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Historical changes and current status of crayfish diversity and distribution in the Laurentian Great Lakes

Jody A. Peters [a,b,*], Matthew J. Cooper [b], Sara M. Creque [c], Matthew S. Kornis [d], Jeffrey T. Maxted [d], William L. Perry [e], Frederick W. Schueler [f], Thomas P. Simon [g], Christopher A. Taylor [h], Roger F. Thoma [i], Donald G. Uzarski [j], David M. Lodge [a,b]

[a] Environmental Change Initiative, University of Notre Dame, Notre Dame, IN 46656, USA
[b] Department of Biological Sciences, University of Notre Dame, Notre Dame, IN 46656, USA
[c] Illinois Natural History Survey, Lake Michigan Biological Station, 400 17 St., Zion, IL 60099, USA
[d] Center for Limnology, University of Wisconsin-Madison, Madison, WI 53706, USA
[e] School of Biological Sciences, Illinois State University, Normal, IL 61790, USA
[f] Bishops Mills Natural History Centre, RR#2 Bishops Mills, Ontario K0G 1T0, Canada
[g] Department of Biology, Indiana State University, 600 Chestnut Street, Terre Haute, IN 47809, USA
[h] Prairie Research Institute, Illinois Natural History Survey, 1816 S. Oak St, Champaign, IL 61820, USA
[i] Department of Evolution, Ecology and Organismal Biology, The Ohio State University, Columbus, OH 43212, USA
[j] Institute for Great Lakes Research, CMU Biological Station and Department of Biology, Central Michigan University, Mount Pleasant, MI 48859, USA

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ABSTRACT

Despite increasing recognition of the importance of invertebrates, and specifically crayfish, to nearshore food webs in the Laurentian Great Lakes, past and present ecological studies in the Great Lakes have predominantly focused on fishes. Using data from many sources, we provide a summary of crayfish diversity and distribution throughout the Great Lakes from 1882 to 2008 for 1456 locations where crayfish have been surveyed. Sampling effort was greatest in Lake Michigan, followed by lakes Huron, Erie, Superior, and Ontario. A total of 13 crayfish species occur in the lakes, with Lake Erie having the greatest diversity (n = 11) and Lake Superior having the least (n = 5). Five crayfish species are non-native to one or more lakes. Because *Orconectes rusticus* was the most widely distributed non-native species and is associated with known negative impacts, we assessed its spread throughout the Great Lakes. Although *O. rusticus* has been found for over 100 years in Lake Erie, its spread there has been relatively slow compared to that in lakes Michigan and Huron, where it has spread most rapidly since the 1990s and 2000, respectively. *O. rusticus* has been found in both lakes Superior and Ontario for 22 and 37 years, respectively, and has expanded little in either lake. Our broad spatial and temporal assessment of crayfish diversity and distribution provides a baseline for future nearshore ecological studies, and for future management efforts to restore native crayfish and limit non-native introductions and their impact on food web interactions.

Introduction

Although invertebrates, especially benthic invertebrates, are critical components of the Great Lakes food web (Mills et al., 2003; Nalepa et al., 1998), they are little studied compared to fish (Taylor and Ferreri, 1999; Tyson et al., 2009). Benthic invertebrates perform essential ecosystem services including sediment mixing, nutrient cycling, and energy flow through the food web (Covich et al., 1999). Crayfish, in particular, have been little studied in the Great Lakes, even though they are the largest sized benthic invertebrate, often achieve high abundance, and are keystone species in nearshore freshwater food webs (Hobbs and Lodge, 2009).

Studies that have considered the role of crayfish in Great Lake food webs, while typically conducted at small spatial and temporal scales, have found that crayfish are important as prey, predators, and competitors (Table 1). Non-native crayfish species in the Great Lakes have disrupted communities of indigenous species and have led to rapid and striking ecological change which is consistent with their effects on inland lake food webs (Berrill, 1978; Capelli, 1982; Taylor and Redmer, 1996). Likewise, one of the biggest threats to native crayfish diversity within the U.S. comes from the introduction of non-native crayfish (Perry et al., 2002).

* Corresponding author at: 294 Galvin, Notre Dame IN 46556, USA. Tel.: +1 574 631 1852.
E-mail address: peters.63@nd.edu (J.A. Peters).

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Table 1
Crayfish interactions identified from studies in the Great Lakes.

