J. N. Am. Benthol. Soc., 2007, 26(2):253–260

PIT tags increase effectiveness of freshwater mussel recaptures

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Abstract. Translocations are used increasingly to conserve populations of rare freshwater mussels. Recovery of translocated mussels is essential to accurate assessment of translocation success. We designed an experiment to evaluate the use of passive integrated transponder (PIT) tags to mark and track individual freshwater mussels. We used eastern lampmussels (*Lampsilis radiata radiata*) as a surrogate for 2 rare mussel species. We assessed internal and external PIT-tag retention in the laboratory and field. Internal tag retention was high (75–100%), and tag rejection occurred primarily during the first 3 wk after tagging. A thin layer of nacre coated internal tags 3 to 4 mo after insertion, suggesting that long-term retention is likely. We released mussels with external PIT tags at 3 field study sites and recaptured them with a PIT pack (mobile interrogation unit) 8 to 10 mo and 21 to 23 mo after release. Numbers of recaptured mussels differed among study sites; however, we found more tagged mussels with the PIT-pack searches with visual confirmation (72–80%) than with visual searches alone (30–47%) at all sites. PIT tags offer improved recapture of translocated mussels and increased accuracy of posttranslocation monitoring.

Key words: PIT tags, freshwater mussels, survival, recapture, *Lampsilis radiata radiata*, translocation.

A goal in the national strategy for the conservation of native freshwater mussels is to "develop, evaluate, and use the techniques necessary to hold and translocate large numbers of adult mussels" (National Native Mussel Conservation Committee 1997). Successful recovery of translocated mussels is essential for accurate assessment of translocation success. Previous studies of freshwater mussel translocation used visual searches to recover mussels with varied success (Layzer and Gordon 1993, Havlik 1995, Bolden and Brown 2002, Cope et al. 2003). Survival estimates of translocated mussels often are based on the number of mussels recaptured or found dead, and mussels that are not recaptured are assumed to have emigrated from the study site (Dunn and Sietman 1997, Hamilton et al. 1997, Dunn et al. 2000). A review of 33 mussel translocation studies found a mean estimated survival rate of 51% (but mortality was not reported in 27% of the studies); the average recapture rate was 43% (range: 1–97%) (Cope and Waller 1995).

Passive integrated transponder (PIT) tags may be an effective tool for tracking translocated mussels to increase accuracy of survival estimates. PIT tags are electronic glass-encased microchips that are activated by an inductive coil. They can be attached to an organism internally or externally. The tag is passive until activated by a fixed or portable reader with an antenna. When activated, the tag transmits a unique code to the reader, identifying the individual organism (Gibbons and Andrews 2004). Tag longevity is indefinite because an internal power source is not needed. In aquatic systems, PIT tags have been used extensively to study fish passage past stationary antennae or readers (Zydlewski et al. 2001). Portable PIT-tag systems are used in shallow waters to assess spatial distributions of local fish populations, fine-scale

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movements, and microhabitat preferences (Roussel et al. 2000, Hill et al. 2006). This mobile application is ideally suited to freshwater mussel translocation studies because mussel movements often occur over short distances.

Traditional mussel recapture methods depend on visual encounters and excavation to locate burrowed mussels. PIT tags may enhance mussel recapture at sites where visibility is poor (e.g., turbid water) or when mussels are burrowed in sediments. Reliability of any tagging method depends on tag retention. The tagging method selected for freshwater mussels depends on shell thickness and the type of habitat into which the tagged mussels will be placed. Internal tagging may be best for thick-shelled species, whereas external PIT-tag placement may be more appropriate for thin-shelled species. In a fast-flowing environment with a rocky substrate, an external PIT tag might be dislodged, whereas an internal PIT tag would be protected from abrasion.

