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Exploratory Study of Dismantling Sea Lamprey to Reduce Egg and Larval Production in Two Lake Champlain Basin Tributaries

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Exploratory study of dismantling sea lamprey nests to reduce egg and larval production in two Lake Champlain Basin tributaries

Report submitted to the Lake Champlain Basin Program

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Executive summary

Lamprey nests are conspicuous in streams and rivers where adults spawn and can be targeted for management actions. This study investigated whether a long-tined garden rake and nest sampler could be used to dislodge eggs and larvae from a nest's substrate and be recovered once swept downstream. We found that eggs did not adhere to the substrate and could be suspended into the water column via raking. Results indicated that we were able to remove majority of eggs and larvae from a nest's substrate following 100 raking strokes (eggs: 0=63% ±16% C.I.; larvae:0=61% ±18% C.I.). A larger number of raking strokes would be needed to remove most all eggs and larvae from nests in Lewis Creek (150 strokes: 0=75% ±13% C.I. eggs, 0=69% ±20% C.I. larvae; 200 strokes: 0=81% ±12% C.I. eggs, 0=72% ±18% C.I. larvae). Egg distributions and depth of deposition likely varies among streams within the Basin. For some streams, 50 to 100 raking strokes may be sufficient to dislodge most eggs and larvae from nests; whereas on others, eggs and larvae may be more deeply embedded and a substantial level of raking effort would be needed, such as that observed in Lewis Creek. Future studies should consider evaluating the depth at which eggs occur in nests in a variety of streams, substrates, stream flows, and spawning conditions.

Most all eggs and larvae swept from nests and recovered in deployed nets, were recovered in the first net (eggs: 0=99.6%, range 99.0 – 100%; larvae: 0=93.9, range 90.9 – 96.9%). Data showed that larvae may have been able to escape the 0.505 mm plankton mesh used in this study. A mesh size of 0.36 mm appeared sufficiently small to capture, collect, and retain all lamprey life-stages. Eggs and larvae were widely distributed about a nest depression ($0.5m^2$), and the data indicated that larger areas ($2.5m^2$) – relative to the nest depression – might need to be targeted to eliminate the majority of eggs and larvae occurring in and around lamprey nests in Lewis Creek. No invertebrate group appeared decimated by raking. It would be expected that nest raking would damage only limited locations in the stream when compared to the short term but longitudinal and bank-to-bank effects of TFM on macroinvertebrates. Stream-specific assessments would be needed to fully evaluate non-target impacts of nest dismantlement given the variety of aquatic communities in the Basin. Results from this study indicated that 3% ($880\ m^2$) of the entire study stream reach in Lewis Creek would have to be raked with over 250,000 raking strokes to recover about 75% of the eggs and larvae produced in and around lamprey nests in 2002. The fact that this assessment was done in Lewis Creek, one of the most productive lamprey streams in the Basin, places these results in important context. Additional studies planned for Malletts Creek were not completed because lamprey enclosures were repeatedly washed away by high stream flows. We were unable to address four of the seven planned objectives for this study because of these difficulties. Future studies should consider a combination of controlled laboratory and field experiments because of the variable and high stream flows expected during lamprey spawning.

Efficiency estimates for management actions targeting eggs and larvae through nest dismantlement were provided. Population sensitivity and elasticity analyses should be conducted with the life-history model to determine the effect, if any, nest raking might have on sea lamprey population growth in Lake Champlain Several factors were identified that may reduce the efficacy of nest dismantlement as a management tool. Perhaps most importantly, outside of nest egg survival – whether it occurs and if so its magnitude – was identified although untested by this study. Survival of eggs outside of the nest would limit the utility of management actions targeting nests to reduce sea lamprey population growth. These survival

data are needed before managers can fully assess the efficacy of nest dismantlement as a management tool.

Nonetheless, combined alternative methods implemented in concert and targeting multiple life-history stages have a higher likelihood of achieving effective control. For this reason, the U.S. Fish and Wildlife Service may want to consider dismantling lamprey nests on streams where lamprey populations are currently controlled through trapping. It would be expected that egg and larvae production would be reduced through dismantlement of nests established above temporary barriers associated with trap sets. Additional experimental application of nest dismantlement within the Basin should be based upon: 1) whether eggs deposited outside of lamprey nests survive and contribute to parasitic production, 2) the likelihood of nest dismantlement to affect sea lamprey population growth as determined by the life-history model, 3) its integration into a suite of alternative control methods targeting multiple life stages, 4) its application in small to mid-sized streams where nests can be found and their numbers managed, and 5) where stream-specific evaluations suggest minimal non-target impacts.

Introduction

Sea lamprey control has been an important component of efforts to re-establish lake trout and landlocked Atlantic salmon in Lake Champlain. A long-term integrated pest-management program was initiated in 2002 in the basin by the states of New York and Vermont and the U.S. Fish and Wildlife Service through the Lake Champlain Fish and Wildlife Management Cooperative (Cooperative). As part of this program's implementation, the Cooperative is investigating alternatives to lampricides for possible use in the Basin. Determining the feasibility of alternatives to lampricides for control of sea lamprey *Petromyzon marinus* presents a clear challenge to fisheries managers. Years of research on sea lamprey control methods in the Great Lakes have demonstrated multiple difficulties in applying and documenting effective non-chemical sea lamprey control techniques. For example, sterile male releases have been used since the early 1990's to augment trapping and Bayluscide treatments in the St. Marys River, yet the program's effectiveness continues to be evaluated by control agents in the Great Lakes after a decade of use (Twohey et al. 2003). Additionally, managing lamprey populations given biological and ecological uncertainties is difficult. Lamprey spawn in numerous tributaries throughout Lake Champlain, ranging in size from small brooks to the largest river in the basin. In the Great Lakes, lamprey control has been ongoing since the 1950's and it is the largest coordinated, international fisheries management effort in the Great Lakes. Even so, we don't know some basic life-history information about this prehistoric jawless fish, such as whether eggs deposited outside of nests survive and contribute to larval production. To address these challenges, the Lake Champlain Fish and Wildlife Management Cooperative formed the Sea Lamprey Control Alternatives Workgroup. This group's mission is to engage stakeholders interested in investigating alternative control technologies and provide a forum where research priorities can be discussed and funding leveraged. It has also served as an avenue for stakeholders to provide technical, management, and research input into alternative control investigations

A study to examine nest raking was funded by a grant from the Lake Champlain Basin Program as part of a larger study to develop a stage-based population viability model for sea lamprey (Howe et al. 2004). The model is expected to help mangers and the workgroup to evaluate control opportunities for different life-stages of lamprey, and the potential for management actions to affect lamprey population growth in Lake Champlain. The model is expected to provide a foundation to move the workgroup forward in assessing alternative control technologies based on sound science. It would also provide the necessary means for identifying the life stages that are most sensitive to control and where best to focus control efforts (Howe et al. 2004). Population viability models were originally developed for managing and investigating threatened and endangered species populations at risk of extinction (Botsford and Brittnacher 1998, Crouse et al. 1987, Crowder et al. 1994, Morris et al. 1999). Whereas, Howe et al. (2004) used the population viability model to discover how best to reduce populations of sea lamprey from its currently over-abundant status.

Although models can be used for identifying life stages most important in regulating population growth (Crouse et al. 1987, Crowder et al. 1994), they cannot determine whether a control strategy is technically feasible, effective, or if non-target impacts are acceptable. The objective of this study was to determine if nest dismantling could be used to remove lamprey production from a stream by targeting lamprey nests with minimal non-target impacts. Data

gathered from this study will be used in the model to assess if the technique can be used to diminish population growth of sea lamprey in selected tributaries of Lake Champlain.

Objectives:

1. Establish whether nest raking can effectively remove sea lamprey eggs and larvae from nests.

2. Identify impacts to non-target organisms resulting from raking and manual dismantlement of sea lamprey nests.

3. Assess whether number and diversity of non-target organisms differ between nest and non-nest areas within spawning habitat.

4. Estimate number of nests created by sea lamprey of known number and sex.

5. Estimate proportion of spawned eggs retained within sea lamprey nests.

6. Estimate survival rate of sea lamprey eggs retained in nest surviving to larval emergence.

7. Assess whether sea lamprey eggs not in nests occur, survive, and contribute to total production of larvae.

Methods

Lewis Creek

Study objectives were split between two studies in two streams: Lewis Creek (Objectives 1 – 3) and Malletts Creek (Objectives 4-7). The study in Lewis was designed to determine if nest dismantling could be used to remove lamprey production from a stream by targeting lamprey nests. Lewis Creek is a tributary of east-central Lake Champlain that drains into Hawkins Bay, Vermont (N44° 14" 47', W73° 16"42"). Sea lamprey have access to 14.2 km of Lewis Creek, and the upper extent of their migration is blocked by a man-made low-head barrier (Zerrenner 2001). The majority of spawning sea lamprey occurs downstream of Ferrisburg Falls, which serves as a partial barrier about 4.8km downstream from the low-head barrier. Intensive agriculture occurs along the riparian zones, creating high water temperatures and stream productivity (Zerrenner 2001).

Habitat quantification.—One meter resolution aerial photographs were obtained for the reach of Lewis Creek extending from the Rt. 7 bridge to the falls upstream, a distance of 8.3 km. Reach length was measured from aerial photographs along the centerline of the stream. Stream width was estimated by averaging 3-7 measurements made perpendicular to the centerline of the stream. These measurements were used to calculate the area of each stream reach identified during field examination. Stream breaks were identified in the field and drawn on aerial photographs. Each reach between two stream breaks was classified as riffle (low or high gradient), run, or pool. Habitat classification followed Bovee (1982).

Nest sampling.—Sea lamprey nests were identified in Lewis Creek by walking the stream reach and identifying all lamprey nests. Protocols used for identifying and enumerating nests in streams were followed (FTC 1999). Experimental nest sites were in most cases randomly selected from identified nests. A sampling device modified after Manion (1968) was positioned

immediately downstream of each nest prior to raking. This sampler consisted of a 0.505 mm mesh plankton net attached to a 0.7-m wide X 0.25-m high galvanized metal frame. Metal wings, 0.8-m long, having a rubber gasket weighted at the bottom, with attached chain were spread and anchored with rebar pins driven into the streambed upstream of the sampler. The metal wings and gasket were designed as a seal to prevent loss of sea lamprey eggs, larvae, and non-target organisms by drift under and around the net opening. A removable cod end was used to facilitate sample removal without disturbing the positioning of the anchored net frame.

A long-tined garden rake was used to vigorously and deeply rake the bottom substrate immediately upstream of the net opening between the outstretched metal wings. The raked area between the wings was approximately 0.5 m^2. The top margin of the net frame and wings always protruded above the water surface.

The number of rake strokes required to completely deplete a nest of eggs was estimated by incrementally increasing the number of rake strokes until eggs captured approached zero. Following this determination, all subsequent samples were collected using equal effort. Each nest was dismantled with 200 raking strokes. Sampling was partitioned into four separate 50-stroke raking increments: initial dismantlement (strokes 1-50), pass 1 (strokes 51-100), pass 2 (strokes 101-150), and pass 3 (strokes 151-200). Number of eggs/larvae within a nest was estimated by the sum of catch during initial dismantlement and the population estimate, *N*, from a 3-pass depletion on passes 1 - 3 (*N*: see below for Q*uantification Methodology* for 3-pass depletion estimates, equations 1-5). A repeated measures analysis of variance was used to test if percent reduction per 50-stroke raking increment significantly declined with increasing number of passes. Orthogonal mean contrasts for a repeated measures analysis of variance were used for pair-wise comparisons

Since it is unknown whether dislodged eggs and larvae would survive if swept from a nest and allowed to deposit in downstream substrate, it was necessary to determine if we could capture and retain nest production. A second sampling device, with similar construction to our primary nest sampler, was positioned immediately downstream to assess "lost catch." The tail and cod end of the upstream sampler was extended inside of the downstream sampler with wings extended so as to capture any eggs or larvae escaping the upstream sampler. Lost catch, or those eggs and larvae not captured in the primary nest sampler, was determined by comparing numbers of eggs and larvae captured in the second drift net to those in the primary nest sampler. A Fisher's exact test was used to compare between the capture frequencies of eggs and larvae in deployed nets. Data was arranged in a 2 x 2 contingency table (net: nest sampler vs. lost catch nets; and, nest production: eggs vs. larvae).

Lamprey egg deposition and egg and larval distributions around the nest were evaluated by sampling areas outside of the nest depression by positioning the sampling device in four adjacent areas to the nest (upstream, downstream, right side, and left side). Each area sampled was about 0.5 m^2. Samples were separated by pass, and sorted and analyzed by a two-pass depletion method (see below for *Quantitative methodology* for 2-pass depletion estimates, equations 6–7).

Time and effort involved in nest raking and various related tasks were quantified to assist

in the assessment of nest dismantling as a management technique. Stream flow, substrate size and embeddedness, water depth, water velocity, water temperature and other physical habitat conditions were recorded during the study period.

Non-target effects.—The effect of nest dismantlement on non-target organisms was assessed by documenting the species of vertebrates and invertebrates collected by nest dismantlement. These data were collected for nests 3, 4, 16 and 17, and provided information on numbers of non-target organisms impacted. Observed physical damage to invertebrates was also quantified. This evaluation would become important only if lamprey production does not need to be collected downstream of nests – i.e., eggs and larvae do not survive outside of nests and can be allowed to remain in the stream after being dislodged. Outside of nest sampling also occurred on nests 16 and 17. These samples provided additional information on numbers and diversity of organisms potentially affected by nest dismantlement both within the nest-proper and in immediately surrounding areas.

Sample enumeration, identification, and quality control.—Lamprey eggs, larvae, fish eggs, and macroinvertebrates were separated from the benthos detritus under a dissecting microscope. Samples were set in 5% formalin and later transferred to 35% isopropanol for storage and processing. Trained volunteers, work study students, or paid staff sorted samples and separated lamprey eggs and larvae, fish, and macroinvertebrates for further sample enumeration and identification. In some situations, samples were initially picked for lamprey eggs and larvae and sorted later for invertebrates. A sample splitter was used on half of the samples to cut processing time, while still providing statistically reliable data (Smith and Richardson 1977). Eggs and larvae were enumerated from each sample and macroinvertebrates were identified to the lowest taxonomic level from a subsample of nests. Dr. Peter Wimmer, retired, Middlebury College and current member of the Vermont Invertebrate Scientific Advisory Committee and the Alternatives Workgroup, identified all insect macroinvertebrate from samples. Questionable identifications were verified through Dr. Ross T. Bell, Professor Emeritus of entomology, University of Vermont. Identification of specimens was made using a number of keys (Merritt and Cummins 1988; Ross 1944; Wiggins 1996; Edmunds et. al. 1976; Johannsen 1969; Berner and Pescador 1988; Betten 1934; Hitchcock 1974; Smith 2001; Thorp and Covich 2001; Burkes 1953; Needham et al. 1903). Identified specimens were then stored by family in screw-cap vials containing location and determination labels and filled with 50% isopropanol.

Quantitative methodology.—Numbers of eggs and larvae per nest were estimated through Zippin's (1956, 1958) removal method. Numbers of eggs and larvae located within the nest depression and numbers remaining after complete dismantlement (200 raking strokes) were estimated. Quantification methods developed by Lockwood and Schneider (2000) were used:

1. $$T = \sum_{i=1}^{k} C_i ;$$

2. $$X = \sum_{i=1}^{k} (k - i) C_i ;$$

where,

i	=	pass number,
k	=	number of removals (passes),
C_i	=	number of eggs/larvae caught in the $i^{\underline{th}}$ sample,
X	=	an intermediate statistic used in equation 3,
T	=	total number of eggs/larvae caught in all passes.

An iterative process determined the maximum likelihood estimate of the number of eggs and larvae located within the nest (N) was estimated by substituting values for n until equation 3 was satisfied where n is the smallest integer (rounded to one decimal place – following Lockwood and Schneider 2000:

3. $$\left[\frac{n+1}{n-T+1}\right]\prod_{i=1}^{k}\left[\frac{kn-X-T+1+(k-i)}{kn-X+2+(k-i)}\right]\leq 1;$$

Probability of capture (p) and variance of N were then estimated by solving equations 4 and 5, respectively, as follows (Lockwood and Schneider 2000):

4. $$p=\frac{T}{kN-X};$$

5. $$\mathrm{var}(N)=\frac{N(N-T)T}{T^2-N(N-T)\left[\frac{(kp)^2}{1-p)}\right]};$$

A chi-square goodness of fit test was used to evaluate if catch probabilities were equal (White et al. 1982) and whether the above depletion estimates were valid (Lockwood and Schneider 2000). Depletion samples with unequal catch probabilities (i.e., $\chi^2 \geq 3.841$) were analyzed using the computer program, MARK (Huggins 1991, Huggins 1989). This program was designed to calculate population estimates from depletion methods with unequal capture probabilities during passes. Numbers of eggs and larvae captured during initial dismantlement were added to N to derive estimates of nest production. One nest was sampled with a greater number of passes to test the accuracy of the depletion estimate. Up to seven replicates, each with 50 strokes was used for this purpose.

Lamprey egg deposition and egg and larval distributions around the nest were evaluated by sampling areas outside of the nest depression by positioning the sampling device in four adjacent areas to the nest (upstream, downstream, right side, and left side). Each area sampled was about 0.5 m^2 and sampled with two passes, each with 100 raking strokes. Samples were separated by pass, sorted, and analyzed by a two-pass depletion method where the population in each area was estimated by solving for N in equation 6 as follows:

6. $$N = \frac{C_1^2}{C_1 - C_2}$$

where the variance is calculated according to Lockwood and Schneider 2000 (equation 7):

7. $$\text{Variance of } N = \frac{C_1^2 C_2^2 (C_1 + C_2)}{(C_1 - C_2)^4}$$

where,

C1	=	number of eggs/larvae removed during the first pass,
C2	=	number of eggs/larvae removed in the second pass,
N	=	population estimate,

It was assumed the sum of catch ($C_1 + C_2$) was N when C_2 exceeded C_1.

Malletts Creek

The study in Malletts Creek was designed to estimate life-history parameters for inclusion in the sea lamprey population viability model. We attempted to address objectives 4 through 7 by releasing a known number of sea lamprey into an isolated study reach in Malletts Creek. Malletts Creek is a tributary of the Malletts Bay Basin (N 44°34'18", W 73°10' 41"). It originates in the town of Milton, VT and has a total length of approximately 18.9 kilometers. Sea lamprey have access to approximately three kilometers from the mouth up to a set of falls located upstream from U.S. Route 7. Previous surveys have identified the falls as a barrier to upstream migrations of sea lamprey. Malletts Creek is known to have populations of the Vermont-endangered northern brook lamprey *(Ichthyomyzon fossor)* below the falls.

Lamprey enclosures.—We attempted to estimate the number of nests and egg production from a known number of adult spawning-phase sea lamprey. The study location on Malletts was located immediately above the falls. Temporary mesh hardware cloth barriers were placed upstream and downstream of the study reach in an attempt to prevent movement of lamprey out of the study reach. Migratory-phase lamprey were captured as part of the U.S. Fish and Wildlife Service's annual trapping program and used to populate the enclosure with a known number of sea lamprey. Lamprey were held for 24 hours to assess handling mortality and determine maturation, size and weight, and sex of study animals. Lamprey were tagged by latex injection on the dorsal fin for subsequent identification using yellow, orange, and pink latex elastomere. It was assumed marking did not disrupt spawning behavior.

Egg survival.—To estimate survival to hatch and whether eggs survive outside of nests, eggs were removed from sea lamprey nests, counted, and placed into mesh enclosures with a collection chamber at the downstream end. The enclosures were anchored into the streambed at the nest location and surrounding substrate in an attempt to approximate site-specific conditions both inside and outside of nests. If an enclosure effect existed, it was assumed to be constant between areas within and outside of a nest. We planned on using a chi-square test arranged in a 2 x 2 contingency table to test for differences in dead and alive eggs between enclosures. Attempts were made to allow eggs to incubate within the enclosure. Continuous temperature

recorders were used to monitor water temperature and assess accumulated temperature degree units from time of observed spawning to hatch. Comparisons between hatch rates from inside and outside of nests were planned to investigate whether eggs deposited outside of nests can survive and contribute to larval production.

