GREAT LAKES FISHERY COMMISSION
Research Completion Report[1]

Lake Trout (Salvelinus namaycush) Spawning Habitat on Clay Banks Reef, Northwestern Lake Michigan

by

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INTRODUCTION

Intensive commercial fishing and sea lamprey predation extinguished the native lake trout in Lake Michigan in about 1956 (Wells and McLain 1973). Efforts in the 1960s to sharply reduce sea lamprey abundance and to reintroduce lake trout into the lake by planting hatchery-reared juveniles were highly successful, as evidenced by an abundance of spawning-age lake trout. Spawning occurred throughout the lake and viable sac-fry were produced from these spawnings in a few areas of the lake, but evidence for survival of lake-produced fish beyond the first summer of life is fragmentary and disjunct (Jude et al. 1981; Wagner 1981a, 1982; Goodyear et al. 1982; Anonymous 1986; Casselman 1986). In contrast, viable fry, produced from natural spawnings of stocked lake trout have been reported recently from Lakes Huron and Ontario and substantial numbers of mature lake trout with intact, unclipped fins (presumably lake-produced fish) have been found in one area in Lake Huron (Nester and Poe 1984; Marsden, et al. 1988; Marsden and Krueger 1991; Bowen and Argyle 1992; Johnson and Weber 1992). Moreover, field bioassays in 1986-89 showed that gametes taken from hatchery broodstock and from feral lake trout of hatchery origin and incubated on historically important spawning grounds in Lake Huron produced viable, swim-up fry at rates similar to those of eggs from those same sources that were incubated in Lake Superior, where habitat quality is high and the lake trout population is self-sustaining (GLFC 1990; 1991). These successes elsewhere raised concerns among Lake Michigan fishery managers that support for rehabilitation of self-sustaining lake trout stocks in Lake Michigan might erode significantly unless natural reproduction was also soon demonstrated there.

We undertook this study to evaluate the potential for lake trout reproduction on Clay Banks Reef. We believed several factors favored the site as one where natural reproduction could be demonstrated. The Clay Banks area was a fishing ground for native lake trout (Kumlien and True 1887) and was also believed to be a spawning ground for native lake trout (Coberly and Horrall 1980, Goodyear et al. 1982). The Clay Banks area is presently included within the Primary Rehabilitation Zone for lake trout in Wisconsin waters of Lake Michigan (Figure 1). This rehabilitation zone extends along portions of Door and Kewaunee counties in Wisconsin and is one of several such "sanctuaries" (Stanley et al. 1987) established to facilitate the reestablishment of self-sustaining stocks of lake trout in Lake Michigan. The Wisconsin Department of Natural Resources (WDNR) sharply restricts lake trout exploitation in the Door-Kewaunee sanctuary and 200,000 to 400,000 yearling lake trout have been stocked there annually since 1980 (LMLTTC 1985). As a result, large numbers of adult lake trout in spawning condition congregate each year on Clay Banks Reef (WDNR, unpublished data) and spawning is believed to occur there. Furthermore, a survey by divers (Stamm et al. 1981) revealed Clay Banks Reef had rocky substrates suitable for spawning and fry production by lake trout and found no indication that these substrates had been significantly degraded by eutrophication, even though the reef is less than 16 km from the mouth of the Sturgeon Bay ship canal that carries the nutrient-rich outflow of southern Green Bay.

In the present study, we employed habitat mapping and survey techniques (Edsall et al. 1989, 1992a 1992b; Manny and Edsall 1989), field bioassays (Manny et al. 1989), and egg traps (Marsden et al. 1991) to examine the potential for successful natural reproduction by lake trout on the reef. Our specific research objectives were to: (1) map the location of substrates that were suitable for spawning and the production of viable lake trout fry; (2) find areas, if any, where lake trout were depositing eggs; and (3) determine if gametes taken from spawners on the reef and incubated on the reef would hatch and produce viable fry.

LAKEBED MAPPING

Methods.-- We surveyed the Clay Banks Reef area with an EG&G (217 Middlesex Turnpike, Burlington, MA 10803, USA) side-scan sonar, which included a Model 260 image-correcting microprocessor, Model 360 digital tape recorder, and Model 272-T 100-kHz towfish with time-varied gain[4]. Survey methods were similar to those used to map lake trout spawning grounds at 10 other locations in the Great Lakes (Edsall et al. 1989, 1992a 1992b). We deployed the towfish by its cable from a deck-mounted boom and adjusted the length of the cable so that the towfish traveled 2-4 m below the surface of the water when the survey vessel cruised at 7-8 km/h. The towfish directed a beam of acoustical energy to the lake bed, received and amplified the signal returning from the lake bed, and transmitted it to the microprocessor and tape recorder. The microprocesssor converted the signal into a strip chart record showing the physical features of the surface of the lake bed along a 200-m wide swath beneath the towfish. We pulled the towfish along 24 parallel transects 2-4 km long that were 120 m apart and covered the area to be mapped. To facilitate navigation, the transects followed Loran-C isograms with a bearing of about 249 degrees.

In the laboratory we used the strip charts to assemble a mosaic map of the lake bed at 1:1000 scale (Figure 2). We classified substrate components by size according to Wentworth (1922) as sand (< 2 mm in diameter), gravel (2-64 mm), rubble (65-256 mm), cobble (257-999 mm), and boulder (> 999 mm). Where we found a mixture of these components, we described the substrate by the two components that covered the largest and second largest amounts of lake bed.

We manually extracted water depth data from the profile section of each strip chart (Edsall et al. 1989) and then used Environmental Systems Research, Inc. (380 New York Street, Redlands, CA 92373, USA) PC ARC/INFO and PC TIN software to digitize the mosaic map and produce a computer-drawn map showing substrate and water depth distributions, and ROV sites throughout the surveyed area (Figure 3).

