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Comparison of conservation strategies for unionids threatened by zebra mussels (*Dreissena polymorpha*): periodic cleaning vs quarantine and translocation

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Abstract. Native unionid mussel populations have recently declined throughout North America as a result of zebra mussel (*Dreissena polymorpha*) fouling. Periodic cleaning of fouled unionids and cleaning followed by translocation have been suggested as methods for reducing mortality. *Leptodea fragilis* and *Potamilus alatus* were used to determine survival, recovery of energetic stores, and accumulation of newly settled zebra mussels after cleaning and replacement in situ. Both species had high survival, and *L. fragilis* increased energetic stores after cleaning. *Elliptio complanata* and *Lampsilis radiata* were used to compare conservation strategies for unionids fouled by zebra mussels. Survival and glycogen content were used to evaluate stress induced by cleaning and replacement in situ, cleaning and translocation, and cleaning, quarantine, and translocation, relative to the stress in fouled unionids and control (never fouled) unionids. New zebra mussel settlement was assessed to estimate the frequency of cleanings needed. Cleaned *E. complanata* and *L. radiata* maintained significantly higher glycogen levels and had higher survival than fouled unionids in all treatments; however, 30% of *L. radiata* died while in quarantine but no *E. complanata* died. Translocated unionids were difficult to relocate in the riverine refugium. The inability to find translocated unionids, coupled with high survival and energetic stores in cleaned and replaced unionids, indicate that cleaning and replacement is an effective conservation strategy. Cleaning and replacement may be used as the 1st step to conserve small populations of fouled unionids living in environments where food is not limiting and where collection and cleaning are logistically feasible.

Key words: glycogen, unionids, zebra mussels, translocation, quarantine, conservation.

Native unionid mussel populations face many anthropogenic threats. Chemical pollution, alteration of water flow caused by dams and water diversions, siltation, and loss of obligatory host fish species have been implicated in the decline and extirpation of bivalve populations (Fuller 1974). Over 70% of the 297 species of North American freshwater mussels are endangered, threatened, or of special concern (Williams et al. 1993). Biofouling by zebra mussels may increase the North American unionid extinction rate by 10 times, with a rate estimated at 12% per decade (Ricciardi et al. 1998). Zebra mussels have caused declines in unionid abundance in many North American lakes and rivers (Mackie 1991, Gillis and Mackie 1994, Nalepa 1994, Schloesser and Nalepa 1994, Ricciardi et al. 1996, Strayer and Smith 1996, Schloesser et al. 1997).

Current conservation plans for unionids threatened by zebra mussels focus on 3 alternative strategies: 1) captive care, propagation, and reintroduction, 2) cleaning, quarantine, and translocation, and 3) periodic cleaning and replacement in situ. The 1st strategy involves unionid aquaculture to supplement endangered populations or restore extirpated ones. The 2nd strategy aims to remove zebra mussels from unionids, hold unionids in quarantine to ensure they remain free of zebra mussels, and transplant them to a new habitat, or refugium, that has a low probability of future zebra mussel infestation. The 3rd strategy involves only collecting, cleaning, and replacement of unionids in situ. Unionids that are cleaned and replaced in situ can recover glycogen stores (a biochemical indicator of energetic reserves) after 10 wk (Hallac and Marsden 2000). The frequency of periodic cleanings needed to maintain viable unionid populations has not been evaluated, and will undoubtedly vary among species and aquatic systems.

Zebra mussels 1st appeared in the south end of Lake Champlain, Vermont, in 1993, and have spread rapidly to most areas of the lake, except the northeast arm, which is mostly free of adult

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zebra mussels (Eliopolous and Stangel 1998). Because of losses from zebra mussel fouling in Lake Champlain, in 1999 Vermont listed 5 unionid species as endangered and 1 as threatened. Populations of *Alasmidonta undulata, Anodontoides ferussacianus, Lampsilis cardium, Leptodea fragilis, Potamilus alatus,* and *Pyganodon grandis* are in immediate need of attention because of zebra mussel fouling. Most populations of these unionids are small (<1000 individuals), and are confined to areas in and around river mouths.

A relocation in 1997 of 60 *L. fragilis* and 144 *P. alatus* to a riverine refugium resulted in retrieval of only 17 individuals, with 8 alive, 1 y later (M. Lyttle, US Fish and Wildlife Service, personal communication). In light of the poor success of this strategy, we sought to evaluate the optimal conservation strategy for native unionid mussels threatened by zebra mussels in Lake Champlain. We compared a periodic cleaning strategy to a quarantine and translocation strategy by evaluating survival, energetic stores after intervention, our ability to monitor unionids involved in each strategy, and the frequency of cleanings needed to minimize mortality and stress.

