

Rapid Communication**First record of *Faxonius propinquus* (Girard, 1852) in the Delaware River watershed and new records of another non-native crayfish species, *Procambarus acutus* (Girard, 1852)**

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Received: 10 May 2023**Accepted:** 19 August 2023**Published:** 27 September 2023**Handling editor:** David Hudson**Thematic editor:** Stelios Katsanevakis**Copyright:** © Morrill and KellerThis is an open access article distributed under terms of the Creative Commons Attribution License ([Attribution 4.0 International - CC BY 4.0](https://creativecommons.org/licenses/by/4.0/)).**OPEN ACCESS****Abstract**

Faxonius propinquus is considered native to the Susquehanna River watershed but is not native to the nearby Delaware River watershed in North America. Here we show that *Faxonius propinquus* is now established in the Delaware River watershed, which is reason for concern. We also provide published records to describe more fully the distribution of *Procambarus acutus*, a species considered non-native in the Delaware River when found upstream of the Atlantic Coastal Plain. We provide evidence that indicates that *F. propinquus* has become established in the Lehigh River, a subwatershed in the Upper Delaware River, and that *P. acutus* has expanded into this portion as well. In addition, we provide evidence of hybridization occurring between the native *Faxonius limosus* and a non-native congener.

Key words: *Faxonius limosus*, hybridization, distribution, established, Lehigh River**Introduction**

Crayfish are one of the most imperiled taxa in the United States, 22.5% of species are at least threatened, according to criteria from the International Union for the Conservation of Nature (IUCN) (Richman et al. 2015; Taylor et al. 2019). The primary threats to crayfish populations are habitat degradation, chemical pollution, overexploitation, and invasive species (Taylor et al. 2007, 2019). Introduction of invasive species is the greatest threat to crayfish biodiversity worldwide (Lodge et al. 2000). In North America, invasive crayfish species are primarily introduced via bait buckets of anglers (Lodge et al. 2000; DiStefano et al. 2011) and can become established in new watersheds altering structure and function of ecosystems (Gherardi 2010). These crayfish can negatively impact native species through competition, habitat alteration, and hybridization (Daniels 1998; Parker et al. 1999; Lodge et al. 2000; van der Wal et al. 2013; Rozansky et al. 2021). To better understand how to conserve native crayfish populations and manage invasive crayfish species, it is important to first catalogue and describe the distributions of these species.

The Delaware River begins at the confluence of its East and West branches near Hancock, New York, and flows 531 kilometers south before emptying into the Atlantic Ocean near Cape May, New Jersey (Delaware River Basin Commission 2013). The watershed (including its tidal estuary) encompasses over 35,169 kilometers² and five states, New York, Pennsylvania, New Jersey, Delaware, and Maryland (Delaware River Basin Commission 2013). It has two major tributaries, the Schuylkill and Lehigh Rivers, which encompass 4,902 kilometers² and 3,519 kilometers², respectively (Fishcer 2003). The first comprehensive survey of crayfishes in the Pennsylvania portion of the Delaware River watershed took place in 1906 (Ortmann 1906) and only three species of crayfish were found: *Cambarus bartonii* (Fabricius, 1798), *Lacunicambarus diogenes* (Girard, 1852), and *Faxonius limosus* (Rafinesque, 1817). At that time, *C. bartonii* and *F. limosus* were widely distributed within the region (Ortmann 1906) and there was no mention of non-native species. Since the work of Ortmann (1906), five non-native crayfish species have been documented in the lower Delaware River Watershed; they are: *Faxonius obscurus* (Hagen, 1870), *Faxonius rusticus* (Girard, 1852), *Faxonius virilis* (Hagen, 1870), *Procambarus acutus* (Girard, 1852), and *Procambarus clarkii* (Girard, 1852) (Lieb et al. 2011a). Overall, published records of non-native species in the Delaware River watershed are sparse.

