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REGULAR ARTICLE

ASSESSMENT OF A SHORT-DISTANCE FRESHWATER MUSSEL RELOCATION AS VIABLE TOOL DURING BRIDGE CONSTRUCTION PROJECTS

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ABSTRACT

Freshwater mussels have undergone dramatic population declines due largely to habitat alteration. A commonly employed measure to minimize the effects of anthropogenic habitat disturbance on mussels is short-distance relocations of individuals. However, quantified survival data are lacking to gauge the success of relocations. To evaluate the suitability of short-distance relocations as a conservation tool for freshwater mussels, we experimentally relocated two common species, Mucket (*Actinonaias ligamentina*) and Plain Pocketbook (*Lampsilis cardium*), in an active construction zone. We marked 100 mussels with passive integrated transponders, released them ∼200 m upstream of the construction site, and monitored them monthly throughout the spring and summer 2013-2015. We used Cormack-Jolly-Seber models to estimate apparent survival rates and found survival was lowest the first two months after relocation but increased and stabilized thereafter. Our models predict 93% of the relocated *A. ligamentina* and 71% of the *L. cardium* remained alive three years post-relocation. We conclude short-distance relocations are a viable minimization tool for protecting freshwater mussels at bridge construction sites, but further study is needed examine the factors driving the initial mortality.

KEYWORDS - relocation, translocation, bridge construction, habitat alteration, PIT tags

INTRODUCTION

The precipitous decline of freshwater mussels in North America has been well documented and is attributed to anthropogenic habitat alterations (Williams et al. 1993; Lydeard et al. 2004; Strayer et al. 2004). Despite efforts to conserve and protect remaining mussel populations, anthropogenic habitat alterations often continue to affect biologically significant areas. One example is the instream work, such as the creation of temporary dams or crane pads, required during construction of new bridges or repairing existing ones. Instream work can cause direct mortality of freshwater mussels in the construction zone, or indirect mortality through increased siltation or altered water levels (Oblad 1980; Trdan and Hoeh 1993).

According to the U.S. Department of Transportation, a quarter of the approximate 607,380 bridges in the United States are structurally deficient or functionally obsolete (Islam et al. 2014; Lo 2014). Therefore, one would expect an increased need for instream work for repairs or replacement, and thus an increased need for biological mitigation and disturbance minimization techniques to help conserve freshwater mussels (Miller and Payne 2006). Frequently, short-distance relocation of mussels out of the construction zone is the preferred minimization method as it is both time and cost-effective (Oblad 1980; Trdan and Hoeh 1993; Dunn and Sietman 1997). However, relocation effectiveness (e.g., recovery and survival) is not well documented (Cope and Waller 1995; Cope et al. 2003). Follow-up monitoring is often short-term, published in obscure gray literature, and fails to identify mortality or detectability rates (Cope and Waller 1995; Cope et al. 2003). Additionally, little is known regarding what environmental or species-specific factors affect relocation success. Therefore, despite its widespread use, little support exists for short-distance relocation as an effective minimization tool for protecting freshwater mussels at bridge construction sites.

