National Park Service
U.S. Department of the Interior

Northeast Region
Philadelphia, Pennsylvania

Status of Native and Invasive Crayfish in Ten National Park Service Properties in Pennsylvania

Technical Report NPS/NER/NRTR—2007/085

ON THE COVER
Top left - Rusty crayfish (*Orconectes rusticus*);
Top Right – A member of the *Cambarus acuminatus* species complex [*Cambarus* (*Puncticambarus*) sp.];
Bottom left - Marsh Creek, Eisenhower National Historic Site;
Bottom right - Baptism Creek, Hopewell Furnace National Historic Site.
Photographs by: David A. Lieb and Paula Mooney.

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Technical Report NPS/NER/NRTR—2007/085

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NPS D-039 April 2007

Table of Contents

Page

Tables v

Figures vii

Abstract ix

Executive Summary xi

Acknowledgments xiii

Introduction 1

Study Area 3

Methods 7

Results 9

Overview of Crayfish Collections 9

Species Distributions 9

Relative Abundance 9

Discussion 23

Conclusions and Management Recommendations 25

Literature Cited 27

Tables

Page

Table 1. Crayfish collections at 10 National Park Service properties in Pennsylvania. 10

Table 2. Crayfish collections at individual sites within 10 National Park Service properties in Pennsylvania. 12

Figures

Page

Figure 1. National Park Service properties and associated crayfish sampling sites in eastern Pennsylvania. 4

Figure 2. National Park Service properties and associated crayfish sampling sites in western Pennsylvania. 5

Figure 3. Pennsylvania with National Park Service properties and *Cambarus bartonii* locations included. 11

Figure 4. Pennsylvania with National Park Service properties and *Orconectes obscurus* locations included. 15

Figure 5. Pennsylvania with National Park Service properties and *Orconectes limosus* locations included. 16

Figure 6. Pennsylvania with National Park Service properties and *Orconectes rusticus* locations included. 17

Figure 7. Pennsylvania with National Park Service properties and *Orconectes virilis* locations included. 18

Figure 8. Pennsylvania with National Park Service properties and *Cambarus* (*Puncticambarus*) sp. (a member of the *Cambarus acuminatus* species complex) locations included. 19

Figure 9. Pennsylvania with National Park Service properties and *Procambarus* sp. locations included. 20

Abstract

The crayfish fauna of Pennsylvania was last inventoried approximately 100 years ago. Since then exotic crayfish have been introduced into Pennsylvania, which, along with landscape changes and habitat alterations, threaten the state's native crayfish. Because contemporary species lists are not available for most of the state, assessments of changes in Pennsylvania's crayfish fauna are not possible. To address this problem, we surveyed 42 streams located within 10 widely spaced National Park Service (NPS) properties in Pennsylvania. Our goal was to collect a sample of all the surface-dwelling crayfish species from each site. Our surveys resulted in the collection of 1,246 crayfish belonging to seven species. *Cambarus bartonii* was found at most sites and was usually the most abundant crayfish collected; whereas, other native species were either limited to NPS properties in the western (*Orconectes obscurus*) or eastern (*Orconectes limosus*) part of the state and were often less abundant. Exotic species (*Orconectes rusticus*, *Orconectes virilis*) dominated most of the sites where they were found but were generally restricted to southcentral Pennsylvania. Collections of *Cambarus* (*Puncticambarus*) sp. (a member of the *Cambarus acuminatus* species complex) and *Procambarus* sp. were limited to a few individuals from a few sites. These results indicate that at least 60% of the surface-dwelling crayfish species that are known to occur in Pennsylvania are found on NPS properties. The presence of a reproducing population of *Cambarus* (*Puncticambarus*) sp., which is probably one of the most threatened aquatic species in the state, at Valley Forge National Historic Park (VAFO) is particularly noteworthy. Unfortunately, exotic crayfish are a major problem for some NPS properties with several streams that support high densities of exotics completely devoid of natives. Additionally, one rusty crayfish was found in the Upper Delaware Scenic and Recreational River (UPDE) property indicating that the park may be in the very early stages of a rusty crayfish invasion. Efforts to prevent future introductions of exotic crayfish and protect existing populations of native crayfish from urbanization and associated habitat destruction are needed (particularly at VAFO) if the NPS's aquatic resources are to be preserved.

Executive Summary

The crayfish fauna of Pennsylvania was last inventoried approximately 100 years ago by Arnold Ortmann. Since that time, the nonnative rusty crayfish (*Orconectes rusticus*) and the northern crayfish (*Orconectes virilis*) have been introduced into Pennsylvania. These introductions are of concern because nonnative crayfish are one of the biggest threats to native crayfish in North America. The invasion of the rusty crayfish into Pennsylvania is particularly troubling because rusty crayfish are very aggressive and invasions elsewhere have resulted in the extirpation of native crayfish. Landscape changes (urbanization) and associated habitat destruction also pose a significant threat to Pennsylvania's native crayfish.

Because crayfish are functionally important in many aquatic systems and facilitate the transfer of nutrients up through the food chain to fish and other vertebrates, declines in native crayfish populations may have far-reaching consequences on aquatic communities in Pennsylvania. Currently, natural resource managers lack the information needed to identify the extent or consequences of these declines and their relationship to crayfish invasions (exotics), land use changes, and habitat alterations. This is because adequate contemporary data is lacking for much of the state's aquatic resources (including those on National Park Service lands). To address this problem, we surveyed 42 streams (53 sites) located within 10 widely spaced National Park Service (NPS) properties in Pennsylvania. These sites ranged in size from headwater streams to large rivers and were situated in a variety of land use settings (urban, agriculture, forest, mixed). Our goal was to collect a sample of all the surface-dwelling crayfish species from each site.

Our surveys resulted in the collection of 1,246 crayfish belonging to seven species. Crayfish were absent from the Lackawaxen River [Upper Delaware Scenic and Recreational River (UPDE)] and the headwaters of Blair Gap Run [Allegheny Portage Railroad National Historic Site (ALPO)], despite an abundance of suitable habitat at both sites, but were present at the other 51 sites that were surveyed. *Cambarus bartonii* was found at most sites and was usually the most abundant crayfish collected; whereas, other native species were either limited to NPS properties in the western [*Orconectes obscurus*; Johnstown Flood National Memorial (JOFL), ALPO] or eastern [*Orconectes limosus*; Delaware Water Gap National Recreation Area, (DEWA), UPDE] part of the state and were often less abundant. Exotic species (*Orconectes rusticus*, *Orconectes virilis*) dominated most of the sites where they were found but were generally restricted to parks in the south-central part of the state [Gettysburg National Military Park (GETT), Eisenhower National Historic Site (EISE)]. Collections of *Cambarus* (*Puncticambarus*) sp. (a member of the *Cambarus acuminatus* species complex) and *Procambarus* sp. were limited to a few individuals from a few sites. These results indicate that at least 60% of the surface-dwelling crayfish species that are known to occur in Pennsylvania are found on NPS properties. The presence of a reproducing population of *Cambarus* (*Puncticambarus*) sp., which is probably one of the most threatened aquatic species in the state, at Valley Forge National Historic Park (VAFO) is particularly noteworthy. Unfortunately, exotic crayfish are a major problem for some NPS properties with several streams that support high densities of exotics completely devoid of natives. Additionally, one rusty crayfish was found in UPDE, indicating that the park may be in the very early stages of a rusty crayfish invasion. Efforts to prevent future introductions of exotic crayfish and protect existing populations of

native crayfish from urbanization and associated habitat destruction are needed (particularly at VAFO) if NPS's aquatic resources are to be preserved.

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Introduction

The crayfish fauna of Pennsylvania was thoroughly inventoried at the turn of the 20th century (Ortmann 1906). Since that time, the rusty crayfish (*Orconectes rusticus*) and the northern crayfish (*Orconectes virilis*) have been introduced into Pennsylvania (Taylor et al. 1996). Other nonnative crayfish appear poised to enter Pennsylvania. For example, the papershell crayfish (*Orconectes immunis*), which is native to New York and Ohio, has successfully invaded much of New England, including Massachusetts, New Hampshire, Vermont, and Connecticut (Taylor et al. 1996), and has been reported from a few locations in Pennsylvania (although its breeding status is unknown) (D. A. Lieb, The Pennsylvania State University, unpublished data). The red swamp crayfish (*Procambarus clarkii*) is not naturally found north or east of Kentucky but has successfully invaded several nearby states (Maryland, Virginia, Ohio) (Taylor et al. 1996). The proximity of reproducing populations of papershell and red swamp crayfish, along with their documented ability to invade new areas, makes future introductions of these crayfish into Pennsylvania likely. In fact, it is possible that these crayfish species have already invaded Pennsylvania unbeknown to the scientific community.

Crayfish introductions are of concern because nonnative crayfish are one of the biggest threats to native crayfish in North America (Butler et al. 2003). Nonnative crayfish displace native crayfish from preferred habitat, making them more susceptible to predators (Garvey et al. 1994), and hybridize with native crayfish, altering the genetic makeup of native stocks (Lodge et al. 2000). Nonnative crayfish also compete with native crayfish for food resources (Lodge et al. 2000). The invasion of the rusty crayfish into Pennsylvania is of particular concern because rusty crayfish are very aggressive and invasions elsewhere have resulted in the extirpation of native crayfish (Lodge et al. 2000).

