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Reproductive Success of Stocked Lake Trout in Southwestern Lake Michigan

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Center for Aquatic Ecology

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EXECUTIVE SUMMARY

The objectives of this study are to (1) determine the efficacy of remote methods for measuring lake trout spawning activity, (2) examine differences in spawning activity and spawning success between natural and man-made (hereafter referred to as "artificial") sites where lake trout spawn, (3) identify lake trout egg and fry predators that may reduce recruitment of lake trout to natural and artificial sites, and (4) examine viability and hatching rates of lake trout eggs spawned in the wild at natural and artificial sites. In the first year of this project preliminary data were collected in an effort to assess the efficacy (and efficiency) of remote video and sonar as indicators of spawning activity, using collections of eggs by gangs of egg nets and egg traps as a direct indicator of spawning activity. We studied the intensity of spawning activities at a breakwall in Indiana during the fall of 1994 by deploying egg bags (a method of estimating the cumulative rate of egg deposition over a substratum), and conducted a diver survey of the substrate at the site. We estimated the densities of emergent fry at the same Indiana site by deploying fry traps during the spring of 1995 and by trawling for fry during the same period. During October 1994 through April 1995 we collected egg and fry predators by gillnetting, trawling, and trapping, and examined the gut contents of lake trout, burbot, alewife, and sculpin samples that were obtained. During the winter of 1994-1995, we reared wild-spawned lake trout eggs and samples of eggs obtained from gillnetted feral lake trout.

The following preliminary conclusions are drawn from data collected during the first year of the three-year project.

1. Lake trout deposited more eggs at Burns Harbor (an artificial site: 1.80 eggs/gang/day) than at Wilmette Reef R-2 (a natural site: 0.15 egg/gang/day) during 1994, as indicated by sampling using gangs of egg nets and egg traps.

2. Lake trout spawning aggregations were difficult to detect by remotely operated vehicle (ROV) video under the poor water visibility that prevailed at Burns Harbor in 1994. Only one lake trout was seen during 2.25 h of ROV video collected on 17 November and 16 December 1994. No lake trout were seen on 1.0 h of ROV video collected at Wilmette Reef R-2 on 27 October. Aggregations of fishes observed by sonar at Burns Harbor during fall 1994 could not be clearly identified as lake trout, and some may have been carp.

3. Deposits of cobble suitable for lake trout spawning are extensive at the Burns Harbor site, but are limited to the west breakwall, with only small areas of cobble on the north breakwall. The substrate along the north wall will change substantially after repairs undertaken by the Army Corps of Engineers during summer 1995 are completed.

4. Several potential natural spawning sites lying between Highland Park and Waukegan did not appear suitable for lake trout spawning.

5. We successfully reared wild-spawned lake trout eggs in the laboratory, and found no differences in hatching rates, rates of abnormality, or rates of development, when compared with stripped eggs that were reared in parallel.

6. Of 155 fishes of seven species obtained by gillnetting over spawning sites, two species, burbot (*Lota lota*) and lake trout (*Salvelinus namaycush*), consumed lake trout eggs. Eleven percent of 56 burbot collected at Julian's Reef and Wilmette Reef R-4 contained lake trout eggs. One burbot contained more than 100 eggs. During spring trawling and trapping operations, we captured 135 potential fry predators, including alewife (*Alosa pseudoharengus*) and mottled sculpin (*Cottus bairdi*), at Burns Harbor, but none contained lake trout fry.

INTRODUCTION

Lake trout (*Salvelinus namaycush*) are native to the Great Lakes, and were present in large numbers in Lake Michigan when Europeans settled the shores of the lake. By the late 1950's lake trout populations were completely extirpated, in large part due to overfishing and the negative impacts of exotic species such as the sea lamprey (*Petromyzon marinus*). The goal of federal and state agencies involved in lake trout management is to reestablish naturally reproducing lake trout populations. To achieve this goal in Lake Michigan, lake trout from several strains have been stocked since 1965. The stocked lake trout survive to maturity, but evidence of successful natural reproduction has been limited and no recruitment of naturally produced fish has occurred. Lake trout fry and eggs have been collected in Grand Traverse Bay (Peck 1979, Stauffer 1981, Wagner 1981) and along the south-eastern shore (e.g., Dorr et al. 1981, Jude et al. 1981). Most of these eggs and fry were found on artificial substrate such as power plant rock cribs and marina breakwalls. More recently, lake trout eggs have been found at several shallow, inshore sites in Lake Michigan (Marsden 1994). These sites provide accessible areas at which the factors that affect lake trout reproduction can be intensively studied.

The key to the failure of lake trout rehabilitation occurs at some point between spawning and recruitment of yearlings into the wild population. Lake trout stocked as yearlings survive well to the adult stage; thus, wild-spawned fry which survive beyond their first year of life have a high probability of recruiting to the adult population. Reproductive failure may be due to a number of factors, including the following: (1) adult fish may not find or recognize appropriate spawning areas, (2) traditional spawning areas may be degraded by anthropogenic inputs into the lakes, and be unable to incubate eggs successfully, (3) changes in the biota of the lakes, including the introduction of exotic species and changes in the population balance between lake trout and their natural predators, may result in excessively high overwinter loss of eggs or mortality of young fry, (4) contaminants accumulated in the tissue of female trout and subsequently transferred to the eggs may affect egg and fry development, and (5) the numbers of eggs produced may be insufficient (due to low adult stocks, high predation, or a combination of several factors) to produce a recruitable population of fingerlings. This study focuses primarily on items (2) and (3), and includes an assessment of egg survival to hatching and emergence.

Lake trout spawning areas are traditionally identified by the presence of ripe fish in the fall (Coberly and Horrall 1980, 1982; Thibodeau and Kelso 1990, Goodyear et al. 1982). However, this information provides only circumstantial evidence of spawning activity because lake trout may not necessarily spawn in the area where they are caught (e.g., Horns, 1991, Holey et al. in press). Direct evidence of lake trout spawning activity requires proof of eggs deposited on the substrate, either through observation by divers, or collection in devices set in or on the substrate. Visual evidence of lake trout aggregations using SCUBA or underwater video appears to be a good indicator of spawning activity in a particular location because lake trout are unlikely to be seen in high concentrations unless spawning is taking place nearby. At several sites where lake trout spawning is known to occur, large numbers of lake trout have been readily observed by divers; these fish did not avoid either remotely operated cameras or divers (Marsden and Krueger 1991; Neal Foster, USF&WS and John Fitzsimons, Canada Centre for Inland Waters, personal communications). Such close aggregations of trout appear to be indicative of spawning activity.