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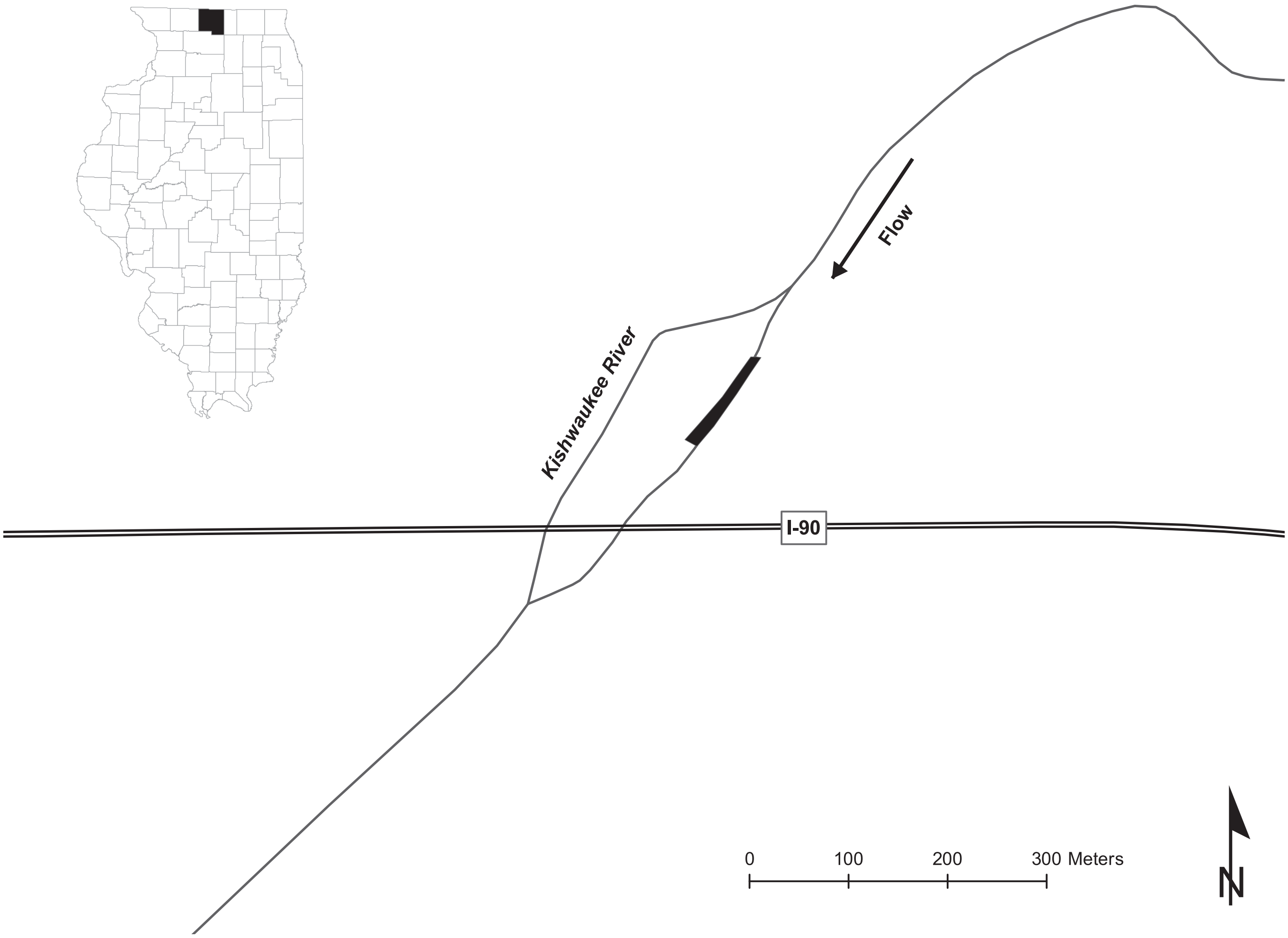

Figure 1. Kishwaukee River (Rock River drainage) at the Interstate 90 bridge, southeastern edge of Rockford, Winnebago and Boone counties, Illinois (42.24721°N, 88.94394°W). The blackened polygon indicates the relocation area.

To assess the efficacy of short-distance relocations of freshwater mussels, we experimentally relocated 100 individuals during a bridge reconstruction project on the Jane Addams Memorial Tollway (I-90) over the Kishwaukee River in northern Illinois. We estimated apparent survival rates for two mussel species over three years while examining several factors potentially influencing survival, including individual size, species, time and environmental measurements. Tracking apparent survival rates over a prolonged period allows us to better determine if short-distance relocations are a predictable and viable conservation tool for minimizing the effects of bridge construction on freshwater mussels.

