N., R.G. Poulin, J.A. Martino, D.L. Parker, and C.M. Somers. 2012. Proximity to hibernacula and road type influence potential road mortality of snakes in southwestern Saskatchewan. Canadian Field-Naturalist 123: 194–203. https://doi.org/10.22621/cfn.v126i3.1360

Gardiner, L.E., C.M. Somers, J.A. Martino, D.L. Parker, and R.G. Poulin. 2013. Balancing the dumbbell: summer habitats need protection in addition to winter dens for northern snake communities. Journal of Wildlife Management 77: 975–982. https://doi.org/10.1002/jwmg.555

Graves, B.M., and D. Duvall. 1995. Aggregation of squamate reptiles associated with gestation, oviposition, and parturition. Herpetological Monographs 9: 102–119. https://doi.org/10.2307/1466999

Iverson, J.B., C.A. Young, T.S.B. Akre, and C.M. Griffiths. 2012. Reproduction by female Bullsnakes (Pituophis catenifer sayi) in the Nebraska Sandhills. Southwestern Naturalist 57: 58–73. https://doi.org/10.1894/0038-4909-57.1.58

Kapfer, J.M., J.R. Coggins, and R. Hay. 2008a. Estimates of population size, measurements of sex ratios, and reported mortality rates for Bullsnakes (Pituophis catenifer sayi) at a site in the upper midwestern United States. Journal of Herpetology 42: 265–269. https://doi.org/10. 1670/07-2021.1

Kapfer, J., J. Coggins, and R. Hay. 2008b. Spatial ecology and habitat selection of Bullsnakes (Pituophis catenifer sayi) at the northern periphery of their geographic range. Copeia 2008: 815–826. https://doi.org/10.1643/ce-07-104

Kapfer, J.M., M.J. Pauers, D.M. Reineke, J.R. Coggins, and R. Hay. 2008c. Environmental, behavioral, and habitat variables influencing body temperature in radio-tagged Bullsnakes, Pituophis catenifer sayi. Journal of Thermal Biology 33: 174–179. https://doi.org/10.1016/j.j therbio.2007.11.005

Kapfer, J.M., C.W. Pekar, D.M. Reineke, J.R. Coggins, and R. Hay. 2010. Modeling the relationship between habitat preferences and home-range size: a case study on a large mobile colubrid snake from North America. Journal of Zoology 282: 13–20. https://doi.org/10.1111/ j.1469-7998.2010.00706.x

Kissner, K.J., and J. Nicholson. 2003. Bullsnakes (Pituophis catenifer sayi) in Alberta: literature review and data compilation. Alberta species at risk report 62. Alberta Sustainable Resource Development, Fish and Wildlife Division, Edmonton, Alberta, Canada. Accessed 26 May 2020. http://www.assembly.ab.ca/lao/library/egovdocs/ 2003/alsrd/138571.pdf.

Lourdais, O., B. Heulin, and D.F. Denardo. 2008. Thermoregulation during gravidity in the Children's Python (Antaresia childreni): a test of the preadaptation hypothesis for maternal thermophily in snakes. Biological Journal of the Linnean Society 93: 499–508. https://doi.org/10. 1111/j.1095-8312.2007.00925.x

Martino, J.A., R.G. Poulin, D.L. Parker, and C.M. Somers. 2012. Habitat selection by grassland snakes at northern range limits: implications for conservation. Journal of Wildlife Management 76: 759–767. https://doi.org/10.10 02/jwmg.313

Martinson, A.J. 2009. Modeling road mortality of prairie rattlesnakes and bullsnakes in Alberta. M.Sc. thesis, University of Calgary, Calgary, Alberta, Canada. https:// doi.org/doi:10.11575/PRISM/2937

Moriarty, J.J., and M. Linck. 1998. Reintroduction of Bullsnakes into a recreated prairie. Pages 43–52 in Minnesota's Amphibians and Reptiles: Their Conservation and Status: Proceedings of a Symposium. Edited by J.J. Moriarty and D. Jones. Serpent's Tale, Lansboro, Minnesota, USA.

Powell, G.L., P. Peller, and A.P. Russell. 2018. Incidentally gathered natural history information on Bullsnakes (Pituophis catenifer sayi) in southeastern Alberta. Canadian Field-Naturalist 132: 140–149. https://doi.org/10.22621/ cfn.v132i2.2046

SCDC (Saskatchewan Conservation Data Centre). 2019. Saskatchewan's ecoregions. SCDC, Regina, Saskatchewan, Canada. Accessed 26 May 2020. http://biodiversity. sk.ca/eco.htm.

Somers, C.M., C.F. Graham, J.A. Martino, T.R. Frasier, S.L. Lance, L.E. Gardiner, and R.G. Poulin. 2017. Conservation genetics of the Eastern Yellow-bellied Racer (Coluber constrictor flaviventris) and Bullsnake (Pituophis catenifer sayi): river valleys are critical features for snakes at northern range limits. PLoS ONE 12: e0187322. https://doi.org/10.1371/journal.pone.0187322

Williams, K.E., K.E. Hodges, and C.A. Bishop. 2015. Hibernation and oviposition sites of Great Basin Gophersnakes (Pituophis catenifer deserticola) near their northern range limit. Journal of Herpetology 49: 207–216. https://doi.org/10.1670/13-162

Wright, J.D. 2008. Bullsnake, Pituophis catenifer sayi, nesting biology in Alberta. Canadian Field-Naturalist 122: 138–141. https://doi.org/10.22621/cfn.v122i2.572

Wright, J.D. 2016. Which is Canada's largest snake? Establishing the record to species and individual. Canadian Herpetologist 6: 3–7. Accessed 26 May 2020. http:// canadianherpetology.ca/resources/TCH/The%20 Canadian%20Herpetologist%20vol%206%20no%20 1%20Spring%202016.pdf.

The Canadian Field-Naturalist

First records of two freshwater mussel Species at Risk, Mapleleaf (*Quadrula quadrula*) and Lilliput (*Toxolasma parvum*), in the Canard River, Ontario, with implications for freshwater mussel recovery in the Detroit River

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Abstract
Freshwater mussels of the family Unionidae are among the world's most imperilled animals. A third of Canadian species have been assessed by the Committee on the Status of Endangered Wildlife in Canada as Extirpated, Endangered, Threatened, or Special Concern, with losses attributed to natural system modifications such as damming, pollution, exploitation for buttons and pearls, urbanization, and the introduction and subsequent effects of aquatic invasive species. In the Great Lakes basin, the introduction of dreissenid mussels in the 1980s caused catastrophic declines, with remnant populations restricted to lotic riverine habitats. In southwestern Ontario, the Canard River is the largest remaining direct tributary of the Detroit River that could provide a source of mussels to aid natural recovery. In 2019, nine sites in the Canard River were sampled using a timed-search approach (4.5 person-hours/site) with a combination of tactile searching by hand and mussel scoops (7-mm mesh) or underwater viewers. The search yielded 362 individuals of eight species, including two Species at Risk, Mapleleaf (*Quadrula quadrula*) and Lilliput (*Toxolasma parvum*), which had never been previously recorded in the Canard River.

Key words: Bivalve; Unionidae; Great Lakes; Zebra Mussel; *Dreissena polymorpha*; Quagga Mussel; *Dreissena rostriformis bugensis*; Asian Clam; *Corbicula fluminea*

Introduction

Freshwater bivalves have undergone large-scale global declines and are now among the most imperilled taxa in the world with ~40% of species considered at risk (Lopes-Lima *et al.* 2018). Within this group, the freshwater mussels of the order Unionida and family Unionidae are the most at risk. Lopes-Lima *et al.* (2018) report that 45% of the more than 800 species of Unionida have undergone assessment by the International Union for Conservation of Nature and are considered Near-Threatened, Threatened, or Extinct while at least two-thirds of the ~300 North American members of the family Unionidae are considered at risk (Williams *et al.* 1993; Lopes-Lima *et al.* 2018). In Canada, 46% of Unionida are considered vulnerable to extirpated (CESCC 2016) and 19 species (35%) of Unionidae have already been assessed as Extirpated, Endangered, Threatened, or Special Concern by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC).

Global declines have been attributed to a variety of causes including natural system modifications, such as damming, pollution, exploitation for buttons and pearls, urbanization, and the introduction and subsequent effects of aquatic invasive species (COSEWIC 2016; Lopes-Lima *et al.* 2018). Although all of these have contributed to the decline of Canadian freshwater mussels, the arrival and establishment of dreissenid mussels (Zebra Mussel [*Dreissena polymorpha*] and Quagga Mussel [*Dreissena rostriformis bugensis*]) in the Great Lakes basin in the mid-1980s proved particularly catastrophic (Mackie 1991; Ricciardi *et al.* 1998). In little more than a decade after their arrival, dreissenids had contributed to the near total extirpation of freshwater unionid mussels from Lake St. Clair (Nalepa *et al.* 1996), the Detroit River (Schloesser *et al.* 1998, 2006), and the western basin of Lake Erie (Schloesser and Nalepa 1994).

As the planktonic veliger larvae of dreissenid mussels are not well adapted to establishment in lotic systems, it was recognized early that upstream riverine habitats would represent important refuges for Ontario mussels (Clarke 1992). Two major river systems (Sydenham and Thames Rivers) and several smaller ones (Belle, Puce, and Ruscom Rivers for Lake St. Clair; Canard River for the Detroit River; Big Creek and Clear Creek in the western basin of Lake Erie) provide Canadian refuges for freshwater mussels of Lake St. Clair, the Detroit River, and the western basin of Lake Erie. The Sydenham and Thames Rivers represent Canada's most speciose rivers, with historical complements of 35 species in each system and relatively intact assemblages of 34 and 32 species remaining in each system, respectively (McNichols-O'Rourke *et al.* 2012). The smaller tributaries of the southern shore (Belle, Puce, and Ruscom Rivers) have comparably smaller and less speciose assemblages (4–8 species; McNichols-O'Rourke *et al.* 2012; Fisheries and Oceans Canada unpubl. data); however, these five systems all represent potential sources of recolonizers for the Lake St. Clair system.

In contrast to the multiple rivers of the Lake St. Clair drainage, the Canard River represents the one river system in Canada that drains directly into the Detroit River. Morris and Di Maio (1998–1999) provided the only available information on the Canard River mollusc fauna when they surveyed three sites on the river in 1993, collecting only 15 individuals of five species. Despite the low species richness and abundance, the direct outflow of the Canard River into the Detroit River makes it a potentially important source of natural recolonizers of the Detroit River if recovery is likely to occur. The study described here was designed to assess the current status and distribution of the freshwater mussel assemblage of the Canard River with the goal of understanding the potential for this assemblage to contribute to future natural recolonization of the Detroit River.

Methods

The Canard River, located in southwestern Ontario on the Essex Clay Plain, is a small low-gradient river draining an area of 347 km². Land use in Essex County, including the Canard River watershed, is primarily agricultural (80–85%); only 4.5% of the watershed is forested and <1% is considered wetland (Essex Region Conservation Authority 2015). Riparian forest is sparse in the Canard River watershed with only 7.9% of riverbanks forested. Natural flow patterns in the system have been heavily altered in some areas through realignment by artificial means to support agriculture, and provincial guidelines for nitrates, nitrites, ammonia, total phosphorus, and suspended solids are regularly exceeded (Essex Region Conservation Authority 2015).

On 15 July 2019, visual reconnaissance of the watershed was conducted to determine which sites would be sampled between 16 and 18 July 2019. Sites were evaluated based on location in the watershed (coverage and proximity to other sites), access, water depth, turbidity, substrate type, and any evidence of the presence of mussels (e.g., shells or middens). The three sites surveyed by Morris and Di Maio (1998–1999) in 1993 were revisited during this reconnaissance trip. In total, nine sites were selected for a full survey based on the parameters outlined above: two represented the historical sites of Morris and Di Maio (1998–1999) and seven were new. These sites were arranged such that seven, including both historical sites, were located in the main branch of the Canard River and two were located in the south branch (Table 1; Figure 1).