We designed an experiment to evaluate the use of PIT tags to mark and track individual freshwater mussels as part of a larger study to determine the feasibility of translocations of 2 state-listed threatened mussel species (tidewater mucket [*Leptodea ochracea*] and yellow lampmussel [*Lampsilis cariosa*]) in response to an impending dam removal. The objectives of our study were to evaluate internal and external PIT-tagging methods, retention, and posttagging survival in freshwater mussels and to determine the effectiveness of PIT-tag technology for mussel recaptures. We used the relatively common eastern lampmussel (*Lampsilis radiata radiata*) as a surrogate for the listed species to develop the method. We tested internal tagging methods for future use with thick-shelled species (e.g., yellow lampmussel) and external attachment for use with thin-shelled species (e.g., tidewater mucket).

Methods

Internal PIT tagging: mantle separation

We used 2 methods to place internal PIT tags. For method 1 (mantle separation), we placed the mussels in sandy substrate, waited until they were actively siphoning and slightly gaped, and then inserted a micropipette tip between the valves to separate them by ~5 mm. We teased the mantle tissue away from the shell and inserted the PIT tag (Digital Angel, South St. Paul, Minnesota) between the mantle and shell along the midventral margin. We also marked all mussels externally with numbered bee tags (The Bee Works, Orillia, Ontario) cemented (GC Fuji I Glass Ionomer Luting Cement; Henry Schein, Melville, New York) to the posterior end of the left valve. We sealed the bee tags with Delton Light Curing Pit and Fissure Sealant (Henry Schein). Control mussels received only the numbered bee tags. We were able to tag ~20 mussels/h with this method. Most of our time was spent waiting for mussels to gape so we could insert the micropipette tip.

In October 2004, we collected eastern lampmussels (55–101 mm length, $n = 164$) from the impoundment that will be dewatered following the Fort Halifax dam removal in the Sebasticook River near Winslow, Maine. In November 2004 (24–35 d after capture), we partitioned the mussels into a control ($n = 40$) and 3 tag-type treatment groups: 23-mm tags ($n = 40$), 12-mm tags ($n = 44$), and 12-mm tags with an antimigration cap (a plastic sleeve encasing one end of the 12-mm tag to encourage tissue adherence; Biomark, Boise, Idaho; $n = 40$). Each group consisted of mussels of all sizes (control: length 55–99 mm, 23-mm tags: length 58–101 mm, 12-mm tags: length 58–99 mm, 12-mm tags with cap: length 58–96 mm).

We maintained mussels in the Aquaculture Research Center (ARC), University of Maine, Orono, Maine, in three $2.44 \times 0.61 \times 0.30$-m fiberglass tanks filled with sand (13 cm deep) and recirculating water. We divided the mussels in each group among 3 replicates (13–15 mussels/replicate) and distributed 1 replicate from each group in each tank.

We fed the mussels an algal diet (*Phaeodactylum tricornutum*, *Chaetocerus-B.*, and *Nannochloropsis oculata*; Algae Spat Formula [Innovative Aquaculture Solutions, Inc., Vancouver, British Columbia]) 3 times/wk. During each feeding, we stopped water recirculation and applied 40 to 50×10^9 algal cells/tank (R. Mair, Virginia Polytechnic Institute and State University, personal communication). To simulate changes in seasonal water temperature, we gradually reduced water temperature from 18°C (October) to 10°C (December) and maintained 10°C until the following April, then gradually increased the temperature to 18°C by June. We monitored the mussels for mortality 3 times/wk and examined them for tag retention in November 2004 and in February, April, and June 2005.

Internal PIT tagging: mantle incision

We developed a 2nd internal PIT-tagging method (mantle incision) with techniques from the cultured pearl industry (H. Dan, Virginia Polytechnic Institute and State University, personal communication). We implanted PIT tags by inserting a micropipette tip between the mussel valves to separate them by ~5 mm, making an incision with a scalpel in the midventral mantle tissue, inserting the tag between the mantle and the shell through the incision, and then removing the micropipette tip. We also marked all mussels externally with bee tags on the posterior end of the left valve. Inserting the tags took little time (20 mussels/h). Most of our time was spent waiting for mussels to gape so we could insert the micropipette tip.