METHODS

Study Area

The study site was located in the Kishwaukee River (Rock River drainage) at the Interstate 90 bridge, southeastern edge of Rockford, Winnebago and Boone counties, Illinois (Figure 1). The study area was bordered by land owned by the Winnebago County Forest Preserve District and the Boone County Conservation District. At base flow, the stream was approximately 53 m wide, 1 m deep, and had a flow rate of <0.15 m/sec. The streambed was sandy gravel; no aquatic vegetation or undercut banks were evident, but isolated, small patches of wood debris were present. This reach of the Kishwaukee River is biologically significant and rated as a Unique Aquatic Resource because of high freshwater mussel and fish diversity, including rare taxa (Bertrand et al. 1996; Shasteen et al. 2013). The Kishwaukee River basin is characterized by open oak woodland and prairie country on low undulating land, but the landscape is primarily agriculture with croplands accounting for nearly two-thirds of the surface area (Page et al. 1992; Shasteen et al. 2013). The flow of the Kishwaukee River is unimpeded except for a $\sim$3.5 m dam in Belvidere, approximately 10 km upstream of our study area (Page et al. 1992).

Table 1. List of the 22 additive models assembled to assess the survival of 100 relocated mussels in response to a short-distance relocation experiment in the Kishwaukee River at the I-90 bridge, Winnebago/Boone counties, Illinois. All models included intercepts (Int) for apparent survival rates and individual detection probabilities. Variable include species, time, shell length, maximum flow rate in the previous month, water depth at census, flow rate at census, and air temperature at census.

Covariates	Apparent Survival	Individual Detection
0 - Null	Int	Int
1	Int	Depth, Int
1	Int	Flow, Int
1	Int	Length, Int
1	Int	Species, Int
1	Int	Temp, Int
1	Int	time, Int
1	Length, Int	Int
1	Max Flow, Int	Int
1	Species, Int	Int
1	time, Int	Int
2	Length, Int	Length, Int
2	Species, Int	Species, Int
2	time, Int	time, Int
4	Species, time, Int	Species, time, Int
5	Species, time, Int	Species, time, Temp, Int
6	Species, time, Int	Species, Time, Depth, Temp, Int
6	time, Max Flow, Int	time, Depth, Flow, Temp, Int
7	Species, time, Int	Species, time, Depth, Flow, Temp, Int
8	Species, time, Max Flow, Int	Species, time, Depth, Flow, Temp, Int
10	Species, time, Length, Max Flow, Int	Species, time, Length, Depth, Flow, Temp, Int
14 - Global	Species, time, Length, Depth, Flow, Max Flow, Temp, Int	Species, time, Length, Depth, Flow, Max Flow, Temp, Int

Survey Techniques

We conducted a qualitative, haphazard survey of the freshwater mussel fauna in the Kishwaukee River at the I-90 bridge (Figure 1) in May 2013 before bridge reconstruction. The fauna comprised 15 species, including the state-threated Black Sandshell (*Ligumia recta*), but was dominated by the Mucket (*Actinonaias ligamentina*) and Plain Pocketbook (*Lampsilis cardium*). These two common species were used to assess apparent survival rates in response to a short-distance relocation. During the same 2013 survey, we collected 58 adult Muckets (85-137 mm, mean size = 115 mm) and 42 adult Plain Pocketbooks (17 females – 81-124 mm, mean size = 104 mm; and 25 males – 60-127 mm, mean size = 103 mm) in the vicinity of the I-90 bridge. Passive integrated transponder (PIT) tags are an effective tool for monitoring relocated mussels (Kurth et al. 2007), therefore, we externally outfitted individuals with 12.5 mm, 134.2 kHz PIT tags (BioMark, Inc., Boise, ID) using Devcon marine grade epoxy (Danvers, MA). Tagged mussels were held in damp towels overnight while the epoxy cured and then relocated the next morning, resulting in a handling time of approximately 16h. Tagged mussels were relocated to a 100 m area approximately 200 m upstream of the construction site in the eastern channel (Figure 1). We chose the eastern channel for relocation because habitat was comparable to the source site (e.g., sandy gravel run with moderate current), and we wanted to eliminate any siltation effects resulting from the bridge construction. Animals were deposited on the streambed surface and not buried. Marked individuals were monitored monthly with an aquatic PIT tag reading system (BioMark FS2001F-ISO or BioMark HPR Plus with portable BP antennas) from July-October 2013, May-October 2014 and April-September (sans June) 2015; weather and water conditions (e.g., ice or high flows) prohibited sampling at other times. We scanned the relocation area plus a 75 m buffer downstream for marked mussels during each monitoring event.