Physical data were collected at each site using a range of equipment. Air temperature (Hanna HI98311 DiST 5 EC/TDS/Temperature Tester; ITM Instruments Inc., Newmarket, Ontario, Canada), wind speed (Kestrel 2000 Pocket Wind Meter; ITM Instruments Inc., Newmarket, Ontario, Canada), and weather by visual observation were recorded from the side of the river before the survey began. Additional

TABLE 1. Sites, in upstream to downstream order, and dates of surveys by Fisheries and Oceans Canada in 2019.

| Site code	Drainage	Water body	Latitude, °N	Longitude, °W	Survey date
CRD-CRD-01	Lake Erie	Canard River (main branch)	42.12329	82.84820	18 July
CRD-CRD-09	Lake Erie	Canard River (main branch)	42.13216	82.87779	17 July
CRD-CRD-08	Lake Erie	Canard River (main branch)	42.14094	83.00359	17 July
CRD-CRD-02	Lake Erie	Canard River (main branch)	42.15915	83.01888	18 July
CRD-CRD-06	Lake Erie	Canard River (main branch)	42.17483	83.03442	16 July
CRD-CRD-05	Lake Erie	Canard River (main branch)	42.18673	83.07065	16 July
CRD-CRD-10	Lake Erie	Canard River (south branch)	42.14268	83.06861	18 July
CRD-CRD-07	Lake Erie	Canard River (south branch)	42.16492	83.07537	17 July
CRD-CRD-04	Lake Erie	Canard River (main branch)	42.16947	83.09765	16 July
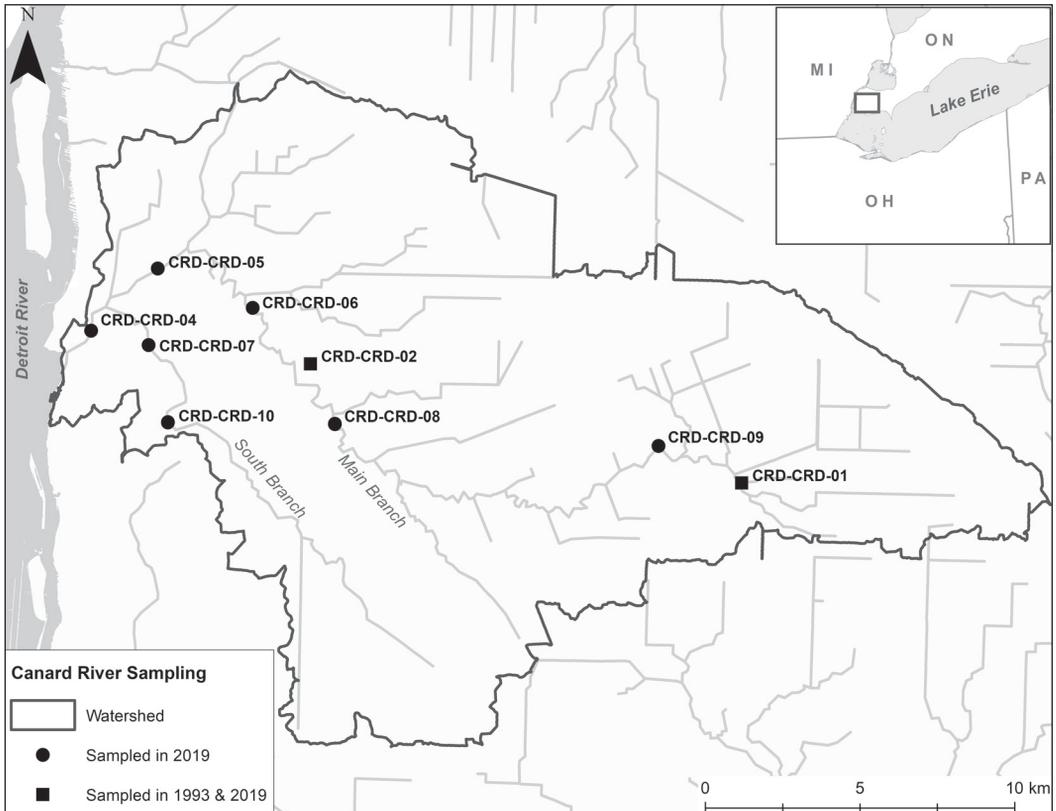
Figure 1. Location of nine sites surveyed in the Canard River by Fisheries and Oceans Canada in 2019.

parameters were collected from the river: water clarity (60-cm turbidity tube; Hoskin Scientific Ltd., Oakville, Ontario, Canada), water velocity (OTT MF Pro Flow Meter; OTT HydroMet, Loveland, Colorado, USA), and water chemistry, including water temperature, conductivity, total dissolved solids, optical dissolved oxygen, pH, and turbidity (EXO handheld display and EXO2 Multiparameter Sonde; YSI Inc., Yellow Springs, Ohio, USA). These measurements were made at a single point in the search area before the survey began. Once the survey was complete, the length of reach searched was measured using a laser 1200s range finder 7 × 25 (Nikon Corporation, Melville, New York, USA). The average depth throughout the search area was measured using a metre stick. Degree of siltation, stream habitat type as per the Ontario Stream Assessment Protocol (Stanfield 2010), and substrate composition were estimated visually and averaged across the search area. Definitions of substrate sizes were taken from Stanfield (2010): boulder (>250 mm in diameter), rubble (65–250 mm), gravel (2–65 mm), sand (<2 mm), and "other" material (mud, muck, silt, and detritus).

Surveys were conducted in wadable habitats (maximum depth searched = 1.56 m) following the timed-search methods of Metcalfe-Smith *et al.* (2000), whereby each site was surveyed for 4.5 person-hours (p-h) by a four- or five-person crew using a combination of mussel viewers, mussel scoops (7-mm mesh; Wright *et al.* 2017), and tactile searching. Each animal found alive was identified (Clam Counter, version 1.3.4, Toronto Zoo, Toronto, and Fisheries and Oceans Canada, Ottawa, Ontario, Canada; https://play. google.com/store/apps/details?id=com.torontozoo. clamcounter&hl=en), counted, measured using calipers (maximum length), and visually sexed (if sexually dimorphic) before being returned to the river. Shells of species not observed alive at the site were also counted and recorded. Evidence of dreissenid mussel infestation (presence of live animals or remnant byssal threads attached to individual mussels) was recorded for each site.

When at least 100 individuals of a species were collected, length–frequency distributions were examined using a Shapiro-Wilk test for normality in RStudio version 1.1.383 (RStudio Team 2016).

Normality tests were used to assist with interpreting the length–frequency distributions. Recent recruitment was assessed by determining the proportion of individuals of each species considered to be juveniles, based on shell length less than an established cut-off value. For Mapleleaf (*Quadrula quadrula*), the cut-off value was 50 mm as stated in COSEWIC (2016). For Giant Floater (*Pyganodon grandis*), the general cut-off of 25 mm as outlined in Haag and Warren (2007) was used as no species-specific data were available.

Results

The Canard River sites can be characterized as having little flow (<0.07 m/s), poor visibility, moderate to high turbidity, soft substrates, and a moderate to high degree of siltation (Table 2). In all, 362 live individuals representing eight species were observed across the nine sites (Table 3, Figures S1–S8). Site abundance and species richness were greatest at sites in the middle portion of the main branch (sites CRD-CRD-02, 08, and 09; sites 02 and 08 are rather unremarkable with regard to the physical data shown in Table 2). Of these 362 individuals, 119 (33%) were Species at Risk (SAR) representing two species: Mapleleaf (federally Special Concern, SARA Registry 2019a) and Lilliput (*Toxolasma parvum*; federally Endangered, SARA Registry 2019b; Figure 2). Giant Floater was the most abundant species (140 individuals) representing 39% of all unionids detected. Mapleleaf was the most abundant SAR (105 individuals) and the second-most abundant species overall representing 29% of unionids found. Paper Pondshell (*Utterbackia imbecillis*), although low in abundance (<4% of all individuals), was the most widespread species, as it was found at five of the nine sites (55%). Total unionid species richness ranged from zero at CRD-CRD-01 to eight species at CRD-CRD-02 and CRD-CRD-08. Live SAR richness at a site ranged from zero (four sites) to two species at CRD-CRD-02 and CRD-CRD-08. No additional species were detected as only shells/valves. Four of the species found, including both SAR, had not been detected in the Canard River previously (*Q. quadrula*, *T. parvum*, *T. truncata*, and *U. imbecillis*). One live Fatmucket (*Lampsilis siliquoidea*) was found during the 1993 surveys but no evidence of this species was detected in 2019. Evidence of dreissenid infestation (live animals or byssal threads attached to individual mussels; proportion of animals infested not recorded) was found at the two most downstream sites on the main branch (CRD-CRD-04 and CRD-CRD-05) as well as the most upstream site in the south branch (CRD-CRD-10). Although no evidence of dreissenids was found at the downstream site on the south branch

TABLE 2. Physical data collected at each site surveyed in the Canard River by Fisheries and Oceans Canada in 2019.

Parameter	Sites, in upstream to downstream order								
	CRD-CRD-01	CRD-CRD-09	CRD-CRD-08	CRD-CRD-02	CRD-CRD-06	CRD-CRD-05	CRD-CRD-10	CRD-CRD-07	CRD-CRD-04
Weather	Clear/ sunny	Sunny, hot, humid	Overcast, some sun	Clear/sunny	Overcast, humid	Overcast, slight rain	Clear, sunny	Overcast, rain	Cloud, overcast
Air temperature, °C	28.6	35.8	25.7	23.4	27.7	26.7	24.3	24.5	26.1
Wind speed, km/h	2.5	1.5	0.0	2.0	2.4	5.7	0.0	0.0	1.9
Length of reach searched, m	120	288	140	186	73.5	78	74	57	42
Average depth searched, m	0.48	0.66	0.10	0.55	1.25	1.35	0.75	1.44	1.45
Water clarity, m	0.060	0.100	0.090	0.020	0.268	0.171	0.051	0.297	0.342
Water velocity, m/s	0.061	0.010	0.005	0.031	0.008	0.007	0.069	0.007	0.007
Water temperature, °C	24.10	27.90	25.60	25.40	26.60	27.20	22.80	24.64	26.20
Conductivity, μS/cm	952.0	1014.0	841.0	2488.0	1215.0	623.0	579.0	620.0	350.1

TABLE 2. *Continued.*

| Parameter | Sites, in upstream to downstream order | | | | | | | | |
	CRD-CRD-01	CRD-CRD-09	CRD-CRD-08	CRD-CRD-02	CRD-CRD-06	CRD-CRD-05	CRD-CRD-10	CRD-CRD-07	CRD-CRD-04
Total dissolved solids, mg/L	610.160	643.146	542.266	1629.274	790.125	387.150	396.346	405.456	222.393
Optical dissolved oxygen, %	80.6	43.2	53.0	66.7	53.2	54.1	73.9	61.8	47.6
Optical dissolved oxygen, mg/L	6.65	3.47	4.16	5.40	4.30	4.28	6.40	5.11	3.78
pH	7.94	7.67	7.85	7.87	7.68	7.95	8.00	7.99	7.73
Turbidity, FNU	59.40	60.42	120.67	54.5	26.68	33.55	79.52	13.72	11.77
Degree of siltation	Slight	Slight	Heavy	Heavy	Medium	Medium	Medium	Heavy	Heavy
Riffle, %	0	0	0	0	0	0	0	0	0
Pool, %	0	10	0	0	0	0	0	0	0
Run, %	0	0	0	0	0	100	0	0	100
Flat, %	100	90	100	100	100	0	100	100	0
Bedrock, %	0	0	0	0	0	0	0	0	0
Boulder, %	0	5	0	0	0	0	0	5	0
Rubble, %	5	5	0	0	0	0	0	0	0
Gravel, %	10	15	5	0	0	0	1	10	0
Sand, %	0	10	10	5	0	0	1	0	0
Silt , %	0	0	0	0	0	0	0	35	0
Clay, %	50	50	30	40	0	0	35	5	0
Muck, %	35	15	35	50	80	60	40	30	80
Detritus, %	0	0	20	5	20	40	23	15	20

Table 3. Results of timed-search surveys at nine sites in the Canard River by Fisheries and Oceans Canada in 2019.

