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Rapid Communication

New records of the non-native virile crayfish *Faxonius virilis* (Hagen, 1870) from the upper Snake River drainage and northern Bonneville Basin of the western United States

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Abstract

The virile crayfish *Faxonius virilis* (Hagen, 1870) is a widespread non-native species across North America, and may be an emerging invasive species globally. We report new records for *F. virilis* from the upper Snake River drainage and northern Bonneville Basin of the western United States. We sampled 162 sites for crayfish during the summers of 2016 and 2017, detecting *F. virilis* at 22 of these sites, which ranged from small streams to wadeable rivers, as well as artificial reservoirs and a large natural lake (Bear Lake, Idaho and Utah). We also report the first records for *F. virilis* from the large, mainstem Snake River. However, we did not find *F. virilis* in the Snake River headwaters of western Wyoming, and detections of this species were few in the Snake River drainage below Shoshone Falls in south central Idaho. We also found no *F. virilis* in eastern Oregon. The widespread distribution of *F. virilis* in the upper Snake River drainage and northern Bonneville Basin may be a conservation concern for native crayfishes in this region, specifically the pilose crayfish *Pacifastacus gambelii* (Girard, 1852) and the Snake River pilose crayfish *Pacifastacus connectens* (Faxon, 1914). We recommend that research is undertaken to address ecological interactions of non-native *F. virilis* with native species, communities, and ecosystems in the western United States, and that education, outreach, and regulatory options be pursued to further limit the introduction and spread of this species.

Key words: Bear Lake, Bear River, Idaho, *Pacifastacus connectens*, *Pacifastacus gambelii*, pilose crayfish, Utah, Wyoming

Introduction

The introduction of non-native crayfishes is a leading contributor to population declines and increased risk of extinction for native crayfishes globally (Lodge et al. 2000; Richman et al. 2015). Non-native crayfishes are regularly introduced via pathways such as fishing bait, stocking for ecosystem management or harvest, and releases of aquarium pets or laboratory organisms (Svärdson 1995; Larson and Olden 2008; DiStefano et al. 2009; Peters and Lodge 2009). Non-native crayfishes can manifest unwanted impacts as invasive species by displacing native crayfishes through mechanisms including competition and disease transmission (e.g., Bohman et al. 2006; Twardochleb et al. 2013). Further, these invasive crayfishes can transform the structure and function of entire freshwater ecosystems due to their high population densities, generalist feeding habits across trophic levels, and burrowing behaviors that mobilize sediment and occasionally damage infrastructure (e.g., Harvey et al. 2011; Hansen et al. 2013; Kreps et al. 2016).

The virile crayfish *Faxonius virilis* (Hagen, 1870; Figure 1), formerly *Orconectes virilis* (Crandall and De Grave 2017), is under-studied in proportion to its large non-native range. Native throughout much of the north central United States and south central Canada east of the continental divide, *F. virilis* has been introduced to California (Light et al. 1995), the desert Southwest (Moody and Sabo 2013), the Pacific Northwest (Larson et al. 2010), and throughout the Appalachian region of the eastern United States

(e.g., Kilian et al. 2010). *Faxonius virilis* has also occasionally been found established outside of North America, including the United Kingdom (Ahern et al. 2008) and the Netherlands (Souty-Grosset et al. 2006; Filipová et al. 2010). Given its expansive non-native range, studies evaluating impacts of, and developing management options for, *F. virilis* are surprisingly scarce. However, *F. virilis* has been found to compete with rare native fish for food in the southwestern United States (Carpenter 2005), and affect ecosystem processes like rates of leaf litter breakdown in desert streams that historically lacked crayfish (Moody and Sabo 2013). In response to these impacts of invasive *F. virilis*, control and eradication methods including electrofishing removal and treatment with rotenone have been explored (Rogowski et al. 2013; Recsetar and Bonar 2015).

