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INVASION NOTE

Invasive zebra mussels (*Driessena polymorpha*) and Asian clams (*Corbicula fluminea*) survive gut passage of migratory fish species: implications for dispersal

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Abstract The introduction and spread of invasive species is of great concern to natural resource managers in the United States. To effectively control the spread of these species, managers must be aware of the multitude of dispersal methods used by the organisms. We investigated the potential for survival through the gut of a migrating fish (blue catfish, *Ictalurus furcatus*) as a dispersal mechanism for two invasive bivalves: zebra mussel (*Driessena polymorpha*) and Asian clam (*Corbicula fluminea*). Blue catfish (N = 62) were sampled over several months from Sooner Lake, Oklahoma, transported to a laboratory and held in individual tanks for 48 h. All fecal material was collected and inspected for live mussels. Survival was significantly related to water temperature in the lake at the time of collection, with no mussels surviving above 21.1 C°, whereas 12 % of zebra mussels (N = 939) and 39 % of Asian clams (N = 408) consumed in cooler water survived gut passage. This research demonstrates the potential for blue catfish to serve as a dispersal vector for invasive bivalves at low water temperatures.

Keywords Invasive species · Zebra mussels (*Driessena polymorpha*) · Asian clam (*Corbicula fluminea*) · Blue catfish (*Ictalurus furcatus*) · Gut passage · Dispersal mechanisms

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Introduction

Zebra mussels (*Driessena polymorpha*) and Asian clams (*Corbicula fluminea*) differ from several native North American freshwater bivalves by having non-parasitic planktonic larvae (Mackie 1991; Sprung 1993), which limits their natural upstream dispersal capabilities, such that upstream movements by these two invasive species have been largely attributed to anthropogenic means (Carlton 1993; Kappes and Haase 2011).

Various natural upstream dispersal mechanisms for zebra mussels and Asian clams have been suggested, for example: transport of larval zebra mussels from one water body to another attached to the feathers of waterfowl (Johnson and Carlton 1996), and consumption

Table 1 Summary statistics of Asian clams (AC) and zebra mussels (ZM) passed through the guts of blue catfish captured from Sooner Lake, Oklahoma from March 2010 to March 2011

Month	Mean water temperature (°C)	Blue catfish					Asian clams (AC)			Zebra mussels (ZM)		
		Number caught	Number with bivalves	Mean TL ± (SD) mm	Number with AC	Number with ZM	% alive	Number measured[a]	Mean SL ± (SD) mm	% alive	Number measured[a]	Mean SL ± (SD) mm
Early March 2010	14.0	6	3	674 (66)	3	3	64.0	98	19.5 (3.1)	22.1	146	7.8 (3.0)
Late March 2010	15.0	3	3	667 (46)	3	3	59.0	152	18.9 (3.1)	9.7	280	7.3 (2.3)
Early June 2010	28.8	8	4	534 (58)	4	2	0.0	81	20.2 (2.9)	0.0	21	10.5 (3.1)
Late June 2010	30.3	7	2	625 (51)	2	2	0.0	73	20.0 (3.0)	0.0	11	8.5 (2.6)
July 2010	36.7	3	1	554 (21)	1	0	0.0	23	16.9 (1.9)	n/a	n/a	n/a
August 2010	31.1	6	5	534 (30)	5	0	0.0	171	20.0 (3.2)	n/a	n/a	n/a
November 2010	21.1	7	7	623 (20)	7	1	1.2	155	19.8 (3.4)	0.0	41	5.3 (1.7)
Early January 2011	10.0	9	0	621 (145)	0	0	–	–	–	–	–	–
Late January 2011	10.0	7	0	623 (50)	0	0	–	–	–	–	–	–
March 2011	17.0	6	3	715 (148)	2	3	0.0	3	20.0 (1.6)	22.6	33	8.5 (4.4)
Total		62	28		27	14	21.2	756		11.2	532	

