

Abundance and arboreal tendencies of slugs in forested wetlands of southwestern Nova Scotia, Canada

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Abstract

Non-native slugs, such as *Arion*, are becoming a concern for land managers in Nova Scotia, Canada, particularly in forested wetlands. They appear to have a highly diverse diet and may pose a particular risk to native slug species and to rare or at-risk lichens. We provide novel information on the distribution, abundance, arboreal tendencies, and seasonality of slugs in forested wetlands across southwestern Nova Scotia. We collected a total of 402 slugs representing seven species including two native species, Pale Mantleslug (*Pallifera dorsalis*) and Meadow Slug (*Deroceras laeve*), and five non-native *Arion* taxa. The three most abundantly caught taxa were Northern Dusky Arion (*Arion fuscus*), *D. laeve*, and Western Dusky Slug (*Arion subfuscus*). *Arion fuscus* and *D. laeve* were collected on the forest floor and on lichen-bearing trees, while *A. subfuscus* was collected only on the ground. All three taxa showed differences in collectability between July and September and low arboreal tendencies. We highlight that further studies are needed to better understand the biology and ecology of this largely neglected invertebrate group that seems to be dominated by non-native *Arion* species in the study region. Such information is crucial for conservationists and forest managers untangling the question of how non-native slugs affect native slug taxa and other groups including at-risk lichens.

Key words: *Arion fuscus*; biodiversity conservation; biological invasion; forested wetlands; slug community

Introduction

Gastropods are an ecologically important invertebrate group that constitute a considerable proportion of the forest floor biomass in northern forests (Hawkins *et al.* 1997; Jordan and Black 2012). They are important decomposers of forest litter, contributing directly to soil formation and nutrient recycling (Jennings and Barkham 1979; Oli and Gupta 2000; Meyer *et al.* 2013), and are important sources of food and calcium for several animal groups including invertebrates (Symondson *et al.* 2002) and birds and small mammals (Allen 2004). They also play a significant role in the dispersal of vascular plants (Lanta 2007), bryophytes (Boch *et al.* 2014), lichens (Boch *et al.* 2016), and even some small animals (Türke *et al.* 2018), mainly through endozoochory (i.e., dispersal of propagules via gut passage; McCarthy and Healy 1978; Boch *et al.* 2011). However, such roles may be significantly altered where non-native gastropods invade ecosystems (Buschmann *et al.* 2005; Holland *et al.* 2007; Strauss *et al.* 2009).

Biological invasions typically proceed in three steps: introduction, initial establishment, and subsequent spread (Robinson 1999; Suarez *et al.* 2001; Diez *et al.* 2008). Over any significant distance, such invasions are usually human-mediated (Hobbs 2000; Cowie and Robinson 2003; Ding *et al.* 2008; Capinha *et al.* 2015). Non-native slugs have become increasingly serious agricultural pests in most European countries where they are responsible for significant economic losses (Runham and Hunter 1970; Castillejo *et al.* 1996; Kozłowski 2012) and have serious negative impacts on natural biodiversity (Blattmann *et al.* 2013; Zemanova *et al.* 2018). Such effects are steadily becoming a worldwide problem. Since the arrival of Europeans in North America, several non-native slugs including a number of *Arion* species (Nekola 2014; Zemanova *et al.* 2018) have become distributed across the continent (even a coarse estimate of the number of taxa involved is difficult to determine because it depends upon varying interpretations of species complexes and cryptic taxa). Some

of these slugs have become a great concern for land managers (Hammond and Byers 2002; Hahn *et al.* 2011). In Nova Scotia, Canada, non-native slugs are generally thought to increase grazing pressure on rare and at-risk lichens such as the Endangered Atlantic population of Boreal Felt Lichen (*Erioderma pedicellatum*; Cameron 2009; COSEWIC 2014; SARA Registry 2021). However, the prevalence and severity of slug grazing on lichen communities have not been well documented in North America.