Methods

A periodic cleaning strategy was used to examine survival, ability to recover glycogen stores, and new zebra mussel settlement after cleaning of *L. fragilis* or *P. alatus*. Because these species are endangered in Vermont, we could not use them to compare conservation strategies. Instead, we used *Elliptio complanata* and *Lampsilis radiata,* the most common species in Lake Champlain (Fiske and Levy 1996), to compare quarantine and translocation vs periodic cleaning and replacement in situ.

Rare species cleaning experiment

All experimental mussels were collected using SCUBA, and individually marked using a portable hobby drill (Dremel®) and stone grinding bit to inscribe a number through the periostracum. On 11 June 1998, 12 *L. fragilis* and 25 *P. alatus* were cleaned of zebra mussels and penned with 31 *L. fragilis* and 55 *P. alatus* that remained fouled, at the mouth of Otter Creek, Lake Champlain. Fouled and cleaned unionids were randomly distributed throughout four 0.71- m^2, open-topped chicken wire pens that were secured to the substrate with 8 rebar stakes. The pens served as an enclosed area that allowed unionids to burrow; the diameter of the chicken wire (25 mm) and open top allowed normal water flow through the area. On 15 September 1998, we removed all live and dead unionids from the pens. A Fisher's exact test was used to examine differences in survival between cleaned and fouled unionids. Zebra mussels were removed from each fouled unionid to calculate dreissenid:unionid mass ratios (Ricciardi et al. 1996), which were determined by obtaining the blotted wet mass (tissue and shell) of the removed zebra mussels and of the unionid. Newly settled zebra mussels were removed from cleaned unionids, weighed, counted, and measured. The number of zebra mussels >5 mm total length was determined. These 5-mm zebra mussels were inadvertently missed by cleaning, or were adults that migrated from nearby substrate and settled on the unionids after cleaning. The masses, total numbers, and numbers >5 mm of new zebra mussel settlement were compared between species using *t*-tests.

Glycogen was used as a biochemical indicator of energetic reserves. We could not obtain never-fouled *L. fragilis* and *P. alatus* as controls for the glycogen analysis because of their scarcity at uninfested sites in the lake. Non-destructive biopsies were taken from each unionid by using a small wooden wedge to keep valves open while removing a 7 to 10 mg sample of anterior foot tissue, after which unionids were returned to the lake (Berg et al. 1995, Naimo et al. 1998). Foot tissue was frozen at −15°C up to 30 d prior to glycogen analysis. Analyses were done using an alkaline digestion and phenol-sulfuric acid spectrophotometric method (Montgomery 1957) modified by Naimo et al. (1998), and *t*-tests were used to examine differences between glycogen content in cleaned and fouled unionids.

Periodic cleaning vs quarantine and translocation

We used SCUBA to collect 175 fouled *E. complanata* and 175 fouled *L. radiata* on 7 July 1998 from Button Bay, Lake Champlain. These unionids were randomly divided into 4 groups as shown in Fig. 1. Group 2 was 15 individuals larger than the other groups to ensure sufficient sample size, considering the likelihood of the