During the summers of 2016 and 2017, we investigated the current distributions and habitat associations of two poorly known native crayfishes of the western United States: the pilose crayfish *Pacifastacus gambelii* (Girard, 1852) and the Snake River pilose crayfish *Pacifastacus connectens* (Faxon, 1914) (unpublished data). We sampled 162 sites across Idaho, Nevada, Oregon, Utah, and Wyoming coinciding with the proposed native ranges of these two species (Larson and Olden 2011). Our sampling focused on the upper Snake River drainage and adjacent endorheic desert basins like the Bonneville Basin, which includes the Great Salt Lake (Larson and Williams 2016). During our sampling, we found non-native *F. virilis* widespread in many waterbodies from which the species had not previously been documented. In particular, we expanded the known distribution of *F. virilis* in this region relative to past distributional records of the species from Idaho (Clark and Lester 2005), Utah (Johnson 1986), and Wyoming (Hubert 2010), previously summarized by Larson and Olden (2011) and thus updated distributions for *F. virilis* from the upper Snake River drainage and northern Bonneville Basin of the western United States.

Material and methods

We sampled for crayfish at 78 sites between July 16th and August 10th 2016, and 84 sites between July 2nd and August 3rd 2017. At each site, we either conducted an hour long timed search with two observers (105 sites), or set baited crayfish traps overnight (57 sites). We used timed searches at 88 lotic (wadeable streams to large rivers) and 17 lentic sites (lakes and reservoirs), and baited trapping at 42 lotic and 15 lentic sites. In most cases, choice of timed search or baited trapping was *ad hoc* in response to our schedule that day (e.g., we often trapped at sites near where we camped for the night), although baited trapping was sometimes required at sites where timed searches were not feasible (below).

Figure 1. Virile crayfish *Faxonius virilis* (Hagen, 1870) collected from the Bear River, Bear River State Park, Wyoming, United States on July 16th, 2016. Image from E.R. Larson.

Timed searches used hand nets, D-frame nets, or seines depending on habitat size or other attributes. We used hand nets in the smallest streams where larger nets were difficult to use, and to search the wadeable littoral zones of reservoirs and lakes by overturning potential crayfish shelter like cobble and large woody debris. We used D-frame nets and seines in larger wadeable streams and rivers, following an approach approximating quantitative kick seining for crayfishes (e.g., Engelbert et al. 2016). Timed searches generally covered 100–200 m of linear habitat in either lotic or lentic environments.

At some sites—including those too deep, too steep, or with too limited public access to sample by our timed search methods—we set crayfish traps (0.42 m long by 0.21 m diameter with two 60-mm openings) overnight that were baited with dry dog food. When trapping, we set four to six traps per site for approximately 16 hours at depths ranging from a half meter to several meters deep. All baited traps were set from the banks of streams or rivers or the shores of lakes or reservoirs; we did not use a boat to sample offshore or deeper locations.

We identified all crayfish collected to species, and crayfish identifications were verified by a recognized expert (B.W. Williams). Voucher specimens were preserved in 90% ethanol and deposited at the North Carolina Museum of Natural Sciences (NCSM) Non-Molluscan Invertebrate Collection. We provide NCSM catalog numbers for *F. virilis* vouchers in the Supplementary material Table S1.