Results

Malletts Creek

Lamprey enclosure.—The stream reach (approx. 600 feet long) above the most downstream falls on Malletts Creek was located and fenced on 29 May 2002. This location was selected because no threatened or endangered brook lampreys were believed to occur within the reach, and permitting restrictions precluded study areas below the falls. Twenty-one males and 25 female sea lamprey were measured, weighed, sexed, marked, and transferred to the enclosed reach between 30 May and 3 June (Appendix 6). High flows on June 1 over-topped barriers and marked fish were recovered in a downstream trap site. Nest building behavior was observed on 3 June and two nests were observed on 5 June. Nine nests were observed on 8 June. A major flood occurred on 11-19 June. This flood either eroded or deposited gravels destroying or making all nests undetectable. High flows occurred throughout the latter part of May and June and presented several difficulties in completing the objectives for this part of the study. The lamprey enclosures on Malletts Creek were repeatedly washed away, and study animals were known to have spawned above and below our study site.

Egg survival.—Two egg enclosures were deployed in Malletts Creek, each with about 100 eggs. Enclosures were positioned within the substrate inside and outside of a lamprey nest. Egg incubation failed when floodwater filled incubation chambers with silt and sand.

Only one-third of days (8 of 23) had stream flows that allowed for identification and study of lamprey nests between the completion of the Quality Assurance Project Plan (QAPP) and the last nest sample on 2 July 2002 (see analysis of stream flows for Lewis Creek, Figure 1). These difficulties necessitated that we abandon the study objectives 4, 5, 6 and 7 on Malletts Creek and focus project effort to Lewis Creek and addressing objectives 1, 2, and 3.

Lewis Creek

Nest assessments.—Permission was received to work on Lewis Creek between the Route 7 and the Ferrisburg Falls. This stream reach covers the majority of sea lamprey spawning habitat. Sampling devices and raking methods were tested on June 6th following completion of the project QAPP. Habitat assessments and sea lamprey nest counts were conducted within this reach on 10 June (Tables 1 and 2). Three hundred and fifty-two nests were counted, classified according to habitat type in which they occurred, and located on aerial photographs (Appendix 1a, 2a, 3a, 4a). Ten nests were found occupied by spawning sea lamprey and averaged 2.9 (1-6) fish per nest. Nests were again counted on 26 June. On this date, the same area except for the upper 600 feet of the reach was surveyed (area previously contained 289 nests). A thunderstorm prevented completion of the entire survey. Only 67 sea lamprey nests were counted on this date. Seven of these nests were new nests made subsequent to the flood event. These observations indicate that more than 80 % of all sea lamprey nests were either eroded or buried during the flood event in mid-June. Nests that survived the flood were found in locations near shore or

otherwise protected from the effects of the flow with the exception of the low-gradient riffle reach about 400 feet above the Route 7 Bridge (Appendix 1b, 2b, 3b, and 4b). More than half of all nests in this reach survived the flood (Appendix 1a and 1b).

Nearly 90% of all lamprey nests on Lewis Creek were observed in low-grade riffles (Table 2). Low-grade riffle habitat was distributed throughout the entire reach and comprised 50% of the entire habitat type (15,978 m^2; Table 1). Less than 15% of sea lamprey nests occurred in high-grade riffles, runs, or pools, although it represented 50% of the available habitat. Nests with spawning adults on the nest were in water that averaged about 25 cm depth and 0.3 m/sec water velocity.

Egg and larvae.—Seventeen nests were sampled within the study reach on Lewis Creek between 6 June and 2 July 2002. We found that eggs did not adhere to the substrate and could be suspended into the water column via raking. Raking effort was increased to four replicate passes employing 50 vigorous rake strokes per sample in an attempt to obtain enough effort to provide for a depletion estimate of total eggs and larvae within the nest depression. Numbers of eggs and larvae captured during nest dismantlement and subsequent depletion passes generally declined (Tables 3 and 4). Most samples had unequal catch probabilities, necessitating the use of MARK to calculate *N* for eggs for all but nests 6, 13, 15, and 16 (Table 3) and Nests 5, 6, 7, 15, and 17 for larvae (Table 4). Egg production ranged from 1 ($\forall 0$) to 19,012 (nests 15 and 2, respectively; Table 3). Larvae production ranged from 0 ($\forall 0$) to 22,483 (nests 15 and 14, respectively; Table 4).

Two nests, nests 16 and 17, were assessed for egg and larval distributions in areas immediately adjacent to the nest depression. The majority of larval production was found within the nest depression (55% and 65% for nests 16 and 17, respectively), while egg production appeared more variable (23% and 77% for nests 16 and 17, respectively)(Table 6). Substantial numbers of larvae were found upstream of nests 16 and 17, while eggs were downstream of these nests. Three-quarters of the larvae and one-fourth of the eggs were found to the right of nest 16 (Table 6).

On average, we were able to recover about 80% of eggs and 70% of larvae located within a nest depression after 200 raking strokes (Tables 7, 8 and 9). Number of eggs and larvae collected per 50 raking-stroke increments decreased with increasing numbers of passes (Figure 2). The greatest recovery of eggs and larvae occurred during the initial dismantlement of the nest (mean = 33 - 34%). The percent reduction per 50 raking-stroke increment significantly declined from the initial dismantlement through pass 3 (repeated measures analysis of variance: eggs; P=0.0010 and larvae; P=0.0029)(Figure 2). Orthogonal mean contrasts for a repeated measures analysis of variance showed significant differences among all non consecutive raking increments but for passes 2 and 3 for larvae which differed consecutively (P=0.0443)(Figure 2). Cumulative percent recovery began leveling off at 100 strokes for larvae and 150 strokes for eggs within the nest depression (Figure 2).

Comparisons of 7- and 3-pass depletion estimates indicated that eggs were deeply distributed within the substrate for Nest 7 (Table 10). A layer of eggs was encountered during the initial dismantlement of the nest and a second during passes 3 and 4 (between 150 and 250

raking strokes). The 3-pass depletion overestimated the 7-pass depletion by 80% for eggs and underestimated the 7-pass for larvae by 300% (Table 10). The study proposal called for stone-by-stone dismantlement of a subset of nests to compare to depletion population estimates. Eggs and larvae within nests were not confined to the crescent-shaped mound located on the downstream side of the nests but were distributed throughout the bottom and sides of the nest cavity in sand and gravels. Stone-by-stone dismantlement of nests was found to be infeasible given the wide distribution and substrate in which eggs and larvae occurred.

Collections of eggs and larvae from a secondary net deployed downstream from our nest sampling device indicated that we were effective at recovering and retaining eggs and larvae swept from nests and recovered in deployed nets (Table 11). We were more effective at collecting eggs (99.6%) than larvae (93.9%: Fisher exact test; df=1; N=29,470; P<0.0001).

Parameter estimates for the stage-based population viability model (PVA) are summarized in Table 12. The product of three variables presented in Table 12 estimate the percent of nest production that can be removed from a stream with increasing effort of 50 raking-stroke increments. They are: *i*) percent egg/larvae production targeted (Tables 5 and 6), *ii*) raking effort and its efficiency at removing egg/larvae from the substrate (Tables 7, 8 and 9), and *iii*) percent of production recovered once swept from the nest (Table 11).

Non-targets assessments.—Collections of non-target vertebrates captured during the dismantlement of nests 3, 4, 16, and 17 are presented in Table 13. Few Teleosti eggs and larvae were recovered from dismantled nests when compared to the numbers of sea lamprey eggs and larvae. One notable exception was nest 17 where 225 fish larvae were found within the nest depression and one 25 mm smallmouth bass (*Micropterus dolomieui*). Most macroinvertebrate taxon were found in similar densities within and outside of nest 17, with the exception of Bivalvia and to a lesser extent Megaloptera (Table 14). Sixty-nine percent of Bivalvia and 46% of Megaloptera were within the nest depression when compared to all outside areas of the nest. Recovery of macroinvertebrates taxon indicates that most taxon will be removed from the substrate when dismantling nests and recovering lamprey eggs and larvae in deployed nets (range, 77%-100%; Table 15).

Specimens were handled and placed in containers three times prior to the final cleaning and determination of invertebrates. In several instances specimens and debris had been packed tightly into jars, and crushing and dismemberment may have resulted. In other instances, it appeared that the formalin preservative had not reached all the specimens and fungal growth resulted, causing the specimens to become soft and easily fragmented. This damage was not quantified and would be attributed to nest dismantlement effects. Nonetheless, it was apparent that many organisms had been damaged as a direct result from dismantling. Some invertebrates lost a leg or cerci which may be survivable while others had had lost several legs and/or gills or had suffered crushing. This is probably not survivable damage. While no exact count of damaged specimens was kept, estimates of the percent damage for each taxon and type of damage were noted. Table 16 provides a qualitative overview of damage in groups in which more than 10 specimens were encountered. The Ephemeroptera, among the Hexapods, suffered the greatest amount of damage, loosing gills and several legs as well as being crushed (Table 16). A few genera, in particular *Potamanthus* (F. Potamanthidae), rarely suffered damage. The

genus *Ephron*, (F. Polymitarcidae) was almost always heavily damaged. Subimagos were always missing most legs and caudal filaments and were often crushed. Members of the Coleoptera experienced less damage than other groups while damage in the Trichoptera was different from genus to genus (Table 16). Diptera are a highly varied group and consequently damage differed from family to family with Chironomidae showing minimal damage while the Simulidae and some Tipulidae were more subject to crushing, in particular the genus *Antocha*. Plecoptera and Megaloptera showed low levels of damage. In the Plecoptera there is some leg and cerci loss. Occasional crushing occurred in both Plecoptera and Megaloptera, in particular the Sialidae.

Among the non-hexapod invertebrates, the Gastropoda were the most heavily damaged (Table 16). The families Physidae and Lymnaeidae were usually crushed to a degree that was probably lethal. Other gastropods and the Bivalvia experienced less damage. Small specimens of the zebra mussel were encountered in the above and below samples from nest 16. This is a new record for Lewis Creek.

A comparison of the number of taxa collected in June and July 2002 from Lewis Creek was made with the taxa collected by Langdon and Fiske (1991, 2002) between 1988 and 2002 (Appendix 11a-c). Comparisons were made to these data from this study because it served as a long-term data set for Lewis Creek and sampling targeted multiple stream habitats. Comparisons were used to identify which invertebrates occurring in Lewis Creek may be impacted from management efforts directed towards lamprey nests. However, analysis of Trichoptera indicated that many of the observed differences in taxon were likely a result of differences in seasonality of collections: spring, nest dismantling; fall, Langdon and Fiske (1991, 2002)(Appendix 11a-c).

Discussion

Malletts Creek

Confining known numbers of sea lamprey within a stream reach is a well established method to research and evaluate nesting success and potential control methods in the Great Lakes. It has been used successfully to evaluate the effectiveness of releasing sterilized male lamprey to reduce the reproductive potential of an isolated population (Hanson and Manion 1980) and to estimate egg and larval production, given a known number of adults (Manion and McClain 1971, Applegate and Smith 1950). This study attempted to repeat those efforts in Malletts Creek by evaluating whether nest dismantlement could be used to decrease spawning success and develop important survival parameters for use in the sea lamprey population viability model. Several difficulties were encountered during the study in Malletts Creek. First, the temporary barriers installed to keep lamprey confined were repeatedly washed away. Lamprey were known to have spawned above and below our study site, although a successive flood completely eroded all evidence of nesting. Secondly, a narrow window for sampling existed between the time nests were constructed and larvae hatched. Complicating the completion of this study was that river flows throughout most of June were not conducive to nest studies. Although the maximum stream discharge that allowed us to identify nests, install sampling equipment, and sample nests was above the historical average for late May and most of June – the period of most spawning activity in the Basin – only 34% of days had flows favorable for sampling. Several important objectives were unattainable because of these reasons. Perhaps most importantly was whether

eggs deposited outside of nests can survive and contribute to larval production. Results from the sea lamprey life-history model clearly indicated that the efficacy of nest dismantlement would be greatly diminished if it occurs. The Lake Champlain Basin Program issued a Request for Proposals in 2004 to evaluate out-of-nest survival. Future studies should consider a combination of controlled laboratory and field experiments because of the variable and high stream flows expected in the Basin during lamprey spawning.

Lewis Creek

Depletion methodology and validity of estimates

The primary objective of the Lewis Creek study was to determine if nest dismantlement could be used as a management tool to reduce lamprey production within a stream. Determining the percentage of eggs and larvae that can be manually disrupted from the substrate and recovered in downstream nets was an important component of this assessment. We needed to know how many eggs or larvae occurred within a nest and how many could be recovered in downstream nets. We compared known numbers of eggs and larvae recovered in nets with estimates of egg and larvae production occurring within nests derived from depletion. Unbiased depletion estimates was an important consideration for this study and their validity were contingent upon meeting the following assumptions (Lockwood and Schneider 2000):

1. *All eggs/larvae must be equally vulnerable to capture during a pass;*
2. *Emigration and immigration of eggs/larvae during sampling periods must be negligible;*
3. *Vulnerability to capture of eggs/larvae must remain constant for each pass;*
4. *Collection effort and conditions that affect collection efficiency must remain constant.*

Unbiased estimates for this study were dependent in part on each egg/larvae being equally vulnerable to capture during passes (assumption 1). This assumption was improbable for eggs and larvae within a lamprey nest given that eggs are buried in the substrate: those buried on top would be the most vulnerable to capture during the initial disruption, while those on bottom wouldn't be vulnerable until the nest had largely been destroyed. For this reason, the nest was initially dismantled with 50 raking strokes. Following this it was expected that eggs and larvae would be equally vulnerable to capture by creating a random mixture of eggs/larvae within the nest. Depletion estimates were calculated on the successive three passes following initial dismantlement. Analysis of capture probabilities indicated that most were unequal between passes (test statistic $\chi^2 \geq \chi^2_{0.95}$). It is likely these probabilities differed because of violations of one or more of the depletion methodology assumptions: assumption #1 because eggs and larvae may have been distributed more deeply in the gravels than expected, or assumption #3 because eggs and larvae immigrated into the sampled area from locations immediately adjacent to the nest depression. Further discussions of these assumptions are provided below.

Assumption 1.—Sampling indicated that a large percentage of egg/larvae production was recovered from areas outside but immediately adjacent to the nest depression and deeply within the substrate on Lewis Creek (Tables 6 and 10). It is possible that eggs and larvae were distributed widely relative to the nest depression within the gravels, or that nests 16 and 17 were superimposed on other nests. Superimposition was possible, if not probable, because a flood prior to nest sampling but during the spawn buried, scoured, or at minimum surficially destroyed

most of nests. Hundreds of lamprey were known to have spawned within the reach being studied, and few areas with suitable spawning habitat went unused. Data from nest 7 also indicated that eggs and larvae were layered deeply within the substrate (Table 10). This nest was raked with 350 strokes and it appeared that one layer of eggs was encountered during the initial dismantlement (*N*=1,053, 1 – 50 raking strokes) and a second during passes 3 and 4 (*N*=1,854, 151 through 200 strokes; and, 2,417, 201 through 250 strokes). A deep, multiple layering of eggs and larvae in Lewis Creek would undoubtedly bias the depletion estimates obtained in this study (See below, *egg and larval distributions,* for additional discussion on egg/larval distributions).

Assumption 2.—High egg and larval densities were observed in areas immediately adjacent to the nest depression (Table 5). These areas may have caused us to violate the no emigration/immigration assumption because we did not isolate areas of substrate when sampling. It's possible that eggs and larvae recruited into our sample from areas outside of the nest, especially during the latter passes of the depletion: as the number of raking strokes increased, so too did the likelihood of disturbing eggs and larvae outside of the sampled area. If densities were high outside of the nest – especially relative to numbers within – large numbers of eggs or larvae may have recruited into the latter passes of our depletion. Outside of nest sampling occurred on two nests, nests 16 and 17 (Tables 5 and 6). These nests had no apparent neighbor although they were sampled after the June flood. Egg production was three times greater to the right of the nest 16 than that observed within the nest itself. If eggs were being recruited into our sample from adjoining areas, we would have expected the probability of capture to differ among successive passes of the depletion. However, this was not the case (Table 3, Nest 16). This evidence indicates that eggs were not recruiting (immigrating) into our samples from areas outside of the nest. Sample areas were partially confined by the wings of the nest sampler and efforts were made to only disrupt those areas defined for dismantlement. These efforts may have been sufficient to prevent eggs and larvae from immigrating into our sample from surrounding substrates.

Depletion estimate validity.—It's believed that capture probabilities were different among many of the passes of the depletion estimates because the 50 initial raking strokes were insufficient to create a random mixture of eggs and larvae from which to sample (Tables 3 and 4). It is likely that eggs and larvae were deep within the substrate or layered in Lewis Creek because: 1) multiple spawning events resulted in nest superimposition, 2) the presence of deeply distributed, quality spawning substrate, 3) presence of multiple nest structures or condos (described latter), and 4) a flood event mid-way through the spawn that buried, but did not necessarily destroy lamprey production from some nests. Future studies using raking and depletion should consider using larger numbers of raking strokes during the initial dismantlement of a nest, especially if it is suspected that eggs and larvae are deeply distributed in the substrate. Unequal capture probabilities among raking passes in this study necessitated the use of MARK for calculating depletion estimates for most nests. This program allows for unequal capture probabilities during passes but associated variances and confidence intervals on estimates are large (Tables 3 and 4). Likely violation of assumption 1 make the estimates suspect.

Assessment of nest dismantlement as a management tool

Information was needed on whether lamprey production could be targeted through manual dismantlement of their nests; this study assessed a variety of objectives to determine its utility as a management tool. Key among these were: 1) can a relatively small, well-defined area be targeted to dismantle and remove lamprey production; 2) can a high percentage of eggs/larvae be removed from the stream; and, 3) what level of effort would be needed to dismantle a lamprey nest using a common, long-tined garden rake.

Egg and larvae distributions.— Sampling outside of the nest was conducted to determine the area that would be needed to effectively dismantle a lamprey nest and recover egg/larvae production from areas within and around it. Our data indicated that about one-half of the egg and larvae production occurred within the nest depression on Lewis Creek (Table 6). The area sampled for nests (0.5 m^2) was about three times larger than the average sized nest (45 cm wide x 40 cm long; Manion and Hanson 1980). Our samples included the nest depression and downstream crest or lip where most eggs were expected to be deposited (Applegate 1950). Eggs and larvae were found in large numbers upstream and downstream and to the sides of the nest. These data indicate that a large area – relative to the nest depression – would have to be targeted to destroy the majority of production occurring in and around nests in Lewis Creek. Control agents would have to target an area about 2.5 m^2 centered about the nest depression to completely remove all eggs/larvae from the nest area. The following caveats need to be noted: 1) we were unable to verify whether the collected eggs and larvae were derived from the dismantled nest or from another unidentifiable nest or egg drift from upstream nests and deposition into substrate near our study nests, and 2) sampling methodology (i.e., raking) may have influenced some egg and larval distributions observed. A large percentage of larvae were recovered from areas upstream of nests. Larvae may have been redistributed during sampling. Raking strokes were started on the downstream end of the nest depression and raked upstream. Larvae may have been moved with the substrate from the downstream to upstream end of the nest. Why larvae would be moved but not eggs is unknown.

The effects of floods on the lamprey production from nests are not well documented in the literature. Our nest counts in early June documented a large number of nests with clearly defined, crescent-shaped nest depressions (Table 2). Following the large sustained high-flow event in mid June, we saw a substantial reduction in identifiable nests (Appendices 1-4). While it was apparent that the surficial characteristics of the nests in Lewis Creek had been destroyed, it is unknown whether the flood destroyed the entire nest and its production. If control agents cannot readily identify lamprey nests and target identifiable production hotspots, the effectiveness of nest dismantling as a management tool may be limited. Future studies would be needed to determine if flows that destroy enough surficial characteristics to cause them to be unidentifiable might also destroy the eggs and larvae incubating in them.

Lamprey nests are conspicuous in streams and rivers where they spawn. Nests are constructed in water depths ranging from 13 to 170 cm and in water velocities between 0.5-1.5 m/s (Manion and Hanson 1980). Sea lamprey will move as much as 25 pounds of gravel out of the nest depression and have a downstream crest height up to 25 cm (Scott and Crossman 1998). These characteristics and their unique crescent-shaped construction make them readily identifiable in most streams in the Basin. Counts of nests have been used to estimate spawner abundance in Lake Champlain (FTC 1999), and have been routinely enumerated in streams for

scientific study throughout the Great Lakes (Hanson and Manion 1980, Manion 1968, Manion and Hanson 1980, Manion and McLain 1971). Although these studies used the number of nests to index sea lamprey spawner abundance, it becomes more important to have a complete or near complete census of nests for control purposes. Nests that go unnoticed or unidentified will not be dismantled and will likely decrease the efficacy of the method. It's believed that most lamprey nests can be identified and targeted during most years in small to mid-sized streams and rivers in the Basin (J. Gersmehl, retired biologist, USFWS, personal communication). However, nests constructed in areas not easily accessible to control agents (e.g., deep water) or where they are difficult to identify (e.g., under cover; Cochran and Gripentrog 1992) may decrease the efficacy of this method.

