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REGULAR ARTICLE

SURVIVAL OF TRANSLOCATED CLUBSHELL AND NORTHERN RIFFLESHELL IN ILLINOIS

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ABSTRACT

Translocation of freshwater mussels is a conservation tool used to reintroduce extirpated populations or augment small populations. Few studies have evaluated the effectiveness of translocations, mainly because estimating survival is challenging and time-consuming. We used a mark-recapture approach to estimate survival of nearly 4,000 individually marked Clubshell (*Pleurobema clava*) and Northern Riffleshell (*Epioblasma rangiana*) translocated to eight sites over a five-year period into the Salt Fork and Middle Fork Vermilion rivers in central Illinois. Survival differed among sites and between species; Clubshell were approximately five times more likely to survive than Northern Riffleshell. Survival also increased in the fourth year following a release and decreased following high-flow events. Translocating numerous individuals into multiple sites over a period of years could spread the risk of catastrophic high-flow events and maximize the likelihood for establishing self-sustaining populations.

KEY WORDS: reintroduction, freshwater mussel, high flow, PIT tag, unionids

INTRODUCTION

North American freshwater mussels have undergone drastic population declines during the past century and are one of the most imperiled groups of animals in the world (Williams et al. 1993; Lydeard et al. 2004; Strayer et al. 2004). Translocation has been used for decades to augment populations or reintroduce mussels into regions where species have declined or are extirpated (Coker 1916; Ahlstedt 1979; Sheehan et al. 1989). Much time and effort is placed on collecting, marking, and transporting mussels for translocation, but few studies have evaluated the effectiveness of mussel reintroductions. More than a quarter of all translocation projects conducted prior to 1995 failed to report on the efficacy of those efforts (Cope and Waller 1995).

Obtaining precise and unbiased estimates of mussel survival is challenging, even for translocated individuals. Mussels often burrow beneath the substrate surface when not actively feeding or reproducing, making them difficult to detect (Amyot and Downing 1998; Watters et al. 2001; Strayer and Smith 2003). Furthermore, an unequal proportion of the population is often sampled, such as larger individuals, those found in easy-to-sample areas, or those at or near the surface (Strayer and Smith 2003; Meador et al. 2011). Reliable estimates of survival can be obtained using capture-mark-recapture techniques (Hart et al. 2001; Meador et al. 2011). Capture-mark-recapture methods are often time-intensive due to the effort needed to capture and mark a large number of individuals, but marking individuals already captured for translocation can be easily incorporated.

The federally endangered Clubshell (*Pleurobema clava*) and Northern Riffleshell (*Epioblasma rangiana*) were formerly widespread in the Ohio River and Great Lakes basins but have experienced significant range reductions during the last century. The recovery plan for the Clubshell and Northern Riffleshell set objectives of reestablishing viable populations in 10 separate river drainages across the species' historical range via augmentation and reintroduction (USFWS 1994). Bridge construction on the Allegheny River, Pennsylvania, which supports large populations of both species, prompted a salvage operation to remove thousands of individuals from the impacted area. In an attempt to meet recovery plan objectives, these individuals were translocated to multiple streams within seven states where the species had declined or had been extirpated.

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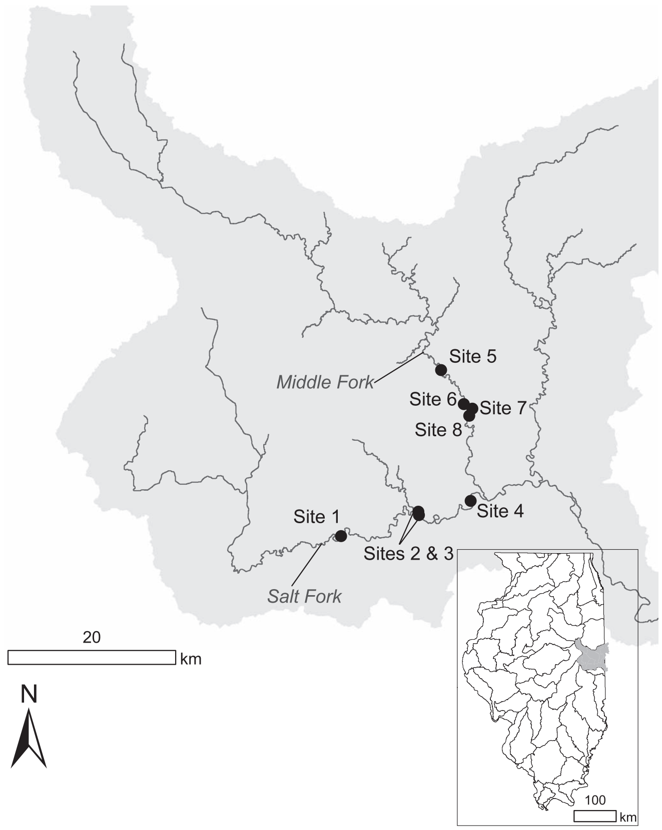

Figure 1. The Clubshell and Northern Riffleshell release sites in the Vermilion River basin (Wabash River drainage), Illinois.

Beginning in 2006, the Illinois Department of Natural Resources and the Illinois Natural History Survey partnered with the U.S. Fish and Wildlife Service and state agencies in Ohio, Pennsylvania, and West Virginia to translocate Clubshell and Northern Riffleshell from the Allegheny River to the Vermilion River system (Wabash River basin) in Illinois, where both species occurred historically (Cummings and Mayer 1997; Tiemann et al. 2007). Pilot translocations ($n <$ 75 individuals) first occurred in 2010 at one site each in the Salt Fork and Middle Fork Vermilion rivers, and more widespread translocations occurred at eight sites in 2012, 2013, and 2014. We conducted a five-year capture-mark-recapture study focusing on those individuals released in 2012, 2013, and 2014 to estimate survival of translocated mussels. Specifically, our goals were to evaluate (1) how survival differed according to species, sex, and mussel size, (2) how survival varied spatially (among sites and between rivers), and (3) how survival varied temporally after release.