We used a Benthos, Inc. (47 Egerton Drive, North Falmouth, MA 02556, USA) MiniROVER MK II remotely operated vehicle (ROV) equipped with a high-

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[4] Mention of trade names or manufacturers does not imply U.S. Government endorsement of a commercial product.

resolution, color video camera to view and videotape the lake bed at 38 sites within the surveyed area (Figure 3). These videotapes provided a permanent record of the lake bed that we used to interpret the mosaic and evaluate the quality of the substrate. The skids on which the ROV rested, extended into the field of view of the video camera and we used the distance between them (18 cm) as a scale to estimate distances and the size of rocks that we saw on the lake bed. We estimated substrate interstitial depth (the depth to which lake trout eggs and fry could settle within the loose rock substrate) from the size and amount of piling of loose rock, and the degree to which the interstices were filled with sand and other fine sediments. We used the ROV skids to move rocks and sand to determine the degree of infilling, and to determine the thickness of the layer of sand on bedrock substrates, and the firmness of clay substrates.

We judged the suitability of the substrates as fry production habitat on the basis of recent studies by others (Wagner 1982, Peck 1986, Nester and Poe 1987, Marsden et al. 1988, Marsden and Krueger 1991) that showed substantial numbers of fry were produced by stocked lake trout only on reefs used historically by native lake trout, or on artificial reefs that resembled those used successfully by the native fish. Collectively these studies suggested that piled, angular or rounded rock 5-50 cm in diameter, with interstitial spaces more than 30 cm deep was the most suitable substrate for fry production by stocked lake trout in the Great Lakes.

Photographs of the lake bed presented in this report were taken with a still camera from videotape images displayed on a video screen in the laboratory.

Results.-- Clay Banks Reef is a rocky shoal that extends to the 20-m depth contour from the shoreline near Stoney Creek, about 10 km north of Algoma, Wisconsin (Figure 1). The reef derives its name from the red-clay bluffs of the wave-cut headland of glacial till that forms the lake shore behind the beach front. Dolomitic limestone bedrock that dips downward under the lake to the east and south (Sly and Thomas 1974) lies beneath the till and other unconsolidated sediments in the area. An earlier survey of the reef conducted by divers indicates the lake bed on the reef is composed of sand, small rock, and clay (Stamm et al. 1981). The rock occurs at depths of about 4-40 m as small, densely packed or piled bedrock rubble on low ridges of hard clay or bedrock that run parallel to shore. Pockets of silt up to 1.5 m deep occur in some areas between the ridges.

We surveyed and mapped 844.2 hectares of lake bed at Clay Banks (Figure 3). The mapped area extends along 6 km of shoreline, and lakeward from about the 4-m depth contour (minimum safe operating depth of the survey vessel) to the 20-m depth contour. We identified four major substrates on the reef and surrounding lake bed. Rubble and bedrock--RB (226.7 hectares)-- formed most of the western border of the mapped area and was the dominant substrate at depths of 4-16 m. Rubble and sand--RS (368.3 hectares)-- occurred in a wide band across the central portion of the shoal at 4-20 m ; this substrate formed about half of the northwestern border, the entire southeastern border, and small portions of the western and eastern borders of the mapped area. Sand and rubble--SR (183.8 hectares)-- was the dominant substrate in the northeastern portion of the mapped area at 14-20 m, where it formed portions of the northwestern, northeastern, and eastern borders of the mapped area; two prominent bands of sand and rubble also extended south into the rubble and sand substrate. Sand--S (25.4 hectares)-- was a major substrate on the east-central portion of the mapped area at 18-20 m and it formed a portion of the eastern boundary of the mapped area.

In the rubble and bedrock area, the surface of the lake bed was tightly packed rubble, except where patches of smooth bedrock up to several meters in diameter were exposed, or where loose piles of rubble occurred (Figure 4). Sand infilling was evident only in the northern end of the area (Figure 4; site 35) and exposed bedrock was most common in the southern half of the area (Figure 4; sites 13, 14,and 17). The rubble piles were several meters in diameter and were scattered throughout the area but were most abundant in the southern half. Most piles seemed to be composed of only one or two layers of loose rubble on top of bedrock or a base of tightly packed, small rubble. Interstitial depth in the piles was generally 20 cm or less, but approached 30 cm in some of the larger ones where the rubble was more deeply piled. These rubble piles with interstitial depths of 20-30 cm were the best habitat for lake trout spawning and fry production that we found in the study area. Boulders up to 3 m in diameter were a conspicuous feature on the mosaic throughout much of the area, but they were not a major substrate component. Periphyton was common on the surface of most of the loose rocks and was especially evident on rubble at sites 15 and 19 (Figure 4).

The rubble and sand substrate area was the most physically complex portion of the reef. Although rubble and sand were the dominant substrates, substrate composition was highly variable, and reflected the transition from the rubble and bedrock substrate on the west to the sand and rubble and sand substrates to the east (Figure 5). In the northwestern portion of the area the substrate was rubble or rubble piles with light to moderate infilling by sand and interstitial depths of generally less than 20 cm (Figure 5; sites 34, 36,and 38). Near the middle of the mapped area, rubble remained the dominant substrate, but infilling by sand decreased the interstitial depth to less than 10 cm (Figure 5; sites 18, 20, and 23). Farther south we found several large, isolated, rubble piles with little or no infilling and interstitial depths of 20-30 cm (Figure 5; site 16). Rubble piles without infilling and interstitial depths of 20 cm or more also occurred near the southeastern boundary of the area (Figure 5; sites 3, 10,and 16), and an eroded mound of stiff, red-clay till with rock inclusions was present at one of the sites (Figure 5; site 8). The rubble piles with interstitial depths greater than 20 cm at sites 3, 10, and 16 were the only suitable spawning and fry production habitat we found in the rubble and sand substrate. The southeastern boundary substrate was small rubble extensively infilled by sand (Figure 5; sites 1, 4, and 9). At the northwestern and southwestern tips of the mapped area the substrate included pockets of organically rich sand that emitted gas bubbles when disturbed by the skids of the ROV (Figure 5; site 6).