In ideal spawning habitat or areas with high concentrations of spawners, lamprey will build nests immediately adjacent to each other or on top of each other, resulting in nest structures called community nests or condos (Manion and McLaine 1971). Nest construction within condos can be occur so close together that individual nests loose their identity and nesting may span completely across a river (Manion and Hanson 1980). In Lewis Creek, some individual lamprey nests were indiscernible because of condo construction. Large swaths of the creek's bottom would have to be raked in these areas because specific nests could not be targeted. Although condo structures may decrease the ability of control agents to target discrete areas within a stream, the number of spawning events that can be interrupted per raking effort may be higher within condo structures than in discrete nests. This would be expected as the number of spawners increases within a condo and if their construction increases the occurrence of nest superimposition, favorable hydrological conditions for egg deposition, or an increased incidence of polygamy – perhaps brought about by a hyper concentration of sex pheromone (Li et al. 2003). The effect of condo structures on the efficacy of nest dismantlement was untested by this study.

Removal of egg and larvae production.—It is unknown whether dislodged eggs and larvae die. Because of this uncertainty, eggs/larvae would have to be collected from nests were dismantlement proposed as a management tool. This study investigated whether eggs/larvae washed from nests during dismantlement could be captured downstream. Our analysis of lost catch indicated that the nest sampling device was effective at collecting and retaining eggs and larvae swept from nests and captured in nets: 99.6% of eggs and 93.9% of larvae recovered were retained by the first net (Table 11). Data indicated, however, that eggs were captured more efficiently than larvae (Fisher's exact test, $P<0.0001$). We observed larvae escaping from the 0.505 mm mesh plankton net (i.e., protruding through the mesh) used on the cod end of our sampling device. Our secondary net – used to assess the lost catch – had 0.36 mm mesh. This sized mesh appeared small enough for capturing and retaining all lamprey larvae. It is recommended that 0.36 mm mesh be used when collecting sea lamprey larvae from nests. Ripe eggs have been found to range in size from 0.80 to 1.25 mm in diameter (Scott and Crossman 1998). The 0.505 mm mesh used in this study should be adequate for retaining sea lamprey eggs but not larvae from dismantlement.

It was important to measure the level of effort needed to dismantle nests. Nest raking would have the greatest utility as a management tool if moderate numbers of strokes were required to remove egg/larvae production from a stream. We evaluated the percent of production

removed by 50 raking-stroke increments: initial dismantlement (1-50), pass 1 (51-100), pass 2 (101-150), and pass 3 (151-200)(Figure 2). There was a significant decrease in the percent reduction between passes 1 and 2 for larvae (P=0.0443) and between passes 1 and 3 for eggs (P=0.0125)(Figure 2). Likewise, the cumulative percent removal began to level off after 100 strokes for larvae and 150 strokes for eggs (Figure 2). Our data indicated that a large number of strokes would be needed to remove egg and larvae production from a nest depression in Lewis Creek. Other researchers have found lamprey eggs distributed 7 to 15 cm deep in the substrate (Manion and Hanson 1980). The maximum substrate depth that could be disturbed with a garden rake was about 46 cm on Lewis and about 15 cm on Malletts Creek. Lewis Creek has high quality spawning gravels that extended deeply into the streambed, whereas in Malletts a clay hardpan was observed almost immediately below a thin layer of imbedded gravels. It is unknown the depth at which eggs occurred in Malletts Creek because no recognizable nests survived the spawning-period floods. Nonetheless, assuming the clay hardpan in Malletts was impermeable to eggs, eggs would have likely been distributed more deeply in Lewis Creek. This comparison indicates that egg distributions and depth of deposition likely varies among streams within the Basin. For some streams, 50 to 100 raking strokes may be sufficient to dislodged eggs and larvae from nests; on others, eggs and larvae may be deeply distributed and a substantial level of effort will be needed to dismantle lamprey nests, such as that observed in Lewis Creek. Future studies should consider evaluating the depth at which eggs occur in nests in a variety of stream habitats, substrates, stream flows, and spawning conditions. Freeze core sampling may serve as an effective means for determining these distributions (Bretschko 1990).

Our sampling device and associated raking required substantial effort. The device consisted of a 0.7-m width X 0.25-m height galvanized metal frame; 0.8-m long metal wings with attached rubber gaskets weighed to the stream bottom with chains; and, rebar pins driven into the streambed for anchoring. The principal investigator and one assistant were able to dismantle about five lamprey nests (0.5 m^2) and outside areas (2.0 m^2) per day using this method. Other collection techniques, such as those commonly used to capture aquatic insects (e.g., D-frame aquatic nets, Surber samplers, or drift nets; Merritt and Cummins 1988), may be more efficiently deployed to increase numbers of nests that can be dismantled per day. However, these techniques may not be as efficient at recovering eggs and larvae swept from nests. This was untested by this study.

The number of eggs/larvae recovered from nests was compared to the depletion estimate obtained from the nests (Table 7). The difference gave an estimate of the effectiveness of removing eggs/larvae from the nest depression. These data indicate that we were able to remove most of the eggs and larvae from a nest's substrate (eggs: mean = 81%, ± 12 and larvae: mean = 72%, ± 18) after 200 raking strokes. What affect this may have on sea lamprey population growth was not evaluated in this study. However, Table 12 summarizes the parameters investigated for inclusion in the sea lamprey life-history model. These data indicate that if only nest depressions were targeted for eggs on Lewis Creek and we used 200 raking strokes for dismantlement, we would remove about 41% of the total egg production occurring in and around nests: 0.5 (proportion of eggs targeted; Table 6) x 0.81 (efficiency of removing eggs from substrate; Tables 7 and 8) x 1.0 (efficiency of recovering eggs; Table 11). These parameters for nest raking should be considered by the Sea Lamprey Control Alternatives Workgroup to explore levels of raking effort, with the expected reductions in spawning success and modeled

effects on sea lamprey population growth.

Lewis Creek is a known large producer of sea lamprey in the Lake Champlain Basin. It has high quality spawning habitat that is easily accessible to spawning-phase sea lamprey from Lake Champlain. If nest dismantling were proposed as a management action on Lewis Creek, a large amount of effort would be needed to target lamprey production. We estimated 352 nests occurred in the study reach prior to the flood in mid June. We found that nests were easily identified in Lewis Creek and could be targeted. However, combining the number of nests with the area needed to target all the lamprey production occurring in and around a nest (2.5 m^2), indicated that 5% (765 m^2 of 15,978 m^2) of all the low-grade riffle habitat and 3% (880 m^2 and 31,658 m^2) of the entire study stream-reach in Lewis Creek would have to be raked with over 250,000 raking strokes to recover about 70% of the egg and larvae production occurring in and around lamprey nests (Table 12).

It has been estimated that only 14% of total lamprey egg production is deposited in lamprey nests (Manion and Hanson 1980); however, it is largely unknown whether fertilized eggs survive outside nests and contribute to larval production. Broadcasting eggs into the stream flow is not an uncommon life-history strategy for stream-spawning fishes within the Lake Champlain Basin. It is feasible that some lamprey eggs are deposited outside of nests and also survive. Outside of nest egg survival, if it occurs, would reduce the efficacy of management actions targeted at nests because production areas could not be targeted. The potential for substantial larval production occurring away from nests, should be investigated to determine if it occurs and its magnitude. This information is needed before managers can fully evaluate the potential for nest dismantlement as a management tool. Additionally, reductions in survival realized from nest dismantlement may be offset by an increase in survival during latter stages of larval development or shifts in demographic processes that regulate population growth called compensatory mechanisms – such as changes in sex ratio, larval growth, or age at metamorphosis. For example, the first year class of ammocoetes established after chemical treatment have been found to grow faster than those established in succeeding years (Purvis 1979); or, ammocoetes have been found to metamorphose earlier in low-density than high-density cages (Mormon 1987). The most recent work on this subject, however, has shown neither a strong or repeatable influence of density-dependent compensatory mechanisms on sea lamprey populations (Jones et al. 2003). Jones et al. (2003) suggested that density-independent factors (e.g., favorable spawning conditions leading to a banner year in recruitment) may have a greater influence on whether alternative control methods may be successful. For example, we estimated that 70 and 80% of eggs/larvae could be targeted from observed nests through dismantlement on Lewis Creek (Table 12); however, favorable survival of the remaining egg/larvae from density-independent effects may lead to occasional large year-classes. An alternative control strategy based only on nest dismantlement will not allow mangers to respond to increases in burrowing larval recruitment because the control action is taken before recruitment occurs (Jones et al. 2003). The highest likelihood of achieving effective alternative control – that is, a reduction in parasitic lamprey entering Lake Champlain – are those methods implemented in concert and targeting multiple life-history stages. With this in mind, the U.S. Fish and Wildlife Service conduct a stream-trapping control program on seven tributaries in the Lake Champlain Basin. Considerable effort is spent each spring installing traps and temporary barriers to catch and prevent lamprey from reaching their spawning grounds on these streams.

While in most years the program is successful in this effort (USFWS, unpublished data), lamprey can and do occasionally make their way around the traps. In most cases, only a few spawning pairs make it above the traps to the spawning the grounds. Since few pairs of lamprey – given their high fecundity (> 50,000 eggs/female; Manion and Hanson 1980) – may negate the control efforts of the trapping program, the Service may want to consider nest dismantlement as a management tool in these instances. This recommendation is based on: 1) the expectation that only a few nests would have to be targeted and dismantled, unlike rivers and streams with unfettered access to spawning grounds, 2) most of the streams trapped are relatively small where it's believed most nests are easily identified, 3) substantial control effort has already been expended on these streams, and 4) combined or "cumulative" alternative control strategies directed toward different life-stage stages have the greatest likelihood of success.

Non-target effects

Vertebrates.— Few Teleosti eggs and larvae were recovered from dismantled nests when compared to the numbers of sea lamprey eggs and larvae: 233 icthyoplankton and 1 juvenile smallmouth bass compared to 9,474 lamprey eggs and 19,043 larvae (Table 13). The presence of larval fish in the samples from Lewis Creek did not appear widespread (none in nests 3 and 4, and one in nest 16), although in one nest, nest 17, 225 were recovered (Table 13). Few fish or icthyoplankton were recovered from areas outside of nests 16 and 17 (Table 13). It appeared unlikely that nest raking would have dramatic impacts on the fish populations in Lewis Creek. Quality spawning habitat is widespread in Lewis Creek and it composed a large percentage of total habitat within the stream (50%, Table 1). The widespread spawning habitat may help to broadly distribute spawning activity for other fishes in Lewis Creek; however, this may not be the case for all streams and rivers within the basin. In the Poultney River, for example, all sea lamprey spawning habitat is located in a 0.8 km stream reach below Carvers Falls (Walrath and Swiney 2001). Riffle spawners, such as walleye, spawn over the same gravels where lamprey build nests. Although walleye spawn in cooler water temperatures (spawning begins at 4.4-5.5ºC, peaks at around 6.7-8.9ºC, and ends at around 11.1ºC, Scott and Crossman 1998) than lamprey (0 range: 14.0 - 22.0ºC, Manion and Hanson 1980), it is possible that lamprey begin spawning prior to the emigration of walleye fry from the spawning grounds. This overlap would be of particular concern for nest raking in the Poultney River because walleye and lamprey are concentrated into a small area of suitable habitat. It is recommended that the stream's habitat and fish assemblage be considered for potential impacts by nest raking. Site-specific studies to quantify impacts may be needed.

Macroinvertebrates.— The degree of damage to invertebrates was based on that observed in preserved specimens. These assessments indicated that only two groups suffered heavy, probably lethal damage directly from raking nests: Ephemeroptera and Gastropoda. Other groups experienced less serious damage. Observations indicated that some macroinvertebrates may have minimal bodily damage from manual nest dismantlement if they possess one or more of the following characteristics: 1) are able to release their hold on substrate, 2) can swim, 3) are small, or 4) have a tough exoskeleton, shell, case or integument. If lamprey eggs and larvae are collected from a nest following dismantlement – a recommended action given uncertainty about egg and larvae survival outside of nests – most all invertebrates collected would be killed, regardless of their physical disposition. No invertebrate group appeared decimated by raking, and it would be expected that nest raking would damage only

limited locations in the stream when compared to the short term but longitudinal and bank-to-bank effects caused by TFM (Langdon and Fiske 1991, Gilderhus and Johnson 1980, Weisser et al. 2003). Drift from upstream would be expected to repopulate the disturbed areas in a short period of time.

Among the Ephemeroptera, *Ephron* (F. Polymitarcidae), a large insect, suffered > 70% damage in the form of lost legs, gills and caudal filaments along with crushing. The genus *Potamanthus* (F. Potamanthidae), which is similar in size to *Ephron*, suffered little damage from raking. Both of these animals inhabit cavities between stones but *Ephron* constructs a tube that goes deeper into the finer sands and gravels in which it resides and filter feeds. *Potamanthus* is more active and crawls about on rock surfaces (Edmunds et al. 1976). Because of the behavioral differences, *Potamanthu*s is more likely to escape into the flow rather than be trapped within a tube as is *Ephron*. Thus *Ephron* is more likely to be crushed and otherwise damaged between the stones disturbed by raking. It also has a much softer body than *Potamanthus*. Small nymphs, like the smaller Baetidae, Siphlonuridae and Tricorythidae were marginally damaged because they apparently release their hold on the substrate and are carried by the water away from the rake-disturbed substrate. *Isonychia* (F. Oligoneuridae) are large but are also strong swimmers and may be able to avoid crushing by staying in the clear water column away from the moving stones. Members of the family Heptageniidae are flattened clingers to rocky substrate. They suffered intermediate damage, mostly loss of legs and gills with some crushing. This is possibly caused by behavior in which they cling to the rock until they are damaged, at which time they release their grip and drift.

Members of the Coleoptera suffered less damage than did other orders. The larvae and adults of Elmidae are small and have very tough exoskeletons. They suffered little damage. Psephenidae larvae are flattened, not very hard, and cling tightly to stones. Not surprisingly, they sustained more crushing damage for reasons similar to the Heptageniidae mayflies, described above, than do the Elmidae. The Gyrinidae are larger (about 1 cm) and fairly soft bodied and suffered some crushing damage.

Trichoptera vary from family to family and often from genus to genus within a family. *Neophylax* (F. Uenoidae), *Psilotreta* (F. Odontoceridae), *Oecetis* and *Ceracl*ea (F. Leptoceridae) all have sturdy cases made of coarse sand and fine gravel so are not often damaged by raking. The Hydropsychids all build filter nets with attached fine gravel retreats in which the larva reside when not feeding from the net. They hang on to the retreat or net when the stones between which the net is laid are moved leading to some crushing injuries. The Helicopsychids suffer crushing because of the high profile of their fine sand grain snail-shell shaped case. The Hydroptilidae escape damage because of their small size which allows the flow to pick them up and transport them out of the area of disturbance (Wiggins 1996, Merritt and Cummins 1988).

Diptera are a highly heterogeneous group of varying sizes and shapes, and habitat needs. The Chironomidae are the most plentiful and the smallest dipterans. The larvae are either free living or reside in silk and silt tubes in the finer substrates and on rock surfaces. However, they escaped most crushing because of their small size. The Ceratopogonidae are also small and likewise escape damage. The Tipulidae tend to have very tough, flexible larval integument and are free roaming so appear to escape crushing, with the exception of *Antocha* which has a less

tough integument and may hang on to stones as they are disturbed resulting in a relatively high (20%) crush rates. The Simulidae are soft bodied and attached to the substrate and also experienced relatively high (20%) crushing.

Plecoptera (F. Perlidae) and Corydalidae (O. Megaloptera) are not affected much by raking. The Plecoptera are sturdily constructed and may release their grip on the substrate when disturbed while the Corydalidae have a very tough, flexible integument. The Sialidae (O. Megaloptera) are smaller and not as well adapted for larger, high-flow streams. They live in organic detritus stuck between stones and their integument is thin and more subject to damage than that of the Corydalidae. They may retain their hold on disturbed substrates resulting in more crushing damage.

The Mollusca, (Class Gastropoda) particularly the families Physidae and the Lymnaeidae are heavily damaged by crushing (> 80%). They have thin, globose shells and tend to remain attached to stones when disturbed and are easily crushed. The Bithyniidae and Planorbidae have heavier shells which appeared to resist crushing better. Their behavior may also be helpful. The Cl. Bivalvia either have very hard shells, are small or both thus rendering them fairly safe from crushing at about 10%. Small Dreissnidae appear to be highly resistant to damage.

Management Implications

- Eggs were not adhered to the substrate and could be suspended into the water column via raking.

- There was a substantial reduction in identifiable sea lamprey nests on Lewis Creek following a large sustained flow event. If control agents cannot readily identify lamprey nests and target identifiable production hotspots, the effectiveness of nest dismantlement may be limited, at least under some conditions.

- Because the fate of dislodged eggs and larvae was not investigated and remains unknown, it is recommended that nest dismantlement include the collection and destruction of eggs and larvae. This study found that of the lamprey production swept from nests and recovered in downstream nets, 99.6% of eggs and 93.9% of larvae were retained by the first net.

- Data suggested that eggs were more effectively collected than larvae because they were able to escape the 0.505 mm plankton mesh used in this study. Plankton mesh 0.36 mm appeared sufficiently small to capture, collect, and retain lamprey from dismantled nests. The device used to collect eggs and larvae washed from a nest in this study required substantial labor to deploy. Collection methods commonly used to capture aquatic insects (e.g., D-frame aquatic nets or drift nets) may be effective alternatives. These devices were untested in this study however.

- Unequal capture probabilities among raking passes in this study necessitated the use of MARK for calculating depletion estimates for most nests. This program allows for unequal probabilities but associated variances and confidence intervals on estimates are large. Likely violation of one or more depletion assumptions make the estimates suspect.

• Considerable raking effort was needed to suspend and wash eggs and larvae from the substrate in Lewis Creek. Analysis of raking effort needed suggests that 150 vigorous raking strokes would be needed to recover about 70% of eggs and larvae occurring within a nest depression. Egg distributions and depth of deposition likely varies among streams within the Basin. For some streams, 50 to 100 raking strokes may be sufficient to dislodged eggs and larvae from nests; on others, eggs and larvae may be more deeply distributed and a substantial level of effort will be needed to dismantle lamprey nests, such as that observed on Lewis Creek.

• Limited sampling within and outside of nests indicated that lamprey eggs and larvae may be distributed widely. Our data indicated that approximately 50% of eggs/larvae production would be targeted if only those areas within the nest depression (about 0.5 m^2) were targeted. These data indicate that a larger area (2.5m^2) – relative to the nest depression – should be targeted to eliminate the majority of lamprey production occurring in and around nests on Lewis Creek.

• Results from this study indicate that 3% (880 m^2) of the entire study stream reach in Lewis Creek would have to be raked with over 250,000 raking strokes to recover about 75% of the eggs and larvae produced in and around lamprey nests (N=352) in 2002.

• In Lewis Creek, some individual lamprey nests were indiscernible because of "condo" construction. Large swaths of the creek would have had to be raked because specific nests could not be targeted. Although condo structures may decrease the ability of control agents to target discrete areas within a stream, the number of spawning events that can be interrupted per raking effort may be higher within a condo structure than discrete nests. This would be expected as the number of spawners increases within a condo and if their construction increases the occurrence of nest superimposition, favorable hydrological conditions for egg deposition, or an increased incidence of polygamy – perhaps brought about by a hyper concentration of sex pheromone (Li et al. 2003). The effect of condo structures on the efficacy of nest dismantlement was untested by this study.

• It's believed that most lamprey nests can be identified and targeted during most years in small to mid-sized streams and rivers in the Basin (J. Gersmehl, retired biologist, USFWS, personal communication). However, nests constructed in areas not easily accessible to control agents (e.g., deep water) or in areas where they are difficult to identify (e.g., under cover; Cochran and Gripentrog 1992) may decrease the efficacy of this method.