Role	Crayfish species	Reference	Great Lakes or connecting waterbody
Predation on lake trout (*Salvelinus namaycush*) eggs	*O. rusticus*	Claramunt et al. (2005); Jonas et al. (2005)	Michigan
	O. propinquus	Jonas et al. (2005)	Huron
	Orconectes spp.	Fitzsimons et al. (2007)	Michigan
	Orconectes spp.	Fitzsimons et al. (2002)	Ontario
Predation on lake sturgeon (*Acipenser fulvescens*) eggs	*O. propinquus*	Nichols et al. (2003)	St. Clair River
Predation on and reduction of invertebrate standing stocks	*O. rusticus*	Stewart et al. (1998)	Lake Erie
Displacement of native crayfishes	*O. rusticus*	Janssen et al. (2005)	Michigan
Competition for shelter	*O. virilis* and *O. propinquus*	Quinn and Janssen (1989)	Michigan
Hybridization with native crayfish	*O. rusticus*	Perry et al. (2002)	Michigan
Prey for yellow perch (*Perca flavescens*)	Not specified	Wells (1980); Janssen and Quinn (1985)	Michigan
	Not specified	Elrod et al. (1981)	Ontario
Prey for rockbass (*Ambloplites rupestris*)	Not specified	Elrod et al. (1981)	Ontario
Prey for lake sturgeon	*O. rusticus*	J. Peters personal observation	Huron
Prey for burbot (*Lota lota*)	Not specified	Clemens (1951)	Erie
	Orconectes spp.	Fratt et al. (1997)	Michigan
Prey for small mouth bass (*Micropterus dolomieu*)	Not specified	Wickliff (1920)	Erie
Prey for freshwater drum (*Aplodinotus grunniens*)	Not specified	Herdendorf (1985)	Erie
Prey for channel catfish (*Ictalurus punctatus*)	Not specified	Herdendorf (1985)	Erie
Prey for round goby (*Neogobius melanostomus*)	Not specified	Ray and Corkum (1997)	Detroit River
Prey for herring gulls (*Larus argentatus*)	*O. propinquus*, *O. virilis*, *Cambarus robustus*	Ewins et al. (1994)	Lakes Huron, Erie, and Ontario, and their connecting channels
Prey for double-crested cormorants (*Phalacrocorax auritus*)	*Orconectes* spp.	Seefelt and Gillingham (2006)	Michigan
Predation on zebra mussels (*Dreissena polymorpha*)	*O. propinquus*	MacIssac (1994)	Laboratory experiments with crayfish collected from St. Clair River
	O. propinquus	Martin and Corkum (1994)	Laboratory experiments with crayfish collected from Detroit River

Despite this no study has specifically examined the spatial and temporal distribution of crayfish across the entire Great Lakes, though Simon and Thoma (2006) evaluated spatial distributions of multiple crayfish species in Lake Michigan. Rather, the historical and current distributions of crayfishes have been examined extensively in inland water bodies in the states/province surrounding the Great Lakes (e.g., Illinois: Page, 1985; Taylor and Redmer, 1996; Indiana: Hay, 1891; Simon, 2001; Michigan: Pearse, 1910; Creaser, 1931; Minnesota: Helgen, 1990; New York: Crocker, 1957; Ohio: Turner, 1926; Thoma and Jezerinac, 2000; Ontario: Crocker and Barr, 1968; Pennsylvania: Ortmann, 1906; Wisconsin: Creaser, 1932; Hobbs and Jass, 1988; Olden et al., 2006).

The goals of our paper were threefold. First, we examine the number of ecological studies based in the Great Lakes that have focused on fishes compared to invertebrates in general and crayfishes in particular. Second, we provide the current state of the spatial and temporal records of crayfish diversity and distribution in the Great Lakes from 1882 to 2008 as collected from the literature, museum records, private and academic collections and personal collecting trips by the authors. Third, we applied inclusion and proportion curves (methods previously used with herbarium records; Delisle et al., 2003; Pysek et al., 2003, 2008), to quantify the spread of *Orconectes rusticus*, the most widely distributed crayfish in the Great Lakes. *O. rusticus* is non-native and considered invasive throughout much of the basin. Inclusion curves provide a rigorous method of assessing the rate at which a non-native species is found relative to native species, with native species records providing a control for the spatiotemporal distribution of sampling effort. Proportion curves were used to identify specific time periods of *O. rusticus* spread relative to native crayfish sampling. For both types of curves, the number of records for all species is expected to increase through time (as more surveys are conducted), but the number of records for an invasive species (here *O. rusticus*) is expected to increase greater relative to those of non-invasive species. First we compare *O. rusticus* spread to that of native species, and then we compare the rate of *O. rusticus* spread among lakes. Thus, we provide a case study of *O. rusticus*, an invasion with mostly unknown but potentially large impacts for the Great Lakes (Table 1).

Methods

Fish, invertebrate and crayfish studies in the Great Lakes

First, to understand how crayfish research in the Laurentian Great Lakes compares to that of fish and other invertebrates over the past century (1882–2008), we used an ISI Web of Knowledge literature search (last conducted February 1, 2010). Searches were run using three sets of search terms: 1) "Great Lakes" fish, 2) "Great Lakes" invertebrates, and 3) "Great Lakes" crayfish. Articles that did not pertain to the three taxa of interest or to the Laurentian Great Lakes were removed from the analysis.

Crayfish diversity and distribution in the Great Lakes

Next, we compiled records of crayfish diversity and distribution from a comprehensive dataset of locations and years of crayfish records. Variables collected for each record were: location (as described by latitude, longitude, site descriptions, state, country, specific lake or connecting waterway), Great Lake category (either a. within a lake or b. in tributaries to the lakes located $\leq$1 km of the lake), crayfish species, year found, source and collection method (see Online Supplementary Information (SI) Tables: S1 (locations), S2 (institutional sources) and S3 (bibliographic sources) for detailed lists).

Crayfish were considered in the Great Lakes if they were found in lakes Superior, Michigan, Huron, Erie, or Ontario or their connecting waterways (i.e., St. Clair River, Lake St. Clair, Detroit River, Niagara River, and the St. Lawrence River) and tributaries within 1 km of the lakes and connecting waterways. Records downstream of Highway 17 (49.01989, −88.25011) were included for the Nipigon River flowing into Lake Superior. The boundary between lakes Superior and Huron was defined as the Soo Locks at Sault Saint Marie, MI. Lakes Huron and Michigan were separated at the Straits of Mackinac. Records west of Cornwall, Ontario were included for the St. Lawrence River.

Records were collected through 2008 from museums, government agencies, private or university contacts, personal collections by the authors and published literature (see the Online Supplementary