Relative abundance of pond snails in Turnbull National Wildlife Refuge, Washington, and the spread of an invasive snail

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ABSTRACT.—Freshwater gastropods comprise a diverse and highly imperiled taxonomic group that is threatened by anthropogenic factors including the introduction of nonnative species. We surveyed 10 wetland ponds in Turnbull National Wildlife Refuge to assess the possible expansion of the nonnative European ear snail (*Radix auricularia*) and to determine the genus richness and relative abundance of native gastropods. D-frame dip nets were used to sample gastropods at 4 locations in each pond. Six genera of gastropods were found, including *R. auricularia* in 6 ponds where it was not previously known. *Radix auricularia* is now the dominant genus in Middle Pine and Lower Pine Lakes, with relative abundances of 84.13% and 92.31%, respectively. Due to the high abundance and spread of *R. auricularia* in Turnbull National Wildlife Refuge, resource managers need to investigate the snail's impacts and implement strategies to reduce possible negative effects of this nonnative snail on native gastropods and other wildlife.

RESUMEN.—Los gasterópodos de agua dulce son taxones muy diversos que se encuentran amenazados por factores antropogénicos, estos incluyen la introducción de especies no nativas. Para determinar la posible expansión, así como la riqueza de género y la abundancia relativa de gasterópodos nativos, evaluamos la posible propagación del caracol europeo no nativo (*Radix auricularia*) en diez estanques, en el Refugio Nacional de Vida Silvestre Turnbull. Para muestrear gasterópodos en cuatro zonas de cada estanque, se usaron redes de inmersión con marco en forma D. Se encontraron seis géneros de gasterópodos, incluyendo *R. auricularia*, que fue encontrado en seis lagunas en las que anteriormente no se conocía que habitara. *Radix auricularia* es ahora el género dominante en los lagos Middle Pine y Lower Pine, con una abundancia relativa de 84.13% y de 92.31%, respectivamente. Debido a la alta abundancia y propagación de *R. auricularia* en el Refugio Nacional de Vida Silvestre Turnbull, los administradores de recursos necesitan investigar su impacto e implementar estrategias, para reducir el posible efecto negativo sobre los gasterópodos nativos y demás animales salvajes.

In North America over 70% of freshwater gastropods are listed as imperiled or presumed extinct (Lysne et al. 2008, Evans and Ray 2010). The main factors for reduced gastropod diversity are habitat loss, water pollution, and the introduction of invasive species (Lysne et al. 2008, Strong et al. 2008). The effects of invasive species on aquatic ecosystems are often irreversible and lead to reduced biodiversity due to predation on and competition with native species (Strayer 1999, Lysne et al. 2008). Invasive gastropods threaten the diversity of native gastropods by consuming large amounts of primary producer biomass (Riley et al. 2008, Strayer 2010) and altering ecosystem functions (Hall et al. 2003, Arango et al. 2009).

One nonnative gastropod for which we have only limited information about its effects in native ecosystems is the European ear snail (*Radix auricularia*). This nonnative gastropod is found in 22 of the 50 United States (Brown et al. 2008), including California, Idaho, Montana, Oregon, and Washington (Kipp et al. 2017). *Radix auricularia* is native to Eastern Europe and temperate Asia where it resides in slow-moving rivers and streams, ponds, lakes, and wetlands. This species has a wide tolerance for temperatures (4 °C to 32 °C) and specific electrical conductivities (200 to 1200 µS/cm; Spyra 2010, Vinarski and Serbina 2012, von Oheimb et al. 2016). In areas of Eastern Europe, *R. auricularia* has reached

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Fig. 1. Location of Turnbull National Wildlife Refuge in Washington State (inset) with the locations of the 10 wetland ponds surveyed in our study. All locations were in the public access area or in the Eastern Washington University Turnbull Laboratory for Ecological Studies area of the refuge. The symbols in parentheses indicate the dominant genus at each pond: *Gyrulus* sp. (G), *Lymnaea* sp. (L), *Physa* sp. (P), *Planorbella* sp. (Pl), *Radix auricularia* (R).

high population sizes, accounting for up to 54.4% of snail abundance and 23% of snail biomass (Vinarski and Serbina 2012). Additionally, Adam and Lewis (1992) have shown that in permanent lentic environments, *R. auricularia* can compete with native snails.

Because *R. auricularia* was known to reside in Middle Pine Lake in Turnbull National Wildlife Refuge (TNWR; Kipp et al. 2017), we conducted a survey of wetland ponds in the

refuge to determine the relative abundance and genus richness of native gastropods while also determining whether the nonnative European ear snail had expanded its range. We predicted that *R. auricularia* had expanded its range in the refuge and that it would be the dominant snail genera in some ponds.

We assessed gastropod relative abundance by dip-net sampling in wetland ponds in TNWR (47.4° N, 117.6° W), which is located 10 km south of Cheney, Washington (Fig. 1). We surveyed snails from 10 wetland ponds (areas with <3 m of water, high densities of macrophytes, and seasonal changes in surface area and volume) in the public access area or in the Eastern Washington University Turnbull Laboratory for Ecological Studies area of TNWR during May and June of 2012. Sampled ponds were dominated by large emergent macrophytes including cattails, grasses, and sedges. Wetland ponds experienced seasonal drying of the shoreline and reduction in surface area during the summer.