• Assessments of physical damage to invertebrates from raking nests indicated that only two groups suffered heavy, probably lethal damage directly from nest dismantlement. These were the Ephemeroptera and Gastropoda. Other groups experienced less serious damage. Observations indicated that some macroinvertebrates may have minimal bodily damage from manual nest dismantlement if they possess one or more of the following characteristics: 1) are able to release their hold on substrate, 2) can swim, 3) are small, or 4) have a tough exoskeleton, shell, case or integument. However, if eggs and larvae are collected from nest dismantlement – a recommended action given we don't know if egg and larvae survive after being washed from a nest – most all invertebrates would be destroyed, regardless of their physical disposition following nest dismantlement.

• No invertebrate group appeared decimated by raking. It would be expected that nest raking would damage only limited locations in the stream when compared to the short term but longitudinal and bank-to-bank effects caused by TFM (Langdon and Fiske 1991, Gilderhus and Johnson 1980, Weisser et al. 2003). Drift from upstream would be expected to repopulate the disturbed areas in a short period of time.

• The U.S. Fish and Wildlife Service may want to consider dismantling lamprey nests to reduce egg/larvae production from a small number of nests resulting from lamprey passing their temporary barriers and spring trapping sets. This recommendation is based on the premise that most spawning-phase lamprey are removed or blocked from reaching their spawning grounds by this program and that few nests would have to be targeted, when compared to rivers with unfettered access by sea lamprey. A review of the literature found that combined alternative control methods implemented in concert and targeting multiple life-history stages have a higher likelihood of achieving effective control.

• Additional experimental application of nest dismantlement within the Basin should be based upon: 1) whether eggs deposited outside of lamprey nests survive and contribute to parasitic production, 2) the likelihood of nest dismantlement to affect sea lamprey population growth as determined by the life-history model, 3) its integration into a suite of alternative control methods targeting multiple life stages, 4) its application in small to mid-sized streams where nests can be found and their numbers managed, and 5) where stream-specific evaluations suggest minimal non-target impacts.

Suggested Future Studies

• Parameter estimates for management actions targeted at sea lamprey egg and larval survival through nest dismantlement were provided. Population sensitivity and elasticity analyses should be conducted with the life-history model to determine what effect, if any, nest raking might have on population growth of sea lamprey.

• Outside of nest egg survival – whether it occurs and if so its magnitude – needs to be known before managers and researchers can fully assess management actions targeting nest production. The Lake Champlain Basin Program issued a Request for Proposals in 2004 to evaluate this survival parameter for the sea lamprey life-history model.

• Determine if flows that destroy enough surficial characteristics to cause them unidentifiable might also destroy the eggs and larvae incubating in them.

• Evaluate the depth at which eggs occur in nests in a variety of streams, substrates, stream habitats and flows, and spawning conditions.

• Determine the effect of community nests on the efficacy of nest dismantlement.

• Future studies should consider a combination of controlled laboratory and field experiments because of the variable and high stream flows expected in the Lake Champlain Basin during lamprey spawning.

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Table 1.—Macro habitat distribution and quantity from the Route 7 Bridge upstream to North Ferrisburg Bridge. Low-grade and high-grade riffles were denoted by LG-R and HG-R, respectively.

Distance (meters)	Area (square meters) by macro habitat type			
	LG-R	HG-R	Run	Pool
223		3746		
243			160	
347	1903			
513				2789
638			1900	
682				568
704	937			
803	1505			
817			147	
923	933			
1044			1900	
1095	801			
1064				310
1091	500			
1145		632		
1165				220
1197	416			
1230	264			
1360	1508			
1600	5136			
1707	2076			
1752				603
1915		2706		
Total	15979	7084	4107	4490
% of total	50	22	13	14

Table 2.—Distribution and number of sea lamprey nests on Lewis Creek from the Route 7 Bridge upstream to North Ferrisburg Bridge, 10 June 2002. Low-grade and high-grade riffles were denoted by LG-R and HG-R, respectively.

Distance (meters)	Number of lamprey nests	Number of lamprey nests by habitat type			
		LG-R	HG-R	Run	Pool
223	13		13		
243	0				
347	39	39			
513	0				
638	14			14	
682	2				2
704	18	18			
803	33	33			
817	0				
923	39	39			
1044	0				
1095	6	6			
1064	4				4
1091	11	11			
1145	2		2		
1165	0				
1197	17	17			
1230	6	6			
1360	39	39			
1600	48	48			
1707	50	50			
1752	0				
1915	11		11		
Total	352	306	26	14	6
% of total		87	7	4	2

Table 3.— Number of lamprey eggs collected (6/7/02 – 7/2/02) from sea lamprey nests dismantled in Lewis Creek, Vermont.

Nest	Date	Initial Dismantlement	Pass 1	Pass 2	Pass 3	Unequal catch probabilities	Lower 95%	Estimate	Upper 95%
2	6/07/02	182	3,375	7,046	2,101	Yes	[a]	19,012	[a]
3	6/19/02	515	461	347	64	Yes	1,388	1,765	284,619
4	6/20/02	5,076	336	1,186	346	Yes	6,946	8,322	997,745
5	6/20/02	48	0	4	3	Yes	[a]	76	[a]
6	6/20/02	84	31	14	8	No	135	141	147
7	6/20/02	1,053	76	136	1,854	Yes	3,139	15,088	7,243,277
8	6/21/02	312	117	21	61	Yes	511	577	117,372
9	6/21/02	226	486	124	164	Yes	1,001	1,693	621,537
10	6/21/02	3,637	33	6	10	Yes	[a]	3,730	[a]
11	6/21/02	5,336	4,820	0	211	Yes	[a]	11,707	[a]
12									
13	6/26/02	330	863	103	19	No	1,314	1,317	1,320
14	6/26/02	1,072	548	1,312	7	Yes	2,940	3,813	1,285,767
15	6/26/02	0	1	0	0	No	1	1	1
16	7/02/02	6	592	176	58	No	842	854	866
17	7/02/02	70	80	96	65	Yes	311	407	109,137
Mean		1,196	788	705	331			3,864	

[a] calculated standard error through MARK was 0 for estimate.

Table 4.— Number of lamprey larvae collected (6/7/02 – 7/2/02) from sea lamprey nests dismantled in Lewis Creek, Vermont.

Nest	Date	Initial Dismantlement	Pass 1	Pass 2	Pass 3	Unequal catch probabilities	Lower 95%	Estimate	Upper 95%
2	6/07/02	0	3	0	9	Yes	12	66	148,077
3	6/19/02	3,564	2,089	206	273	Yes	6,136	8,198	1,174,872
4	6/20/02	6,626	708	1,394	1,610	Yes	[a]	12,582	[a]
5	6/20/02	8	0	1	0	No	9	9	9
6	6/20/02	0	3	0	0	No	3	3	3
7	6/20/02	2	1	2	0	No	5	5	5
8	6/21/02	38	8	0	5	Yes	51	71	55,216
9	6/21/02	10	162	12	42	Yes	226	349	168,506
10	6/21/02	513	14	2	5	Yes	534	538	11,101
11	6/21/02	0	34	0	1	Yes	[a]	57	[a]
12									
13	6/26/02	753	4	243	21	Yes	1,055	22,312	13,403,474
14	6/26/02	8,072	4,072	5,644	1,053	Yes	[a]	22,483	[a]
15	6/26/02	0	0	0	0	No		0	
16	7/02/02	30	1,998	343	189	Yes	2,561	3,488	623,034
17	7/02/02	7	5	1	0	No	13	13	13
Mean		1,308	607	523	214			3,130	

[a] calculated standard error through MARK was 0 for estimate.

Table 5.—Sampling outside of nests to determine magnitude of eggs and larvae occurring adjacent to lamprey nests.

Location	Rep 1	Rep 2	95% Lower Est.	Estimate	95% Upper Est.
			Nest 16		
			Eggs		
Up [a]	2	5		7	
Down	67	31	93	125	156
Right	2,682	0	2,682	2,682	2,682
			Larvae		
Up [a]	367	664		1,031	
Down	5	0	5	5	5
Right	1,841	0	1841	1,841	1,841
			Nest 17		
			Eggs		
Up	2	0	0	2	0
Down	82	7	88	90	92
Right [a]	0	32		32	
Left	0	0		0	
			Larvae		
Up	0	0		0	
Down	0	0		0	
Right	7	0		7	
Left	0	0		0	

[a] Catch during the second pass exceeded catch from the first pass. Sum of catch was assumed to be the estimate

Table 6.—Numbers of eggs and larvae and percent of total for samples in and areas adjacent to lamprey nests in Lewis Creek, Vermont.

Nest	Within: $0.5m^2$ No.(% of total)	Up: $0.5m^2$ No.(% of total)	Down: $0.5m^2$ No.(% of total)	Right: $0.5m^2$ No.(% of total)	Left: $0.5m^2$ No.(% of total)	Total: $2.5m^2$ No.
			Eggs			
16	854 (23)	7 (0)	125 (3)	2,682 (73)	-	3,668
17	407 (77)	2 (0)	90 (17)	32 (6)	0 (0)	531
mean	(50.0)	(0.3)	(10.2)	(39.6)	0	
			Larvae			
16	3,488 (55)	1,031 (16)	5 (0)	1,841 (29)	-	6,365
17	13 (65)	7 (35)	0 (0)	0 (0)	0 (0)	20
mean	(59.9)	(25.6)	(0)	(14.5)	0	

Table 7.—Percent efficiency of recovering eggs and larvae from dismantled sea lamprey nests in Lewis Creek, Vermont.

Nest	Estimated production	Number captured	Percent Efficiency [a]
	Eggs		
2	19,012	12,704	67
3	1,765	1,387	79
4	8,322	6,944	83
5	76	55	72
6	141	137	97
7	15,088	3,119	21
8	577	511	89
9	1,693	1,000	59
10	3,730	3,686	99
11	11,707	10,367	89
12			
13	1,317	1,315	100
14	3,813	2,939	77
15	1	1	100
16	854	832	97
17	407	311	76
Mean ∀ 95% CI			81 ∀ 12
	Larvae		
2	66	12	18
3	8,198	6,132	75
4	12,582	10,338	82
5	9	9	100
6	3	3	100
7	5	5	100
8	71	51	72
9	349	226	65
10	538	534	99
11	57	35	61
12			
13	22,312	1,021	5
14	22,483	18,841	84
15	0	0	
16	3,488	2,560	73
17	13	13	100
Mean ∀ 95% CI			72 ∀ 18

[a] Percent efficiency = (Number captured)/(Estimated production)

Table 8.—Cumulative percent of eggs collected from sea lamprey nests by number of raking strokes from a common garden rake in Lewis Creek, Vermont. ∀ 95% confidence intervals reported about the mean cumulative percent recovery of eggs.

Nest	**Initial Dismantlement** 50 raking strokes **Cum. percent**	**Pass 1** 100 raking strokes **Cum. percent**	**Pass 2** 150 raking strokes **Cum. percent**	**Pass 3** 200 raking strokes **Cum. percent**
2	1.0	18.7	55.8	66.8
3	29.2	55.3	75.0	78.6
4	61.0	65.0	79.3	83.4
5	63.2	63.2	68.4	72.4
6	59.6	81.6	91.5	97.2
7	7.0	7.5	8.4	20.7
8	54.1	74.4	78.0	88.6
9	13.3	42.1	49.4	59.1
10	97.5	98.4	98.6	98.8
11	45.6	86.8	86.8	88.6
12				
13	25.1	90.6	98.4	99.8
14	28.1	42.5	76.9	77.1
15	0.0	100.0	100.0	100.0
16	0.7	70.0	90.6	97.4
17	17.2	36.9	60.4	76.4
Mean	34.0 ∀ 16.1	62.7 ∀ 15.5	75.3 ∀ 13.2	81.3 ∀ 11.8

Table 9.—Cumulative percent of larvae collected from sea lamprey nests by number of raking strokes from a common garden rake in Lewis Creek, Vermont. ∀ 95% confidence intervals reported about the mean cumulative percent recovery of larvae.

Nest	**Initial Dismantlement** 50 raking strokes **Cum. percent**	**Pass 1** 100 raking strokes **Cum. percent**	**Pass 2** 150 raking strokes **Cum. percent**	**Pass 3** 200 raking strokes **Cum. percent**
2	0.0	4.5	4.5	18.2
3	43.5	69.0	71.5	74.8
4	52.7	58.3	69.4	82.2
5	88.9	88.9	100.0	100.0
6	0.0	100.0	100.0	100.0
7	40.0	60.0	100.0	100.0
8	53.5	64.8	64.8	71.8
9	2.9	49.3	52.7	64.8
10	95.4	98.0	98.3	99.3
11	0.0	59.6	59.6	61.4
12				
13	3.4	3.4	4.5	4.6
14	35.9	54.0	79.1	83.8
15				
16	0.9	58.1	68.0	73.4
17	53.8	92.3	100.0	100.0
Mean	32.9 ∀ 19.8	60.7 ∀ 17.9	68.6 ∀ 19.6	72.1 ∀ 17.7

Table 10.—Comparison of 7- and 3-pass Huggin's depletion estimates on nest 7, Lewis Creek, Vermont.

Nest 7	Initial	Pass 1	Pass 2	Pass 3	Pass 4	Pass 5	Pass 6	Pass 7	Lower N	N	Upper N
						Eggs					
7 reps	1,053	76	136	1,854	2,417	683	398	280	6,900	7,996	469,614
3 reps	1,053	76	136	1,854	-	-	-	-	3,139	15,088	7,243,277
						Larvae					
7 reps	2	1	2	0	4	3	3	1	17	17	17
3 reps	2	1	2	0	-	-	-	-	5	5	5

Table 11.—Estimated lost catch of egg and larvae production from three nests in Lewis Creek, Vermont. The nest sampling device retained on average 99.5% of eggs and 93.4% of larvae swept from nests and recovered in deployed nets.

Nest	No. collected [a]	Est. production	Lost catch	% lost [c]
		Eggs		
13	1,315	1,317	4	0.3
14	2,939	3,813	31	1.0
15	1	1	0	0.0
Mean				0.4
		Larvae		
13	1,021	22,312	33	3.1
14	18,841	21,583	1,881	9.1
15	0	0	0	-
Mean				6.1

[a] Number of eggs and larvae collected in the net immediately downstream from the nest.
[b] Number of eggs and larvae collected in the secondary downstream net.
[c] % lost = (Lost catch) / ((No. collected)+(Lost catch))

Table 12.—Parameters to be used in the sea lamprey stage-based life-history model to evaluate the effects of nest dismantling on sea lamprey population growth. Parameters plus measures of variability (95% confidence intervals or range) provided. To determine the proportion of nest production removed from the substrate around a nest, we estimate from the product of: (Area targeted) x (Raking effort) x (% recovered). For example, 40% of larvae would be estimated to be removed from a nest if: 1) raking were to target only the nest depression (0.60), 2) 150 raking strokes were used to dismantle the nest (0.69), and 3) we account for proportion of larvae retained once swept from a nest (0.94).

Area targeted		Raking effort (No. strokes) [c]				Proportion recovered [d]
Nest [a]	Nest + adjacent areas [b]	50	100	150	200	
Proportion egg production targeted		Efficiency of raking substrate to remove eggs				
0.50	1.00	0.34	0.63	0.75	0.81	1.0
range: 0.23 – 0.77		CI ∀ 0.16	CI ∀ 0.16	CI ∀ 0.13	CI ∀ 0.12	range: 1.0 – 0.99
Proportion larvae production targeted		Efficiency of raking substrate to remove larvae				
0.60	1.00	0.33	0.61	0.69	0.72	0.94
range: 0.55 – 0.65		CI ∀ 0.20	CI ∀ 0.18	CI ∀ 0.20	CI ∀ 0.18	range: 0.97 – 0.91

[a] Data obtained from Tables 5 and 6.

[b] It is assumed that100% of a nest's production would be targeted if 2.5 m^2 of substrate were targeted in and around a nest (i.e., nest depression, upstream, downstream, right, and left sides).

[c] Data obtained from Tables 7, 8 and 9. It was assumed that the efficiency of recovering eggs from the substrate of a nest depression was the same efficiency for recovering eggs from the substrate outside of a nest.

[d] Percent recovery of eggs and larvae retained by deployed nets downstream from nests. Data obtained from Table 11.

Table 13.—Numbers of vertebrate non-target organisms collected in Lewis Creek during dismantlement of nests 3, 4, 16 and 17.

Nest	In-nest	Outside	Species
3	0	-	-
4	0	-	-
16	1	1	2 Teleostei larvae
17	225	6	230 Teleostei larvae, 1 smallmouth bass *Micropterus dolomieui*

Table 14.— Numbers collected and estimated number (± 2 × standard error) of invertebrates located within and outside of Nest 17 on Lewis Creek, Vermont.

Order	Downstream 0.5 m^2	Upstream 0.5 m^2	Right 0.5 m^2	Left 0.5 m^2	Within Nest Depression 0.5 m^2		Total 2.5 m^2
					No.	% of Total	
Trichoptera	249 (∀22)	124	134 (∀17)	1,111 (∀3,105)	299 (∀29)	16	1,917
Ephemeroptera	548 (∀7)	548 (∀78)	360 (∀67)	699 (∀54)	830 (∀21)	28	2,985
Coleoptera	296 (∀11)	209	651 (∀1,125)	452 (∀218)	428 (∀30)	21	2,036
Diptera	338 (∀10)	1,133 (∀186)	785 (∀552)	783 (∀161)	905 (∀28)	23	3,944
Plecoptera	18 (∀38)	2	33 (∀29)	8	14 (∀2)	19	75
Odonata	0 (∀0)	0 (∀0)	0 (∀0)	1 (∀0)	0 (∀0)	0	1
Annelida	70 (∀1)	188 (∀6)	45	400 (∀4,746)	146 (∀2)	17	849
Bivalvia	1 (∀0)	5 (∀2)	2 (∀0)	3	25 (∀1)	69	36
Gastropoda	1 (∀0)	3 (∀0)	1 (∀0)	1	2 (∀0)	25	8
Arachnida	5 (∀3)	4 (∀7)	2 (∀0)	6 (∀2)	8 (∀0)	32	25
Megaloptera	6 (∀0)	1	6	0	11 (∀0)	46	24
Nematoda	17 (∀8)	21 (∀4)	1	7	8 (∀0)	15	54
Platyhelminthes	7 (∀1)	4	5 (∀3)	7 (∀1)	3 (∀0)	12	26

Table 15.—Mean number of invertebrates located within the nest depression for nests 3, 4, 16 and 17 on Lewis Creek and mean % captured after nest dismantlement. Percent captured was estimated from: (number captured) ÷ (estimated no. in nest) [a].

Order	Mean no. in nest (range)	Mean % captured (range)
Trichoptera	652 (267 – 1,020)	77 (67-87)
Ephemeroptera	809 (276-1,112)	86 (78-91)
Coleoptera	1,219 (427-1,966)	84 (77-94)
Diptera	1,418 (622-3,027)	93 (90-98)
Plecoptera	36 (17-53)	79 (64-100)
Odonata	4 (0-9)	76 (67-84)
Annelida	50 (10-146)	87 (70-100)
Bivalvia	162 (25-513)	95 (87-100)
Gastropoda	13 (2-31)	98 (90-100)
Arachnida	15 (8-25)	96 (84-100)
Megaloptera	3 (0-11)	100 (100)
Nematoda	15 (8-28)	90 (71-100)
Platyhelminthes	12 (3-30)	92 (67-100)

[a] Data obtained from Appendices 7, 8, 9 and 10.