Procambarus acutus is considered non-native in portions of the watershed but this species is native to areas of the watershed that flow over the Atlantic Coastal Plain in the states of New Jersey, Pennsylvania, and Delaware (Francois 1959; Lieb et al. 2011a). Lieb et al. (2011a) documented the first published records of *F. obscurus* in the Delaware watershed and noted the expansion of *P. acutus* into the Piedmont Plateau of the Schuylkill River sub-watershed. Additionally, there is only one record of *P. acutus* north of the fall line in the Delaware River watershed near its headwaters in Downsville, New York taken in 1990 (New York State Museum identifier 36562; Bloomer and Taylor 2020 <https://americancrayfishatlas.web.illinois.edu/>); otherwise, there are no published records for *P. acutus* in waters north of the fall line in the Delaware River watershed.

Faxonius rusticus and *F. obscurus* are the only other non-native species with published records of occurrence in the Upper Delaware River watershed (Lieb et al. 2011b). There is one erroneous record of *Faxonius propinquus* (Girard 1852) in the Delaware River watershed from Black Lake in Lake Superior State Park, New York (Museum of Comparative Zoology identifier 15130). This is in the Upper Delaware River watershed; however, communications with curators at the Museum of Comparative Zoology confirmed this record to be a mistake. Instead, this specimen was likely taken from Black Lake in Edwardsville, New York, far north of the Delaware River watershed.

Overall, there have been few published accounts of non-native crayfish within the Delaware River watershed. Here we provide an account of two crayfish species that are either non-native to the Delaware River watershed or non-native to a portion of the watershed. Specifically, we provide the first published account of *F. propinquus*, a non-native crayfish, in the Delaware River watershed and provide published records to more fully describe the range of *P. acutus*, a species native to the watershed, but non-native to portions upstream of the Atlantic Coastal Plain.

Materials and methods

We performed 192 surveys of wadeable streams throughout the Delaware River watershed from 2013–2022. At each site, multi-pass backpack electrofishing was used to survey a 100 m long length of stream. All fish, amphibians, and crayfish encountered were collected (Delaware River Watershed Initiative (DRWI) 2015; Supplementary material Table S1; only crayfish data are provided). One site in the Upper Lehigh River was resampled in 2022 using single-pass backpack electrofishing to survey for crayfish only and to re-confirm the presence of *F. propinquus* at this site. Crayfish specimens were identified using various guides (Crocker 1957; Hobbs 1989; Taylor et al. 2015) and preserved in 70% ethanol. Specimens were handled and preserved following Drexel University IACUC protocol # 20259. These specimens have been accessioned into the collection at the Academy of Natural Sciences (ANSP) (ANSP identifier C20000–C20010) in Philadelphia, Pennsylvania except for five *C. bartonii* and one *F. obscurus* in 2014 and one *C. bartonii* and two *P. acutus* in 2022.

Results and discussion

Our study documents the first published record of *F. propinquus* (ANSP identifier C20005) in the Delaware River watershed and documents the persistence of their occurrence in the Upper Lehigh River sub-watershed. It also better describes the published range for *P. acutus* within the Delaware River watershed (Figure 1). Across all surveys from 2013 to 2022, two occurrences of *F. propinquus* were recorded and seven occurrences of *P. acutus* were recorded, five of which are new published localities for this species (Table 1).

Eighteen confirmed *F. propinquus* (Crocker 1957; Taylor et al. 2015) were documented in the Upper Lehigh River in 2014, comprising about 35% of all crayfish captured (Table 2). These specimens were collected in the Upper Lehigh River just west of Gouldsboro, Pennsylvania, and are the first published record of *F. propinquus* in the Delaware River watershed (Figure 1). Three other species of crayfish, *C. bartonii*, *F. limosus*, and *F. obscurus*, were documented at this site as well, comprising 9.8%, 33.3%, and 2%, respectively, of the total number of crayfish captured (Table 2).