We sampled each pond at 4 sites that were separated by at least 100 m and located at each cardinal direction, resulting in a total of 4 samples for each pond surveyed. Using a D-frame dip net, we sampled each site in the first meter from the waterline and to a depth of 0.5 m. The D-frame dip net for sweep net sampling in wetlands has been shown to provide evenly distributed relative abundances, yield the most macroinvertebrate taxa, and have the lowest coefficient of variation between samples (Turner and Trexler 1997). Each site had a total of 3 min of sampling effort that was followed by shoreline cleaning of samples (using multiple buckets of filtered pond water to remove vegetation and mud) following methods of Prezant and Chapman (2004); however, a stack of sieves (including 500- μ m, 1.4-mm, and 2.8-mm sieves) were used instead of a single 5 mm sieve in order to retain smaller snails. Specimens were preserved in 70% ethanol before identification to genus using Brown (2001). We calculated relative abundance of each snail genus in each pond by dividing the total number of snails of one genus by the total number of snails in that pond.

We found 6 different genera of pulmonate snails from 3 families (Lymnaeidae, Physidae, and Planorbidae) with a mean genus richness of 4.4 per pond and a range of 2 to 6 genera in a pond (Table 1). We found 3 genera of

TABLE 1. Genus richness and relative abundance of snails surveyed from 10 wetland ponds on Turnbull National Wildlife Refuge, Washington. Collection date in 2012 for each pond is shown in parentheses next to the pond name. The bold number represents the relative abundance of the dominant genus for each pond.

Pond (sample date)	Snails (n)	Genus richness	Snail genus					
			<i>Gyraulus</i>	<i>Planorbella</i>	<i>Physa</i>	<i>Lymnaea</i>	<i>Fossaria</i>	<i>Radix</i>
Turnbull Lab (1 May)	898	5	41.1%	1.34%	31.2%	24.4%	2.0%	0.0%
Eagle (4 May)	2571	6	40.0%	0.16%	47.7%	11.9%	0.1%	0.3%
Crater (7 May)	621	4	86.5%	0.16%	7.6%	0.2%	0.0%	0.0%
Lower Finley (9 May)	621	6	65.2%	7.89%	4.7%	13.0%	7.1%	2.1%
30 Acre (16 May)	456	4	6.6%	0.0%	45.0%	48.1%	0.0%	0.4%
Kepple (18 May)	232	5	7.3%	20.3%	3.9%	56.5%	0.0%	12.1%
Blackhorse (21 May)	280	5	13.2%	9.6%	3.6%	72.9%	0.0%	0.7%
Wheeler (28 June)	511	4	41.3%	47.4%	0.2%	11.2%	0.0%	0.0%
Middle Pine (14 May)	397	5	0.0%	6.6%	6.8%	0.3%	2.3%	84.1%
Lower Pine (27 Jun)	13	2	0.0%	0.0%	7.7%	0.0%	0.0%	92.3%

TABLE 2. Comparison of 8 gastropod surveys showing the number of gastropod species and genera for aquatic ecosystems found throughout the Northern Hemisphere.

Location	Habitat	Number of species	Number of genera	Source
Northumberland, UK	52 ponds	14	12	Zealand and Jeffries 2009
Idaho, USA	4 high-elevation lakes	15	9	Lysne et al. 2011
Arkansas, USA	1 bayou drainage	13	12	Minton et al. 2008
Lake Michigan, USA	9 insular lakes	18	13	Harris et al. 2011
Michigan, USA	37 ponds	24	17	Hoverman et al. 2011
Idaho, USA	1 river/reservoir	11	10	Lysne and Clark 2009
Kaliningrad, Russia	3 coastal lakes/1 river	29	11	Filippenko 2011
Pennsylvania, USA	398 streams and springs	37	22	Evans and Ray 2010

Lymnaeidae (*Lymnaea*, *Radix*, and *Fossaria*), 1 genus of Physidae (*Physa*), and 2 genera of Planorbidae (*Gyraulus* and *Planorbella*) at different relative abundances in the 10 ponds surveyed (Table 1), with the dominant genus in each pond constituting over 40% of the relative abundance for that pond. The invasive snail *R. auricularia* was found in 7 ponds, with relative abundances between 0.3% in Eagle Pond and 92.3% in Lower Pine Lake (Table 1). We found that the dominant genus varied among ponds, with *R. auricularia* being the dominant genus at Middle Pine and Lower Pine Lakes (Table 1).

Our survey of gastropods at TNWR showed results that were similar to 2 studies of gastropods in Idaho. In a survey of 4 high-elevation lakes, Lysne et al. (2011) found 5 families and 9 genera of gastropods, which included all of the families and 5 of the 6 genera found at TNWR. Gastropods surveyed in a river and reservoir in southern Idaho showed the same pattern, with all 3 families and 5 genera in common with those found at TNWR (Lysne and Clark 2009). *Radix auricularia* was found

in both of the surveys conducted in Idaho (Lysne and Clark 2009, Lysne et al. 2011).