Table 16.—Damage to macroinvertebrates caused by raking [a]

Taxon	Damage type and frequency
DIPTERA	**Chironomidae, Ceratopogonidae:** crushing < 2%. Small, tough integument, rock niche and finest sand and silk tube occupiers.
	Tipulidae: crushing < 5%. Tough integument except for *Antocha* with crushing ~ 20%.
Athericidae	***Atherix:*** ~ 10 % crushed.
Simulidae	soft body, ~20 % crushed.
Tabanidae	No damage. Very tough, flexible integument.
TRICHOPTERA	**Bachycentridae, *Brachycentrus* sp.: < 5% crushing, sturdy cases**
Helicopsychidae	***Helicopsyche* sp.*;*** ~ 20% crushing, most cases contained soft late pupae, preservation a problem.
Hydropsychidae	***Hydropsyche* and *Cheumatopsyche* sp.:** :< 20% crushing
Uenoidae	***Neophylax* sp.:** no crushing, very sturdy case.
Leptoceridae	***Ceraclea:*** < 10% crushing, delicate fine sand grain case.
	Oecetis: little damage, sturdy coarse sand grain case
	Setodes: little damage, sturdy coarse sand grain case.
Hydroptilidae	***Ochrotrichia, Hydroptila, Ithytrichia:*** avoid crushing due to small size.
Odontoceridae	***Psilotreta*** has a sturdy case of coarse sand grains, little damage.
COLEOPTERA	**Elmidae:** < 5% crushing in all genera of adults and larvae due to small size and sturdy exoskeleton.
	Psephenidae: ~ 20% crushing due to soft body and large surface area
	Gyrinidae, *Dineutes:* ~ 10% crushing, larger larvae seem more susceptible.
EPHEMEROPTERA	All families and genera suffer leg, gill, and cerci loss with the exception of very small specimens of **Baetidae, Siphlonuridae** and **Tricorythidae. Potamanthidae, *Potamanthus***, though large rarely showed damage while **Polymitarcidae, *Ephron*** was usually badly damaged showing > 70% damage due to very soft body.
PLECOPTERA	**Perlidae:** all genera, most had cerci missing and an occasional leg, < 5% crushing.
MEGALOPTERA	**Corydalidae, *Nigronia* sp.:** Little damage, tough integument
	Sialidae, *Sialis* sp.; ~ 10% crushing.
MOLLUSCA	**Gastropoda:** severe shell crushing > 80%, especially in **Physidae** and **Lymnaeidae.** Most have some shell damage.
	Bivalvia: ~ 10% with some shell damage.
ANNELIDA	**Oligochaeta:** ~ 10% crushing, high regenerative powers.
	Hirudinea: no damage, tough integument.
NEMATODA	No damage.
PLATYHELMINTHES	**Tricladida:** 20-30% crushing, High regenerative powers.

[a] Groups with fewer than 10 specimens not included.

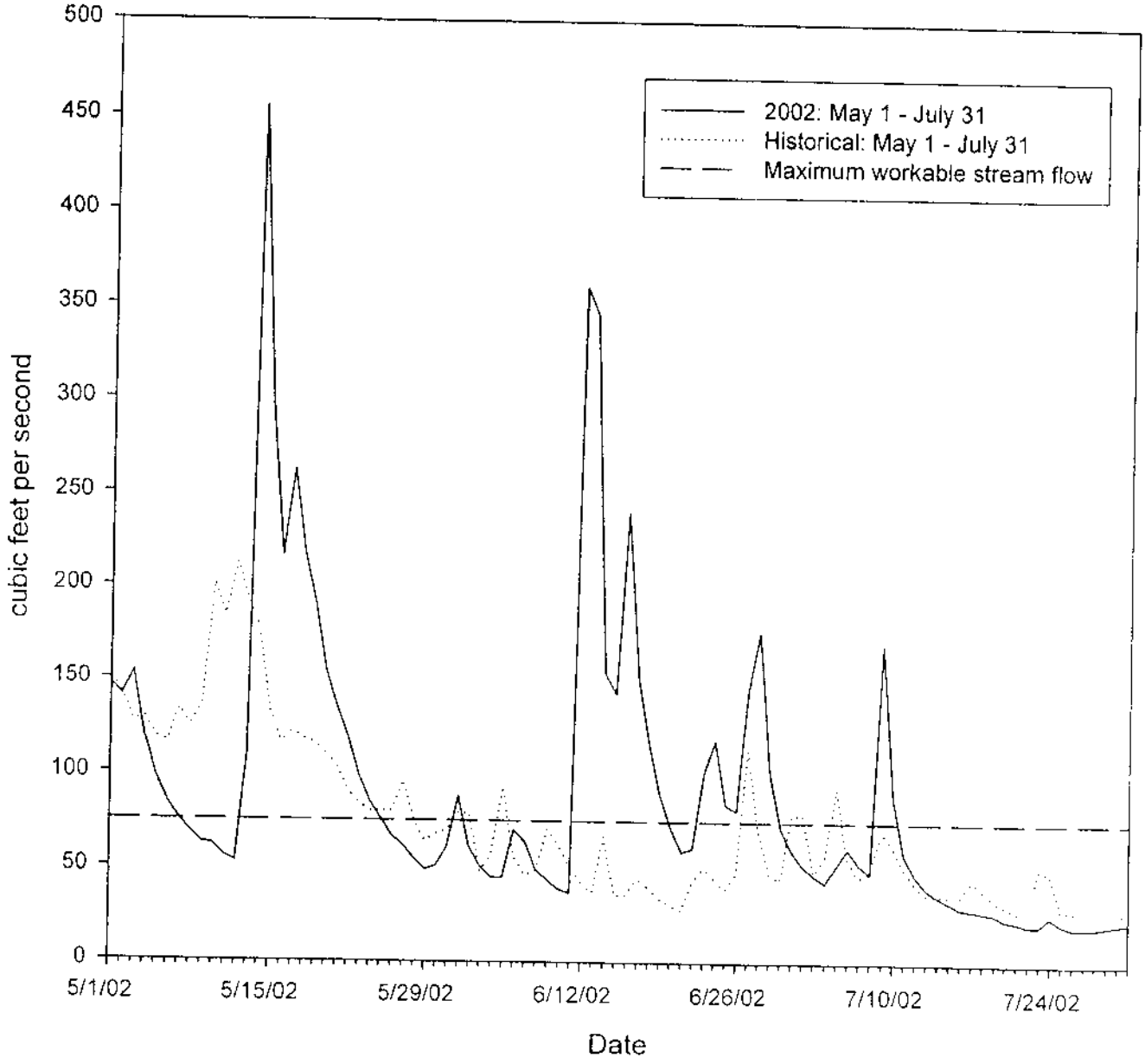


Figure 1.--Daily stream flows during the 2002 sea lamprey spawning period in Lewis Creek. Broken line denotes mean of daily mean discharge for the 13 years of record. Dashed horizontal line denotes workable stream flows in Lewis Creek (i.e., 75 cfs). Stream flows obtained from the Lewis Creek, North Ferrisburg, VT USGS guaging station.

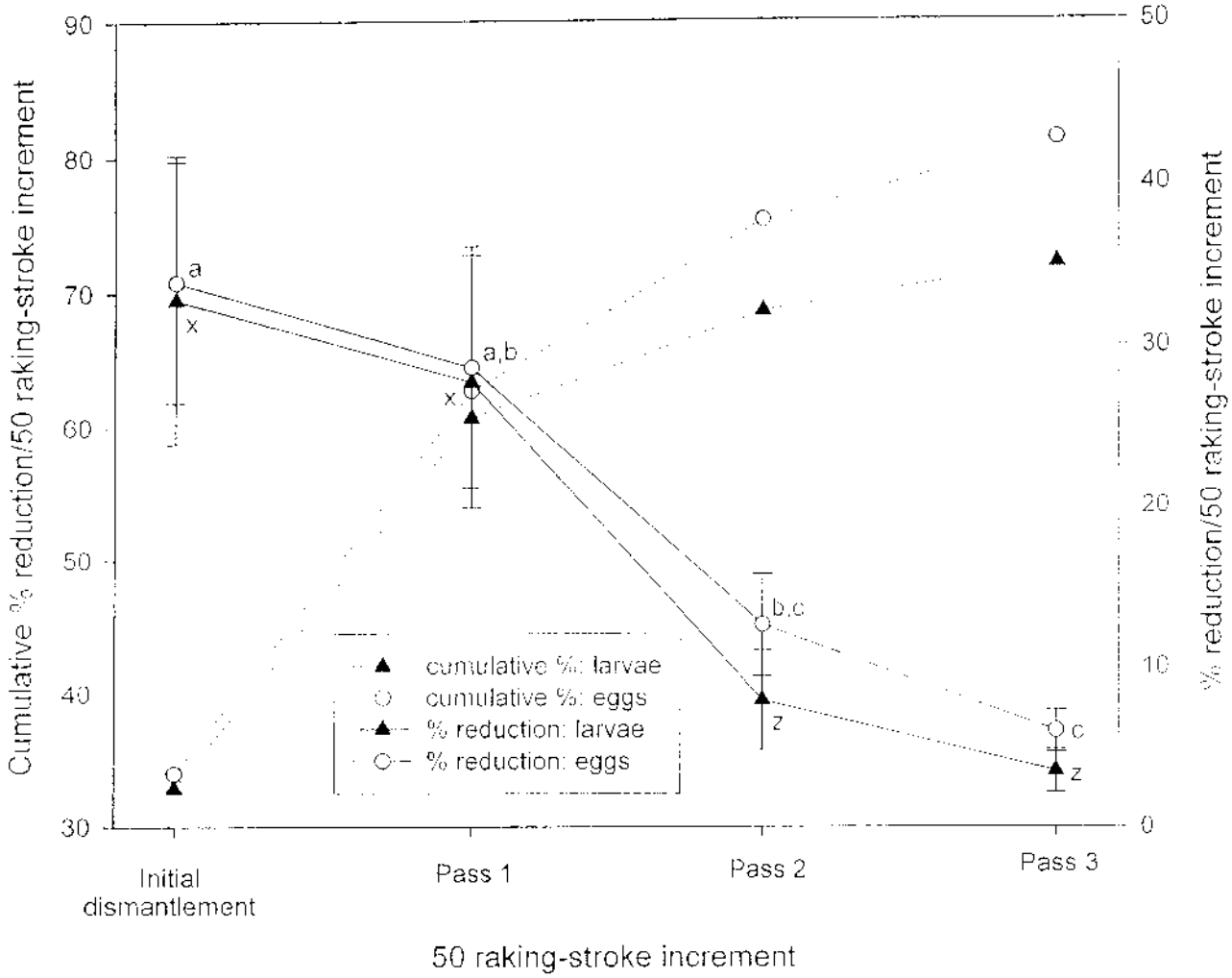
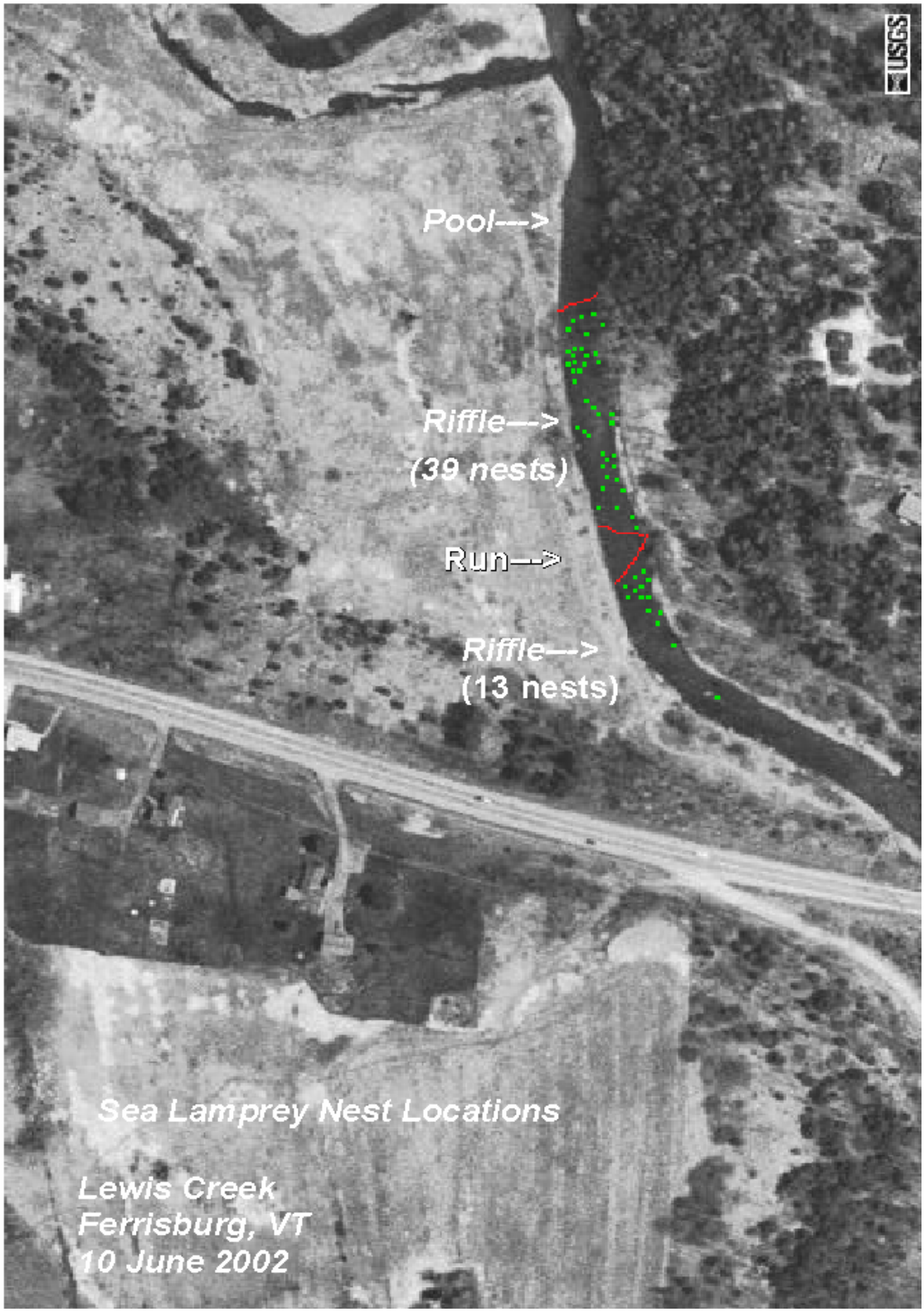
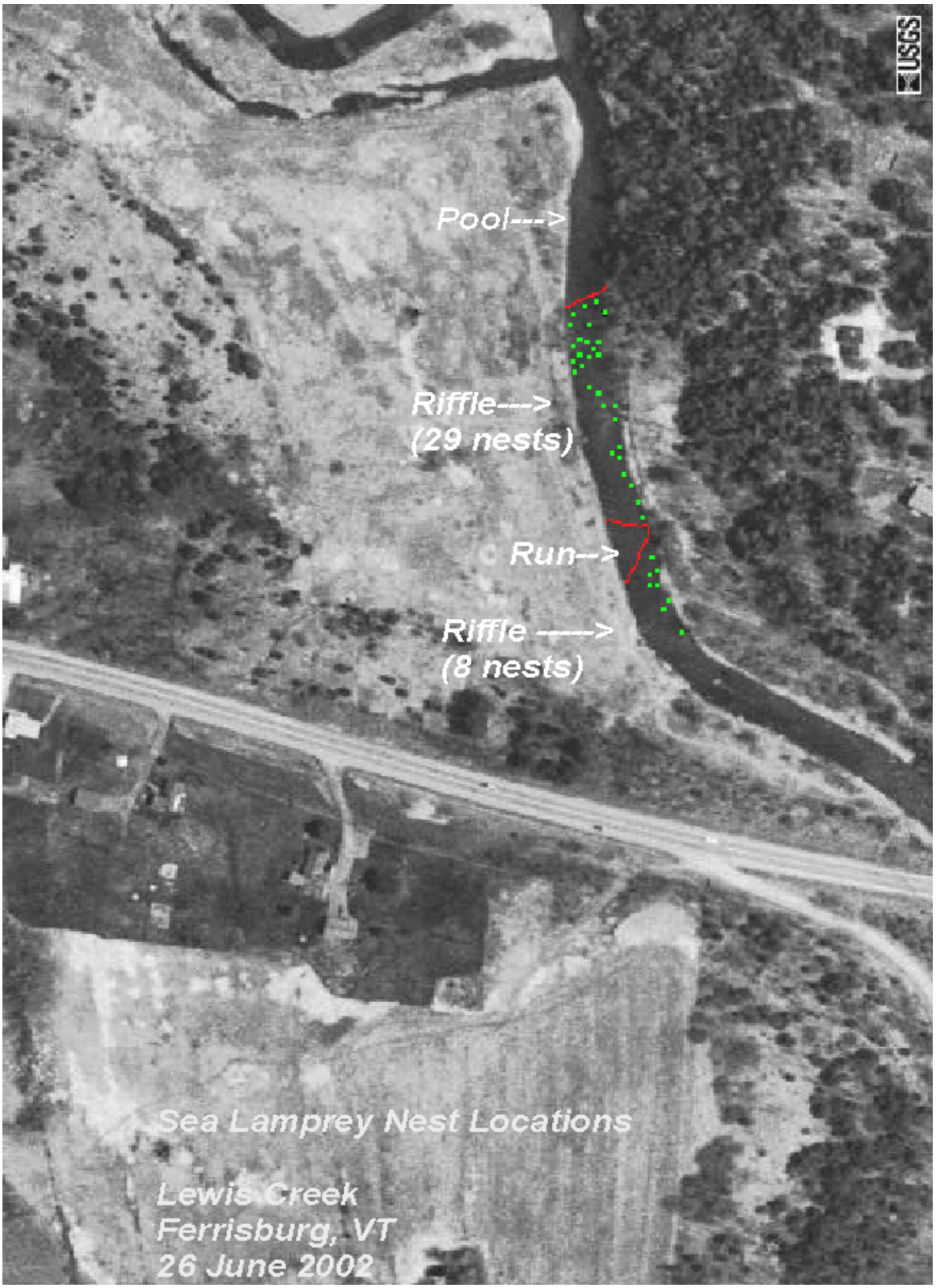


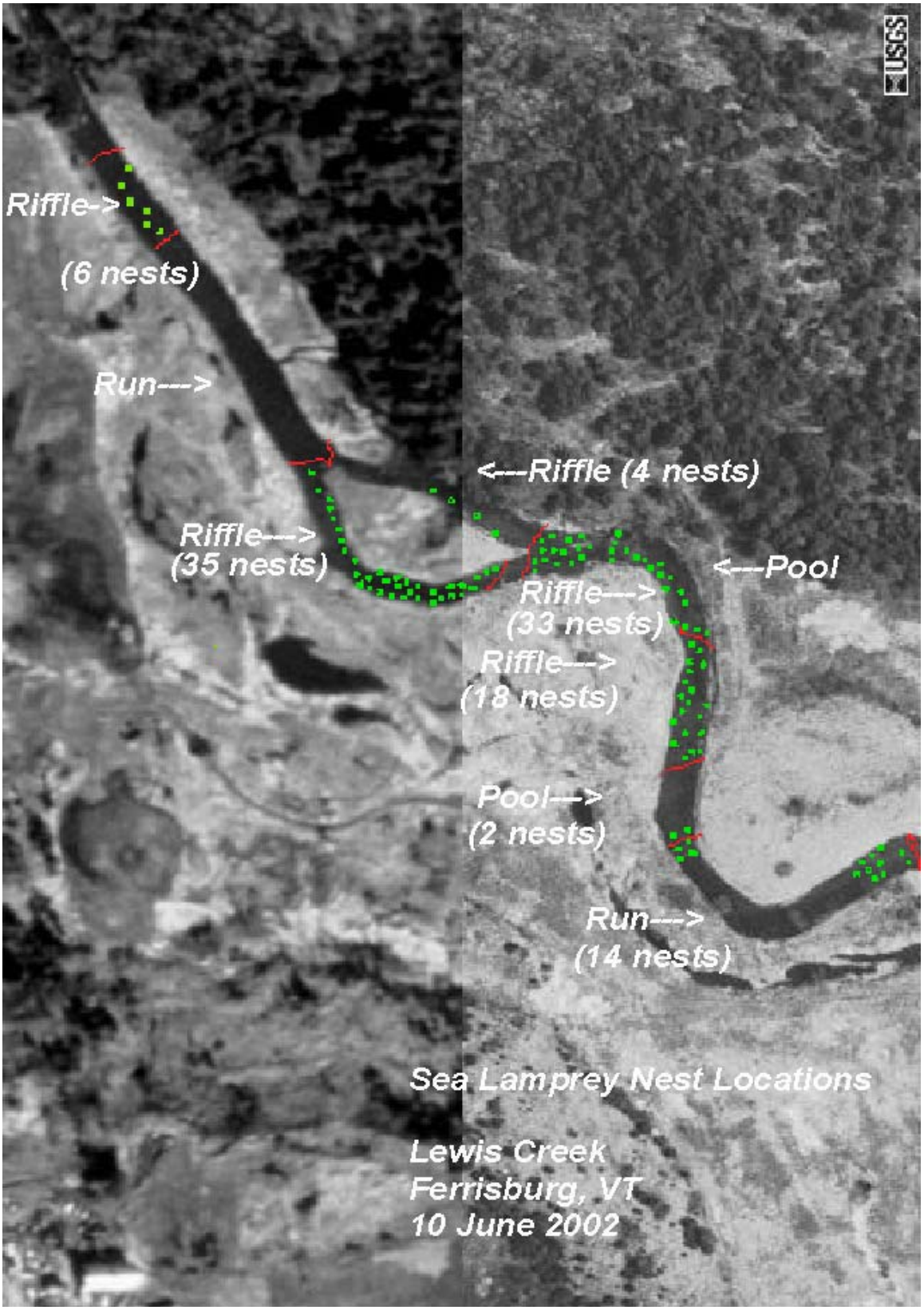
Figure 2.--Cumulative (y1) and percent (y2) reduction per 50 raking-stroke increment for eggs and larvae in lamprey nests. Raking increments were Initial dismantlement (1-50 strokes), Pass 1 (51-100), Pass 2 (101-150), and Pass 3 (151-200). Percent reduction/50 raking-stroke increment signficantly declined with increasing raking effort for eggs (P=0.0010) and larvae (P=0.0029, repeated measures analysis of variance). Significant orthogonal mean contrasts for percent reduction are denoted with different lettering for eggs (a-c) and larvae (x and z).