Landscape changes also pose a significant threat to Pennsylvania's native crayfish. Since Ortmann's original study, cities and towns have expanded and forested/agricultural land has been replaced by urbanized areas complete with roads, housing developments, shopping malls, and business centers. Whereas Ortmann traveled mostly by rail or horseback, a recent study suggests that the majority of Pennsylvania's landscape is now <400 m (1,312 ft) from the nearest road (Riitters and Wickham 2003). Although the effects of urbanization on Pennsylvania's crayfish populations are currently unknown, studies by Lieb and Carline (1999, 2000) in Pennsylvania and Lenat et al. (1979), Garie and McIntosh (1986), and Field and Pitt (1990) elsewhere, which indicate that urban runoff negatively affects macroinvertebrate communities, make it likely that urbanization poses a significant threat to Pennsylvania's native crayfish. Habitat alterations resulting from impoundments, stream channelization, and sedimentation, which may or may not be associated with urbanization, are also a threat to crayfish populations (Butler et al. 2003) and undoubtedly are on the rise in Pennsylvania.

Although crayfish have long been the object of scientific inquiry (see Huxley 1879), their functional importance has only recently been fully appreciated. For example, it is now known that crayfish often account for a major portion of macroinvertebrate biomass and production in aquatic systems (Huryn and Wallace 1987; Momot 1995; Rabeni et al. 1995), exert direct and indirect effects on basal resources (detritus, algae, macrophytes) and other macroinvertebrates (Hart 1992; Creed 1994; Lodge et al. 1994; Usio 2000; Schofield et al. 2001; Creed and Reed

2004; D. A. Lieb, The Pennsylvania State University, unpublished data), and are an important food item for a number of fish species, including some of recreational and commercial importance (Rabeni 1992; Roell and Orth 1993; Lodge and Hill 1994; Dorn and Mittelbach 1999; D. A. Lieb, The Pennsylvania State University, unpublished data). Crayfish are also readily consumed by birds, snakes, raccoons, and otters. Thus, crayfish are functionally important in many aquatic systems and facilitate the transfer of nutrients up through the food chain to fish and other vertebrates.

Because of their functional significance, declines in native crayfish populations may have far-reaching consequences on aquatic communities in Pennsylvania. Currently, natural resource managers lack the information needed to identify the extent or consequences of these declines and their relationship to crayfish invasions (exotics), land use changes, and habitat alterations. Part of the problem is that adequate contemporary data is lacking for much of the state. Some contemporary data is available from unpublished sources (e.g., T. R. Nuttall, Lock Haven University), but relatively few sites have been surveyed comprehensively. Most of the contemporary collections are incidental in nature (e.g., a few specimens collected as part of a fisheries survey) and were not made by crayfish biologists. For this reason, comprehensive, contemporary lists of species are not available for most of the state's aquatic resources (including those on National Park Service lands). Obviously, without reliable contemporary species lists, assessments of changes in Pennsylvania's crayfish fauna (species losses or additions) are not possible. Contemporary surveys may provide additional benefits by uncovering crayfish species that were previously not known from the state, or possibly to science, as occurred during a recent survey of Valley Creek within Valley Forge National Historic Park (VAFO; Lieb et al. 2007). The objective of this project was to provide updated crayfish species lists for ten National Park Service (NPS) properties in Pennsylvania by conducting comprehensive crayfish surveys of selected streams within the parks.

Study Area

Ten NPS properties in Pennsylvania were included in this study: Hopewell Furnace National Historic Site (HOFU), VAFO, Gettysburg National Military Park (GETT), Eisenhower National Historic Site (EISE), Allegheny Portage Railroad National Historic Site (ALPO), Johnstown Flood National Memorial (JOFL), Fort Necessity National Battlefield (FONE), Friendship Hill National Historic Site (FRHI), Delaware Water Gap National Recreational Area (DEWA), and Upper Delaware Scenic and Recreational River (UPDE). These properties are widely scattered across the state and are located in a variety of physiographic and land use settings (Figures 1 and 2). For example, FONE, FRHI, JOFL, ALPO, DEWA, and UPDE are largely found within the Appalachian Plateau Province of Pennsylvania; whereas, HOFU, VAFO, GETT, and EISE are located within the Piedmont Province of Pennsylvania. Park properties were situated in a variety of landscape types—that range from highly urbanized (e.g., VAFO), to largely agricultural (e.g., GETT, EISE), to mostly forested (e.g., ALPO).

Park properties are located within five of the eight major drainage basins of Pennsylvania [see Argent (2000) for a map of the drainage basins]. FONE and FRHI are located within the Monongahela River drainage; JOFL is located within the Allegheny River drainage; ALPO is located within the Susquehanna River drainage; GETT and EISE are located within the Potomac River drainage; and HOFU, VAFO, DEWA, and UPDE are located within the Delaware River drainage.

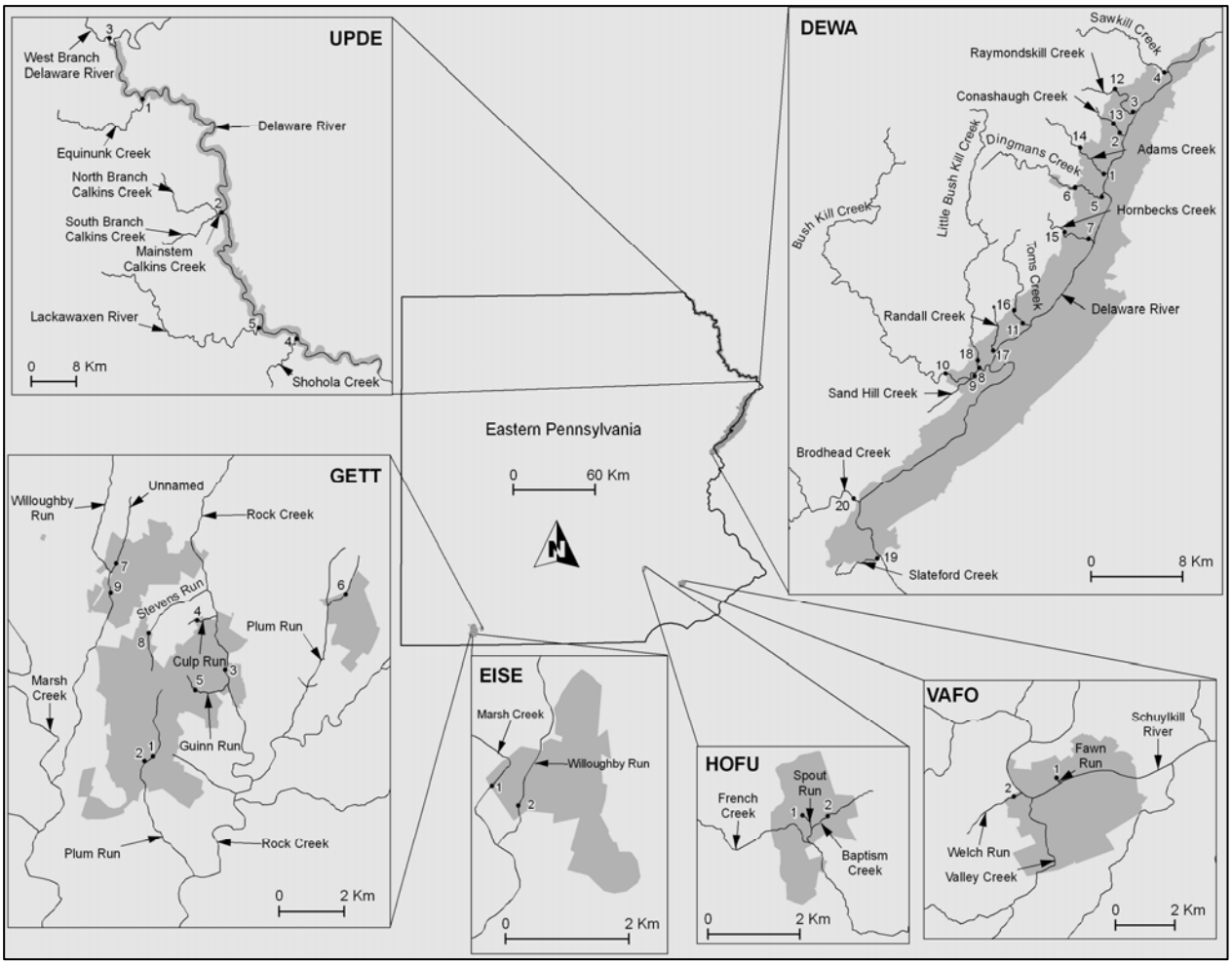

Figure 1. National Park Service properties (in grey) and associated crayfish sampling sites [denoted by closed circles (•) and numbers] in eastern Pennsylvania. Sites are numbered separately for each property. Upper Delaware Scenic and Recreational River (UPDE), Delaware Water Gap National Recreational Area (DEWA), Gettysburg National Military Park (GETT), Eisenhower National Historic Site (EISE), Hopewell Furnace National Historic Site (HOFU), and Valley Forge National Historic Park (VAFO) properties are depicted on the map.