In general, slugs have not been widely studied in North America and most of what we assume about their biology and ecology has been extrapolated from studies of non-native slugs in European agricultural environments (South 1992). Indeed, the ecological functioning of non-native slugs in agricultural landscapes in Europe may not be similar to that seen in forested landscapes in Atlantic Canada. Our aim is to provide new information on the occurrence, distribution, relative abundance, arboreal tendencies, and seasonality of slug species across forested wetlands in southwestern Nova Scotia. Such information is crucial for helping conservationists and forest managers to better conserve native biodiversity in Atlantic Canada.

Methods

Study sites

Slugs were collected in eight mixed-wood forested wetland sites (intact stands ≥ 6 ha that had not been harvested for at least 100 years) in southwestern Nova Scotia (Figure 1). Overall, southwestern Nova Scotia has a humid temperate maritime climate with mean daily temperatures of -5.5°C in January and 18.5°C in July and with annual average precipitation of 1350 mm with $>80\%$ as rain (Environment Canada 2017). The area falls within the Acadian Forest Region, which is characterized by abundant Red Spruce (*Picea rubens* Sargent), Balsam Fir (*Abies balsamea* L.), Yellow Birch (*Betula alleghaniensis* Britton), and maple (*Acer* spp.) trees (Rowe 1972). However, our study sites, chosen specifically for their association with rare lichens, are instead dominated by Red Maple (*Acer rubrum* L.), Black Spruce (*Picea mariana* (Miller) Britton, Sterns & Poggenburgh), and Balsam Fir. Soils are poorly drained (remain wet all year) and support a dense cover of *Sphagnum* spp. and Cinnamon Fern (*Osmundastrum cinnamomeum* (L.) C. Presl). The study sites were chosen primarily

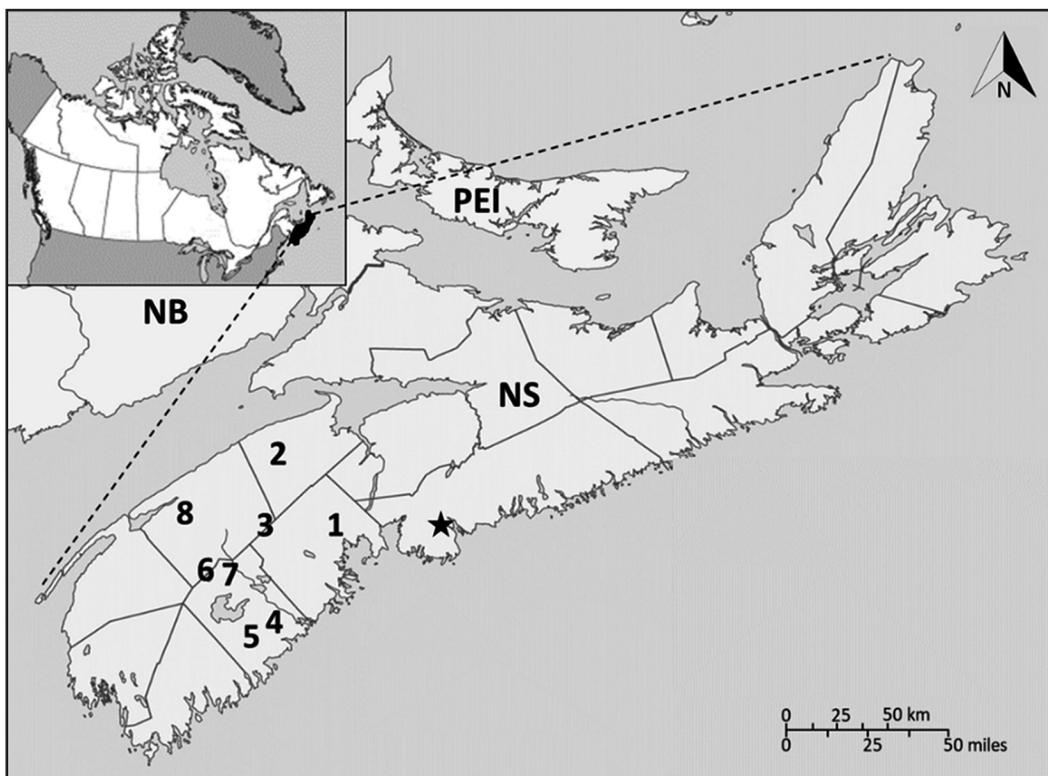


FIGURE 1. Location of slug study sites in Nova Scotia. The black star indicates Halifax. Sites are indicated by numbers. NS = Nova Scotia, NB = New Brunswick, PEI = Prince Edward Island.