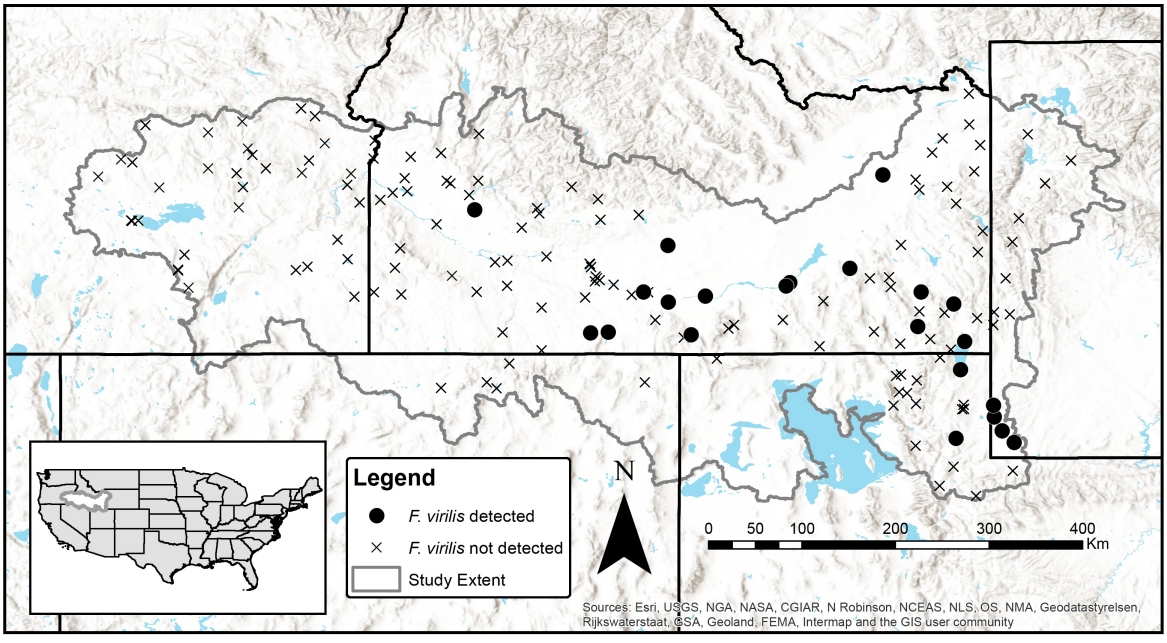

Figure 2. Sites where virile crayfish *Faxonius virilis* (Hagen, 1870) were and were not detected from the upper Snake River drainage and northern Bonneville Basin of the United States during the summers of 2016 and 2017, as well as where this species was reported within or immediately adjacent to the student extent by Johnson (1986), Clark and Lester (2005), and Hubert (2010).

Results

We detected *F. virilis* at 22 of 162 sites sampled for crayfish during the summers of 2016 and 2017 (Figure 2, Table S1). *Faxonius virilis* almost always occurred allopatrically, but was sympatric with the native crayfish *P. gambelii* at one site near the town of Murtaugh on the mainstem Snake River. Twelve sites where we detected allopatric *F. virilis* were historically occupied by the native crayfish species *P. connectens* or *P. gambelii* (Larson and Olden 2011; Larson and Williams 2016).

Ten of the 22 sites where we found *F. virilis* were in the Bonneville Basin of Utah and Wyoming, including the upper Bear River and one of its mainstem reservoirs (Woodruff Narrows) and one of its tributary reservoirs (Sulfur Creek), multiple sites in the middle Bear River of southeastern Idaho, the northern and southern shorelines of Bear Lake in both Idaho and Utah, and a small reservoir in northeastern Utah. These represent the first published records of *F. virilis* from Bear Lake.

Within the Snake River drainage, the majority (8 of 12) of *F. virilis* detections were above Shoshone Falls. These included four sites in the mainstem of the Snake River, ranging from near the town of Roberts downstream to near the town of Murtaugh, with intervening locations at Massacre Rocks State Park and the town of Burley. These represent the first records of *F. virilis* from the Snake River. We also found *F. virilis* in the Portneuf River near the town of Pocatello, a reservoir in a headwater tributary to the Snake River above Shoshone Falls, a very small tributary stream close to the Snake River near Massacre Rocks State Park, and Dierkes Lake near the town of Twin Falls adjacent to the Snake River.

Below Shoshone Falls, no *F. virilis* were found in any mainstem Snake River sites. We did collect *F. virilis* from two reservoirs in the upper Salmon Falls Creek drainage, the Little Wood River near the town of Richfield, and a small reservoir southeast of Boise. Cumulatively, we found *F. virilis* in habitats including extremely small tributary streams, mid-sized wadeable rivers, reservoirs, a large natural lake, and the large, mainstem Snake River (Figure 3).

Sites where we found *F. virilis* were generally in lower elevation, warmer valley bottoms, whereas the species was generally absent from higher gradient, colder mountain streams and rivers, such as those draining the Teton or Uinta mountains. We do not know if this distributional pattern reflects biological tolerances or habitat preferences of *F. virilis*, or instead is attributable to differing introduction efforts by humans between these sparsely vs. more densely populated locations.