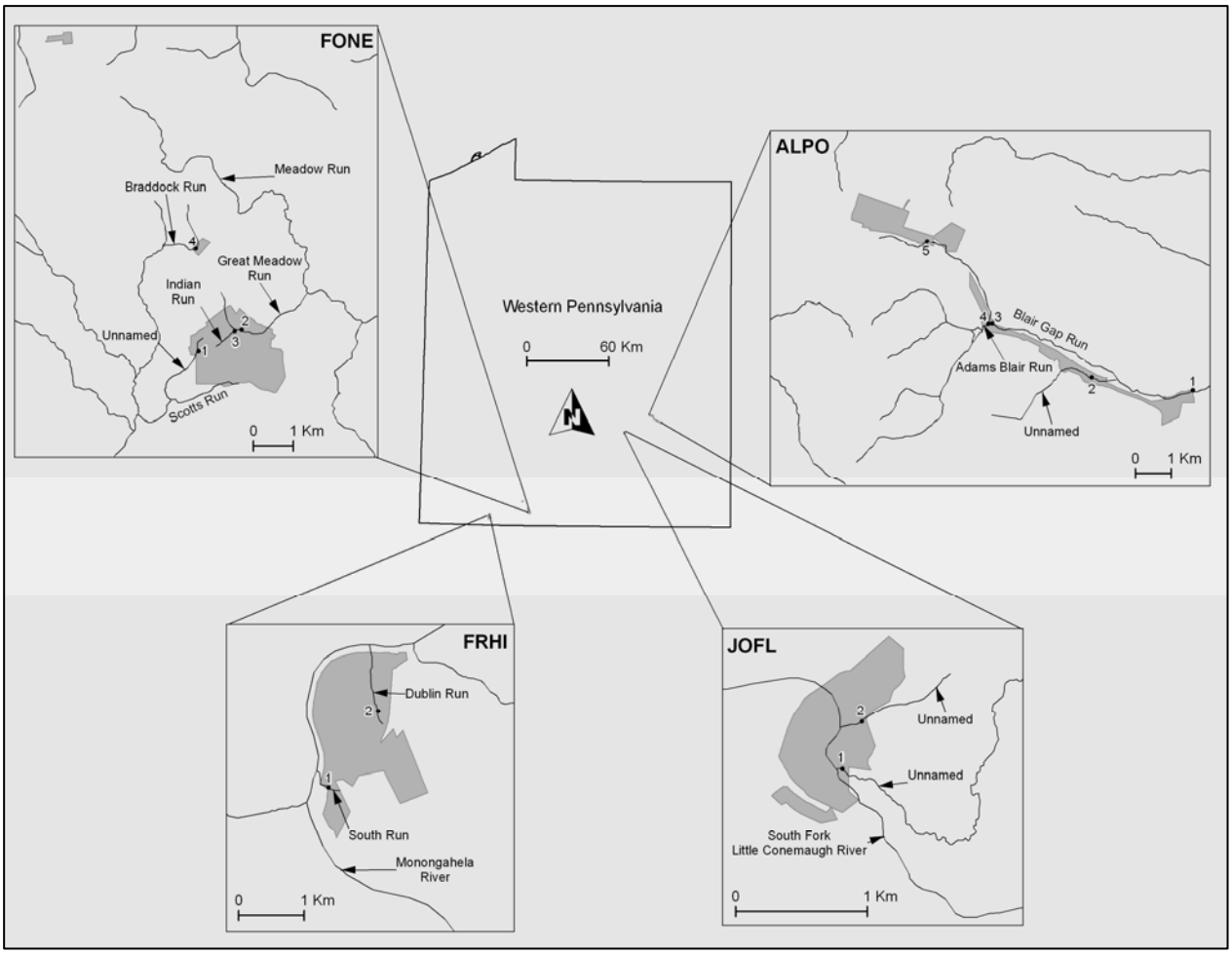

Figure 2. National Park Service properties (in grey) and associated crayfish sampling sites [denoted by closed circles (•) and numbers] in western Pennsylvania. Sites are numbered separately for each property. Fort Necessity National Battlefield (FONE), Allegheny Portage Railroad National Historic Site (ALPO), Friendship Hill National Historic Site (FRHI), and Johnstown Flood National Memorial (JOFL) properties are depicted on the map.

Methods

A total of 42 streams (53 sites) were sampled for this project (Figures 1 and 2). Sites were located on a variety of stream types and sizes, including small headwater streams (e.g., Indian Run, FONE, <0.5m [1.6 ft]wide), mid-sized streams (e.g., Marsh Creek, EISE, ~20m [66 ft] wide), and large rivers (West Branch of the Delaware River, UPDE, >50m [164 ft] wide). Surrounding vegetation ranged from closed-canopy, mostly forested to open-canopy, mainly grasses. Generally, only sites on permanent streams that fell within park boundaries were sampled. The only exception was the West Branch of the Delaware River site, which was located just upstream from the UPDE property boundary. That site was chosen because some habitat types could not be sampled efficiently at downstream locations that were within UPDE (some habitat types were difficult to access at downstream sites). Because the sampling site was only a few hundred meters upstream of the UPDE boundary, the fauna at the sampling site was likely the same as that found within the section of the West Branch of the Delaware River that falls within the UPDE property.

The number of sites sampled per stream varied from 1–3 depending on the length of stream contained within the park. At each site, multiple pool-riffle sequences were thoroughly searched and crayfish were collected from all available habitat types. Our goal was to collect a sample of all the crayfish species from each site we surveyed. At each site, the length of stream sampled varied from approximately 35–400 m (115–1,312 ft) and the time spent sampling varied from about 1 to 6 person hours, depending on stream size and habitat availability. Collections were made with dip nets and kick screens and were qualitative in nature, which allowed us to provide species lists and relative abundance data for each site. Dip net samples were collected by sweeping the net through shoreline root masses, aquatic vegetation, and leaf deposits, and by turning over rocks and chasing crayfish into the net. Kick-screen samples were collected by stretching a 2.8 × 2.0 m bag seine with 5 mm mesh across the stream channel, and disturbing (kicking, overturning rocks) the stream bottom upstream of the seine. Dislodged crayfish were swept into the seine by the current. Each site was visited on one occasion during daylight hours. Sampling occurred from 10 March–13 July 2005. Due to budgetary constraints, crayfish density (individuals per m^2) was not measured and burrowing species and species inhabiting standing waters were not collected during this study. Specimens were generally identified to species, although some immature individuals (particularly females) could only be identified to genus. Voucher specimens of each species were deposited at the Carnegie Museum of Natural History, Pittsburgh, Pennsylvania, or the Academy of Natural Sciences of Philadelphia, Philadelphia, Pennsylvania. The remaining specimens are housed at The Pennsylvania State University.

Results

Overview of Crayfish Collections

A total of 1,246 crayfish belonging to seven species were collected during this survey (Table 1). Collections included three species that are native to Pennsylvania (*Cambarus bartonii*, *Orconectes limosus*, *Orconectes obscurus*), two exotic species (northern crayfish, rusty crayfish), and two species whose status is currently unknown pending additional surveys (*Cambarus* [*Puncticambarus*] sp. [a member of the *Cambarus acuminatus* species complex, see 'Discussion']) or the collection of mature specimens that can be identified to species (*Procambarus* sp.). Crayfish were absent from the Lackawaxen River (UPDE, Site 5) and the headwaters of Blair Gap Run (ALPO, Site 5), despite an abundance of suitable habitat at both sites, but were present at the other 51 sites that were surveyed (Table 2). Individual parks and individual sites typically supported 1-2 species of crayfish. Common species pairs included *Cambarus bartonii* and *Orconectes obscurus* (found in ALPO and JOFL), *Cambarus bartonii* and *Orconectes limosus* (found in DEWA and UPDE), and *Cambarus bartonii* and *Orconectes virilis* (found in GETT).

Species Distributions

Of the three native species collected during this survey, *Cambarus bartonii* exhibited the widest distribution. It was found at 43 of the 53 sites and 9 of the 10 properties that were sampled (Figure 3; Tables 1 and 2). In contrast, *Orconectes obscurus* was limited to NPS properties in western Pennsylvania and was only found at three sites and two properties (ALPO, JOFL) (Figure 4; Tables 1 and 2). Similarly, *Orconectes limosus* was limited to NPS properties in eastern Pennsylvania and was found at eight sites and two properties (DEWA, UPDE) (Figure 5; Tables 1 and 2).

Exotic species exhibited limited distributions within Pennsylvania's NPS properties and, except for the collection of one rusty crayfish in UPDE, were restricted to properties in the south-central part of the state. More specifically, rusty crayfish were found at three sites and two properties (EISE, UPDE) and northern crayfish were found at ten sites and two properties (EISE, GETT) (Figures 6 and 7; Tables 1 and 2).

Cambarus (*Puncticambarus*) sp. and *Procambarus* sp. were also limited to specific NPS properties. During this survey, *Cambarus* (*Puncticambarus*) sp. was only found at one VAFO site (Figure 8; Tables 1 and 2); although previous surveys indicated that it occurs at several other sites within VAFO (see 'Discussion'). *Procambarus* sp. was also found at only one site and one property (EISE) (Figure 9; Tables 1 and 2).

Relative Abundance

Native species dominated collections at eight of the 10 NPS properties that were surveyed (Table 1). *Cambarus bartonii* was typically the most abundant native species collected, accounting for at least 75% of the individuals collected at five properties (DEWA, FRHI, HOFU, UPDE, VAFO) and at least 50% of the individuals collected at two other properties (ALPO, FONE).

Table 1. Crayfish collections at 10 National Park Service properties in Pennsylvania. Each park was visited on one occasion during daylight hours. Sampling occurred from 10 March–13 July 2005. NPS properties abbreviated as in Figures 1 and 2.

Park	Species	Number collected	Relative abundance (%)*
ALPO	*Cambarus bartonii*	23	61
	Cambarus sp.	8	21
	Orconectes obscurus	3	8
	Orconectes sp.	4	11
DEWA	*Cambarus bartonii*	205	79
	Orconectes limosus	56	21
EISE	*Orconectes rusticus*†	349	95
	Orconectes virilis†	10	3
	Orconectes sp.	3	1
	Procambarus sp.	5	1
FONE	*Cambarus bartonii*	58	51
	Cambarus sp.	56	49
FRHI	*Cambarus bartonii*	20	80
	Cambarus sp.	5	20
GETT	*Cambarus bartonii*	38	21
	Cambarus sp.	6	3
	Orconectes virilis†	127	72
	Orconectes sp.	6	3
HOFU	*Cambarus bartonii*	132	94
	Cambarus sp.	8	6
JOFL	*Cambarus bartonii*	18	42
	Cambarus sp.	3	7
	Orconectes obscurus	20	47
	Orconectes sp.	2	5
UPDE	*Cambarus bartonii*	44	86
	Orconectes limosus	6	12
	Orconectes rusticus†	1	2
VAFO	*Cambarus* (*P.*) sp.‡	1	3
	Cambarus bartonii	24	80
	Cambarus sp.	5	17

* Relative abundance is the percentage of total crayfish found within each park. Relative abundances calculated separately for each Park and due to rounding errors may not sum to exactly 100%.