for a long-term study on lichen community dynamics as they relate to logging and its interaction with slug grazing (S.H. and K.A.H. unpubl. data). Criteria for selecting study sites included: (a) presence of Red Maple and lowland-associated tree species in the canopy, according to provincial forest inventory data (Province of Nova Scotia 2021), (b) an intact forested portion of at least 6 ha, and (c) an estimated depth to water table of <0.5 m (Province of Nova Scotia 2007).

Slug surveys

Slugs were collected using pitfall traps. Initially we set out 224 traps in eight wetland forested sites. At each site, there were seven 5 × 50 m plots spaced 20 m apart with three tree traps (one trap per tree on canopy-height Red Maple; Figure 2) and one ground trap (1 m away from one of the trees) in each of the seven plots (8 sites × 7 plots × 4 traps = 224 traps). We had more tree traps than ground traps because we were more interested in potentially arboreal species, a requirement for grazing on epiphytic lichens. The efficacy of our tree pitfall traps was unknown compared with ground pitfall traps and cardboard sheet traps, which have been commonly used in previous studies of terrestrial slugs (e.g., Moss and Hermanutz 2010; Rodriguez-Cabal *et al.* 2015; Lucid *et al.* 2018; De Smedt *et al.* 2019). In addition to the initial 224 traps set out within the eight forested wetland study sites, we also placed one pitfall trap on the ground in an adjacent clearcut area to determine if additional species were present in the disturbed areas around these wetland forested sites.

All traps consisted of 100 ml plastic specimen jars (6 cm diameter openings), baited with ~20 ml of Budweiser beer (Anheuser-Busch, LLC [USA]/Labatt Brewing Company [Canada]). Pitfall traps on the ground were pressed into the duff layer and covered with a 30 × 20 cm cardboard sheet that acted as a protective roof. Slugs accessed the ground pitfall traps through a gap of at least 1.5 cm between the cardboard and the trap. Pitfall traps on trees were suspended from the rim of a wide hole in the bottom of a wooden box (15 × 15 × 20 cm) affixed to a tree trunk ~1.3 m above the ground (Figure 2). The inner side of each box was open to the tree trunk and positioned carefully so as to frame a targetted lichen thallus, most often Tree Lungwort (*Lobaria pulmonaria*). The outer side of the box swung open to allow collector access to the enclosed pitfall trap. A gap of 1.5 cm was provided between the inner edges of the wooden box and the bark of the tree to allow slugs to enter the box.

Trapping took place over two time periods in 2019: 11–29 July (19 days) and 23–27 September (five days). In July, the traps were typically emptied after nine days, allowing for two separate collecting

events during the 19-day collection period. In September, there was only a single collecting event lasting five consecutive days. Once collected, the specimens were preserved in 70% ethanol.

Slugs were identified to the lowest taxonomic level practical by J.E.M. using standard references including, but not limited to Chichester and Getz (1973), Davies (1977, 1979), De Wilde (1983), De Winter (1984), Backeljau and Marquet (1985), Backeljau and van Beeck (1986), Backeljau and de Bruyn (1988), Garrido *et al.* (1995), Pinceel *et al.* (2004), Skujienė (2004), Jordaens *et al.* (2006), Rowson *et al.* (2014a,b), and Gural-Sverlova and Gural (2015). It should be noted that slug taxonomy is still very much in a state of flux. In recent years, ongoing refinements in both morphological and molecular knowledge have contributed to increasingly defensible species descriptions and delineations. However, these same refinements have also contributed to the discovery of many new “cryptic species” (two or more species formerly “classified as a single nominal species because they are at least superficially morphologically indistinguishable” [Bickford *et al.* 2007: 149]), and “genetically-defined forms”, both of which are very difficult, if not impossible, to distinguish using traditional morphological methods.