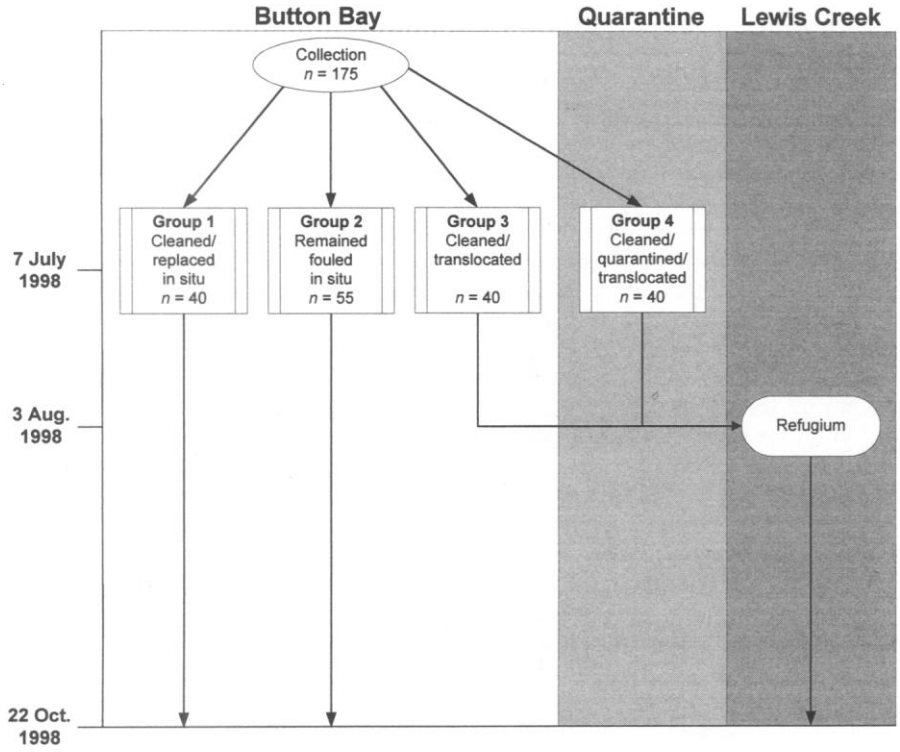

FIG. 1. Experimental design used to test conservation strategies. We collected 175 *Elliptio complanata* and 175 *Lampsilis radiata* on 7 July 1998 at Button Bay Lake Champlain, Vermont. The unionids were randomly placed into 4 groups. Groups 1 and 2 remained in pens at Button Bay for the duration of the experiment. Group 3 remained at Button Bay until 3 August 1998 and was then transported to the refugium. Group 4 was quarantined after collection until 3 August 1998 and then transported to the refugium. All mussels were removed from Button Bay and the refugium on 22 October 1998.

group exhibiting mortality during the experiment. Unionids were cleaned by manually scraping off all zebra mussels and scrubbing both valves with a stiff-bristled brush. Translocated unionids received a 2nd scrubbing and 2 rinses with river water.

Groups 1 and 2 were randomly distributed among four 0.71-m^2, open-topped chicken wire pens at Button Bay, where they remained for the duration of the experiment. On 3 August 1998, we transported Groups 3 and 4 to 4 chicken wire pens at the Lewis Creek refugium, a zebra mussel-free tributary of Lake Champlain with habitat similar to Button Bay. Group 4 unionids were held in the Missisquoi quarantine facility, Swanton, Vermont from 7 July 1998 until 3 August 1998. The quarantine facility consisted of a 946-L recirculating system with a physical and biological filtration unit. In quarantine, unionids were fed Algamac-2000, a medium consisting of spray dried cells of *Schizochytrium* sp. algae on an irregular schedule but not more than once per day.

We retrieved all unionids on 22 October 1998 by excavating the sediment down to 15 cm. We searched the substrate ~5 m around each pen for any unionids that had escaped.

Dreissenid:unionid mass ratios were determined for fouled unionids using the method described above. Projected dreissenid:unionid mass ratios for 1999 were calculated for each cleaned unionid that was left in situ by estimating growth of new zebra mussel settlement in 1998 and new settlement in 1999. Growth was estimated using a length-frequency histogram to assess the length of the newly settled zebra mussels 1 y from the 1st cleaning at Button Bay (Fig. 2). An average mass for 1-y old (4–15 mm) zebra mussels of 0.064 g was multiplied by the number of zebra mussels on each unionid, and

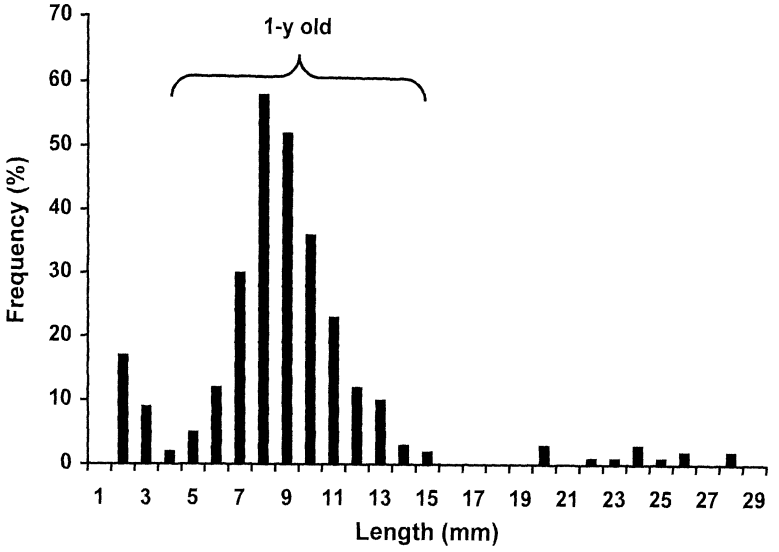

FIG. 2. Lengths of zebra mussels at Button Bay, Lake Champlain, Vermont, in summer 1998. One-year-old zebra mussels were used to calculate the projected dreissenid:unionid mass ratios.

