ILLINOIS NATURAL HISTORY SURVEY

Reproductive Success of Stocked Lake Trout in Southwestern Lake Michigan

F-125-R-2

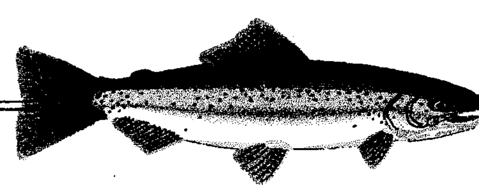
Annual Report
to
Illinois Department of Natural Resources

Center for Aquatic Ecology

Michael A. Chotkowski and J. Ellen Marsden

Illinois Natural History Survey
Lake Michigan Biological Station
400 17th Street
Zion, Illinois 60099

September 1996



Aquatic Ecology Technical Report 96/9

Reproductive Success of Stocked Lake Trout in Southwestern Lake Michigan

Second Annual Report, for the period
July 1, 1995 - June 30, 1996

Michael A. Chotkowski and J. Ellen Marsden

Lake Michigan Biological Station
Center for Aquatic Ecology, Illinois Natural History Survey

Submitted to
Division of Fisheries, Illinois Department of Natural Resources
in fulfillment of the reporting requirements of
Federal Aid Project F-125-R

J. Ellen Marsden
Principal Investigator
Center for Aquatic Ecology

David P. Philipp
Center Director
Center for Aquatic Ecology

September 1996

This study is conducted under a memorandum of understanding between the Illinois Department of Natural Resources and the Board of Trustees of the University of Illinois. The actual research is performed by the Illinois Natural History Survey, a division of the Illinois Department of Natural Resources. The project is supported through Federal Aid in Sport Fish Restoration by the U.S. Fish and Wildlife Service, the Illinois Department of Natural Resources, and the Illinois Natural History Survey. The form, content, and data interpretation are the responsibility of the University of Illinois and the Illinois Natural History Survey, and not the Illinois Department of Natural Resources.

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

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 fall of 1995 we continued our investigation of the intensity of spawning at a breakwater in Indiana by egg netting and trapping, and by deploying egg bags (a method of estimating the cumulative rate of egg deposition over a substratum). In the spring of 1996 we conducted diver surveys of new substrate deposited at the site by the Army Corps of Engineers. We estimated the densities of emergent fry over both old and new substrate at the same Indiana site by deploying fry traps during the spring of 1996 and by trawling for fry during the same period. During October 1995 through June 1996 we collected egg and fry predators by gillnetting, trawling, and trapping, and examined the gut contents of lake trout, alewife, and sculpin samples that were obtained. During the winter of 1995-1996, we initiated experimental studies of the effect of zebra mussel fouling on incubation of lake trout eggs (a study postponed until next winter by mechanical problems) and completed a study of the comparative foraging success of round gobies (*Neogobius melanostomus*) and mottled sculpin (*Cottus bairdi*) on lake trout eggs and fry over various particulate substrata in the laboratory.

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

1. Lake trout deposited more eggs at Burns Harbor (an artificial site: 0.691 eggs/device-day) than at Fort Sheridan (a natural site: <0.001 eggs/device-day), as indicated by sampling using gangs of egg nets and egg traps.

2. Deposits of cobble suitable for lake trout spawning are extensive at the Burns Harbor site, and have increased dramatically because of repairs undertaken by the Army Corps of Engineers during 1995 and 1996 as part of an ongoing breakwater rehabilitation project. Two new, disjunct underwater reefs with substantial lake trout spawning habitat have been built to date, and both new reefs hosted spawning lake trout during the fall of 1995 (as indicated by captures of pre-emergent lake trout fry during spring 1996).

3. None of 73 fishes of 6 species captured during 1995 IDNR index gillnetting of natural lake trout spawning sites had recently consumed lake trout eggs. During spring trawling and trapping operations, we captured 428 potential fry predators, including alewife (*Alosa pseudoharengus*) and mottled sculpin (*Cottus bairdi*), at Burns Harbor, but none contained lake trout fry.

4. Preliminary laboratory experiments designed to explore the potential for the exotic round goby (*Neogobius melanostomus*) as predators of lake trout eggs and fry at Burns Harbor and other sites revealed no substantial differences between round gobies and mottled sculpin, a known egg and fry predator. In conjunction with other knowledge, our results suggest that round gobies might severely impact lake trout reproductive efforts at Burns Harbor, when gobies become abundant there.