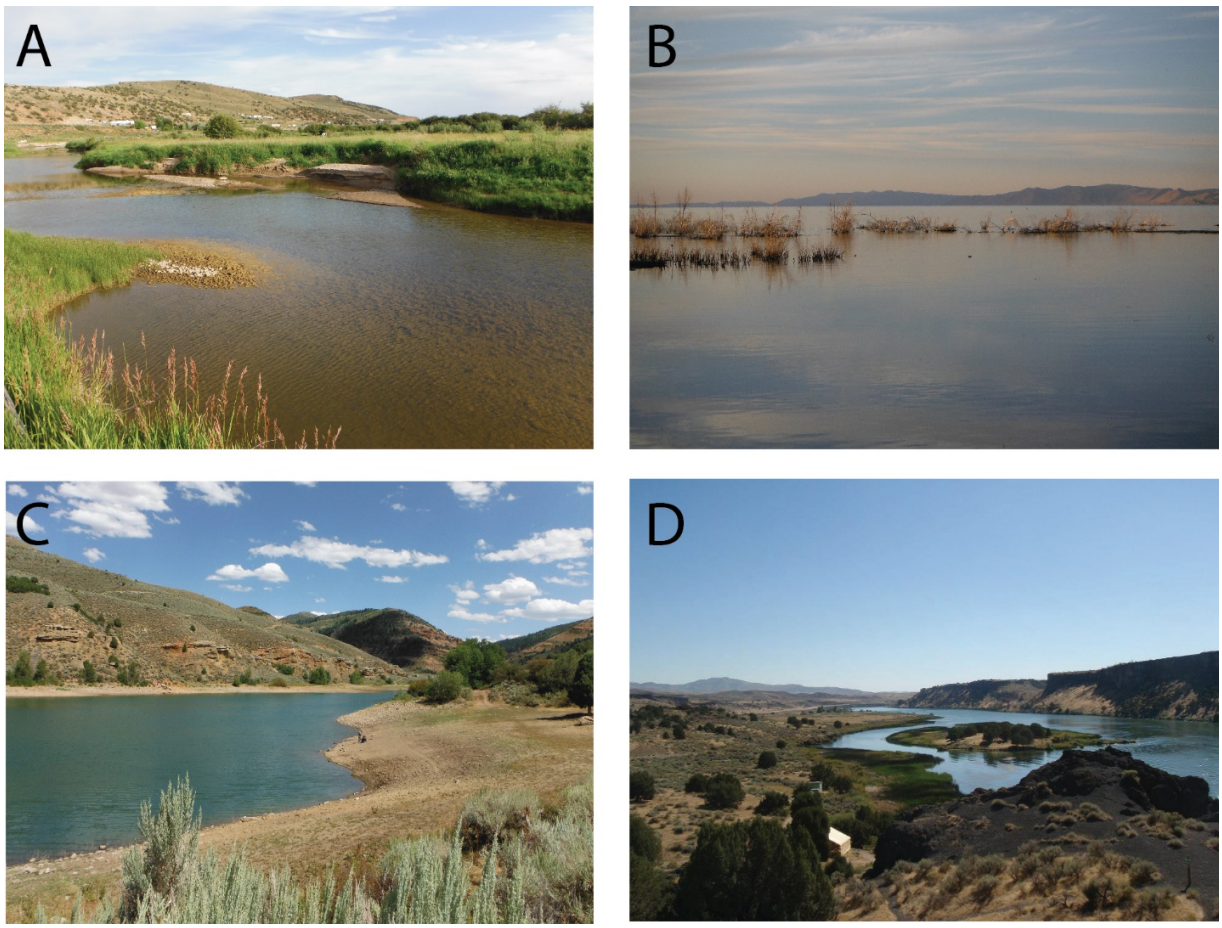

Figure 3. Representative sites where virile crayfish *Faxonius virilis* (Hagen, 1870) were collected from the upper Snake River drainage and northern Bonneville Basin of the United States, including wadeable rivers like the Bear River north of Evanston, Wyoming (A), the southern shoreline of large, natural Bear Lake in northeastern Utah (B), reservoirs like Lost Creek Reservoir in northeastern Utah (C), and the large, mainstem Snake River at Massacre Rocks State Park, Idaho (D). All images from E.R. Larson.