In June 2005, we collected 112 eastern lampmussels (43–101 mm length) from the Sebasticook River impoundment and randomly assigned the mussels into 3 groups consisting of a control ($n = 27$) and 2 tag-type treatment groups (23-mm tags: $n = 43$, 12-mm tags with cap: $n = 42$) with 3 replicates/group (9–15 mussels/replicate), being careful to include mussels of all sizes in each group. We did not test the 12-mm tags without caps because of poor retention in the mantle-separation experiment.

We maintained tagged mussels in the ARC for 21 d to ensure tag retention and then placed 1 replicate from each group in sand in each of 3 enclosures (1 × 2-m polyvinyl chloride [PVC] pipe and rebar frames covered in hardware cloth) in Unity Pond, Maine. Unity Pond is a 1039-ha lake connected to the Sebasticook River upstream of the Winslow mussel collection site. Unity Pond contains a natural population of eastern lampmussels and thus is suitable habitat for the species. Before placing the mussels in the enclosures, we reinserted rejected tags ($n = 9$). We examined the mussels to assess tag retention and survival 60 d (August 2005) and 371 d (June 2006) after tagging.

External PIT tagging

We tested the reliability of external PIT-tag attachment and determined the probability of recapturing translocated PIT-tagged mussels that were not confined to enclosures (as in the previous experiment). We placed external PIT tags on 238 eastern lampmussels (41–88 mm length) collected during September and October 2004 from various sites in Unity Pond ($n = 90$), Sandy Stream (a 1st-order, spring-fed stream that drains into Unity Pond; $n = 88$), and the Sebasticook River impoundment near Winslow ($n = 60$). We chose these water bodies because they had naturally occurring populations of eastern lampmussels and the 2 listed species, and because, based on neutral markers, Sebasticook River and Sandy Stream populations of these mussels were genetically similar (Kelly 2004).

We tagged mussels by cementing a PIT tag to the posterior end of the right valve and a numbered bee tag to the posterior end of the left valve. After the first 30 tags (at Unity Pond), we completely encapsulated the PIT tag in dental cement to increase tag retention. We placed tagged mussels in water before the cement was fully cured (~5 min after application) to avoid overdrying and cracking of the cement. We tagged ~30 mussels/h with this method. Most of our time was spent waiting for the bee-tag sealant to dry. We used 23-mm tags at all sites. We also used some 12-mm tags at Sandy Stream and Unity Pond because of a limited supply of cement.

TABLE 1. Numbers of mussels tagged with passive integrated transponder tags in each translocation treatment during September and October 2004.

Site	Tagged and replaced (site control)	Moved within water body	Translocated from Sebasticook River
Sandy Stream	30	26	32
Unity Pond	30	30	29
Sebasticook River	30	30	–

We compared survival of translocated mussels among within-water body, between-water body, and within-site (control) translocation treatments. We measured, tagged, and moved mussels to 1 × 2-m plots or replaced them where they had been found (Table 1). We marked the corners of the plots with stakes with flagging, and recorded Global Positioning System (GPS) locations for each plot and for each of the tagged mussels that were returned to their original location.

We recaptured externally PIT-tagged mussels with a mobile PIT detection unit (PIT pack). The PIT pack used Destron Fearing FS1001A DC-powered, full duplex transceivers and custom-designed portable antennas. When a PIT tag was within range of an antenna (~0.5 m), the tag emitted a 134.2-kHz (ISO standard frequency) radio frequency, which was transmitted back to the receiver for decoding. The antennas, enclosed in an airtight PVC wand and attached to the transceiver, consisted of several wraps of 12- to 18-gauge wire, with inductance values ranging from 325 to 375 μH and a set of capacitors (Hill et al. 2006). The capacitors were attached to an antenna lead cable from the transceiver, fixing the capacitance between 33 and 44 nF. The fixed capacitance was used within the transceiver in conjunction with the adjustable capacitance to tune the resonance frequency of the system to 134.2 kHz (Hill et al. 2006). We tuned the adjustable capacitor while antennas were submerged. We conducted all field experiments with the PIT pack tuned to phase 0 to 2%, signal 1 to 20%, and current 2.5 to 5.0 amps.

