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Short communication

Do schools and golf courses represent emerging pathways for crayfish invasions?

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Abstract

Prevention is frequently promoted as the most desirable management strategy for biological invasions. Crayfish introductions are typically associated with aquaculture and bait bucket releases, but here we report two alternate pathways that may be responsible for the recent invasion of *Procambarus clarkii* (Girard, 1852) and *Orconectes virilis* (Hagen, 1870) in Washington State, U.S.A. Using distributional data and personal interviews we identified (1) school science programs, which use crayfish as laboratory organisms, as a likely pathway of introductions, and (2) golf courses bordering lakes, in which ponds have been constructed and are suspected to be stocked with *O. virilis* to control aquatic macrophytes. Particularly concerning, we found the highly invasive crayfish *Orconectes rusticus* (Girard, 1852) in use as a laboratory organism at multiple schools, although this species is not known to be established in the region. Vector management is critical for interrupting the transfer of invasive species, and our study has identified two emerging pathways that require greater research attention and stricter regulation.

Key words: biological supply, laboratory organisms, *Orconectes rusticus*, *Orconectes virilis*, pond management, *Procambarus clarkii*

Prevention is widely recognized as the cornerstone of most invasive species management strategies, because once a species establishes a self-sustaining population, eradication is near impossible and impacts on native communities are inevitable (Hulme 2006). Successful prevention relies on identifying where non-native species are being introduced and where they originate from, and intervening through a suite of management strategies such as education and regulation (Vander Zanden and Olden 2008). For invasive crayfish, which have demonstrated impacts on native populations, communities, ecosystems and human economies (Lodge et al. 2000; Gherardi 2007), well-documented pathways of introduction include intentional stocking for aquaculture and human harvest as well as bait bucket releases by fisherpersons. Alternately, other pathways like the aquarium, pond management, and biological supply trades may be increasing in importance but remain understudied (Lodge et al. 2000).

During 2007 and 2008 we surveyed 58 lakes in western Washington State, U.S.A., to document the geographic distributions of invasive crayfish. Our efforts represent the first dedicated crayfish survey in this region and were initiated in response to the discovery in 2000 of the non-native crayfish *Procambarus clarkii* (Girard, 1852) in an urban lake near the city of Seattle (Mueller 2001). We used baited minnow traps (20 per lake) and direct observation along snorkel transects (2 divers, 30 minutes) to assess the presence-absence and abundance of crayfish in the lake littoral zone. Our regional survey discovered *P. clarkii* in 10 lakes (17% of sampled lakes), and resulted in the first recorded observation of the non-native crayfish *Orconectes virilis* (Hagen, 1870) in three lakes (Figure 1, Annex 1).

We hoped to prevent future introductions of *P. clarkii* and *O. virilis* in Washington by identifying the pathways through which these species are being transported. During the spring and summer of 2008, we surveyed over 30 aquarium stores and 7 bait shops in the region and found none selling *P. clarkii* or *O. virilis* (Olden JD, unpub. data). Moreover, we know of no deliberate introductions of invasive crayfish for aquaculture or human harvest at any time in the region's history. However, we did discover that elementary and middle school science programs

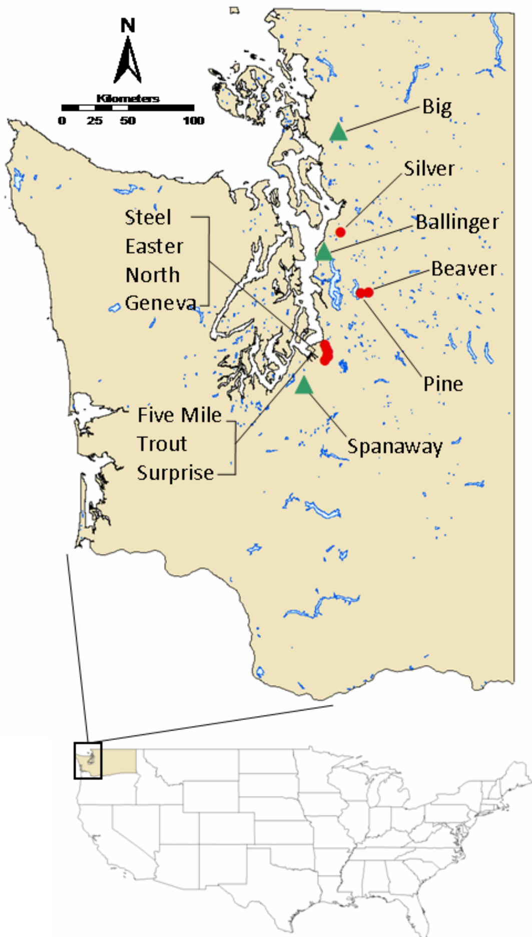

Figure 1. Lakes in western Washington State, U.S.A., with known populations of *Procambarus clarkii* (red circles) and *Orconectes virilis* (green triangles).