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 breakwaters. 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, due to 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. 1995). 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 which 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 end 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 breakwaters, 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 Burns Harbor breakwaters (Capt. Dan Carlson, personal communication). Higher numbers of eggs per trap-day have been collected at the Burns Harbor breakwater than at any of six natural sites where lake trout spawn along the southwestern shore; hatched fry were also caught in spring at the breakwater (Marsden 1994). The breakwater 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 in southwestern Lake Michigan (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 have positive or negative implications for the goal of 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 Burns Harbor breakwater (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., 1995). 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. One exotic species, the round goby *Neogobius melanostomus*, has moved to the forefront as a potential predatory threat to lake trout eggs and fry. The round goby became established in southern Lake Michigan in 1993, and has since become very dense (up to 50 adults and YOY juveniles per square meter, unpubl. data) at sites near Calumet Harbor, which lies on the Illinois/Indiana border. The center of the round goby's range in Lake Michigan is only about 30 km from an important lake trout spawning site at Burns Harbor, Indiana. Round gobies are ecologically similar to mottled sculpin (*Cottus bairdi*), and because they have shown a capacity to achieve densities far higher than those observed for mottled sculpin (which rarely exceed 15 adults and YOY juveniles per square meter in southern Lake Michigan), we are concerned about their potential to exert predatory pressure on lake trout eggs and fry when they arrive at Burns Harbor in the near future.

Study sites referred to in this report

Most of the work referred to in this report (the exception being IDNR 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 breakwater of Burns Harbor, 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. The Army Corps of Engineers is presently building new reefs north of the east limb of the breakwater, and has modified the west breakwater by addition of new rubble substrate.

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.

Waukegan Wire Mill refers to a water intake line and crib located approximately 1.5 km SSW of the entrance to the north basin of Waukegan Harbor (42º 20.243'N, 87º 49.089'W), near a paint factory. The intake line extends for a distance of approximately 1 km eastward from shore, ending in a circular intake crib, composed of quarried cobble, that lies in approximately 8 m of water. In September 1996, egg bags will be buried on the Waukegan wire mill and a marker buoy will be deployed in preparation for egg trapping.

METHODS

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

Job 101.1: Gillnet for adult lake trout

As part of the IDNR annual lake trout assessment, trout were collected using 242 m graded mesh gillnets at three nearshore sites and two offshore sites during the 1995 spawning season. Nets were set at Waukegan (Loran coordinates 33253.1/49742), Fort Sheridan (33288.5/49829.5), and Wilmette Reef R-2 (33314.9/49941.2) on 17 October and again on 31 October (at Loran coordinates 33253.3/49742.3, 33292.2/49829.2, and 33313.4/49939.1, respectively). Nets were set at Julian's Reef (Loran coordinates 33231.6/49874.4 for 28 m depth site, and 33233.2/49876.7 for 37 m site) on 30 October and again on 7 November (at Loran coordinates 33231.4/49874.7, and 33234.2/49874.6, respectively). Nets set on 30 October at Julian's Reef were fished for four nights (because of heavy seas); all the other sets were fished for one night.

Job 101.2: Deploy ROV at spawning areas

Because of the extremely limited success of ROV work conducted in 1994, no additional work was conducted during the 1995 spawning season.

Job 101.3: Test sonar for detection of spawning aggregations

We performed sonar transects of the Burns Harbor site on 17 October and 29 November 1995, and at Fort Sheridan on 20 October and 16 November. On each Burns Harbor date we made several passes parallel to the west breakwall, in depths of 8–13 m, which correspond to the upper and lower limits of spawning habitat at the site. At Fort Sheridan we used a search pattern technique, crossing the reef at approximately 50 m intervals. During each pass, we traveled at low speed (<4 kts) and looked for echoes from distinct objects that were 1-2 m above the substrate and higher in the water column. 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 the Burns Harbor site on 17 October and retrieved on 29 November; two more were set at the Fort Sheridan site from 20 October to 16 November. 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

Surveys of an intake crib 1.1 km west of Burns Harbor and the outer breakwater of Pastrick Marina that occurred in August 1995 (actually part of the present reporting period) were described in the 1994–1995 report. In 1996, an extensive survey was conducted at Burns Harbor to (1) determine what changes have resulted from the deposition of new rubble at the west breakwater site, and (2) to evaluate the prevalence of rubble substrate on two new reefs that the

Army Corps of Engineers (ACE) has built to seaward from the north limb of the breakwater. No other new artificial sites worthy of exploration have come to our attention.

Job 102.2: Assess adult densities at natural and artificial sites
Adult densities at five natural sites were obtained from IDNR gillnetting (Job 101.1).

Job 102.3: Collect eggs using egg bags
Twenty 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 in September 1995. Ten egg bags were buried in 6 m of water on a reef at Fort Sheridan (42º 13.6'N, 87º 47.6' W) on 23 August 1995.

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

Job 103.1: Collect lake trout egg and fry predators (fish)
We dissected out the stomachs of fishes gillnetted during the fall 1995 gillnetting activities described in Job 101.1. We also collected whole fishes during trawling operations in the spring of 1996, and during fry trapping operations conducted during the same period. Guts and whole fishes were fixed in 90% ethanol for storage. Alewife guts were examined on site or pierced to promote perfusion by the alcohol preservative and examined in the laboratory.