TL Total Length, *SL* Shell Length

[a] Not all shells collected were measured. If there were more than 300 shells in a sample a sub-sample was measured

and subsequent gut passage of Asian clams by birds and fishes (Parmalee 1965; Voelz et al. 1998). However, gut passage through waterfowl is unlikely due to the high body temperatures of birds (Thompson and Sparks 1977). McMahon (1982) suggested that the spread of Asian clams across North America was probably expedited by their live gut passage through fishes, but it is not known whether zebra mussels or Asian clams are able to survive such gut passage; if they can, this could allow dispersal of these otherwise sedentary organisms, allowing colonization of new habitats (Domaneschi et al. 2002; Brown 2007).

Several shelled gastropods are capable of surviving passage through the intestinal tracts of fishes (Domaneschi et al. 2002; Brown 2007; Bruce and Moffitt 2009). Many North American fishes consume zebra mussels and Asian clams, including common carp (*Cyprinus carpio*), redear sunfish (*Lepomis microlophus*), freshwater drum (*Aplodinotus grunniens*), smallmouth buffalo (*Ictiobus bubalus*) and blue catfish (*Ictalurus furcatus*) (French 1993; Thorp et al. 1998; Magoulick and Lewis 2002). Of these fishes, all but the blue catfish possess pharyngeal tooth structures that crush the shells (French 1993; Ledford and Kelly 2006), so bivalves consumed by blue catfish are more likely to reach the stomach intact. Ingestion by blue catfish and subsequent gut passage may then be an effective natural dispersal mechanism for zebra mussels and Asian clams, should the mussels survive.

Our objectives were therefore to determine (1) what proportion of zebra mussels and Asian clams survive when consumed and passed by blue catfish under natural conditions, and (2) how shell size and water temperature affect mortality rates of passed bivalves.

Methods

We collected blue catfish on 10 dates between March 2010 and March 2011 using jug-fishing methods at Sooner Lake (Pawnee County, Oklahoma), which contains abundant populations of blue catfish, Asian clams and zebra mussels. Jug-fishing is more efficient than electrofishing at low temperatures (Bodine and Shoup 2010) and does not cause regurgitation by captured fish that can occur with gill nets. Jugs were checked frequently (i.e., every 1–2 h) to reduce stress of hooked fish. Surface water temperature was recorded from two locations near the jugs on each sampling occasion. All fish collected were transported in oxygen-aerated 530-L tanks to the laboratory. Feces from each hauling tank, which could not be attributed to any individual fish, were pooled and examined as separate samples.

In the laboratory, fish were measured (±1 mm total length [TL]) and placed in individual 1,987-L aerated tanks with water temperatures within 3 °C of the lake temperature on the day of collection. The tanks had false bottoms, constructed of 5 × 10 cm galvanized mesh, placed approximately 8 cm above the tank bottom to prevent fish from re-consuming any expelled mussels. After 48 h, the fish were removed and fecal material was collected and stored in individual aerated buckets. All zebra mussels and Asian clams were counted, measured (shell length) and recorded as alive or dead. They were considered alive if they closed their shells when prodded with