Scientific name	Common name	Sites, in upstream to downstream order									Total	% Relative abundance	% Frequency of occurrence
		CRD-CRD-01	CRD-CRD-09	CRD-CRD-08	CRD-CRD-02	CRD-CRD-06	CRD-CRD-05	CRD-CRD-10	CRD-CRD-07	CRD-CRD-04			
Lasmigona complanata	White Heelsplitter	—	38	13	5	—	1	—	—	—	57	15.75	44.44
Leptodea fragilis	Fragile Papershell	—	3	7	12	—	—	—	—	—	22	6.08	33.33
Potamilus alatus	Pink Heelsplitter	—	—	1	1	—	—	—	S(1)	—	2	0.55	22.22
Pyganodon grandis	Giant Floater	S(3), V(4)	9	61	64	S(1)	—	2	4	—	140	38.67	55.56
Quadrula quadrula	**Mapleleaf**	—	—	**65**	**34**	**2**	—	—	—	**4**	**105**	**29.01**	**44.44**
Toxolasma parvum	**Lilliput**	**V(1)**	—	**8**	**5**	—	**1**	—	**V(2)**	—	**14**	**3.87**	**33.33**
Truncilla truncata	Deertoe	—	—	1	7	—	—	—	—	—	8	2.21	22.22
Utterbackia imbecillis	Paper Pondshell	—	—	4	4	2	2	—	—	2	14	3.87	55.56
Total abundance		0	50	160	132	4	4	2	4	6	362		
Live species richness		0	3	8	8	2	3	1	1	2	8		
Total species richness		2	3	8	8	3	3	1	3	2	8		
Effort, person-h		4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	40.5		

Note: Species at Risk are in bold. S(#) represents individuals that were detected as a shell (both valves) and the number of shells detected. V(#) represents individuals that were detected as a single valve and the number of valves detected. Voucher photographs are available in Figures S1–S8.

FIGURE 2. Two federally listed mussel Species at Risk were found in the Canard River: a. Mapleleaf (*Quadrula quadrula*) and b. Lilliput (*Toxolasma parvum*). Photos: Fisheries and Oceans Canada.

(CRD-CRD-07), shells of the invasive Asian Clam (*Corbicula fluminea*) were found there.

Mapleleaf were 23.3−114.4 mm (mean 82 mm) in length and represented a non-normal, left-skewed distribution (W = 0.76, P = 0.003; Figure 3). Juveniles recently recruited into the population represented 4.7% (five individuals) of the observed Mapleleaf. Giant Floater lengths were 52.2−170.0 mm (mean 114.9 mm) and represented a non-normal, left-skewed distribution (W = 0.657, P < 0.001; Figure 4). No individuals below the 25 mm length threshold representing juveniles were detected, although Giant Floater is a very fast-growing species and perhaps not well represented by that generalized cut-off threshold length.

Discussion

In contrast with the severe impacts of the dreissenid invasion observed in the nearby Detroit River (Schloesser *et al.* 2006), it is clear that the Canard River still maintains a relatively intact mussel assemblage. Morris and DiMaio (1998–1999) collected only 15 specimens of five species from three sites in 1993, whereas our study collected over 20 times the number of individuals (362) and four additional spe-
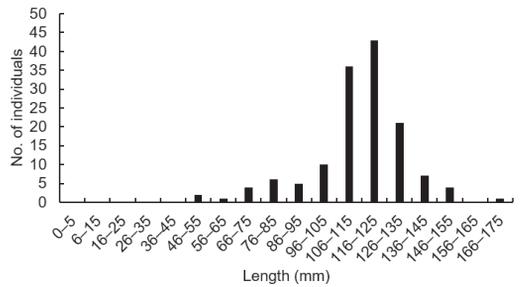

FIGURE 3. Frequency distribution of length of Mapleleaf (*Quadrula quadrula*) observed in the Canard River (*n* = 105) by Fisheries and Oceans Canada in 2019.

FIGURE 4. Frequency distribution of length of Giant Floater (*Pyganodon grandis*) observed in the Canard River (*n* = 140) by Fisheries and Oceans Canada in 2019.
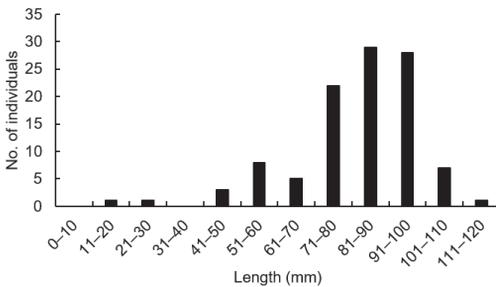
cies. However, we are cautious in interpreting this as a meaningful change because of the difference in effort between this study and that of Morris and DiMaio (1998–1999). Our study employed the 4.5 p-h effort recommended by Metcalfe-Smith *et al.* (2000) for sampling freshwater mussel communities in southern Ontario, whereas the earlier study used only a 1 p-h effort, and we surveyed three times as many sites. In terms of catch-per-unit-effort (CPUE), that of the historical study was 5 individuals/h, while that of the current study was 8.9 individuals/h. By comparison, the similarly sized Ruscom and Belle rivers on the nearby south shore of Lake St Clair support eight and four species respectively, with CPUE of 15 and 1.6 animals/h (McNichols-O'Rourke *et al.* 2012).

The discovery of new occurrences for two SAR in the Canard River is important as neither Mapleleaf nor Lilliput was detected during the 1993 sampling of Morris and DiMaio (1998–1999). Metcalfe-Smith *et al.* (2000) indicated that increasing the search effort from 1.5 p-h (slightly more than used in the historical survey) to the 4.5 p-h used here can result in a doubling of the detection of rare species and an over-

all species detection increase of 37%. It is possible that the detection of these two SAR may simply be the result of increased effort as predicted by Metcalfe-Smith *et al.* (2000). Lilliput fits the Metcalfe-Smith *et al.* (2000) definition of a rare species and only represented <4% of mussels at any site. However, given that Mapleleaf was the second-most abundant species found during this study, it does not meet the definition of a rare species; it was found to occur at a rate of 7.5 individuals/h at a site that was sampled in 1993 without detection. Thus, it seems likely that there has been a change in its distribution and/or abundance over the last 16 years.

In a large study looking at the distribution of mussels on the United States side of the Lake St. Clair/Detroit River/western Lake Erie corridor, Zanatta *et al.* (2015) surveyed 141 sites at 48 separate locations and found that Mapleleaf was the most abundant species, particularly in the western basin of Lake Erie. After looking at the historical work of Nalepa and Gauvin (1988) and Clark (1944), Zanatta *et al.* (2015) suggested that this dominance by Mapleleaf represented a real change from historical conditions, facilitated by the ability of the species to shed attached dreissenid mussels and its short brooding time (e.g., equilibrium life history strategy of Haag 2012). New locations for Mapleleaf have recently been found in other Canadian waters, including several coastal wetlands of Lake Ontario (Wright *et al.* 2020), and Hoffman *et al.* (2018) have shown that Mapleleaf likely moved into Lake Ontario after the opening of the Welland Canal by way of its highly vagile host Channel Catfish (*Ictalurus punctatus*). COSEWIC recently reassessed the status of the Great Lakes–Upper St. Lawrence designatable unit of Mapleleaf in Canada and recommended a change in status from Threatened to Special Concern in part because of the discovery of new locations for the species (COSEWIC 2016). All of these lines of evidence support the conclusion that Mapleleaf is expanding its range in southern Ontario and the discovery in the Canard River likely represents a new occurrence.

The significance of refuge sites for the preservation and eventual recovery of unionid mussels in the Great Lakes basin has been known for some time. Early in the dreissenid invasion process, Clarke (1992) recognized that Ontario's Sydenham River and its rich mussel fauna would likely act as an important repository for mussel diversity as dreissenids spread throughout the Great Lakes basin. Coastal wetland habitats in Lake St. Clair and Lake Erie were identified early as important habitats because of a combination of flow patterns and physical habitat properties that combine to keep dreissenid settlement rates low (Nichols and Amberg 1999; Zanatta *et al.* 2002;

Bowers and Szalay 2004). Early in the response to the dreissenid invasion, the National Native Mussel Conservation Committee (1998) in the United States developed a national strategy that included recognition of the importance of riverine refuges. Cope *et al.* (2003) assessed whether *in situ* refuges were an effective means to protect threatened mussel populations, and recent efforts have been made to predict where these refuges may occur in the lower Great Lakes (Bossenbroek *et al.* 2018).

Schloesser *et al.* (2006) concluded that there were no natural refuges for native mussels along the main channel of the Detroit River and that native mussels were extirpated from the system. However, in the face of declines in dreissenid mussels in Lake St. Clair (the main source population) during the 1990s and projected continued declines, they believed that recovery might be possible if a refuge could be found. The discovery of a refuge population in the Canard River in 2019, so closely associated with the Detroit River, represents a significant source of potential recolonizers of the Detroit River. Eight years earlier, Zanatta *et al.* (2015) found no sign of live mussels at three of four locations in the Detroit River drainage on the United States side. Only the furthest downstream location, at the mouth of the Huron River near the outflow of the Detroit River, yielded live unionids. However, its extreme downstream location and the low abundance of mussels (nine) bring into question the importance of this location to recovery of the Detroit River fauna. Recently, Allred *et al.* (2020) initiated the first native mussel surveys of the Detroit River itself since Schloesser *et al.* (2006). Surveying 56 sites, they found live unionids at only five, with two (both immediately downstream of the Canard River outflow) yielding 96% (212/220) of all individuals, further supporting the idea that the Canard River may be an important source of individuals for future recovery in the Detroit River.

The presence of an intact mussel assemblage in the Canard River is an encouraging sign for future recovery of freshwater mussels throughout the Lake St. Clair/Detroit River/western Lake Erie corridor. Additional sampling in the Canard River system and other nearby rivers and wetlands, including those of the southern Lake St. Clair shoreline (e.g., Puce River) and western Lake Erie (e.g., Big Creek complex), will help evaluate the ongoing status of this assemblage and determine whether other Canadian refuges exist. The simultaneous discovery of new populations of two federally listed SAR in the Canard River will support the recovery of these species and indicates that the Canard River will likely play an important role in the restoration and recovery of Canada's freshwater mussel fauna in the future.

Author Contributions

Acknowledgements

Literature Cited

Allred, S.S., D.A. Woolnough, T.J. Morris, and D.T. Zanatta. 2020. Status update for native mussels in the Detroit River. Page 20 *in* Proceedings of the 2019 Canadian Freshwater Mollusc Research Meeting: December 3–4, 2019, Burlington, Ontario. *Edited by* T.J. Morris, K.A. McNichols-O'Rourke, and S.M. Reid. Technical report 3352. Fisheries and Aquatic Sciences, Fisheries and Oceans Canada, Ottawa, Ontario, Canada. Accessed 27 April 2020. https://waves-vagues.dfo-mpo.gc.ca/Library/4084724x.pdf.

Bossenbroek, J.M., L.E. Burlakova, T.C. Crail, A.Y. Karatayev, R.A. Krebs, and D.T. Zanatta. 2018. Modeling habitat of freshwater mussels (Bivalvia: Unionidae) in the Lower Great Lakes 25 years after the *Dreissena* invasion. Freshwater Science 37: 330–342. https://doi.org/10.1086/697738

Bowers, R., and F. De Szalay. 2004. Effects of hydrology on unionids (Unionidae) and Zebra Mussels (Dreissenidae) in a Lake Erie coastal wetland. American Midland Naturalist 151: 286–300. https://doi.org/10.1674/0003-0031(2004)151[0286:eohouu]2.0.co;2

CESCC (Canadian Endangered Species Conservation Council). 2016. Wild species 2015: the general status of species in Canada. CESCC, Ottawa, Ontario, Canada. Accessed 28 April 2020. https://www.registrelep-sara registry.gc.ca/virtual_sara/files/reports/Wild%20Species%202015.pdf.

Clarke, A.H. 1992. Ontario's Sydenham River, an important refugium for native freshwater mussels against competition from the zebra mussel *Dreissena polymorpha*. Malacology Data Net 3: 43–55.

Clark, C.F. 1944. The fresh-water naiads of Auglaize County, Ohio. Ohio Journal of Science 44: 167–176.