used to calculate the mean dreissenid:unionid mass ratio for each species after growth of mussels that settled in 1998. New settlement for the next season was estimated by adding twice the mass of the 1st year's settlement; a factor of 2 accounted for the enhanced unionid plus zebra mussel surface area that would be available for veliger settlement in the next season. Estimates of mass resulting from growth in 1998 and new colonization in 1999 were added to obtain a total dreissenid:unionid mass ratio for 1999.

Newly settled zebra mussel data were collected as described above from unionids that were cleaned and left in situ. The masses, numbers, and numbers >5 mm of newly settled zebra mussels were compared between species using *t*-tests.

Survival and ability to retrieve experimental animals were assessed for each treatment and species. Retrieval of translocated mussels is notably problematic (Cope and Waller 1995). Chi-square tests were used to examine differences in % survival among treatments. Fisher exact tests replaced chi-square tests when 20% of the values in the contingency table were <5 (SigmaStat, version 2.0, Jandel Scientific, San Rafael, California).

Control unionids for the glycogen analysis were collected from the Lamoille River delta, a site free of zebra mussels. All unionids were sacrificed and a 7 to 10 mg sample of anterior foot tissue was taken and frozen at −15°C for glycogen analysis (see above). A 1-way ANOVA and Tukey's test for multiple comparisons was used to examine differences in glycogen content among treatments for each species.

Results

Rare species cleaning experiment

Survival of cleaned *L. fragilis* and *P. alatus* was significantly higher than for fouled individuals ($p < 0.05$ and $p < 0.001$, respectively; Table 1). Glycogen content in cleaned *L. fragilis* was significantly higher than in fouled mussels ($p < 0.05$), whereas glycogen content in cleaned and fouled *P. alatus* was not significantly different ($p < 0.13$). The dreissenid:unionid mass ratio was 0.36 ± 0.19 (mean ±1 SD) for fouled *L. fragilis* and 0.36 ± 0.15 for fouled *P. alatus*. There were no significant differences between the 2 unionid species in the mass, number, and number >5 mm of newly settled zebra mussels after 3 mo ($p > 0.05$).

Periodic cleaning vs quarantine and translocation

Eighty-nine to 100% of the cleaned and fouled unionids were retrieved from the in situ enclosures, whereas only 43 to 75% were retrieved from the lotic refugium (Table 2). Among trans-

TABLE 1. Response of 2 species of unionids to zebra mussel removal and replacement in situ, and mass, number, and number >5 mm of newly settled zebra mussels. – = not applicable.

Species	Treatment	Survival (%)	*n*	Mean (±1 SD) glycogen (mg/g)	*Dreissena* (mean ±1 SD)		
					Mass (g)	No.	No. >5 mm
Leptodea fragilis	Fouled	81	25	8.3 ± 3.9	–	–	–
	Cleaned	100	12	12.2 ± 3.2	1.9 ± 2.3	59.7 ± 50.5	1.1 ± 1.7
Potamilus alatus	Fouled	76	42	9.1 ± 3.1	–	–	–
	Cleaned	100	25	11.0 ± 5.5	2.0 ± 2.4	80.7 ± 88.4	1.1 ± 2.1

located unionids, fewer *L. radiata* than *E. complanata* were retrieved, and fewer quarantined than non-quarantined unionids were retrieved. Survival of fouled *L. radiata* was lower than survival in all other treatments. Survival of *E. complanata* did not differ among treatments.