We also conducted two laboratory studies to evaluate the potential of round gobies (*Neogobius melanostomus*) to predate lake trout eggs and fry. An outline of the study is presented here: a manuscript is in preparation for submission to a peer-reviewed journal. A copy of the manuscript or reprint will be enclosed in the Segment 3 Annual Report. We compared mottled sculpin and round goby lake trout egg consumption rates in the laboratory and determined the minimum size for a goby predator to successfully ingest a lake trout egg. To measure consumption rate, we placed individual fishes in aquaria and then gave them an ample supply of lake trout eggs, counting the number of eggs consumed daily and replenishing the supply. We tested fishes of 46–60 mm SL to determine which were able to consume eggs.

We also conducted a factorial experiment to measure the effects of (1) substrate particle size and (2) prey developmental stage on round goby foraging success rates in the laboratory. Experimental trials were conducted in aquaria partially filled with substrate. The experiment was partly duplicated with mottled sculpin predators, for comparative purposes. In each trial, a small number of prey items (eggs or fry) was distributed uniformly throughout the substrate before a predator was introduced. After the predator was given several days to forage, the aquarium was disassembled to determine how many prey items were consumed. Four substrate treatments were used: no substrate, cobble (25 cm average particle size), an angular quarried limestone gravel (7–10 cm particle size), and a smooth river gravel (6–9 cm particle size). The cobble treatment was identical to the actual substrate at Burns Harbor, excepting the absence of fouling zebra mussels. Four developmental stage treatments were used: eggs, sac fry, an older, intermediate fry category, and emergent fry. A complete ANCOVA design was used (with standard length as the covariate).

Job 103.2: Analyze contents of fish stomachs

Guts of 73 potential egg predators and 428 potential fry predators, collected in Job 103.1, were examined.. If material was present in the gut, it was 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.

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

Job 104.1: Set and retrieve fry traps at spawning sites

Forty-one fry traps (Marsden et al. 1988) were deployed at an artificial reef at the Burns Harbor site on 12 April 1996. The traps were retrieved, examined, and replaced on 18 April, 2 May, 8 May, 17 May, 30 May, and 6 June 1996; the last devices were removed on 2 July.

Job 104.2: Trawl for post-emergent fry near spawning sites

Trawling operations were conducted at Burns Harbor on 18 April, 2 May, and 30 May 1996, using a 3.3 m semi-balloon otter trawl towed behind a 5.5 m Boston Whaler. The 18 April and 2 May trawls were conducted near midday; the 30 May trawls were conducted after dusk, between 2040 and 2130. 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 806 lake trout were captured in gill nets. Gillnet lifts yielded more lake trout later in the fall (31 October, 7 November), than earlier (17 October, 30 October), and more fish were caught offshore than nearshore (**Table 1**). The most fish caught at a single site were caught at Julian's Reef on 7 November 1995.

Job 101.3: Test sonar for detection of spawning aggregations

Sonar observations yielded many distinct above-substrate echoes during transects at Burns Harbor on 17 October 1995 but only a few on 29 November 1995. On both days, sonar performance was degraded by a substantial northern swell. Most echoes were isolated, discrete echoes indicative of individual fishes, but swarms of echoes were observed over known spawning habitat on the west breakwater on 17 October. Unfortunately, confirming diver observations or ROV video could not be obtained because of sea conditions and very poor water visibility.

Sonar observations at Fort Sheridan on 20 October and 16 November yielded no interesting echoes.

Job 101.4: Set and retrieve egg collection devices
One whole gang of egg nets and egg traps retrieved at Burns Harbor on 29 November yielded 1870 eggs and egg chorions, while a partial gang consisting of 6 nets and 5 traps yielded 87 eggs and egg chorions (**Table 2**). One whole gang of egg nets and egg traps retrieved at Fort Sheridan on 16 November 1995 yielded no eggs and 4 egg chorions, while a partial gang consisting of 21 nets and 22 traps yielded 1 dead egg and 3 egg chorions.

Study 102: Comparison of spawning at natural and artificial sites

Job 102.1: Survey potential artificial spawning sites
The ACE construction project underway at Burns Harbor has already extensively modified the spawning habitat. Large areas of rubble have been deposited on the west breakwater, increasing the areal extent of rubble by perhaps 50%. The largest increase is at the seaward end of the site, where rubble substrate now extends nearly to the corner of the breakwater. We have not noted modifications to the north breakwater.