The sand and rubble substrate exhibited the most distinctive images in the mosaic (Figure 2). Sand with scattered rubble occurred in long, narrow ribbons up to 50 m wide that ran parallel to the shoreline and extended with only minor interruptions from the northernmost boundary of the mapped area to its southeastern boundary. Patches up to 125 m wide occurred where several ribbons met. Sand ripples with crests aligned perpendicular to the shoreline and crest-to-crest distances of up to 1 m were conspicuous, small-scale features near site 30 on patches of sand and scattered rubble that were up to 40 m wide and 300 m long. The large-scale pattern of sand deposition shown on the mosaic and the size and orientation of the sand ripples indicate that sand is being transported through the area by moderately strong alongshore currents, perhaps during storms. Most of the rubble in the area occurred between the ribbons or patches of sand (Figure 6). This rubble was small, densely packed, and heavily infilled with sand; larger rubble occurred in low, mounded patches that were also heavily infilled with sand. The sand substrate on the east-central edge of the mapped area was a relatively featureless plain with a slightly undulating surface. We found no suitable spawning and fry production habitat in the sand and rubble or sand substrate areas.

SEDIMENT TRAP STUDIES

Methods.-- To determine the rate at which suspended sediments were deposited on the reef over winter and the composition of those sediments, we set one sediment trap (Manny et al. 1989) at each of sites 5, 13, 15, and 22 on November 1, 1990 (Table 1). Each trap held four upright, polyvinyl chloride tubes (52 mm internal diameter, 360 mm high) in which replicate samples (N=4) of suspended sediment could settle. The ratio of tube height to tube diameter exceeded 5, as recommended by Hargrave and Burns (1979) and Bloesch and Burns (1988) for traps set in areas with high current velocity. Divers placed the traps in shallow excavations in the lake bed and surrounded them with rock rubble so that the tops of the sediment collection tubes were roughly even with the upper surface of the layer of rock rubble. A 40 kg anchor also helped hold each trap in place. On April 23, 1991, divers found the sediment traps at sites 13, 15, and 22, capped the sediment collection tubes in situ, and brought them to the surface. The trap set at site 5 was not found. The sediment collection tubes were placed in insulated containers at 6.7°C and shipped by air to the laboratory where we measured sediment height in the tube; water, organic matter, and ash content; and particle size composition after ignition (Buchannan 1971).

Results.-- Sediment height in the collection tubes averaged 18-24 cm among sites 13, 15, and 22 (Table 2). Sediments were predominantly fine sand, very fine sand, and silt and clay; organic matter averaged < 3% by weight of the samples. Comparison of the sediment trap samples from Clay Banks Reef with those taken in identical traps deployed on historical lake trout spawning reefs in Lake Superior and Lake Huron (Figures 7 and 8) revealed that sedimentation (measured as sediment height in the tubes) at Clay Banks was about twice that at Partridge Island Reef in Lake Superior and about 25% higher than at Port Austin Reef in Lake Huron. The particle-size distribution was skewed toward the finer grain sizes at Clay Banks and a substantially higher portion of the sample there was silt and clay. Water content and ash content of the sediments at Clay Banks were both about intermediate between values for Partridge Island Reef and Port Austin Reef. Organic matter content was substantially higher at Clay Banks than at Partridge Island Reef and about the same as at Port Austin Reef.

We can only speculate about the significance of our sediment trap data, because a quantitative link between sedimentation and the suitability of lake trout spawning and fry production habitat has not yet been established. Preliminary information from recent studies (GLFC 1990, 1991) shows that viable lake trout fry were produced from eggs in Plexiglas incubators that were set on Partridge Island Reef in Lake Superior, where native lake trout reproduce successfully, and on Port Austin Reef in Lake Huron. These results suggest that overwinter sedimentation is not a major factor limiting spawning and fry production by lake trout on Clay Banks Reef.

SPAWNER ABUNDANCE STUDIES

Methods.-- In 1990 and 1991 we set graded-mesh, multifilament, nylon gillnets on Clay Banks Reef during the spawning season to determine the relative abundance and composition (size, age, sex ratio, and genetic strain) of the population of sexually mature lake trout concentrated there (Table 3). The standard net was 2 m deep, 333.3 m long, and contained equal lengths of 11.4-, 19.7-, 21.7-, and 23.6-cm mesh netting (stretched measure). In both years the nets were set overnight and lifted the next day. In 1990 the nets were set at water depths of 7.7-13.3 m and in 1991 at 8.0-13.3 m.

Results.-- The mean catch of adult lake trout per net-night was almost identical in 1990 and 1991 (157 vs 154) and the relative abundance of females in the catch in 1990 (20 %) and 1991 (24 %) also differed little (Table 3). In 1990, the catch increased from 132 fish on October 17 to 243 fish on October 23, and then decreased to 130 and 123 fish on October 30 and 31. The catch of females was highest on October 17 (41 fish), intermediate on October 23 (33 fish), and lowest on October 30-31 (20-22 fish), suggesting that spawning in the area may have peaked before October 23. Fin clips on the adult lake trout caught on Clay Banks Reef during the spawning season in 1990 and 1991 revealed all were Lake Superior lean-strain fish. The mean age of the 512 males taken in 1990 was 6.9 years and the mean age of the 116 females was 7.7 years. The 236 males and 73 females caught in 1991 averaged 7.6 and 8.3 years.

Spawner density at Clay Banks Reef in 1980-90 (measured as catch in an overnight set of 305 m of 11.4-cm-stretched-measure, multifilament, nylon gillnet) was considerably higher than published values for all but one other location in the Great Lakes, including sites where native and stocked lake trout were reproducing successfully (Table 4); the single exception occurred in Grand Traverse Bay, where the abundance of female spawners was slightly higher than the abundance on Clay Banks Reef (30 vs 27).

EGG DEPOSITION STUDIES

Methods.-- To determine if lake trout were depositing eggs on Clay Banks Reef, we set gangs of egg traps on October 15, 1990 and again on September 27-October 1, 1991 at 10 of the 38 ROV sites on the reef (Figure 4; Table 1).