All slugs resembling either “*Arion fuscus*” or “*Arion subfuscus*” were dissected and subsequently assigned to one of these two taxa on the basis of their distinct gonad morphologies (Garrido *et al.* 1995; Pinceel *et al.* 2004; Jordaens *et al.* 2006; Rowson *et al.* 2014b; Gural-Sverlova and Gural 2015). However, each of these two taxa has been found to include multiple cryptic forms (Pinceel *et al.* 2004, 2005a,b; Rowson *et al.* 2014a), so each should more properly be thought of as a “species complex” or a “species aggregate”. Gastropod voucher specimens have been deposited in the Natural History collections of the Nova Scotia Museum in Halifax, Canada (accession number N020-018).

Statistical analyses

We compared specimen counts between tree and ground traps from the forested wetlands using a Mann-Whitney *U*-test in the software PAST (Hammer *et al.* 2001). The Mann-Whitney *U*-test is a non-parametric alternative used to examine significant differences between two groups of single variables with no specific distribution (McKnight and Najab 2010). Although the total number of traps was initially 224, several traps were damaged or destroyed by wildlife in both months and on both substrates. Moreover, the number of sampling days varied among study sites and the number of traps varied between substrates (168 tree and 56 ground traps). Therefore, for a fair comparison between trap types across study sites we



FIGURE 2. A tree trap used to collect slugs on lichen trees in southwest Nova Scotia. A plastic jar baited with beer was placed in the bottom of the trap. The inner side of the box was open, against the tree trunk. The outer side of the box served as a door to retrieve collected slugs and to rebait the traps.

used the number of slugs per trap per sampling day (x):

$$x = \frac{y}{ji}$$

where for each site, y = number of slugs, j = number of days traps were baited, and i = number of traps. We included all active traps including intact traps with zero slugs, but damaged and inactive traps were excluded. The number of undamaged traps was 165 in July and 152 in September.

We also performed a Mann-Whitney U -test to compare the occurrence of slug species between forested wetlands and adjacent clearcuts. For this analysis, we used the number of slugs per trap per sampling day in both forest and clearcut habitats. Only ground traps were used in this analysis.

Results

We collected 315 slugs in the forested wetlands (Table 1) and 87 slugs in adjacent clearcut areas (Table 2), for a total of 402 slugs of seven species. Of these seven, only two, Pale Mantleslug (*Pallifera dorsalis*; Nearctic) and Meadow Slug (*Deroceras laeve*; Holarctic) are native to North America, whereas the other five species are non-native *Arion* species: Northern Dusky Arion (*Arion fuscus*), Western Dusky Slug (*Arion subfuscus*), Forest Arion (*Arion (Carinarion) cf. silvaticus*), Orange-banded Arion (*Arion (Carinarion) cf. fasciatus*), and Dark-face Arion (*Arion cf. distinctus*). (Note: common names from Turgeon *et al.* [1998] except for dusky slugs and Northern Dusky Arion from Rowson *et al.* [2014b].) Although the single specimen of *Arion (Carinarion) cf. fasciatus* and the two specimens of *Arion (Carinarion) cf. silvaticus*

were clearly members of the *Arion (Carinarion)* complex, they were in poor condition when examined and could therefore not be identified with certainty. The same should be noted for the single specimen of *Arion cf. distinctus*.