throughout Washington use live invasive crayfish as laboratory organisms. Multiple statewide programs in teacher training and curriculum development encourage the use of crayfish in school laboratories and often provide organisms. According to a senior school science administrator, approximately 60% of Washington schools use crayfish in the laboratory. Based on a series of phone interviews, science curriculum administrators have reported ordering over 600 crayfish per year for distribution to their schools, indicating that this emerging pathway may represent a source of high propagule pressure.

These crayfish are ordered from biological supply companies, and in many instances schools are unaware of the particular crayfish species they are using. We toured two Seattle-area science distribution centers and found *P. clarkii*, *O. virilis*, and, unexpectedly, *Orconectes rusticus* (Girard, 1852) available for classroom use. *O. rusticus* is highly invasive and widely distributed in the central and eastern United States (Lodge et al. 2000; Olden et al. 2006), but is not known to be established in Washington. Due to the apparent common use of this crayfish in Washington schools, we believe that an established *O. rusticus* population will inevitably be discovered in the region. Although some schools collect crayfish from teachers after laboratory use, primarily for redistribution to other teachers to reduce costs and secondarily to prevent releases, this is not practiced by all schools and some teachers express hesitancy to euthanize crayfish following use. We know of at least one instance in which a teacher provided *P. clarkii* to students as personal pets following their use in the laboratory (Mueller KW, pers. comm.). Once crayfish have been given to students as pets, we assume eventual release to natural water bodies is common. In support of this hypothesis, clustered distributions of *P. clarkii* in western Washington (Figure 1), often in close proximity to schools using live crayfish in their science curriculum, may indicate areas where the species has been used and subsequently released by school children.

Also notable, the three lakes where *O. virilis* has been documented all have golf courses immediately adjacent to their shorelines, with directly draining golf course ponds (Figure 2). By contrast, all other surveyed lakes do not have adjoining golf courses. Golf courses regularly stock non-native species for aquatic macrophyte control (Smayda and Packard 1994) and crayfish have been introduced to ponds and lakes for this purpose (Dean 1969). In conversations with one western Washington golf course manager, we could not confirm any known introductions of crayfish for pond management. However, our inquiries to other golf courses were not answered, and therefore this does not preclude the existence of this introduction pathway. Furthermore, it is also possible that unwanted pets or laboratory animals may be released by the public into golf course ponds and then able to disperse into adjacent natural waterways (Rowley et al. 2005). Relative to fish, crayfish are especially well-equipped to disperse out of golf course ponds and into adjacent aquatic ecosystems because of their ability to walk over land (Claussen et al. 2000). The close association between *O. virilis* populations and golf courses provides strong support for a novel introduction