Statistical Analysis

We conducted survival analyses in R (R Core Team 2015) using the RMark package (Laake 2013) with Cormack-Jolly-Seber models. We modeled the effects of species, time, shell length (mm), maximum flow rate in the previous month (m/sec), water depth at census (m), flow rate at census (m/sec), and air temperature at census (°C) as covariates affecting individual detection probabilities and apparent survival rates (Table 1). Water-related covariates were taken from the nearby Kishwaukee River, Belvidere, IL gauging station (USGS 05438500) located approximately 9 km upstream and air temperature was taken on site. We fit 22 survival models, which included an intercept only model (null), global model (all covariates), all single effects models, and a series of step-

Table 2. AIC results for 22 Cormack-Jolly-Seber survival models including the global and null models for a short-distance relocation experiment for 100 mussels in the Kishwaukee River at the I-90 bridge, Winnebago/Boone counties, Illinois. Where Ψ = apparent survival, p = individual detection probability, K = number of parameters, S = Species, t = time, L= initial mussel length, D = depth, F = flow, MF = max flow, and T = temp.

Rank	Model	K	Deviance	AIC$_C$	ΔAIC$_C$	w_i
1	$\Psi_{(S+t)}$, $p_{(S+t)}$	32	1001.36	1765.52	0.00	1.00
2	Global	16	1751.01	1783.78	18.26	0.00
3	$\Psi_{(S+t+MF)}$, $p_{(S+t+D+F+T)}$	10	1767.68	1787.99	22.47	0.00
4	$\Psi_{(t)}$, $p_{(t)}$	30	915.26	1790.51	24.99	0.00
5	$\Psi_{(S+t+L+MF)}$, $p_{(S+t+L+D+F+T)}$	12	1766.74	1791.17	25.66	0.00
19	Null	2	1035.35	1851.93	86.41	0.00

wise models where we eliminated from the global model until we reached the species and time effects only (Table 1). To determine the best-fit model, we used an AIC approach (Burnham and Anderson 1998), whereby our 95% confidence set of candidate models included those with Akaike weights summing to 0.95. Finally, all graphics were produced using ggplot2 in R (Wickham 2009).

RESULTS

Of the 22 models analyzed, the top model included both species and time effects on apparent survival rates and individual detection probabilities (Table 2). The species and time model carried high support despite consisting of 32 parameter estimates (Table 2). None of the other 21 models had any significant support suggesting individual length and environmental covariates (depth, flow rate, maximum flow rate and temperature) had no discernable effects on apparent survival rates or individual detection probabilities (Table 2).

Individual detection probabilities varied by species and over time with probabilities lower for *A. ligamentina* versus *L. cardium*, but confidence intervals broadly overlapped (Table 3; Figure 2). Probabilities varied between 0.392 – 0.587 for *A. ligamentina* and 0.479 – 0.669 for *L. cardium* (Table 3; Figure 2). Although individual detection probabilities fluctuated, they appeared fairly stable (Table 3; Figure 2). We observed the lowest detection probabilities for the May 2014 sample and the highest for the May 2015 survey (Table 3; Figure 2).

Apparent survival rates differed for each species but showed little monthly variation (Table 3; Figure 3). Overall, the first two months post-relocation had the lowest apparent survival rates for both species (Table 3; Figure 3). The apparent survival rates rapidly increased thereafter, except for a small decrease that occurred around the time the earthen causeway at the bridge was removed post-construction (Table 3; Figure 3). For *A. ligamentina*, apparent survival rates were lowest between the first two survey transitions (~0.966) then rose to ~1.000 survival throughout the remainder of the study (Table 3; Figure 3). Apparent survival rates for *L. cardium* were lowest between the first two survey transitions (~0.848) but then rapidly rose to ~0.995 (Table 3; Figure 3). From our initial relocation of 58 *A. ligamentina* and 42 *L. cardium*, our models predict we have 54 (95% C.I. 45,56) and 30 (95% C.I. 14,35) surviving individuals of each species, respectively, and equates to 93.1% (77.6% – 95.6%) of the relocated *A. ligamentina* and 71.4% (33.3% – 83.3%) of the *L. cardium* surviving to the last survey.