† Not native to Pennsylvania.

‡ *Cambarus* (*Puncticambarus*) sp.; a member of the *Cambarus acuminatus* species complex.

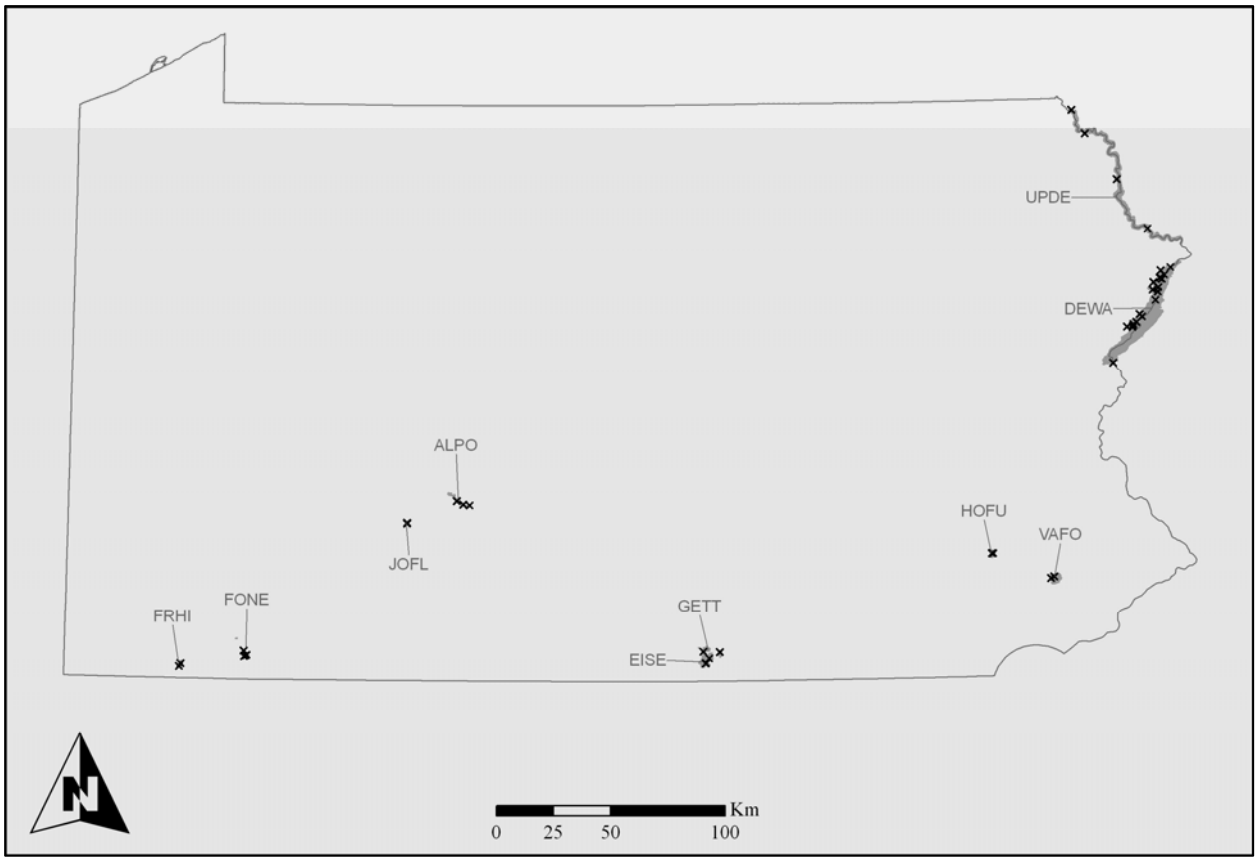

Figure 3. Pennsylvania with National Park Service properties (in grey) and *Cambarus bartonii* locations [denoted by **x**] included. Each park was visited on one occasion during daylight hours. Sampling occurred from 10 March–13 July 2005. Park abbreviations as in Figures 1 and 2.

Table 2. Crayfish collections at individual sites within 10 National Park Service properties in Pennsylvania. Each park was visited on one occasion during daylight hours. Sampling occurred from 10 March–13 July 2005. NC indicates that no crayfish were collected at that site. The following abbreviations used: tr=tributary, WB=West Branch, SF=South Fork, R=River, Un=unnamed, and L=Little. Park abbreviations as in Figures 1 and 2.

Park	Stream	Site	Latitude, Longitude	Species	N	Rel abund (%)*
ALPO	Adams Blair Run	4	40.43273, 78.52025	*Cambarus bartonii*	2	50
				Orconectes obscurus	2	50
	Blair Gap Run	1	40.41599, 78.45256	*Cambarus bartonii*	3	43
				Orconectes sp.	4	57
		3	40.43278, 78.51903	*Cambarus bartonii*	7	88
				Orconectes obscurus	1	13
		5	40.45336, 78.54076	NC	NC	NC
	Un tr to Blair Gap Run	2	40.41914, 78.48606	*Cambarus bartonii*	11	58
				Cambarus sp.	8	42
DEWA	Adams Creek	1	41.23926, 74.86641	*Cambarus bartonii*	12	100
		14	41.26031, 74.89008	*Cambarus bartonii*	13	100
	Brodhead Creek	20	40.99335, 75.13753	*Orconectes limosus*	1	100
	Bushkill Creek	8	41.09174, 75.00281	*Cambarus bartonii*	9	100
		10	41.08829, 75.03781	*Cambarus bartonii*	7	100
	Conashaugh Creek	2	41.27100, 74.84804	*Cambarus bartonii*	7	100
		13	41.27584, 74.85761**	*Cambarus bartonii*	54	100
	Dingmans Creek	5	41.22220, 74.86913	*Cambarus bartonii*	6	86
				Orconectes limosus	1	14
		6	41.22971, 74.89656	*Cambarus bartonii*	13	72
				Orconectes limosus	5	28
	Hornbecks Creek	7	41.18989, 74.88419	*Cambarus bartonii*	2	100
		15	41.19581, 74.90902	*Orconectes limosus*	38	100
	L Bushkill Creek	18	41.09816, 75.00406	*Cambarus bartonii*	1	100
	Randall Creek	17	41.10548, 74.98750	*Cambarus bartonii*	9	100
	Raymondskill Creek	3	41.28725, 74.83373	*Cambarus bartonii*	2	25
				Orconectes limosus	6	75
		12	41.30567, 74.85138	*Cambarus bartonii*	4	44
				Orconectes limosus	5	56
	Sand Hill Creek	9	41.08550, 75.00794	*Cambarus bartonii*	30	100
	Sawkill Creek	4	41.31704, 74.79946	*Cambarus bartonii*	1	100
	Slateford Creek	19	40.94677, 75.11499	*Cambarus bartonii*	19	100
	Toms Creek	11	41.12599, 74.95592	*Cambarus bartonii*	6	100
		16	41.13627, 74.96823**	*Cambarus bartonii*	10	100
EISE	Marsh Creek	1	39.79295, 77.27826	*Orconectes rusticus*†	282	96
				Orconectes virilis†	8	3
				Orconectes sp.	3	1
	Willoughby Run	2	39.79032, 77.27343	*Orconectes rusticus*†	67	91
				Orconectes virilis†	2	3
				Procambarus sp.	5	7

Table 2. Crayfish collections at individual sites within 10 National Park Service properties in Pennsylvania (continued). Each park was visited on one occasion during daylight hours. Sampling occurred from 10 March–13 July 2005. NC indicates that no crayfish were collected at that site. The following abbreviations used: tr=tributary, WB=West Branch, SF=South Fork, R=River, Un=unnamed, and L=Little. Park abbreviations as in Figures 1 and 2.