METHODS

Mussel Collection and Transportation

Mussels were collected from the Allegheny River at the U.S. Highway 62 Bridge, Forest County, Pennsylvania. The Allegheny River at this site is approximately 200 m wide and drains an area of approximately 10,000 km^2. Mean daily discharge is approximately 56 m^3/s at the end of August and nearly 425 m^3/s at the beginning of April (average of 71 yr; USGS gage 03016000). We collected 197, 758, and 807 Clubshell and 957, 249, and 777 Northern Riffleshell in 2012, 2013, and 2014, respectively. We measured total length of each individual as the greatest distance from the anterior to posterior shell margin (nearest 1 mm), and affixed a 12.5 mm, 134.2 kHz PIT tag (BioMark, Inc., Boise, Idaho) to the right valve and a uniquely numbered HallPrint Shellfish tag (HallPrint, Hindmarsh Valley, South Australia) to the left valve. Northern Riffleshell averaged 45.6 mm long (range 15–70 mm) and Clubshell averaged 52.2 mm long (range 18–84 mm). We also determined the sex of each Northern Riffleshell based on shell morphology, although a few smaller individuals were classified as "unknown" (male:female ratio = 1.34:1); Clubshell sexes cannot be differentiated by external shell morphology and were all classified as "unknown." Clubshell and Northern Riffleshell were placed in coolers between damp towels and transported in climate-controlled vehicles to Illinois.

Mussel Translocation and Release

We selected release sites based on the presence of presumably suitable habitat for Northern Riffleshell and Clubshell, which consisted of clean, stable sand, gravel, and cobble riffles (Watters et al. 2009), abundant and diverse mussel populations (INHS 2017), and presence of suitable host fishes (i.e., darters and minnows) for both mussel species (Cummings and Mayer 1992; Tiemann 2008a, 2008b; Watters et al. 2009). Based on these criteria, we selected four sites each in the Salt Fork and Middle Fork Vermilion rivers in east-central Illinois (Fig. 1). These streams are an order of magnitude smaller than the Allegheny River, each 30–40 m wide and draining approximately 1,100 km^2. Mean daily discharge in the Salt Fork is 0.4 m^3/s at the end of August and 4.3 m^3/s at the beginning of April (average of 45 yr; USGS gage 03336900); mean daily discharge in the Middle Fork is 0.9 m^3/s at the end of August and 8.5 m^3/s at the beginning of April (average of 38 yr; USGS gage 03336645).

We released 3,745 mussels (both species combined) among all eight sites from 2012 to 2014 (Table 1). Mussels were released in the late summer, following a quarantine and acclimatization period (14 d for 2012 mussels and 4–5 d for 2013–2014 mussels, differences between years due to logistics). We hand-placed mussels into the substrate at each site within an area demarcated by site-specific landmarks (such as trees, boulders, water willow beds, or other discernible feature) to facilitate recapture surveys. The size of marked release areas varied with site and were between 3–10 m wide and 20–100 m long. Sites with greater suitable area received more mussels, but all sites were stocked at less than 50% of the density observed at the collection site on the Allegheny River, which is 5.5/m^2 for Northern Riffleshell and 7.5/m^2 for

Table 1. Number of Clubshell and Northern Riffleshell released into the Salt Fork and Middle Fork Vermilion rivers in 2012, 2013, and 2014.

	2012		2013		2014	
Site	Clubshell	Riffleshell	Clubshell	Riffleshell	Clubshell	Riffleshell
Salt Fork						
1	-	291	-	-	-	-
2	106	196	258	-	-	-
3	91	470	250	-	-	-
4	-	-	50	50	277	290
Middle Fork						
5	-	-	50	50	-	-
6	-	-	50	50	175	180
7	-	-	50	50	181	174
8	-	-	50	49	174	133
Totals	197	957	758	249	807	777

Clubshell (Enviroscience, Inc., personal communication); these densities are similar to those seen for these species at other locations (Crabtree and Smith 2009). We stocked Clubshell at greater densities than Northern Riffleshell due to presumed historical presence based on historical shell collection records (INHS 2017). Logistical constraints (e.g. land access, previous stocking, mussel availability) largely dictated which sites received mussels in multiple years.

Field Surveys

We surveyed for PIT-tagged Clubshell and Northern Riffleshell during 12 sampling periods from 2012 to 2016 (Appendix 1). We used a robust design sampling protocol that included primary and secondary samples (Fig. 2; Kendall and Nichols 1995; Kendall et al. 1997). We attempted to conduct primary samples every 3–4 mo to represent each season (spring, summer, autumn, winter), but environmental conditions prevented us from collecting all samples during every year. We used two to three observers during each primary sample. Each observer was considered an independent sample and represented a secondary sample in the robust design framework. We detected PIT-tagged mussels using BioMark FS2001F-ISO or BioMark HPR Plus receivers with portable BP antennas (BioMark). Each observer independently traversed the stream in a systematic manner from a unique starting point while slowly sweeping the streambed with an antenna. Surveys continued until the release site was covered completely and extended 5–10 m downstream after detections ceased. Each sample typically required 2–3 h/site.

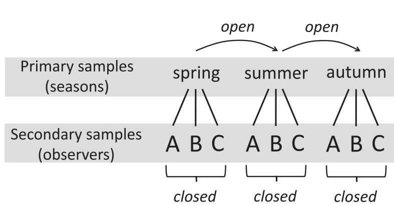

Figure 2. Robust design as employed in this study, with primary samples (seasons) and secondary samples (observers).