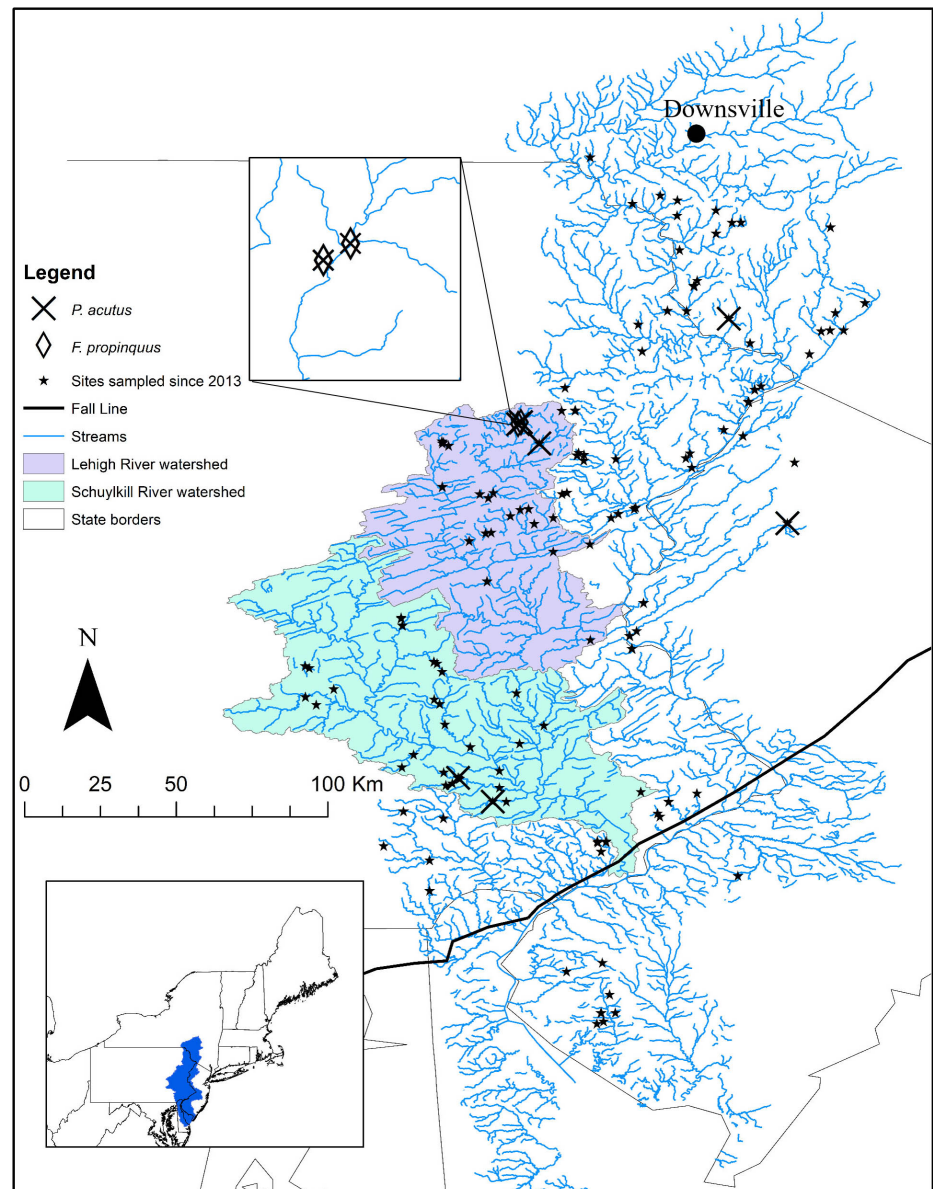


Figure 1. Delaware River Watershed Initiative records for *Faxonius propinquus* and *Procambarus acutus* in the Delaware River watershed. The panel in the bottom left shows the position of the Delaware River watershed (blue) in the Mid-Atlantic Region of North America. The panel in the top left depicts the two sites where *F. propinquus* was documented, with the northern site being the original point of detection in 2014.

Table 1. The GPS location (WGS84), year surveyed, and locality for two non-native crayfish species records in the Delaware River Watershed. PA = Pennsylvania. NY = New York. NJ = New Jersey.

