

## FEATURE: INTRODUCED SPECIES

# The Bait Industry as a Potential Vector for Alien Crayfish Introductions: Problem Recognition by Fisheries Agencies and a Missouri Evaluation



Jim Rathert, Missouri Department of Conservation

Rusty crayfish (*Orconectes rusticus*)

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## INTRODUCTION

Crayfishes are an important component of many North American freshwater ecosystems and are considered to be "keystone species" (sensu Paine 1969) or "ecological dominants" (sensu Simberloff 1998) by many ecologists (Momot et al. 1978; Creed 1994; Parkyn et al. 1997). They process organic matter (Momot et al. 1978; Parkyn et al. 1997), affect the physical structure of aquatic habitats (Statzner et al. 2003; Creed and Reed 2004) and the structure of benthic invertebrate communities (Momot et al. 1978; Rabeni et al. 1995; Whitledge and Rabeni 1997), transfer energy among trophic levels (Momot et al. 1978; Momot 1995), and are documented prey for over 200 species of mammals, birds, reptiles, amphibians, fishes, and insects (DiStefano 2005), including many important sport fishes (summarized in DiStefano 2005). About 77% of the world's crayfish fauna (405 species and subspecies) inhabit North America (Taylor 2002). Many of these species have small natural ranges, often limited to a single drainage basin, and are therefore vulnerable to extirpation caused by habitat or ecosystem alterations (Lodge et al. 2000a; Taylor et al. 2007).

**ABSTRACT:** "Bait-bucket introductions" related to the fishing bait industry are the suspected primary cause of alien (non-indigenous) crayfish introductions that have damaged North American aquatic ecosystems. Our 2008 survey of U.S. and Canadian fisheries agencies revealed that 49% of respondents reported aquatic resource problems that were believed to have been caused by bait-bucket introductions of alien crayfishes. Most respondents reported existing regulations designed to address those problems; however, only 4% prohibited the use of live crayfish bait. Our 2002–2007 examination of Missouri bait shops revealed sales of illegal and invasive alien crayfishes by bait shop proprietors who could not identify the species they were selling. Fisheries agencies should consider more effective bait regulations and education to prevent negative impacts to aquatic biodiversity, habitat, and fisheries that can result from alien crayfish introductions.

## La industria de la carnada como potencial vector de introducción de langostino: reconocimiento del problema por agencias de pesquerías y una evaluación en Missouri

**RESUMEN:** Se sospecha que la introducción de especies exóticas a través de cubetas con carnada, ha impactado negativamente los ecosistemas acuáticos de Norteamérica. Un muestreo que realizamos en el 2008 a agencias de pesquerías en Canadá y Estados Unidos de Norteamérica, reveló que el 49% de los corresponsales reportaron problemas relacionados a recursos acuáticos que se cree fueron causados por introducción de langostinos exóticos en cubetas con carnada. La mayor parte de los corresponsales reportaron la existencia de regulaciones para abordar el problema; sin embargo, solo el 4% de éstas prohíbe el uso de langostinos vivos como carnada. Nuestro examen realizado a tiendas de carnada en Missouri durante el periodo 2007-2007, reveló venta de langostinos ilegales e invasivos por parte de los propietarios de las tiendas, quienes no pudieron identificar las especies que vendían. Las agencias de pesquerías debieran contemplar regulaciones y programas de educación más efectiva en cuanto al uso de carnada para prevenir los impactos negativos que la introducción de langostinos exóticos tiene sobre la biodiversidad acuática, los hábitats y las pesquerías.



Bait-bucket introductions are believed to be among the most common vectors for alien aquatic species. Nearly half of U.S. and Canadian fisheries agencies reported aquatic resources problems believed to be caused by bait-bucket introductions of alien crayfishes.

At least 363 native crayfish species occur in the United States and Canada and 48% of these crayfishes require conservation (listed as endangered, threatened, or vulnerable species; Taylor et al. 2007). Lodge et al. (2000a) cited the introduction of alien (non-indigenous; see Occhipinti-Ambrogi and Galil 2004) crayfishes as the single greatest threat to crayfish biodiversity worldwide and implicated the live bait trade as the most important vector for the introduction of alien crayfishes in North America. In a series of recommendations to reduce alien crayfish introductions, Lodge et al. (2000b) called for all U.S. states to ban the use of live crayfishes as bait. In response to this recommendation, we conducted an evaluation of crayfish bait sales in the state of Missouri to gain insight into the potential for the Missouri bait industry to act as a vector for the introduction of alien crayfishes. Additionally, we conducted a survey of U.S. state and Canadian provincial and territorial fisheries agencies to determine the extent of bait-bucket crayfish introduction problems and the level of regulation used by these agencies to control introductions.

Many recent studies have documented aquatic resource problems associated with introductions of alien crayfishes (Lodge et al. 2000a; Taylor et al. 2007). Introduced alien crayfishes have displaced native crayfishes and reduced biodiversity (Lodge et al. 1986; Light et al. 1995; Daniels 1998); adversely affected or displaced native amphibians (Gamradt and Kats 1996; Kats and Ferrer 2003), reptiles (Fernandez and Rosen 1996b), and fishes (Guan and Wiles 1997; Dorn and Mittelbach 1999); adversely affected sport fisheries (Hobbs et al. 1989; Dorn and Mittelbach 1999; Wilson et al. 2004); and altered the structure and function of stream, lake, and marsh communities (Feminella and Resh 1989; Olsen et al. 1991; Charlebois and Lamberti 1996). Introductions of two crayfish species in particular, the rusty crayfish (*Orconectes rusticus*) and the red swamp crayfish (*Procambarus clarkii*), have negatively impacted aquatic ecosystems at many localities (Hobbs et al. 1989; Taylor 2002). *Orconectes rusticus* is native to drainages in Indiana, Ohio, Kentucky, and the southeastern corner of Michigan, but has been introduced to drainages in 17 additional U.S. states and 2 Canadian provinces (Taylor et al. 2007). Due to its aggressive behavior and larger size, *O. rusticus* commonly reaches high densities in introduction locations, resulting in displacement of native crayfishes (Momot 1996; Taylor and Redmer 1996; Olden et al. 2006), destruction of important macrophyte beds and decreased macrophyte species richness (Wilson et al. 2004), and declines in native fish populations (Wilson et al. 2004). Likewise, *P. clarkii* is native to 12 states in the south-central United States and has been introduced to 9 western and 6 eastern states (Taylor et al.