Arion fuscus was present in all eight forested wetland sites and was the most abundant taxon, representing half of all slugs collected. *Deroceras laeve* was also present in all forested wetland sites. However, *A. subfuscus* was present in only two forested wetland sites (Table 1) and in an additional adjacent clearcut (site 8; Table 2). Together, these three species represented the vast majority of slugs caught in both forested wetlands (Table 1) and adjacent clearcuts (Table 2). More *A. fuscus* and *A. subfuscus* were caught in July than in September in both forested wetland and adjacent clearcuts, whereas *D. laeve* showed the opposite pattern in forested wetlands, with more being caught in September than in July (Table 1). The exception was site 1 where 20 individuals were collected in July and only three were collected in September (Table 1). A total of six *D. laeve* were caught in adjacent clearcuts (Table 2). Of the two uncommon taxa, *A. cf. distinctus* was caught at a single forested wetland in July, while single *A. cf. silvaticus* were caught in both July and September in the same forested wetland site as was *A. cf. distinctus* (Table 1); neither species was caught in adjacent clearcuts (Table 2). Fifty-seven of the 66 individuals of *A. fuscus* and all individuals of *A. subfuscus*, *P. dorsalis*, and *A. cf. fasciatus* found in clearcuts were collected in July.

In forested wetlands, we recorded the native species *D. laeve* and the four non-native *Arion* species:

TABLE 1. Numbers for each species of slug caught at each of the eight forested wetland sites in July/September in southwest Nova Scotia. The number in each cell is total number of individuals per month for July/September, whereas the numbers in parenthesis are the total number of individuals collected per species summing all individuals collected in all the eight sites and in both months. Exact locations of the trapping sites are available upon request for approved users.

Slug species	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Total
<i>Arion cf. distinctus</i> (Mabille, 1868), Dark-face Arion	1/0	—	—	—	—	—	—	—	1/0 (1)
<i>Arion fuscus</i> (O.F. Müller, 1774), Northern Dusky Arion	16/6	9/2	3/0	2/0	6/5	32/5	33/10	1/6	102/34 (136)
<i>Arion subfuscus</i> (Draparnaud, 1805), Western Dusky Slug	78/4	—	—	—	—	—	—	0/1	78/5 (83)
<i>Arion (Carinarion) cf. fasciatus</i> (Nillson, 1823), Orange-banded Arion	—	—	—	—	—	—	—	—	—
<i>Arion (Carinarion) cf. silvaticus</i> Lohmander, 1837, Forest Arion	1/1	—	—	—	—	—	—	—	1/1 (2)
<i>Deroceras laeve</i> (O.F. Müller, 1774), Meadow Slug	20/3	0/2	0/2	0/1	1/12	6/18	1/10	2/15	30/63 (93)
<i>Pallifera dorsalis</i> (A. Binney, 1842), Pale Mantleslug	—	—	—	—	—	—	—	—	—
Total	130	13	5	3	24	61	54	25	315

TABLE 2. Numbers for each species of slug caught in adjacent clearcuts in July/September in southwest Nova Scotia. Similar to Table 1, the column “Total” is the total number of individuals per month July/September and the numbers in parenthesis are the total number of individuals collected in all the eight sites and in both months.

Slug species	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Total
<i>Arion</i> cf. <i>distinctus</i> (Mabille, 1868), Dark-face Arion	—	—	—	—	—	—	—	—	—
<i>Arion fuscus</i> (O.F. Müller, 1774), Northern Dusky Arion	—	11/4	3/0	—	4/1	7/0	1/0	31/4	57/9 (66)
<i>Arion subfuscus</i> (Draparnaud, 1805), Western Dusky Slug	5/0	—	—	—	—	1/0	—	5/0	11/0 (11)
<i>Arion</i> (<i>Carinarion</i>) cf. <i>fasciatus</i> (Nillson, 1823), Orange-banded Arion	—	—	—	—	—	—	—	1/0	1/0 (1)
<i>Arion</i> (<i>Carinarion</i>) cf. <i>silvaticus</i> Lohmander, 1837, Forest Arion	—	—	—	—	—	—	—	—	—
<i>Deroceras laeve</i> (O.F. Müller, 1774), Meadow Slug	1/0	1/0	—	—	0/1	1/0	1/0	0/1	4/2 (6)
<i>Pallifera dorsalis</i> (A. Binney, 1842), Pale Mantleslug	—	—	—	—	—	2/0	1/0	—	3/0 (3)
Total	6	16	3	0	6	11	3	42	87