Two new reefs have been built approximately 30 m north of the north breakwater. Both are lozenge shaped, with dimensions of approximately 120 m x 30 m, with the major axis parallel to the breakwater. The new reefs are not emergent structures, but extend only to within about 6.5 m of the surface. Diver surveys of both new reefs (one was still under construction at the time) revealed that each is surrounded by a uniform band of rubble at depths of 9–12 m, bordered above by 8–10 ton armor stone and below by sand. The rubble deposits on the new reefs appear to be ideal lake trout spawning habitat. 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.

Job 102.3: Collect eggs using egg bags
Severe marine weather prevented us from recovering either of the egg bag clusters at Burns Harbor and Fort Sheridan. We recovered some of the devices in 1996 and plan to bury clusters of 5 bags at four sites at Burns Harbor (2 on the west breakwater, 1 each at the new reefs) 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
The guts of 43 lake trout, 17 gizzard shad, 8 yellow perch, one rainbow trout, and one chinook salmon were collected during IDNR's fall gillnet operations (see Job 101.1).

Fry predators
In all, 330 alewife (*Alosa pseudoharengus*), 88 mottled sculpin, and 5 native crayfish (*Orconectes* spp.) were captured during spring fry trapping operations. Several other species, including

Notropis hudsonius, *Etheostoma nigrum*, and *Gasterosteus aculeatus* were captured, but not examined, nor reported here.

Round goby experiments
Round gobies consumed approximately 27% fewer eggs per unit standard length per day than did round gobies. Their maximal consumption rates (for a 24 h period) were also lower than those of sculpins. Round gobies less than 56 mm SL were unable to ingest lake trout eggs, whereas mottled sculpin as small as 42 mm SL successfully did so.

Both substrate particle grade and prey developmental stage affected foraging success by round gobies. Round gobies were substantially more successful at obtaining prey over the no substrate or cobble substrate treatments than over the gravel treatments, although success rates over the no substrate and cobble treatments were indistinguishable. In a parallel study of mottled sculpin with only eggs as prey, identical results were obtained. When gobies foraged over the no substrate or cobble substrata, substrate grade was irrelevant, and predators were very successful. When foraging over the gravel substrata, emergent fry were much more vulnerable than the other developmental stages, and were taken in numbers indistinguishable from those observed during predation over the no substrate and cobble substrate treatments.

Job 103.2: Analyze contents of fish stomachs
Egg predators
None of 73 fishes examined contained lake trout eggs (**Table 4**). One ripe female lake trout 90 cm in total length was observed to regurgitate lake trout eggs after being removed from the gillnet on 30 October.

Fry predators
Eighty-eight sculpin guts examined contained either nothing (60.2%) or various amphipod and cladoceran remains (Table 5). Three hundred thirty-four alewife guts contained no lake trout eggs; the 224 that were examined for other gut contents contained either nothing (70.9%) or contained unidentifiable arthropod remains.

<u>Study 104: Assessment of sac-fry and emergent fry production</u>

Job 104.1: Set and retrieve fry traps at spawning sites
Overall, fry trapping operations yielded 212 lake trout fry at Burns Harbor (**Table 3, Figure 1**). The fry captures were widely distributed among the traps at both the west breakwater and new reef sites. In addition, fry trapping operations yielded 83 small mottled sculpins, as described in Jobs 103.1 and 103.2 above. 13 traps were lost or destroyed, most of them by equipment deployed at the site by the ACE contractor after our trap arrays were in place.

Job 104.2: Trawl for post-emergent fry near spawning sites
Four daytime trawl hauls taken on 18 April and 2 May yielded no post-emergent lake trout fry. Three nighttime hauls taken on 30 May 1996 also yielded no post-emergent fry.

DISCUSSION

As in 1994, index gillnetting of lake trout on putative spawning sites captured larger numbers of trout at offshore than at nearshore sites, and generally larger numbers were captured later in the season (**Table 1**). Egg collecting operations at Fort Sheridan during the period when gillnetting took place yielded less than 0.001 eggs/trap-day, in contrast with yields as high as 0.39 eggs/trap-day at Burns Harbor, a difference of over three orders of magnitude.

Detection of lake trout spawning aggregations by remotely operated vehicle (ROV) video was out of the question under the weather conditions that prevailed at Burns Harbor in 1995. Extended stretches of good water transparency and weather at Burns Harbor in 1996 may permit us to refine the remote sensing method of spawning aggregation detection.

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 transects obtained at Burns Harbor (west breakwater site) in 1995 revealed denser aggregations of putative fish echoes than in 1994. We find support for our belief that these are lake trout echoes in the higher rates of egg deposition that coincidentally occurred in 1995. As in 1994, however, no echoes of fishes obtained by sonar could be unambiguously associated with simultaneous diver or video observations of lake trout. We plan to continue this investigation in conjunction with our studies of ROV video, if field conditions permit, in 1996.