One objective of this study is to test the effectiveness of sonar and a remotely operated video to visualize spawning aggregations of lake trout.

The nearshore area of southwestern Lake Michigan offers relatively little spawning substrate that is adequate for egg incubation (Marsden 1994). Lake trout need deep (>15cm) interstitial spaces in cobble into which eggs can settle and be protected from predation and damage by water movements. Much of the southern floor of Lake Michigan is composed of hard clay, sand, and small gravel; cobble areas are rare, dispersed, and generally comprise only scattered rocks with few interstices. However, several human structures offer the equivalent of appropriate spawning substrate. These structures include breakwalls, water intake cribs, and the rocky rubble used to protect water intake pipes. Fishermen annually observe lake trout in fall aggregating around near-shore structures such as the Buffington Harbor and Port of Indiana breakwalls (Capt. Dan Carlson, personal communication). Higher numbers of eggs per trap-day have been collected at the Port of Indiana breakwall than at any of six natural sites where lake trout spawn along the southwestern shore; hatched fry were also caught in spring at the breakwall (Marsden 1994). The breakwall likely offers optimal incubation habitat because the substrate is deep and there has been a limited buildup of organic matter which would decrease interstitial water quality. We hypothesize that lake trout spawn on human structures because natural substrate is inadequate (insufficient or of poor quality), and human structures may be highly attractive due to their interstitial depth and water quality.

The potential use of artificial reefs as spawning sites for lake trout is currently receiving considerable attention (e.g., Habitat Workshop of the Great Lakes Fishery Commission RESTORE conference, Ann Arbor, MI, Jan. 1994; Army Corps of Engineers Habitat Conference, March 1994; EPA-funded feasibility study for an artificial reef near Sturgeon Bay). The use of human structures, or artificial reefs, by spawning lake trout may work for or against population restoration. These structures may offer suitable egg incubation habitat in areas where natural habitat is absent or degraded, and thus permit higher levels of reproductive success than would be possible on natural substrates. On the other hand, artificial reefs could be an attractive nuisance. Most human structures are built, as a consequence of their function, in shallow water (<15m). Many are also near or attached to the shore, and are thus readily accessible to fishermen. Shallow waters are also inhabited by a variety of egg predators in fall, and potential fry predators in spring. Slimy sculpins (*Cottus cognatus*) inhabit the interstitial spaces of rocky reefs and are a primary egg predator (Savino and Henry 1991, Scott and Crossman 1973). Crayfish (*Orconectes spp.*) also inhabit rocky reefs and consume lake trout eggs (Savino and Miller 1991, Horns and Magnusson 1981). In Lake Michigan, the recently introduced rusty crayfish (*Orconectes rusticus*) may be a more voracious predator than its less aggressive native counterparts (Olsen et al. 1991). Common carp (*Cyprinus carpio*) inhabit shallow waters, and have been observed to eat lake trout eggs at the Port of Indiana breakwall (Marsden, personal observations). In spring, alewife and yellow perch enter shallow water areas to spawn; alewife have been observed to eat lake trout fry in the wild, and could potentially decimate a newly emergent population of fry (Krueger et al., in press). Yellow perch (*Perca flavescens*) are known to eat lake trout eggs, though they are unlikely to eat hatched fry. All of these predators are unique to shallow areas; lake trout eggs spawned on reefs below 30m are vulnerable only to deepwater sculpins (*Myoxocephalus thompsonii*) and burbot (*Lota lota*). Shallow reefs also expose eggs to wave energy, and the reef substrate is vulnerable to fouling by zebra mussels. Thus, lake trout which are attracted to shallow artificial reefs to spawn may be vulnerable to several sources of mortality, including human predation, and their reproductive effort may be wasted. Another objective of this study is to examine the relative vulnerability of lake trout eggs and fry to predation by native and exotic species at natural and artificial spawning sites.

Study sites referred to in this report
Most of the work referred to in this report (the exception being IDOC gillnet sampling) was conducted at three sites. Gillnet sites not described on this list are identified by Loran coordinates when mentioned in the text and tables. Additional descriptions of the sites are given in Appendix 1.

Burns Harbor refers to an artificial, partly exposed deposit of cobble underlying the west breakwall of Burns Harbor, Port of Indiana, at Loran coordinates 33370/50315. The cobble bed at Burns Harbor is deep, fairly open, and forms a slope extending from the lake bottom at 12 m upward to a covering bed of 8-10 ton anchor stone at 5-7 m.

Fort Sheridan refers to a series of natural shoals of heavily infilled cobble, peaking at various depths from 5 to 8 m, lying in inshore waters east of Fort Sheridan, IL. In August 1995, egg bags were buried at Fort Sheridan at Loran coordinates 33295.1/49828.4.

Wilmette Reef R-2 refers to a natural shoal of heavily infilled cobble peaking at approximately 5m depth, located near a buoy at Loran coordinates 33283/49923 off Wilmette IL.

METHODS

Study 101: Assessment of methods for detecting lake trout spawning sites

Job 101.1: Gillnet for adult lake trout
In cooperation with IDOC, lake trout were sampled using 242 m graded mesh gillnets at six sites during the 1994 spawning season, including two inshore natural sites which had previously been used during a related project. Nets were set at Waukegan (Loran coordinates 33255/49745), Fort Sheridan, and Wilmette Reef R-2 on 12 October and 23 October 1995, and at Julian's Reef (Loran coordinates 332306/498752 for 28 m depth site, 332335/498748 for 37 m site), and Wilmette Reef R-4 (Loran coordinates 332704/499200) on 17 October and 15 November 1995. Nets were also set at Clemson Shoal (Loran coordinates 414833/873209) by Jeff Camalick on 17 Oct. 1994. All nets were set for 24 hours.

Job 101.2: Deploy ROV at spawning areas
During the 1994 spawning season, the LMBS remotely operated underwater video (ROV; Hydrobotics, Canada) was used to film spawning sites in efforts to record the presence of lake trout spawning aggregations. The ROV was operated on 27 October at Wilmette Reef R-2 and on 17 November and 16 December at Burns Harbor. Two strategies were used in 1994. First, the ROV was used to survey cobble substrate in areas where we believed lake trout would be present. These surveys usually lasted 30-60 minutes and concentrated on filming the bottom few

meters of the water column, where lake trout should be. Second, the ROV was "dropped" in the water over spots where we saw sonar echoes indicative of the presence of fishes. These excursions lasted for shorter periods of 10-20 minutes.