Cope, W.G., M.C. Hove, D.L. Waller, D.J. Hornbach, M.R. Bartsch, L.A. Cunningham, H.L. Dunn, and A.R. Kapuscinski. 2003. Evaluation of relocation of unionid mussels to *in situ* refugia. Journal of Molluscan Studies 69: 27–34. https://doi.org/10.1093/mollus/69.1.27

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2016. COSEWIC assessment and status report on the Mapleleaf *Quadrula quadrula*, Great Lakes–Upper St. Lawrence population and Saskatchewan–Nelson Rivers population, in Canada. COSEWIC, Ottawa, Ontario, Canada.

Essex Region Conservation Authority. 2015. Essex Region Source Protection Area: updated assessment report. Essex Region Conservation Authority, Essex, Ontario, Canada. Accessed 10 July 2020. https://essexregionconservation.ca/wp-content/uploads/2018/04/chapter-2-watershed-characterization.pdf.

Haag, W.R. 2012. North American Freshwater Mussels: Natural History, Ecology and Conservation. Cambridge University Press, Cambridge, United Kingdom. https://doi.org/10.1017/CBO9781139048217

Haag, W.R., and M.L. Warren. 2007. Freshwater mussel assemblage structure in a regulated river in the Lower Mississippi River Alluvial Basin, USA. Aquatic Conservation: Marine and Freshwater Ecosystems 17: 25–36. https://doi.org/10.1002/aqc.773

Hoffman J.R, T.J. Morris, and D.T. Zanatta. 2018. Genetic evidence for canal-mediated dispersal of Mapleleaf, *Quadrula quadrula* (Bivalvia: Unionidae) on the Niagara Peninsula, Canada. Freshwater Science 37: 82–95. https://doi.org/10.1086/696127

Lopes-Lima, M., L.E. Burlakova, A.Y. Karatayev, K. Mehler, M. Seddon, and R. Sousa. 2018. Conservation of freshwater bivalves at the global scale: diversity, threats and research needs. Hydrobiologia 810: 1–14. https://doi.org/10.1007/s10750-017-3486-7

Mackie, G.L. 1991. Biology of the exotic zebra mussel *Dreissena polymorpha* in relation to native bivalves and its potential impact in Lake St Clair. Hydrobiologia 219: 251–268. https://doi.org/10.1007/BF00024759

McNichols-O'Rourke, K.A., A. Robinson, and T.J. Morris. 2012. Summary of freshwater mussel timed search surveys in southwestern Ontario in 2010 and 2011. Manuscript report 3009. Fisheries and Aquatic Sciences, Fisheries and Oceans Canada, Ottawa, Ontario, Canada. Accessed 28 April 2020. https://waves-vagues.dfo-mpo.gc.ca/Library/349416.pdf.

Metcalfe-Smith, J.L., J. Di Maio, S.K. Staton, and G.L. Mackie. 2000. Effect of sampling effort on the efficiency of the timed search method for sampling freshwater mussel communities. Journal of the North American Benthological Society 19: 725–732. https://doi.org/10.2307/1468129

Morris, T.J., and J. Di Maio. 1998–1999. Current distributions of freshwater mussels (Bivalvia: Unionidae) in rivers of southwestern Ontario. Malacological Review 31/32: 9–17.

Nalepa, T.F., and J.M. Gauvin. 1988. Distribution, abundance, and biomass of freshwater mussels (Bivalvia: Unionidae) in Lake St. Clair. Journal of Great Lakes Research 14: 411–419.

Nalepa, T.F., D.J. Hartson, G.W. Gostenik, D.L. Fanslow, and G.A. Lang. 1996. Changes in the freshwater mussel community of Lake St. Clair: from Unionidae to *Dreissena polymorpha* in eight years. Journal of Great

Lakes Research 22: 354–369. https://doi.org/10.1016/S0 380-1330(96)70961-9

National Native Mussel Conservation Committee. 1998. National strategy for the conservation of native freshwater mussels. Journal of Shellfish Research 17: 1419–1428.

Nichols, S.J., and J. Amberg. 1999. Co-existence of zebra mussels and freshwater unionids: population dynamics of *Leptodea fragilis* in a coastal wetland infested with zebra mussels. Canadian Journal of Zoology 77: 423–432. https://doi.org/10.1139/z98-241

Ricciardi, A., R.J. Neves, and J.B. Rasmussen. 1998. Impending extinctions of North American freshwater mussels (Unionoida) following the zebra mussel (*Dreissena polymorpha*) invasion. Journal of Animal Ecology 67: 613–619. https://doi.org/10.1046/j.1365-2656.1998.00220.x

RStudio Team. 2016. RStudio: Integrated Development Environment for R. RStudio, Inc. Boston, Massachusetts, USA.

SARA (*Species at Risk Act*) Registry. 2019a. Species profile: Mapleleaf (*Quadrula quadrula*), Great Lakes – Upper St. Lawrence population. Government of Canada. Accessed 9 July 2020. https://species-registry.canada.ca/index-en.html#/species/933-640.

SARA (*Species at Risk Act*) Registry. 2019b. Species profile: Lilliput (*Toxolasma parvum*). Government of Canada. Accessed 9 July 2020. https://species-registry. canada.ca/index-en.html#/species/1236-901.

Schloesser, D.W., W.P. Kovalak, G.D. Longton, K.L. Ohnesorg, and R.D. Smithee. 1998. Impact of Zebra and Quagga Mussels (*Dreissena* spp.) on freshwater unionids (Bivalvia: Unionidae) in the Detroit River of the Great Lakes. American Midland Naturalist 140: 299–313.

Schloesser, D.W., J.L. Metcalfe-Smith, W.P. Kovalak, G.D. Longton, and R.D. Smithee. 2006. Extirpation of freshwater mussels (Bivalvia: Unionidae) following the invasion of Dreissenid Mussels in an interconnecting river of the Laurentian Great Lakes. American Midland Naturalist 155: 307–320. https://doi.org/10.1674/0003-0031(2006)155[307:eofmbu]2.0.co;2

Schloesser, D.W., and T.F. Nalepa. 1994. Dramatic decline of unionid bivalves in offshore waters of western Lake Erie after infestation by the Zebra Mussel, *Dreissena polymorpha*. Canadian Journal of Fisheries and Aquatic Science 51: 2234–2242. https://doi.org/10.1139/f94-226

Stanfield, L. 2010. Ontario stream assessment protocol. Version 8. Fisheries Policy Section. Ontario Ministry of Natural Resources. Peterborough, Ontario, Canada. Accessed 7 May 2020. https://docs.ontario.ca/documents/2575/226871.pdf.

Williams, J.D., M.L. Warren, Jr., K.S. Cummings, J.L. Harris, and R.J. Neves. 1993. Conservation status of the freshwater mussels of the United States and Canada. Fisheries 18: 6–22. https://doi.org/10.1577/1548-8446 (1993)018<0006:csofmo>2.0.co;2

Wright, K.A., K.A. McNichols-O'Rourke, and T.J. Morris. 2020. Timed-search surveys of freshwater mussels in coastal wetland and riverine sites in lakes Ontario, Erie, and St. Clair in 2015. Manuscript report 3192. Fisheries and Aquatic Sciences, Fisheries and Oceans Canada, Ottawa, Ontario, Canada. Accessed 27 April 2020. https://waves-vagues.dfo-mpo.gc.ca/Library/40862793.pdf.

Wright, K.A., K.A. McNichols-O'Rourke, M.N. Sheldon, and T.J. Morris. 2017. Freshwater mussel surveys of the Welland River watershed: 2014–16. Manuscript report 3115. Fisheries and Aquatic Sciences, Fisheries and Oceans Canada, Ottawa, Ontario, Canada. Accessed 10 July 2020. https://waves-vagues.dfo-mpo.gc.ca/Library/40624857.pdf.

Zanatta, D.T., J.M. Bossenbroek, L.E. Burlakova, T.D. Crail, F. de Szalay, T.A. Griffith, D. Kapusinski, A.Y. Karateyev, R.A. Krebs, E.S. Meyer, W.L. Paterson, T.J. Prescott, M.T. Rowe, D.W. Schloesser, and M.C. Walsh. 2015. Distribution of native mussel (Unionidae) assemblages in coastal Lake Erie, Lake St. Clair, and connecting channels, twenty-five years after the dreissenid invasion. Northeastern Naturalist 22: 223–235. https://doi.org/10.1656/045.022.0115

Zanatta, D.T., G.L. Mackie, J.L. Metcalfe-Smith, and D.A. Woolnough. 2002. A refuge for native freshwater mussels (Bivalvia: Unionidae) from the impacts of the exotic Zebra Mussel (*Dreissena polymorpha*) in Lake St. Clair. Journal of Great Lakes Research 28: 479–489. https://doi.org/10.1016/S0380-1330(02)70599-6

SUPPLEMENTARY MATERIAL:

Digital Voucher Specimens.

FIGURE S1. White Heelsplitter (*Lasmigona complanata*). Photos: Fisheries and Oceans Canada.

FIGURE S2. Fragile Papershell (*Leptodea fragilis*). Photos: Fisheries and Oceans Canada.

FIGURE S3. Pink Heelsplitter (*Potamilus alatus*). Photos: Fisheries and Oceans Canada.

FIGURE S4. Giant Floater (*Pyganodon grandis*). Photos: Fisheries and Oceans Canada.

FIGURE S5. Mapleleaf (*Quadrula quadrula*). Photos: Fisheries and Oceans Canada.

FIGURE S6. Lilliput (*Toxolasma parvum*). Photos: Fisheries and Oceans Canada.

FIGURE S7. Deertoe (*Truncilla truncata*). Photos: Fisheries and Oceans Canada.

FIGURE S8. Paper Pondshell (*Utterbackia imbecillis*). Photos: Fisheries and Oceans Canada.

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.
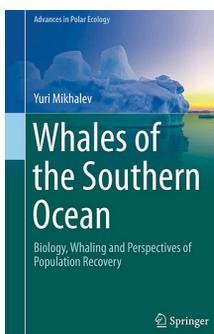
BIOLOGY

Whales of the Southern Ocean: Biology, Whaling and Perspectives of Population Recovery. Advances in Polar Ecology Volume 5

By Yuri Mikhalev. 2020. Springer Nature. 382 pages, 179.99 USD, Cloth, 139.00 USD, E-book.

Whales of the world, particularly large baleen whales, have been the target of human exploitation for millennia. Indigenous peoples around the world have targetted whales for subsistence hunts for thousands of years, but these hunts are typically sustainable, simply because the populations of hunters are relatively small and the whales often stay far offshore out of the reach of hunters in small boats. However, over the past several centuries, whale hunts became commercialized, and this led to vast over-exploitation and the near extinction of many populations of whales in every ocean of the world, including the ice-covered polar seas. Large whaling ships would embark on long expeditions, and would track whales even in some of the most hard to reach stretches of ocean. In the latter years of whaling (i.e., within the past century), tens of thousands of whales were harvested every year by commercial whalers. Most commercial whaling has ceased, following the huge efforts of scientists and conservationists involved in the International Whaling Commission. However, the effect of commercial whaling is still felt in all the world's oceans, and it is possible that many populations of whales will never fully recover.

Whales of the Southern Ocean fits within this context. Author Yuri Mikhalev is a Russian scientist who led part of Russia's science mission during whaling expeditions in the Southern Ocean. He uses his vast knowledge of Russian whaling operations in the Southern Ocean to provide a relatively detailed overview of the history of whaling, particularly from the lens of Russian whalers. The author then goes on to use data that he collected on the biology of whales in the Southern Ocean based on whales harvested by Russian whalers, and examines trends in length-weight relationships, growth laws, reproductive biology, and the spatial distribution of different whales species from the Southern Ocean. The amount of data available from whaling operations is vast, and many of the details presented in this book could be very useful for whale biologists. In the final chapter, the author discusses the ecology of different species of whales and their potential for recovery following the cessation of commercial whaling.

Overall, *Whales of the Southern Ocean* is full of very interesting information, but it would be quite dense for non-specialists. Multiple chapters are quite data-heavy, and are definitely written for a specialist audience. This book would be a very good resource for whale biologists, particularly for those who study whales in the Southern Ocean. However, I'm not sure that the audience extends far beyond this specialized group.

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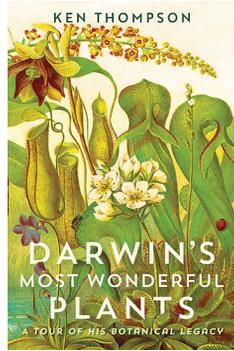
BOTANY

Darwin's Most Wonderful Plants: A Tour of His Botanical Legacy

By Ken Thompson. 2019. University of Chicago Press. 256 pages, 25.00 USD, Cloth.