The ACE breakwater rehabilitation program currently underway has increased the amount of substrate available for lake trout spawning, because additional rubble has been applied to the west breakwater, and new reefs are being constructed near the north breakwater. Furthermore, the presence of pre-emergent fry on the older of the new reefs indicates that lake trout have already begun to spawn there. Spawning intensity on the west wall increased 605% between 1994 and 1995 (from an average of 0.098 eggs/device-day to an average of 0.691 eggs/device-day), and fry production increased 4518% (from an average of 0.0035 fry/device-day during 24 April–2 June 1994 to an average of 0.1617 fry/device-day in 1996). Clearly, the increase in egg densities was due to higher rates of spawning on the reef by lake trout. We hypothesize that the addition of new cobble has made the site more attractive to lake trout; also, rubble that is not fouled by zebra mussels may be more attractive than fouled rubble. The large increase in fry production may have resulted from the increase in spawning intensity, superiority of the new substrate for egg incubation, transient reduction in the intensity of interstitial predation pressure while the new substrate is colonized by sculpins or crayfish, or a combination of these factors. The density of adult lake trout at the site can only be evaluated by gill-netting, and pre-construction density data are not available. The improvement in egg incubation success may be due to absence of zebra mussels, which clog interstitial spaces and contribute large volumes of organic sediment, or to a paucity of egg and fry predators, which may not have had time to colonize the new substrate. Traps were heavily encrusted with zebra mussels in 1994 and 1995, but were relatively clean of mussels in 1996, indicating that the majority of the traps in 1996 were set on substrate which was devoid of mussels. The capture rate of sculpins in fry traps in 1996 (0.075 sculpins/trap-day) was similar to that observed in 1995 (0.062 sculpins/trap-day), but divers observed many fewer sculpins on new substrate than on old. In the fall of 1996 we will test the effect of zebra mussels on egg deposition and fry hatch by deploying egg nets and fry traps on new (zebra mussel-free) and old (zebra mussel encrusted substrate), and by conducting the laboratory experiment outlined in Appendix 2.

Our laboratory studies of round goby predation on lake trout eggs in no way refuted the hypothesis that these gobies will perform similarly (per capita) to mottled sculpin as lake trout egg and fry predators. They consumed somewhat fewer eggs per unit standard length than did sculpins, but they were very successful when foraging for eggs and fry over a substrate similar to that in the field at Burns Harbor. Round gobies have achieved much higher densities at certain sites in southern Lake Michigan than did native sculpins, and because the closest of these sites is only ca. 20 km away from Burns Harbor, we posit that a goby invasion of the spawning habitat at Burns Harbor is likely and may be a devastating "nail in the coffin" of the rehabilitative contribution of Burns Harbor spawners. In August 1996, we received a report from J. Francis of the Indiana DNR that round gobies have been captured at Burns Harbor.

Examination of gut contents of fish caught on spawning sites in fall and spring revealed no fishes with lake trout eggs in their guts. In previous years we have captured burbot with eggs in their stomachs at Julian's Reef, and in the fall of 1995 we used a robotic ROV to collect three large sculpins at Julian's Reef, all of which had lake trout eggs in their stomachs. These data indicate that there is a high likelihood of finding lake trout eggs in predator stomachs if eggs are present; by extension, they suggest that lake trout eggs are not plentiful on the nearshore natural reefs which we sampled in fall. The discovery of only one sculpin with lake trout fry in its gut, and no alewife containing alewife, suggests that our sampling methods are not reaching those predators that are closest to the sources of fry. The per-effort capture rates we obtained while fry trapping indicate that we are getting fry traps into the field early enough, so earlier spring sampling is not likely to be helpful. During 1996–1997 we will try sampling using additional techniques, including the use of an alewife gillnet and a speargun, to obtain larger catches of potential egg and fry predators that have best access to the resource.

ACKNOWLEDGMENTS

We appreciate the assistance of W. Brofka, K. Wolfe, C. Dolan, T. Keniry, J. Stein, J. Janssen, and S. Robillard, and other persons who assisted with field work, laboratory work, equipment maintenance, and other activities associated with this project. We again thank M. Kneuer for her administrative support and plentiful good humor.

LITERATURE CITED

Coberly, C. E., and R. M. Horrall. 1980. Fish spawning grounds in Wisconsin water of the Great Lakes. University of Wisconsin, Sea Grant Institute.

Coberly, C. E., and Horrall, R. M. 1982. A strategy for re-establishing self-sustaining lake trout stocked in Illinois water of Lake Michigan. Madison, WI. University of Wisconsin Marine Studies Center, report no. 42. 104 pp.