We searched the release sites for externally PIT-tagged mussels ~30 d after tagging (October 2004) and visually confirmed recaptures with snorkeling. If the PIT-tag reader registered a tag but no mussel was observed, we assumed the mussel had burrowed into the substrate. To minimize substrate disturbance, we did not excavate burrowed mussels preparing to overwinter. These data were not used in the calculations of recapture success because the signals may have been from detached tags.

During June and July 2005 (271–355 d after tagging) and July and August 2006 (670–750 d after tagging), we searched again for PIT-tagged mussels at the release sites, beginning at the last location recorded with GPS during October 2004. In 2005, we conducted initial searches without the PIT pack to provide recapture percentages with visual searches only. We visually searched each site for 2 d. Approximately 1 wk later, we searched the sites using PIT-pack searches with visual confirmation and excavation to confirm recaptures (3–4 d/site). In 2006, we repeated the PIT-pack searches with visual confirmation (3 d/site). Water clarity was too poor to conduct visual searches in 2006. If the PIT pack detected a tagged mussel, but we did not see the mussel, we excavated the area within 0.5 m of the signal to 15 to 45 cm deep to determine if the signal was coming from a burrowed mussel or an unattached tag. If we found no tagged mussel after excavation, we assumed the tag had become detached. We searched (with snorkeling and the PIT pack) the sites at Unity Pond and the Sebasticook River 4 times each to at least 3 m beyond the perimeter of the original study area to detect mussels that may have moved. We also searched the shorelines for valves from dead mussels. Extensive ice scouring and spring flooding substantially reconfigured the substrate at the Sandy Stream site, so in addition to searching the study area plus 3 m beyond the perimeter, we also swept the antenna bank to bank downstream of the site for 200 m over a total of 3 d. We calculated recapture rates by dividing the number of mussels recaptured at each site by the number tagged.

Data analysis

We used adjusted χ^2 for small sample sizes (Gotelli and Ellison 2004) for all analyses.

We compared long-term tag retention among tag types and mussel mortality among treatments and controls for both mantle separation and mantle incision methods. We compared the percentages of recaptures using visual searches alone with the number of recaptures using PIT-pack searches with visual confirmation.

Results

Mussel retention of internal PIT tags in the laboratory (mantle separation)

Five percent of the PIT tags were rejected within 2 wk of internal placement via mantle separation. By 100 d after tagging, rejection had increased to 10% for 12-mm tags with caps, 12.5% for 23-mm tags, and 30% for 12-mm tags without caps. High mortality with this method was more troubling than the rejection rates. By 100 d after tagging, mortality rates were 3% for the control group (no tags), 10% for the group with 12-mm tags with caps, 25% for the group with 23-mm tags, and 27% for the group with 12-mm tags without caps. This mortality may have been caused by inexperience with the tagging procedures and mussel aquaculture husbandry (mortality in control mussels was 3% 100 d after tagging and 73% 244 d after tagging), so we discontinued using the 12-mm tags without caps, switched to the mantle-incision method, and retained the tagged mussels in field enclosures.

Long-term tag retention did not differ among tag types (adjusted $\chi^2 = 5.61$, $p = 0.691$, df = 8), and mortality did not differ among the tag-type and control groups (adjusted $\chi^2 = 7.97$, $p = 0.716$, df = 11) 100 d after tagging. We examined the condition of the PIT tags in all mussels that died over winter. By 90 d after tagging, all 12-mm PIT tags with caps were coated with nacre and attached to a valve. By 120 d after tagging, 23-mm and 12-mm PIT tags without caps that had not been rejected were similarly attached.