2007). In the western United States, *P. clarkii* has been reported to consume eggs of endangered fish (Mueller et al. 2006) and adversely affect amphibian breeding (Gamradt et al. 1997). Introductions of *P. clarkii* and other North American crayfishes that carry the plague fungus, *Aphanomyces astaci*, have decimated native crayfish populations across Europe (Lodge et al. 2000a; Gil-Sánchez and Alba-Tercedor 2002) and adversely affected native amphibian breeding and species richness (Cruz et al. 2006; Rodríguez et al. 2005).

Missouri has a diverse crayfish fauna, with at least 35 native species from 6 genera. Eight species are endemic to relatively small drainages in the Missouri Ozarks Ecoregion and an additional 12 species have native distributions limited to only parts of southern Missouri and neighboring Arkansas, Oklahoma, and Kansas (Pflieger 1996). Due to the limited distribution and ecological importance of many crayfish species, effects of introduced alien crayfishes pose a serious threat to aquatic ecosystems, fisheries, and crayfish biodiversity throughout Missouri and North America. Alien crayfish introductions were recently documented in two drainages (Riggert et al. 1999; Magoulick and DiStefano 2007) in southern Missouri. In both locations, alien crayfishes have the opportunity to interact with native species that are state listed as imperiled (Missouri Natural Heritage Program 2009), and listed by the American Fisheries Society as threatened (Taylor et al. 2007). Three of those native imperiled crayfishes have already disappeared from significant portions of their ranges that are occupied by alien species (Riggert et al. 1999; Magoulick and DiStefano 2007). Other potential effects to these aquatic systems remain unknown. Additional alien crayfish introductions have been noted in other Missouri drainages but the ecological effects of these have not been documented.

We are unaware of any studies that have assessed the pervasiveness of alien crayfish introductions across the United States and Canada. Several authors have implicated bait-bucket introductions by anglers as a major cause of these problems on the continent, and controlling the sale and use of live crayfishes for fishing bait has been cited as a legitimate management alternative (Eng and Daniels 1982; Ludwig and Leitch 1996; Lodge et al. 2000a, 2000b; Burkholder and Wallace 2001). Anglers often release live bait in waters near where it was purchased, but they also often travel across basin boundaries, potentially releasing live bait in other watersheds (Litvak and Mandrak 1993; Ludwig and Leitch 1996). At least three U.S. states (Arizona, Virginia, and Wisconsin) have banned either the use or sale of live crayfishes as bait and the Canadian province of Manitoba

has banned the possession of crayfishes on all waters (Manitoba Angler's Guide 2008).

Current Missouri regulations allow bait vendors to sell only the following four crayfish species that are native to the state and appear on the Missouri Approved Aquatic Species List (MAASL): the virile (northern) crayfish (*O. virilis*), calico (papershell) crayfish (*O. immunis*; this species was added to the MAASL in 2004 following the first year of this study), White River crawfish (*P. acutus*), and *P. clarkii* (Missouri Department of Conservation [MDC] 2009). Crayfishes sold in bait shops must not be obtained from public waters of the state (i.e., they must come from a private commercial source either from inside or outside the state, which ironically may present potential population genetics and disease transfer problems), and bait vendors must keep written receipts documenting the source of their crayfish stocks (MDC 2009). In addition, anglers possessing a valid Missouri fishing license may harvest up to 150 crayfishes per day from waters of the state for use as bait, but they may not be released into waters from which they did not originate (MDC 2009).

Interestingly, only one of the species on the MAASL, *O. virilis*, occurs throughout most of the state. The historical widespread distribution of this species in Missouri may have been smaller, and much of its current distribution is believed to be due to human introductions (W. Pflieger, MDC retired, pers. comm.), possibly via bait sales and subsequent illegal releases by anglers. The other three species on the MAASL have more limited distributions; *O. immunis* is native to the northern half of Missouri and western Osage River basin whereas *P. acutus* and *P. clarkii* were limited historically to a small portion of southeast Missouri, and *P. acutus* also occurred historically in the main-stem Mississippi River (Pflieger 1996). This suggests that even legal sales of crayfishes (as currently allowed by the MAASL) might be a vector for alien species introductions throughout the state. Additional concern is warranted because species on the MAASL have caused problems elsewhere. *Oreocnectes virilis* has adversely effected native amphibians, reptiles, and invertebrates (Fernandez and Rosen 1996a; Fernandez and Rosen 1996b); displaced native crayfish populations (Schwartz et al. 1963); and demonstrated a capability to impact native fishes in North America (Carpenter 2005; Rogowski and Stockwell 2006). As previously mentioned, *P. clarkii* has caused numerous problems in Europe and the western United States, and *P. acutus* is suspected of causing declines of native crayfishes in New York state (Pickett and Sloan 1985). Furthermore, anglers that use crayfishes collected from the wild as bait may also contribute to introduction of many other alien crayfish species due to their lack of knowledge of regulations prohibiting the release of live bait and angler travel between bodies of water and across watershed boundaries.

The wider goal of this study was to determine whether the incidence of bait-bucket introductions of alien crayfishes is problematic as perceived by U.S. state and Canadian provincial and territorial fisheries agencies. We also chose to focus in detail on the role of bait shops in one state, Missouri, as a potential vector for the introduction of illegal native or alien crayfish species into Missouri waters. Specific objectives were to determine:

1. The proportion of U.S. state and Canadian provincial and territorial fisheries agencies that are aware of aquatic resource problems with freshwater alien crayfish species in which bait-bucket introductions are a suspected cause, and the regulatory responses to those problems.
2. The proportion of Missouri bait shops that conducted illegal crayfish sales (illegal because crayfish species were not on the MAASL or were obtained from illegal sources),
3. The presence of illegal and possibly invasive alien species in Missouri's bait industry,
4. If legal native crayfishes species were sold in geographic locations outside of their known historical range,
5. Locations (state of origin) of commercial sources (distributors) of crayfishes sold in Missouri bait shops, and
6. Whether bait shop owners/managers knew what crayfish species they sold.

The introduction of alien crayfish is a significant threat to the conservation of aquatic biodiversity and ecosystem function. Understanding the roles of the bait industry in the introduction or prevented introduction of alien crayfishes is an essential step towards effective management of invasive species and aquatic resources.