Faxonius virilis was abundant at most sites where it was detected by hour-long timed searches (Table S1). We collected a mean of 79.9 *F. virilis* (range of seven to 312) per hour at sites sampled by timed search, with high *F. virilis* catches recorded in both lotic and lentic environments (Table S1). Conversely, *F. virilis* catch per crayfish trap was relatively low regardless of habitat type. We collected a mean of 0.60 *F. virilis* (range of 0.17 to 1.83) per trap at these sites. Given the apparent superior detection probability of hour-long timed searches for *F. virilis*, it is possible that we failed to detect this crayfish from some of our trap-sampled sites.

Discussion

Our study demonstrates that the non-native crayfish *F. virilis* is widespread in the upper Snake River drainage and Bonneville Basin of southeastern Idaho, western Wyoming, and northern Utah in the United States. We expand on past, more isolated records for this species from Idaho (Clark and Lester 2005), Utah (Johnson 1986), and Wyoming (Hubert 2010). We report the first records of *F. virilis* from the mainstem Snake River, as well as the first published records of *F. virilis* from Bear Lake, where this non-native crayfish was found on both northern and southern shorelines. Our failure to find the native crayfishes *P. connectens* and *P. gambelii* at 21 of the 22 sites occupied by *F. virilis*—despite 12 of these being historic locations for native crayfishes (Larson and Olden 2011; Larson and Williams 2016)—suggests that *F. virilis* may represent a conservation threat to native crayfishes in this region. Similarly, its poorly known community and ecosystem effects would benefit from further study (Moody and Sabo 2013).

Faxonius virilis was first reported from this region by Johnson (1986), who documented the species from several reservoirs in the Provo and Weber River drainages of Utah. Some early *F. virilis* introductions within Utah were initiated by management agencies to provide forage for non-native, warm water sportfish (Johnson 1986). Our record for *F. virilis* from the southern shoreline of Bear Lake in Utah is particularly notable in this state. In Idaho, Clark and Lester (2005) reported *F. virilis* from China Creek, a tributary to Salmon Falls Creek. We greatly expand on published records for *F. virilis* in southern Idaho, including multiple sites in the mainstem Snake River. Within Wyoming, *F. virilis* was previously found to be widespread in the Bear River and adjacent reservoirs in the vicinity of the town of Evanston (Hubert 2010). Our collections support this finding, but replicate it in a more broadly accessible publication. Our sampling confirms the proposal of Larson and Olden (2011) that *F. virilis* is more widespread in parts of the western United States than previously recognized. In contrast, we did not find *F. virilis* in eastern Oregon, and the species was rare in the Snake River and associated tributaries below Shoshone Falls. Similarly, the species was not found in the Snake River and its tributaries within western Wyoming. These results demonstrate that although relatively common, opportunity remains to contain further spread, or prevent new introductions, of *F. virilis* in this region.

Given its widespread distribution within the upper Snake River drainage and northern Bonneville Basin, *F. virilis* may pose a conservation threat to the native crayfishes *P. connectens* and *P. gambelii*. Our work on conservation status, current distributions, and habitat associations for these native crayfishes is ongoing. However, like Hubert (2010), we almost never found these native crayfishes occurring in sympatry with *F. virilis*, and *F. virilis* had seemingly displaced native crayfishes from their historic range at 12 study sites from which they were previously reported. Both *P. connectens* and *P. gambelii* are extremely data poor, lacking effectively any published studies on their ecology or conservation status (Larson and Olden 2011; Larson and Williams 2016). We recommend immediate study on potential interactions of *P. connectens* and *P. gambelii* with *F. virilis* that could guide conservation of native crayfishes in this region. For example, we do not know if apparent displacement of native crayfishes by *F. virilis* is driven by factors like competition or disease transmission (Bohman et al. 2006; Twardochleb et al. 2013), which may warrant different management responses. Similarly, the effects of non-native warm water sportfish like smallmouth bass *Micropterus dolomieu* (Lacepède, 1802) on both native and non-native crayfishes in the western United States are unknown (Carey et al. 2011), but differential susceptibility to fish predators has been found to affect native crayfish displacement by invasive crayfish elsewhere (DiDonato and Lodge 1993).