These sites were selected after review of the mosaic map and the ROV videotapes, and included eight (sites 5, 8, 13 14, 15, 17, 22, and 25) where the substrate seemed suitable for spawning and fry production by lake trout and two (sites 9 and 16) where the substrate was not. The egg traps consisted of two vacuum-molded polystyrene halves, 22 cm in diameter and 5-cm high, assembled by friction fit over a PVC rim (Marsden et al. 1991).

In 1990, we set two gangs of egg traps at sites 9 and 15 and one gang at each of the other nine sites. Each gang consisted of 25 egg traps attached individually to a 30-m-long ground line, at 1.2-m intervals, by 0.6-m-long droppers. The ground line and droppers were 4.7-mm diameter nylon rope. The ground line was stretched tightly across the lake bed, anchored at both ends, and weighted at intervals with lead to keep it on the bottom. Marker buoys were attached at both ends of the ground line to facilitate retrieval. In 1991, we set two 30-trap gangs at site 22 and one 30-trap gang at each of the other 9 sites. The ground line for each gang was 30.5-m of 0.5-cm (link-stock diameter) chain that was stretched across the lake bed, and anchored and marked with buoys at both ends. Egg traps were attached to the ground line at 1-m intervals with 0.3-m-long droppers of 0.5-cm chain. Divers retrieved the egg traps set in 1990 on November 11, 1990 and those set in 1991 on November 4-5, 1991. We opened the egg traps on shore and recorded the egg catch.

Results.-- In 1990, we recovered 142 of the 297 egg traps that we set, but only 115 of those recovered were intact and capable of retaining eggs. One trap at site 13 contained one dead lake trout egg and the other traps were empty. In 1991, we recovered 292 of the 330 egg traps we set and 236 of those were intact and in working order. One trap at site 25 contained one dead lake trout egg. Egg trap losses in 1990 were partly due to exceptionally stormy weather in October and November and partly to the materials we used to anchor the traps. The anchors were not able to hold some egg trap gangs firmly in place; buoys were lost from some egg trap gangs; and the nylon rope used for the ground lines and droppers became twisted and tangled, interfered with the operation of the traps, and probably contributed to trap loss. In 1991, better weather probably reduced trap loss. The use of chain for ground lines and droppers, heavier anchors, and more securely fastened buoys improved trap operation and also helped us retrieve a greater portion of the traps. Never-the-less, one gang of 30 traps was lost at site 22 because wave and current action had bunched and tangled the gang to the point that the divers were unable to retrieve it.

The low catches of eggs in 1990 and 1991 indicate there was little or no spawning at the locations where the traps were set. Studies by others (Marsden and Krueger 1991) showed that the traps can effectively collect lake trout eggs when lake trout spawn near them. Mean catches of 0.02-2.33 eggs per trap night, totaling 6,446 eggs over three years of sampling on Stoney Island reef in eastern Lake Ontario were reported by Marsden and Krueger (1991). Because the two eggs that we collected were taken in traps that were set on the shoreward edge of the mapped area, we conclude that most of the fish that spawned on Clay Banks Reef probably did so on the shallower portions of the reef between the shoreline and sites 13 and 25. On two occasions during the side-scan sonar and ROV survey, we observed waves breaking on the reef in an area several hundred meters wide, about midway between shore and sites 13 and 25, indicating that there is a shallow, rocky shoal or bedrock outcrop in that area that might attract spawning lake trout.

EGG INCUBATION STUDIES

Methods.-- To determine if gametes from the adult lake trout that congregated on Clay Banks Reef during the spawning season could produce viable swim-up fry on the reef, we artificially spawned 39 females with 76 males (2 males with each female) that we caught in gillnets on October 23, 1990 (Table 3) and put the eggs into Plexiglas incubators (Manny et al. 1989, after Hulsman et al. 1983). Divers deployed these incubators, which each held 50 eggs, at 7 sites on the reef (Figure 3, Table 1). As a control on gamete viability of the Clay Banks fish, we used eggs from an artificial spawning of 16 female and 142 male lake trout captured in gillnets in Lake Manitou, Ontario, Canada on October 22, 1990. These eggs were shipped by air, arrived at the study site on October 23, were loaded into incubators, and were deployed with the eggs from Clay Banks fish.

We set the egg incubators in gangs of 12. In each gang, incubators were attached individually to a 16-m-long ground line at 1.5-m intervals with 1-m-long droppers. The ground line and droppers were 0.5-cm (link-stock diameter) chain. The ground line was anchored at both ends and marked with buoys. Divers set each incubator on edge in a shallow excavation among the loose rock rubble and covered it with a layer of rock rubble to simulate the microhabitat occupied by naturally spawned eggs in substrate interstices.

Storms prevented us from placing all of the incubators in the lake on the same day as we had planned. On October 23, we set two gangs of incubators containing eggs from Clay Banks fish and one gang containing eggs from Lake Manitou fish in the lake at site 22 (Figure 3). We held the other incubators on shore in lake water at lake temperature until wave heights diminished and allowed us to set them in the lake. On October 25, we set one gang of incubators with Clay Banks eggs at sites 14 and 15 and one gang with Lake Manitou eggs at site 15. On October 31 we set one gang of incubators containing Clay Banks eggs at each of four other sites (4, 5, 8, 13). Lake water temperatures were 8.9 °C on October 23 and fell gradually to 7.8 °C by October 31.

On October 23, we randomly selected 12 incubators containing eggs from Clay Banks fish and 12 incubators containing eggs from Lake Manitou fish to serve as controls for the effects of incubation in the lake. On October 24, we shipped the control incubators by air to the laboratory (National Fisheries Research Center-Great Lakes, Ann Arbor, Michigan) and held them at simulated Lake Michigan temperatures [mean (SD) °C: October, 7.1 (0.3); November, 5.2 (1.1); December, 4.2 (0.3); January, 4.3 (0.5); February, 3.7 (0.5)] through hatching.