## METHODS

### Survey of U.S. and Canadian fisheries agencies

We sent an e-mail survey to fisheries agency chiefs or administrators in all 50 U.S. states, 10 Canadian provinces, and 3 Canadian territories on 10 January 2008, preceded by an introductory e-mail notification from the MDC Fisheries Division Chief, and followed by an e-mail survey reminder on 16 January 2008. We collected responses through February 2008. The survey contained two questions (second question with multiple parts; Table 1) requiring simple "yes" or "no" responses. However, the last portion of the second ques-

**Table 1.** Responses to e-mail survey of fisheries chiefs/administrators from 50 U.S. states, 10 Canadian provinces, and 3 Canadian territories about alien crayfish introductions. Survey had two questions, with multiple parts to the second question (parts "a" through "f" below). Overall response rate was 78% ( $n = 49$ ). Frequencies (%) of "yes" and "no" responses are provided with actual response numbers in parentheses. Rows where cumulative responses do not sum to 49 indicate item nonresponse.

Question	Response	
	Yes	No
1. Is your agency aware of any aquatic resource problems with freshwater alien (non-indigenous) crayfish species in your state or province in which "bait-bucket introductions" are a suspected cause?	49% (24)	51% (25)
2. Has your state/province implemented any of the following management strategies or regulations to avoid or in response to problems caused by "bait-bucket introductions" of alien (non-indigenous) freshwater crayfish? <sup>1</sup>		
a. Prohibit the use of all live crayfish as bait.	4% (2)	94% (45)
b. Restrict the use of live crayfish as bait.	39% (18)	61% (28)
c. Restrict the release of live crayfish bait into natural waters.	58% (28)	42% (20)
d. Restrict the sale of live crayfish as bait.	37% (17)	63% (29)
e. Restrict sales of crayfish bait to only certain species.	27% (12)	73% (33)
f. Prohibit or restrict the use of dead crayfish as bait.	6% (3)	94% (46)

<sup>1</sup>Question number 2, part "g" provided respondents the opportunity to provide any other information that they deemed important or relevant to management strategies and/or regulations.

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### Survey of Missouri bait shops

**Development of bait shop survey database.**—During autumn of 2002 we compiled a computerized list of 370 Missouri potential bait vendors (Figure 1) from several sources including Internet telephone listings and web searches, and consultation with the Missouri Department of Agriculture and MDC regional fisheries and law enforcement staff. All 370 shops were contacted during a December 2002 telephone census to determine whether and when (time of year; DiStefano et al. 2008a) they sold crayfishes. Businesses that did not answer their telephones after two calls during standard business hours (34 shops) or that had disconnected telephone numbers (48 shops) were removed from the list. This census resulted in a database of 135 bait shops that indicated they sold crayfishes sometime during the year.

**Bait shop survey.**—Responses from the telephone census were used to generate a list of bait shops to be surveyed (80 shops in 2003, 98 shops in 2004; Figure 2). The 2003 survey was conducted by MDC law enforcement staff (conservation agents) during one day (4 April 2003) to minimize communication among shops and reduce potential sampling bias. This sampling period was selected to coincide with availability of crayfishes in shops (determined in previously described telephone census) and the limited availability of conservation agents. We also considered the seasonal availability of reproductively active (form I) male crayfishes, which are most reliable for species identification (Hobbs 1976; Pflieger 1996), and occur during early autumn through late spring for many Missouri species. Seventy-four shops were successfully surveyed in April 2003 (six visited shops were closed). During each

shop visit, agents purchased a randomly-selected sample of three dozen crayfishes (or all crayfishes in the shop if that number was less than three dozen), sealed them in airtight plastic bags, froze them to preserve color and integrity (DiStefano et al. 1994), and transported the frozen samples to a central laboratory for taxonomic identification.

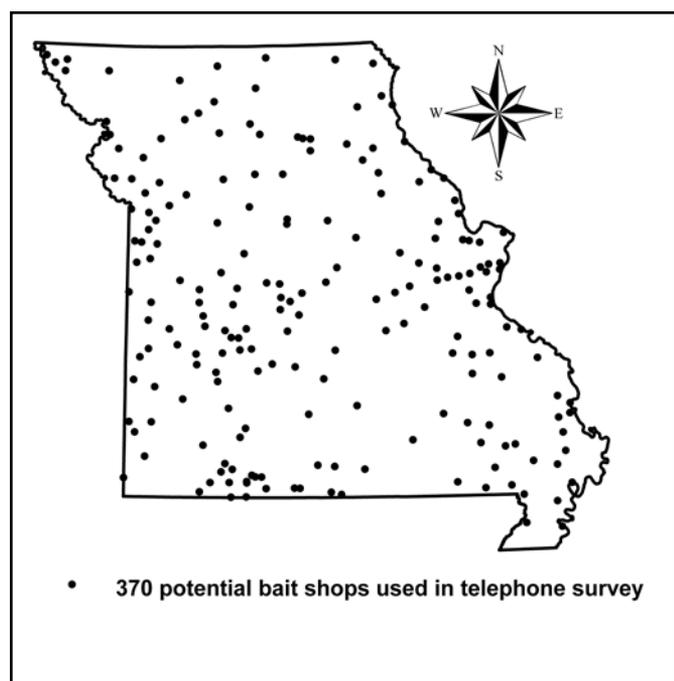
To determine if a greater number of crayfishes with an acceptable proportion of form I males could be collected by sampling bait shops later in the spring (in preparation for the 2004 sample), 16 shops were visited again during 7–10 May 2003. These shops were closed or did not possess crayfishes during the April 4th survey, but they indicated they would be receiving crayfishes later in the spring. Conservation agents were not available to inspect shop receipts during the May 2003 16-shop survey.

The 2004 sampling trips occurred about 10 days later in the year (13–15 April) than in 2003 due to availability of staff. Twenty-five additional shops that had indicated in the telephone census that they typically sold crayfishes by late April or early May were added to the 2004 sampling list for a total of 98 surveyed shops in 2004 (Figure 2). Agents followed similar procedures as in 2003.