A. fuscus, *A. subfuscus*, *A. (Carinarion) cf. silvaticus*, and *A. cf. distinctus*. *Arion fuscus* was the dominant species followed by, in order, *D. laeve* and *A. subfuscus*. *Arion fuscus*, *A. cf. silvaticus*, and *D. laeve* were caught on both the “tree” and the “ground” substrates. The abundance of *A. fuscus* was higher in ground traps (117 individuals) than in tree traps (19) with significant differences found between substrates (using the number of slugs per trap per sampling day) for July ($U = 7$; $P < 0.005$) and September ($U = 9$; $P < 0.004$; Table 3). *Deroceras laeve* was numerically more abundant in ground traps (81 individuals) than in tree traps (12), however significant differences between substrates were observed only in September ($U = 4$; $P < 0.001$; Table 3). *Arion subfuscus* and *A. cf. distinctus* were collected exclusively in ground traps.

In clearcuts, we collected a total of 87 slugs of five species: two native species *D. laeve* and *P. dorsalis*, and three non-native *Arion* species: *A. fuscus*, *A. subfuscus*, and *A. (Carinarion) cf. fasciatus* (Table 2). For *A. fuscus* (the only species that showed high abundance in both forested wetlands and adjacent clearcuts and which was, overall, the most numerous species caught), habitat comparisons were restricted to July because of very low capture rates in September. We did not find a significant difference in the abundance of *A. fuscus* between forested wetlands and adjacent clearcuts ($U = 23$; $P < 0.366$; ground traps only). We collected the most slugs and the most species of slugs in sites 1 and 8 (Tables 1 and 2).

Discussion

Understanding the life span and temporal cycles of reproduction is critical to making sense of the

biology and ecology of slugs. Of the seven slug taxa we recorded, the three species that were commonly caught (*A. fuscus*, *D. laeve*, and *A. subfuscus*) varied in the number of captures between July and September. More *A. fuscus* and *A. subfuscus* were caught in July, while more *D. laeve* were caught in September in seven of the eight study sites. The lower numbers of *A. subfuscus* caught in July supports the generally held view that *A. subfuscus* adults lay eggs during late summer or early fall and die soon afterwards. This slug has a life span of less than one year and overwinters either as eggs or as newly hatched young (Taylor 1907; Barnes and Weil 1945; Ord and Watts 1949; Bett 1960; Chichester and Getz 1973; Jennings and Barkham 1975; Bless 1977; Beyer and Saari 1978; Hutchinson *et al.* 2017). The lower numbers of *A. fuscus* in July suggests a life cycle generally similar to that of *A. subfuscus*. Unfortunately, there appear to be no published seasonal data for slugs identified as *A. fuscus*—a taxon long confused with *A. subfuscus*.

In contrast with *Arion* spp., *D. laeve* was more abundantly caught in September. However, it is difficult to infer a seasonal pattern for this species because it has a life span of less than one year (Faber *et al.* 2006; Mohamed and Ali 2011) and lays eggs continuously after maturity (Chichester and Getz 1973; Jordaens *et al.* 2006). All life stages of *D. laeve* can be found throughout the year, including winter, suggesting overlapping generations (Taylor 1907; Getz 1959; Quick 1960; Chichester and Getz 1973; Boag and Wishart 1982; Jordaens *et al.* 2006). Most *D. laeve* we caught in September were extremely small, indicating recent hatching. Approximately how many of these very small young slugs might have survived to

TABLE 3. Descriptive statistics for the three most abundantly caught species (Northern Dusky Arion [*Arion fuscus*], Meadow Slug [*Deroceras laeve*], and Western Dusky Slug [*Arion subfuscus*]) collected in the eight forested wetlands (adjacent clearcuts not included) in southwest Nova Scotia. We tested for significant differences in the number of slugs between tree and ground traps. Mann-Whitney values (*U*) and respective *P*-values are reported.