Job 101.3: Test sonar for detection of spawning aggregations
We performed sonar transects of the Burns Harbor site on four occasions during November - December 1994, including the dates of ROV work. In each case we traveled at low speed parallel to the breakwall at a distance of 20-50 m and looked for echoes from distinct objects that were 1-2 m above the substrate. Sonar echoes matching the search criteria were interpreted to represent fishes or aggregations of fishes.

Job 101.4: Set and retrieve egg collection devices
We deployed gangs consisting of 25 each of two devices, egg nets and egg traps (Horns et al. 1989, Marsden et al. 1991), designed to lie flat on the substrate and capture broadcast eggs. Two gangs of devices were set at Wilmette Reef R-2 from 6 October - 8 November 1994; two more were set from 8 November to 24 November. Two gangs of devices were set at Burns Harbor from 7 October to 7 November, and one gang was set from 7 November to 1 December. Numbers of live eggs, dead eggs, and egg chorions ("shells") present in the collecting devices were recorded.

Study 102: Comparison of spawning at natural and artificial sites

Job 102.1: Survey potential artificial spawning sites
Buffington Harbor breakwall was surveyed in July 1994 to determine whether appropriate substrate exists to support lake trout spawning. In August 1995, a strip of cobble stretching from nearshore to an intake crib approximately 0.75 miles offshore of a pump outbuilding approximately 2 km west of the Burns International Waterway was examined. The breakwall at Pastrick Marina was surveyed in August, 1995. Additional surveys were postponed due to boat repairs; remaining sites will be surveyed in late summer, 1995.

Job 102.2: Assess adult densities at natural and artificial sites
Adult densities at six natural sites were obtained from IDOC gillnetting (Job 101.1). Data on lake trout densities at artificial sites, including Burns Harbor and sites identified in Job 102.1 above, will be collected in cooperation with IDOC, Indiana DNR, and USACE in Chicago (contact: Phil Moy) in 1995 and 1996.

Job 102.3: Collect eggs using egg bags
Ten egg bags, which are devices designed to measure the cumulative deposition rates of lake trout eggs upon a substrate (Perkins and Krueger 1994), were deployed at Burns Harbor on 11 October 1994; eight were retrieved on 20 December 1994. An attempt was made to bury egg bags at Wilmette Reef R-2. However, an examination of the substrate (during a SCUBA dive) revealed that there was insufficient depth of cobble to bury the bags.

Ten egg bags were buried at Fort Sheridan on 23 August 1995. Eighteen egg bags will be deployed at Burns Harbor after the breakwall repair work there is completed (expected completion date: 1 October 1995).

Study 103: Assessment of primary sources of egg and fry mortality

Job 103.1: Collect lake trout egg and fry predators (fish)

We collected the guts of fishes gillnetted during the fall 1994 gillnetting activities described in Job 101.1. We also collected whole fishes during trawling operations in the spring of 1995, and during fry trapping operations conducted during the same period. Guts and whole fishes were fixed in 90% ethanol for storage.

Job 103.2: Analyze contents of fish stomachs

Guts of 155 potential egg predators and 135 potential fry predators, collected in Job 103.1, were examined to determine whether contents were present. If contents were present, they were sorted and identified. We first counted lake trout eggs, where present; we also counted fishes, zebra mussels, crayfish, parasites, and rocks or other inorganic matter that may have been present. Any fish remains were categorized as sculpins or others.

Job 103.3: Rear wild-spawned lake trout eggs

Two sets of lake trout eggs were incubated. One set consisted of two batches of wild-spawned eggs collected on 1 December and 20 December 1994; these eggs were reared first in ventilated mesh boxes and then in flat trays. The other set consisted of one large batch of eggs stripped from feral adults on 16 November 1994; these eggs were distributed among four flat trays for incubation.

Boxes and trays of eggs were reared in incubation trays in a raceway with a constant raw water flow. Boxes and trays were usually picked daily to remove eggs infected with fungus. Dead or fungus-infected eggs were removed to Stockard's solution and later examined under a dissecting microscope to determine at what stage the eggs succumbed. Developmental state was categorized as follows: indeterminate, unfertilized, pre-eyed, eyed, and hatched. Eggs that contained no visible embryonic matter were categorized as unfertilized, while pre-eyed and eyed eggs contained embryonic matter (presence of eyes separating the 'pre-eyed' from 'eyed'). Eggs were classified as semi-hatched if the chorion was broken and some part of a larval trout was protruding from the chorion. Eggs were described as indeterminate if there was doubt whether they contained embryonic matter, or if they were degraded by fungus or mechanical damage and their developmental state could not be assessed.

Study 104: Assessment of sac-fry and emergent fry production

Job 104.1: Set and retrieve fry traps at spawning sites

Thirty-six fry traps (Marsden et al. 1988) were deployed at an artificial reef at the Burns Harbor site on 24 April 1995. The traps were retrieved, examined for contents, and replaced on 29 April

1995, 12 May 1995, and 22 May 1995, and then removed on 2 June 1995. No natural site which is likely to yield fry, based on egg collection data, has yet been identified.

Job 104.2: Trawl for post-emergent fry near spawning sites
Trawling operations were conducted at Burns Harbor on 12 May 1995, using a 3.3 m semi-balloon otter trawl towed behind a 5.5 m Boston Whaler. Tows were carried out parallel to the breakwall at a distance of 60-150 m, in depths of 10-15 m.

RESULTS

__Study 101: Assessment of methods for detecting lake trout spawning sites__

Job 101.1: Gillnet for adult lake trout
A total of 534 lake trout were captured in gill nets. Gillnet lifts generally yielded more lake trout later in the fall (24 October, 16 November), than earlier (13 October, 18 October), and more fish were caught offshore than nearshore (Table 1, Fig. 1). The most fish caught at a single site were caught at Julian's Reef on 16 October 1994.

Job 101.2: Deploy ROV at spawning areas
In all, only one lake trout was discernible in 3.25 h of ROV video taken during the 1994 spawning season: a sluggishly swimming individual of approximately 60 cm SL that swam in front of the camera at Burns Harbor on 16 December 1994. Water transparency at Burns Harbor was generally poor during the 1994 spawning season, due to frequent severe storms. In no case during 1994 were we able to directly connect sonar observations of "fish" echoes to fishes observed on video.