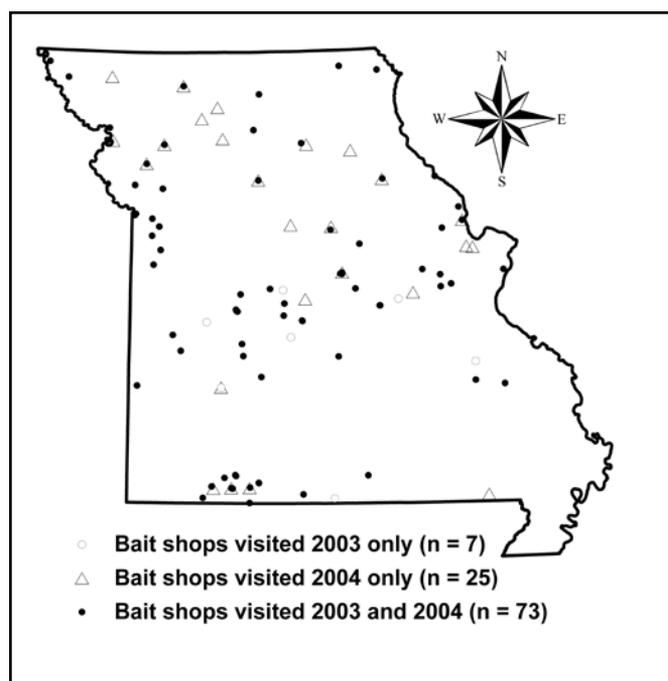
Upon each visit, agents inspected each bait shop’s records and receipts during both years to determine the source for crayfish stocks and assess whether shops were in compliance with regulations requiring bait vendors to have dated receipts indicating the commercial source of their bait stock. If a shop had no records for its stock, the agent gathered as much information as possible about the source of the bait from the shop attendee. Agents recorded all information on provided datasheets (available in DiStefano et al. 2008a).

Taxonomic identifications were performed on thawed specimens in the laboratory with dichotomous crayfish keys for North America (Hobbs 1976) and Missouri (Pflieger 1996). All form I males were identified to species. Positive species identifications

**Figure 1.** Location of potential bait shops ( $N = 370$ ) surveyed by telephone in 2002. When multiple bait shops were located within the same town, a single point represents the town location.



**Figure 2.** Location of bait shops visited by agency personnel in 2003 and 2004 ( $n = 105$ ). When multiple bait shops were located within the same town, a single point represents the town location.



were made for all form II (reproductively inactive) *Procambarus* spp. specimens and many *Orconectes* spp. specimens that were in good physical condition; the remaining form II males were identified to genus. Female crayfishes were enumerated but not taxonomically identified; therefore all references to taxonomically identified crayfishes throughout this report refer to only males. All crayfish specimens for which taxonomic identifications were questionable were forwarded to the Illinois Natural History Survey Center for Biodiversity (C. A. Taylor) for taxonomic verification.

### Determining bait shop knowledge of crayfish stocks

Following the bait shop survey we conducted an additional telephone survey of the 135 Missouri bait shops that had previously indicated that they sold crayfishes to determine whether they knew what species of crayfish they sold. We surveyed only bait shop owners or managers (for consistency), and the order of calls was randomly determined. The survey was conducted from November 2006 to January 2007. Three questions were posed to each shop owner/manager: (1) "Do you ever sell crayfish or crawdads in your shop?", (2) "Do you know what type of crayfish or crawdads you sell in your shop?", and (3) "What type do you sell?". Meyer et al. (2007) provides a detailed summary of the survey script and protocols for how each telephone call outcome (e.g., unanswered call, disconnected telephone number, etc.) was addressed.

## RESULTS

### Survey of U.S. and Canadian fisheries agencies

We recorded a 78% (49 of 63) overall response rate to our e-mail survey of fisheries agencies; 86% among U.S. states and 46% among Canadian provinces and territories. Nearly half (49%) of those respondents indicated that they were aware of an alien freshwater crayfish problem in their state, province, or territory in which the suspected cause was bait-bucket introduction (Table 1). Most respondents (61%) reported existing regulations designed to address their alien crayfish problems (answered "yes" to some part of question 2), and an additional 29% of respondents cited existing regulations on use, sale, and transport of live bait that were not necessarily in response to identified alien crayfish problems.

We observed substantial variability in regulations governing the use, sale, and transport of crayfishes as bait. Most respondents (58%) restrict release of live crayfish bait into natural waters and 39% of respondents reported that they restrict the use of live crayfish as bait to some degree. Two respondents (4%; Alberta and Nova Scotia) prohibit the use of all live crayfishes as bait on all waters, and two additional respondents (Arkansas and Maryland) reported that they are considering a similar regulation. An additional 16% (Arizona, Idaho, Minnesota, Ontario, Utah, Virginia, Washington, and Wyoming) have eliminated the sale of live crayfishes for bait through direct prohibition or by prohibiting live transport, and another 10% (British Columbia, Minnesota, New York, Quebec, and Wisconsin) prohibit the use or possession of live crayfishes on specific waters. Seven respondents (14%; Arizona, Idaho, Minnesota, Ontario, Utah, Washington

and Wyoming) permit the use of live crayfishes for bait only in the body of water from which they were captured.

Some respondents reported on non-regulation management strategies they have implemented to address alien crayfish introduction problems. These strategies included encouraging the public to catch and kill alien crayfishes (e.g., Alberta and Arizona) and educational outreach to the bait industry, pet/aquarium industry, or educators (e.g., Arizona, Mississippi and Missouri).

### Survey of Missouri bait shops

**Species composition of bait crayfishes.**—In April 2003, we sampled 929 crayfishes (500 males, 429 females) from 32 Missouri bait vendors. The other 42 bait shops we surveyed had no crayfishes in stock. Samples included 309 (61.8%) form I and 191 (38.2%) form II males. Crayfishes from 29 shops were taxonomically identified; samples from the other three shops included only females. A total of 376 male crayfishes were identified to species, 116 additional males were identified to genus, and 8 males (1.6% of all males) were not identified due to decomposition. Two crayfish genera and six species were present in bait shop samples (Table 2). The majority (76.8%) of male crayfishes were in the genus *Orconectes* including *O. virilis*, *O. immunis*, *O. rusticus*, *O. nais* (the water nymph crayfish), and form II *Orconectes* spp. which could not be positively identified to species (Table 2). The remaining male crayfishes (21.6%) belonged to the genus *Procambarus* and included two species, *P. acutus* and *P. clarkii* (Table 2).