Slug species	Sampling month	# sites with detections	# traps with detections		% traps with detections per trap-day, mean \pm SD		Number of slugs		Statistical test
			Tree	Ground	Tree	Ground	Tree	Ground	
<i>A. fuscus</i>	July	8	6	24	3%	43%	0.02 \pm 0.03	0.24 \pm 0.26	<i>U</i> = 7; <i>P</i> < 0.005
	Sept	6	1	18	1%	32%	0.003 \pm 0.008	0.17 \pm 0.12	<i>U</i> = 9; <i>P</i> < 0.004
<i>D. laeve</i>	July	6	6	13	4%	23%	0.01 \pm 0.02	0.03 \pm 0.04	<i>U</i> = 36; <i>P</i> < 0.73
	Sept	8	4	22	2%	39%	0.01 \pm 0.08	0.26 \pm 0.22	<i>U</i> = 4; <i>P</i> < 0.001
<i>A. subfuscus</i>	July	3	0	8	0%	13%	0	0.07 \pm 0.21	Absent in tree traps
	Sept	2	0	4	0%	9%	0	0.03 \pm 0.06	

maturity is unknown, because survivorship curves for slugs are not well reported.

So far, we have treated *D. laeve* as a native species in North America; however, there is some uncertainty with it being native or non-native throughout the continent. Pilsbry (1948) suggested that the species originated in Eurasia and arrived in the Americas by two routes: once via Beringia during the Pleistocene i.e., native and once more recently via human transport across the Atlantic Ocean from Europe. Preliminary genetic analysis (Araiza-Gómez *et al.* 2017) has identified at least three, more or less discrete groups of *D. laeve*, concentrated primarily in the United Kingdom, Ireland and Switzerland, and North America including Mexico. Rumi *et al.* (2010) had earlier found *D. laeve* to be additionally present, supposedly as introductions, throughout the Americas and elsewhere. Given the number of slug species thought to have been introduced to eastern North America from Europe in post-Columbian times (Chichester and Getz 1969; Nekola 2014; Zemanova *et al.* 2018) it is possible that at least some Nova Scotian populations of *D. laeve* are of European origin. Consequently, *D. laeve* could be considered to be both native and introduced within our region. Whether or not such a reality might lead to different ecological impacts is unknown because we do not know of any detailed comparative studies of habitat preferences, food preferences, or feeding behaviour involving both eastern North American and European *D. laeve* populations.

Most *Arion* species are generalists that feed on a wide variety of items including litter, herbs, ferns, bryophytes, fungi, and lichens (Beyer and Saari 1977, 1978; Asplund and Gauslaa 2010; Boch *et al.* 2013, 2016), as well as animals such as worms and small

gastropods (Barker and Efford 2004). Some slug taxa, including *Arion* spp., have definite food preferences. For example, *A. subfuscus* and *D. laeve* have a significant preference for mushrooms (Chichester and Getz 1969, 1973; Beyer and Saari 1977; Maunder and Voitek 2010). The apparent preference of *A. fuscus*, *A. subfuscus*, and *D. laeve* for the forest floor may be associated with a high diversity of edible plants and fungi, coupled with a dense litter layer not available on trees. Dense understorey vegetation contributes to cool shade and abundant moisture, both of which can be particularly important for slugs that are highly susceptible to desiccation (Thompson *et al.* 2006; Nicolai and Ansart 2017), especially small immature individuals during hot summer days.

The history of *A. fuscus* in North America remains poorly known. It was first confirmed for the United States using molecular methods by Barr *et al.* (2009). L'Heureux (2016) and L'Heureux and Angers (2018) subsequently found it to be common in southern Quebec, Canada, and additionally reported the first Nova Scotia record from a single locality near Kempt in the southwestern part of that province. During the present study, we collected *A. fuscus* from eight additional localities in southwestern Nova Scotia, suggesting that it may be quite common in that region.

To our knowledge, our two specimens of *A. (C.) cf. silvaticus* represent the first likely records for Nova Scotia. However, additional sampling and better-preserved specimens are needed to confirm its presence. Although we did not record *P. dorsalis* within forested wetlands, we did find it in adjacent clearcuts.