Gastropod genus richness in TNWR appears to be lower than in other ecosystems. In 8 gastropod surveys, genus richness ranged from 9 to 22 (Table 2), whereas only 6 genera were found in TNWR. Possible explanations for the low genus richness at TNWR include pond surface area (Hrabik et al. 2005, Harris et al. 2011, Hoverman et al. 2011), pH (Dillon 2000, Harris et al. 2011, Hoverman et al. 2011), conductivity (Dillon 2000, Hrabik et al. 2005, Harris et al. 2011), predator presence and abundance (Brönmark 1992, Brown et al. 1998, Turner and Chislock 2007, Michot et al. 2008, Covich 2010), and anthropogenic effects (Rohr and Crumrine 2005, Evans and Ray 2010) such as interactions with invasive species (Strayer 1999, Lysne et al. 2008, Riley et al. 2008, Strayer 2010) including *R. auricularia* (Adam and Lewis 1992).

The expansion of *R. auricularia* in the wetlands of TNWR is troubling. *Radix auricularia* was previously known from a single historic population (first recorded in 1968) at Middle

Pine Lake (Kipp et al. 2017) but has expanded its range to include 6 additional ponds and has become the dominant genus in Middle Pine and Lower Pine Lakes (Table 1). Although *R. auricularia* has been in TNWR for approximately 50 years, we do not have a definitive date of first introduction or any subsequent data on expansion during this period prior to our survey. We therefore cannot attest to the rate of spread of this invasive snail over time. However, the spread of *R. auricularia* from Middle Pine Lake to Lower Pine Lake is expected because these 2 lakes are connected by an intermittent stream. The higher abundance of this nonnative snail in Kepple Lake may be attributed to the relatively large size of the lake (it was the largest lake in our survey), which may have increased the likelihood that ducks and other waterfowl would transport snail eggs or juveniles to this pond. Because TNWR is a refuge managed for migrating waterfowl, this method of dispersal may account for *R. auricularia*'s dispersal to ponds not connected during high flow events (Boag 1986). Alternatively, the spread of *R. auricularia* may be due to human activities, including the unintentional transport of eggs and small snails on equipment and waders during pond maintenance, scientific or management surveys, or waterfowl hunts. Resource managers need to increase awareness of invasive species in their areas of authority by educating the public in how to reduce transmission of *R. auricularia* and other invasive species among locations.

The expansion of *R. auricularia* at TNWR may result in lower abundance and diversity of native gastropods. Most freshwater snails feed on periphyton and detritus, and studies have shown that snail survival rates decline during times of food scarcity (Brown 1982, Osenburg 1989). In permanent lentic environments, *R. auricularia* has been shown to reduce and extirpate native snail populations (Adam and Lewis 1992). If *R. auricularia* and native snails in TNWR are competing for the same food source, *R. auricularia* could out-compete native snails, lowering native snail abundance. Additionally, Deng (1997) found that *R. auricularia* preyed on juvenile snails. If *R. auricularia* commonly uses juvenile snails as a food source, then native snail populations may be negatively influenced. Furthermore, if *R. auricularia* has better defenses than native

snails or is inedible to native predators in invaded ecosystems, then native snails may experience increased predation rates because the less desirable *R. auricularia* would be avoided by predators. Differential predation of snail species has been shown for dragonfly nymphs (Younes et al. 2016), fly larvae (Fu and Meyer-Rochow 2012), and water bug adults (Younes et al. 2017).

Another way that native snails could be affected by *R. auricularia* is through trematode parasite interactions. In its native range, *R. auricularia* is commonly infected with a dozen different trematode parasites (Adam and Lewis 1993, Soldanova et al. 2010) that ultimately inhabit piscivorous birds, waterfowl, and mammals, including livestock. In introduced areas, *R. auricularia* has been found with trematode infections (Larson 2018). Thus, *R. auricularia* could bring nonnative parasites that may infect native snails or it could act as a reservoir host, increasing the parasite population and potentially increasing infections in native snails. The invasive species could, however, act as a decoy host resulting in a reduced parasite population and diluting the number of infections in native snails (Torchin and Mitchell 2004, Telfer and Bown 2012).

More research on the presence of *R. auricularia* in eastern Washington wetlands would give a better understanding of the scope of this nonnative species in these ecosystems. The extent to which *R. auricularia* competes with native snails could be determined through competition experiments, grazing trials, and stable isotope analysis. It would also be beneficial for managers to determine whether *R. auricularia* in eastern Washington are harboring trematode parasites that can infect waterfowl, wildlife, or livestock to determine whether there are risks of transmission to these species.

Our survey of gastropods in TNWR showed lower genus richness than observed in similar gastropod surveys. Because gastropods are an important food and calcium resource for waterfowl (Petrie 1996, Scheuhammer et al. 1997, Ross et al. 2005, Michot et al. 2008), resource managers at TNWR and other public lands need to assess their gastropod populations to determine whether low richness levels are associated with lower waterfowl populations. Additionally, the effects of invasive species on

wetland ecosystems need to be quantified to determine whether these organisms are having negative impacts on native populations.

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