Species	Latitude	Longitude	Year	Nearest Town
<i>Faxonius propinquus</i>	41.22072	-75.51926	2015	Gouldsboro, PA
	41.22602	-75.51064	2014, 2022	Gouldsboro, PA
<i>Procambarus acutus</i>	40.10072	-75.594435	2015	Yellow Springs, PA
	40.17085	-75.69727	2015	Bucktown, PA
	40.92654	-74.72038	2014	Byram Township, NJ
	41.16301	-75.45667	2013, 2015	Tobyhanna, PA
	41.22072	-75.51926	2013, 2015	Gouldsboro, PA
	41.53343	-74.89412	2021	Eldred, NY
	41.22602	-75.51064	2022	Gouldsboro, PA

Table 2. Total number caught, % of total catch, sex, length ranges, and ANSP museum identifiers for crayfish caught at the Upper Lehigh River site in 2014 and 2022. UID = unable to be identified to species.

Year	Species	Total	% Catch	FI male	FII male	Female	Carapace Length (cm)	Identifier
2014	<i>Cambarus bartonii</i>	5	9.8	–	–	–	–	–
	<i>Faxonius limosus</i>	17	33.3	4	–	13	1.4–3.3	C20006
	<i>Faxonius obscurus</i>	1	2.0	–	–	–	–	–
	<i>Faxonius propinquus</i>	18	35.3	5	5	8	1.3–3.6	C20005
	<i>Faxonius hybrid</i>	2	3.9	–	2	–	1.8	C20007
	UID	8	15.7	–	2	6	1.2–1.7	C20010
2022	<i>Cambarus bartonii</i>	3	7.7	1	–	1	2.1–3.1	C20004
	<i>Faxonius limosus</i>	1	2.6	–	–	1	2.9	C20009
	<i>Faxonius obscurus</i>	10	25.6	–	5	5	1.9–2.9	C20008
	<i>Faxonius propinquus</i>	10	25.6	–	7	3	2.0–3.1	C20003
	<i>Procambarus acutus</i>	8	20.5	3	2	3	1.8–4.4	C20000
	<i>Faxonius hybrid</i>	2	5.1	–	1	1	4.3–4.8	C20001
	UID	5	12.8	–	4	1	1.8–2.6	C20002



Figure 2. Image of rostrum of *F. propinquus* specimen with median carina evident. Photograph by Daniel P. Morrill.

Faxonius propinquus was readily distinguishable from other species due to the presence of a conspicuous median carina on its rostrum (Crocker 1957; Taylor et al. 2015) (Figure 2). This species distribution in the state of Pennsylvania was originally described as restricted to the Lake Erie watershed in the northwestern part of the state (Ortmann 1906). Since then, however, this species has also been documented in the Susquehanna River, in northern Pennsylvania and is considered native there (Kuhlmann 2008). The Susquehanna River watershed is adjacent to the Delaware River watershed. Specimens from the Ohio State University Museum of Biological Diversity (identifier 43374) were found at a locality in the Susquehanna River watershed that is only 48 kilometers northwest of the original point of detection in the Delaware River watershed, a distance able to be transported by humans.

We revisited the original site of detection in 2022 to confirm that *F. propinquus* introduction was not transient. In 2022, a total of 10 confirmed *F. propinquus* (Crocker 1957; Taylor et al. 2015) were documented, comprising

25.6% of the crayfish captured. Four other species of crayfish, *C. bartonii*, *F. limosus*, *F. obscurus*, and *P. acutus* were detected as well, comprising 7.7%, 2.6%, 25.6%, and 20.5%, respectively, of the captured crayfish (Table 2).

While comparisons with the 2014 sample are difficult due to differences in sampling effort, it is notable that, of the 39 crayfish captured, only one *F. limosus* was captured in 2022 (Table 2). This is concerning considering it was the second most abundant crayfish captured in 2014 and three invasive species were found at the site, with one species, *F. obscurus*, greatly increasing in abundance (Table 2). Others have found that sites with non-native species typically do not support *F. limosus* populations (Swecker et al. 2010; Lieb et al. 2011a). Non-native crayfish species can negatively impact native species through altered trophic structures, competition, and hybridization (Daniels 1998; Parker et al. 1999; Lodge et al. 2000; van der Wal et al. 2013; Rozansky et al. 2021). This may explain why there appeared to be a drastic decline in the abundance of *F. limosus* at this site between 2014 and 2022.