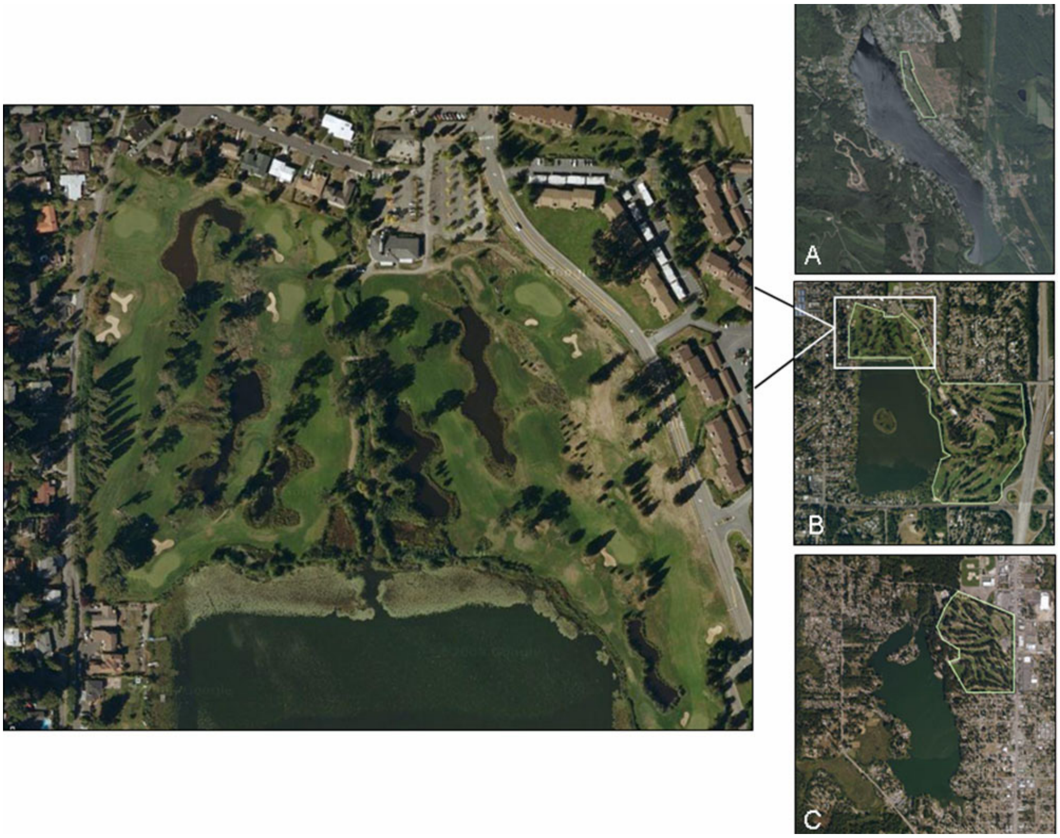

Figure 2. Golf courses (outlined in green) along shorelines of lakes in western Washington State, U.S.A., with known populations of *Orconectes virilis*. Big Lake (A) with Overlook Golf Course, Lake Ballinger (B) with Ballinger Lakes and Nile Temple golf courses, and Spanaway Lake (C) with Lake Spanaway Golf Course. Inset shows many drainage ponds in Ballinger Lakes Golf Course that are located in close proximity with the lake shoreline. Image source: Google Earth.

pathway for crayfish invasions and deserves greater investigation in the future.

Integrated vector management aims to reduce the introduction of non-native species via particular transport pathways, vectors, and geographic routes. Although this approach is recognized as an efficient management strategy, it requires the identification of introduction pathways by which invasive propagules are arriving and sealing them off. In many instances, individuals importing and releasing non-native species are unaware of potential ecological and economic consequences of their actions, and education can slow or cease introductions. With respect to the likelihood for crayfish invasion through school science programs, emphasizing the importance of not releasing laboratory animals and encouraging the use of indigenous crayfish may reduce the incidence of future invasions in freshwater ecosystems. The potential role of golf course ponds in facilitating species introductions is deserving of further investigation and could require regulatory oversight. In conclusion, environmental change and shifting human behaviors are likely to increase the importance of alternative pathways for aquatic species introductions. We encourage scientists and resource managers to consider the full gamut of potential pathways for non-native crayfish invasions.

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Annex 1. Occurrences of *Procambarus clarkii* and *Orconectes virilis* in western Washington State, U.S.A. Catch per unit effort (CPUE) is crayfish per Gee minnow trap (set for 24 hours) baited with dry dog food.

Location	Species	Record coordinates		Record Date	CPUE
		Latitude, ºN	Longitude, ºW		
Beaver Lake	*Procambarus clarkii*	47.5913	-121.9987	15.07.2008	0.15
Easter Lake	*Procambarus clarkii*	47.3240	-122.3188	9.07.2008	0.05
Five Mile Lake	*Procambarus clarkii*	47.2728	-122.2860	18.07.2008	0.15
Lake Geneva	*Procambarus clarkii*	47.2917	-122.2815	10.07.2008	0.15
North Lake	*Procambarus clarkii*	47.3058	-122.2900	18.09.2007	0.33
Pine Lake	*Procambarus clarkii*	47.5879	-122.0452	18.06.2008	0.75
Silver Lake	*Procambarus clarkii*	47.8928	-122.2093	8.08.2008	0.65
Steel Lake	*Procambarus clarkii*	47.3279	-122.3028	17.09.2007	0.33
Surprise Lake	*Procambarus clarkii*	47.2468	-122.3017	8.07.2008	0.05
Trout Lake	*Procambarus clarkii*	47.2664	-122.2797	8.07.2008	0.40
Lake Ballinger	*Orconectes virilis*	47.7825	-122.3291	26.06.2008	0.40
Big Lake	*Orconectes virilis*	48.3825	-122.2330	13.08.2008	0.35
Spanaway Lake	*Orconectes virilis*	47.1103	-122.4475	31.07.2008	0.05