Glycogen content in Groups 1, 3, and 4 *E. complanata* was not significantly different from the control treatment (Table 2). However, Group 2 *E. complanata* had significantly lower glycogen content than all other treatments. Glycogen content in Group 1 *L. radiata* was similar to controls. Group 3 *L. radiata* glycogen content was similar to Group 1 but was significantly lower than controls. Group 4 *L. radiata* had similar glycogen content to Group 3 but glycogen was significantly lower than Group 1 and the control treatment; thus, a cumulative effect of management steps was apparent. All treatments had significantly higher glycogen content than Group 2 *L. radiata.*

The dreissenid:unionid mass ratio prior to cleaning fouled unionids was slightly higher for *E. complanata* than *L. radiata* (Fig. 3). Mean masses of newly settled zebra mussels on *E. complanata* and *L. radiata* were not significantly different ($p < 0.53$; Fig. 4A). The mean number of newly settled zebra mussels on *E. complanata* was significantly lower than on *L. radiata* ($p < 0.001$; Fig. 4B). A higher number of adult zebra mussels >5 mm long were observed on *E. complanata* than *L. radiata*; however, the numbers were not significantly different ($p < 0.16$; Fig. 4C). The higher number of adult zebra mussels >5 mm on *E. complanata* may have compensated, in mass, for the lower mean number because adult zebra mussels weigh more than juveniles. The projected dreissenid:unionid mass ratio for

TABLE 2. Percent retrieval and survival (retrieved animals only) of *Elliptio complanata* and *Lampsilis radiata* for Groups 1 (cleaned), 2 (fouled), 3 (cleaned/translocated), 4 (cleaned/quarantined/translocated), and controls (never fouled). Mean (±1 SD) glycogen content is from foot tissue. Treatments (within species) sharing the same letter are not significantly different (Fisher's exact test; $\alpha = 0.05$). (– = no data, *n* = number of animals).

Species	Treatment group	Field experiment			Glycogen	
		n	% retrieved	% alive	*n*	Concentration (mg/g wet)
Elliptio complanata	1	40	95	100 a	38	19.4 ± 4.1 a
	2	55	100	94.5 a	40	10.6 ± 4.8 b
	3	40	75	96.6 a	28	21.9 ± 4.0 a
	4 (quarantine period)	40	100	100	–	–
	4	40	65	88.5 a	23	20.8 ± 4.0 a
	Control	–	–	–	25	21.1 ± 3.6 a
Lampsilis radiata	1	40	95	92.1 b	33	20.2 ± 4.4 a,b
	2	55	89	53.1 a	25	9.7 ± 3.7 d
	3	40	55	81.8 b	17	17.2 ± 3.7 b,c
	4 (quarantine period)	40	100	70	–	–
	4	28	43	82.4 b	14	15.2 ± 4.4 c
	Control	–	–	–	25	21.1 ± 3.7 a

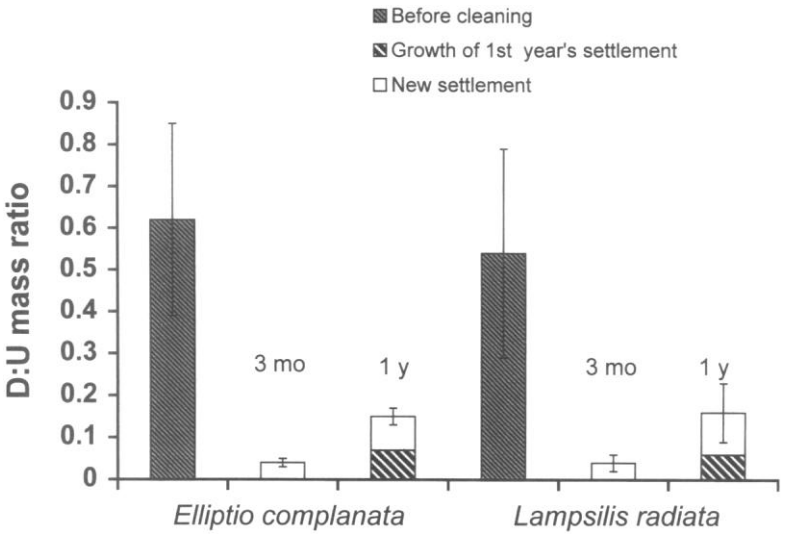

FIG. 3. Dreissenid:unionid (D:U) mass ratios (mean ±1 SD) for *Elliptio complanata* and *Lampsilis radiata* before cleaning, 3 mo after new settlement, and projected D:U mass ratios after estimated growth of newly settled zebra mussels in 1998 and new settlement in 1999.

E. complanata and *L. radiata* cleaned and replaced in situ in 1999 was 0.15 and 0.16, respectively (Fig. 3). No adult or juvenile zebra mussels were found on Groups 3 and 4 after being held in the refugium for 10 wk.