Finally, we suggest that education and outreach to anglers, aquarium hobbyists, the biological supply trade, or users of live seafood could prevent further introductions and spread of *F. virilis*, as could regulation or policy changes related to the transport and possession of live crayfish (DiStefano et al. 2009; Peters and Lodge 2009; Larson and Olden 2011). We know little about past or present pathways of introduction of this crayfish to this region, aside from some early introductions for sport fish forage in Utah (Johnson 1986). Given the lack of study of crayfish in this region, we also cannot quantify rates of secondary spread or natural dispersal of *F. virilis* populations from existing records (e.g., Wilson et al. 2004). Regardless, much of the western United States, such as Oregon, is not yet invaded by *F. virilis*, and there are many areas where this non-native crayfish cannot spread on its own due to dispersal barriers like drainage divides, dams, and waterfalls (Fausch et al. 2009). Urgent priority should be given to minimizing the introduction, establishment, and spread of *F. virilis* in this region through educational outreach and regulatory mechanisms focused on human users of live crayfish. Such an effort would also benefit from better understanding the habitat or environmental requirements that can support *F. virilis* populations in order to prioritize where to apply education or management intervention most efficiently (Vander Zanden and Olden 2008). We are skeptical that sufficient presence records exist for *F. virilis* in our study region to accurately model the habitat requirements of an invader that is still spreading and not yet at equilibrium with its environment (Václavík and Meentemeyer 2012). However, a larger-scale habitat modeling effort for this crayfish using available data layers such as Domisch et al. (2015) and its known native and non-native occurrence records would benefit many management jurisdictions concerned with this invader (e.g., Morehouse and Tobler 2013).

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References

Ahern D, England J, Ellis A (2008) The virile crayfish, *Orconectes virilis* (Hagen, 1870) (Crustacea: Decapoda: Cambaridae), identified in the UK. *Aquatic Invasions* 3: 102–104, https://doi.org/10.3391/ai.2008.3.1.18

Bohman P, Nordwall F, Edsman L (2006) The effect of the large-scale introduction of signal crayfish on the spread of crayfish plague in Sweden. *Bulletin Français de la Pêche et de la Pisciculture* 380–381: 1291–1302, https://doi.org/10.1051/kmae:2006026

Carey MP, Sanderson BL, Friesen TA, Barnas KA, Olden JD (2011) Smallmouth bass in the Pacific Northwest: a threat to native species; a benefit for anglers. *Reviews in Fisheries Science* 19: 305–315, https://doi.org/10.1080/10641262.2011.598584

Carpenter J (2005) Competition for food between an introduced crayfish and two fishes endemic to the Colorado River basin. *Environmental Biology of Fishes* 72: 335–342, https://doi.org/10.1007/s10641-004-2588-z

Clark WH, Lester GT (2005) Range extension and ecological information for *Orconectes virilis* (Hagen 1870) (Decapoda: Cambaridae) in Idaho, USA. *Western North American Naturalist* 65(2): 164–169

Crandall KA, De Grave S (2017) An updated classification of the freshwater crayfishes (Decapoda: Astacidea) of the world, with a complete species list. *Journal of Crustacean Biology* 37: 615–653, https://doi.org/10.1093/jcbiol/rux070

DiDonato GT, Lodge DM (1993) Species replacements among *Orconectes crayfishes* in Wisconsin lakes: the role of predation by fish. *Canadian Journal of Fisheries and Aquatic Sciences* 50: 1484–1488, https://doi.org/10.1139/f93-169

DiStefano RJ, Litvan ME, Horner PT (2009) The bait industry as a potential vector for alien crayfish introductions: problem recognition by fisheries agencies and a Missouri evaluation. *Fisheries* 34: 586–597, https://doi.org/10.1577/1548-8446-34.12.586

Domisch S, Amatulli G, Jetz W (2015) Near-global freshwater-specific environmental variables for biodiversity analyses in 1 km resolution. *Scientific Data* 2: 150073, https://doi:10.1038/sdata.2015.73