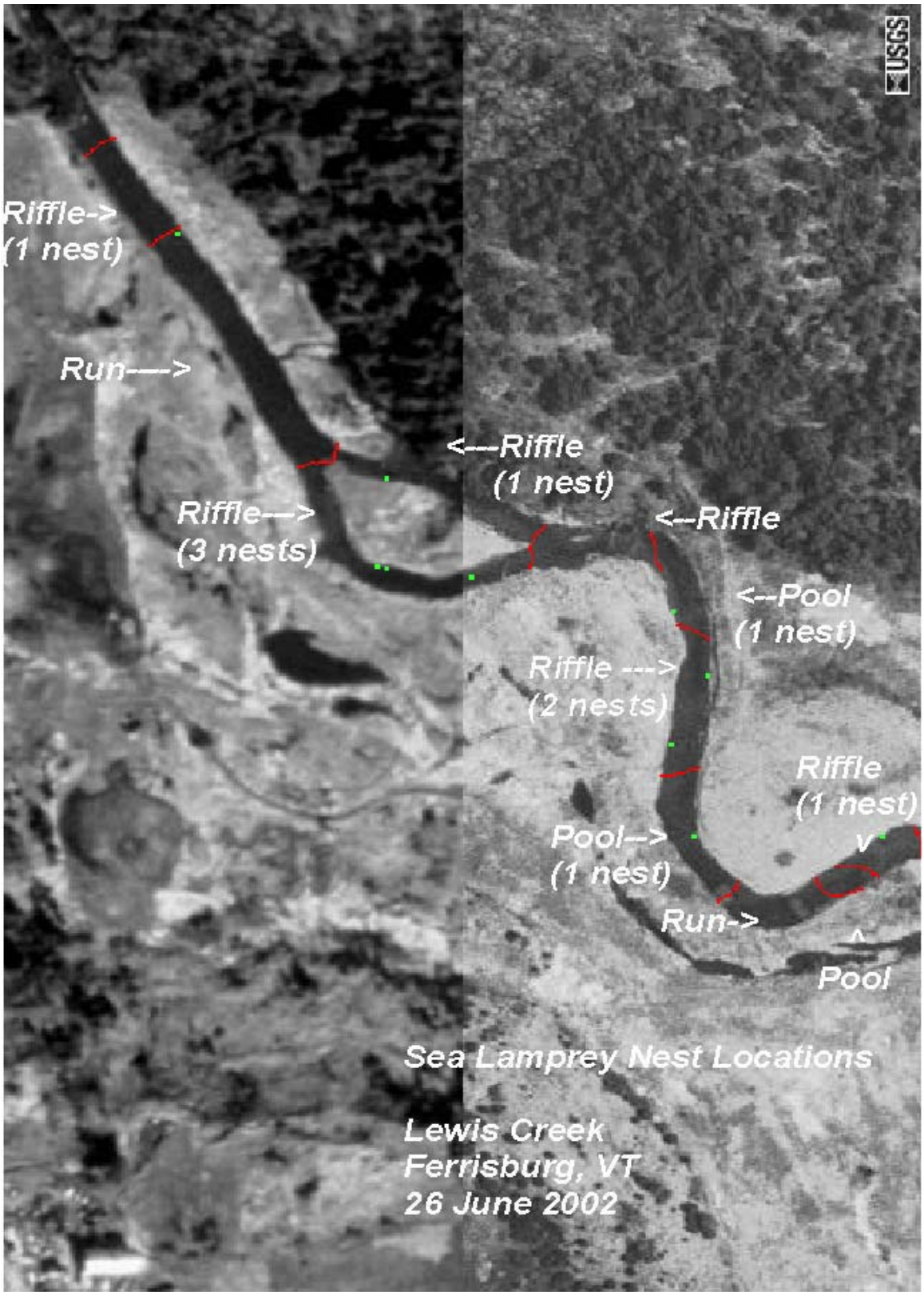
Appendix 1a.—Location and number of sea lamprey nests prior to flooding in Lewis Creek, 2002.



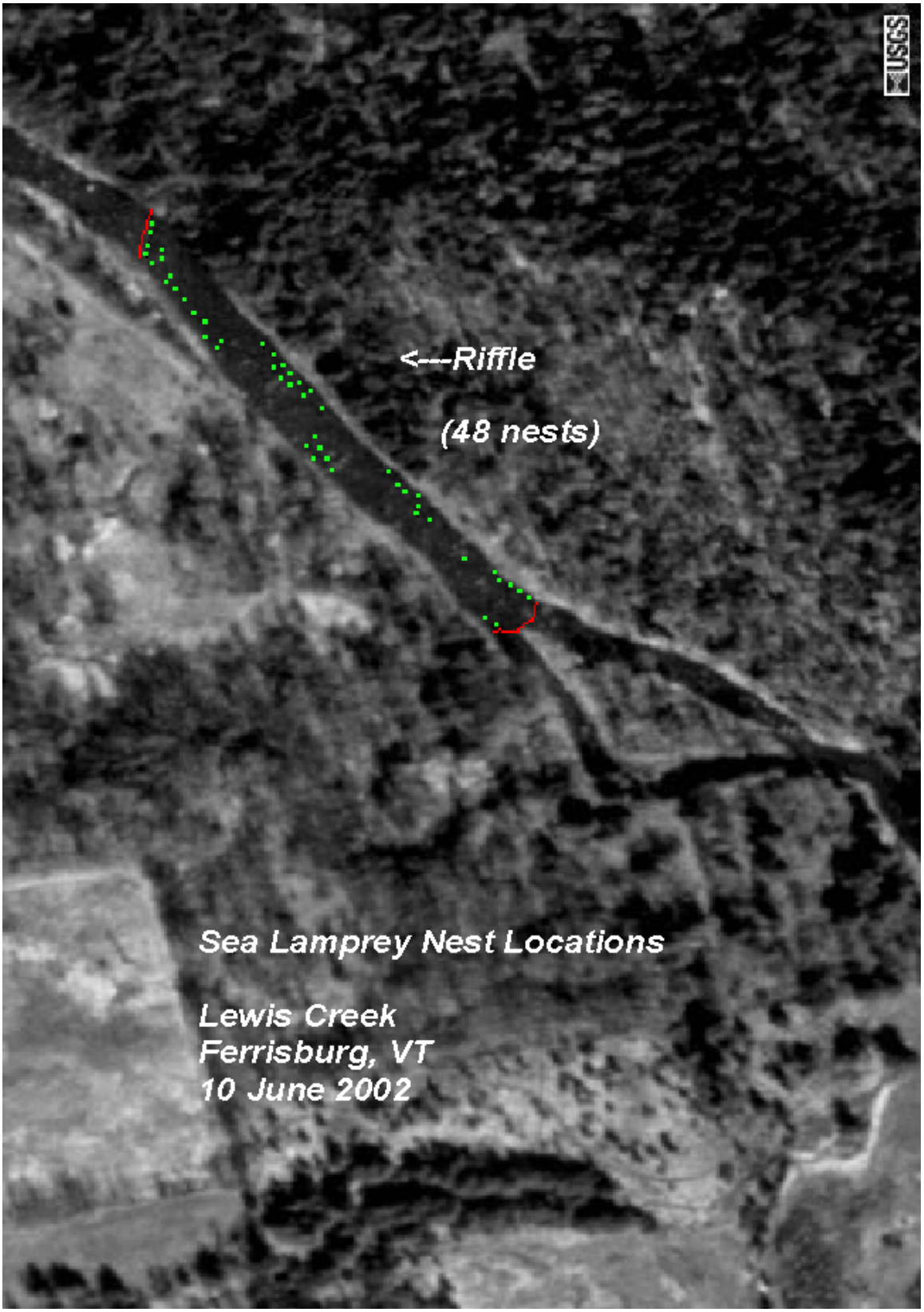
Appendix 1b.—Location and number of sea lamprey nests in Lewis Creek following flooding in 2002.



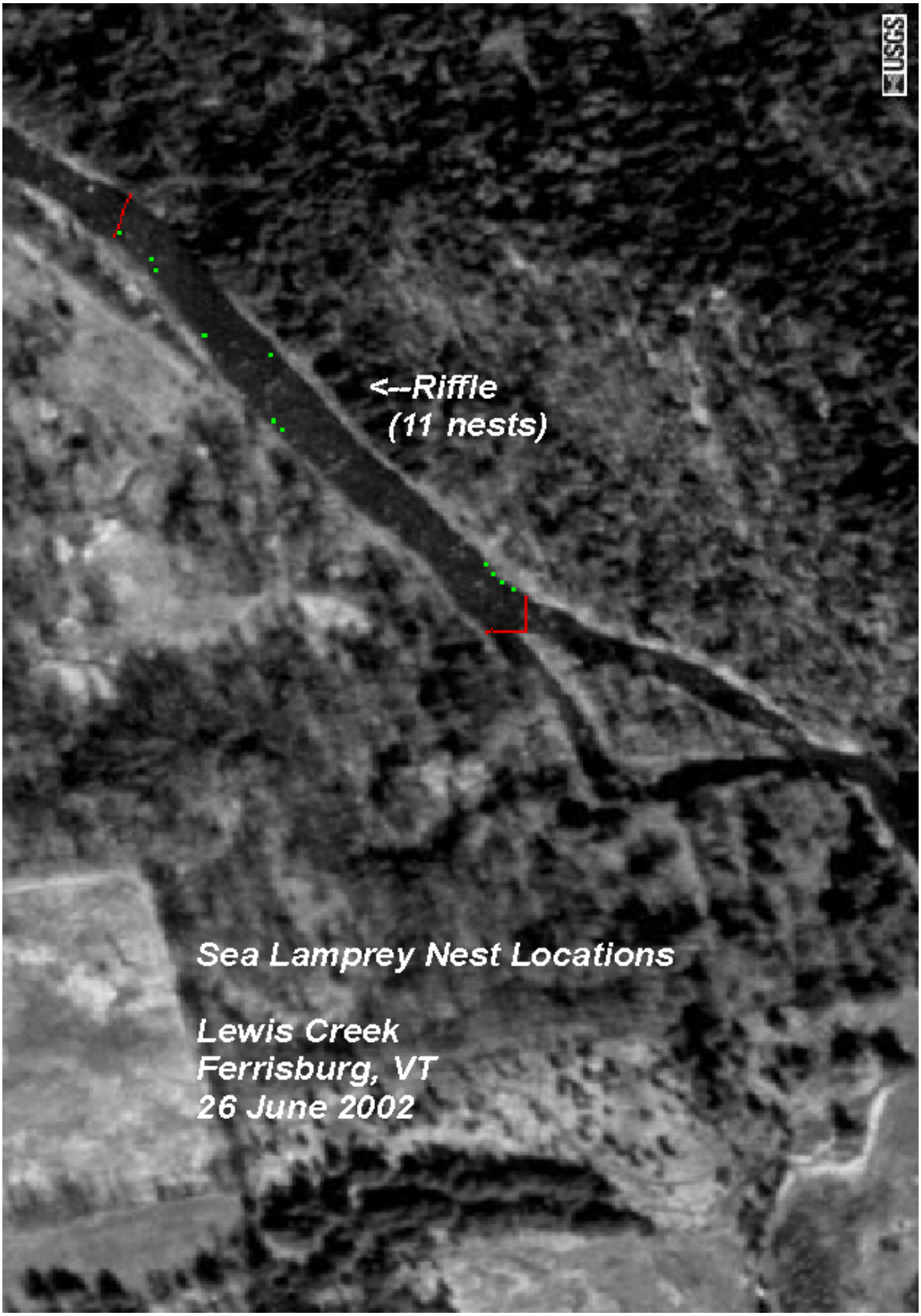
Appendix 2a.—Location and number of sea lamprey nests prior to flooding in Lewis Creek, 2002.



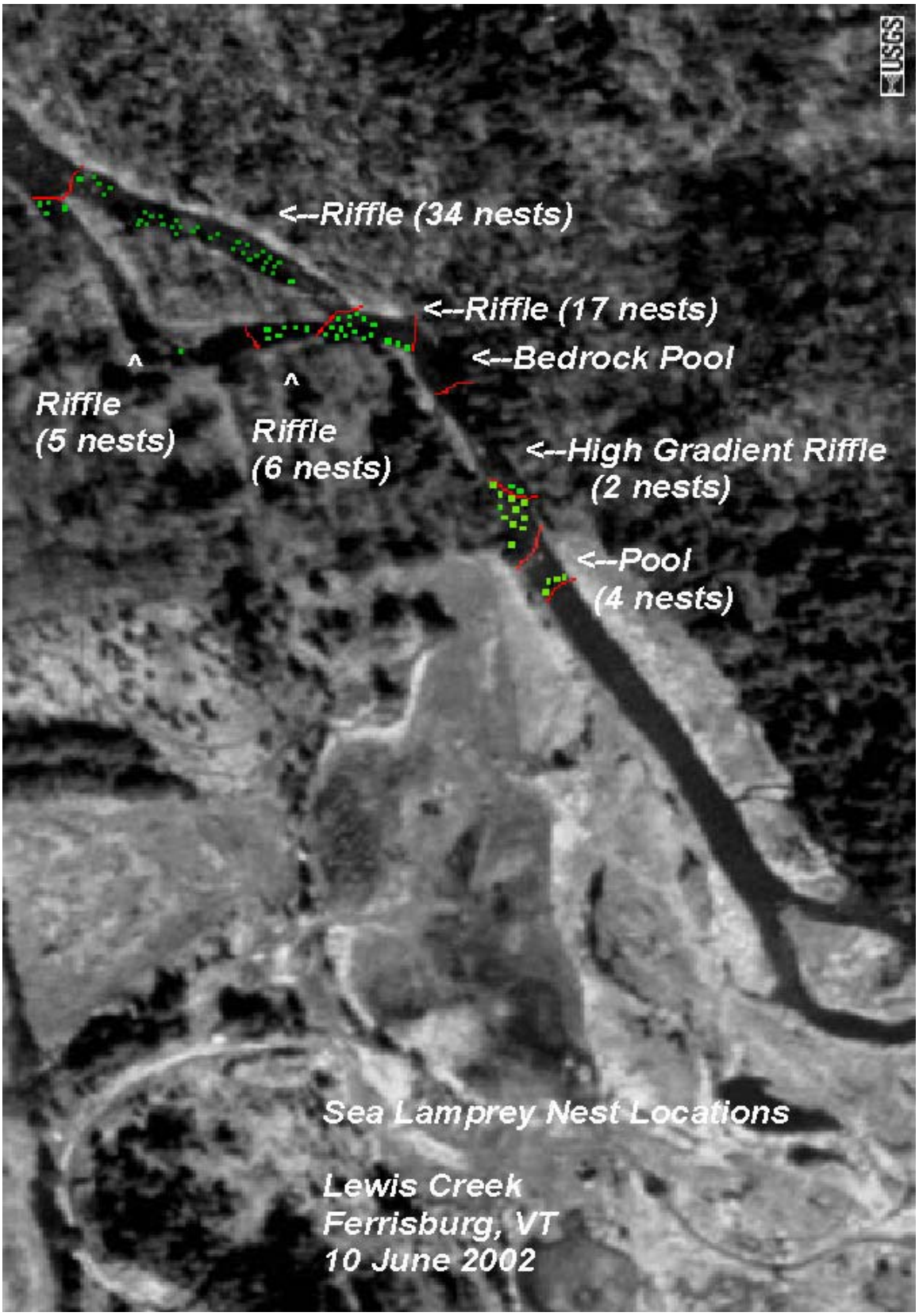
Appendix 2b.—Location and number of sea lamprey nests in Lewis Creek following flooding in 2002.



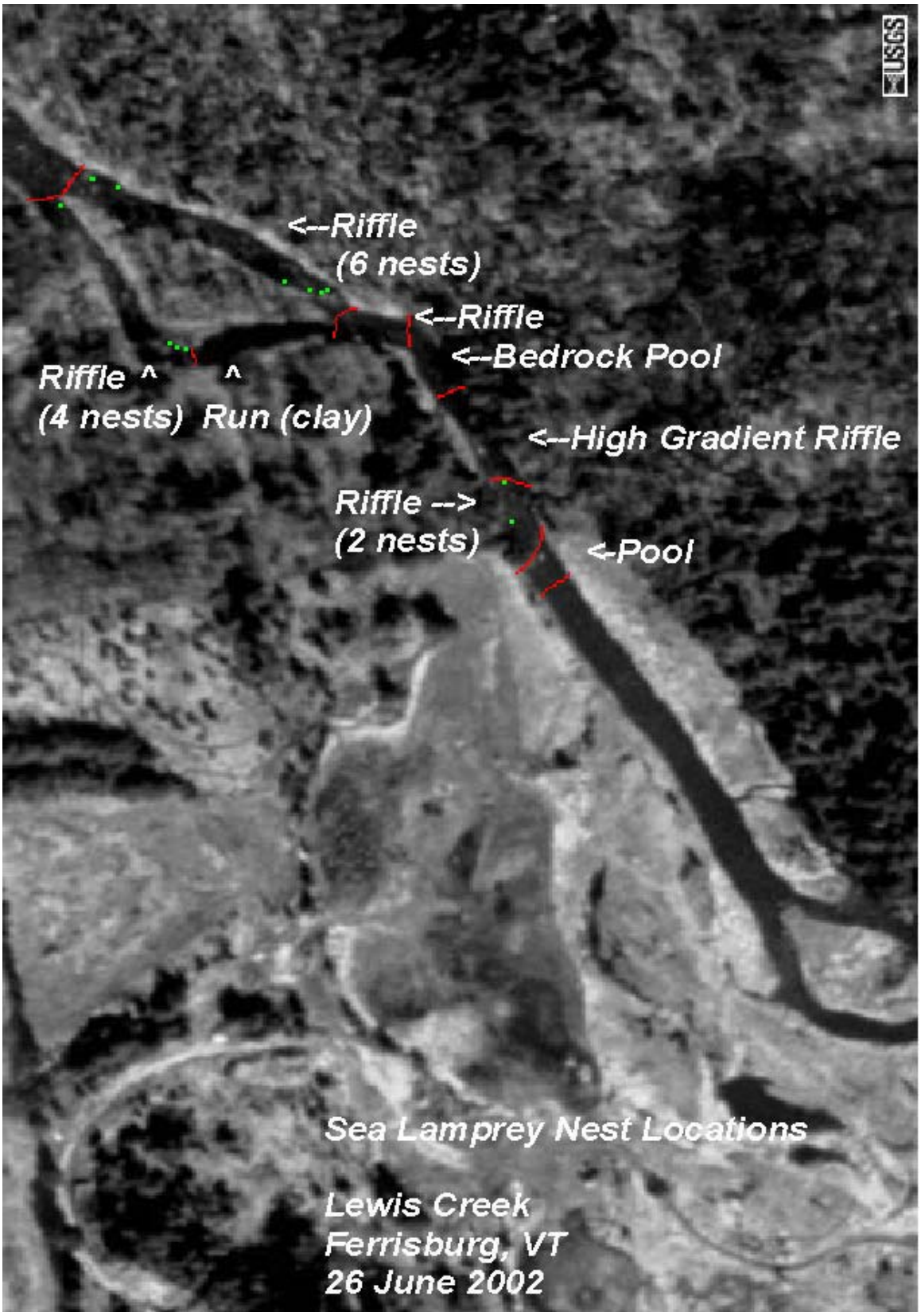
Appendix 3a.—Location and number of sea lamprey nests prior to flooding in Lewis Creek, 2002.