Statistical Analyses

We used the Huggins Robust Design model (Huggins 1989, 1991) to estimate apparent survival while accounting for imperfect detection and to estimate of the numbers of individuals remaining after each sampling period. Population estimates from the Huggins Robust Design model (Huggins 1989, 1991) are derived using the actual number of individuals observed during a primary sample and detection probability. We were interested in the influence of individual traits (sex, length, and species), environmental factors (site within river and whether or not flood events had occurred between primary sampling periods), and number of years following release on survival. We fit a single model that included all covariates instead of fitting a suite of models and comparing model fit (Burnham and Anderson 2002). Consequently, we attained estimates for each species released at each site during each year by estimating a species effect, site effect, and an effect of years following release, along with the individual covariates of sex and length and the environmental covariate of the presence of a flood. We did not include group (site or species) by sampling period interactions because we had no reason to believe that survival would vary along that spatio-temporal scale (Anderson and Burnham 2002). We constrained our model so there was no immigration or emigration between primary samples, which we believed was biologically reasonable given the limited vagility of freshwater mussels (Amyot and Downing 1998; Schwalb and Pusch 2007). We fit detection as a function of sampling period and site to encompass differences in sampling efficiency due to variation in flow, temperature, and depth among dates and variation in habitat conditions among sites. We did not account for species-specific differences in detection because we used PIT tags and hand-held readers for both species and did not believe detection would differ by species when using this method.

Table 2. Parameter estimates (β coefficients), standard errors (SE), log-odds (e^{β}), and log-odds lower and upper 95% confidence limits (CL) of monthly survival of translocated Clubshell and Northern Riffleshell relative to site, years following release, species, sex, mussel length, and presence of flood between primary samples. Parameter estimates should be interpreted in relation to the baseline, which was Northern Riffleshell of average length and unknown sex at Site 1, four years postrelease, and during a period with no flooding, as indicated.

Parameter	Estimate	SE	Log-odds	Lower CL log-odds	Upper CL log-odds
Intercept	4.760	0.891			
Individual traits					
Clubshell versus Riffleshell	1.670	0.623	5.312	1.567	18.011
Male versus unknown	0.207	0.620	1.230	0.365	4.150
Female versus unknown	−0.117	0.621	0.890	0.263	3.004
Length	0.009	0.004	1.009	1.003	1.016
Environmental factors					
Site 2 versus Site 1	−0.853	0.085	0.426	0.361	0.504
Site 3 versus Site 1	−1.402	0.079	0.246	0.211	0.287
Site 4 versus Site 1	−0.007	0.165	0.993	0.718	1.374
Site 5 versus Site 1	−0.999	0.130	0.368	0.286	0.475
Site 6 versus Site 1	−1.063	0.132	0.345	0.267	0.448
Site 7 versus Site 1	−1.757	0.128	0.173	0.134	0.222
Site 8 versus Site 1	−0.958	0.142	0.384	0.290	0.507
Flood versus No Flood	−0.530	0.077	0.589	0.506	0.685
Years following release					
Year 1 versus Year 4	−1.260	0.658	0.284	0.078	1.030
Year 2 versus Year 4	−1.666	0.661	0.189	0.052	0.691
Year 3 versus Year 4	−1.228	0.660	0.293	0.080	1.066

Post hoc analyses indicated that inclusion of species-specific detection had very little influence on survival probabilities (i.e., estimates were within 0.01%). We determined if a flood occurred between primary samples using the Indicators of Hydrologic Alteration software package (IHA; Richter et al. 1996) and discharge data for both streams from the U.S. Geological Survey National Water Information System (https://waterdata.usgs.gov/il/nwis/rt; gages 03336900 and 03336645). We did not differentiate between small floods and large floods as identified by IHA, and anything equivalent to or greater than a 2-yr flood event was considered a flood. We used the Huggins' p and c extension in Program MARK (White and Burnham 1999) with initial capture probability (p, probability of detecting an individual at least once during a primary sample) equal to recapture probability (c, probability of detecting an individual during a primary sample given it is detected) because secondary samples occurred via the same method on the same day. We interpreted the strength and biological meaning of each model covariate using the beta coefficients (β) and their 95% confidence intervals and log-odds ratios, which approximate how much more likely it is for an event (survival) to occur based on the beta coefficient (log-odds ratio = e^{β}, Gerard et al. 1998; Hosmer and Lemeshow 2010).

RESULTS

Detection rate averaged 0.78 across both species (range of averages = 0.66–0.90; Appendix 1). Detection was generally greatest in autumn. Average detection in autumn samples was about 1.25 times greater than for spring and summer samples; we had only one winter sample because of high flows and frozen conditions. However, detection probabilities were highly variable among sites and sampling periods (Appendix 1).

Monthly survival varied among species, sites, and sampling periods. Average monthly survival was 0.981 for Clubshell and 0.905 for Northern Riffleshell; these values translate to an approximate annual survival of 0.79 for Clubshell and 0.30 for Northern Riffleshell, irrespective of site, individual traits, and years following release. The β coefficient and log-odds ratio showed that, overall, Clubshell was approximately 5 times more likely to survive than Northern Riffleshell, but the precision of this estimate was low (95% confidence interval = 1.57–18.00×; Table 2). There was no difference in survival among males, females, and mussels of unknown sex; confidence intervals included zero for all coefficients (Table 2). There was no appreciable effect of size on survival. The log-odds ratio indicated that individuals were 1.009 times more likely to survive (95% confidence interval = 1.003–1.016) for every mm increase in length (Table 2).

Survival was greatest at Sites 1 and 4 on the Salt Fork and lowest at Site 7 on the Middle Fork (Figs. 3–6). Log-odds ratios showed that mussels were nearly 6 times less likely to survive at Site 7 than Site 1, and mussels were 2–4 times less likely to survive at Sites 2, 3, 5, and 6 (Table 2). Survival was reduced following floods. The log-odds ratio showed that