Park	Stream	Site	Latitude, Longitude	Species	N	Rel abund (%)*
FONE	Braddock Run	4	39.83302, 79.60108	*Cambarus bartonii*	27	93
				Cambarus sp.	2	7
	Great Meadow Run	2	39.81514, 79.58733	*Cambarus bartonii*	12	19
				Cambarus sp.	50	81
	Indian Run	3	39.81478, 79.58935	*Cambarus bartonii*	6	75
				Cambarus sp.	2	25
	Un tr to Scotts Run	1	39.81024, 79.59974	*Cambarus bartonii*	13	87
				Cambarus sp.	2	13
FRHI	Dublin Run	2	39.77799, 79.92220	*Cambarus bartonii*	15	75
				Cambarus sp.	5	25
	South Run	1	39.76738, 79.93076	*Cambarus bartonii*	5	100
GETT	Culp Run	4	39.82853, 77.22500	*Cambarus* sp.	3	43
				Orconectes virilis†	4	57
	Guinn Run	5	39.80964, 77.22598	*Cambarus bartonii*	2	67
				Orconectes sp.	1	33
	Un tr to Willoughby Run	7	39.84450, 77.25380	*Orconectes virilis*†	14	100
	Plum Run 1	1	39.79149, 77.24121	*Cambarus bartonii*	2	11
				Orconectes virilis†	11	61
				Orconectes sp.	5	28
		2	39.79020, 77.24428	*Cambarus bartonii*	3	12
				Cambarus sp.	3	12
				Orconectes virilis†	19	76
	Plum Run 2	6	39.83544, 77.17184	*Cambarus bartonii*	27	90
				Orconectes virilis†	3	10
	Rock Creek	3	39.81516, 77.21516	*Orconectes virilis*†	19	100
	Stevens Run	8	39.82513, 77.24244	*Orconectes virilis*†	6	100
	Willoughby Run	9	39.83642, 77.25590	*Cambarus bartonii*	4	7
				Orconectes virilis†	51	93
HOFU	Baptism Creek	2	40.20717, 75.76261	*Cambarus bartonii*	52	100
	Spout Run	1	40.20740, 75.76910	*Cambarus bartonii*	80	91
				Cambarus sp.	8	9
JOFL	Un tr 1 to SF L Conemaugh R	1	40.34325, 78.77422	*Cambarus bartonii*	11	31
				Cambarus sp.	3	8
				Orconectes obscurus	20	56
				Orconectes sp.	2	6
	Un tr 2 to SF L Conemaugh R	2	40.34652, 78.77249	*Cambarus bartonii*	7	100

Table 2. Crayfish collections at individual sites within 10 National Park Service properties in Pennsylvania (continued). Each park was visited on one occasion during daylight hours. Sampling occurred from 10 March–13 July 2005. NC indicates that no crayfish were collected at that site. The following abbreviations used: tr=tributary, WB=West Branch, SF=South Fork, R=River, Un=unnamed, and L=Little. Park abbreviations as in Figures 1 and 2.

Park	Stream	Site	Latitude, Longitude	Species	N	Rel abund (%)*
UPDE	Calkins Creek	2	41.67189, 75.06333	*Cambarus bartonii*	12	67
				Orconectes limosus	5	28
				Orconectes rusticus†	1	6
	Equinunk Creek	1	41.85565, 75.22492	*Cambarus bartonii*	19	100
	Lackawaxen River	5	41.48639, 74.99190	NC	NC	NC
	Shohola Creek	4	41.47297, 74.91161	*Cambarus bartonii*	1	100
	WB of the Delaware R	3	41.95278, 75.29115	*Cambarus bartonii*	12	92
				Orconectes limosus	1	8
VAFO	Fawn Run	1	40.10846, 75.45197	*Cambarus bartonii*	7	78
				Cambarus sp.	2	22
	Welch Run	2	40.10337, 75.46904	*Cambarus* (*P.*) sp.‡	1	5
				Cambarus bartonii	17	81
				Cambarus sp.	3	14

* Relative abundance is the percentage of total crayfish found within each site. Relative abundances calculated separately for each site and due to rounding errors may not sum to exactly 100%.

** Coordinates not taken at exact sampling location because of extensive canopy cover.

† Not native to Pennsylvania.

‡ *Cambarus* (*Puncticambarus*) sp.; a member of the *Cambarus acuminatus* species complex.

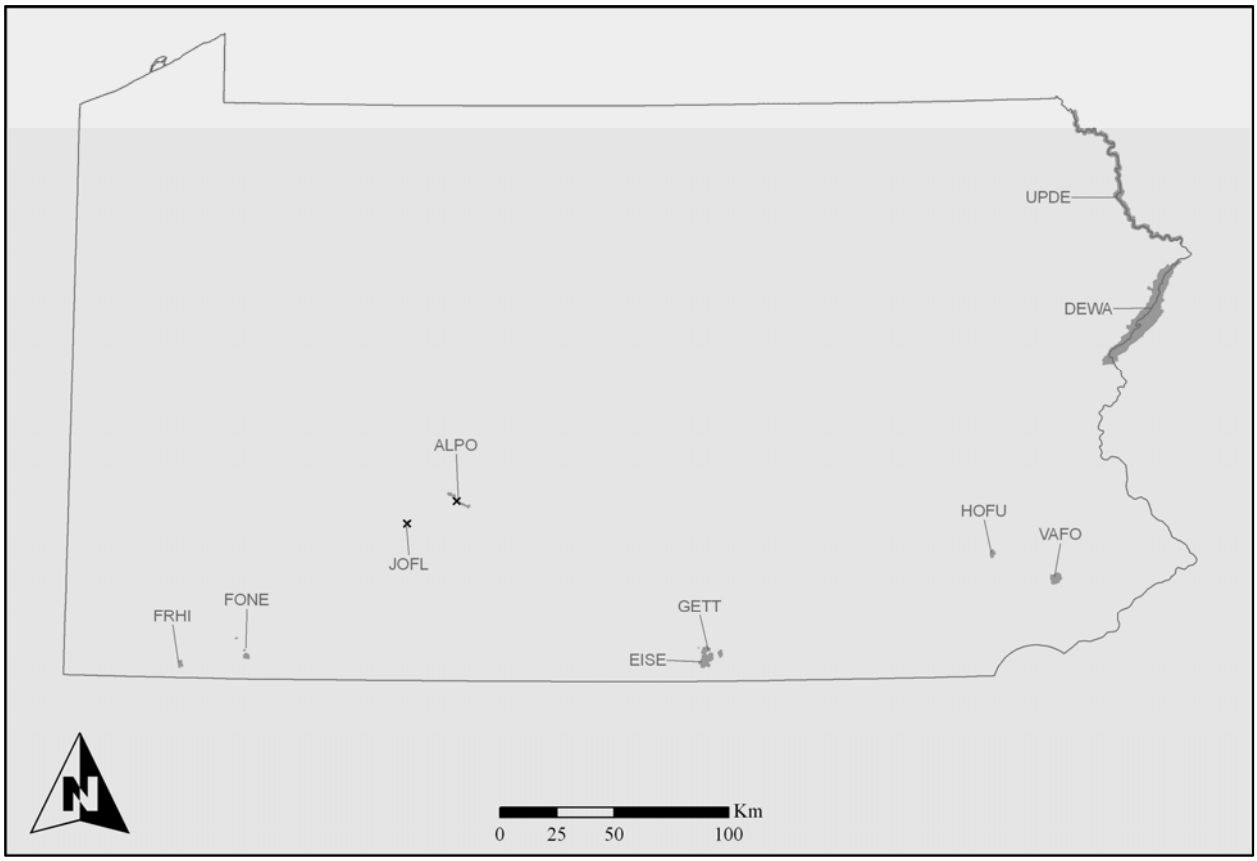

Figure 4. Pennsylvania with National Park Service properties (in grey) and *Orconectes obscurus* locations [denoted by **x**] included. Each park was visited on one occasion during daylight hours. Sampling occurred from 10 March–13 July 2005. Park abbreviations as in Figures 1 and 2.

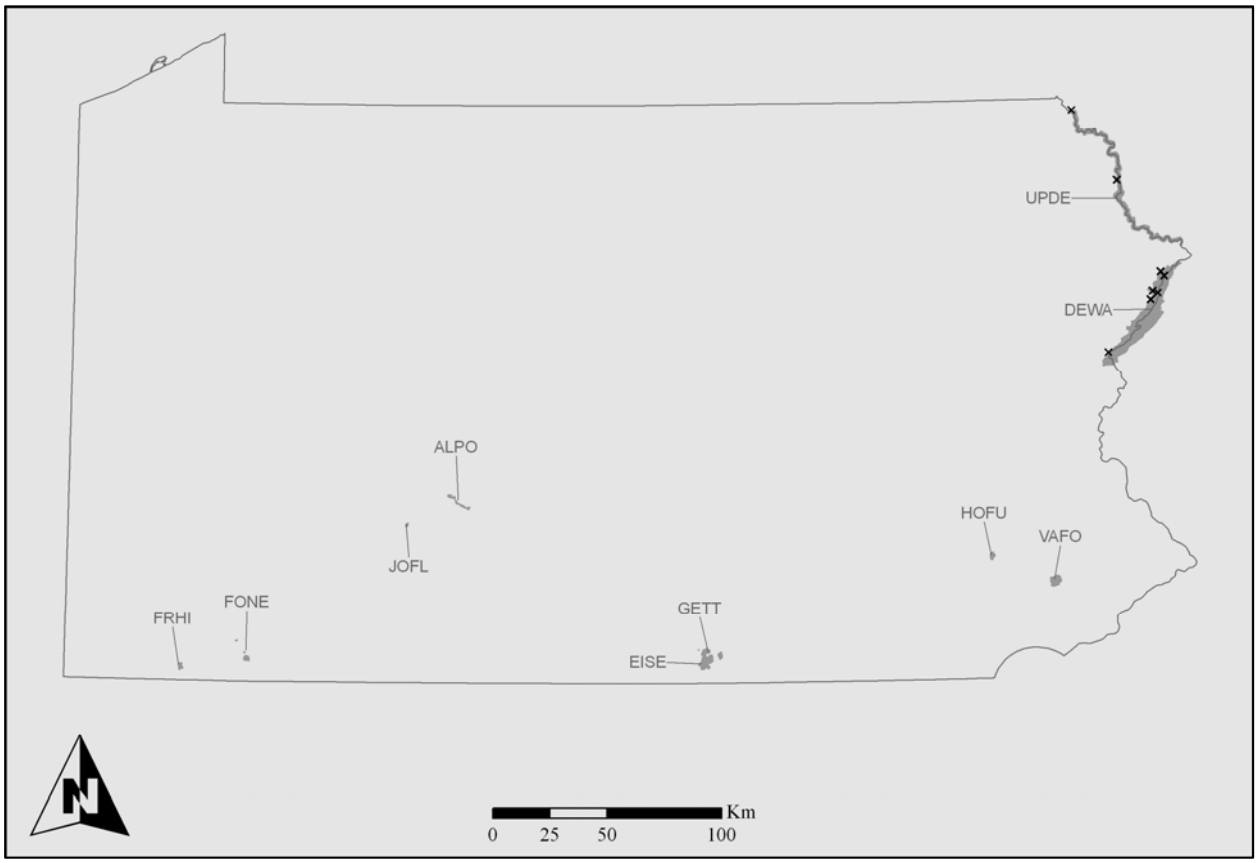

Figure 5. Pennsylvania with National Park Service properties (in grey) and *Orconectes limosus* locations [denoted by **x**] included. Each park was visited on one occasion during daylight hours. Sampling occurred from 10 March–13 July 2005. Park abbreviations as in Figures 1 and 2.