Dorr, J. A., III, D. V. O'Connor, N. R. Foster, and D. J. Jude. 1981. Substrate conditions and abundance of lake trout eggs in a traditional spawning area in southeastern Lake Michigan. N. Am. J. Fish. Manage. 1:165-172

Goodyear, C. D., Edsall, T. A.., Ormsby Dempsy, D. M., Moss, G. D., and Polanski, P. E. 1982. Atlas of the spawning and nursery areas of the Great Lakes fishes. Vol. IV: Lake Michigan. Washington, DC. U. S. Fish & Wildlife Service. FWS/OBS-82/52

Holey, M. E., R. W. Rybicki, J. E. Marsden, G. W. Eck, D. Lavis, M. L. Toneys, T. Trudeau, E. H. Brown, Jr., and R. M Horrall. 1995. Progress toward lake trout restoration in Lake Michigan. J. Great Lakes Res. 21 (suppl. 1):384-399.

Horns, William H.. 1991. Site-specific substrate mapping of Julian's Reef. Illinois Natural History Survey Aquatic Ecology Technical Report 91/7

Horns, W. H., and J. J. Magnuson. 1981. Crayfish predation on lake trout eggs in Trout Lake, Wisconsin. Rapp. P.-v. Reun. Cons. Int. Explor. Mer. 178: 299-303.

Horns, W. H., J. E. Marsden and C. C. Krueger. 1989. An inexpensive method for quantitative assessment of demersal egg deposition. N. Am. J. Fish. Manage. 9:280-286.

Jude, D. J., Klinger, S. A., and Enk, M. D. 1981. Evidence of natural reproduction by planted lake trout in Lake Michigan. J. Great Lakes Res. 7:57-61

Krueger, D. C., D. L. Perkins, E. L. Mills, and J. E. Marsden. 1995. Alewife predation of lake trout fry in Lake Ontario: role of an exotic species in preventing species restoration. J. Great Lakes Res. 21 (suppl. 1):458-469.

Marsden, J. E. 1994. Spawning by stocked lake trout on shallow, inshore reefs in south-western Lake Michigan. J. Great Lakes Res. 20:377-384

Marsden, J. E., C. C. Krueger and C. P. Schneider. 1988. Evidence of natural reproduction by stocked lake trout in Lake Ontario. J. Great Lakes Res. 14:3-8.

Marsden, J. E., and C. C. Krueger. 1991. Spawning by hatchery-origin lake trout in Lake Ontario: data from egg collections, substrate analysis, and diver observations. Can. J. Fish. Aquat. Sci. 48:2377-2384.

Marsden, J. E., C. C. Krueger, and H. Hawkins. 1991. An improved trap for passive capture of demersal eggs during spawning: an efficiency comparison with egg nets. N. Am. J. Fish. Manage. 11:364-368.

Olsen, T. M., D. M. Lodge, G. M. Capelli, and R. J. Houlihan. 1991. Mechanisms of impact of an introduced crayfish (*Orconectes rusticus*) on littoral congeners, snails, and macrophytes. Can. J. Fish. Aquat. Sci. 48:1853-1861.

Peck, J. W. 1979. Utilization of traditional spawning reefs by hatchery lake trout in the upper Great Lakes. Mich. Dept. Nat. Res., Fish. Rep. no. 1871. 33p

Perkins, D. L. and Krueger, C. C. 1994. Design and use of mesh bags to study egg deposition and embryo survival in cobble substrate. N. Am. J. Fish. Manage. 14:866-869.

Savino, J. F. and M. G. Henry. 1991. Feeding rate of slimy sculpin and burbot on young lake charr in laboratory reefs. Environ. Biol. Fishes 31:275-282.

Savino, J. F., and J. E. Miller. 1991. Crayfish (*Orconectes virilis*) feeding on young lake trout (*Salvelinus namaycush*): effect of rock size. Freshwater Ecology 6:161-170

Scott, W. B. and E. J. Crossman. 1973. Freshwater fishes of Canada. Bull. Fish. Res. Bd. Can. 184:966. pp.

Stauffer, T. M. 1981. Collecting gear for lake trout eggs and fry. Prog. Fish-Cult. 43:186-193

Thibodeau, M. L., and Kelso, J. R. M. 1990. An evaluation of putative lake trout (*Salvelinus namaycush*) spawning sites in the Great Lakes. Can. Tech. Rep. Fish. Aquat. Sci. 1739: vii + 31pp.

Wagner, W. C. 1981. Reproduction of planted lake trout in Lake Michigan. N. Am. J. Fish. Manage. 1:159-164

APPENDIX 1

Summary of sites surveyed during Segment 2, with comments about the suitability of observed substrate for lake trout spawning.

Burns Harbor west breakwater. The ACE has reinforced the west breakwater by increasing the thickness of the structure. This was done by applying a large volume of rubble to the structure. The top margin of the new rubble deposits is at its shallowest at about 7.5 m depth, or just below the depth where 8–10 tonne armor stone begins. In most places, the upper margin of new rubble is deeper. It is shallowest at the southern end of the free-standing breakwater, where it joins with the sheet-piling clad harbor bulkhead. The rubble was deposited rather neatly, with a clear and nearly linear junction between the new and old materials along much of the breakwater. We estimate that the areal extent of rubble substrate on the west wall has been increased by approximately 50%.