Within the last two decades, several books have been published that focus on single aspects of Charles Darwin's life. Examples include his eldest daughter (Keynes 2002), his barnacle research (Stott 2003), and his work on coral reefs (Dobbs 2005). Author Ken Thompson continues this trend by exploring in detail Darwin's work with plants in *Darwin's Most Wonderful Plants: A Tour of His Botanical Legacy*. Darwin is, of course, most famously known for his book *The Origin of Species* (Darwin 1859) and many people are likely unaware that he spent many years late in his life studying plants. Thompson succeeds in shedding some light on this often-overlooked part of Darwin's life.

The book is divided into five chapters, with each chapter covering one or more of Darwin's plant books. Chapters 1 (Room at the Top), 2 (Slow Learners), and 3 (The Biter Bite) discuss, respectively, Darwin's books titled *On the Movement and Habits of Climbing Plants* (1865), *The Power of Movement in Plants* (1880), and *Insectivorous Plants* (1875). Chapter 4 (Sex and the Single Plant) encompasses three books: *On the Various Contrivances by which British and Foreign Orchids are Fertilised by Insects, and on the Good Effects of Intercrossing* (1862); *The Effects of Cross and Self-fertilisation in the Vegetable Kingdom* (1876); and *The Different Forms of Flowers on Plants of the Same Species* (1877). Finally, Chapter 5 (The Mysteries of the Cabbage Patch) discusses *The Variation of Animals and Plants Under Domestication* (1868). The book also includes these additional sections: Afterword, Sources, Photo Credits, Thanks, and Index.

The author thoroughly covers each of Darwin's plant books with clarity and intrigue. Darwin studied plants late in life, well after his publication of *The Origin of Species* (Darwin 1859), at Down House, where he had green houses and garden plots to set up experiments and leisurely observe plant behaviour with the help of his staff, children, and grandchildren. Darwin also had plant specimens sent to him and continued his massive correspondence effort to glean information from botanical experts to learn all he could about plants and plant behaviour, especially from his botanist friend Sir Joseph Dalton Hooker,

then the director at the Royal Botanic Gardens, Kew, United Kingdom.

Thompson brings the reader interesting tidbits from Darwin's work as well as modern discoveries in the same vein. For example, in relating Darwin's work with plant carnivory, the author describes a plant in the genus *Philcoxia* with sticky underground leaves that traps and consumes nematodes, a process that was unheard of in Darwin's time (p. 155; see Pereira *et al*. 2012). Thompson seems to continue where Darwin leaves off. In the same spirit of Darwin, he highlights material that Darwin would have been thrilled to observe and study himself, and relates discoveries made years later to Darwin's original observations.

In Chapter 4, Thompson recounts an observation made by Darwin in the 1860s that was not confirmed for over 100 years. Hooker was able to provide Darwin with numerous orchids to occupy his "hothouse" at Down House to facilitate Darwin's further experimentation and observation. One such unique orchid was *Angraecum sesquipedale* from Madagascar. Darwin wrote,

> A green, whip-like nectary of astonishing length hangs down beneath the labellum. In several flowers sent me by Mr. Bateman I found the nectaries eleven and a half inches long, with only the lower inch and a half filled with nectar. What can be the use, it may be asked, of a nectary of such disproportionate length? (p. 162)

Darwin loved these sorts of questions, and he predicted that a moth with a long proboscis would be the likely pollinator. Indeed, 40 years later, the predicted pollinator, the hawkmoth *Xanthopan morganii* var. *praedicta*, was discovered in Madagascar, but a demonstration of the pollination event was not observed until 1997 (p. 164; see Arditti *et al*. 2012).

Thompson's brief discussion regarding Gregor Mendel (Augustinian friar whose work on plants led him to be described as the "Father of Modern Genetics") and Charles Darwin is well worth the read (pp. 211–213). Darwin and Mendel were working at the same time but never met. Darwin was unaware of Mendel's pea experiments; however, Mendel might have been aware of Darwin's work but never made the connection. Darwin was rumoured to have had a copy of Mendel's famous pea paper (Mendel 1865), but the paper remained "uncut" and was never read. Alas, this account appears to be an urban myth, as no copy of the pea paper was found in Darwin's library.

Nonetheless, evolution and genetics would have had a different history had these two great minds connected. See Johnson (2012) and Clark (2017) for additional details on this fascinating story.

Thompson's book, *Darwin's Most Wonderful Plants*, is a must read for anyone interested in Darwin's botanical work, or in the many facets of Darwin's life. Sir Joseph Hooker's words describing Darwin's botanical work provide a lovely summary:

> Darwin still works away at his experiments and his theory, and startles us by the surprising discoveries he now makes in botany; his work on the fertilisation of orchids is quite unique— there is nothing in the whole range of botanical literature to compare with it, and this, with his other works … raise him without doubt to the position of the first naturalist in Europe, indeed I question if he will not be regarded as great as any that ever lived; his powers of observation, memory and judgement seem prodigious, his industry indefatigable and his sagacity in planning experiments, fertility of resources and care in conducting them are unrivalled. (p. 167)

Thompson's work highlights an aspect of Darwin's life that is not as well-known as his evolutionary foundations but brings to light the idea that Darwin's simple musings about the natural world have set in motion entire scientific disciplines tackled today by modern researchers. Charles Darwin was ahead of his time in many areas of scientific thought, and we continue to learn new insights about his life every day.

Note: all of Darwin's written work can be found at http://darwin-online.org.uk/majorworks.html and correspondence at http://www.darwinproject.ac.uk.

Literature Cited

Arditti, J., J. Elliott, I. Kitching, and L. Wasserthal. 2012. 'Good Heavens what insect can suck it'– Charles Darwin, *Angraecum sesquipedale* and *Xanthopan morganii praedicta*. Botanical Journal of the Linnean Society 169: 403–432.

Clark, H.O., Jr. 2017. [Book Review] The Quotable Darwin. Sonoran Herpetologist 30: 81.

Darwin, C. 1859. On the Origin of Species by Means of Natural Selection, or, The Preservation of Favoured Races in the Struggle for Life. John Murray, London, United Kingdom.

Dobbs, D. 2005. Reef Madness: Charles Darwin, Alexander Agassiz, and the Meaning of Coral. Pantheon, New York, New York, USA.

Johnson, P. 2012. Darwin: Portrait of a Genius. Penguin Books, London, United Kingdom.

Keynes, R. 2002. Annie's Box: Charles Darwin, His Daughter and Human Evolution. Fourth Estate, London, United Kingdom.

Mendel, G. 1865. Versuche über Pflanzen-Hybriden. Verhandlungen des Naturforschenden Vereins zu Brunn (Ahhandlungen) 4: 3–47.

Pereira, C.G., D.P. Almenara, C.E. Winter, P.W. Fritsch, H. Lambers, and R.S. Oliveira. 2012. Underground leaves of *Philcoxia* trap and digest nematodes. Proceedings of the National Academy of Sciences 109: 1154–1158.

Stott, R. 2003. Darwin and the Barnacle: the Story of One Tiny Creature and History's Most Spectacular Scientific Breakthrough. W.W. Norton & Company, Inc., New York, New York, USA.

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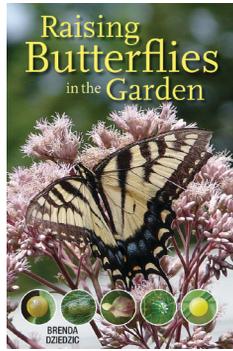
ENTOMOLOGY

Raising Butterflies in the Garden

By Brenda Dziedzic. 2019. Firefly Books. 334 pages, 24.95 CAD, Paper.

When author Brenda Dziedzic noticed there were fewer butterflies around her than when she was younger, she immersed herself in learning about their life histories. Dziedzic is an Advanced Master Gardener, a member of several butterfly associations, and passionate about creating habitats in our yards to benefit pollinator species.

The book begins by concisely describing the differences between butterflies and moths and details their life cycles, anatomies, and taxonomy. For readers planning their own butterfly garden, section two delivers a helpful list of tips that are essential for successful butterfly gardens. Advice ranges from the more obvious (no pesticides, shelter from wind, planting arrangement for viewing, use native plants) to the more specialized, such as providing a place for the butterflies to puddle and stones to sun on. Most interesting of all, I learned that planting species in groups of three or more makes them easier for butterflies to find your garden. Dziedzic clearly has a wealth of gardening knowledge.

Section three deals with raising butterflies and moths indoors. As a biologist, I am reluctant to advocate the removal of anything from its natural habitat to raise indoors, unless it is already in harm's way or for an educational purpose. In light of recent research documenting how indoor-reared Monarch butterflies could not properly migrate (Tenger-Trolander *et al.* 2019), I am wary of this practice. While Dziedic does a wonderful job explaining how to care for butterflies indoors, especially the importance of sanitization to ensure parasite and disease transmission does not occur, she skims over the 'why'. A discussion of conservation and education would be helpful here, especially as the purpose of the book is to create gardens that allow butterflies space to grow in their natural habitat through all parts of their life cycle.

The remainder of the book is a field guide to 40 of the most commonly seen butterflies and moths of North America, with pictures of each species at every stage of the life cycle: egg, caterpillar, chrysalis, and adult. The photos are clear, informative, and stunning, and mostly taken by Dziedzic herself. Her attention to detail is meticulous, and many photos contained a ruler to show relative size. There were even several pictures documenting the transition from pre-chrysalis to emergence, a process many of us never see.

Each butterfly profile also includes a range map and lists of host plants for both the caterpillar and adult life cycle stages. In the introduction, Dziedic writes about the importance of using native species, which can be found through your local plant nursery by using the Latin names. As this is not a regionally-specific book, I appreciate that the Latin name was included for caterpillar host plants, but they are not included for butterfly host plants. The inclusion of the Latin name is useful for finding these species in a seed catalogue or a local plant nursery as species often have multiple common names. Although Dziedic mentions Butterfly Bush (*Buddleia davidii*) at the beginning of her book with a warning of its invasive potential, it is still listed as a host plant. It is important that gardeners do their own research of host plants when planning their gardens. If the reader is new to gardening and the selection of native species, they could accidentally plant species that are invasive to their region if they do not read the preface. This section was helpful for learning which native plant species would host the most pollinators in my garden. However, the book would have benefitted from having separate sections for eastern, western, and southern species. The book's two indices, one for host plants and one for butterfly and moth species, allow readers to easily look up both butterflies and plants that they are interested in while planning their own gardens.

In the section on butterfly pests, Gypsy Moth (*Lymantria dispar dispar*) was mentioned as an invasive species to avoid. However, I was surprised that Cabbage White Butterfly (*Pieris brassicae*), native to Europe and damaging to crops, was not. This would be helpful to know if you are trying to grow any of their host plants, including broccoli, cabbage, cauliflower, or radish, in your vegetable garden.

I recommend this book to people who would like to learn more about butterflies and are looking for a go-to guide for identification at all life stages. The photography makes this a fantastic book to identify what you are seeing outside or to simply learn more about each species. It is a great first book for readers interested in planning pollinator gardens, a launching pad for further exploration into local flora and fauna.

Literature Cited

Tenger-Trolander, A., W. Lu, M. Noyes, and M.R.

Kronforst. 2019. Contemporary loss of migration in monarch butterflies. Proceedings of the National Academy of Sciences 116: 14671–14676. https://doi.org/10.1073/pnas.1904690116

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Herpetology

Secrets of Snakes: The Science Beyond the Myths. W.L. Moody, Jr., Natural History Series

By David A. Steen. 2019. Texas A&M Press. 184 pages and 103 colour photos, 25.00 USD, Flexbound. Also available as an E-book.