On April 23, 1991, divers retrieved the incubators from the lake, after marking each incubator to show whether it had remained buried in the substrate or had been dislodged and was lying on top of the substrate. The incubators were placed in insulated containers in lake water at 6.7 °C and immediately shipped by air to the laboratory. There, we opened the incubators, counted the fry, and determined percent hatch.

Results.-- The loss of incubators that we set on Clay Banks Reef in 1990 was minimal. Only 3 of the 96 incubators containing Clay Banks eggs and 1 of the 24 incubators containing Lake Manitou eggs were not recovered. The causes of incubator loss were not determined but we believe the clips attaching the incubators to the dropper chains failed in exceptionally stormy weather in October and November. These storms probably also contributed to the dislodgement of incubators from the substrate and to the infilling of incubators with sand. Thirty of the incubators containing Clay Banks eggs and 12 of those containing Lake Manitou eggs were lying on top of the substrate when the divers retrieved them. None of the cells of the incubators that had been dislodged from the substrate exhibited infilling. Six buried incubators containing Clay Banks eggs and one buried incubator containing Lake Manitou eggs had an average of 18 cells (range, 4-36) filled with sediment.

Control eggs taken from Clay Banks and Lake Manitou fish and incubated in the laboratory began hatching on February 8, 1991, 50% hatch occurred on February 15, and 100% hatch on February 21. Hatching of eggs incubated on Clay Banks Reef was completed before the incubators were brought into the laboratory on April 23, 1991. The mean percentage hatch was higher for eggs from Clay Banks fish than for eggs from Lake Manitou fish and was higher in the laboratory than on Clay Banks Reef; however, the only statistically significant difference occurred between the Clay Banks eggs that were incubated in the laboratory and the Lake Manitou eggs that were incubated on Clay Banks Reef (Table 5). Differences in the mean percentage hatch between incubators that remained buried in the substrate and those that were dislodged were minor and not statistically significant (Table 6).

There is little published information describing the hatching success of lake trout eggs held in incubators of the type we used in this study. The mean percentage hatch for both Clay Banks and Lake Manitou eggs held in incubators on Clay Banks Reef (Table 5) was nearly twice that of Jordan River Hatchery eggs held in the same incubators on Port Austin Reef, Lake Huron, in 1986-87 (24%; Manny et al. 1989) and generally higher than for eggs from Lake Superior lake trout held in those incubators at Partridge Island Reef, Lake Superior (18%) and on Port Austin Reef (43%) in 1987-88 (GLFC 1990, 1991).

SUMMARY AND CONCLUSION

The results of our side-scan sonar and ROV survey of Clay Banks Reef are in good agreement with published information on the geology of the area (Sly and Thomas 1974) and the results of a diver survey of the reef conducted in 1980 (Stamm et al. 1981). Substrate suitable as spawning and fry production habitat for stocked lake trout, as described by other recent studies (Wagner 1982; Peck 1986; Poe and Nester 1987; Marsden et al. 1988; Marsden and Krueger 1991), is restricted to scattered piles of rubble with interstitial depths of about 20-30 cm that lie on bedrock, hard clay, or small, compacted rubble. On

Clay Banks Reef, such rubble piles occur at water depths of about 8-16 m, in the rubble and bedrock substrate and, less frequently, in the rubble and sand substrate (Figures 3-5).

Overwinter sedimentation does not appear to limit fry production by lake trout on Clay Banks Reef. Overwinter sedimentation on the reef is heavier than reported for Partridge Island Reef in Lake Superior, where native lake trout reproduce successfully, but is similar to overwinter sedimentation on Port Austin Reef in Lake Huron (Figure 7), where field bioassays showed hatching and production of viable fry (GLFC 1990, 1991). The sediment we collected on Clay Banks Reef contained more organic matter, silt, and clay than sediment collected on Partridge Island and Port Austin reefs, as would be expected from the presence of clay tills on Clay Banks Reef and the adjacent headland and the proximity of the reef to the nutrient-rich outflow of southern Green Bay.

The abundance of adult lake trout on Clay Banks Reef during the spawning season appears to be high enough to support successful natural reproduction on the reef. Spawner abundance on the reef exceeded that on five reefs in Lake Superior, where native lake trout reproduce successfully; is higher than in Thunder Bay, Lake Huron, where lake trout of hatchery origin are reproducing successfully; and is higher than at five other locations in Lake Michigan, including Grand Traverse Bay and the northeast shore (Table 4), where fry production was observed in the 1970s.

The Clay Banks fish that we spawned artificially for this study produced viable eggs that hatched at rates similar to control eggs from Lake Manitou in Ontario. The hatching rate for the Clay Banks eggs was also higher than those of eggs from Lake Superior and Lake Huron lake trout incubated at Partridge Island and Port Austin reefs (GLFC 1990; 1991). These results suggest that natural spawning by Clay Banks fish could produce viable offspring on Clay Banks Reef.

Our egg trapping studies conducted on Clay Banks Reef during the 1990 and 1991 spawning seasons yielded only two naturally spawned lake trout eggs and our catch rate was much lower than that reported by Marsden and Krueger (1991) in identical traps at Stoney Island, Lake Ontario, where substantial spawning by stocked lake trout was observed. The two eggs we collected were in traps set at the shoreward edge of the study area, suggesting that at least limited spawning occurred there or between the study area and the shoreline. We observed waves breaking offshore between the study area and the shoreline and believe that there may be substrate there that would be attractive to spawning lake trout. We were unable to conduct studies in that area because the water depth approached the grounding depth of the vessels that were available to us for use in this study.

We conclude that the Clay Banks Reef has the potential to support successful natural reproduction by stocked lake trout presently found on the reef during the spawning season. We believe some spawning and fry production might be occurring on the portion of the reef that we surveyed and also on adjacent areas of the reef between the surveyed area and the shoreline. We recommend that a survey be conducted from a shallow-draft vessel, by divers or with an ROV, to determine if the substrate between the shoreline and the area covered by the present study is suitable for spawning and fry production by stocked lake trout. If suitable substrate is found, we recommend that studies be conducted to determine if lake trout are depositing eggs there and to evaluate the potential of the substrate to support the production of viable fry.