Job 101.3: Test sonar for detection of spawning aggregations
Sonar observations yielded numerous distinct above-substrate echoes during transects at Burns Harbor in November and December 1994. In most cases these were isolated, discrete echoes indicative of individual fishes, but a few clusters of smaller echoes were observed, especially off the northwest corner of the breakwall, where the predominantly north-south running west breakwall meets the predominantly east-west running north breakwall.

Job 101.4: Set and retrieve egg collection devices
Gangs of egg nets and egg traps retrieved at Wilmette Reef R-2 on 8 November contained 5 egg chorions, while those retrieved on 14 November contained 3 live eggs and 7 egg chorions (Table 2). Gangs retrieved at Burns Harbor on 7 November contained 8 live eggs, 1 dead egg, and 1 egg chorion; the single gang collected on 1 December contained 77 live eggs, 41 dead eggs, and 27 egg chorions.

Study 102: Comparison of spawning at natural and artificial sites

Job 102.1: Survey potential artificial spawning sites

Of the artificial sites visited, only Burns Harbor and the cobble strip 2 km west of Burns International Waterway appear to have good potential as lake trout spawning habitat. The Burns Harbor site, which was surveyed in an earlier study, consists of a extensive deposition of cobble bedding stone at the base of the outer side of the west breakwall forming Burns Harbor. The cobble varies from an estimated 0.5 to 2.5 m deep, with open interstitial spaces and a heavy covering of zebra mussels. The substrate over the intake west of Burns International Waterway consists of a convex mound of cobble extending 25-75cm above the surrounding sand, heavily infilled with sand and overgrown with zebra mussels, that extends from shallow water less than 4 m deep out to a crib located in a depth of approx. 8.5 m. We surveyed at least 150 m of the cobble strip and found that many mottled sculpins and johnny darters (*Etheostoma nigrum*) inhabit it. We were initially led to investigate the site by anecdotal reports of fisherman who describe the site as an excellent lake trout angling spot during the autumn months. Observations of all sites visited are summarized in Appendix 1.

Job 102.2: Assess adult densities at natural and artificial sites

No gillnet assessments of adult lake trout densities have been undertaken at artificial sites, as yet. We expect that these data will be collected in 1995 and 1996.

Job 102.3: Collect eggs using egg bags

Eight egg bags retrieved at Burns Harbor on 20 December 1994 yielded 502 live eggs, 240 dead eggs, and 98 egg chorions. We found both of the remaining bags in the following spring, but recovered only one, having planned to use the remaining bag still in the field as a datum around which to deploy bags during the 1995 spawning season. Unfortunately, it is likely that the bag will have been buried during the breakwall repair work now underway. Ten egg bags were buried at Fort Sheridan in August, and we plan to bury bags at one or more other sites (including Burns Harbor) before the commencement of spawning this year.

Study 103: Assessment of primary sources of egg and fry mortality

Job 103.1: Collect lake trout egg and fry predators (fish)

Egg predators

Guts of 56 burbot, three brown trout, one chinook salmon, 55 lake trout, one carp, one freshwater drum, and 37 yellow perch were collected during gillnet operations on lake trout spawning reefs during October - November 1994.

Fry predators

Twenty-nine alewife (*Alosa pseudoharengus*) and one johnny darter (*Etheostoma nigrum*) were collected by trawling at Burns Harbor, Port of Indiana, on 12 May 1995. In addition, 105 small mottled sculpins (all less than 75 mm SL) were collected in fry traps.

Job 103.2: Analyze contents of fish stomachs

Egg predators

Of 155 fishes examined, 3.87% contained lake trout eggs; these fishes were burbot and lake trout (Tables 3 and 4).

Fry predators

Ninety-seven sculpin guts examined contained either nothing (67%) or various amphipod and cladoceran remains (Tables 3 and 4). Twenty-nine alewife guts contained either nothing (86%) or unidentifiable material, with one exception: a 148 mm (TL) alewife had consumed a zebra mussel or zebra mussel shell fragment.

Job 103.3: Rear wild-spawned lake trout eggs

Wild-spawned eggs

Two groups of eggs were incubated: 77 eggs from the 1 December 1994 egg net/egg trap collection at Burns Harbor, and 502 eggs found in egg bags lifted at Burns Harbor on 20 December 1994. The smaller group was initially incubated in a ventilated plastic box, whereas the larger group was incubated in a mesh-lined floating wooden tray. The smaller group was abandoned as a separate entity on 31 January 1995 and combined with the larger in a tray. Before the groups were merged, dead eggs were picked from the small collection on seven dates, yielding 61 dead eggs (Table 5). A small but unknown number of eggs in the small group was lost after becoming wedged between the mesh and the bottom of the incubation box: these losses were not noticed until after the tray was removed from service. Dead eggs were picked from the larger group on thirteen occasions between 20 December 1994 and 31 January 1995, yielding 101 dead eggs. Dead eggs were picked from the combined egg tray on twelve occasions between 31 January 1995 and 26 March 1995, yielding 117 dead eggs. An unknown number of eggs was destroyed in a water system malfunction that occurred on 25 March 1995; these eggs were not examined after death.

In all, 278 dead eggs were examined. Of these, 100 were described as "indeterminate" because mechanical damage or opacity of the contents prevented evaluation of their developmental stage. The proportion of late-stage eggs (eyed and semi-hatched) increased after 23 January 1995; however, there were no apparent patterns in the death rates either instantaneously or over the whole incubation period, except in the smaller (1 December 1994) group prior to consolidation. Higher overall mortality rates in this group were probably due to poor water flow through the plastic incubation box.

The combined tray of eggs from egg bags yielded 135 live fry through 18 April 1995; these fry were frozen for subsequent genetic analysis (Appendix 2). We computed a minimum overall fertilization rate for the samples we incubated by summing observed numbers of pre-eyed eggs (21), eyed eggs (77), semi-hatched eggs (43), and fry (135), and dividing this figure by the total number of eggs incubated (579). This calculation yielded a conservative fertilization rate of 47.7% for the eggs that we incubated; it is likely that many of the eggs whose status we could not evaluate ('indeterminate' category) were also fertilized.