DISCUSSION

Our data suggested short-distance relocation is a viable tool for mussel conservation but will not eliminate all mortality. In our study, *A. ligamentina* and *L. cardium* had comparable detection rates and our models predicted 93% of the relocated *A. ligamentina* and 71% of the *L. cardium* were alive three years post-relocation. Previous studies have shown recovery (=detectability) and survival rates are highly variable among relocations and are dependent upon biotic and abiotic factors, including environmental conditions and handling stress (Dunn et al. 2000; Bolden and Brown 2002; Villella et al. 2004). In a review of 33 papers on mussel relocation, Cope and Waller (1995) reported a mean mortality of relocated mussels at 49% based on an average recovery rate of 43%. Recovery and survival rates have been reported as low as <10% (Sheehan et al. 1989; Cope and Waller 1995, and references therein) and as high as >90% (Dunn and Sietman 1997; Peck et al. 2014). In our study, the greatest mortality occurred the first two months post-relocation.

Survivorship

Four stress related factors can explain the early decrease in apparent survival rates for the relocated individuals, but unfortunately, they are not mutually exclusive. First, some mussels might already have been in a stressed state given localized construction activities, and/or simply were in poorer body condition before relocation. Second, our prolonged handling time might have exacerbated or initiated a stressed condition of the mussels. Third, animals became stressed when placed in unfamiliar habitat in the release area. Finally, our placement did not include burying mussels; thus, they might have incurred additional stress seeking proper refuge. All four stress related factors could have individually, or more likely synergistically, manifested in the initial decrease in apparent survival rates. Of the four factors, we feel the first two coupled together – poor body condition and prolonged handling time –

Table 3. Transformed parameter estimates (real), standard errors, and 95 % confidence intervals for the species and time Cormack-Jolly-Seber survival model.

Individual Detection Probability

	Actinonias ligamentina				*Lampsilis cardium*			
Sample	Est.	S_{err}	Lower CI	Upper CI	Est.	S_{err}	Lower CI	Upper CI
Jul 2013	0.518	0.039	0.442	0.593	0.605	0.040	0.523	0.681
Aug 2013	0.445	0.038	0.372	0.521	0.533	0.042	0.451	0.614
Sep 2013	0.559	0.036	0.488	0.627	0.643	0.037	0.567	0.713
Oct 2013	0.576	0.041	0.495	0.653	0.659	0.041	0.575	0.734
May 2014	0.392	0.044	0.310	0.481	0.479	0.049	0.384	0.575
Jun 2014	0.531	0.028	0.475	0.586	0.617	0.033	0.552	0.679
Jul 2014	0.562	0.026	0.511	0.612	0.647	0.030	0.586	0.703
Aug 2014	0.562	0.027	0.509	0.614	0.647	0.031	0.584	0.704
Sep 2014	0.526	0.033	0.461	0.591	0.613	0.037	0.539	0.681
Oct 2014	0.579	0.032	0.515	0.640	0.662	0.034	0.591	0.725
Apr 2015	0.516	0.032	0.452	0.578	0.603	0.037	0.529	0.672
May 2015	0.587	0.030	0.528	0.644	0.669	0.033	0.601	0.731
Jul 2015	0.497	0.036	0.427	0.567	0.584	0.041	0.502	0.661
Aug 2015	0.574	0.037	0.500	0.644	0.657	0.040	0.575	0.731
Sep 2015	0.575	0.032	0.511	0.637	0.658	0.036	0.584	0.725