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Table 1. Deployment of sediment traps, egg incubators, and egg traps on Clay Banks Reef. Sediment traps and incubators were set only in 1990.

ROV site	Number of sediment traps	Number of incubators by egg source		Number of egg traps	
		Clay Banks	Lake Manitou	1990	1991
5	1	12		25	30
8		12		25	30
9				50	30
13	1	12		25	30
14		24		25	30
15	1	12	12	47	30
16				25	30
17				25	30
22	1	24	12	25	60
25				25	30
Total	4	96	24	297	330

Table 2. Physical and chemical characteristics of sediments collected in sediment traps set on November 1, 1990 at three sites on Clay Banks Reef and retrieved on April 23, 1991; mean and (in parentheses) one standard deviation; each trap contained four sediment collection tubes (N = 4).

Characteristic	Site number		
	13	15	22
Height in trap (cm)	24 (0.3)	18 (2)	24 (0.7)
Wet weight (g)	720 (72)	679 (25)	784 (29)
Dry weight (g)	401 (59)	432 (32)	520 (29)
Ash weight (g)	387 (58)	423 (33)	507 (28)
Water content (%)	44 (3)	36 (6)	34 (1)
Ash content (%)	54 (3)	62 (6)	65 (1)
Organic matter (%)	3.4 (0.3)	2.2 (0.4)	2.6 (0.1)
Particle size[1]			
Gravel and coarse sand (>499 µm)	3 (0.4)	4 (0.6)	8 (0.6)
Medium sand (250-499 µm)	10 (0.3)	16 (1.4)	22 (0.9)
Fine sand (125-249 µm)	23 (2.7)	34 (3.3)	34 (2.3)
Very fine sand (63-124 µm)	28 (0.8)	26 (1.1)	15 (0.7)
Silt and clay (<63 µm)	36 (1.7)	20 (1.2)	21 (0.7)

[1] as % of total ash weight.

Table 3. Abundance of adult lake trout in spawning condition on Clay Banks Reef in 1990 and 1991.

Date	Effort[1]	Total number caught	Females	
			Number	Percent of total
1990				
October 17	1	132	41	31
October 23	1	243	33	14
October 30	1	130	20	15
October 31	1	123	22	18
Mean[1]	1	157	27	20
1991				
October 25	2	309	73	24
Mean[1]	1	154	37	24

[1] One unit of effort equals one standard, graded-mesh, nylon, multifilament gillnet set for one night and then lifted. The standard net was 2 m deep and 333.3 m long and contained equal legnths of 11.4, 19.7, 21.7, and 23.6 cm mesh netting (stretched measure).

Table 4. Abundance of adult lake trout during the spawning season at various locations in the upper Great Lakes[1].

Location	Stock characteristics[2]			Sexes combined	Females	Years
	S	N	H			
Lake Michigan						
Clay Banks[3]			+	107.8	26.8	1980-90
Green Bay[4]			+	4.4	1.3	1974-76
Beaver Island[4]			+	2.5	0.6	1973-75
Charlevoix[4]			+	14.0	6.4	1973-75
Grand Traverse Bay[4]			+	71.0	30.0	1976
Northeast shore[5]			+	82.1	---	1973-79
Lake Huron						
Thunder Bay[6]	+		+	87.7	---	1983-85
Lake Superior						
Western Apostle Is.[7]	+	+	+	13.7	3.0	1985
Presque Isle Reef[8]	+	+	+	17.0	3.7	1982
Gull Island Shoal[9]	+	+		66.8	---	1970-77
Sand Cut Reef[10]	+	+	+	26.3	---	1967-76

[1] Number caught in overnight set of 305 m of 11.4 cm mesh (stretched measure) gillnet.

[2] S = self-sustaining stock; N = native fish; H = hatchery fish.

[3] Present study and WDNR unpublished data.

[4] Peck 1979.

[5] Wagner 1981b.

[6] Weber 1987.

[7] Bronte 1985.

[8] Peck 1982.

[9] Swanson 1982.

[10] Krueger et al. 1986.

Table 5. Percentage hatch (mean ± 95% confidence interval) of lake trout eggs held in Plexiglas incubators in the laboratory or on Clay Banks Reef in Lake Michigan. Eggs were placed in the incubators on October 23, 1990.

Site of incubation	Egg source	Number of incubators	Hatch
Laboratory	Clay Banks	12	62 ± 16
	Lake Manitou	12	53 ± 12
Clay Banks Reef	Clay Banks	93	46 ± 4
	Lake Manitou	23	37 ± 8

Table 6. Percentage hatch (mean ± 95% confidence interval) of lake trout eggs in Plexiglas incubators that remained buried or were dislodged from the substrate at Clay Banks Reef in Lake Michigan. All incubators were buried on the reef on October 24-31, 1990 and retrieved on April 23, 1991.

Egg source	Incubator position at retrieval	Number of incubators	Hatch
Clay Banks	Buried	63	49 ± 5
	Dislodged	30	40 ± 9
Lake Manitou	Buried	11	36 ± 14
	Dislodged	12	38 ± 9