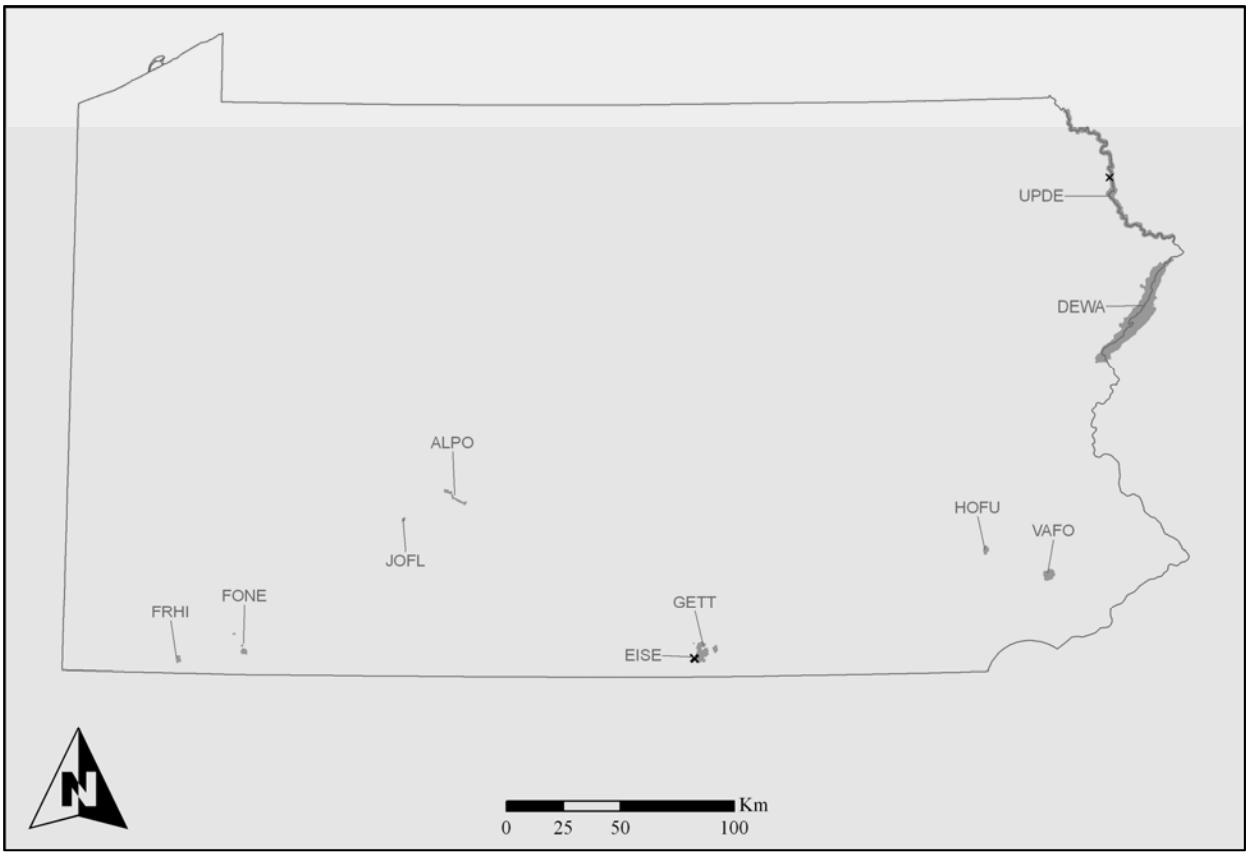

Figure 6. Pennsylvania with National Park Service properties (in grey) and *Orconectes rusticus* locations [denoted by **x**] included. Each park was visited on one occasion during daylight hours. Sampling occurred from 10 March–13 July 2005. Park abbreviations as in Figures 1 and 2.

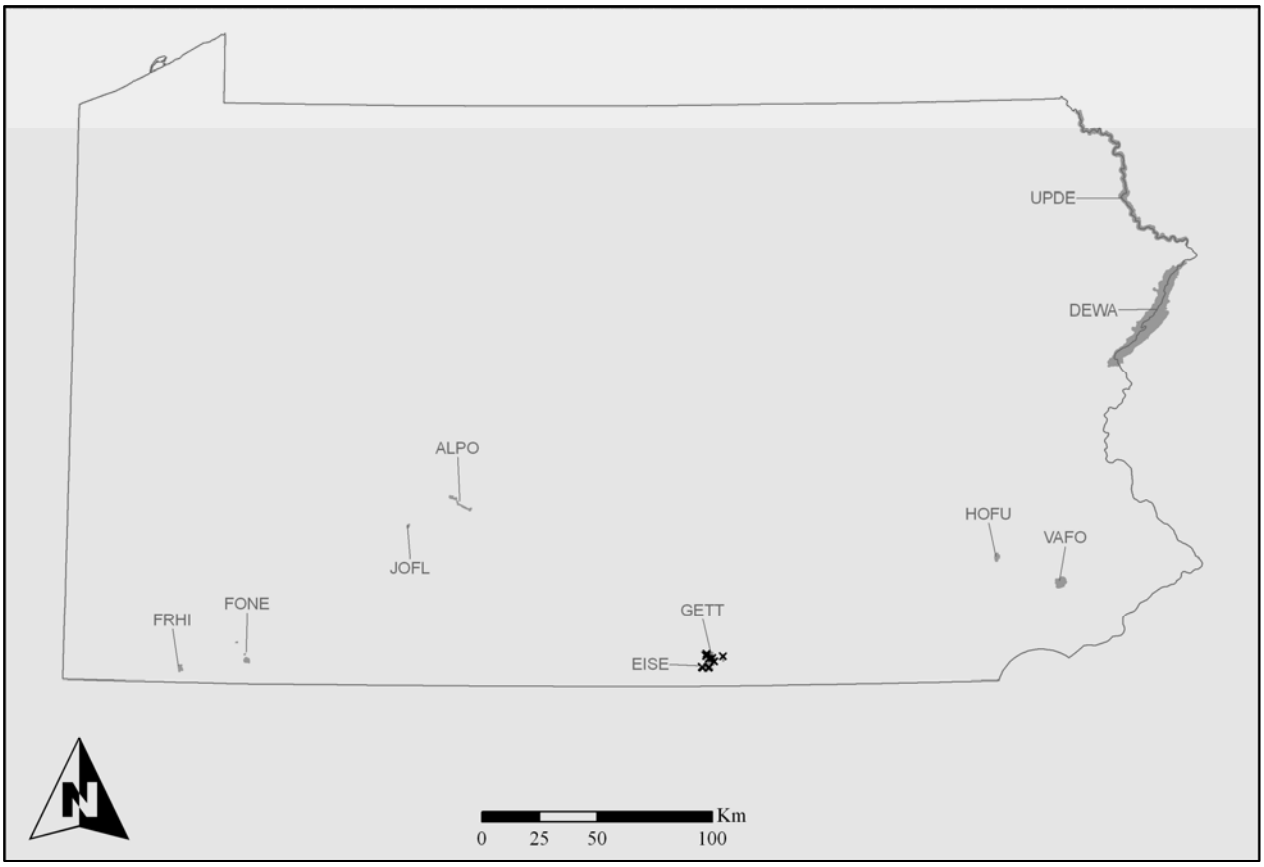

Figure 7. Pennsylvania with National Park Service properties (in grey) and *Orconectes virilis* locations [denoted by **x**] included. Each park was visited on one occasion during daylight hours. Sampling occurred from 10 March–13 July 2005. Park abbreviations as in Figures 1 and 2.