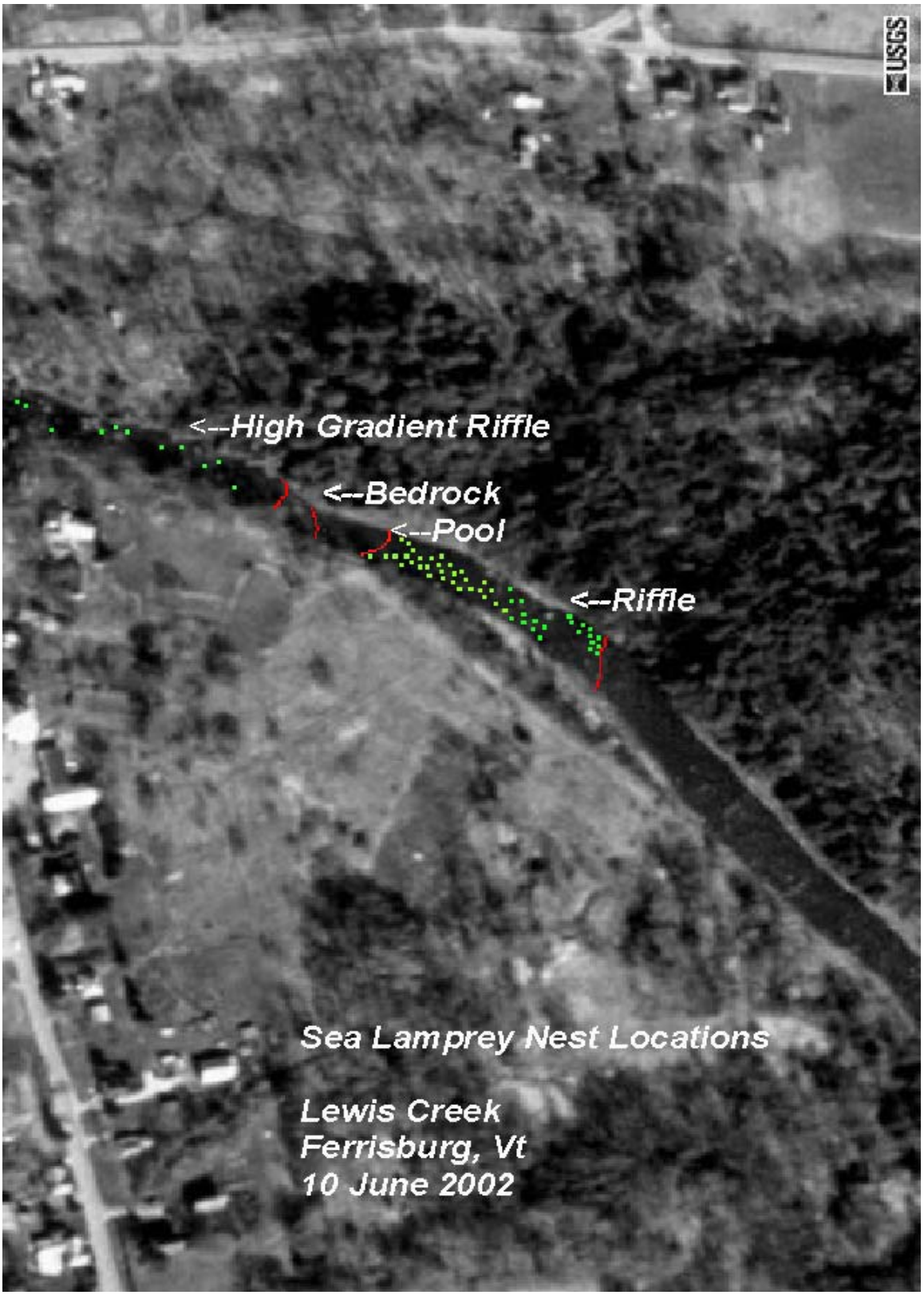
Appendix 3b.—Location and number of sea lamprey nests in Lewis Creek following flooding in 2002.



Appendix 4a.—Location and number of sea lamprey nests prior to flooding in Lewis Creek, 2002.



Appendix 4b.—Location and number of sea lamprey nests in Lewis Creek following flooding in 2002.



Appendix 5a.—Location and number of sea lamprey nests prior to flooding in Lewis Creek, 2002.

Appendix 6.—Date, sex, length, weight, and marking of sea lamprey transferred above the barrier falls on Malletts Creek. 29 females and 21 males were transferred to the enclosed area.

Specimen	Date	Sex	Length (mm)	Weight (g)	Color	Location
1	5/29/02	F	509	281	Orange	
2	5/29/02	F	453	272	Orange	
3	5/29/02	M	457	183	Yellow	
4	5/29/02	F	513	266	Orange	
5	5/29/02	M	478	225	Yellow	2nd Dorsal
6	5/29/02	M	502	304	Yellow	
7	5/29/02	F	455	194	Orange	
8	5/29/02	F	423	170	Orange	
9	5/30/02	F	394	223	Pink	
10	5/30/02	M	498	273	Yellow	2nd Dorsal
11	5/30/02	F	349	102	Pink	1st Dorsal
12	5/30/02	F	414	150	Pink	1st Dorsal
13	5/30/02	F	417	158	Pink	1st dorsal
14	5/30/02	F	394	136	Pink	1st dorsal
15	5/30/02	M	480	232	Yellow	1st dorsal
16	5/30/02	F	552	177	Pink	1st dorsal
17	5/30/02	M	368	126	Yellow	1st dorsal
18	5/30/02	M	395	132	Yellow	1st dorsal
19	5/30/02	M	421	199	Yellow	1st dorsal
20	5/30/02	M	441	178	Pink	1st dorsal
21	5/30/02	F	508	296	Pink	1st dorsal
22	5/30/02	F	408	97	Pink	1st dorsal
23	5/30/02	F	538	340	Pink	1st dorsal
24	5/30/02	F	373	103	Pink	1st dorsal
25	5/30/02	M	455	207	Yellow	1st dorsal
26	5/30/02	F	440	262	Pink	1st dorsal
27	5/30/02	M	358	118	Yellow	1st dorsal
28	5/30/02	F	335	163	Pink	1st dorsal
29	5/30/02	F	460	228	Pink	1st dorsal
30	5/30/02	F	398	152	Pink	1st dorsal
31	5/30/02	F	424	137	Pink	1st dorsal
32	5/30/02	M	368	114	Yellow	1st dorsal
33	5/30/02	F	426	221	Pink	1st dorsal
34	5/30/02	M	458	209	Yellow	1st dorsal
35	5/30/02	F	398	142	Pink	1st dorsal
36	5/30/02	M	340	91	Yellow	1st dorsal
37	5/30/02	M	332	96	Yellow	1st dorsal

Appendix 6.—Continued.

Specimen	Date	Sex	Length (mm)	Weight (g)	Color	Location
38	5/30/02	M	440	209	Yellow	1st dorsal
39	5/30/02	F	468	211	Pink	1st dorsal
40	5/30/02	F	446	187	Pink	1st dorsal
41	5/31/02	F	482	241	Orange	1st dorsal
42	5/31/02	M	532	265	Yellow	1st dorsal
43	5/31/02	M	430	151	Yellow	1st dorsal
44	5/31/02	F	558	296	Orange	1st dorsal
45	5/31/02	M	470	207	Yellow	1st dorsal
46	5/31/02	F	486	257	Orange	1st dorsal
47	5/31/02	M	494	216	Yellow	1st dorsal
48	5/31/02	M	474	194	Yellow	1st dorsal
49	6/3/02	F	453	299	Blue	1st dorsal
50	6/3/02	F	477	221	Blue	1st dorsal

Appendix 7.— Numbers collected and estimated number of invertebrates located within the Nest 3 nest depression on Lewis Creek, Vermont.

Order	Initial Dismantlement	Pass 1	Pass 2	Pass 3	Unequal capture prob.	Lower 95%	Estimate	Upper 95%	% recovery from nest [a]
Trichoptera	155	101	75	85	Yes	416	541	123,826	77
Ephemeroptera	67	86	64	27	No	253	276	299	88
Coleoptera	486	412	130	70	Yes	1,098	1,410	551,499	78
Diptera	286	156	84	50	No	596	622	648	93
Plecoptera	13	13	7	0	No	33	33	33	100
Odonata	0	0	0	0	Yes		0		
Annelida	4	1	1	2	Yes	8	10	5,552	80
Bivalvia	61	4	6	1	Yes		74		97
Gastropoda	9	1	1	2	Yes	13	15	5,557	100
Arachnida	5	4	3	4	No	13	19	25	84
Nematoda	7	1	1	0	No	9	9	9	100
Platyhelminthes	1	0	2	0	Yes	3	4	6,689	67
Megaloptera	1	1	0	0	No	2	2	2	100
Mean									

[a] % recovery from nest depression = (Catch from initial dismantlement + Pass 1 + Pass 2 + Pass 3) / Estimate

Appendix 8.— Numbers collected and estimated number of invertebrates located within the Nest 4 nest depression on Lewis Creek, Vermont.

Order	Initial Dismantlement	Pass 1	Pass 2	Pass 3	Unequal capture prob.	Lower 95%	Estimate	Upper 95%	% recovery from nest [a]
Trichoptera	234	152	98	202	Yes	686	1,020	381,057	67
Ephemeroptera	526	204	64	78	Yes	872	1,112	298,761	78
Coleoptera	974	292	258	178	Yes	1,702	1,966	203,113	87
Diptera	1862	324	332	202	Yes	2,720	3,027	384,690	90
Plecoptera	26	0	4	4	Yes	34	53	97,640	64
Odonata	6	0	2	0	Yes	8	9	6,694	84
Annelida	2	4	4	6	No	11	23	35	70
Bivalvia	304	60	40	44	Yes	448	513	136,961	87
Gastropoda	10	8	6	4	No	25	31	37	90
Arachnida	2	4	2	0	No	8	8	8	100
Nematoda	10	0	2	0	Yes	12	13	6,698	89
Platyhelminthes	8	16	6	0	No	30	30	30	100
Megaloptera	0	0	0	0	Yes		0		
Mean									

[a] % recovery from nest depression = (Catch from initial dismantlement + Pass 1 + Pass 2 + Pass 3) / Estimate

Appendix 9.— Numbers collected and estimated number of invertebrates located within the Nest 16 nest depression on Lewis Creek, Vermont.

Order	Initial Dismantlement	Pass 1	Pass 2	Pass 3	Unequal capture prob.	Lower 95%	Estimate	Upper 95%	% recovery from nest [a]
Trichoptera	181	285	125	90	Yes		780		87
Ephemeroptera	395	221	180	100	Yes	896	1,018	111,770	88
Coleoptera	279	457	171	103	Yes	1,046	1,071	1,096	94
Diptera	369	517	158	51	No	1,104	1,115	1,126	98
Plecoptera	9	18	2	3	Yes	32	40	43,944	80
Odonata	2	0	1	1	Yes	4	6	5,519	67
Annelida	4	13	2	1	No	20	20	20	100
Bivalvia	20	11	4	2	No	37	37	37	100
Gastropoda	0	1	0	1	No	2	2	2	100
Arachnida	9	9	6	1	No	25	25	25	100
Nematoda	1	8	11	0	Yes	20	28	25,378	71
Platyhelminthes	4	8	0	0			12		100
Megaloptera	0	0	0	0			0		
Mean									90 ∀ 6.9

[a] % recovery from nest depression = (Catch from initial dismantlement + Pass 1 + Pass 2 + Pass 3) / Estimate

Appendix 10.— Numbers collected and estimated number of invertebrates located within the Nest 17 nest depression on Lewis Creek, Vermont.

Order	Initial Dismantlement	Pass 1	Pass 2	Pass 3	Unequal capture prob.	Lower 95%	Estimate	Upper 95%	% recovery from nest [a]
Trichoptera	64	50	47	48	Yes		267		78
Ephemeroptera	458	136	104	56	No	790	830	870	91
Coleoptera	137	75	54	61	Yes		427		77
Diptera	642	72	45	57	Yes	816	909	118,738	90
Plecoptera	5	3	0	4	Yes	12	17	19,243	71
Odonata	0	0	0	0			0		
Annelida	109	22	8	5	No	142	146	150	99
Bivalvia	20	1	0	3	Yes	22	25	28	96
Gastropoda	2	0	0	0			2		100
Arachnida	8	0	0	0			8		100
Megaloptera	6	1	3	1	No	11	11	11	100
Nematoda	8	0	0	0			8		100
Platyhelminthes	3	0	0	0			3		100
Mean									91∀ 6.2

[a] % recovery from nest depression = (Catch from initial dismantlement + Pass 1 + Pass 2 + Pass 3) / Estimate

Appendix 11a. — Comparisons of collections of Trichoptera between nest raking and Langdon and Fiske (1991, 2002), and the influence of seasonality on collections.

A comparison of the samples taken from this study with those taken by Langdon and Fiske (1991 and 2002) between 1988 and 2002 constitutes Appendix 11b-c. Comparisons of samples by Langdon and Fiske (1991 and 2002) with this study showed many differences. This comparison, however, was complicated because the samples were taken at different times of the year: fall (between 21 September and 28 October; Langdon and Fiske (1991 and 2002)) and late spring and early summer (19 June and 2 July; this study). Thus many of the differences may be attributed to seasonal differences in macroinvertebrate populations rather than distributional differences – i.e., in sea lamprey spawning habitat vs. those more widely distributed in Lewis Creek. A total of 111 taxa were collected in Lewis Creek between Langdon and Fiske (1991 and 2002) and this study (Appendix 11c). In the raking samples 86 were present and 85 taxa were present in the Langdon and Fiske (1991 and 2002; Appendix 11b). Sixty were present in both sets of samples while 25 were present only in Langdon and Fiske (1991 and 2002) and 26 only in the nest raking samples.

Some adjustments to the raw data were made to make data directly comparable between Langdon and Fiske (1991 and 2002) and this study. The Chironomidae were keyed to genus, and in some instances to species in the Langdon and Fiske (1991 and 2002) studies. This study chose to lump all Chironomidae together, including those reported by Langdon and Fiske (1991 and 2002). Langdon and Fiske (1991 and 2002) separated the Hydropsychidae into three genera: *Hydropsyche, Symphytopsyche* and *Cheumatopsyche*. The convention to recognize *Hydropsyche* and not *Symphytopsyche* was adopted for this comparision (Wiggins 1996). Though many specimens in both data sets were identified to genus or even species, only genus or higher taxonomic categories were used for comparisons. This was done partly because of the uncertainty involved in determining many larvae beyond genus but also to keep the taxon numbers comparable and manageable. Appendix 11b compares families of insect larvae and orders or phyla of other invertebrates.

Rather than explore all differences between the Langdon and Fiske (1991 and 2002) and this study, only Trichoptera were examined closely. Most information utilized in this discussion comes from Betten 1934, Flint 1960, Ross 1944, and Wiggins 1996. The Trichoptera were reviewed by family and genus to explore why genera may have been absent from one or the other data sets based on the time of year the two sets of data were collected.

One member of the Brachycentridae, the genus *Micrasema* was found only in Landon and Fiske (1991 and 2002). This genus has its flight period in late spring. Thus only eggs or very small, easily over-looked larvae were likely present at the time of this study. The Leptocerid, *Ceraclea mintieus*, flies in late summer, thus only the nest raking samples contain larvae while eggs or very small, easily missed larvae were present at the time Langdon and Fiske (1991 and 2002) sampled. Among the Hydroptilidae, *Ochrotrichia* were present only in this study. It ecloses during the summer and mature larvae and pupae were found. The new larvae are very small in the Fall, possibly explaining their absence in Langdon and Fiske (1991 and 2002). *Ithytrichia* has a similar life-cycle pattern and also was only found in this study. *Leucotrichia*, were found only in Langdon and Fiske (1991 and 2002). This genus ecloses in the

late spring and early summer and mature larvae were likely present by early fall. For the family Apataniidae, genus *Apatania*, we were unable to find suitable references on its life history. It must have an early summer or late-spring flight period since no larvae were taken in this study but were present in samples by Langdon and Fiske (1991 and 2002). Two Limnephilidae, *Pycnopsyche* and *Hydatophylax*, were taken. *Pycnopsyche* emerges in late summer and was seen only in this study, while *Hydatophylax* adults emerge in the spring and early summer so large larvae were taken only by Langdon and Fiske (1991 and 2002). Among the Phylopotamidae, *Dolophilodes* were only taken by Langdon and Fiske (1991 and 2002). Adults emerge during the spring and early summer with 5th instar larvae present by fall. There were two members of the Lepidostomatidae taken, both only by Langdon and Fiske (1991 and 2002) samples. *Lepidostoma* adults are present in spring and summer with different species eclosing at different times. Early instar larvae and adults would be present in late spring depending on the species present (not known) and would have likely been missed in this study, while by fall the larvae would be nearly mature and were taken by Langdon and Fiske (1991 and 2002). Theliopsyche, a late spring and early summer ecloser with mature larvae present in late summer and early fall, were only found by Langdon and Fiske (1991 and 2002) samples. One representative of the family Goeridae, the genus *Goera*, was found in the Langdon and Fiske (1991 and 2002) samples. The adult flight period is in early summer with mature larvae being found by fall. The Glossosomatid, *Glossosoma*, was found only by Langdon and Fiske (1991 and 2002) samples. It has a late-spring emergence and flight period with the larvae feeding on periphyton from mid to late summer to fall when they are mature. One member of the Rhyacophilidae, *Rhyacophila vuphiphes* or *vuphipes* Milne (there seems to be some disagreement as to the spelling of the species designation) was found in Lewis Creek in as mature larvae 25 July, and as pupae 16 August, 1971 at the Route 7 bridge (Wimmer 1979), but was not found in either set of samples compared here. This is a fairly common species in branch streams of the New Haven River and mature larvae have been taken several times in early September in Muddy Brook where Painter Road crosses it in the town of Middlebury, Vt. This species was not observed in this study or in Langdon and Fiske (1991 and 2002).

From the analysis of the Trichoptera, it is evident that most of the differences between the two sample sets can be partially explained by the timing of sampling. Other factors, like habitat where samples were taken, substrate type, and water velocity and depth, were not available and could not be compared. It seems reasonable that similar seasonal differences and unmeasured environmental parameters can explain most of the differences seen in both studies.

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Appendix 11b.—A comparison of Langdon and Fiske (1991, 2002) macroinvertebrate samples, 1988-2001, with nest dismantling samples, 2002. Presence only is indicated.