Mussel retention of internal PIT tags in field enclosures (mantle incision)

All mussels in the control and tag-type groups (mantle incision) were still alive 60 d after tagging (40 d after transport from the ARC to the Unity Pond enclosures) (Table 2). One 23-mm tag was rejected after the mussels were placed in the enclosures; this rejected tag was not one of the tags that had been rejected and reinserted within the 2-wk posttagging observation period. By June 2006 (371 d after tagging), 2 mussels in the enclosures had died (1 control, 1 with a 23-mm tag), and one 12-mm tag with cap was rejected. Long-term tag retention did not differ among tag types (adjusted $\chi^2 = 4.26$, $p = 0.833$, df = 8), and mortality did not differ among control and tag-type groups (adjusted $\chi^2 = 3.72$, $p = 0.882$, df = 11) 371 d after tagging.

Retention of external PIT tags and recapture of mussels in the field

Overall, ~93% of the recaptured tagged mussels retained the PIT tag (Table 3). Recapture rates with PIT-pack searches with visual confirmation exceeded recaptures from visual searches alone at all study sites during June and July 2005 (adjusted $\chi^2 = 10.198$, $p = 0.0014$, df = 1; Fig. 1). During June and July 2005 and July and August 2006, we used a combination of visual searches alone and PIT-pack searches with visual

TABLE 2. Percent mortality and % tag retention (60 d and 371 d after tagging using the mantle-incision method) of eastern lampmussels with internal passive integrated transponder tags in field enclosures in Unity Pond, Maine.

	60 d after tagging		371 d after tagging	
Treatment	% mortality	% tag retention	% mortality	% tag retention[a]
23-mm tag ($n = 43$)	0	98	2.5	97.5
12-mm tag with cap ($n = 41$)	0	100	0	97.4
Control (no tag) ($n = 27$)	0	–	4.3	–

[a] Includes mussels that died with retained tags

confirmations to recapture 77% of externally tagged mussels at Unity Pond and 80% of externally tagged mussels in the Sebasticook River (combined results from 2005 and 2006 recaptures). In Sandy Stream, where ice scouring and spring flooding reconfigured the substrate, we recovered only 25% of the tagged mussels. Ninety-five percent of the mussels we did recapture were found using PIT-pack searches with visual confirmation, and only 1 mussel was found using visual searches alone. In Sandy Stream, we found 71% of recaptured mussels >100 m from their October 2004 locations, whereas we found recovered mussels in Unity Pond and the Sebasticook River <2 m from their September–October 2004 locations. Seventeen percent (Unity Pond), 17% (Sebasticook River), and 3.5% (Sandy Stream) of the recaptured mussels found with the PIT pack were completely burrowed into the substrate (Fig. 1). We found most burrowed mussels within 6 cm of the sediment surface. However, the PIT pack detected 1 tagged (23-mm tag) living mussel burrowed 45 cm into the substrate and 3 tagged dead mussels 20 to 30 cm below the substrate surface in Sandy Stream. We also found 1 dead mussel with a PIT tag during shore sweeps at the Sebasticook River site.

Discussion

Tagging methods

Low mortality (<2%), high tag retention (~97%), and evidence that tags had fused to the shell 3 to 4 mo after tagging suggest that internal PIT tagging using the mantle-incision method may be a viable method of tagging thick-shelled freshwater mussel species that can be pried open for tag insertion without damaging the shell. Long-term survival of captive freshwater mussels is low (Patterson et al. 1997, 1999, Nichols and Garling 2002), and high mortality of captive mussels in our study (73–93% 255 d after tagging) might be attributed to inadequate nutrition, winter water temperatures in the ARC that exceeded temperatures at the mussel collection sites, and physiological stresses experienced by captive mussels that were gravid when captured. The low mortality of mussels tagged with the mantle-incision method and placed in the enclosures at Unity Pond supports this assertion. We strongly recommend field trials rather than aquaculture experiments for testing methods intended for use in the field to remove uncertainty of the effects of captivity on mussel survival.

External PIT-tag retention also was high (~93%)

TABLE 3. Percent recapture, % mortality, and % tag retention of externally passive integrated transponder–tagged eastern lampmussels in translocation experiments within and among sites (~21 mo after tagging) in Maine.