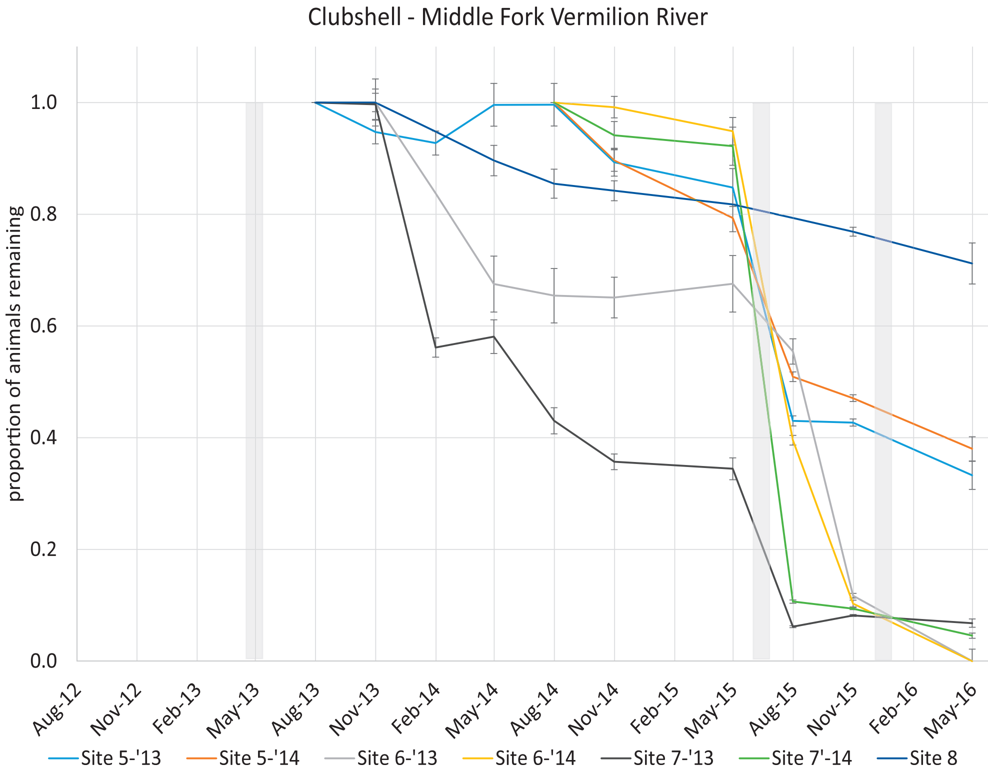

Figure 3. Derived estimates of proportion of Clubshell remaining at each release site in the Middle Fork from 2012 to 2016. Gray boxes indicate when a flood occurred. Numbers of individuals released per year per site can be viewed in Table 1.

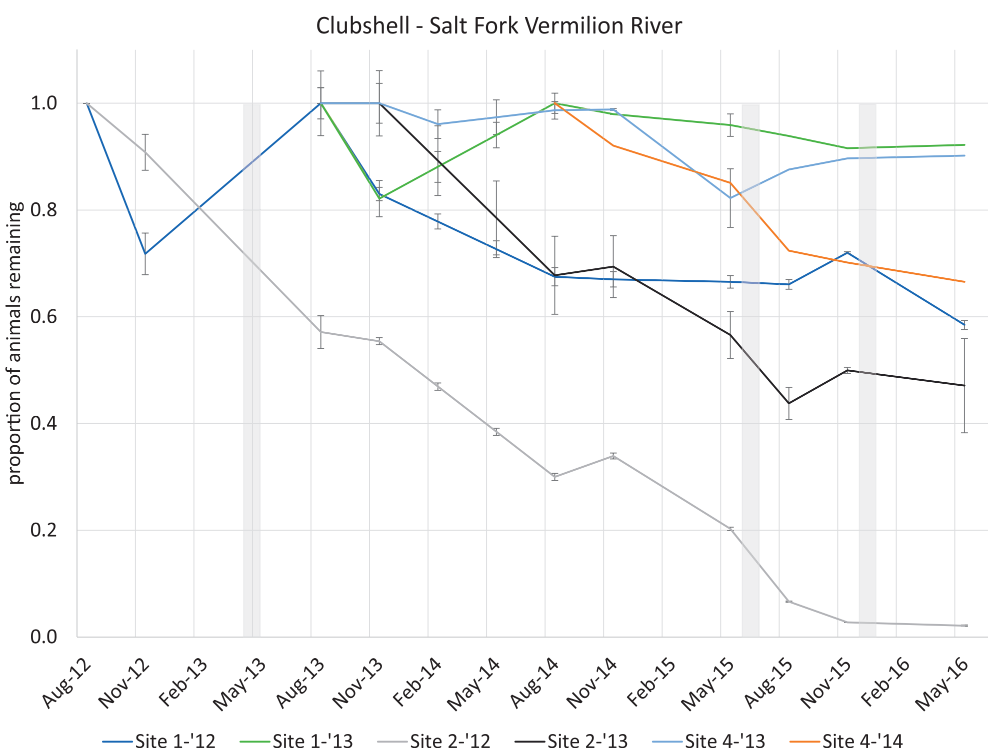

Figure 4. Derived estimates of proportion of Clubshell remaining at each release site in the Salt Fork from 2012 to 2016. Gray boxes indicate when a flood occurred. Numbers of individuals released per year per site can be viewed in Table 1.