All three *Faxonius* species detected at the site can hybridize (Crocker 1957; Smith 1981; Perry et al. 2001a; Merovich et al. 2022). Crocker (1957) specifically reports finding *F. limosus* × *F. propinquus* hybrids in New York state. Two specimens in 2014 (ANSP identifier C20007) and two specimens in 2022 (ANSP identifier C20001) may be *F. limosus* hybrids. Three of the specimens are from two males with hepatic spines typical of *F. limosus*, but with non-divergent gonopods that most closely resemble a non-native congener, either *F. propinquus* or *F. obscurus* (Crocker 1957; Hobbs 1989; Taylor et al. 2015) (Figure 3). The fourth specimen is a female with hepatic spines, but with an annulus ventralis that lacks a distinct overhanging ridge, typical of *F. limosus*, and most resembles a non-native congener, either *F. propinquus* or *F. obscurus* (Crocker 1957; Hobbs 1989) (Figure 3). Crocker (1957) described hybrids of *F. limosus* × *F. propinquus* with a low median carina typical of *F. propinquus* on specimens, but we did not detect this character in any of our suspected hybrids. Because they lack a median carina, these specimens may represent hybrids with *F. obscurus*, but genetic testing would be necessary to determine proper classification. Genetic testing could not be done by the researchers due to budgetary constraints but could be done on these specimens in the future as they were preserved in ethanol. Hybridization of non-native crayfish with the native *F. limosus* is extremely concerning because it may generate individuals that displace the native populations faster than non-hybrids (Perry et al. 2001a, b; Arcella et al. 2014). Hybridization or competition with these suspected hybrids may explain why we observed a much lower abundance of *F. limosus* specimens in 2022 than 2014.

Two other non-native crayfish species were detected at this site, *F. obscurus* and *P. acutus*. *Faxonius obscurus* is native to the western part of Pennsylvania