Snakes are one of the few groups of animals that commonly elicit fear in a high percentage of people. Fear of snakes has led to much misinformation about them, including many long-held beliefs (or myths) about snake biology and behaviour. The author of *Secrets of Snakes*, David Steen, has studied snakes for many years, and is also a well-known science communicator. Steen is frequently asked questions on the many myths about snakes, particularly in the United States, and decided to write this book to answer some of the most common questions and to dispel these myths. The myths that venomous snakes can be identified by the triangular shape of their head, venomous coral snakes can be identified based on one specific colour pattern, and cottonmouths will chase people are just some of those that Steen takes on in this book. Spoiler alert: these three myths, along with many others in the book, are false. However, Steen does a great job of explaining why these myths are false while simultaneously educating the reader about these species.
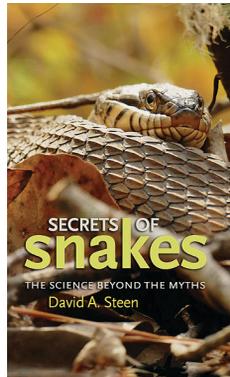
As an ecologist who studied snakes for my Ph.D. research, and as an avid naturalist who has continued to appreciate snakes, I found *Secrets of Snakes* a pleasure to read. Steen's writing style is easy to read, and he kept me interested throughout the book with various stories from the field and anecdotes from research on the various topics. However, the myths that Steen addresses are mostly focussed on species that occur in the United States and not in Canada. For example, cottonmouths and copperheads do not occur in Canada, but are the main focus of many of the chapters. For this reason, I would not recommend this book to the average Canadian naturalist, simply because the myths about snakes that Steen addresses are too regionally specific and do not involve species or myths that most Canadians would come across. I would, however, wholeheartedly recommend this book to naturalists interested in snakes or any naturalists interested in exploring the fauna of the United States.

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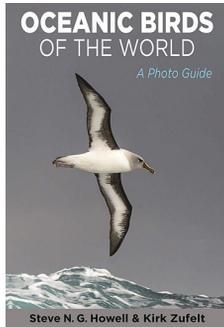University of Victoria, Victoria, BC, Canada

ORNITHOLOGY

Oceanic Birds of the World: A Photo Guide

By Steve N.G. Howell and Kirk Zufelt. 2019. Princeton University Press. 359 pages, 106 maps, and 2200 colour photos, 35.00 USD, Cloth.

Seabird-watching is a distinctive sub-genre of birding. Those who indulge must either suffer the discomforts of long hours on some wind and rain-swept headland, staring out to sea, or the threat of seasickness in a small wave-tossed boat. We commoners can only dream of having a royal yacht for our seabirding platform, as Prince Philip did back in the day when the Crown still owned *Britannia* (H.R.H. Duke of Edinburgh, *Birds from Britannia*, 1962).

Uncomfortable as the pursuit of seabirds may be, it has many exponents, and none so dedicated as the authors of this book. I seldom reach for superlatives, but I think the word monumental would not be out of place for this amazing collection of seabird photographs, covering not only every species and plumage, but a variety of angles and poses for each. The Wandering Albatross (*Diomedea exulans* complex), for example, here treated as five 'species' (Snowy, Gough, Gibson's, Antipodes, and Amsterdam), is illustrated by ten plates comprising no less than 92 individual pictures, covering every conceivable age and morph of a species that changes plumage through six cycles. The sheer complexity is daunting and the fact that these peripatetic birds may overlap throughout the southern oceans means that identifications to species outside of their segregated breeding islands can be extremely challenging.

The importance of the word "Oceanic" in the title needs to be stressed. This is a book to identify birds seen far offshore: strictly coastal species, such as cormorants, most gulls, and many terns are not included. This is a slight drawback for those watching birds in inshore waters because, while this tome is ideal for identifying shearwaters and petrels, there are many species that you may see on the continental shelf for which you will need a standard field guide. So this is not a one-stop shop for those going to watch birds at sea. Moreover, the authors assume that the only way to see oceanic birds away from their breeding sites is by going out on a boat, thus ignoring the noble activity of seawatching (called seawatching because you mostly just see the sea) performed from many headlands in Europe and North America and where many of the species featured in this book appear regularly.

I was happy to read in the section How to Use this Book: "It is realistic ... to accept that many birds at sea get away as unidentified, and that quite a few species (such as cryptic storm-petrel taxa) are not known to be safely identifiable in the field"; and "In some cases it is better to describe distribution by habitat and region rather than to imply false precision with maps" (pp. 8–9). Not everyone recognises such limitations but even the best observers, perhaps especially the best observers, understand the limitations of current knowledge of oceanic birds. Many views, especially of 'difficult' species, such as Short-tailed and Sooty Shearwater (*Ardenna grisea, Ardenna tenuirostris*), must be filed as genus species.

I had a few reservations. The provision of maps is not comprehensive: only two genera of auks, one gull, and five terns qualify and there are no maps for phalaropes. There is no obvious reason for the exclusions. Moreover, quite a few tern pictures show birds perched on the ground or on water—hardly ever seen when you are offshore. These are just quibbles, though. The text is delightfully brief and to the point and the illustrations, many of which combine photos of similar species on the same background, mimicking the colour plates of a more typical field guide, are fantastic. Anyone who plans to seawatch or take a pelagic birding trip needs this guide.

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OTHER

A Sand County Almanac and Sketches Here and There

By Aldo Leopold. Introduction by Barbara Kingsolver. 2020. Oxford University Press. 240 pages, 15.95 CAD, Paper. Originally published in 1949.

Aldo Leopold's seminal work, *A Sand County Almanac and Sketches Here and There*, is 70 years old this year. In that time, it has become a landmark in popular ecological literature, ranked alongside Rachel Carson's *Silent Spring*. Yet despite its broad relevance and large impact, the book begins with a narrow focus and a small scale. In the first section, Leopold details chronologically by month (hence, *Almanac*) examples of his own experiences of nature in rural Wisconsin. Through these stories, Leopold portrays nature not only in isolation, or in simple juxtaposition to humans, but in a web of diverse and complex interactions between humans and (the rest of) nature. This is a beautifully written book about nature's raw wonder, but it is equally about nature's give and take in a world increasingly shaped by humans.
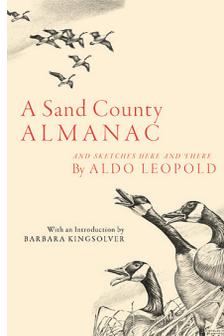
Leopold builds on the foundation of tangible local experience to pursue the book's greater ambition: exposing the common human failure to engage with the natural environment, and the loss that ensues. His description of the draba plant could be a metaphor for all of nature in the Anthropocene: "it subsists on the leavings of unwanted time and space", relegated to surviving on the margins of what human society deems to matter, straddling a fine line between being taken for granted and extinction (p. 24).

Yet equally central to Leopold's account is the wild's will to persist in the face of the tame, and the opportunity for awe that this contrast offers the observant human. Throughout the book, Leopold suggests that to struggle in contemplating the grandeur of nature is no more nor less than to be human. In this same struggle lies the potential for insights that stretch the human mind and spirit: an opportunity to be entertained, to be inspired, and to encounter and contemplate the truly unknown.

The second portion of the book, *Sketches Here and There*, features a series of chapters detailing Leopold's experiences in various parts of North America. These verbal vignettes are less detailed and methodical than the *Almanac* but maintain its rhetorical style, recounting eloquently yet accessibly a set of diverse and dynamic interactions between humans and nature, which to Leopold represent cause for both hope and concern. The third and final section of the book crystallizes these feelings into conclusions about the place of nature in contemporary culture and implications for land management, producing the 'land ethic' for which Leopold became famous.

On the whole, this book has aged well and still rings true. Indeed, the modern reader may gloss over the truth that on several important ideas, Leopold was ahead of his time. His speculations on the complex relationships of wolves, deer, and mountains foreshadow the ecological conceptualization some 20 years later of keystone species and the ensuing reintroduction of wolves to Yellowstone National Park and elsewhere. He questions whether natural richness is adequately considered in calculations of wealth and poverty—"Do economists know about lupines?"—decades before Robert F. Kennedy challenged the premise of Gross National Product or Gro Harlem Brundtland popularized the notion of sustainable development (p. 96).

While many concepts in the book will be familiar, some of the language and facts will likely not. Leopold frequently uses colloquial or archaic terms, which in general are more pleasing than problematic, e.g. bluebill for scaup, teeter-snipe for Spotted Sandpiper. The writing is movingly dated in other ways too. In this book, Passenger Pigeon exists in living memories as well as museums; an offhand reference to Imperial Woodpecker stands out because the bird is since believed to have gone extinct. To journey with Leopold is to journey in time as well as in place.

To guide the reader in this journey, Leopold's essays, accompanied by the original illustrations of Charles W. Schwartz, are collected in this edition with an introduction by modern novelist Barbara Kingsolver, who deftly places the book within the frame of today's environmental movement and crisis. Politicization and polarization are making the communication of ecological imperatives more challenging than ever. Kingsolver is right to suggest that Leopold's effective telling of nature's stories in clear, neutral, loving language is a contribution of perennial value.

These writings were and remain an ecological call to action in the face of a natural world under threat. Yet this is not a work of desperation. To the contrary, Leopold is doubly hopeful: of humans' ability

to acknowledge and conserve nature, and of nature's resilience when given a chance. This book is fundamentally a celebration of the human potential, when nurtured, to notice nature, and of the miraculous experiences possible for those who do. To anyone who has wondered at the natural world, or who cares about retaining the option, it is well worth reading.

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NEW TITLES

Prepared by Barry Cottam

Please note: Only books marked † or * have been received from publishers. All other titles are listed as books of potential interest to subscribers. Please send notice of new books—or copies for review—to the Book Review Editor.

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BIOLOGY

Eco-Evolutionary Dynamics. By Andrew P. Hendry. 2020. Princeton University Press. 416 pages, 45.00 USD, Paper. Cloth and E-book editions published in 2016.

One of Us: A Biologist's Walk Among Bears. By Barrie K. Gilbert. Edited by Kaylene Johnson-Sullivan. Illustrations by Shea Wyatt. 2019. FriesenPress. 264 pages, 33.99 USD, Cloth, 14.99 USD, Paper, 6.99 USD, E-book.

Urban Evolutionary Biology. Edited by Marta Szulkin, Jason Munshi-South, and Anne Charmantier. 2020. Oxford University Press. 320 pages, 100.00 CAD, Cloth, 49.95 CAD, Paper. Also available as an E-book.

BOTANY

Amber Waves: The Extraordinary Biography of Wheat, from Wild Grass to World Megacrop. By Catherine Zabinski. 2020. University of Chicago Press. 216 pages, 24.00 USD, Cloth or E-book.

Aquatic Dicotyledons of North America: Ecology, Life History, and Systematics. By Donald H. Les. 2017. CRC Press. 1334 pages, 275.00 USD, Cloth, 247.50 USD, E-book, and **Aquatic Monocotyledons of North America: Ecology, Life History, and Systematics**. By Donald H. Les. 2020. CRC Press. 556 pages, 260.00 USD, Cloth, 234.00 USD, E-book. Available together as **Aquatic Plants of North America: Ecology, Life History and Systematics**. By Donald H. Les. 2020. CRC Press. 2030 pages, 450.00 USD, Cloth.

Entangled Life: How Fungi Make Our Worlds, Change Our Minds and Shape Our Futures. By Merlin Sheldrake. 2020. Random House. 368 pages, 28.00 USD, Cloth. Also available as an E-book.

A History of Plants in 50 Fossils. By Paul Kenrick. 2020. CSIRO Publishing. 160 pages, 34.99 AUD, Cloth.

The Journeys of Trees: A Story about Forests, People, and the Future. By Zach St. George. 2020. W.W. Norton. 256 pages, 26.95 USD, Cloth.

Moss from Forest to Garden: A Guide to the Hidden World of Moss. By Ulrica Nordström. 2019. Countryman Press. 192 pages, 26.95 USD, Cloth.

Where the Slime Mould Creeps. Third Edition. By Sarah Lloyd. Forewords by Ann Jones and Gael Vizard. 2020. Tympanocryptis Press. 122 pages and colour plates, 21.99 GBP, Paper.

CLIMATE CHANGE AND CONSERVATION

Apocalypse Never: Why Environmental Alarmism Hurts Us All. By Michael Shellenberger. 2020. HarperCollins. 432 pages, 29.99 USD, Cloth, 14.99 USD, E-book.

Brave New Arctic: The Untold Story of the Melting North. By Mark C. Serreze. 2018. Princeton University Press. 264 pages, 24.95 USD, Cloth, 272 pages, 17.95 USD, Paper.