Stripped eggs
We noted no differences in rates of hatching, rates of abnormality, or rates of fry development between trays of stripped eggs and the small sample of wild-spawned eggs we reared. However, whereas the stripped eggs began to eye in mid-January 1995, the wild-spawned eggs began to eye on 26 December 1994, suggesting (assuming equality of development rates) a spawn date of approx. 1 November 1994.

Study 104: Assessment of sac-fry and emergent fry production

Job 104.1: Set and retrieve fry traps at spawning sites
Overall, fry trapping operations yielded five emergent lake trout fry and three egg chorions (Table 2). Three emergent fry, 1 dead emergent fry, and one egg chorion were collected on 29 April 1995, one live emergent fry and two egg chorions were collected on 12 May 1995, and no lake trout fry or egg chorions were collected on 22 May or 2 June 1995. The fry captures were widely distributed among the traps, and on 29 April spanned more than 150 m of reef. In addition, fry trapping operations yielded 105 small mottled sculpins, as described in Jobs 103.1 and 103.2 above. No fry traps were lost in 1995.

Job 104.2: Trawl for post-emergent fry near spawning sites
No lake trout fry were captured during trawling operations in 1995. Five trawl hauls yielded (in total) 29 alewife and one johnny darter as described in Jobs 103.1 and 103.2 above.

DISCUSSION

Index gillnetting of lake trout on putative spawning sites captured higher numbers of trout at offshore versus nearshore sites, and generally higher numbers were captured later in the season than earlier (Fig. 1a and 1b). The largest total catch of fish was at the two sites on Julian's Reef. Egg collections at Wilmette R-2 during the period when gillnetting took place yielded only 0.005 eggs/trap-day, in contrast to 0.1 eggs/trap-day at Burns Harbor, an artificial site. Clearly, correlation of egg trapping success with presence of lake trout would be valuable. State agency support and assistance is needed to conduct such collections; this assistance will be sought in 1995.

Lake trout spawning aggregations were difficult to detect by remotely operated vehicle (ROV) video under the conditions that prevailed at Burns Harbor in 1994. Only one lake trout was seen during 2.25 h of ROV video collected on 17 November and 16 December 1994, and no lake trout were seen on 1.0 h of ROV video collected at Wilmette Reef R-2 on 27 October. Our efforts were hampered by poor water transparency on most field days at the Burns Harbor site in 1994. Extended stretches of good water transparency and weather at Burns Harbor may permit us to refine the remote sensing method of spawning aggregation detection in 1995.

Aggregations of fishes observed by sonar at Burns Harbor during fall 1994 could not be clearly identified as lake trout, and some may have been carp. Sonar observations were obtained at

Burns Harbor on four occasions during November-December 1994, including both days when ROV video was collected. However, no echoes of fishes obtained by sonar could be unambiguously associated with simultaneously collected video. We plan to continue this investigation in conjunction with our studies of ROV video, and in addition we plan to use diver-observers to confirm sonar sightings in the field.

Of several artificial sites surveyed, Burns Harbor had the best and most extensive deposits of cobble suitable for lake trout spawning. This cobble is currently limited to the west harbor breakwall; however, the structure of the north wall substrate will change substantially after repairs undertaken by the Army Corps of Engineers during summer 1995 are completed. During an August visit to the site, work was underway to repair the west breakwall and heavy equipment was in use directly over our study site. Of the natural sites from Highland Park to Waukegan we examined during the summer of 1995, only Fort Sheridan and a portion of Highland Park appeared suitable for lake trout spawning.

Examination of gut contents of fish caught on spawning sites in fall and spring revealed that only burbot and lake trout consumed lake trout eggs; both of these species are known lake trout egg predators (Scott and Crossman 1973). At natural sites in southern Lake Michigan; 11% of burbot and 3.64% of lake trout stomachs contained lake trout eggs. We have not yet identified fry predators at either natural or artificial sites. Earlier spring sampling, and sampling using additional techniques such as spearfishing, will likely yield larger catches of potential egg and fry predators in the next two segments of the project.

Wild-spawned eggs reared in the laboratory developed normally, with 23% (135 of 579) of the eggs collected in fall yielding sac or emergent fry in the spring. Given the physical jarring and abuse that these egg received in the collection gear and during processing, and the fact that they were not reared in appropriate hatching trays, this hatch rate is respectable compared with rates obtained in a National Fish Hatchery (54% in chilled water, 18% in ambient temperature water; Ostergaard 1987). Results obtained during this first year support our working hypothesis that there is no difference in viability between fertilized stripped eggs and wild-spawned eggs. Furthermore, the conservative fertilization rate estimate of 47.7% implies that normal spawning activity is occurring, and not simply the broadcast of unfertilized eggs by isolated females. No obvious signs of contaminant or nutrient deficiency syndromes were noted.

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Table 1. Summary of lake trout collected by gillnet sampling during 1994 spawning season.

Lift date	Site	Loran coordinates	Depth (m)	Number of lake trout
13 October	Waukegan	33255/49745	5.5	3
24 October	Waukegan	33254/49744	5.5	17
13 October	Fort Sheridan	33290/49833	11	1
24 October	Fort Sheridan	33289/49831	11	30
13 October	Wilmette Reef R-2	33313/49938	12.9	16
24 October	Wilmette Reef R-2	33313/49938	11-12.9	69
18 October	Julian's Reef	332306/498752	27.6	53
16 November	Julian's Reef	332313/498752	27.6	128
18 October	Julian's Reef	332335/498748	37	65
16 November	Julian's Reef	332313/498741	27.6-37	51
18 October	Wilmette Reef R-4	332704/499200	11-15	15
16 November	Wilmette Reef R-4	332777/499193	12.9-18.4	85
17 October	Clemson Shoal	414833/873209	12	1

Table 2. Lake trout eggs and fry collected in the fall of 1994 and spring of 1995 in southwestern Lake Michigan. Calculation of captures per trap-day do not include chorions.