Site[a]	Treatment	Number tagged	% recapture	% mortality[b]	% tag retention[c]
Unity Pond	Translocated from Sebasticook River impoundment	29	93.1	0	100
	Translocated within Unity Pond	32	74.2	0	78.3
	Site control (not moved)	30	63.3	0	89.5
Sebasticook River	Translocated within Sebasticook River impoundment	30	93.3	0	96.4
	Site control (not moved)	30	66.7	6.7	100
Total		151	78.0	1.3	93.2

[a] Sandy Stream data omitted because of winter ice scouring and spring flooding

[b] Percent mortality calculated only for recaptured mussels

[c] Retention calculated as % recaptured mussels retaining tags

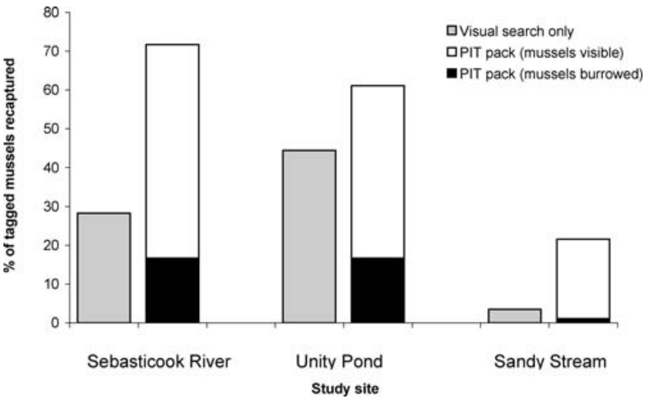

FIG. 1. Percentages of mussels externally tagged with passive integrated transponder (PIT) tags recaptured using different methods during June and July 2005.

when the PIT tag was completely encapsulated in cement and the mussel was placed in water within 5 min of cementing. However, retention was more variable with external tagging than with internal tagging methods, and ranged from ~78 to 100% at the Unity Pond site 9 mo after tagging. We attribute low retention to incomplete coverage with cement. Retention of tags completely encapsulated with cement ranged from 89.5 to 100%. We observed evidence of some cement loss from recaptured mussels; occasional reapplication of cement will ensure long-term retention of external PIT tags. Internal tag placement via mantle incision is a viable alternative to external attachment in environments where tag loss from abrasion is likely.

Previous studies assessed external freshwater mussels tagging methods with visual searches to relocate mussels marked with numbered tags (Lemarié et al. 2000) or coded wire tags inserted into mussels held in suspended pocket-nets (Layzer and Heinricher 2004). Both of these tagging methods resulted in higher tag retention than in our study, but mussels tagged using these methods can be detected only with visual searches. PIT tags provide an alternative tool for finding mussels, and this method is especially useful for long-term monitoring or where visual searches are impractical or time consuming.

Mussel recapture efficiency

The proportion of mussels visible at the substrate surface may vary by locality, time of year, species, and gender. Smith et al. (2001) detected only 31% of clubshells (*Pleurobema clava*) at the substrate surface, whereas 52% of northern riffleshells (*Epioblasma torulosa rangiana*; 80% females, 45% males) were visible. Wick (2006) observed that >90% of eastern lampmussels had burrowed to 10 to 15 cm at Sandy Stream by August, but only 26% had burrowed in the Sebasticook River impoundment at that time.

Because the water was turbid, we found burrowed mussels and mussels that would have been overlooked had the sites been searched only visually. For example, water clarity in Unity Pond was routinely poor, and only 47% of tagged mussels were recaptured visually, whereas 72% of tagged mussels were recaptured with the PIT pack and visual confirmation. In the Sebasticook River, where the visibility was compromised by silt covering the mussels, the recaptures with the PIT pack and visual confirmation (80%) were >2× those of the visual searches alone (29%). Initially, PIT tags also provided a visual cue of tagged mussels in clear water, but after several months in the water, the cement was stained or covered with algae and indistinguishable from the shell. When first applied, the white cement might provide a visual cue to predators, but only 1 shell was found in a shoreline midden in our study. Tinting the cement a dark color might eliminate this possible problem.