Can We Save the Planet? A Primer for the 21st Century. By Alice Bell. 2020. Thames & Hudson. 144 pages, 18.95 USD, Paper.

Climate Change and Infectious Fish Diseases. Edited by Patrick T.K. Woo, Jo-Ann Leong, and Kurt Buchmann. 2020. CABI. 552 pages, 235.00 USD, Cloth.

Dangerous Earth: What We Wish We Knew About Volcanoes, Hurricanes, Climate Change, Earthquakes, and More. By Ellen Prager. 2020. University of Chicago Press. 272 pages, 25.00 USD, Cloth, 18.00 USD, E-book.

Drivers of Landscape Change in the Northwest Boreal Region. Edited by Carl Markon, Amanda L. Sesser, Aimee P. Rockhill, Dawn R. Magness, Don Reid, John Delapp, Phil Burton, Eric Schroff, and Valerie Barber. 2020. University of Alaska Press. 225 pages, 29.95 USD, Cloth, 24.95 USD, E-book.

The Garden Jungle: or Gardening to Save the Planet. By David Goulson. 2019. Jonathan Cape. 288 pages, 35.99 CAD, Cloth.

*Grassroots Stewardship: Sustainability Within Our Reach. By F. Stuart Chapin, III. 2020. Oxford University Press. 240 pages, 34.95 USD, Cloth. Also available as an E-book.

The Hidden Life of Ice: Dispatches from a Disappearing World. By Marco Tedesco with Alberto Flores d'Arcais. Foreword by Elizabeth Kolbert. 2020. The Experiment. 160 pages, 19.95 USD / 25.95 CAD, Cloth.

Planetary Health: Protecting Nature to Protect Ourselves. By Samuel Myers and Howard Frumkin. 2020. Island Press. 536 pages, 39.00 USD, Paper or E-book.

The Selfish Ape: Human Nature and Our Path to Extinction. By Nicholas P. Money. 2019. Reaktion Books. 152 pages, 20.00 USD, Cloth. E-book forthcoming.

Trees and Global Warming: The Role of Forests in Cooling and Warming the Atmosphere. By William J. Manning. 2020. Cambridge University Press. 338 pages, Cambridge Core. 74.95 CAD, Cloth, 52.00 USD, Adobe E-book. https://doi.org/10.1017/9781108635370

Vacant to Vibrant: Creating Successful Green Infrastructure Networks. By Sandra Albro. 2019. Island Press. 200 pages, 25.00 USD, Paper or E-book.

ENTOMOLOGY

Aliens Among Us: Extraordinary Portraits of Ordinary Bugs. By Daniel Kariko. 2020. Liveright. 160 pages, 20.00 USD, Cloth.

Chasing Dragonflies: A Natural, Cultural, and Personal History. By Cindy Crosby. Illustrations by Peggy Macnamara. 2020. Northwestern University Press. 248 pages, 24.95 USD, Paper or E-book.

Desert Navigator: The Journey of an Ant. By Rüdiger Wehner. 2020. Belknap Press. 400 pages, 18 colour photos, and 153 colour illustrations, 59.95 USD, Cloth.

The Future Role of Dwarf Honey Bees in Natural and Agricultural Systems. By D.P. Abrol. 2020. CRC Press. 322 pages, 150.00 USD, Cloth, 57.95 CAD, E-book.

*The Inside Out of Flies. By Erica McAlister. 2020. Firefly Books and London Natural History Museum. 288 pages, 24.95 CAD, Cloth.

The Language of Butterflies: How Thieves, Hoarders, Scientists, and Other Obsessives Unlocked the Secrets of the World's Favorite Insect. By Wendy Williams. 2020. Simon & Schuster. 256 pages, 26.00 USD, Cloth, 13.99 USD, E-book.

The Pocket Book of Insect Anatomy. By Marianne Taylor. 2020. Bloomsbury Wildlife. 224 pages and

250 colour photos and illustrations, 15.99 GBP, Paper, 8.95 GBP, E-book.

HERPETOLOGY

Key to the Herpetofauna of the Continental United States and Canada. Third Edition. By Robert Powell, Joseph T. Collins, and Errol D. Hooper, Jr. 2019. University Press of Kansas. 184 pages, 19.95 USD, Paper.

RSPB Spotlight: Snakes. By Jules Howard. 2020. Bloomsbury Wildlife. 18.00 USD, 128 pages and 200 colour photos, Paper, 14.40 USD, E-book.

ORNITHOLOGY

All the Birds of the World. Handbook of the Birds of the World (HBW) Series. Edited by Josep Del Hoyo. 2020. Lynx Edicions. 968 pages, 20 865 illustrations, and 11 558 colour distribution maps, 85.00 EUR, Cloth.

Bird Migration. By Ian Newton. 2020. William Collins. 608 pages, 21.99 CAD, Paper.

Bird Senses: How and What Birds See, Hear, Smell, Taste and Feel. By Graham R. Martin. 2020. Pelagic Publishing. 270 pages, 51.80 CAD, Paper.

Gyrfalcon: The One Who Stays All Winter. By Norman Barichello. 2020. FriesenPress. 184 pages, 36.49 USD, Paper, 8.99 USD, E-book.

Invasive Birds: Global Trends and Impacts. Edited by Colleen T. Downs and Lorinda A. Hart. 2020. CABI. 384 pages, 190.00 USD, Cloth.

Monograph of the Pheasants. By Alain Hennache and Michel Ottaviani. Translated by Philippe B. Wilson and Geoffrey Davison. 2020. World Pheasant Association. 455 pages, 150 colour photos, and 19 distribution maps, 60.00 GBP + Packaging & Postage, Cloth. Order from office@pheasant.org.uk.

Multimedia Identification Guide to North Atlantic Seabirds: Shearwaters: Jouanin's & White-Chinned Petrels. By Bob Flood and Ashley Fisher. Illustrated by John Gale. 2020. Scilly Pelagics. 439 pages, 550+ colour photos, 150+ colour illustrations, and colour distribution maps, USB memory stick, 40.00 GBP.

Owls of the Eastern Ice: The Quest to Find and Save the World's Largest Owl. By Jonathan C. Slaght. 2020. Allen Lane. 368 pages, 20.00 GBP, Cloth or E-book.

Raptor Prey Remains: A Guide to Identifying What's Been Eaten by a Bird of Prey. By Ed Drewitt. 2020. Pelagic Publishing. 256 pages and 750+ colour photographs, 43.15 CAD, Paper.

Understanding Bird Behavior: An Illustrated Guide to What Birds Do and Why. By Wenfei Tong. Foreword by Ben C. Sheldon. 2020. Princeton University Press. 224 pages, 27.95 USD, Cloth. Also available as an E-book.

ZOOLOGY

The Book of Eels: Their Lives, Secrets and Myths. By Tom Fort. 2020. William Collins (Harper Collins imprint). 368 pages, 18.99 CAD, Paper.

The Bowhead Whale *Balaena mysticetus*: Biology and Human Interactions. Edited by J.C. George and J.G.M. Thewissen. 2020. Academic Press. 516 pages, 120.00 USD, Cloth.

*The Cougar Conundrum: Sharing the World with a Successful Predator. By Mark Elbroch. 2020. Island Press. 280 pages, 30.00 USD, Paper or E-book.

Curious Creatures on Our Shores. By Chris Thorogood. 2019. Bodleian Library in association with the Oxford University Museum of Natural History. 128 pages and 50 colour illustrations, 15.00 GBP, Cloth.

Great Adaptations: Star-Nosed Moles, Electric Eels, and Other Tales of Evolution's Mysteries Solved. By Kenneth Catania. 2020. Princeton University Press. 240 pages, 27.95 USD, Cloth. Also available as an E-book.

Jellyfish. By Peter Williams. 2020. Reaktion Books. 224 pages, 19.95 USD, Paper. E-book forthcoming.

Mole. By Steve Gronert Ellerhof. 2020. Reaktion Books. 240 pages, 19.95 USD, Paper. E-book forthcoming.

Monarchs of the Sea: The Extraordinary 500-Million-Year History of Cephalopods. By Danna Staaf. 2020. The Experiment. 256 pages, 15.95 USD / 21.00 CAD, Paper.

On the Prowl: In Search of Big Cat Origins. By Mark Hallett and John M. Harris. Illustrated by Mark Hallett. 2020. Columbia University Press. 272 pages, 35.00 USD, Cloth or E-book.

OTHER

*Chasing Nature: An Ecologist's Lifetime of Adventures and Observations. By Robert E. Wrigley. Illustrated by Rob Gillespie. 2020. FriesenPress. 367 pages, 67.49 CAD, Cloth, 53.99 CAD, Paper, 20.99 CAD, E-book. Signed premium copies available from the author (robertwrigley@mymts.net) for 55.00 CAD, Paper, + 17.00 CAD, shipping.

A Dominant Character: The Radical Science and Restless Politics of J.B.S. Haldane. By Samanth Subramanian. 2020. W.W. Norton. 400 pages, 40.00 USD, Cloth.

Genesis: The Deep Origin of Societies. By Edward O. Wilson. 2020. Liveright. 160 pages, 15.95 USD, Paper.

The Great Naturalists. By Robert Huxley. 2019. Thames & Hudson. 272 pages, 16.95 USD, Paper.

*Horizon. By Barry Lopez. 2019. Vintage Canada. 592 pages, 21.00 CAD, Paper, 13.99 CAD, E-book.

The Multifarious Mr. Banks: From Botany Bay to Kew, The Natural Historian Who Shaped the World. By Toby Musgrave. 2020. Yale University Press. 386 pages, 35.00 USD, Cloth.

The Oceans: A Deep History. By Eelco J. Rohling. 2020. Princeton University Press. 272 pages, 18.95 USD, Paper.

Planting the World: Joseph Banks and his Collectors: An Adventurous History of Botany. By Jordan Goodman. 2020. William Collins (Harper Collins imprint). 560 pages, 36.99 CAD, Cloth, 14.99 CAD, E-book.

Practical Field Ecology: A Project Guide. Second Edition. By Charles Philip Wheater, Penny A. Cook, and James R. Bell. 2020. Wiley-Blackwell. 464 pages, 72.00 CAD, Paper, 57.99 CAD, E-book.

Science and the Production of Ignorance: When the Quest for Knowledge Is Thwarted. Edited by Janet Kourany and Martin Carrier. 2020. MIT Press. 328 pages, 45.00 USD, Paper.

The Scientific Method: An Evolution of Thinking from Darwin to Dewey. By Henry M. Cowles. 2020. Harvard University Press. 384 pages, 35.00 USD, Cloth.

Surroundings: A History of Environments and Environmentalisms. By Etienne S. Benson. 2020. University of Chicago Press. 296 pages, 82.50 USD, Cloth, 27.50 USD, Paper. Also available as an E-book.

River Master: John Wesley Powell's Legendary Exploration of the Colorado River and Grand Canyon. By Cecil Kuhne. 2020. Countryman Press. 288 pages, 16.95 USD, Paper.

The Wicked Problem of Forest Policy: A Multidisciplinary Approach to Sustainability in Forest Landscapes. Edited by William Nikolakis and John L. Innes. 2020. Cambridge University Press. 410 pages, 97.95 CAD, Cloth. https://doi.org/10.1017/9781108684439

News and Comment

Compiled by Amanda E. Martin

Upcoming Meetings and Workshops

Canadian Herpetological Society Conference and Annual General Meeting

The Canadian Herpetological Society Conference and Annual General Meeting to be held as an online meeting 11–13 September 2020. Registration for this event is free but limited to Society members. More information is available at http://canadianherpetology.ca/conf/index.html.

American Fisheries Society Annual Meeting

The annual meeting of the American Fisheries Society to be held as an online meeting 14–25 September 2020. Registration is currently open. More information is available at https://afsannualmeeting.fisheries.org/.

Student Conference on Conservation Science-New York

The Student Conference on Conservation Science-New York to be held as on online meeting 7–9 October 2020. Registration is currently open. More information is available at https://www.amnh.org/research/center-for-biodiversity-conservation/convening-and-connecting/sccs-ny.

Entomological Society of Ontario Video Presentations 2020

The 157th annual conference of the Entomological Society of Ontario will be replaced by a series of five minute lightning talks contributed by students, early-career researchers, and others. These presentations will be uploaded to the ESO YouTube channel for viewing. More information is available at https://www.entsocont.ca/agm-2020.html.