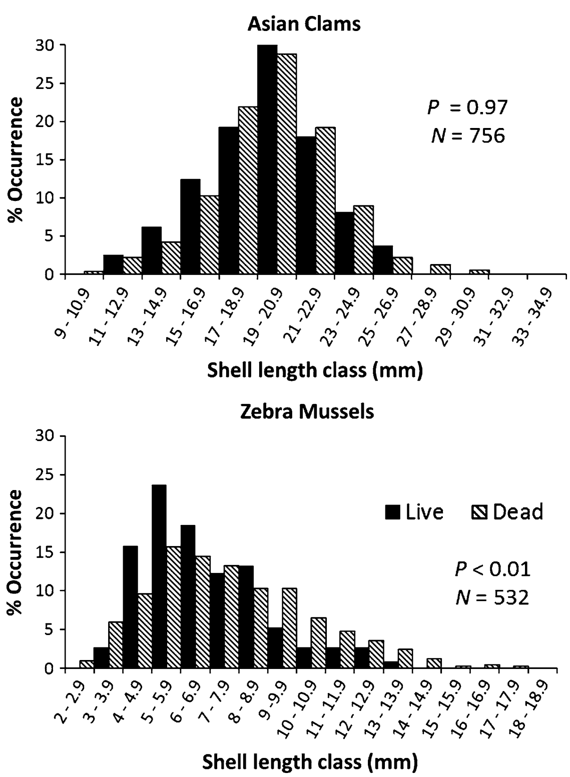

Fig. 1 Frequency of occurrence of different sizes of live and dead Asian clams and zebra mussels that passed through blue catfish guts. *P* value tests the hypothesis that frequency distributions differ between live and dead mussels for the two species based on a Kolmogorov–Smirnov test. Not all recovered zebra mussel shells were measured. In situations where more than 300 shells were present a sub-sample was used

blunt forceps, extended their siphon or foot, or if their shells were tightly closed and resisted opening with forceps (Morse 2009).

Differences in distributions of shell lengths between dead and live mussels, pooled among fish, were tested with Kolmogorov–Smirnov (KS) tests. Logistic regression with repeated measures (fish treated as subjects) was performed using SAS Proc Glimmix to determine the relationships between percent mussel survival and mussel shell length and water temperature.

Results

We collected 62 blue catfish from which we recovered 756 Asian clams (161 alive) and 1012 zebra mussels (114 alive; Table 1). Bivalves were found in feces of 28 of the fish and from 8 of the 10 collecting occasions.

Both bivalve species survived gut passage to varying degrees (Table 1; Fig. 1). Survival was documented in 27 % of fish that consumed zebra mussels and 22 % that consumed Asian clams. Shell length did not differ significantly between live and dead Asian clams passed through the fish guts (D = 0.05; $P = 0.97$), but live zebra mussels were significantly smaller than dead ones (D = 0.19; $P < 0.01$). Shell size was a significant predictor of gut passage survival for zebra mussels ($F_{1,\,516} = 9.04$, odds ratio = 0.88, $P < 0.01$), but not for Asian clams ($F_{1,\,728} = 0.18$, odds ratio = 0.99, $P = 0.68$). Survival of both species was temperature dependent with greater survival in cooler water temperatures (Asian clams $F_{1,\,25} = 111.91$, odds ratio = 0.48, $P < 0.01$; zebra mussels $F_{1,\,13} = 13.84$, odds ratio = 0.65, $P = 0.01$; Fig. 2).

Discussion

Asian clams and zebra mussels were both capable of surviving passage through the gut of blue catfish to