Low recaptures in Sandy Stream probably were caused by extensive downstream displacement of mussels in late winter and early spring when ice scour and high water flows during snowmelt reconfigured the stream bottom. The low recapture rates of PIT-tagged mussels at this site were attributed to tag loss from severe abrasion, burial in sediment beyond the detection limit, or transport beyond the regions searched.

Limitations of PIT tags in field applications

Debris on the substrate and signal interference caused by nearby iron objects (Hill et al. 2006) can affect reliability of the PIT pack. The antenna configuration we used also is limited to sites with water depth <2 m. Maximum effective depth and antenna range are not necessarily uniform among sites; these limitations should be identified at each field site so that mussel absence can be distinguished from nondetection caused by equipment limitations. Reducing the antenna size for use while snorkeling, waterproofing the PIT pack for diver use, and lengthening the antenna handle are modifications that will broaden field use of this tool. At present, PIT-tag use is limited to larger mussels (length >20 mm). However, smaller tags with greater detection ranges are in development, and eventually it should be possible to tag smaller mussels, at least externally. Although internal tags were retained, the ~3-wk captive period to ensure tag retention could limit the usefulness of internal tags. Internally tagged mussels should be held in field enclosures during the initial posttagging period when tag rejection may occur. Retaining a subset of internally tagged mussels may be a viable alternative for estimating tag retention proportions when large numbers of mussels are translocated.

The initial cost of the PIT tags and reader may exceed start-up costs for other mussel-tagging methods. The PIT pack (transceivers, batteries, antenna) we used cost ~$10,000 to construct and was designed for research on a variety of organisms such as fish, mussels, and amphibians. Smaller units can be developed for ~$2500. The PIT tags we used cost $3.50 each, but the tags work indefinitely. On the other hand, the percentage of tagged mussels recaptured using PIT tags far exceeded the percentage recaptured during visual searches. Visual searches can be time consuming and labor intensive. For long-term monitoring of individuals and populations, the added initial costs may be recouped over time, and it may be possible to share the costs with other investigators using PIT tags.

In conclusion, PIT tags permit repeated, nondestructive sampling of individuals with little disturbance, last indefinitely, and appear to have negligible effects on short-term survival of freshwater mussels. PIT tags were retained using both internal and external attachment methods. Thus, the choice of tagging method will depend on shell thickness, habitat characteristics, and ease of implementation in the field.

The need for freshwater mussel translocations to protect and conserve threatened and endangered mussel species will increase as aquatic habitat alteration continues. Superior recapture rates with PIT tags suggest that this tool is valuable for use in mussel translocations and monitoring and may improve accuracy of survival estimates for assessing translocation success. Because PIT tags have indefinite longevity, they can be used in monitoring both translocated mussels and populations at sites of concern, especially populations of endangered or threatened species. Moreover, because PIT tags provide reliable individual identification, they may be a useful tool for monitoring the growth and survival of individual mussels.

Acknowledgements

The authors thank C. Currier and R. Clark for field assistance, N. Greenberg (University of Maine Aquaculture Research Center), B. Swartz, and K. Kemper (Maine Department of Inland Fisheries and Wildlife), and R. Mair, H. Dan, and R. Neves (Virginia Polytechnic Institute and State University) for advice and assistance. We thank G. Zydlewski, M. Kinnison, B. Swartz, 2 anonymous referees, and D. Strayer for reviewing early drafts of the manuscript. Our research was funded by the Maine Department of Inland Fisheries and Wildlife through the State Wildlife Grants Program and the Endangered and Nongame Wildlife Fund, and by the US Geological Survey–State Partnership Program, the US Geological Survey Maine Cooperative Fish and Wildlife Research Unit, the Maine Outdoor Heritage Fund, and the University of Maine, Department of Wildlife Ecology. Reference to trade names and commercial products does not imply endorsement or recommendation by the US Government. This is article no. 2903 of the Maine Agricultural and Forest Experiment Station.

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Received: 4 April 2006
Accepted: 18 December 2006