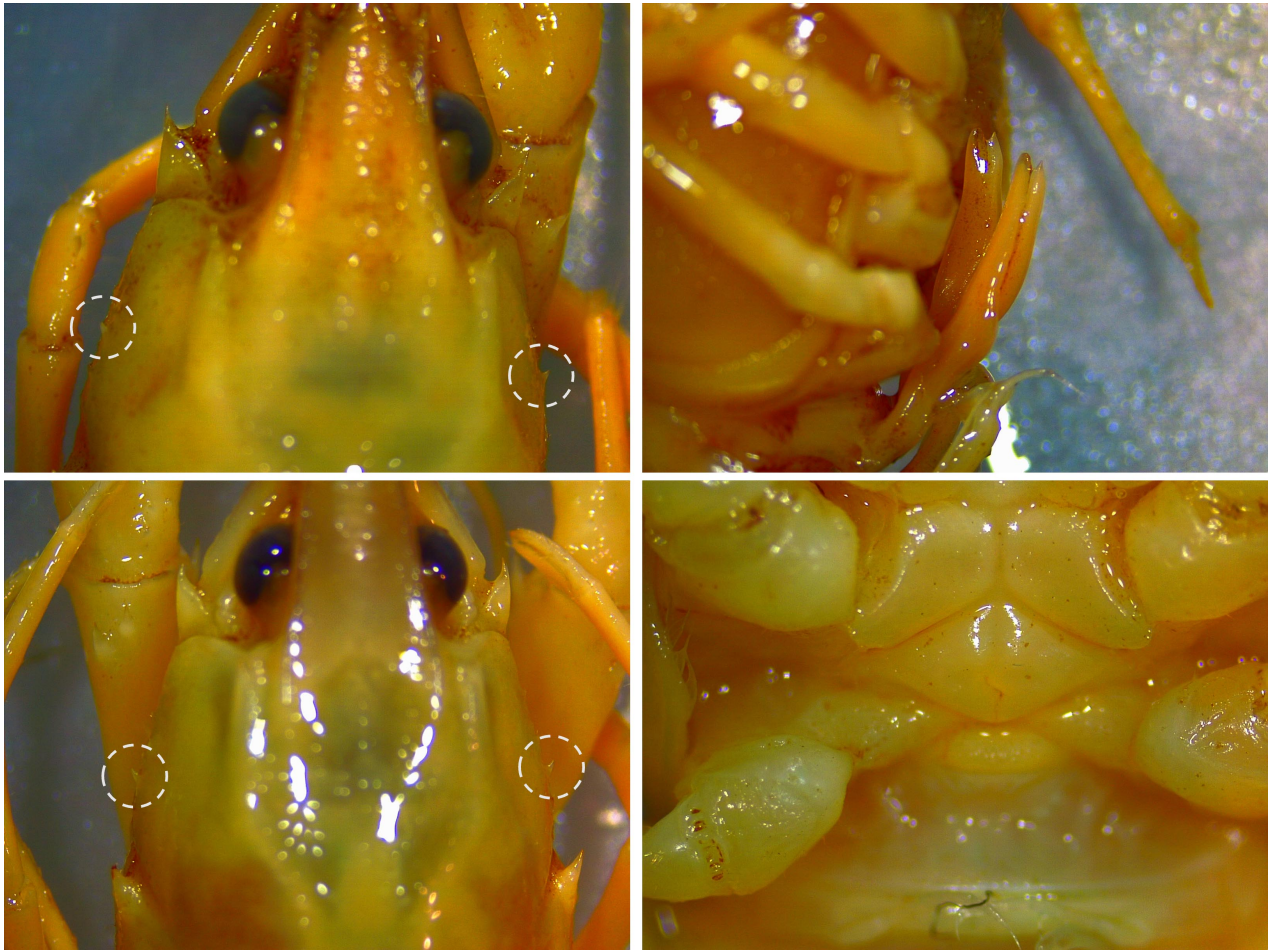


Figure 3. Images of two suspected hybrids, collected in 2022, from the Upper Lehigh point of detection of *F. propinquus*. A is the view of the rostrum for the Form II male. Circles indicate locations of hepatic spines. B is the view of the gonopods for the same Form II male. C is the view of the rostrum for the female. Circles indicate locations of hepatic spines. D is the view of annulus ventralis for the same female. Photographs by Samantha Mosloskie.

in the Ohio, Monongahela, and Allegheny River watersheds (Ortmann 1906; Lieb et al. 2011a). This species has been introduced elsewhere in the state and was first documented in the Delaware River watershed by Lieb et al. (2011a) and has since been documented in the Upper Delaware River watershed (Lieb et al. 2011b).

Similarly, *P. acutus*, which is native to extreme southeast Pennsylvania in the Atlantic Coastal Plains physiographic province, was recorded as expanding north in the Delaware River watershed (Lieb et al. 2011a). They only recorded this species as far north in Pennsylvania as the Schuylkill River sub-watershed (Figure 1). We similarly have detected *P. acutus* in the Schuylkill River sub-watershed (Figure 1). However, our study expands the known range of *P. acutus* north of the Schuylkill River sub-watershed into many parts of the Upper Delaware River watershed, where previously published records only provide one locality of occurrence, near the headwaters in Downsville, New York (New York State Museum identifier 36562; Bloomer and Taylor 2020 <https://americancrayfishatlas.web.illinois.edu/>) (Figure 1).

Currently, *P. acutus* appears to be widespread throughout the Upper Delaware River watershed. We found *P. acutus* at five sites (Figure 1) north of the Schuylkill River sub-watershed, with the earliest record from 2013 (Table 1). Three of these sites are the first published records of this species in the Lehigh River sub-watershed, including the site where *F. propinquus* was first detected. The northernmost site we found *P. acutus* was located in Halfway Brook, just northwest of Port Jervis, New York. This locality is about 64 kilometers south of Downsville, New York, which is the only locale in Upper Delaware where *P. acutus* was previously reported. The other record is farther east in New Jersey, near Byram Township (Figure 1). The distance between collections for *P. acutus* indicates separate introduction events, likely resulting from movement by humans. It was not until 2015 that it became illegal to sell live crayfish as bait in Pennsylvania. The site in the Upper Lehigh River, where three non-native species were found (two prior to the 2015 regulation), is partially owned by a sportsman (hunting/fishing) club, supporting the hypothesis that bait buckets are one method by which *P. acutus* may have been introduced in this region. Though *P. acutus* was not detected at this site in 2014, it was detected at this location in 2022, and was detected at a lower site (1.26 km downstream) in 2013 (prior to the 2015 regulation) and 2015. Reproductive males and different size classes were detected for this species (Table 2), supporting its establishment in the Upper Lehigh.