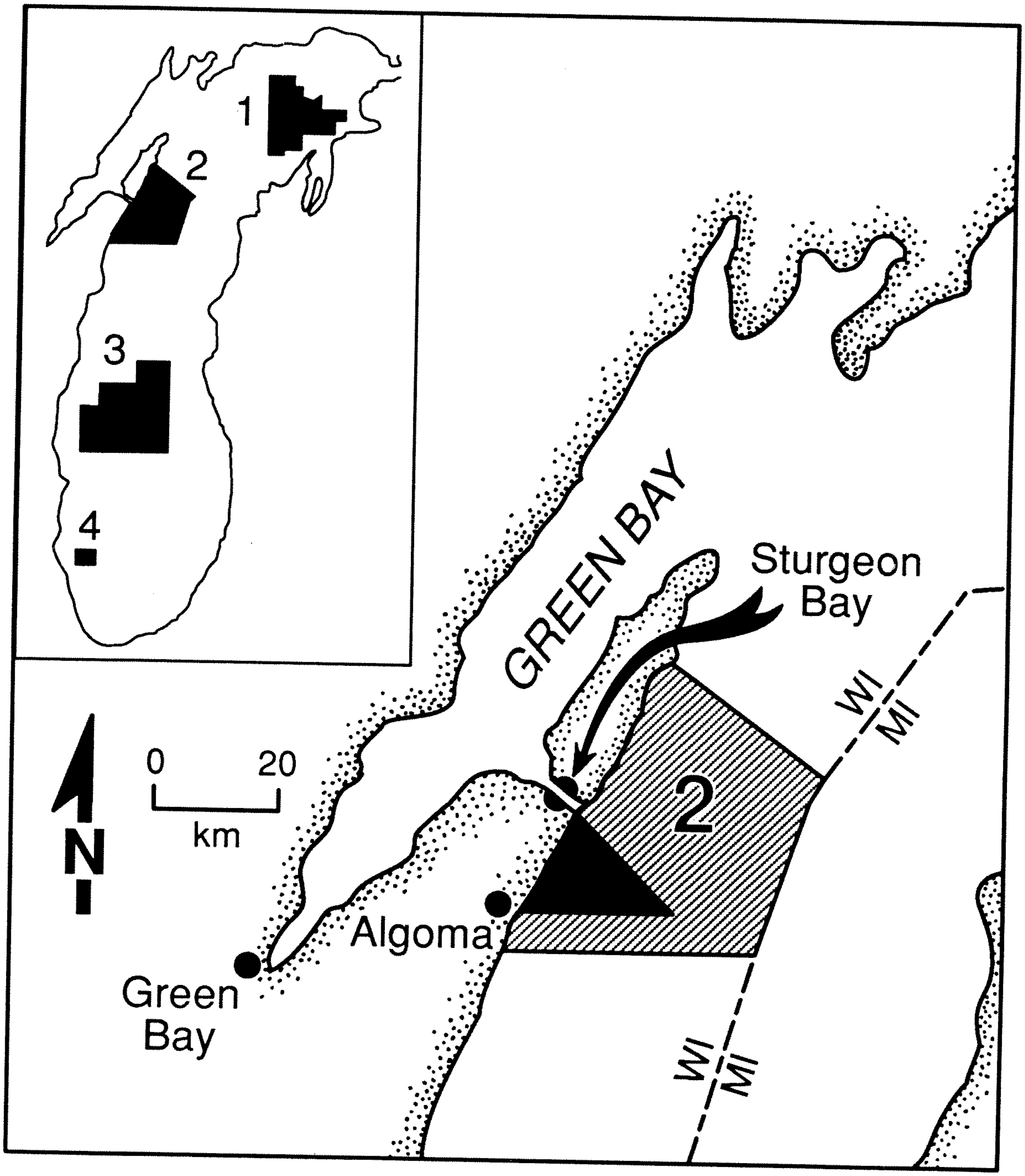


Figure 1. Clay Banks Reef is located in the dark triangle, in a Primary Rehabilitation Zone (shaded area), which abuts portions of Door and Kewaunee counties in Wisconsin and is a sanctuary for lake trout. Commercial take of lake trout is prohibited in the sanctuary, and commercial fishing and retention of lake trout by anglers is prohibited within the dark triangle. Lake trout sanctuaries are identified by number: 1= Fox Island, 2= Door-Kewaunee, 3= Mid-lake, 4= Julians Reef (after LMLTTC 1985, Stanley et al. 1987).