Discussion

Rare species cleaning experiment

Although survival was significantly higher for cleaned than fouled *L. fragilis* and *P. alatus*, it was difficult to determine whether energetic stores were fully recovered after cleaning and replacement in situ in the absence of baseline glycogen data from never-fouled mussels. The low mass, number, and number >5 mm of newly settled zebra mussels indicated that cleaned unionids would be under minimal stress until the following season. Zebra mussels have been in Lake Champlain since 1993, so low dreissenid:unionid mass ratios (0.36) suggest that both species are protected from rapid zebra mussel fouling, possibly because of unionid burrowing behavior.

The glycogen content of *L. fragilis* was higher in cleaned than fouled specimens; however, glycogen levels in cleaned *P. alatus* were similar to those in the fouled treatment. Because of the lack of baseline glycogen data, we cannot conclude either that the glycogen content in cleaned *L. fragilis* was similar to normal, healthy specimens, or that unchanged glycogen content in *P. alatus* implies that recovery did not occur. This lack of baseline data may be a general problem in studies where biochemical indicators of energetic stores are assessed for rare species or when never-fouled unionids cannot be found.

Depressed glycogen levels in the absence of mortality may be an early warning that recovery from many years of light zebra mussel fouling is either slow or impossible in these species. Haag et al. (1993) observed significant declines in glycogen prior to significant changes in unionid survival when fouled by zebra mussels. Glycogen levels in cleaned and control *E. complanata* and *L. radiata* from our study were markedly higher than in *L. fragilis* and *P. alatus*. Using the same glycogen assay, Naimo et al. (1998) found that nonfouled *Amblema plicata* had an average glycogen content of 22.3 ± 1.4 mg/g in foot tissue. Because other species maintain higher glycogen levels than we measured in *L. fragilis* and *P. alatus*, our results may indicate that they were stressed. A cautionary and conservative outlook is warranted for these species of concern when fouled by zebra mussels. We recommend cleaning *L. fragilis* and *P. alatus* every year to prevent massive zebra mussel fouling

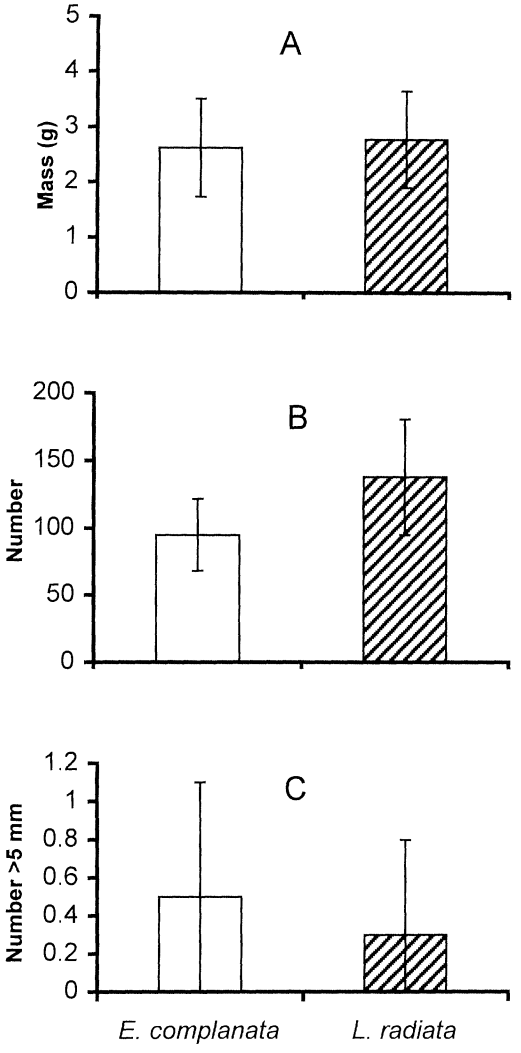

FIG. 4. Mean (±1 SD) mass (A), number (B), and number >5 mm total length (C) of newly settled zebra mussels on cleaned *Elliptio complanata* and *Lampsilis radiata* at Button Bay, Lake Champlain, Vermont, 3 mo after cleaning, 1998.

and possible energetic loss. Additional biochemical indicators of stress that can be compared among species irrespective of sex and season would be highly desirable for future studies.

Periodic cleaning vs quarantine and translocation

High survival and glycogen content, and the ability to relocate and monitor unionids when cleaned appear to make in situ cleaning the optimal conservation strategy for threatened unionids in Lake Champlain. The magnitude of new zebra mussel settlement and projected dreissenid:unionid mass ratios suggest that cleaning is effective at reducing most fouling caused by zebra mussels for a period of ≥1 y.