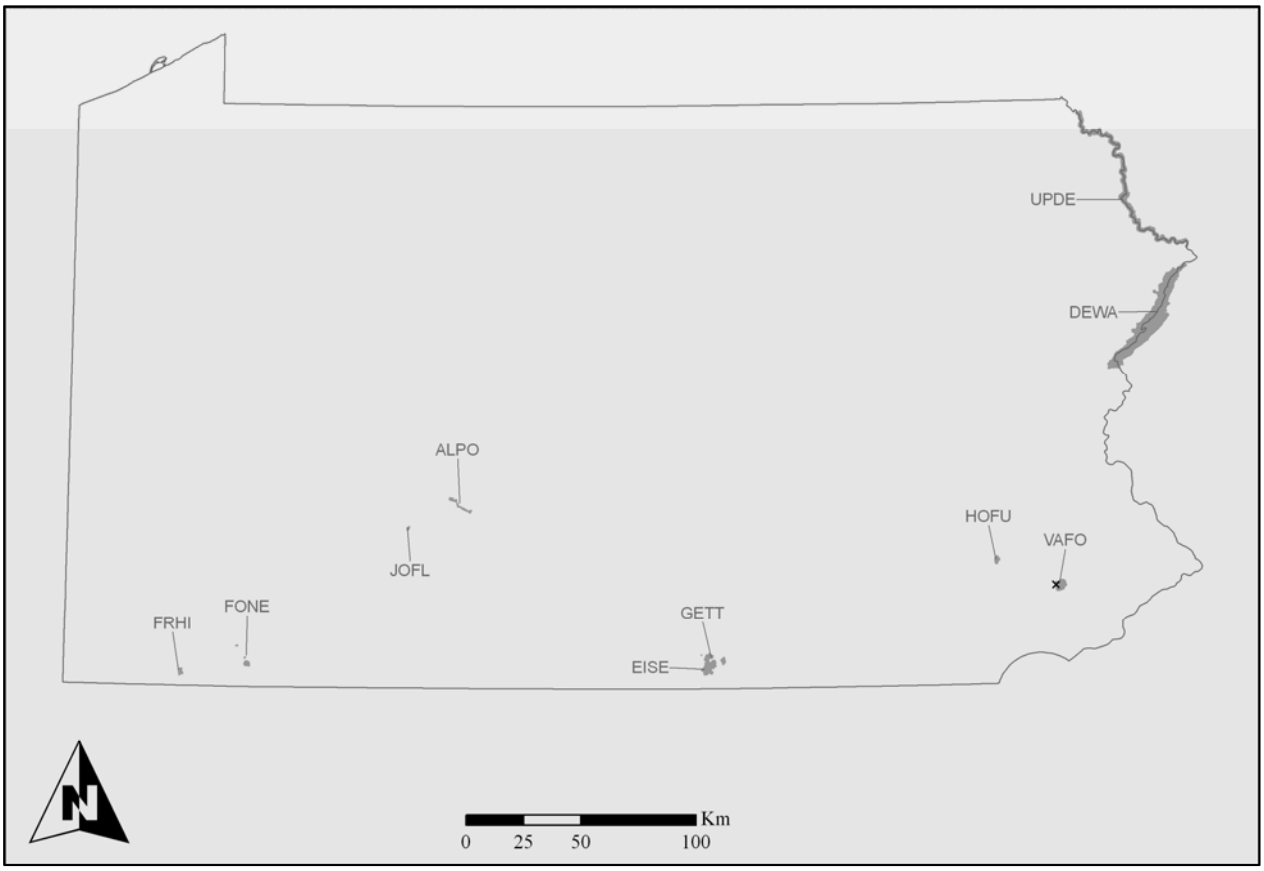

Figure 8. Pennsylvania with National Park Service properties (in grey) and *Cambarus* (*Puncticambarus*) sp. (a member of the *Cambarus acuminatus* species complex) locations [denoted by **x**] included. Each park was visited on one occasion during daylight hours. Sampling occurred from 10 March–13 July 2005. Park abbreviations as in Figures 1 and 2.

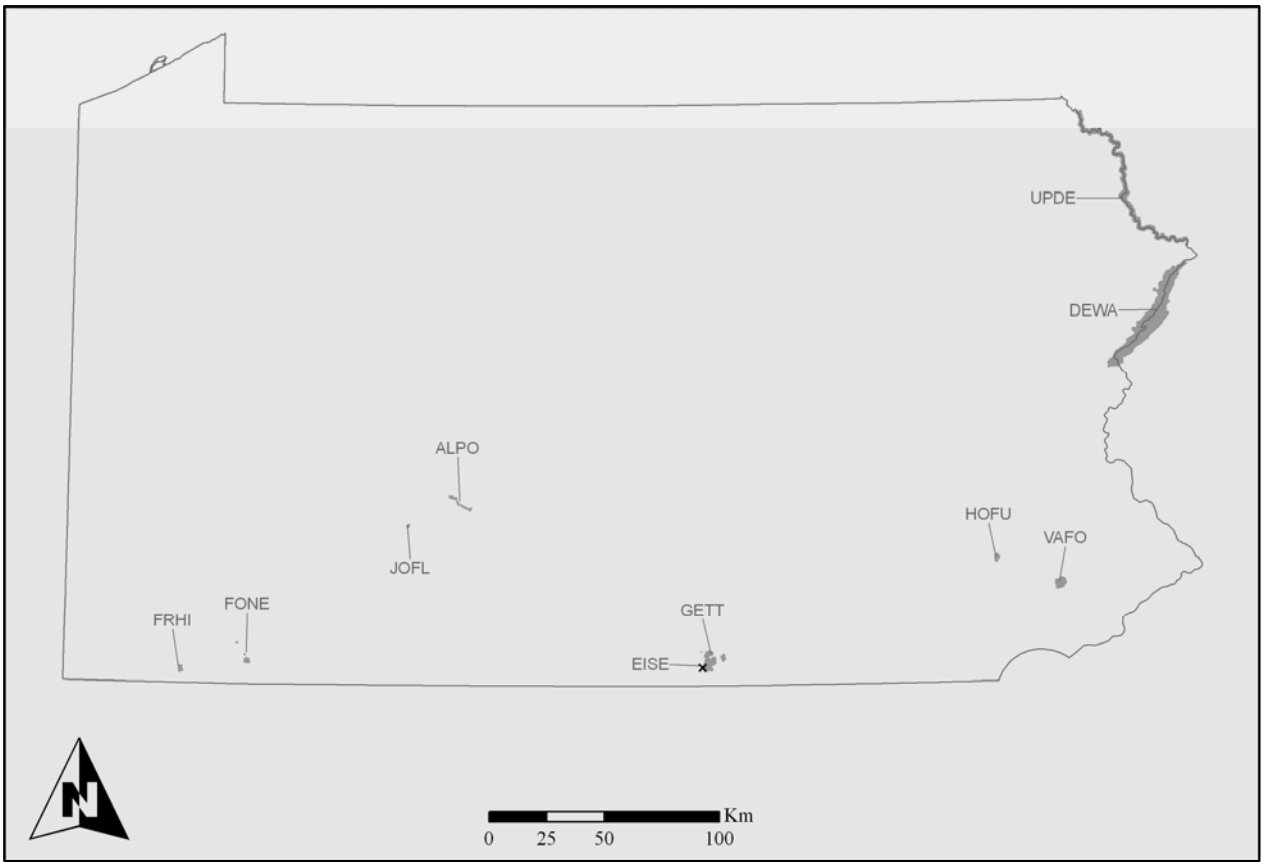

Figure 9. Pennsylvania with National Park Service properties (in grey) and *Procambarus* sp. locations [denoted by **x**] included. Each park was visited on one occasion during daylight hours. Sampling occurred from 10 March–13 July 2005. Park abbreviations as in Figures 1 and 2.

Although *Orconectes obscurus* was collected at two NPS properties, it was only common at one of them (JOFL, 47% of the individuals collected). *Orconectes limosus* was also collected at two NPS properties, but was relatively uncommon at both (12–21% of the individuals collected).

Although exotic species were only present at three NPS properties (see above), they dominated collections at two of them, accounting for 98% of the crayfish collected at EISE and 72% of the crayfish collected at GETT (Table 1). In contrast, exotics were uncommon at UPDE, accounting for only 2% of the crayfish collected. Exotic collections included both rusty crayfish and northern crayfish at EISE (95% and 3% of collections, respectively), but only northern crayfish at GETT and only rusty crayfish at UPDE.

Where found, *Cambarus* (*Puncticambarus*) sp. and *Procambarus* sp. were uncommon (Table 1). More specifically, *Cambarus* (*Puncticambarus*) sp. accounted for 3% of the crayfish collections at VAFO and *Procambarus* sp. accounted for 1% of the crayfish collections at EISE.

Relative abundances at smaller scales (individual sites) reflected the larger scale patterns described above. For example, *Cambarus bartonii* accounted for at least 75% of the crayfish collected at 24 of the 31 sites located within the DEWA, FRHI, HOFU, UPDE, and VAFO properties (Table 2). Within those properties, sites that were not dominated by *Cambarus bartonii*, either were devoid of crayfish (Lackawaxen River, UPDE) or supported substantial populations of *Orconectes limosus* (e.g., Hornbecks Creek, Site 15, DEWA).

Exotic crayfish also tended to be very common at the sites where they were found. For example, northern crayfish dominated collections (>75% of the individuals found) at five of the nine GETT sites and may have completely eliminated native crayfish from sections of three streams (an unnamed tributary to Willoughby Run, Rock Creek, and Stevens Run) contained within the park (Table 2). Similarly, rusty crayfish accounted for >90% of the crayfish collected at both the EISE sites and may, along with the northern crayfish, have extirpated native crayfish from the section of Marsh Creek that flows through the park.

In contrast, *Cambarus* (*Puncticambarus*) sp. and *Procambarus* sp. tended to be uncommon at individual sites. For example, *Cambarus* (*Puncticambarus*) sp. accounted for 5% and *Procambarus* sp. accounted for 7% of the crayfish collected at individual sites (Table 2).

Discussion

A total of seven species [*Cambarus bartonii*, *Cambarus* (*Puncticambarus*) sp., *Orconectes limosus*, *Orconectes obscurus*, *Orconectes rusticus*, *Orconectes virilis*, and immature *Procambarus* (likely *Procambarus acutus*)] were collected from Pennsylvania's NPS properties during this survey. Three of these species (*Cambarus bartonii*, *Orconectes limosus*, *Orconectes obscurus*) are native to Pennsylvania (Taylor et al. 1996), two (*Orconectes rusticus*, *Orconectes virilis*) are well-established exotics (Taylor et al. 1996), and the status of the other two is unknown pending either additional surveys [*Cambarus* (*Puncticambarus*) sp., see Lieb et al. 2007] or the collection of mature specimens that can be identified to species (*Procambarus* sp.). These collections indicate that at least 60% of the epigean (surface-dwelling) crayfish species that occur in Pennsylvania can be found on National Park Service properties (70% if immature *Procambarus* turn out to be *Procambarus acutus*). The only epigean species that are known to occur in Pennsylvania that were not found during this survey were *Cambarus* (*Puncticambarus*) *robustus* (a native), *Orconectes immunis* (an exotic), and *Orconectes propinquus* (a native).