Apparent Survival Rates

	Actinonias ligamentina				*Lampsilis cardium*			
Transition	Est.	S_{err}	Lower CI	Upper CI	Est.	S_{err}	Lower CI	Upper CI
Jun 2013 - Jul 2013	0.965	0.016	0.915	0.986	0.847	0.043	0.743	0.913
Jul 2013 - Aug 2013	0.966	0.016	0.916	0.986	0.848	0.044	0.742	0.915
Aug 2013 - Sep 2013	0.998	0.001	0.991	1.000	0.992	0.006	0.964	0.998
Sep 2013 - Oct 2013	0.999	0.001	0.993	1.000	0.993	0.005	0.970	0.998
Oct 2013 - May 2014	0.999	0.001	0.994	1.000	0.993	0.005	0.974	0.998
May 2014 - Jun 2014	0.996	0.002	0.988	0.999	0.981	0.009	0.952	0.993
Jun 2014 - Jul 2014	0.999	0.001	0.996	1.000	0.993	0.004	0.981	0.998
Jul 2014 - Aug 2014	0.997	0.002	0.991	0.999	0.987	0.008	0.959	0.996
Aug 2014 - Sep 2014	0.999	0.001	0.996	1.000	0.995	0.003	0.984	0.999
Sep 2014 - Oct 2014	0.999	0.001	0.996	1.000	0.995	0.003	0.984	0.999
Oct 2014 - Apr 2015	0.999	0.001	0.997	1.000	0.996	0.003	0.986	0.999
Apr 2015 - May 2015	0.998	0.002	0.986	1.000	0.992	0.009	0.933	0.999
May 2015 - Jul 2015	0.999	0.001	0.994	1.000	0.996	0.004	0.971	1.000
Jul 2015 - Aug 2015	0.998	0.003	0.966	1.000	0.989	0.016	0.847	0.999
Aug 2015 - Sep 2015	1.000	0.001	0.994	1.000	0.998	0.003	0.972	1.000

likely caused stress-induced mortality. We did not collect hemolymph to measure physiological responses so we can only speculate the cause.

We feel some of the individuals might have been in a stressed state and were in poor body condition before our relocation, which occurred only a few months after the drought of 2011–2012 subsided. During the drought, the Kishwaukee River did not dry completely, but several hundred dead and dying mussels were found on exposed areas in our source area while others appeared lethargic (e.g., slow to respond to shadows and touch) in water temperatures exceeding 35°C (J.S. Tiemann, personal observation). Drought, with its extended periods of high water temperatures and reduced stream velocity, could have adversely affected physiological responses and might have decreased the amount of energy available for key biological processes, such as survival (Gasner et al. 2015; Vaughn et al. 2015).

A likely second coupling factor was our handling time. Reducing handling time can become tricky and potentially problematic if animals need to be marked to allow monitoring. Dunn et al. (2000) recommended reducing handling times and avoiding extreme temperature conditions while keeping the

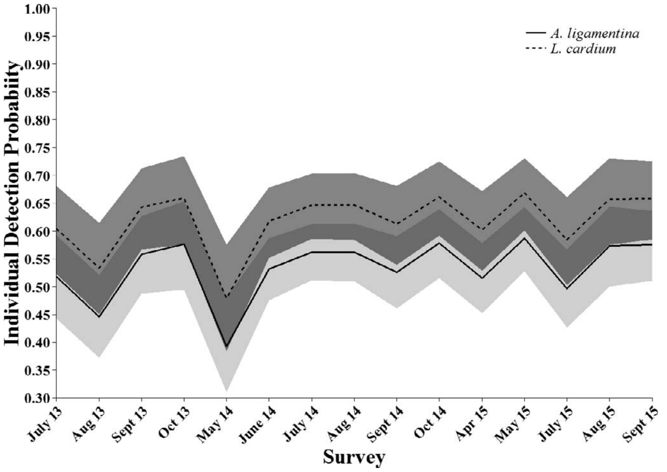

Figure 2. Individual detection probabilities by species to survey, with 95% confidence intervals shaded, a short-distance relocation experiment for 100 mussels in the Kishwaukee River at the I-90 bridge, Winnebago/Boone counties, Illinois.