Site	Date set	Date lifted	Collection gear	# Devices retrieved	Live egg	Dead eggs	Chorions	Fry	Eggs/fry per trap-day
1994									
Wilmette Reef	6 Oct.	8 Nov.	nets & traps	50 ea.	0	0	5	na	0
R-2	8 Nov.	14 Nov.	nets & traps	50 ea	3	0	7	na	0.005
Burns Harbor	7 Oct.	7 Nov.	nets & traps	50 ea.	8	1	1	na	0.003
	7 Nov.	1 Dec.	nets & traps	25 ea.	77	41	27	na	0.098
	11 Oct.	20 Dec.	egg bags	8	502	240	98	na	1.325
1995									
Burns Harbor	24 April	29 April	fry traps	36	0	0	1	4	0.022
	29 April	12 May	fry traps	36	0	0	2	1	0.002
	12 May	22 May	fry traps	36	0	0	0	0	0
	22 May	2 June	fry traps	36	0	0	0	0	0

Table 3. Detailed breakdown of gut contents of 155 fishes collected during fall 1994 lake trout gillnet sampling.

			Percent of fishes containing each of the following:					
Species	N	Percent not empty	Lake trout eggs	Fish	Zebra mussel	Crayfish	Parasite	Rocks, etc.
burbot (*Lota lota*)	56	62.5	11.5	48.2	1.8	1.8	8.9	1.8
lake trout (*Salvelinus namaycush*)	55	21.8	3.6	18.2	0	0	0	0
yellow perch (*Perca flavescens*)	37	64.8	0	29.7	8.1	2.7	0	0
Brown trout (*Salmo trutta*)	3	66.7	0	33.3	0	0	0	0
unidentified salmonid	1	100	0	100	100	0	0	0
chinook salmon (*Oncorhynchus tshawytscha*)	1	100	0	0	0	0	0	0
carp (*Cyprinus carpio*)	1	100	0	0	0	0	0	100
freshwater drum (*Aplodinotus grunniens*)	1	100	0	0	0	0	0	0

Table 4. Summary of gut contents of 274 potential lake trout (LT) egg and fry predators collected during 1994-1995 gillnet, egg collection, and fry trapping operations.

Date	Site	Species	N	Stomach contents	Empty guts	Guts with LT eggs or fry
24 Oct. 1994	Fort Sheridan	*Cyprinus carpio*	1	small rocks	0%	0%
		Salmo trutta	3	fishes, including sculpins	33.3% (1)	0%
		Salvelinus namaycush	2	empty	100% (2)	0%
		Unident. salmonid	1	sculpin; *D. polymorpha* shell fragments	0%	0%
	Waukegan	*Aplodinotus grunniens*	1	fish	0%	0%
		Perca flavescens	2	fishes, including sculpins; crayfish	0%	0%
		Salvelinus namaycush	3	fishes	33.3% (1)	0%
	Wilmette WR-2	*Oncorhynchus tshawytscha*	1	fish	0%	0%
		Salvelinus namaycush	24	fishes; LT eggs	75% (18)	8.3% (2) with eggs
16 Nov. 1994	Julian's Reef	*Lota lota*	45	LT eggs; fishes; parasites; small rocks; *D. polymorpha* shell fragments	48.8% (22)	11.1% (5) with eggs
	Julian's Reef	*Salvelinus namaycush*	17	fishes	82.4% (14)	0%
	Wilmette WR-4	*Lota lota*	1	LT eggs (41); *D. polymorpha* shell fragments	0%	100% (1) with eggs
		Perca flavescens	35	fishes, incl. sculpins; *D. polymorpha* shell fragments	34.3% (12)	0%
		Salvelinus namaycush	9	empty	100% (9)	0%
29 Apr 1995	Burns Harbor (fry trapping)	*Cottus bairdi*	19	unidentifiable matter; arthropods; amphipods	68.4% (13)	0%
12 May 1995	Burns Harbor (fry trapping)	*Cottus bairdi*	8	cladocerans; amphipods	50% (4)	0%
12 May 1995	Burns Harbor (3 trawl hauls)	*Cottus bairdi*	27	cladocerans; amphipods; unidentifiable invertebrates	59.3% (16)	0%
		Alosa pseudoharengus	29	unidentified arthropods; unidentifiable matter; *D. polymorpha* shell fragments	86.2% (25)	0%
		Etheostoma nigrum	2	empty	100% (2)	0%
22 May 1995	Burns Harbor	*Cottus bairdi*	43	cladocerans; amphipods; wood chip	60.4% (26)	0%
		Notropis hudsonius	1	empty	100% (1)	0%

Table 5. Post-mortem examination of dead eggs removed during incubation of wild-spawned lake trout eggs collected at Burns Harbor in 1994. Incubation groups were: 1=egg bag collection of 20 December 1994 (502 live eggs); 2=egg net/egg trap collection of 1 December 1994 (77 live eggs); 3=combination of both egg bag and net/trap collections (groups combined on 31 January 1995). Dashes indicate absence of eggs at a given developmental state.

			Developmental State				
Incubation group	Date eggs removed	Indeterminate	Unfertilized	Pre-eyed	Eyed	Semi-hatched	Total
1	15-Dec-94	-	1	-	-	-	1
1	21-Dec-94	6	-	-	-	-	6
1	23-Dec-94	1	-	1	-	-	2
1	24-Dec-94	-	1	-	-	-	1
1	6-Jan-95	1	-	-	-	-	1
1	13-Jan-95	2	-	-	-	-	2
1	30-Jan-95	1	-	-	-	-	1
1	31-Jan-95	-	7	14	26	-	47
2	21-Dec-94	8	-	-	1	-	9
2	23-Dec-94	1	1	-	-	-	2
2	24-Dec-94	1	-	-	-	-	1
2	26-Dec-94	4	-	-	-	-	4
2	28-Dec-94	2	-	-	-	1	3
2	30-Dec-94	3	-	1	-	-	4
2	3-Jan-95	5	-	1	-	-	6
2	6-Jan-95	13	-	1	-	-	14
2	13-Jan-95	18	-	-	-	-	18
2	18-Jan-95	2	-	-	-	-	2
2	23-Jan-95	-	8	-	1	3	12
2	30-Jan-95	7	-	1	8	9	25
3	1-Feb-95	4	-	-	3	7	14
3	2-Feb-95	-	-	-	-	1	1
3	10-Feb-95	7	-	-	-	2	9
3	13-Feb-95	6	-	-	5	4	15
3	14-Feb-95	1	-	-	-	1	2
3	16-Feb-95	4	-	2	-	-	6
3	18-Feb-95	-	8	-	3	2	13
3	19-Feb-95	1	-	-	1	-	2
3	22-Feb-95	2	-	-	4	7	13
3	28-Feb-95	-	4	-	18	3	25
3	6-Mar-95	-	7	-	7	2	16
3	26-Mar-95	-	-	-	-	1	1
Totals:		100	37	21	77	43	278