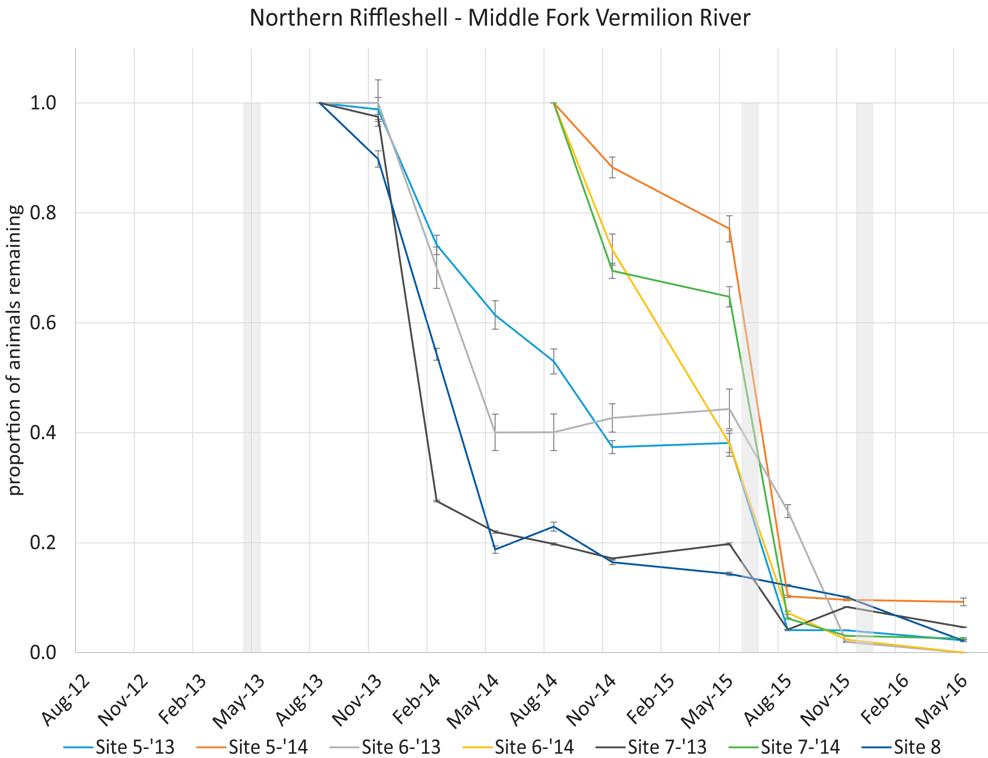

Figure 5. Derived estimates of proportion of Northern Riffleshell remaining at each release site in the Middle Fork from 2012 to 2016. Gray boxes indicate when a flood occurred. Numbers of individuals released per year per site can be viewed in Table 1.

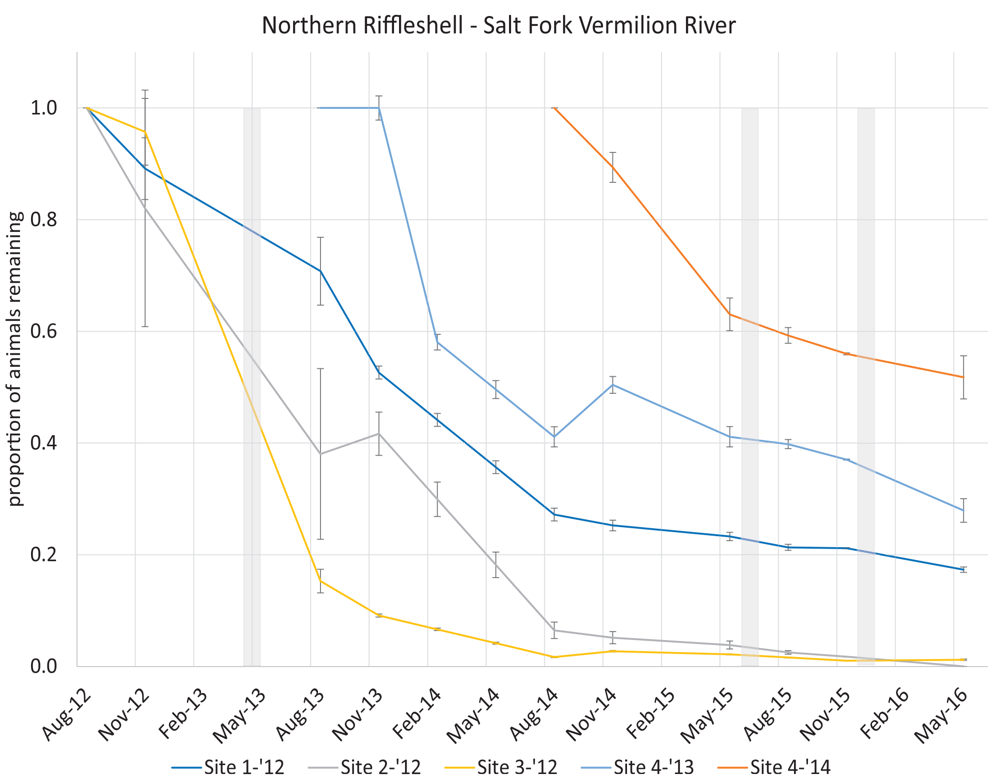

Figure 6. Derived estimates of proportion of Northern Riffleshell remaining at each release site in the Salt Fork from 2012 to 2016. Gray boxes indicate when a flood occurred. Numbers of individuals released per year per site can be viewed in Table 1.

mussels were 1.70 times less likely to survive after floods (95% confidence interval: 1.46–1.98) than after periods with no floods; this is equivalent to a reduction of monthly survival from 0.950 to 0.917 (average of all species and sites). The occurrence of a flood on the Middle Fork during June–July 2015 was associated with a sharp decline in population size for both species (Figs. 3, 5), but the influence of other flood events was not associated with similar declines. We did not model river as a separate factor (see Methods), but survival appeared to be greater in the Salt Fork than in the Middle Fork. An average of 62% of Clubshell and 19% of Northern Riffleshell were alive in the Salt Fork in 2016 compared with only 21% of Clubshell and 4% of Northern Riffleshell in the Middle Fork in 2016 (Figs. 3–6). This difference was apparent despite the fact that most mussels were translocated to the Salt Fork 1–2 yr earlier than in the Middle Fork (Table 1).

Number of years following release was an important determinant of survival. Survival was greatest in the fourth year following a release; individuals were 3.52 times more likely to survive in the fourth year following release (95% confidence interval: 0.97–12.80) compared to the first year following release (Table 2). Survival was lowest in the second year following release; individuals were 1.50 times less likely to survive (95% confidence interval: 1.30–1.70) compared to the first year (Table 2).

DISCUSSION

The long-term efficacy of a reintroduction program depends on the establishment of a self-sustaining population, which requires translocated individuals to survive until they reproduce and replace themselves. It is too early to tell if the Clubshell and Northern Riffleshell reintroduction program into Illinois has been a success because no recruitment has been documented. Reintroduction of the Clubshell appears to have been more successful initially than reintroduction of Northern Riffleshell. Reintroduced Clubshell survived at a much greater rate and represented the majority of individuals remaining after five years of monitoring. Annual survival for Clubshell (0.79) is within the estimated range for other mussel species in the wild, (0.50–0.99, Hart et al. 2001; Villella et al. 2004) and near the estimates of the closely related Southern Clubshell (*Pleurobema decisum*) (0.91, Haag 2012). However, annual survival for Northern Riffleshell (0.30) was well below those values, those reported from French Creek, Pennsylvania, which averaged 0.60 (Crabtree and Smith 2009), and those of the closely related Oystermussel (*Epioblasma capsaeformis*) (0.73, Jones and Neves 2011; Haag 2012).