The current distribution of *F. propinquus* appears restricted to the Upper Lehigh River (Figure 1). The persistence of *F. propinquus* at this site indicates this species has become established in the Upper Lehigh River. This is further supported by the presence of reproductive males and different size classes present (Table 2). Invasive crayfish tend to disperse more quickly downstream (Messenger and Olden 2018). Since 2013, The Academy of Natural Sciences has performed 192 surveys of streams in the Delaware River watershed and only detected *F. propinquus* at one other site. This site was sampled in 2015 and was 1.26 km downstream of the original point of detection in 2014 (Figure 1) and was represented by two *F. propinquus* specimens. Ricklefs and Filbrun (2022) found *F. virilis* dispersed downstream by juvenile drift over several years. They hypothesized that juvenile drift is not a behavior exclusive to *F. virilis* but is likely present in many other crayfish species. Downstream dispersal via juvenile drift may help to identify areas susceptible to future invasion by *F. propinquus* and other non-native species in the Delaware River watershed.

Increases in, and expansion of, non-native crayfish species can negatively impact native crayfish faunas (Daniels 1998; Parker et al. 1999; Lodge et al. 2000; Rozansky et al. 2021) and aquatic communities (Gherardi 2010). Raising awareness of the negative consequences surrounding live crayfish bait has proven ineffective in preventing the dispersal of invasive crayfish

species (Kilian et al. 2012; Nathan et al. 2014) and regulation and enforcement may be necessary. Lieb et al. (2011a) documented five non-native species in the Delaware River watershed. Our study adds a sixth non-native species (*F. propinquus*) and expands the range for another documented non-native species. There is enough evidence that the presence of non-native crayfish species leads to the extirpation of the native *F. limosus* from streams (Swecker et al. 2010; Lieb et al. 2011a). As non-native species continue to establish and disperse, we could see greater reductions in *F. limosus* populations and more local extirpations. For now, the distribution of *F. propinquus* appears to be limited to the Upper Lehigh, which may justify eradication efforts. Eradication efforts are difficult and must take multiple factors into consideration including impacts of treatments on non-target organisms, ability of invasives to avoid treatments, and size selectivity of trapping (Peay et al. 2006; Moorhouse and Macdonald 2011; Hansen et al. 2013; Peay and Dunn 2014), therefore, more research is needed to better characterize distribution of *F. propinquus* to determine if eradication is a viable management option. Future studies should survey the Delaware River watershed, clearly identify ranges for non-native species within the watershed, and assess the impacts these species are having on native crayfish populations and aquatic ecosystems.

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Author's contribution

D.P.M. provided investigation and data collection, species identification, data analysis and interpretation, and original draft writing. D.H.K. provided research conceptualization, data collection, species identification, sample design and methodology, ethics approval, funding provision, and reviewing/editing of the manuscript.

Ethics and permits

Specimens were handled and preserved following Drexel University IACUC protocol # 20259. Permits were provided by the Pennsylvania Fish and Boat Commission # 2022-01-0072, the Pennsylvania Game Commission # 56449, New Jersey Department of Environmental Protection # 22-005, and New York Department of Environmental Conservation # 1536.

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Supplementary material

The following supplementary material is available for this article:

Table S1. All crayfish records collected by Academy staff during DRWI sampling.

This material is available as part of online article from:

http://www.reabic.net/journals/bir/2023/Supplements/BIR_2023_Morrill_Keller_SupplementaryMaterial.xlsx