Figure 1a. Gillnet captures of lake trout at three offshore sites on two dates in fall, 1994

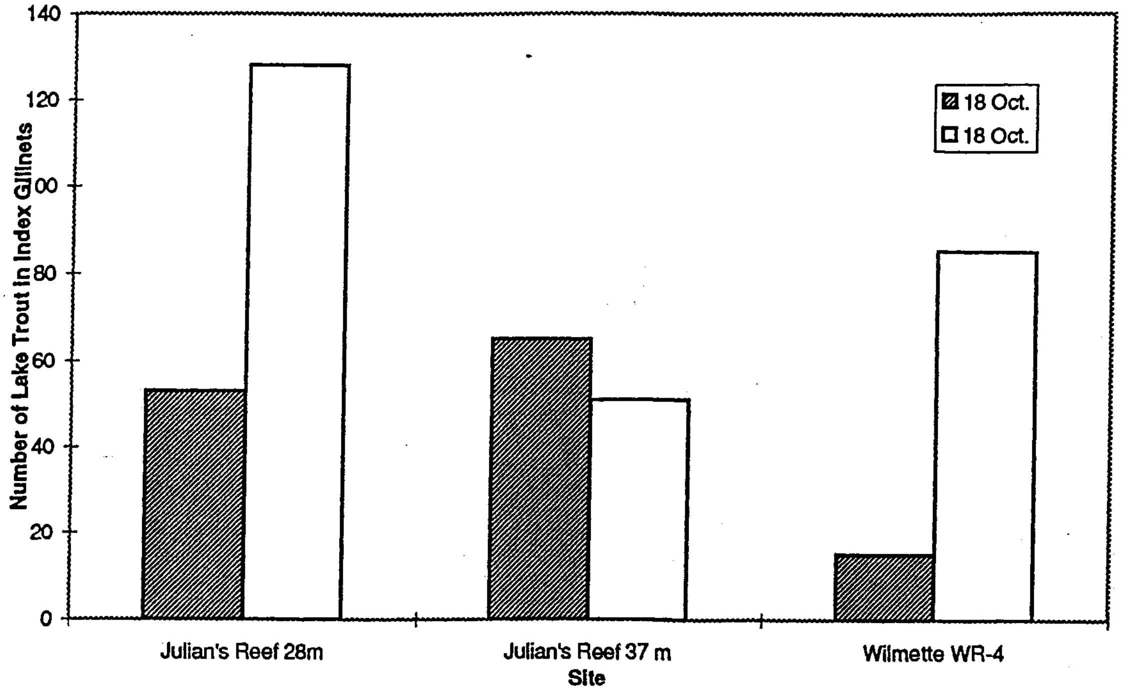
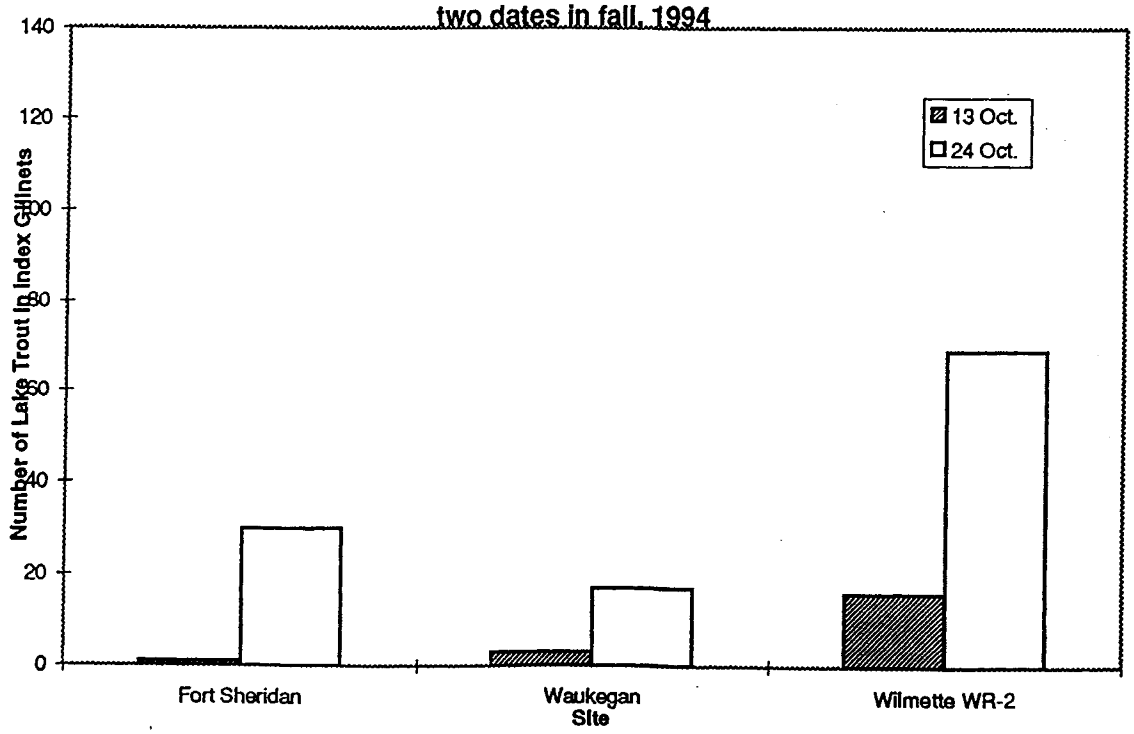


Figure 1b. Gillnet captures of lake trout at three nearshore sites on two dates in fall, 1994



APPENDIX 1

Summary of potential lake trout spawning sites visited during 1994-1995, with comments about the suitability of observed substrate for lake trout spawning.

Buffington Harbor. The outer breakwall was surveyed, and consists of armor stone laid directly on a sand/silt substrate. Occasional piles of cobble bedding stone were found between the armor stones; in places these steeply-sloped piles covered up to 100 m^2. The base of the breakwall, including the cobble piles, was at 7-8 m depth. Zebra mussel colonization was not as dense as at Burns Harbor. The site has poor potential for lake trout spawning, primarily because of the limited size of the cobble areas.