Some species may be inherently more difficult to translocate. There is high variability in the success of translocation projects, ranging from nearly all individuals remaining after a few years to very few if any (e.g., Ahlstedt 1979; Sheehan et al. 1989; Cope et al. 2003). Some of this variation may be explained by inherent life history differences among species, and Clubshell probably lives longer than Northern Riffleshell. For instance, the Southern Clubshell, a congener of Clubshell, can reach 45 yr of age (Haag and Rypel 2011), while Northern Riffleshell is a relatively short-lived species with a maximum age reported in French Creek, Pennsylvania, of 11 yr (Crabtree and Smith 2009). Based on these differences, Northern Riffleshell is expected to have lower survival than Clubshell even in wild populations, and our data show that translocated populations may have even lower survival. Consequently, translocation of short-lived species such as Northern Riffleshell may require larger numbers of individuals and repeated translocations to overcome high mortality and ensure that translocated individuals experience conditions favorable for recruitment.

Differences in hydrology, either between rivers or even within the same river, may play an important role in determining the suitability of sites for freshwater mussel reintroduction (Cope et al. 2003; Carey et al. 2015). The hydrology, land use, and watershed size of the Vermilion River basin differ from the source location of the Allegheny River (Larimore and Smith 1963; Smith 1968; Larimore and Bayley 1996; White et al. 2005), thus some discrepancy in survival between the source and recipient basins may be expected. However, the Salt Fork Vermilion and Middle Fork Vermilion rivers are comparable in size and have similar land use and hydrology, yet we found that survival varied even among sites within a river. Local-scale differences among sites, such as substrate or gradient, can lead to biologically significant differences that influence survival (McRae et al. 2004). We selected release sites based on the best available habitat and species assemblage data, yet unmeasured habitat differences and stochastic events appeared to have a large effect on survival. Similar results have been observed in other translocations, such as siltation due to bank failure following flow diversion (Bolden and Brown 2002), possible washout due to earthen causeway removal (Tiemann et al. 2016), or diminished recovery of relocated individuals in sites with high current velocity in the two years following relocation (Dunn et al. 2000).

High-discharge events present an ongoing threat to the reintroduction of Clubshell, Northern Riffleshell, and similar translocation projects. High-flow events have been problematic in other translocation projects (e.g., Sheehan et al. 1989; Carey et al. 2015) and were clearly detrimental for translocated Clubshell and Northern Riffleshell. Following the flood in June–July 2015, we examined the nearest downstream gravel bar at a few sites and found numerous stranded and dead individuals. Existing native mussel communities in the Salt and Middle Fork Vermilion rivers have persisted throughout similar high-flow events, but translocated mussels may be at a disadvantage. PIT tags can decrease the burrowing rate of individuals (Wilson et al. 2011), and translocated mussels may have lower energetic status (Patterson et al. 1997), which could reduce their ability to anchor themselves in the substrate or rebury after a flood event (Killeen and Moorkens 2016). Additionally, the native mussel community represents individuals that have found optimal locations to withstand scouring and dislodging. The

Clubshell and Northern Riffleshell we translocated may not have had enough time to find optimal locations, which may have made them more vulnerable to dislodgement and may partly explain why individuals survived at a greater rate 4 yr following release.

We provide the following recommendations for conducting and monitoring reintroduction efforts. The best time to monitor Clubshell and Northern Riffleshell was during autumn, when stream flows were low and we observed the greatest probability of detection. Sampling was difficult or impossible during the spring because of high stream flows, which resulted in reduced detectability using handheld readers; sampling also was difficult in winter because of high flows and occasional ice cover. Spreading reintroduction efforts over several geographically separate river systems could lessen risk of failure due to stochastic events such as floods, chemical spills, and biological invasion (e.g., Griffith et al. 1989; Trdan and Hoeh 1993). Translocating individuals over a period of several years might also reduce the overall risk of failure due to isolated events occurring in a particular year. For instance, many Clubshell and Northern Riffleshell, especially in the Middle Fork, were lost during a late spring/early summer high-flow event in 2015. Finally, stocking greater numbers of individuals in multiple translocations for species with naturally low annual survival, such as Northern Riffleshell, may be necessary to maximize chances for natural recruitment.

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Appendix 1. Estimates of detection for each site and during each period; 95% confidence intervals are provided in parentheses.

	Middle Fork				Salt Fork			
Sample Period	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Summer 2012	-	-	-	-	-	-	-	-
Autumn 2012	0.71 (0.68–0.74)	0.67 (0.64–0.71)	0.68 (0.64–0.72)	-	-	-	-	-
Summer 2013	0.72 (0.68–0.75)	0.68 (0.63–0.73)	0.69 (0.63–0.74)	-	-	-	-	-
Autumn 2013	0.79 (0.77–0.81)	0.76 (0.74–0.70)	0.76 (0.72–0.80)	0.87 (0.85–0.89)	0.83 (0.80–0.85)	0.77 (0.73–0.80)	0.81 (0.77–0.85)	0.85 (0.82–0.88)
Winter 2014	-	-	-	0.80 (0.76–0.84)	0.84 (0.80–0.88)	-	0.83 (0.78–0.87)	-
Spring 2014	-	-	-	-	0.76 (0.72–0.80)	0.69 (0.63–0.74)	0.71 (0.66–0.76)	0.79 (0.75–0.84)
Summer 2014	0.70 (0.67–0.72)	0.66 (0.63–0.69)	0.67 (0.64–0.71)	0.81 (0.77–0.84)	0.75 (0.71–0.78)	0.67 (0.63–0.72)	0.73 (0.68–0.78)	0.78 (0.74–0.82)
Autumn 2014	-	0.75 (0.72–0.78)	-	0.85 (0.81–0.87)	0.80 (0.76–0.83)	0.73 (0.68–0.77)	0.78 (0.73–0.82)	0.82 (0.78–0.86)
Spring 2015	-	-	-	0.72 (0.67–0.77)	0.77 (0.73–0.82)	0.70 (0.64–0.75)	0.75 (0.69–0.81)	-
Summer 2015	0.80 (0.78–0.82)	0.78 (0.75–0.80)	0.78 (0.74–0.82)	0.88 (0.86–0.90)	0.84 (0.81–0.87)	0.78 (0.74–0.82)	0.83 (0.78–0.86)	-
Autumn 2015	0.86 (0.84–0.87)	0.83 (0.81–0.85)	0.84 (0.80–0.87)	0.92 (0.90–0.93)	0.88 (0.86–0.91)	0.84 (0.80–0.87)	0.87 (0.84–0.90)	0.90 (0.88–0.92)
Spring 2016	0.78 (0.74–0.81)	0.75 (0.71–0.79)	-	0.87 (0.83–0.89)	0.82 (0.78–0.86)	-	0.81 (0.75–0.85)	0.85 (0.81–0.88)