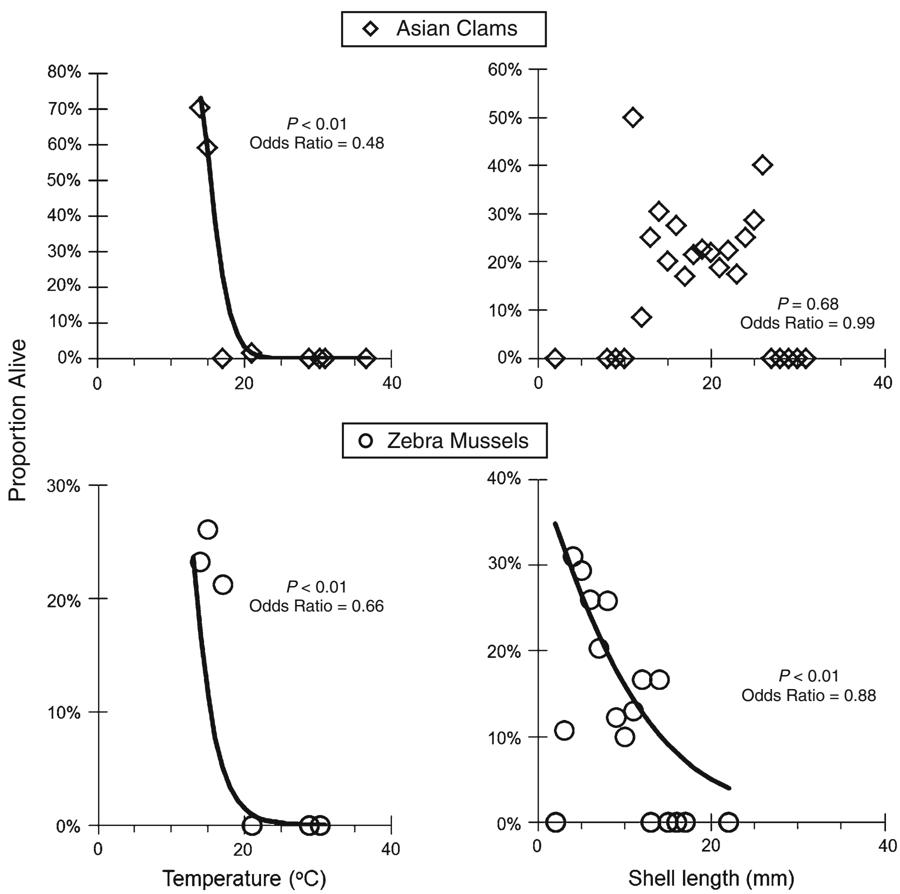

Fig. 2 The logistic relationships between survival and water temperature or shell length of Asian clams and zebra mussels that passed through the guts of blue catfish

some degree. The effectiveness of this process in dispersing mussels remains unknown, but our research demonstrates another possible vector for the spread of these species; one that has rarely been viewed as important because most research has focused on their spread by anthropogenic means (French 1993; Sousa et al. 2008; Keller et al. 2009; Morse 2009).

Our post gut-passage mussel survival estimates are probably conservative because we considered all mussels that passed as being alive at the time of consumption. However, in many cases it was clear that passed mussels were dead when consumed because we found byssal threads from zebra mussels or algae on the inside of some shells. Only dead mussels would have an accumulation of other biota on the inner surface of the shell.

Water temperature influenced survival of both mussel species and could affect the ability of blue catfish to distribute these two invasive species. No mussels survived gut passage at temperatures above 21.1 °C, so gut passage would only be an effective dispersal mechanism at lower water temperatures. Blue catfish are perhaps the most migratory of North American freshwater catfish species (Graham 1999), traveling up to 689 km in a year (Tripp et al. 2011). Their maximum migration distances typically occur when water temperatures are between 8 and 18 °C (Garrett and Rabeni 2011; Tripp et al. 2011), well below the temperature at which we found mussels no longer survive gut passage.

How these mussels fare in the natural environment after passage through a blue catfish gut is unknown. We assessed mussel survival after 48 h in a controlled environment. It is not known if passed individuals would continue to live, grow, and ultimately reproduce in their transplanted environment. However, at least one-third of the zebra mussels and all of the Asian clams that survived were large enough to be reproductively mature: >6 mm for both Asian clam (Sousa et al. 2008) and zebra mussels (Juhel et al. 2003). Although larger zebra mussels were less likely to survive than smaller ones, the smaller mussels were still large enough to be reproductively mature.

Natural movement of blue catfish may not be the only fish-mediated mussel dispersal mechanism. Natural resources agencies may move fish from one water-body to another for management purposes and anglers may move them for recreational angling purposes. Our results indicate that fish that are moved to new locations within 48 h of capture have the potential to deposit live mussels. Further research is needed to determine the gut passage time of blue catfish so a minimum quarantine time can be established that ensures no mussels could be introduced when moving blue catfish between water bodies. Previous studies on evacuation rates of fish usually focus on evacuation of the stomach only (Bromley 1994), not the entire gut. We are aware of no studies that have estimated gut evacuation rates of blue catfish. Our results show that blue catfish may be able to aid the spread of Asian clams and zebra mussels and this knowledge can help inform management of these two invasive species.

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