Crayfish samples from many bait shops contained only one species (determined from identification of male specimens only), but some shops' samples indicated that they sold multiple species (Table 3). We identified three *Orconectes* species, *O. immunis*, *O. rusticus*, and *O. nais*, that were not listed on the MAASL in April 2003 and represented illegal bait sales (Table 2). Ten shops (27.8% of shops surveyed in 2003 that had male crayfishes) sold illegal crayfish species; four of those shops sold illegal alien *O. rusticus*, one shop sold illegal alien *O. nais*, and five of the shops sold the illegal native (to Missouri) crayfish *O. immunis* (one shop sold a mixture of illegal native *O. immunis* and alien *O. rusticus*; Table 3). Our estimates of the proportion of vendors selling illegal crayfishes were conservative due to our inability to taxonomically identify female crayfishes and all form II male crayfishes.

Our visitation of 16 additional bait shops in May 2003 did not produce a higher proportion of shops with crayfishes in stock than the earlier April sampling (during each visit we collected crayfishes from 43% of shops). As expected, this later sampling also failed to produce a higher proportion of taxonomically identifiable form I males than the April sample. The May sample yielded 265 crayfishes (135 males and 130 females) from 7 shops; 8 shops had no crayfishes and 1 shop was not open. Males were present in samples from all 7 shops; but most (85.9%) were not form I males. Most (80.8%) crayfishes collected during May 2003 were *P. acutus* and an additional 0.7% were unidentifiable *Procambarus* spp. (Table 2). Three other species, *O. virilis*, *O. immunis*, and *O. nais*, and unidentifiable *Orconectes* spp. (likely *O. virilis* or *O. nais*) were present in relatively low proportions. No *O. rusticus* were present in May 2003 samples. Six of these seven shops (85.7%) sold *P. acutus* (Table 3). Three shops (42.9%) sold multiple species, but only one of seven shops (14.3%) sold illegal crayfishes (*O. immunis* and *O. nais*).

**Table 2.** Total crayfish, number of male crayfish, and percent of each crayfish species (male specimens only) collected from Missouri bait shops during 2003 and 2004 survey.

Collection date	Total crayfish collected	Number of male crayfish collected	<i>O. nais</i> (%)	<i>O. rusticus</i> (%)	<i>O. immunis</i> (%)	<i>O. virilis</i> (%)	<i>P. acutus</i> (%)	<i>P. clarkii</i> (%)	<sup>a</sup> Unknown <i>Orconectes</i> spp. (%)	<sup>a</sup> Unknown <i>Procambarus</i> spp. (%)
April 2003	929	500 <sup>b</sup>	1.0	15.4	19.4	17.8	20.2	1.4	23.2	0.0
May 2003	265	135	0.7	0.0	0.7	4.5	80.8	0.0	12.6	0.7
April 2004	1196	666	0.0	0.0	14.6	24.5	42.8	6.6	10.1	1.4

<sup>a</sup> Unknown *Orconectes* spp. or *Procambarus* spp. are form II male specimens for which species identification could not be confirmed.  
<sup>b</sup> Eight male crayfish (1.6%) collected on 4/4/2003 were not identified due to decomposition

**Table 3.** Percent of Missouri bait shops visited during survey that were selling male specimens of various crayfish species. Cumulative percentages (species added together) are greater than 100% due to multiple species being sold at individual shops. Bold font indicates crayfish species that were classified as illegal during a given year.

Collection date	Number of shops with male crayfish	<i>O. nais</i> (%)	<i>O. rusticus</i> (%)	<i>O. immunis</i> (%)	<i>O. virilis</i> (%)	<i>P. acutus</i> (%)	<i>P. clarkii</i> (%)	<sup>a</sup> Unknown <i>Orconectes</i> spp. (%)	<sup>a</sup> Unknown <i>Procambarus</i> spp. (%)	Shops selling >1 species (%)
April 2003	29	3.4	13.8	17.2	31.0	34.5	3.4	34.5	0.0	10.3
May 2003	7	14.3	0.0	14.3	14.3	85.7	0.0	42.9	14.3	42.9
April 2004	36	0.0	0.0	13.9	27.8	63.9	11.1	22.2	8.3	22.2

<sup>a</sup>Unknown *Orconectes* spp. or *Procambarus* spp. are form II male specimens for which species identification could not be confirmed.

In April 2004, we sampled 1,196 crayfishes (666 males and 530 females) from 36 of the 98 surveyed bait shops. Forty-five other shops had no crayfishes and the remaining 17 shops were closed or out of business. Proportions of form I (47.4%) and form II (52.6%) males were similar. Male crayfishes identifiable to species were collected from 35 shops and the remaining shop sample contained male crayfishes identifiable only to genus. *Procambarus* species constituted 50.8% of sampled crayfishes, and *P. acutus* were more abundant than *P. clarkii* (Table 2). *Orconectes* species including *O. virilis* and *O. immunis* composed 39.1% of sampled crayfishes; an additional 10.1% of sampled crayfishes were unidentifiable *Orconectes* spp. (Table 2). No illegal species were identified in 2004 samples (*O. immunis* was added to the MAASL in March 2004); however, one bait vendor indicated that he expected a shipment of *O. rusticus* later in the fishing season from a wholesaler in Wisconsin. At least eight shops (22.2%) surveyed in 2004 sold multiple crayfish species (Table 3).

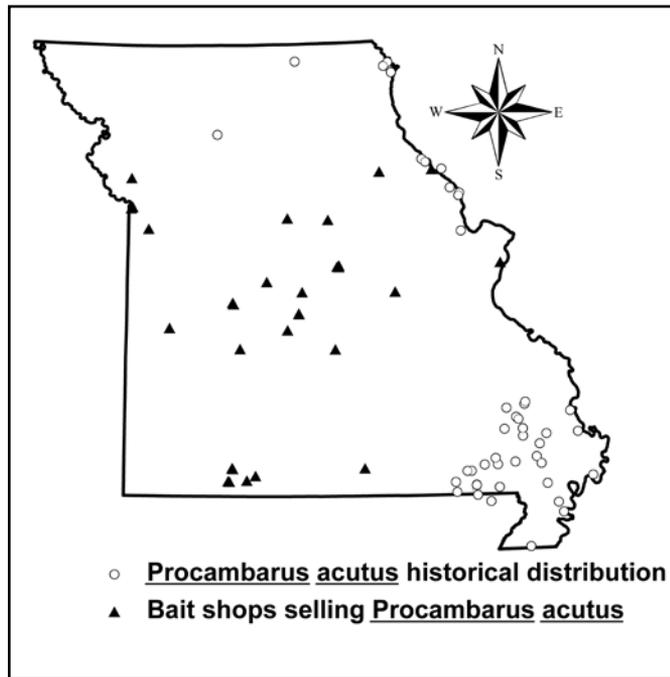
**Comparison of bait shop locations to historical distributions of crayfishes.**—Crayfish samples from bait shops across Missouri indicated that at least four species were being sold at shops outside of the species' known historical geographic distribution. Bait shops selling illegal *O. rusticus* in 2003 were located at four locations in central and eastern Missouri, and illegal *O. nais* were sold at two shops in the western and north-central portions of the state (Figure 3). The majority of shops selling *P. clarkii* and *P. acutus* were located outside of the known historical range of these species (Figures 4 and 5). All bait shops selling *P. clarkii* and *P. acutus* in April and May 2003 were located outside of the known historical range of these species. In 2004, all surveyed shops selling *P. clarkii* and 96% of shops selling *P. acutus* were located outside of the species' known historical distribution. Most bait shops selling *O. immunis* and all shops selling *O. virilis* were located within each species' known range (Figures 6 and 7).