Engelbert BS, Taylor CA, DiStefano RJ (2016) Development of standardized stream-dwelling crayfish sampling methods at site and drainage scales. *North American Journal of Fisheries Management* 36: 104–115, https://doi.org/10.1080/02755947.2015.1111277

Fausch KD, Rieman BE, Dunham JB, Young MK, Peterson DP (2009) Invasion versus isolation: trade-offs in managing native salmonids with barriers to upstream movement. *Conservation Biology* 23: 859–870, https://doi.org/10.1111/j.1523-1739.2008.01159.x

Filipová L, Holdich DM, Lesobre J, Grandjean F, Petrusek A (2010) Cryptic diversity within the invasive virile crayfish *Orconectes virilis* (Hagen, 1870) species complex: new lineages recorded in both native and introduced ranges. *Biological Invasions* 12: 983–989, https://doi.org/10.1007/s10530-009-9526-0

Hansen GJ, Vander Zanden MJ, Blum MJ, Clayton MK, Hain EF, Hauxwell J, Izzo M, Kornis MS, McIntyre PB, Mikulyuk A, Nilsson E, Olden JD, Papeş M, Sharma S (2013) Commonly rare and rarely common: comparing population abundance of invasive and native aquatic species. *PLoS ONE* 8: 77415, https://doi.org/10.1371/journal.pone.0077415

Harvey GL, Moorhouse TP, Clifford NJ, Henshaw AJ, Johnson MF, Macdonald DW, Reid I, Rice SP (2011) Evaluating the role of invasive aquatic species as drivers of fine sediment-related river management problems: the case of the signal crayfish (*Pacifastacus leniusculus*). *Progress in Physical Geography* 35: 517–533, https://doi.org/10.1177/0309133311409092

Hubert WA (2010) Survey of Wyoming crayfish: 2007-2009. Wyoming Game and Fish Department report, 13 pp

Johnson JE (1986) Inventory of Utah crayfish with notes on current distribution. *The Great Basin Naturalist* 46(4): 625–631

Kilian JV, Becker AJ, Stranko SA, Ashton M, Klauda RJ, Gerber J, Hurd M (2010) The status and distribution of Maryland crayfishes. *Southeastern Naturalist* 9: 11–32, https://doi.org/10.1656/058.009.s302

Kreps TA, Larson ER, Lodge DM (2016) Do invasive rusty crayfish (*Orconectes rusticus*) decouple littoral and pelagic energy flows in lake food webs? *Freshwater Science* 35: 103–113, https://doi.org/10.1086/683358

Larson ER, Busack CA, Anderson JD, Olden JD (2010) Widespread distribution of the non-native northern crayfish (*Orconectes virilis*) in the Columbia River Basin. *Northwest Science* 84: 108–111, https://doi.org/10.3955/046.084.0112

Larson ER, Olden JD (2008) Do schools and golf courses represent emerging pathways for crayfish invasions? *Aquatic Invasions* 3: 465–468, https://doi.org/10.3391/ai.2008.3.4.18

Larson ER, Olden JD (2011) The state of crayfish in the Pacific Northwest. *Fisheries* 36: 60–73, https://doi.org/10.1577/03632415.2011.10389069

Larson ER, Williams BW (2016) Historical biogeography of *Pacifastacus crayfishes* and their branchiobdellidan and entocytherid ectosymbionts in western North America. In: Kawai T, Faulkes Z, Scholts G (eds), Freshwater Crayfish: A Global Overview. CRC Press, New York, NY, USA, 669 pp

Light T, Erman DC, Myrick C, Clarke J (1995) Decline of the Shasta crayfish (*Pacifastacus fortis* Faxon) of northeastern California. *Conservation Biology* 9: 1567–1577, https://doi.org/10.1046/j.1523-1739.1995.09061567.x

Lodge DM, Taylor CA, Holdich DM, Skurdal J (2000) Nonindigenous crayfishes threaten North American freshwater biodiversity: lessons from Europe. *Fisheries* 25: 7–20, https://doi.org/10.1577/1548-8446(2000)025<0007:NCTNAF>2.0.CO;2