Unfortunately, exotic rusty crayfish are also present in two NPS properties in Pennsylvania (EISE, UPDE) and another invader, the northern crayfish, is present in GETT and EISE. Exotics appear to be particularly problematic in GETT and EISE with several streams that support high densities of invaders completely devoid of natives. In contrast, rusty crayfish densities are very low in the UPDE property (only one specimen found in Calkins Creek), indicating that the park may be in the very early stages of a rusty crayfish invasion. Actions to prevent further spread and eradicate existing populations of rusty crayfish in UPDE would therefore be prudent if native crayfish populations are to be preserved. The collection of rusty crayfish from EISE and UPDE during this survey and numerous locations in southeastern (SE) Pennsylvania during other ongoing surveys (D. A. Lieb, The Pennsylvania State University, unpublished data) may be bad news for a population of rare crayfish [*Cambarus* (*Puncticambarus*) sp.] that occurs in Valley Creek within VAFO [see Lieb et al. (2007) for additional discussion of the conservation status and taxonomy of this species]. This is because of the known propensity of the rusty crayfish to extirpate native crayfishes in Pennsylvania (D. A. Lieb, The Pennsylvania State University, unpublished data) and elsewhere (Lodge et al. 2000).

During this survey, *Cambarus* (*Puncticambarus*) sp. was only collected from one location (Welch Run, VAFO) where it was extremely uncommon (only one individual collected). Because of its scarcity, it seems unlikely that a reproducing population of *Cambarus* (*Puncticambarus*) sp. occurs in Welch Run. Instead, the individual collected there was probably a vagrant from nearby Valley Creek, where the species is common (Lieb et al. 2007). Based on this survey and other ongoing surveys, we now believe that reproducing populations of *Cambarus* (*Puncticambarus*) sp. are present in fewer than five streams in Pennsylvania (D. A. Lieb, The Pennsylvania State University, unpublished data). All of those streams are located in rapidly expanding urban areas in the vicinity of populations of rusty crayfish, and are therefore at risk for extirpation. In fact, we believe that *Cambarus* (*Puncticambarus*) sp. is likely one of the most threatened aquatic species in Pennsylvania.

The collection of *Cambarus bartonii* from NPS properties across the state, *Orconectes obscurus* from NPS properties in western Pennsylvania (PA), and *Orconectes limosus* from NPS

properties in eastern PA was expected due to their natural distributions (i.e., *bartonii* is found throughout most of PA and *limosus* and *obscurus* are found in eastern and western PA, respectively [Ortmann 1906; Jezerinac et al. 1995]). In contrast, no *a priori* predictions regarding the distributions of *Orconectes rusticus* and *Orconectes virilis* could be made because both are relatively recent invaders, whose distributions in PA are poorly known (D. A. Lieb, The Pennsylvania State University, unpublished data). Similarly, the distributions of *Cambarus* (*Puncticambarus*) sp. and *Procambarus* sp. in PA are not well known (Lieb et al. 2007; D. A. Lieb, The Pennsylvania State University, unpublished data). Thus, the collection of *Orconectes rusticus*, *Orconectes virilis*, and *Procambarus* sp. from NPS properties in south-central PA; *Cambarus* (*Puncticambarus*) sp. from NPS properties in southeastern PA; and *Orconectes rusticus* from NPS properties in northeastern PA was not entirely unexpected.

The absence of *Cambarus* (*Puncticambarus*) *robustus*, *Orconectes propinquus*, and *Orconectes immunis* from NPS properties in this survey was also not unexpected based on their known distributions and biology. For example, although the distribution of *Cambarus* (*Puncticambarus*) *robustus* includes western PA (Ortmann 1906; Jezerinac et al. 1995; Taylor and Schuster 2004), its absence from NPS properties in the western part of the state (e.g., FONE, FRHI) is likely due to its preference for medium to larger streams and rivers (Ortmann 1906; Jezerinac et al. 1995; Taylor and Schuster 2004), which are largely absent from those properties. *Orconectes propinquus* was not collected during this survey because NPS properties do not fall within the known range of the species (Ortmann 1906, Page 1985; D. A. Lieb, The Pennsylvania State University, unpublished data). Similarly, *Orconectes immunis* was absent from our collections because it is currently only known from a few locations in PA (D. A. Lieb, The Pennsylvania State University, unpublished data), which are not on NPS property. Additional information regarding the biology and distribution of the crayfish species that were collected during this survey can be found in the references cited in this and the preceding paragraph.

Of the 53 sites that were surveyed, only the Lackawaxen River (UPDE, Site 5) and the headwaters of Blair Gap Run (ALPO, Site 5) were devoid of crayfish. Inputs of acid mine drainage (AMD) upstream of our sampling site (D. A. Lieb, The Pennsylvania State University, personal observations) may have contributed to the absence of crayfish in the headwaters of Blair Gap Run; whereas, crayfish were absent from our Lackawaxen River site despite the existence of large stretches of suitable habitat and no visible sources of pollution. At other sites crayfish were present but few were collected [e.g., Shohola Creek (UPDE) and Sawkill Creek, Little Bushkill Creek, and Brodhead Creek (DEWA)]. Although it is possible that anthropogenic factors may have contributed to the scarcity of crayfish at some sites, it is also possible that some of these sites naturally support few crayfish. Unfortunately, explanations remain speculative at best because we know little about what factors (anthropogenic or otherwise) influence crayfish abundance in Pennsylvania or elsewhere.

Conclusions and Management Recommendations

Based on this survey and other ongoing surveys, it is clear that NPS properties represent an important reservoir of crayfish diversity in Pennsylvania. At least 60% of the epigean (surface-dwelling) crayfish species that occur in Pennsylvania can be found on NPS property (70% if immature *Procambarus* turn out to be *Procambarus acutus*). The presence of a reproducing population of *Cambarus* (*Puncticambarus*) sp., which is one of the most threatened aquatic species in the state, on NPS property (Valley Creek, VAFO) is particularly noteworthy.

Unfortunately, it seems unlikely, given ongoing threats from urbanization and exotic species, that this reservoir of crayfish diversity can be maintained without proactive strategies to protect existing populations of native crayfish. Currently, seven of the ten NPS properties that were surveyed were free from exotic crayfish, at least at the sites that were sampled. If this is to be maintained, programs aimed at educating the public about the dangers of moving crayfish from one water body to another are needed to prevent introductions of exotic crayfish to waters where they do not currently exist. The establishment of signs along streams, particularly those subject to heavy recreational activity (e.g., fishing pressure), warning the public not to release crayfish into the water would also be beneficial. This is especially needed along Valley Creek because of the presence of a rare crayfish [*Cambarus* (*Puncticambarus*) sp.] there and the existence of nearby populations of rusty crayfish. Because exotic crayfish are difficult to extirpate once they become established (particularly rusty crayfish), educational programs likely offer the best opportunity to prevent future introductions of exotic crayfish (Hamr 2002), and are essential if the native populations of crayfish that occur within Pennsylvania's NPS properties are to be preserved.

Urbanization and resulting habitat alterations and influx of toxic chemicals and sediment (Lieb and Carline 2000) also represent a significant threat to Pennsylvania's aquatic resources (including the crayfish populations that occur on NPS properties). Valley Creek, because of its location in the suburbs of Philadelphia, appears particularly vulnerable (see Kemp and Spotila 1997). Although efforts to mitigate the effects of urbanization on Valley Creek are likely needed to ensure the preservation of the rare crayfish which it supports [*Cambarus* (*Puncticambarus*) sp.], such efforts, and their potential effect on *Cambarus* (*Puncticambarus*) sp., should be considered carefully prior to being enacted. Similarly, any management activities that have the potential to effect Valley Creek's population of *Cambarus* (*Puncticambarus*) sp. should be thoroughly evaluated before being implemented.

Given that crayfish are a functionally important component of streams and rivers in Pennsylvania (see 'Introduction'), it would seem prudent to periodically survey the crayfish communities that exist on NPS properties. This would seem especially important given ongoing threats from urbanization and exotic species and the presence of a very rare crayfish [*Cambarus* (*Puncticambarus*) sp.] on NPS property. The exclusion of crayfish from routine monitoring programs that include other benthic macroinvertebrates is problematic, given the pronounced effect crayfish often have on the rest of the benthic community (see 'Introduction').

Because UPDE appears to be in the very early stages of a rusty crayfish invasion, additional surveys in that particular NPS property are badly needed. Additional collections along the entire length of Calkins Creek and its major tributaries would be the first logical step. This would

allow the extent of the invasion within the Calkins Creek watershed to be determined. Collections from adjacent ponds or lakes, nearby bait shops, and the Delaware River in the vicinity of Calkins Creek should also be made and would provide useful information regarding potential source populations. If it is found that the individual collected during this survey was a vagrant from a nearby pond or lake population than crayfish poisons could be used to treat the lake, preventing future introductions. If it is found that local bait shops are selling rusty crayfish, then those operations could be halted (it is currently illegal to sell or possess rusty crayfish in PA), also preventing future introductions.

It is important to note that, although most of Pennsylvania's epigean crayfish species can be found within park boundaries, individual parks rarely supported more than two species and many supported only one species of crayfish. This highlights the importance of maintaining a network of NPS properties in Pennsylvania that include a variety of locations and habitat types.

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National Park Service
U.S. Department of the Interior

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