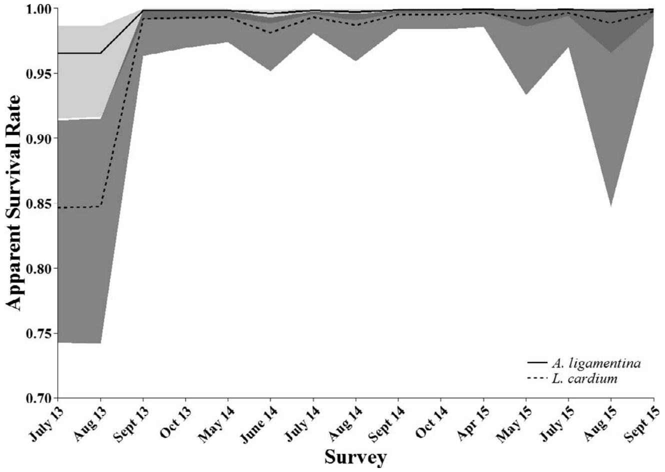

Figure 3. Apparent survival rates by species to survey, with 95% confidence intervals shaded, a short-distance relocation experiment for 100 mussels in the Kishwaukee River at the I-90 bridge, Winnebago/Boone counties, Illinois.

animals moist when conducting relocations. However, the use of PIT tags requires more handling time than other methods, such as plastic tags or glitter glue, because most epoxies need ~12 h to cure completely. Future projects affixing PIT tag with epoxy or cement should consider faster-drying brands (e.g., Fuji Glass Ionomer Luting Cement recommended by Hua et al. 2015) to reduce holding time. We do not feel the mass of the epoxied PIT tag caused stress given the sizes of mussels (mean size was 115 mm for *A. ligamentina* and 103 mm for *L. cardium*) and the minimal amount of epoxy used for the 12.5 mm tags. Although a potentially large upfront cost (e.g., purchasing readers and tags, plus manpower to affix tags), monitoring can be less costly (e.g., less manpower to monitor) and can be done when conditions are less favorable (e.g., slightly turbid or cold waters) compared to hand-picking for animals marked in some other manner (e.g., plastic tags or glitter glue). We believe that PIT tags have several advantages over other methods (e.g. plastic tags) that justify the longer handling times, mainly the two-fold recovery rate over visual tags (Kurth et al. 2007).

We do not believe unfamiliar habitat in the release area caused an initial reduction in apparent survival rate. The lower Kishwaukee River, including both the construction zone and the relocation area upstream of the bridge, is predominantly sandy gravel runs with moderate flow and mussel densities <1 individual/m^2 (J.S. Tiemann, unpublished data). Per the recommendations of previous studies (e.g., Dunn and Sietman 1997; Dunn et al. 2000), the relocation area consisted of suitable habitat and was large enough to harbor both the resident fauna and individuals being relocated. Habitat stability and diversity in the relocation area is a critical factor because the type of preferred habitat varies by species being relocated (Sheehan et al. 1989; Dunn 1993; Dunn and Sietman 1997). Selection of suitable relocation sites should be species specific if quantitative information on the habitat requirements of individual species is known (Cope and Waller 1995; Hamilton et al. 1997). The benefit of short-distance, intrastream relocations can often help eliminate issues with habitat similarity and suitable host fishes (Havlik 1997).

We do not feel our placement method of relocated mussels caused a reduction in apparent survival rates. Our placement method was not extraneous and was similar to standard practices in Illinois (K.S. Cummings, Illinois Natural History Survey, personnel communication). However, several previous projects involving either PIT tags (e.g., Newton et al. 2015) or relocation (e.g., Dunn et al. 2000) hand planted mussels. Therefore, future projects could assess the differences in placement methods (e.g., burying mussel vs. depositing them on the streambed surface).