Moody EK, Sabo JL (2013) Crayfish impact desert river ecosystem function and litter-dwelling invertebrate communities through association with novel detrital resources. *PloS ONE* 8: 63274, https://doi.org/10.1371/journal.pone.0063274

Morehouse RL, Tobler M (2013) Invasion of rusty crayfish, *Orconectes rusticus*, in the United States: niche shifts and potential future distribution. *Journal of Crustacean Biology* 33: 293–300, https://doi.org/10.1163/1937240X-00002120

Peters JA, Lodge DM (2009) Invasive species policy at the regional level: a multiple weak links problem. *Fisheries* 34: 373–380, https://doi.org/10.1577/1548-8446-34.8.373

Richman NI, Böhm M, Adams SB, Alvarez F, Bergey EA, Bunn JJ, Burnham Q, Cordeiro J, Coughran J, Crandall KA, Dawkins KL, DiStefano RJ, Doran NE, Edsman L, Eversole AG, Füreder L, Furse JM, Gherardi F, Hamr P, Holdich DM, Horwitz P, Johnston K, Jones CM, Jones JPG, Jones RL, Jones TG, Kawai T, Lawler S, López-Mejía M, Miller RM, Pedraza-Lara C, Reynolds JD, Richardson AMM, Schultz MB, Schuster GA, Sibley PJ, Souty-Grosset C, Taylor CA, Thoma RF, Walls J, Walsh TS, Collen B (2015) Multiple drivers of decline in the global status of freshwater crayfish (Decapoda: Astacidea). *Philosophical Transactions of the Royal Society B* 370(1662): 20140060, https://doi.org/10.1098/rstb.2014.0060

Recsetar MS, Bonar SA (2015) Effectiveness of two commercial rotenone formulations in the eradication of virile crayfish *Orconectes virilis*. *North American Journal of Fisheries Management* 35: 616–620, https://doi.org/10.1080/02755947.2015.1017127

Rogowski DL, Sitko S, Bonar SA (2013) Optimising control of invasive crayfish using life-history information. *Freshwater Biology* 58: 1279–1291, https://doi.org/10.1111/fwb.12126

Souty-Grosset C, Holdich DM, Noel PY, Reynolds JD, Haffner P (2006) Atlas of Crayfish in Europe. Muséum National d'Histoire Naturelle, Patrimoines Naturels, Paris, France, 64 pp

Svärdson G (1995) The early history of signal crayfish introduction into Europe. *Freshwater Crayfish* 8: 68–77

Twardochleb LA, Olden JD, Larson ER (2013) A global meta-analysis of the ecological impacts of nonnative crayfish. *Freshwater Science* 32: 1367–1382, https://doi.org/10.1899/12-203.1

Václavík T, Meentemeyer RK (2012) Equilibrium or not? Modelling potential distribution of invasive species in different stages of invasion. *Diversity and Distributions* 18: 73–83, https://doi.org/10.1111/j.1472-4642.2011.00854.x

Vander Zanden MJ, Olden JD (2008) A management framework for preventing the secondary spread of aquatic invasive species. *Canadian Journal of Fisheries and Aquatic Sciences* 65: 1512–1522, https://doi.org/10.1139/F08-099

Wilson KA, Magnuson JJ, Lodge DM, Hill AM, Kratz TK, Perry WL, Willis TV (2004) A long-term rusty crayfish (*Orconectes rusticus*) invasion: dispersal patterns and community change in a north temperate lake. *Canadian Journal of Fisheries and Aquatic Sciences* 61: 2255–2266, https://doi.org/10.1139/f04-170

Supplementary material

The following supplementary material is available for this article:

Table S1. Sites where virile crayfish *Faxonius virilis* (Hagen, 1870) were collected from the upper Snake River drainage and northern Bonneville Basin of the United States, with North Carolina Museum of Natural Sciences (NCSM) catalog number (#), site names with state abbreviations, sampling dates (month/day/year), latitudes and longitudes (WGS84), and the number of *F. virilis* collected either per hour of timed search or per number of set traps.

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http://www.reabic.net/journals/bir/2018/Supplements/BIR_2018_Larson_etal_Table_S1.xlsx