Appendix 2. Monthly apparent survival estimates for Clubshell. Years (2012–2014) represent the year animals were released. Numbers in parentheses beside primary sample indicate the number of months since the preceding sample; 95% confidence intervals are provided in parentheses beside survival estimates. Bold rows indicate a flood occurred during that period (e.g., between Su 2013 and Au 2013). Sp = spring, Su = summer, Au = autumn, Wi = winter.

	Salt Fork Vermilion River						
	Site 1		Site 2		Site 3	Site 4	
Primary Samples (mo)	2012	2013	2012	2013	2012	2013	2014
Su 2012–Au 2012 (2)	0.994 (0.993–0.995)	-	0.977 (0.974–0.981)	-	0.987 (0.984–0.989)	-	-
Au 2012–Su 2013 (9)	0.990 (0.989–0.992)	-	0.962 (0.956–0.967)	-	0.978 (0.973–0.982)	-	-
Su 2013–Au 2013 (2)	**0.992 (0.990–0.993)**	**0.994 (0.993–0.995)**	**0.966 (0.962–0.971)**	**0.977 (0.974–0.981)**	**0.980 (0.976–0.984)**	**0.994 (0.992–0.996)**	**-**
Au 2013–Wi 2014 (4)	0.992 (0.990–0.993)	0.994 (0.993–0.995)	0.966 (0.962–0.971)	0.977 (0.974–0.981)	0.980 (0.976–0.984)	0.994 (0.992–0.996)	-
Wi 2014–Sp 2014 (2)	0.992 (0.990–0.993)	0.994 (0.993–0.995)	0.966 (0.962–0.971)	0.977 (0.974–0.981)	0.980 (0.976–0.984)	0.994 (0.992–0.996)	-
Sp 2014–Su 2014 (2)	0.992 (0.990–0.993)	0.994 (0.993–0.995)	0.966 (0.962–0.971)	0.977 (0.974–0.981)	0.980 (0.976–0.984)	0.994 (0.992–0.996)	-
Su 2014–Au 2014 (4)	0.995 (0.993–0.996)	0.992 (0.990–0.993)	0.978 (0.973–0.982)	0.966 (0.962–0.971)	0.987 (0.983–0.990)	0.991 (0.988–0.994)	-
Au 2014–Sp 2015 (5)	0.995 (0.993–0.996)	0.992 (0.990–0.993)	0.978 (0.973–0.982)	0.966 (0.962–0.971)	0.987 (0.983–0.990)	0.991 (0.988–0.994)	0.994 (0.992–0.996)
Sp 2015–Su 2015 (3)	**0.991 (0.988–0.993)**	**0.986 (0.983–0.988)**	**0.963 (0.955–0.97)**	**0.944 (0.934–0.953)**	**0.979 (0.972–0.983)**	**0.986 (0.980–0.990)**	**0.990 (0.986–0.993)**
Su 2015–Au 2015 (3)	0.995 (0.993–0.996)	0.992 (0.990–0.993)	0.978 (0.973–0.982)	0.966 (0.962–0.971)	0.987 (0.983–0.990)	0.991 (0.988–0.994)	0.994 (0.992–0.996)
Au 2015–Sp 2016 (6)	**0.997 (0.990–0.999)**	**0.991 (0.988–0.993)**	**0.989 (0.961–0.997)**	**0.963 (0.955–0.970)**	**0.994 (0.977–0.998)**	**0.991 (0.986–0.994)**	**0.986 (0.98–0.990)**

Appendix 2, extended.

Middle Fork Vermilion River						
Site 5		Site 6		Site 7		Site 8
2013	2014	2013	2014	2013	2014	2013
-	-	-	-	-	-	-
-	-	-	-	-	-	-
0.985 (0.980–0.988)	**-**	**0.984 (0.979–0.988)**	**-**	**0.968 (0.959–0.975)**	**-**	**0.985 (0.981–0.989)**
0.985 (0.980–0.988)	-	0.984 (0.979–0.988)	-	0.968 (0.959–0.975)	-	0.985 (0.981–0.989)
0.985 (0.980–0.988)	-	0.984 (0.979–0.988)	-	0.968 (0.959–0.975)	-	0.985 (0.981–0.989)
0.985 (0.980–0.988)	-	0.984 (0.979–0.988)	-	0.968 (0.959–0.975)	-	0.985 (0.981–0.989)
0.977 (0.971–0.982)	-	0.976 (0.969–0.981)	-	0.953 (0.940–0.963)	-	0.978 (0.972–0.983)
0.977 (0.971–0.982)	0.985 (0.980–0.988)	0.976 (0.969–0.981)	0.984 (0.979–0.988)	0.953 (0.940–0.963)	0.968 (0.959–0.975)	0.978 (0.972–0.983)
0.962 (0.950–0.971)	**0.974 (0.966–0.981)**	**0.960 (0.946–0.97)**	**0.973 (0.964–0.980)**	**0.922 (0.898–0.941)**	**0.947 (0.931–0.959)**	**0.964 (0.951–0.973)**
0.977 (0.971–0.982)	0.985 (0.980–0.988)	0.976 (0.969–0.981)	0.984 (0.979–0.988)	0.953 (0.940–0.963)	0.968 (0.959–0.975)	0.978 (0.972–0.983)
0.975 (0.966–0.982)	**0.962 (0.950–0.971)**	**0.974 (0.963–0.981)**	**0.960 (0.946–0.97)**	**0.953 (0.940–0.963)**	**0.922 (0.898–0.941)**	**0.976 (0.967–0.983)**