The lower apparent survival rate of *L. cardium* should be approached with caution. Most (six of nine) dead individuals were discovered after the earthen causeway was removed, which was three years post-relocation; all of these individuals were recorded alive at least one to two months post-relocation. We are reluctant to speculate the cause of this observation. One possibility is once the causeway was breached, a sudden pulse in water and subsequent drop in water levels caused mussels to become dislodged and potentially stranded in unsuitable areas.

Longitudinal Movements and Detection

Twenty individuals were detected outside of the study area, including one detected in the relocation area in August 2015 but located ~50 m downstream of the relocation area in October 2015 (individual not found in September 2015). While considered sessile organisms, mussels, including *L. cardium*, are known to move >10 m / week during warmer periods (Newton et al. 2015). Relocated mussels have been reported to move at greater rates perhaps to seek more suitable habitat (Bolden and Brown 2002; Peck et al. 2014). However, as time elapses, the movement differences can become non-significant (Peck et al. 2014).

Seventeen individuals were not detected during our study post-release. There are several possible reasons, including predation, tag failure, or mussels moving or being swept beyond our monitoring area. PIT tags decrease burrowing rates, thus increasing the time needed to burrow into the substrate, and thereby increasing the risk of predation or dislodgement during flooding (Wilson et al. 2011). Peck et al. (2014) suggested relocated mussels can be highly susceptible to mammalian predation as a result of increased vulnerability during extremely low water levels. We did not sample the riparian areas for shell middens so we cannot comment on predation. During our July 2013 monitoring event, one tagged *L. cardium* was found while snorkeling but the tag failed to register in the PIT tag reader. We assumed the glass case was compromised post-release. Lastly, we cannot rule out some animals moved upstream of the study area as witnessed by both Bolden and Brown (2002) and Peck et al. (2014). As noted above, mussels can move vast distances in a short period. Future studies could sample riparian areas for middens, as well as sampling buffer areas upstream and downstream of the relocation area, to increase detection rates and strengthen apparent survival rates.

Conservation Implications

The goal of relocation is to collect and relocate mussels in a cost-effective manner while ensuring high survival of the relocated individuals without jeopardizing the resident fauna (Havlik 1997). We recommend at least three years of post-release monitoring to assess apparent survival rates, similar to the recommendations of others (e.g., Cope and Waller 1995; Havlik 1997; Villella et al. 2004). Monitoring for three years not only increases the chances to document reproductive success but also increases the chances of detecting individuals (Cope and Waller 1995; Havlik 1997). Ten individuals went undetected the first two years following relocation only to be found at least once during the third year. Data such as these could affect survival estimates because of individual detection issues (Nichols 1992; Villella et al. 2004). Detecting unaccounted individuals refines survivorship estimates and provides a better estimate of the relocation success (Layzer and Gordon 1993; Cope and Waller 1995; Villella et al. 2004).

Future studies could address the effects of initial mortality by collecting hemolymph during initial relocation and some defined time-period after (e.g., 2 months post-relocation) to examine body condition and measure physiological responses to relocation. In addition, testing for effects of different placement methods (e.g., burying mussel vs. depositing them on the streambed surface) on relocation survival is important. These studies could help explain potential stress related factors that might cause a reduction in apparent survival rates post-relocation. Lastly, if earthen causeways are needed, relocations areas should be placed outside the direct zone of influence to negate any possible effects of the impounded waters or subsequent dam removal. Natural resource agencies should work with construction companies on the timing of construction activities to increase survival of relocated animals. One example is being on site for rescue operations as a causeway is removed.

Future construction relocation work similar to our project should be considered in an objective manner and not a method to circumvent protective conservation legislation (Havlik 1997; Cosgrove and Hastie 2001). Relocations can be simple but are often labor-intensive and time-consuming and require various permits, especially when dealing with threatened and endangered species (Havlik 1997; Miller and Payne 2006). However, by following the steps outlined here and by others (e.g., Dunn and Sietman 1997; Dunn et al. 2000), short-distance mussel relocation can be a viable minimization tool for protecting freshwater mussels during bridge construction projects.

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