Burns Harbor new reef #1. The first new reef was completed in the late summer of 1995. It lies to seaward of the easternmost extremity of the north limb of the breakwater, separated from the older structure by a distance of 30 m. The new reefs were built using the same technology as the breakwater: a cap of 8–10 tonne armor stone blocks over a layer of 45–900 kg stone, beneath which lies a bed of rubble surmounting a foundation of sand. The reef tops are 6.5 m below the surface in a region where the ambient bottom is about 13 m. In two diver surveys, we circumnavigated new reef #1, the armor stone cap of which is approximately 100 m long by 20 m wide. A belt of rubble is exposed around the whole perimeter of the reef, and varies in width from 10–15 m, extending from about 11 m depth up to about 8 m. The rubble belt appears to be ideal lake trout spawning habitat, and we estimate that the rubble area of new reef #1 is about one half the rubble area of the west breakwater site. As of August 1996, the reef is only lightly encrusted with zebra mussels, most of them less than 10 mm in length, and we saw almost no aquatic plants. We saw many yellow perch (*Perca flavescens*) over the reef, and a few smallmouth bass (*Micropterus dolomieu*).

Burns Harbor new reef #2. This reef was completed in July, 1996. The edge of its sand foundation lies 30 m from the edge of the foundation of new reef #1. It is identical in construction to new reef #1, and virtually indistinguishable by diver inspection, except in the absence of zebra mussels.

Clemson and Hyde Park Shoals. We surveyed three distinct reefs. Because their identities are somewhat ambiguous, they are identified here by the Coast Guard marker buoys in the vicinity.

Reef #1. Red can marked "2" at north end of cluster; peak marked as 8' on the NOAA chart.

The reef was about 150 m wide on an east-west transect. The reef lay approximately due west of the marker can. This reef consisted of a central core of solid bedrock with a collar of cobble around it. The slope was moderate (drop from 5 m at top of reef to ambient grade at 10 m over a distance of about 30–50 m). The cobble strip varied in width, but was generally within 5–12 m width. The cobble was generally large, with many particles larger than 25 cm diameter. The cobble was heavily infilled, and much of it was covered in zebra mussels. However, I observed an area at the bottom of the slope (adjacent to a sand plain) that was clean of zebra mussels and weeds. The circumstances made it fairly plain that scouring by sand during periods of high surge was the cause. There were very few fish. In fact, the reef seemed generally rather depauperate of life: even crayfish were less plentiful than usual for the southwest part of the lake. Abundant plants included algae (*Cladophora* spp.?) and much more pond weed (*Chara* spp.). We do not believe that this reef attracts spawning lake trout.

Reef #2. Red bell buoy marked "4" at east end of cluster; peaked marked as 18' on chart.

This reef was perhaps 175m wide. The reef lay to the west and slightly south of the marker buoy. Shallower slope than Reef #1. Reef consisted of faulted bedrock with prominent glacial grooves. There were patches of cobble in the regions we explored, and none of it was attractive, being heavily infilled. In addition, there was substantial zebra mussel encrustation and most of the rocks adhered to the substrate. Again, fishes were uncommon. We do not believe that this reef attracts spawning lake trout.

Reef #3. Red can marked "6" at south end of cluster; peak marked as 7' on chart.

The reef was only 100-140 m wide on an east-west transect. The reef lay southwest of the marker can. The reef consisted of faulted, heavily sculpted bedrock with steep slopes but little cobble around the sides. There was a large basically oval depression running NE-SW, of unknown length, in the reef. This depression contained a sea of drift pond weed (*Chara* spp.) that was at least a third of a meter deep. Peak we observed was at about 2.5 m depth. The cobble we observed was zebra mussel encrusted and adherent, and heavily infilled. We observed few fishes, but they seemed more numerous than at the first site. Crayfish (mostly *Orconectes rusticus*) were fairly abundant. We do not believe that this reef attracts spawning lake trout.

APPENDIX 2

In the winter of 1995–1996, we undertook a new study, inspired by but not answering any of the jobs in this project, 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 constructed cribs of cobble substrate in laboratory raceways to incubate stripped lake trout eggs in them while measuring interstitial dissolved oxygen, pH, and egg mortality rates. Unfortunately, a water system failure ended the experiment without resolution in January 1996. We plan to repeat the experiment, and complete it, in the winter of 1996–1997. The results will be reported in the Segment 3 Annual Report.

Table 1. Summary of lake trout collected by gillnet sampling during 1995 spawning season.