**Bait crayfish sources and records inspection.**—Inspection of bait shop receipts to determine sources of crayfish stocks revealed that two (6.3%) and seven (19.4%) surveyed shops in 2003 and 2004, respectively, could not produce legal records. Two of these shops (one shop from each of 2003 and 2004) claimed that the crayfish were “bycatch” that accompanied shipments of bait fish, but these shops were also unable to produce legal receipts for the bait fish. Records from the remaining shops indicated that

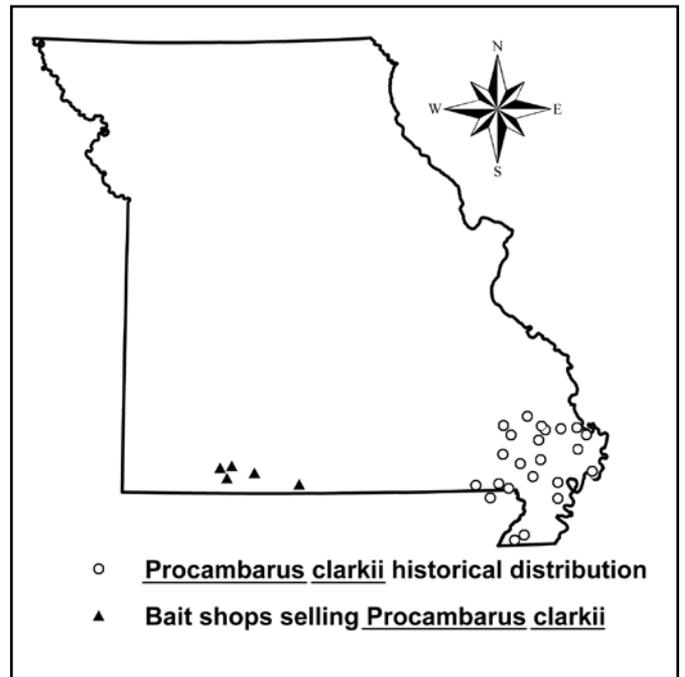
**Figure 3.** Location of bait shops where *Orconectes rusticus* and *Orconectes nais* were collected in 2003.



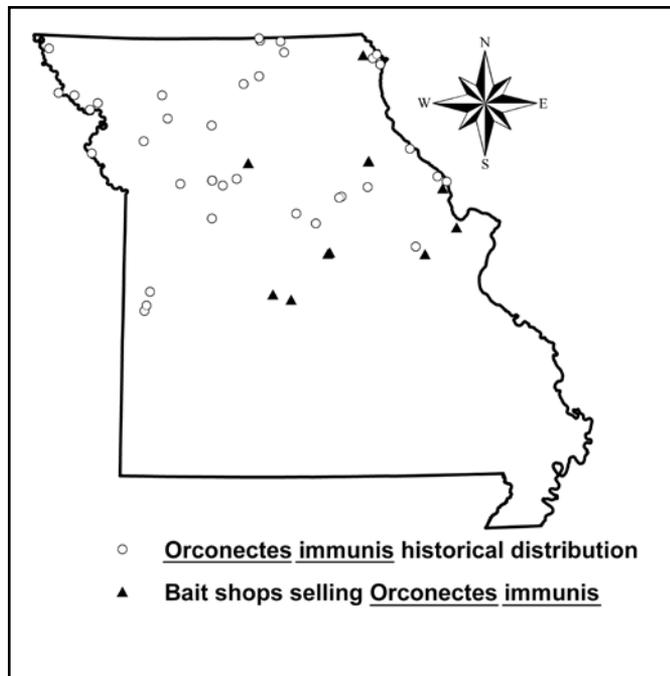
**Figure 4.** Historical distribution of *Procambarus acutus* in Missouri and locations of bait shops where *P. acutus* were collected in 2003 and 2004. The two historical locations in north-central Missouri are believed to be introduced populations (William Pflieger, MDC retired, pers. comm.).



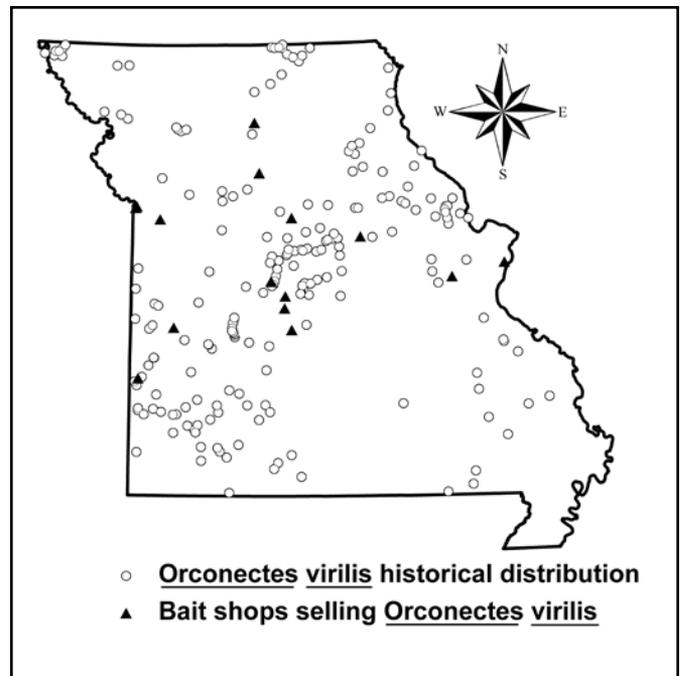
**Figure 5.** Historical distribution of *Procambarus clarkii* in Missouri and locations of bait shops where *P. clarkii* were collected in 2003 and 2004.