Taxon	'88	'89	'90	'91	'92	'93	'94	'01[a]	'02
HEXAPODA									
Coleoptera									
Elmidae: up to 6 genera	X	X	X	X	X	X	X	X	X
Psephenidae: *Psephenus*	X	X	X	X	X	X	X	X	X
Ectopria	X	X	X			X	X		X
Gyrinidae: *Dineutus*									X
Chrysomelidae									X
Cucurlionidae: *Stenopelmis*									X
Hydrophilidae: *Berosus*				X			X		X
Hydrobius									
Georysidae									X
Haliplidae: *Haliplus*		X							
Dytiscidae: *Lacrophilus*			X	X					
Dryopidae; *Helichus*		X	X				X		
Diptera									
Athericidae: *Atherix*	X	X	X	X	X	X			X
Chironomidae; many genera	X	X	X	X	X	X	X	X	X
Ceratopogonidae: up to 4 genera	X	X	X	X		X	X		X
Empidididae	X	X	X			X	X		X
Tipulidae: *Antocha*	X	X	X	X	X	X	X	X	X
Hexatoma	X	X	X	X	X	X	X		X
Limnophila									X
Dicranota	X	X	X						X
Tipula	X		X	X	X				
Ormorisia									X
Simulidae: *Simulium*			X	X	X				X
Tabanidae: *Tabanus*	X								X
Chrysons	X	X							
Hybromitra			X						
Culicidae									X
Ephemeroptera									
Baetidae: *Baetis*	X	X	X	X	X	X	X	X	X
Pseudocloeon		X	X						X
Cloeon	X	X							X
Ephemerellidae: *Ephemerella*	X	X	X	X	X	X	X		X
Serratella		X	X	X	X	X			X
Attenella									X
Drunella					X	X			X
Dannella?									X
Eurylophella							X		X
Heptageniidae: *Stenonema*	X	X	X	X	X	X	X		X
Heptagenia				X					X
Leucrocuta									X
Stenacron			X	X					X
Rithrogena		X							X

Appendix 11b.—(continued)

Taxon	'88	'89	'90	'91	'92	'93	'94	'01	'02
Epeoris			X						
Potamantidae: *Potamanthus*	X	X	X						X
Caenidae: *Caenis*	X		X	X			X		X
Siphlonuronidae: *Ameletus*									X
Oligoneuriidae: *Isonychia*	X	X	X	X		X	X		X
Leptophlebiidae: *Paraleptophlebia*	X	X	X			X	X		X
Tricorythidae: *Tricorythodes*			X	X					X
Polymitarcyidae: *Ephron*									X
Ephemeridae: *Ephemera*		X	X						
Plecoptera									
Perlidae: *Acroneururia*	X	X	X	X	X	X	X		X
Phasgonophora	X	X	X		X		X		X
Neoperla	X	X	X	X	X	X	X		X
Beloneuria									X
Claassenia									X
Perlinella									X
Paragnetina	X	X	X	X	X	X	X		X
Eccoptura									X
Capnidae	X		X			X			
Taenopteryginae: *Taeniopteryx*	X	X	X			X	X		
Brachypteryginae: *Taenionema*	X								
Isperlinae: *Isoperla*	X	X	X						
Leuctridae: *Leuctra?*			X						
Trichoptera									
Brachycentridae: *Brachycentrus*	X	X	X	X	X	X	X	X	X
Micrasema			X						
Hydropsychidae: *Hydropsyche*	X	X	X	X	X	X	X	X	X
Cheumatopsyche	X	X	X	X	X		X	X	X
Helicopsychidae: *Helicopsyche*	X	X	X	X	X	X	X	X	X
Uenoidae: *Neophylax*			X						X
Odontoceridae: *Psilotreta*	X	X	X	X	X		X		X
Leptoceridae: *Setodes*	X		X	X			X		X
Ceraclea									X
Oecetis		X	X	X	X		X		X
Mystacidaes			X						X
Hydroptilidae: *Hydroptila*	X	X	X	X				X	X
Ochrotrichia									X
Ithytrichia									X
Leucotrichia	X	X	X						
Apataniidae: *Apatania*	X	X	X	X	X	X	X		
Limnephilidae: *Pycnopsyche*									X
Hydatophylax			X						
Glossosomatidae: *Glossosoma*	X	X	X		X				
Rhyacophyilidae: *Rhyacophila*			X	X	X		X		X

Appendix 11b.—(continued)

Taxon	'88	'89	'90	'91	'92	'93	'94	'01	'02
Philopotamidae: *Chimarra*	X	X	X	X	X	X	X	X	X
Dolophilodes		X							
Psychomyidae: *Psychomya*		X					X		X
Lepidostomatidae: *Lepidostoma*		X		X			X		
Theliopsyche			X						
Goeridae: *Goera*		X							
Megaloptera									
Corydalidae: *Nigronia*	X	X	X	X		X	X		X
Sialidae: *Sialis*	X	X	X		X	X	X		X
Lepidoptera									
Pyralidae				X					
Odonata									
Zygoptera		X	X	X			X		X
Anisoptera			X		X		X		X
ARACHNIDA									
Hydrachnida				X		X			X
CRUSTACEA									
Amphipoda				X					X
Decapoda					X	X			X
MOLLUSCA									
Bivalvia									
Sphaeridae	X	X	X	X	X		X		X
Dreeissena polymorpha									X
Gastropoda									
Physidae: *Physa*		X	X				X		X
Lymnaeidae: *Lymnaea*									X
Ferrissia	X	X	X						X
Planorbidae	X								X
Amnicola		X	X						
Physella	X								
Planorbidae: *Heliosoma*	X	X							X
Bithyniidae: *Bithynia*									X
ANNELIDA									
Oligochaeta	X	X	X	X		X			X
Hirudinea									X
PLATYHELMINTHES									
Tricladida	X	X							X
NEMATODA									X

[a] 2001 show only major groups.

[b] One species of Trichoptera, ***Rhyacophila vuvhipies,*** was present in Lewis Creek in 1973 but not observed in Langdon and Fiske (1991, 2002) or this study. Specimens identified as ***R. fuscula*** by the Langdon and Fiske (1991, 2002) may actually be this species.

Appendix 11c.—Comparison of higher macro-invertebrate taxon from Langdon and Fiske (1991, 2002) and nest dismantling.

Taxon	Number Total	Number Langdon and Fiske [a]	Number Langdon and Fiske [a] only [b]	Number nest raking	Number nest raking only [c]	Number both
Coleoptera	12	7	3	9	5	4
Diptera	15	12	3	12	3	9
Ephemeroptera	23	18	2	21	5	16
Plecoptera	13	9	5	8	4	4
Trichoptera	26	22	9	17	4	13
Lepidoptera	1	1	1	0	0	0
Megaloptera	2	2	0	2	0	2
Odonata	2	2	0	2	0	2
Arachnida	1	1	0	1	0	1
Crustacea	2	2	0	2	0	2
Annelida	2	1	0	2	1	1
Mollusca	10	7	2	8	3	5
Platyhelminthes	1	1	0	1	0	1
Nematoda	1	0	0	1	1	0
Totals	111	85	25	86	26	60

[a] Data obtained from Langdon and Fiske (1991, 2002).
[b] Number of macro-invertebrate taxon observed only by Langdon and Fiske (1991, 2002)
[c] Number of macro-invertebrate taxon observed only by this study

Appendix 12.—Task 2: Review existing information on Threatened and Endangered species and other species of concern in the Poultney River.

Introduction

Sea lamprey have been found to suppress the Lake Champlain salmonid fishery and every year cause large monetary losses to both the fishing industry and the stocking program (FTC 1999). However, the impacts of sea lamprey are not restricted to sport fishing. They parasitize nearly every species in Lake Champlain that have body sizes large enough to serve as prey. Lamprey wounds are routinely found on lake trout (*Salvelinus namaycush*), Atlantic salmon (*Salmo salar*), brown trout (*Salmo trutta*), walleye (*Stizostedion vitreum*), northern pike (*Esox lucius*), smallmouth bass (*Micropterus dolomieui*), channel catfish (*Ictalurus punctatus*), and white suckers (*Calostomus commersoni*) and at current densities have a dramatic effect on the overall ecosystem of Lake Champlain by altering dynamics within fish populations (FTC 1999). An integral part of managing the lake ecosystems in the Great Lakes has been the control of sea lamprey populations. This policy has also become a part of management effort on Lake Champlain too.

There several different control methods that have been used to successfully control sea lamprey populations, including TFM, TFM/niclosamide combination treatments, trapping, and barriers (Walrath and Swiney 2001). However, due to public apprehension about the long-term, broad-scale application of pesticides, the Cooperative has committed to investigating non-chemical alternatives for controlling lamprey populations in the Basin. In particular, due to the diverse, rare, and in some cases imperiled native biota of the Poultney River and its designation as an Outstanding Water Resource in the state of Vermont, the Cooperative has recommended deferring lampricide treatment for five years after the initiation of the long-term program to fully assess potential non-chemical alternatives. This appendix summarizes some of literature that will need to be considered when evaluating the non-target impacts of alternative control technologies, especially on species of special concern including eastern sand darter (*Ammocrypta pellucida*), channel darter (*Percina copelandi*), walleye, and six endangered and two threatened mussels. It also describes areas that require further research in order to assess impacts of alternative sea lamprey control technologies.

Poultney River

Poultney River is a 39 mi (63 km) tributary to Lake Champlain (1,130 km^2 surface area) located in southern Vermont. Lake Champlain is part of an 8,166 mi^2 watershed that covers parts of Adirondack, Green, and Taconic Mountains (Walrath and Swiney 2001). The Poultney River drains 485 km^2 and has been designated an Outstanding Resource Water by Vermont Water Resources Board (Vermont Department of Environmental Conservation and The Lower Poultney River Citizens Committee 1992) because of the natural, cultural, and scenic values of the lower 22 miles of the river. The spring sea lamprey spawning run is blocked at Carver Falls, approximately 11 mi (15 km) from the river (Mitro 1995). The river is drowned by Lake Champlain below the Coggman Bridge where there are numerous marshes along the banks.

Forty-five out of the 88 fish species in Vermont have been documented in the Poultney River (Walrath and Swiney 2001). Among these are two listed as Endangered and Threatened in Vermont, the channel darter (*Percinia copelandi*) and the eastern sand darter (*Ammocrypta pellucida*), respectively (Walrath and Swiney 2001). The river supports one of the only two walleye spawning runs in the south lake of Lake Champlain (Mitro 1995). The Poultney River has a diverse freshwater mussel community that includes 70% of mussel species known to be present in Vermont (Walrath and Swiney 2001). Six of these mussels are Vermont listed as Endangered (black sandshell, *Ligumia recta*, cylindrical papershell, *Anodontoides ferussacianus*, fluted-shell, *Lasmigona costata*, fragile papershell, *Leptodea fragilis*, pink heelsplitter, *Potamilus alatus*, pocketbook, *Lampsilis ovata*) and two are listed as Threatened (eastern [pearshell] pear, *Margaritifera margaritifera*, and giant floater, *Pyganodon grandis*).

Sea Lamprey Control Strategies

Lampricide

The most efficient control of lamprey has been achieved with lampricides using 3-trifluormethyl-4-nitrophenol (TFM) and 5,2'-dichloro-4'-nitorsalicylanilide (Bayluscide). Both have been extensively used in the Great Lakes since 1958 and in Lake Champlain since 1990 (FTC 1999). TFM has been shown to degrade into nontoxic 3-trifluoromethyl-4-amino-phenol (RTFM) in 3-5 days. The sensitivity of fish species to TFM is variable. However, fish typically found in the tributaries are much less sensitive than sea lamprey and therefore suffer lower mortality. TFM has also been used in combination treatments with Niclosamide.

Structural Barriers

Low-head barriers can be installed in portions of a tributary below spawning habitat that prevent sea lamprey from moving upstream. In order to be effective the barrier must have a head between 12-24 inches and an overhanging lip. During periods of high water lamprey may pass the barrier. In addition, a proportion of lamprey that cannot pass a barrier may return to the lake and spawn in other tributaries. There are several modifications to this system that allow for passage of other species that spawn at the same time. These include traps for manual transfer of desired fish, adjustable-crest dams, electric barriers, and a design that allows passage of only leaping fish.

Trapping of Adults

Adults may be trapped as they move upstream during spawning. This can be done with permanent traps imbedded into barrier dams, or portable traps set out during the spawning migration and later removed.

Gigging of Adults

Adults may be speared or collected when on nests during spawning. Adults are highly visible during nest construction and not easily disturbed off nests making their capture efficient.

Nest Destruction

Nests may be destructed after spawning to decrease the production of larvae.

Trapping of Transformers
Transformers may be trapped as they migrate into the lake. Transformers mainly migrate during the fall, likely in response to environmental cues that initiate migrations downstream to the lake.

Sterilization
Sea lamprey may be collected, sterilized, and released into a tributary. This lowers the reproductive potential of a lamprey spawning population by decreasing the number of successful fertilization events.

Attractants/Repellents
Sea lampreys are strongly attracted to tributaries by olfactory cues. It has been proposed that a spawning run may be diverted to tributaries or traps by the use of attractants and/or repellents.

Non-target impacts of lamprey control strategies on species of special concern in the Poultney River

Walleye

Walleye are one if the most sought after sport fishes in Northern latitudes. Fishermen have noted a decline in catch rate in recent years, and the status of the walleye population in the South Lake area is uncertain (Mitro 1995). Therefore, the impact of sea lamprey control on walleye has become a concern. Walleye are free swimming in lakes during most of adult life and therefore are not sensitive to any lamprey control strategies for a majority of their life history. The only stages that may be sensitive are spawning, egg, larvae, and hatchling.

Life History.— In the late winter/early spring walleye migrate into tributaries to spawn. The walleye spawning migration is initiated in temperatures as low as 2.2ºC. Spawning begins at 4.4-5.5ºC, peaks at around 6.7-8.9ºC, and ends at around 11.1ºC (Scott and Crossman 1998). The timing of spawning runs may vary up to four weeks between years. The run duration is 1-3 weeks; however the peak is only 1 – 10 days (Schneider et al. 2002). In the South Bay of Lake Champlain, spawning occurred between April 2 and April 21 (1983-1987) with temperatures ranging from a mean of 5.6ºC to 8.0ºC (Newbrough *et al*. 1993). Walleyes broadcast their eggs over substrate and do not exhibit parental care. The only areas that have a sufficient amount of oxygen for egg development are regions with gravel/cobble substrate and water flow high enough to prevent sedimentation of debris (Corbett and Powles 1986). Depth at the spawning grounds is usually less than 1 m, but varies from 0.10 – 4.6 m. Walleye spawning in the Poultney River is limited to a high gradient section of the river that runs one kilometer south of Carver Falls (Mitro 1995).

Egg incubation lasts between 2 - 3 weeks and is very dependent on temperature (Scott and Crossman 1998). Hatched larvae develop in tributaries and migrate into lakes before commencing feeding. The yolk sack is absorbed and larvae migrate out 10-15 days after hatching. In the Saginaw River system hatching peaked around 16 – 19ºC (June 1992) and was completed between 14-17 days after spawning. In Oneida Lake hatching occurred 10 days after

deposition. It is more accurate to estimate hatching duration with thermal units (sum of the number of degrees the mean daily temperature is above 0ºC) because development is so temperature dependent. In two Lake Ontario tributaries larvae finished hatching at 247.8 and 241.6 TU. In 10-15 days after hatching the young disperse into open water (Scott and Crossman 1998). In the Poultney River in 1993, just below Carvers Falls, the greatest larval migration occurred on May 8th, the first sampling day, suggesting that the early part of the migration was not recorded (Mitro 1995). In 1994 for both sections (Carver Falls and Cogman Bridge) sampled by Mitro (1995) the peak occurred around May 10th (320 TU) when water temperature reached around 13.4ºC and on May 15th 396 TU) when temperatures were between 12.5 – 13ºC. The mean water temperature during the peak migration was 12.8ºC in the Poultney (1994). The greatest densities occurred around 9 pm.

Channel darter

The channel darter is a small percid that has a disjunct distribution in central North America (Goodchild 1994). It is found in the St. Lawrence River drainage in Vermont and New York. The Channel darter is listed in Vermont as Endangered, however it is not listed in New York. They have been found in the Poultney, Winooski, and LaPlatte rivers below the first barriers.

Life History.—The channel darter is a benthic species found mainly over sand and gravel that feeds typically on aquatic invertebrates (Goodchild 1994). Channel darters in rivers inhabit sluggish riffles and pools where the water is moving fast enough to create silt free gravel substrate (Goodchild 1994). However, due to the presence of vegetation on substrate, water velocity is not too high in these areas (Goodchild 1994). In the Alleghany River system, channel darters were found in July occupying riffles with mean velocity of 0.1 m/s and depth of 0.41 cm (Stauffer et al. 1996). The substrate used was rocks around 25 cm^2. Channel darters move to faster flowing riffles during the spawning season (Goodchild 1994). Males establish mating territories and often maintain body position behind at least one large rock (Scott and Crossman 1998). Spawning occurs in between small rocks or in fine sand immediately behind the rock in the male's territory. Eggs are buried in sand or gravel (Scott and Crossman 1998). Unfortunately, the velocity of the current and the size definition of sand and gravel were not reported in many of the studies. Winn (1953) observed spawning in 2 – 3 feet of water flowing swiftly over gravel with a velocity of about 1.4 ft/sec. The channel darter belongs to a class of darters that have egg burying spawning behavior (Page and Cummings 1984). The females partially bury themselves below the surface of the substrate and then release their eggs (Page and Cummings 1984). Based on the condition of channel darters spawning was observed to take place between May and June (due to wide geographic distribution of the studies). In the Sheboygan River, Lake Michigan, spawning was observed between July 9 - 23 with water temperature of 20.5 - 21ºC (Scott and Crossman 1998). In Virginia spawning has been observed to occur between 20 – 21ºC. However, spawning has not been studied in Vermont.

The distribution of channel darters within the Poultney River has not been well documented. It is unknown what riffles provide the primary habitat for channel darters and the abundance.

Eastern sand darter

The eastern sand darter is a small percid that has a disjunct distribution in east central North America (Scott and Crossman 1998). It is found in the Ohio and Lake Champlain drainage in Vermont and New York (Kuehue and Barbour 1983). The eastern sand darter is listed in Vermont as Endangered, however it is not listed in New York. The Poultney, Missisquoi, Winooski, and Lamoille Rivers support populations of eastern sand darters (Facey 1998). They were found in almost all suitable habitats (Facey 1998). The New York DEC conducted an eastern sand darter survey (1989-1991) in which they found these fish to be abundant in the Poultney (Bouton 1991, Facey 1998). However there were large density fluctuations in sites from year to year (Bouton 1991, Facey 1998).

Life history.—The eastern sand darter is a benthic species found mainly over sand bottomed areas in streams and rivers and sandy lake shoals (Scott and Crossman). It has been reported in areas ranging from silt to gravel (Kuehue and Barbour 1983). The regions where they have been observed have low to moderate water velocities (Kuehue and Barbour 1983, Facey 1998). Eastern sand darters have been found in water less than a half meter deep and just downstream of riffles, adjacent to riffles, and downstream of sand bars (Kuehue and Barbour 1983, Facey 1998). In the Lake Champlain tributary Mettawee River (New York), most fish were found in the depositional sides of the river within 20 m of a bend with at least 90% sand substrate. In these regions the depth was less than 0.5 m and water-column velocity was 0.20 m/s (Facey 1998). In a study in the Birch River (Virginia) eastern sand darters were only found over sand that was between 0.006 – 0.2 cm (diameter) (Welsh and Perry 1998). In the Poultney River, the highest eastern sand darter densities occurred over substrate that was composed of greater than 45% particles between 0.23 – 0.54 mm (Facey and O'Brien 2002). In a survey of the Missisquoi, Winooski, and Lamoille Rivers they were only found over fine sand with nearly no amounts vegetation, mud, or coarse gravel (Facey 1998). Eastern sand darters bury themselves with only eyes exposed in sandy locations (Scott and Crossman 1998). Their diet is mainly composed of midge larvae (Kuehue and Barbour 1983).

Spawning occurs over sandy substrate and during June and July in the Ohio drainage and about two weeks later in the Saint Lawrence drainage (Kuehue and Barbour 1983, Facey 1998). In an Indiana tributary, eastern sand darters spawned in June and July with water temperatures between 20.5 – 23ºC (Facey 1998). Spawning has been observed to occur in the Winooski river between June 6 and 26th in water temperatures between 20.5 –25.5ºC (Facey 1998). There is limited evidence from Lake Champlain drainage area that spawning occurs repeatedly from April to August (Facey and O'Brien 2002)

State-listed freshwater mussels

Poultney River has a diverse freshwater mussel community that includes 70% of mussel species known to be present in Vermont (Walrath and Swiney 2001). Six of these mussels are Vermont listed as Endangered (black sandshell, *Ligumia recta*, cylindrical papershell, *Anodontoides ferussacianus*, fluted-shell, *Lasmigona costata*, fragile papershell, *Leptodea fragilis*, pink heelsplitter, *Potamilus alatus*, pocketbook, *Lampsilis ovata*) and five are listed as threatened (eastern [pearshell] pear, *Margaritifera margaritifera*, and giant floater, *Pyganodon grandis*).

The eastern papershell has only been observed above Carver Falls (Walrath and Swiney 2001) most likely to its close association with it host species trout and salmon. These mussels utilize a variety of fish hosts during their parasitic larval life stage (Waters 1996).

Life-history.—Unionid mussels have a parasitic larval life stage that infects host fish. The distribution of mussels is largely due to the movements of the fish hosts (Watters 1996). There is a lack of studies that have focused on the ecology of unionid mussels in Lake Champlain tributaries. Fitchel (1992) describes the species and numbers of mussels in the Poultney River in four beds. However, he does not provide a description of the substrate or water characteristics at these sights. However, in studies on the Lamoille, Saranac, and Winooski Rivers it has been observed mussels rarely use areas with unconsolidated cobble that has very little interstitial substrate (O'Brien 2002). In the Lamoille River, O'Brien (2002) mainly found mussels in consolidated sand/gravel/cobble and sand/silt substrates. The Saranac River did not have a large or diverse mussel community. In this river mussels were mainly found on substrate composed of a consolidated mix of silt, sand, and gravel. In the Winooski River, there was a limited amount of suitable substrate and the mussels observed were mainly in protected areas near the riverbank and backwaters (O'Brien 2002).

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