Estimating the required frequency of cleanings is necessary to determine the feasibility of this high-maintenance strategy. Our projected dreissenid:unionid mass ratios may have been liberal for 2 reasons. First, up to 60% of unionid populations, especially *E. complanata*, become completely buried during the autumn (Amyot and Downing 1991) and unionid burial in soft sediments may prevent significant fouling (Nichols and Wilcox 1997). This vertical migration may effectively suffocate a portion of the new zebra mussel settlement and, in addition to natural mortality, may reduce new zebra mussel settlement after cleaning. Second, our assumption of twice the magnitude of zebra mussel settlement in 1999 than in 1998 (because of increased surface area for settlement) may be an overestimate. A coating of actively filtering zebra mussels may be a poor surface for juvenile zebra mussels to settle on during the next season.

Elliptio complanata tended to become fouled with more adult zebra mussels and fewer juvenile zebra mussels than *L. radiata* after cleaning, perhaps because *E. complanata* burrow more deeply into the substrate than *L. radiata* (D. E. Hallac and J. E. Marsden, unpublished observations). Infaunal species are minimally susceptible to new zebra mussel settlement, but they are more accessible to migrant adult zebra mussels because the exposed portion of their shell can be attached to readily without travel up the side of a more exposed unionid species. Therefore, the habits of each species involved in a cleaning strategy will dictate the frequency of cleanings needed, as will zebra mussel infestation intensity and reproductive activity. Deeply buried species such as *L. fragilis* and *P. alatus* may need less frequent cleaning than other, less deeply buried species such as *Pyganodon grandis* and *Anodontoides ferussacianus.*

Cleaning was successful in western Lake Erie where survival after 1 y of cleaned and uncleaned unionids was 42% and 0%, respectively (Schloesser 1996). Schloesser (1996) translocated specimens from lentic to lotic conditions, and held them in suspended cages for the experiment. Survival of cleaned unionids may have

been much higher if they were replaced in situ immediately after cleaning.

In our study, no zebra mussels were found on Group 3 or 4 unionids. The simple method of cleaning for our experiment was 100% efficient for translocated unionids. Patterson et al. (1997) reported that, even after cleaning, quarantined unionids remained infested by zebra mussels for up to 60 d.

Although 100% of the *E. complanata* survived the 4-wk quarantine period, only 70% of the *L. radiata* survived. It is not clear why *L. radiata* was negatively affected; these results reinforce the need to study species-specific feeding, substrate, and water-quality requirements for unionids. The stresses of the quarantine, or any captive care facility, can compromise unionids prior to translocation. Unionids in quarantine can lose considerable amounts of glycogen (Patterson et al. 1997). *Lampsilis radiata* is less tolerant than *E. complanata* to zebra mussel fouling and may be especially susceptible to energetic losses caused by the stresses of translocation and quarantine (Hallac and Marden 2000). Results from our study confirm the ecological robustness of *E. complanata* and its overall vigor even in captive conditions (Strayer and Smith 1996).

Glycogen analysis can indicate the stress induced by zebra mussels when mortality has not yet occurred. For example, *E. complanata* had a 94.5% survival when fouled, yet suffered a ~50% reduction in glycogen stores over the control treatment. The survival of *L. radiata* in Groups 3 and 4 was higher than in Group 2 and similar to Group 1. However, glycogen levels in *L. radiata* suggested that the stress of translocation was significant, and translocation with quarantine caused even greater declines in glycogen content. Therefore, the long-term survival of these translocated unionids is uncertain.

Management implications

Translocation involves a number of potentially stressful steps and requires evaluation of possible refugium sites. Translocation may result in low survival (50%), as indicated in a review of 33 mussel relocations (Cope and Waller 1995). Only 35% of >5000 unionids survived 3 y after relocation on the Ohio River (Dunn 1993). In addition, long-term survival of translocated unionids may be difficult to estimate because monitoring relocated populations can be problematic (Sheehan et al. 1989). Our study confirmed the difficulty in recovering unionids from lotic conditions, even when penned. The fate of >50% of Group 4 *L. radiata* could not be determined only 10 wk after relocation. Survival in our study and other relocation studies may be vastly overestimated because of the possibility that most unrecovered unionids died and were washed downstream during high water. Predators may also have accounted for the disappearance of unionids. It may be inappropriate to translocate unionids from lentic to lotic conditions and expect long-term persistence when lake populations may be uniquely adapted to nonflowing conditions.