**Figure 6.** Historical distribution of *Orconectes immunis* in Missouri and locations of bait shops where *O. immunis* were collected in 2003 and 2004.



**Figure 7.** Historical distribution of *Orconectes virilis* in Missouri and locations of bait shops where *O. virilis* were collected in 2003 and 2004.



crayfish stocks were obtained from 20 individual sources from four states in 2003 (Missouri [ $n = 15$  sources], Arkansas [ $n = 3$ ], Illinois [ $n = 1$ ], Kansas [ $n = 1$ ]) and 19 sources from five states in 2004 (Missouri [ $n = 12$ ], Arkansas [ $n = 3$ ], Oklahoma [ $n = 1$ ], Nebraska [ $n = 1$ ], Wisconsin [ $n = 1$ ]). Eight sources of *P. acutus* and one source of *P. clarkii* were located in Missouri but outside

of the known historical range of the species being cultured. The four shops selling *O. rusticus* in April 2003 were supplied by two sources in Missouri that had originally obtained rusty crayfish from a vendor in Wisconsin. During receipt inspections, one shop indicated that their crayfishes were sometimes collected (illegally) from the wild at a city park, and another shop admitted that their

crayfishes were supplied (illegally) by local children from a nearby creek. One bait shop supplied their own crayfishes from a private pond on their property.

### Determining bait shop knowledge of crayfish stocks

Fifty-one percent of the 135 bait shops that we telephoned in 2007 were contacted and agreed to participate in the telephone survey, and only 3 bait shop owners refused to participate. We were unable to contact 47% of the shops.

Thirty-eight (55%) of the 69 shop owners/managers who participated in the telephone survey indicated that they sold crayfishes. Most (87%) of those shops admitted that they did not know what type (species) of crayfish they sold; only 5 bait shops (13%) claimed to know what they sold. However, 4 of the shop owners/managers who claimed to know what species they sold provided crayfish names that were not recognized common names (see Williams et al. 1988; Pflieger 1996; Taylor et al. 2007) for any species in Missouri. Only 1 (2.6%) of 38 survey respondents provided a correct common name for the crayfish species that he sold.

## DISCUSSION

Lodge et al. (2000b) recently advised all U.S. states to ban the use of live crayfishes as bait. Our 2008 survey of all 50 U.S. states, 10 Canadian provinces, and 3 Canadian territories revealed that nearly half of responding agencies were aware of aquatic resource problems believed to be caused by bait-bucket introductions of alien crayfishes, and these agencies reported a wide range of regulations designed to address such problems. Despite these threats, only 4% of responding agencies had prohibited the use of live crayfishes as bait on all waters. However, at least two states (J. Kilian, Maryland Department of Natural Resources, pers. comm.; B. Wagner, Arkansas Game and Fish Commission, pers. comm.) have recently proposed such a regulation. Many agencies responding to our survey reported regulations restricting the use (39% of respondents) and/or sale (37%) of crayfishes as bait (Table 1), but had not enacted a total ban. Several respondents addressed the problem by banning sale or transport of live crayfish. The observed inconsistency in regulations among states, provinces, and territories may also contribute to the problem of alien crayfish introductions (Peters and Lodge 2009).

Our 2002–2007 evaluation indicated that Missouri bait shops are a potential source for the introduction of alien and possibly invasive crayfishes to Missouri's waters. Although we did not specifically document the transfer of crayfishes sold in Missouri bait shops to their release into natural water bodies in Missouri, it is a logical assumption that some of the crayfishes that had been sold would be released into the wild. Previous studies indicated that angler release of bait is common and thus a vector for bait organism introductions (Litvak and Mandrak 1993; Keller et al. 2007) and that anglers transfer bait across drainage basins (Litvak and Mandrak 1993; Ludwig and Leitch 1996). Burkholder and Wallace (2001) documented occurrence of introduced rusty crayfish both in bait shops (illegally) and in nearby streams in one Pennsylvania county. Due to varying levels of supply and demand, the species sold and sources of crayfish stock are likely to change throughout seasons and years. Our

collections of crayfishes from bait shops were conducted during only 1–3 days per sampling year, providing a brief point-in-time evaluation of the species composition of bait stocks. In addition, we did not attempt to identify female crayfishes to species, so this study provides a conservative estimate of the number of bait shops selling illegal and/or alien species. Despite these limitations, our study revealed important findings about the potential for crayfish introductions via the bait industry. We documented the presence of three illegal species (not listed on the MAASL), including the first documentation of rusty crayfish at Missouri bait shops. To date, the state of Missouri has not documented rusty crayfish in state waters, but no specific investigations have been conducted. We also documented the sale of legal crayfish species (currently approved for sale by the MAASL) at bait shops located in multiple watersheds outside of the species' known historical range. In particular, *P. acutus*, native to only south-east Missouri and portions of the main-stem Mississippi River, was found at many bait shops throughout the state. Following completion of this study, we have documented the presence of *P. acutus* in the wild at four separate localities in Missouri that are well outside of this species' native distribution (R. J. DiStefano, MDC, unpublished data). The effects of introduced *P. acutus* on native biodiversity, habitat, and fish populations in these areas are unknown, but monitoring and evaluating these effects should be considered due to numerous documented impacts of a similar species, *P. clarkii*, in other aquatic ecosystems (Gherardi and Acquistapace 2007; Hobbs et al. 1989).

In addition, our study highlighted specific characteristics of the bait industry that may complicate agencies' abilities to regulate crayfish sales or prevent introductions of alien species:

- The bait industry is dynamic and subject to frequent change. Many telephone contact numbers for shops were disconnected or shops were no longer in business. Some shops surveyed via telephone in the autumn of 2002 were no longer in business by the spring of 2003 or 2004. Additionally, new shops opened during the course of our study.
- Bait vendors may not comply with regulations regarding species being sold. At least 27% (10 of 36) of shops selling crayfishes in 2003 sold illegal crayfish species. It is likely that illegal species periodically exist in Missouri bait vendor stocks.
- Many bait vendors obtain crayfishes from many out-of-state sources and occasionally as bycatch with bait fish orders, and some do not retain written documentation of sources. Also, some bait vendors are illegally obtaining crayfishes from wild populations. The importation of crayfishes from out-of-state and the illegal sale of wild crayfishes complicate the ability of state and provincial agencies to regulate crayfish supplies.
- Most bait vendors do not know what species they are selling. Our 2007 telephone survey revealed that 87% of bait shop proprietors readily admitted to not knowing (in fact, 97% did not know) what species they were selling (Meyer et al. 2007).