Entomology 2020

The annual meeting of the Entomological Society of America to be held as an online meeting 11–25 November 2020. The theme of the conference is: 'Entomology for All'. Registration is currently open. More information is available at https://www.entsoc.org/events/annual-meeting.

Editors' Report for Volume 133 (2019)

Several changes to the look of *The Canadian Field-Naturalist* began with volume 133. Coloured text was added to the front cover as was the by-line "Promoting the study and conservation of northern biodiversity since 1880" which used to appear on the first page of each volume. The official symbol of the Ottawa Field-Naturalists' Club (OFNC) also was added to the front cover as was a banner to the first page of each manuscript and journal section. Subtle typographic changes adjusted spacing between letters, words, sections, and in tables. All the major changes were vetted and approved by the OFNC Publications Committee and were made possible by Robert Forsyth joining the production team as the graphic designer responsible for layout. We did however bid good-bye to our long-standing layout typographer, Wendy Cotie, who provided many years of service, initially starting at Gilmore Printers with volume 117, issue 2, in 2003.

Mailing dates for the four issues in volume 133 were: 15 October 2019, 5 December 2019, 24 March 2020, and 9 June 2020; online posting dates were 21 September, 18 November, 29 February, and 9 May, respectively. Summaries of the distribution of paid subscribers to *The Canadian Field-Naturalist* for 2019 are shown in Table 1, and are compared to volume 132. This list does not include free copies distributed to Honorary OFNC members or online access, which is included in OFNC membership dues. Institutional subscribers potentially represent many thousands of users. The total number of paid subscribers decreased by one.

The number of articles published in volume 133 decreased by three relative to the number published in volume 132 while the number of notes increased by three, resulting in the same number of manuscripts published both years ($n = 45$; Table 2). Not surprisingly, there were 20 fewer manuscripts published on amphibians and reptiles in 133, given the first two issues of 132 were Special Issues: Studies on Canadian Amphibians and Reptiles in Honour of Dr. Francis Cook. The single manuscript in the "other" category (Table 2) was on lichens. The number of book reviews and new titles published in volume 133 were slightly down and up, respectively, over the numbers in volume 132 (Table 3). The total number of pages published decreased by 35 for volume 133 over volume 132 (Table 4) with articles contributing less to both the page count (59% in 133 versus 69% in volume 132) and number of manuscripts published (69% versus 76%, respectively; Table 2). There were no Thematic Collections (editor-selected compilations of previously published contributions in both *The Canadian Field-Naturalist* and the regional OFNC publication, *Trail & Landscape*, on a central theme with internet links to each article) nor additional articles on Greatest Canadian Field Naturalists, the latter of which were included in News and Comment in volume 131. There was one Tribute, for Rudolph (Rudy) Frank Stocek.

Only 47 manuscripts were submitted to *The Canadian Field-Naturalist* in 2019, down from the 65 in 2018, which was eight more than submitted in 2017. One was not assigned to an *Associate Editor* because it was not suitable for publication in *The Canadian Field-Naturalist* and was the only manuscript submitted not using the Online Journal System. Only three of the 47 submitted manuscripts were not accepted for publication upon initial submission or review or were

TABLE 1. The 2019 (2018) circulation of *The Canadian Field-Naturalist*. Compiled by Eleanor Zurbrigg from the subscription list for 133(4). This list does not include copies distributed to Honorary Members or online access which is included in OFNC membership dues.

Subscriber Type	Canada	USA	Other	Total
OFNC Members	39 (43)	2 (1)	(0)	41 (44)
Subscriptions:				
Individual	29 (26)	9 (7)	0 (0)	38 (33)
Institutional	66 (66)	88 (90)	11 (12)	165 (168)
Total	134 (135)	99 (98)	11 (12)	244 (245)

TABLE 2. Number of research articles and notes published in *The Canadian Field-Naturalist*, volume 133 (volume 132), by major field of study.

Subject	Articles	Notes	Total
Mammals	9 (3)	5 (0)	14 (3)
Birds	7 (3)	2 (2)	9 (5)
Amphibians and Reptiles	3 (19)	2 (6)	5 (25)
Fishes	3 (0)	0 (1)	3 (1)
Plants	4 (4)	1 (1)	5 (5)
Insects	0 (1)	1 (0)	1 (1)
Non-insect invertebrates	4 (1)	3 (1)	7 (2)
Other	1 (3)	0 (0)	1 (3)
Total	31 (34)	14 (11)	45 (45)

TABLE 3. Number of reviews and new titles published in the Book Review section of *The Canadian Field-Naturalist*, volume 133 (volume 132), by topic.

	Reviews	New Titles
Zoology	20 (26)	138 (148)
Botany	5 (7)	24 (24)
Miscellaneous	12 (9)	153 (122)
Total	37 (42)	315 (294)

insufficiently revised to warrant publication. One was declined but a suitable revision resubmitted; another two were withdrawn by the authors, one of which underwent an initial review and suggestion for revision by an *Associate Editor*. The remainder, 85% ($n = 40$), were accepted or are undergoing revision and review.

In 2018 and 2017, 83 % and 90%, respectively, of the submissions were accepted for publication and either published or underwent further revision and review.

Dwayne Lepitzki, *Editor-in-Chief*, initially reviewed the appropriateness of a submission and assigned an *Associate Editor* (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. Amanda Martin, the *Assistant Editor*, 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. Ken Young sent page charge invoices to authors and tracked the budget while Eleanor Zurbrigg managing subscriptions and mailed printed copies. William Halliday provided digital content to subscribers, posted tables of contents, abstracts, and pdfs on *The Canadian Field-Naturalist* website, and prepared the Index. Our *Associate Editors* managed manuscripts, provided reviews and recommendations, and guided authors through the revisions process. Dave

TABLE 4. Number of pages per section published in *The Canadian Field-Naturalist*, volume 133 (132), by issue.

	Issue				Total
	1	2	3	4	
Editorials/Editors' Report	0 (3)*	0 (4)*	3 (3)	0 (0)	3 (10)
Articles	54 (51)	47 (86)	71 (74)	69 (94)	241 (305)
Notes	11 (12)	24 (2)	10 (11)	11 (12)	56 (37)
Thematic Collections	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Tributes	0 (0)	0 (0)	6 (0)	0 (0)	6 (0)
Book Reviews and New Titles	18 (18)	15 (18)	18 (18)	17 (8)	68 (62)
News and Comment†	4 (2)	2 (2)	4 (2)	1 (2)	11 (8)
Reports‡	12 (12)	0 (0)	0 (0)	0 (0)	12 (12)
Erratum	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Blank page§	1 (0)	0 (0)	0 (0)	0 (0)	1 (0)
Index	– (–)	– (–)	– (–)	9 (8)	9 (8)
Total	100 (98)	88 (112)	112 (108)	107 (124)	407 (442)

*Includes introductions to Special Issue Parts I and II in volume 132.
†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 132.
§Necessary to begin each issue with an odd numbered page.

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. We are indebted to our very dedicated team.

The following *Associate Editors* managed, assessed, and reviewed manuscripts published in volume 133: C. Callaghan, Canadian Wildlife Federation, Ottawa ON (2 manuscripts); P.M. Catling, Agriculture and Agri-Food Canada, retired, Ottawa ON (6); F. Chapleau, University of Ottawa, Ottawa ON (3); J. Foote, Algoma University, Sault St. Marie ON (8); G. Forbes, University of New Brunswick, Fredericton NB (4); W. Halliday, Wildlife Conservation Society Canada, Whitehorse YT and University of Victoria, Victoria BC (7); T. Jung, Yukon Government, Whitehorse YT (1); D. Lepitzki, Banff AB (2); D.F. McAlpine, New Brunswick Museum, Saint John NB (4); G. Mowat, Government of British Columbia, Nelson BC (4); M. Obbard, Ontario Ministry of Natural Resources and Forestry, retired, Peterborough ON (1); J.M. Saarela, Canadian Museum of Nature, Ottawa ON (2); J. Skevington, Agriculture and Agri-food Canada, Ottawa ON (1).

As with many other journals, *Associate Editors* are at times having difficulty finding suitable reviewers; without dedicated *Associate Editors* 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 133 (number of manuscripts reviewed >1 in parentheses): John Acorn, University of Alberta; Noel Alfonso, Canadian Museum of Nature; Jesse Alston, University of Wyoming; Shannon Barber-Meyer, US Geological Survey; Brian Barnes, University of Alaska; René Belland, University of Alberta; David Benson, Marian University; John Benson, University of Nebraska; Jeff Bowman, Ontario Ministry of Natural Resources and Forestry; Diane Boyd, Montana Department of Fish & Wildlife; Sean Boyle, Laurentian University; Susan Carbyn, Agriculture and Agri-food Canada; Jonathan Choquette, Wildlife Preservation Canada; Dean Cluff, Government of Northwest Territories; Jeff Copeland, The Wolverine Foundation; Greg Corace, Seney National Wildlife Refuge; Garret Crow, Calvin College; Rob Dillon, Freshwater Gastropods of North America; Jennifer Doubt, Canadian Museum of Nature; Amanda Edworthy, Washington State University; Bruce Ford, University of Manitoba; Robert Forsyth, Kamloops BC; Doug Heard, University of Northern British Columbia; Katie Gale, Fisheries and Oceans Canada; David Gammon, Elon University; Daniel Gibson, Virginia Tech; Cody Gilbertson, State University of New York; Claire Goodwin, University of New Brunswick; William Halliday, Wildlife Conservation Society Canada and University of Victoria; Doug Heard, University of Northern British Columbia; Andy Horn, Dalhousie University; Amanda Hund, University of Connecticut; Tara Imlay, Canadian Wildlife Service; Tom Jung, Yukon Department of Environment; Andrea Kortello, Grylloblatta Ecological Consulting; Gerald Kuzyk, British Columbia Ministry of Forests, Lands, Natural Resource Operations & Rural Development; Karl Larsen, Thompson Rivers University (2); David LeGros, Ontario Ministry of Natural Resources and Forestry (2); James Lendemer, New York Botanical Garden; Bill Leonard, Olympia WA; Zac Loughman, West Liberty University; Mark Mallory, Acadia University; Nicholas Mandrak, University of Toronto; Shelley Marshall, British Columbia Ministry of Forests, Lands, Natural Resource Operations & Rural Development; Donald McAlpine, New Brunswick Museum (2); Kevin McGraw, Arizona State University; Jonathan Mee, University of British Columbia; Richard Merizon, Alaska Department of Fish and Game; Jerod Merkle, University of Wyoming; Keith Munro, Ontario Federation of Anglers and Hunters; Laurie Murison, Grand Manan Whale and Seabird Research Station (2); Desiree Narango, University of Delaware; Michael Oldham, Ontario Natural Heritage Information Centre (4); Kristiina Ovaska, Biolinx Environmental Research Ltd.; Cynthia Paszkowski, University of Alberta (2); James Paterson, Trent University; Brent Patterson, Ontario Ministry of Natural Resources and Forestry (3); Mark Poesch, University of Alberta; Ray Poulin, Royal Saskatchewan Museum; Jim Pringle, Royal Botanical Gardens, Hamilton ON; Jennifer Provencher, Carleton University; Edward Raynor, University of Nebraska-Lincoln; Claude Renaud, Canadian Museum of Nature; Anton Reznicek, University of Michigan; Gregory Robertson, Environment and Climate Change Canada; Diana Robson, The Manitoba Museum; Fred Schueler, Fragile Inheritance Natural History; Casey Setash, Colorado State University; William Shear, Hampden-Sydney College; Mary Sollows, New Brunswick Museum; Alison Stodola, University of Illinois; Don Sutherland, Ontario Ministry of Natural Resources and Forestry; Gerald Tetreault, Canadian Centre for Inland Waters; Julie Thomas, Government of Yukon (2); Jared Towers, Bay Cetology; James Trager, Missouri Botanical Gardens; Tom Tyning, Berkshire Community College; Nina Vasilieva, Russian Academy of Sciences; Rich Weir, BC Ministry of Environment and Climate Change;

Book Reviews

News and Comment

Upcoming Meetings and Workshops

Mailing date of the previous issue 134(1): 12 August 2020