Lift date	Site	Loran coordinates	Depth (m)	Number of lake trout
17 October	Waukegan	33253.1/49742	5.5	80
31 October	Waukegan	33253.3/49742.3	5.5	80
17 October	Fort Sheridan	33288.5/49829.5	11	34
31 October	Fort Sheridan	33292.2/49829.2	11	74
17 October	Wilmette Reef R-2	33314.9/49941.2	9.2	18
31 October	Wilmette Reef R-2	33313.4/49939.1	7.4-11.1	79
30 October	Julian's Reef	33231.6/49874.4	27.6	78*
7 November	Julian's Reef	33231.4/49874.7	27.6	144
30 October	Julian's Reef	33233.2/49876.7	37	98*
7 November	Julian's Reef	33234.2/49874.6	37	121

*Fished for 4 nights

Table 2. Summary of egg collections obtained in the fall of 1995 in southwestern Lake Michigan

Site	Date set	Date lifted	Collection gear	# Devices retrieved	Live egg	Dead eggs	Chorions
Burns Harbor	17 Oct.	29 Nov.	nets & traps	25/25	1670	70	130
	17 Oct.	29 Nov.	nets & traps	6/5	26	4	57
Fort Sheridan	20 Oct.	16 Nov.	nets & traps	25/25	0	0	4
	20 Oct.	16 Nov.	nets & traps	21/22	0	1	3

Table 3. Summary of fry collections obtained in the spring of 1996 at Burns Harbor. Site legend: new reef #1 refers to the first offshore reef built, which lies at the east end of the north breakwater; new reef #2 lies 30 m west of new reef #1.

Date set	Date lifted	Site	# fry	# Dead eggs	Chorions	# of devices
12 April	18 April	west breakwater	3	4	10	22
18 April	2 May	west breakwater	112	0	0	20
2 May	8 May	west breakwater	33	0	0	21
8 May	17 May	west breakwater	48	0	0	11
17 May	30 May	west breakwater	4	0	0	15
30 May	6 June	west breakwater	0	0	0	10
12 April	18 April	new reef #1	0	0	2	6
18 April	2 May	new reef #1	4	0	0	9
2 May	8 May	new reef #1	1	0	0	14
8 May	17 May	new reef #1	5	0	0	8
17 May	30 May	new reef #1	2	0	0	5
30 May	6 June	new reef #1	0	0	0	5
8 May	17 May	new reef #2	0	0	0	2
17 May	30 May	new reef #2	0	0	0	4
30 May	6 June	new reef #2	0	0	0	3

Table 4. Detailed breakdown of gut contents of 73 fishes collected during fall 1995 lake trout gillnet sampling at inshore sites (Wilmette R2, Fort Sheridan, and Waukegan). Data for 17 October and 31 October have been pooled.

Species	N	Percent not empty	Percent of fishes containing the following: Lake trout eggs	Fish	Zebra mussel	Arthro-pods	Para-sites	Inorg. matter
lake trout (*Salvelinus namaycush*)	43	16.3	0	7.0	0	7.0	0	0
brown trout (*Salmo trutta*)	3	66.7	0	66.7	0	0	0	0
rainbow trout (*Oncorhynchus mykiss*)	1	100	0	100	0	0	0	0
chinook salmon (*Oncorhynchus tschawytscha*)	1	0	0	0	0	0	0	0
gizzard shad (*Dorsoma cepedianum*)	17	0	0	0	0	0	0	0
yellow perch (*Perca flavescens*)	8	75	0	25	0	25	0	0

Table 5. Detailed breakdown of gut contents of 428 potential fry predators collected during spring 1996 lake trout fry trapping and trawling operations at Burns Harbor. Gut contents of 3 species, including *Notropis hudsonius*, *Etheostoma nigrum*, and *Gasterosteus aculeatus*, not reported.

Species	N (SL range)	% not empty	Percent containing: Lake trout fry	Arthropod remains
Fry trapping				
mottled sculpin (*Cottus bairdi*)				
29 April 1996	16 (40–57.2)	31.6	0	15.8
12 May 1996	29 (40–58.3)	48.3	0	48.3
22 May 1996	43 (42–70)[1]	37.2	0	37.2
native crayfish (*Orconectes spp.*)				
12 May 1996	5 (17.9–61.5)[2]	0	0	20
Trawling				
alewife (*Alosa pseudoharengus*)				
2 May 1996	27 (64.1–162)	11.1	0	7.4
2 May 1996[3]	110 (unknown)	>0	0	>0
30 May 1996	197 (87.4–163)	31.5	0	31.5
mottled sculpin (*Cottus bairdi*)				
2 May 1996	1 (63.2)		100 (3 fry)	

Notes:
[1] total length is presented
[2] crayfish carapace length is presented
[3] specimens dissected in the field; only presence/absence of lake trout fry recorded

Figure 1: Rate of lake trout fry capture at Burns Harbor during fry trapping operations in 1996.