Although our study evaluated crayfish bait sales in only one U.S. state, these observations are likely applicable to the bait industry in other U.S. states and Canadian provinces and territories. Problems associated with aquatic invasive species are widespread throughout North America, and many organisms, such as Asian carp species and zebra mussels, have recently received much attention by fisheries agencies. The U.S. Aquatic



Education of bait dealers accompanied by a stronger focus on regulation and enforcement is essential to reducing the introduction of invasive crayfishes. Ninety-seven percent of bait shop managers were unable to name the crayfish species they sold.



Nuisance Species Task Force 2007–2012 Strategic Plan (U.S. ANS Task Force 2007) identifies two main objectives as “identify priority pathways for the introduction of harmful aquatic species into waters of the United States and coordinate specific actions to reduce the likelihood of introduction of harmful nonindigenous aquatic species via these pathways” (Objective 1.2, ANS Task Force 2007) and “investigate the feasibility and mechanisms for interdicting, interrupting, or minimizing priority pathways” (Objective 1.3, U.S. ANS Task Force 2007). This study indicated for crayfish bait what previous studies (Litvak and Mandrak 1993; LoVullo and Stauffer 1993; Ludwig and Leitch 1996; Kircheis 1998; Keller et al. 2007) have indicated for bait fishes and earthworms; the bait industry and bait-bucket introductions by anglers may be significant pathways for the introduction of alien and invasive species. Additionally, we suggest that current management approaches (regulation, enforcement, education) by many agencies relative to the sale and use of crayfish bait do not address some characteristics we documented for Missouri’s bait industry (listed above) that may contribute to the introduction and spread of alien species.

Some respondents to our e-mail survey (Indiana, Iowa, and New York) were aware of established alien crayfish populations, but had not documented problems caused by those introductions. However, there is documentation for other states that

have experienced adverse effects of crayfish introductions of those introduced species (such as hybridization with native species) that were historically sold in bait shops within their states (J. Wallace, Millersville University, Pennsylvania, pers. comm.; M. Demlong, Arizona Game and Fish Department, pers. comm.). In addition to regulating the bait industry, some states reported regulations or concerns associated with the pet/aquarium industry (Missouri, Virginia, and Washington) or school science classes (Arizona, Missouri, and Washington; see Larson and Olden 2008). Several respondents (e.g., Georgia, Iowa, Missouri, Saskatchewan, Virginia, and Washington) also prohibit import or export of some or all live crayfish species; often these are species classified as “aquatic nuisance species.”

Previous studies suggested that fishery agency on-site surveys of or contacts with bait stores may help reduce a lack of awareness of bait regulations by anglers, and a lack of compliance with bait regulations by bait shops, while providing an opportunity to educate store owners and anglers. A survey of Toronto, Ontario, bait shops found that more than half of surveyed anglers were unaware of regulations prohibiting the release of live bait (Litvak and Mandrak 1993). On-site inspections by the Maine Department of Inland Fisheries and Wildlife staff reduced the

incidence of illegal species in bait shop stocks and were used as a mechanism to facilitate working relationships with bait shops (Kircheis 1998). Following our bait shop surveys, MDC has attempted to reduce the introduction and spread of aquatic invasive species through public education efforts and increased communication and partnerships with bait shops (Dent 2006). Beginning in 2007, all bait vendors were required to register with MDC to provide annually updated contact information for dissemination of information and educational literature. Bait vendors were provided with posters and bait-bucket stickers informing anglers that it is illegal to release bait into the wild. The MDC and Illinois Natural History Survey also created a brochure (DiStefano et al. 2008b) to aid bait vendors in identification of legal and illegal invasive crayfish species. Although most bait shops expressed interest in participating in educational programs (Dent 2006), additional efforts are needed to deter the introduction of invasive crayfishes. It should be noted that MDC has not yet evaluated educational efforts intended to reduce alien species introductions or spread. We concur with Lodge et al. (2000b) that all states, provinces, and territories should review their existing regulations and consider a ban on the use of live crayfishes as bait. If such a ban is deemed not feasible or not practical, agencies should consider one or more of these alternatives: (1) restrict use to only preserved crayfish bait which would simplify enforcement and prevent disease transmission (Litvak and Mandrak 1993), (2) restrict use to only those crayfish captured by anglers at the water body where they fish, (3) restrict bait sales and use to limited and safer species, e.g., use of only ubiquitous species or species with minimal chance of surviving bait-bucket introduction; (Litvak and Mandrak 1993), (4) restrict the import of crayfish bait from outside state or provincial boundaries (e.g., Ontario, Saskatchewan), (5) restrict the use of live crayfish bait to only specific water bodies (e.g., British Columbia, New York, Quebec), and (6) cooperate with agencies from bordering jurisdictions on regulations to prevent introductions in watersheds shared by states, provinces, or territories.

With 75% of the world's crayfish diversity inhabiting the North American continent (Taylor et al. 2007), U.S. and Canadian fisheries agencies should strive to conserve native crayfish populations, not only to preserve diversity, but also to maintain the important ecological role that crayfishes perform. Evidence suggests that management practices to reduce the potential for bait-bucket introductions of alien crayfishes would be a significant step in the conservation of those native crayfish populations. Such management practices might also reduce potential adverse effects to ecological functioning of aquatic systems, help sustain fisheries and other native fauna and flora, and prevent substantial economic damage. The combination of our e-mail survey of U.S. state and Canadian provincial and territorial fisheries agencies and an intensive examination of Missouri's bait industry lead us to conclude that traditional approaches to crayfish bait regulation, regulation enforcement, and management have not adequately protected aquatic ecosystems in Missouri and on this continent. State, provincial, and territorial fisheries agencies would be more successful by combining angler education with more focused regulation (and accompanying enforcement) on the sale and use of crayfishes as bait (Litvak and Mandrak 1993; Keller et al. 2007) or by enacting a ban on live crayfish bait as suggested by Lodge et al. (2000b).

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