Expanding our knowledge of optimal unionid habitat by identifying suitable substrate, flow, and water-quality requirements may increase survival of translocated unionids in the future. It may be difficult to locate a refugium that is free of zebra mussels and has similar habitat characteristics to a donor site. Managers must consider translocation site habitat, presence of existing unionids, water quality, and host-fish presence; they must also consider optimal conditions, especially feeding regimes, during quarantine. The quarantine period may require costly equipment, food, facilities, and personnel. Obtaining these facilities and supplies may not be feasible for many states because of lack of funding and concerns about zebra mussel contamination in hatchery and aquaculture systems. Clearly, translocation may be a suboptimal strategy for conservation of unionids threatened by zebra mussels.

The loss of genetic diversity among translocated populations is another potential conservation problem that has not received much attention from resource managers (Villella et al. 1998). Stockwell et al. (1996) reviewed 29 translocation events, ½ of which involved fish, and showed that ~75% of refuge populations had reduced levels of allelic diversity after translocation. Superimposing a lake population of unionids of the same species on a population at the refugium may negatively affect the genetic diversity of both populations. Analyses of interpopulation genetic differentiation are necessary before implementing a translocation plan. Studies of this sort are necessary on a case-by-case basis and may not be feasible either temporally or financially for many states prior to develop-

ing a relocation plan. Cleaning and replacement in situ may also affect the genetic structure of a unionid population if only a small number of unionids is cleaned in a small geographical area and the remaining mussels die; therefore, managers should attempt to clean as many unionids as possible.

Because zebra mussels have become permanent additions to infested ecosystems, managers need to seek long-term conservation strategies. In a cleaning and replacement strategy, unionids are replaced in the water from which they were removed, so the zebra mussel cleaning procedure is less stringent than the procedure prior to placement in quarantine. Zebra mussels can be removed from a fouled unionid in <5 s, thus minimizing handling and emersion time. Leaving a few zebra mussels on a unionid shell is acceptable because the goal is only to remove the bulk of the encrusting mass. Furthermore, the rigid equipment disinfection procedures that are essential for an effective quarantine are not needed when cleaning and replacing unionids. A quarantine period may be stressful for other species in addition to *L. radiata.* Conservation-minded citizens in Vermont were willing to volunteer for 1 or 2 d to aid in the collection and cleaning process, thus reducing the cost for labor.

Unionid declines may not be caused solely by fouling, so managers must consider the limits of cleaning and replacement in situ. The filtering impacts of zebra mussels have profoundly affected ecosystem structure and function (Strayer et al. 1999). Unionid abundance, condition, and recruitment in the Hudson River declined significantly after the arrival of the zebra mussel; however, most unionids were not fouled (Strayer and Smith 1996). Strayer et al. (1999) provided strong evidence that this decline was a result of food limitation. Therefore, cleaning and replacement in situ may not be effective in ecosystems of low and moderate productivity where unionid starvation may occur regardless of fouling. Determining the likelihood of food limitation may be difficult, but sites that are mostly composed of sand and silt may be best suited for cleaning and replacement in situ because local zebra mussel abundances may be low and unionids may be the only substrate for zebra mussel settlement in such habitats (Mellina and Rasmussen 1994). Cleaning and replacement in situ is best suited for small and dense unionid populations inhabiting calm, shallow water (0–3 m) where they can be collected by wading and snorkeling. Deep water requires divers and swift currents make if difficult to collect unionids for cleaning. Collection efficiency and future retrieval may be low for low-density unionid populations.

Short-term conservation may be sufficient under some conditions. Zebra mussels often cause an initial decline in the abundance of unionids, but zebra mussel abundance may eventually decline because of density dependent processes, so that unionids and zebra mussels may eventually coexist (Karatayev et al. 1997). Cleaning and replacement in situ would allow managers to gain time to develop improved captive care and propagation strategies, or wait until zebra mussel populations stabilize and unionids and zebra mussels start to coexist. All conservation strategies tested resulted in a significant improvement in energetic stores in both *L. radiata* and *E. complanata* and in the survival of *L. radiata* compared to unionids fouled by zebra mussels. Unionids that are cleaned and replaced in situ may need to be cleaned as frequently as once per year, but cleanings are likely to be required less often depending upon the burrowing habits of the species of concern. We suggest that a periodic cleaning strategy is an optimal 1st step in conserving small, easily retrievable populations of unionids in systems that have adequate food resources.

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