Burns Harbor. We explored the outer side of the breakwall which forms Burns Harbor on several dives conducted during the fall of 1994 and in May 1995. The breakwall consists of a thick layer of bedding stone, which is cobble, and a thicker top layer of armor stone, each piece of which weighs 2-10 tonnes. The west wall offers excellent spawning substrate for lake trout because the bedding stone varies from 0.5 to 2.5 m in depth and has fairly open interstitial spaces, and because there are large areas of it to the west of the breakwall that are not covered by armor stone. A strip of cobble, 10-30 meters in width, runs for more than 200m from just south of the northwest corner of the breakwall to shallow water north of the junction of the stone breakwall and the sheet piling portion of the wall. At the deep end, the strip of bedding stone lies in depths of 5-14 m, while at the shallow end it lies in depths of 3-6 m. The cobble bedding stone is, however, heavily encrusted with zebra mussels, up to 2 cm thick in places. The impact of the mussels on egg depostion and incubation is unknown; the mussels may prevent eggs from settling into interstitial spaces, and their effluvium (feces and pseudofeces) may degrade the water quality around the eggs.

In contrast to the west wall, there is little to no cobble along the outer side of the north wall of Burns Harbor. We surveyed the westernmost third of the wall by diving, and noted that there is little or no cobble extending beyond the armor stone in most places along the wall. Thus, at the base of most of the wall is level sand. This is the area where the Army Corps of Engineers plans to build new, submerged breakwall structures beginning in 1995.

Calumet Harbor. We explored portions of Calumet Harbor during several dives conducted in the fall of 1994 and in 1995. The wall at the north end of Calumet Park consists of approximately 150 m of sheet piling buttressed by bedding stone, running in a south to north direction, followed by approximately 1 km of armor stone wall with little bedding stone, if any, exposed beneath its edge. Natural low-rise bedrock reefs are present to the east of the wall: one line of reefs runs in along a predominantly north-south axis at a distance of 50-100 m from the wall. We judge the site to have poor potential for lake trout spawning because the cobble deposits are heavily infilled and lie in water less than 5 m deep (in fact, most of the cobble regions lie in 3 or fewer meters of water). High densities of rusty crayfish (*Orconectes rusticus*) and round goby (*Neogobius melanostomus*) were noted, as well as low densities of sculpins.

Calumet Harbor Pier
The base of the south side and the eastern half of the north side of the pier near the Calumet ramps is piled with smooth cobbles 5-35cm in diameter. The largest area of cobble appears to be over 1.5 m deep, with reasonably clear intersitial spaces. The area is heavily colonized with zebra mussels and round gobies. The substrate is ideal for egg incubation, but the shallow water depth (2-4 m) and proximity to shore may not attract spawning trout.

Fort Sheridan. We explored four reefs at Fort Sheridan on 23 August 1995, all within a mile of Loran 33295.1/49828.4. The reefs consist of infilled natural cobble infrequently studded with angular boulders and stretches of sand. All of the reefs that we explored rose from a flat bottom at 8-9 m to peaks at 5-7 m. The individual reefs that we observed were small; all spanned less than 500 m in length. Sonar transects of the reefs and intervening regions suggest that some of the flat regions are covered by at least a surface layer of cobble. We judge the reefs to have moderate potential as lake trout spawning reefs.

Highland Park. We explored a large, flat-topped reef at Highland Park on 5 September 1995. This reef consisted of large areas of bedrock, areas of cracked and broken bedrock where there were large flat pieces of rock measuring several meters on each side strewn about, and smaller areas of rounded cobble. The cobble was infilled. The reef rose from an uneven but generally flat bottom at 8-14 m, and we observed a peak of 5.5 m. We transected a portion of the reef more than 500 m by 500 m, making the Highland Park reef larger than the combined areas of all the reefs we observed at Fort Sheridan. We judge that the area has some potential as a lake trout spawning site; in this regard it is similar to the reefs at Fort Sheridan.

Intake line, west of Burns International Waterway. The substrate over the intake consists of a convex mound of cobble extending 25-75cm above the surrounding sand, heavily infilled with sand and overgrown with zebra mussels, that extends from shallow water less than 4 m deep out to a crib located in a depth of approx. 8.5 m. Approximately 150 m of the cobble strip were surveyed. The substrate is inhabited by numerous crayfish, mottled sculpins, and johnny darters (*Etheostoma nigrum*).

Pastrick Marina. The outer side of the breakwall west of the harbor entrance was briefly explored on 7 August 1995 using skin diving equipment. The base of the breakwall is a thick layer of cobble bedding stone with deep interstitial spaces. The area is richly inhabited by crayfish, small and largemouth bass, freshwater drum, and carp. The substrate would make excellent spawning habitat, but the depth of the substrate (2-6m) makes it unlikely that this site is heavily used by spawning lake trout. Fishermen had no information about presence of absence of lake trout in the fall.

Wilmette Reef R-2. The reef is a natural shoal of heavily infilled cobble peaking at approximately 5m depth, located near a buoy at Loran coordinates 33283/49923 off Wilmette IL.

APPENDIX 2

A genetic examination of the 135 fry which were successfully hatched from wild-caught eggs was conducted in collaboration with Dr. Bernie May at Cornell University with funding from the U. S. Fish and Wildlife Service in Green Bay. We determined the parental origins of the fry using mixed-stock analysis and data from 18 polymorphic allozyme loci. Almost 50% of the parental population was Superior strain, 22-26% was Seneca strain, and the remaining sizable contribution (20-27%) was from the Green Lake strain. Additional details of this study are available in a draft INHS report by J. E. Marsden and B. May, entitled "Identification of parental strains of lake trout eggs captured during spawning in Lake Michigan".

During the winter of 1994-5 we conducted experiments to determine to what extent a new non-indigenous species, the round goby, may pose a threat to interstitial deposits of lake trout eggs. Preliminary results suggest that gobies easily penetrate cobble substrate and readily consume lake trout eggs. Consumption rates of lake trout eggs and fry by gobies were equal to or greater than those of sculpins in laboratory and field experiments reported by other investigators. Further studies directly comparing the performance of round gobies and mottled sculpins are planned for the winter of 1995-96.

We are also planning to undertake a new study in 1995 designed to elucidate the effect that zebra mussels and deposits of mussel pseudofeces have on interstitial water quality and the development of lake trout eggs. We will construct cribs of cobble substrate in laboratory raceways and incubate stripped lake trout eggs in them while measuring interstitial dissolved oxygen, pH, and egg mortality rates.