Appendix 3. Monthly apparent survival estimates for Northern Riffleshell. Years (2012–2014) represent the year animals were released. Numbers in parentheses beside primary sample indicate the number of months since the preceding sample; 95% confidence intervals are provided in parentheses beside survival estimates. Bold rows indicate a flood occurred during that period (e.g., between Su 2013 and Au 2013). Sp = spring, Su = summer, Au = autumn, Wi = winter.

	Salt Fork						
	Site 1		Site 2		Site 3	Site 4	
Primary Samples (months)	2012	2013	2012	2013	2012	2013	2014
Su 2012–Au 2012 (2)	0.971 (0.907–0.991)	-	0.891 (0.706–0.965)	-	0.934 (0.806–0.98)	-	-
Au 2012–Su 2013 (9)	**0.951 (0.852–0.985)**	**-**	**0.828 (0.586–0.942)**	**-**	**0.893 (0.711–0.966)**	**-**	**-**
Su 2013–Au 2013 (2)	0.957 (0.867–0.987)	0.971 (0.907–0.991)	0.844 (0.614–0.949)	0.891 (0.706–0.965)	0.904 (0.735–0.97)	0.970 (0.904–0.991)	-
Au 2013–Wi 2014 (4)	0.957 (0.867–0.987)	0.971 (0.907–0.991)	0.844 (0.614–0.949)	0.891 (0.706–0.965)	0.904 (0.735–0.97)	0.970 (0.904–0.991)	-
Wi 2014–Sp 2014 (2)	0.957 (0.867–0.987)	0.971 (0.907–0.991)	0.844 (0.614–0.949)	0.891 (0.706–0.965)	0.904 (0.735–0.97)	0.970 (0.904–0.991)	-
Sp 2014–Su 2014 (2)	0.957 (0.867–0.987)	0.971 (0.907–0.991)	0.844 (0.614–0.949)	0.891 (0.706–0.965)	0.904 (0.735–0.97)	0.970 (0.904–0.991)	-
Su 2014–Au 2014 (4)	0.972 (0.909–0.991)	0.957 (0.867–0.987)	0.894 (0.71–0.967)	0.844 (0.614–0.949)	0.936 (0.809–0.98)	0.956 (0.862–0.987)	-
Au 2014–Sp 2015 (5)	0.972 (0.909–0.991)	0.957 (0.867–0.987)	0.894 (0.71–0.967)	0.844 (0.614–0.949)	0.936 (0.809–0.98)	0.956 (0.862–0.987)	0.970 (0.904–0.991)
Sp 2015–Su 2015 (3)	**0.953 (0.855–0.986)**	**0.928 (0.793–0.978)**	**0.832 (0.59–0.944)**	**0.762 (0.483–0.916)**	**0.896 (0.715–0.967)**	**0.928 (0.785–0.979)**	**0.951 (0.846–0.986)**
Su 2015–Au 2015 (3)	0.972 (0.909–0.991)	0.957 (0.867–0.987)	0.894 (0.71–0.967)	0.844 (0.614–0.949)	0.936 (0.809–0.98)	0.956 (0.862–0.987)	0.97 (0.904–0.991)
Au 2015–Sp 2016 (6)	**0.986 (0.923–0.997)**	**0.953 (0.855–0.986)**	**0.944 (0.746–0.99)**	**0.832 (0.59–0.944)**	**0.967 (0.836–0.994)**	**0.952 (0.849–0.986)**	**0.928 (0.785–0.979)**

Appendix 3, extended.

Middle Fork						
Site 5		Site 6		Site 7		Site 8
2013	2014	2013	2014	2013	2014	2013
-	-	-	-	-	-	-
-	**-**	**-**	**-**	**-**	**-**	**-**
0.924 (0.78–0.977)	-	0.920 (0.768–0.975)	-	0.851 (0.624–0.952)	-	0.927 (0.785–0.978)
0.924 (0.78–0.977)	-	0.920 (0.768–0.975)	-	0.851 (0.624–0.952)	-	0.927 (0.785–0.978)
0.924 (0.78–0.977)	-	0.920 (0.768–0.975)	-	0.851 (0.624–0.952)	-	0.927 (0.785–0.978)
0.924 (0.78–0.977)	-	0.920 (0.768–0.975)	-	0.851 (0.624–0.952)	-	0.927 (0.785–0.978)
0.890 (0.702–0.966)	-	0.884 (0.688–0.963)	-	0.792 (0.525–0.929)	-	0.894 (0.709–0.967)
0.890 (0.702–0.966)	0.924 (0.78–0.977)	0.884 (0.688–0.963)	0.920 (0.768–0.975)	0.792 (0.525–0.929)	0.851 (0.624–0.952)	0.894 (0.709–0.967)
0.827 (0.578–0.943)	**0.878 (0.675–0.961)**	**0.818 (0.563–0.94)**	**0.871 (0.66–0.959)**	**0.691 (0.391–0.887)**	**0.771 (0.493–0.921)**	**0.833 (0.587–0.946)**
0.890 (0.702–0.966)	0.924 (0.78–0.977)	0.884 (0.688–0.963)	0.920 (0.768–0.975)	0.792 (0.525–0.929)	0.851 (0.624–0.952)	0.894 (0.709–0.967)
0.881 (0.679–0.963)	**0.827 (0.578–0.943)**	**0.874 (0.665–0.961)**	**0.818 (0.563–0.940)**	**0.776 (0.498–0.924)**	**0.691 (0.391–0.887)**	**0.885 (0.687–0.964)**