Implications for biodiversity conservation

Non-native gastropods, such as *Arion* spp., can alter the structure and functioning of ecosystems and

may contribute to the loss of native species (Brown and Gurevitch 2004; Zettler *et al.* 2004), including native gastropods. In Nova Scotia, Davis and Browne (1996) suggested that *Arion* species restrict the occurrence of the native *P. dorsalis* to forest habitats, but evidence for this is scant and we found *P. dorsalis* ($n = 3$) only in the adjacent clearcuts. Competition between non-native and native slugs in North America may not be as strong as has generally been thought; native gastropods also appear to be less abundant in urban areas which are dominated by non-native species (P.M. Catling and B. Kostiuk unpubl. data). Paustian and Barbosa (2012) examined food and microhabitat preferences of Carolina Mantleslug (*Philomyces carolinianus*) and Changeable Mantleslug (*Megapallifera mutabilis*), both native to North America, as well as of the non-native slug *A. subfuscus* (possibly *A. fuscus*), in Maryland, United States. They found that although the overlap in food use was greater between *A. subfuscus* and *P. carolinianus* than between *P. carolinianus* and *M. mutabilis*, the overlap may have been low enough to keep competition to a minimum.

Because *Arion* species, including *A. fuscus* and *A. subfuscus*, are known lichenivorous grazers (Asplund and Gauslaa 2010; Asplund *et al.* 2010; Asplund 2011), their spread into southwestern Nova Scotia might be expected to increase grazing pressure on at-risk tree lichen species including *E. pedicellatum*. Given that we collected *A. subfuscus* only on the ground, and that *D. laeve* prefers mushrooms and we found more of them on the ground than in the tree traps, it seems likely that most of the grazing pressure on tree lichens in southwestern Nova Scotia is attributable to *A. fuscus*. Additionally, *A. fuscus* was recorded in all eight study sites and is much larger in size than *D. laeve* (adults of *A. fuscus* are around 50–70 mm in length while *D. laeve* are 15–25 mm long; Rowson *et al.* 2014b). In Quebec, L'Heureux and Angers (2018) also found *A. fuscus* to be the most abundant and widely distributed slug species. While Cameron (2009) found "*Arion subfuscus*" to be commonly recorded on *E. pedicellatum* thalli in mixed-wood forest remnants in central Nova Scotia, from his description, these slugs may well have been *A. fuscus*.

Due to limited mobility, non-native slugs probably use passive means to quickly colonize new sites. Forest roads are the main access for logging, monitoring, and management of forest resources but can also act as corridors that facilitate the introduction and dispersion of alien species by increasing human activities in previously inaccessible areas (Mortensen *et al.* 2009). Anthropogenic activities, such as clearcut harvesting, can also favour the colonization of non-native slugs including *Arion* species (Kappes 2006). This seems

to be the case for *A. fuscus*, which did not differ in abundance between forest and clearcut habitats. As the eight forested wetlands were adjacent to 2–5 year-old clearcuts, the non-native species, particularly *A. fuscus*, may have been spread by anthropogenic vectors such as off-highway vehicles and forest harvesting equipment then spread to the intact forest. Haughian and Harper (2018) surveyed lichens in our eight study sites and found a higher proportion of gastropod grazing on lichens near clearcut edges than in the forest interior. Despite this evidence, additional examinations of the prevalence, abundance, and effects of *Arion* species on native slugs and lichens in undisturbed habitat are needed.

We have provided novel information on the ecology of slugs in Nova Scotia. There did not seem to be anything special about sites 1 and 8, where we captured the highest diversity and numbers of slugs, except that the traps were open for more days at these two sites than at the other six. Additional studies in different habitats and at multiple spatial and temporal scales are needed to better understand patterns of seasonality, food and habitat preferences, and dispersal capacity of this neglected group. Such information will enable a better understanding of how environmental factors regulate interactions between slug species and between slugs and other taxa, such as lichens and fungi, which will aid conservationists and forest managers to conserve native biodiversity and minimize the spread of non-native species.

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