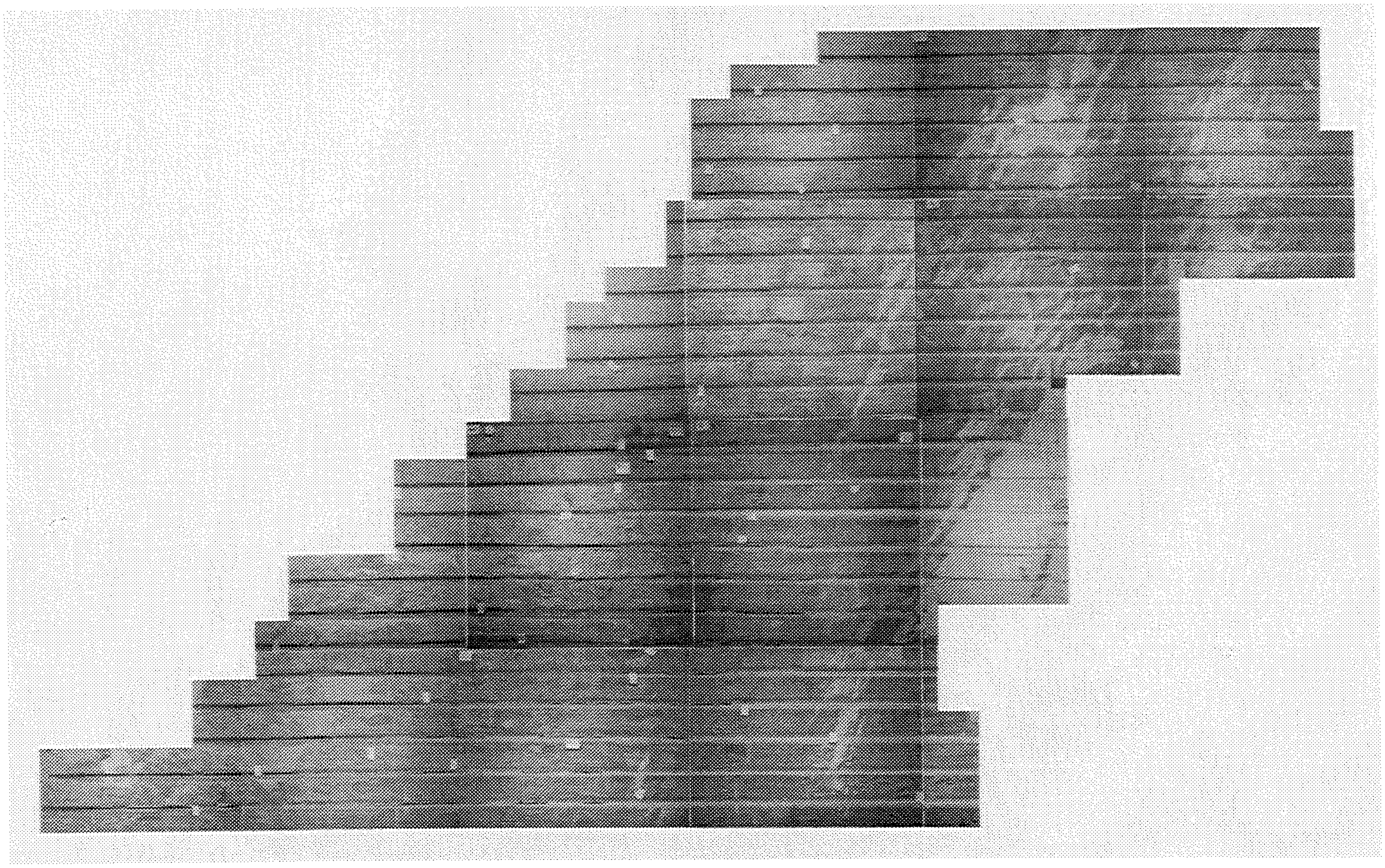


Figure 2. Photograph of the mosaic map of Clay Banks Reef. Substrate types are delineated and identified in Figure 3.

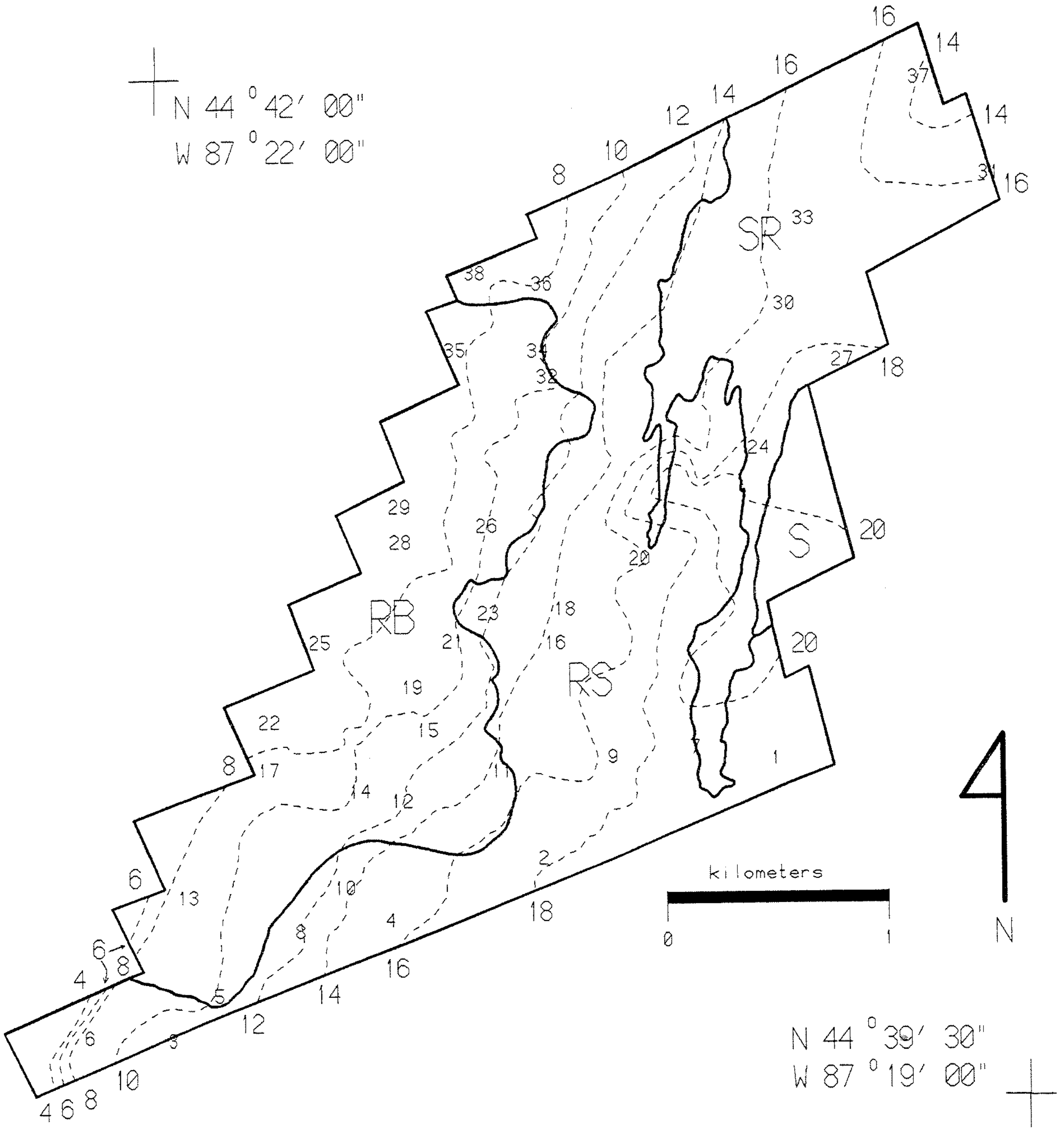


Figure 3. Clay Banks Reef substrates and bathymetry. Water depths (dashed lines) are in meters. ROV sites 1-38 are shown on map face.

Substrate	Hectares
RS - Rubble and sand	368.3
RB - Rubble and bedrock	266.7
SR - Sand and rubble	183.8
S - Sand	25.4
Total	844.2

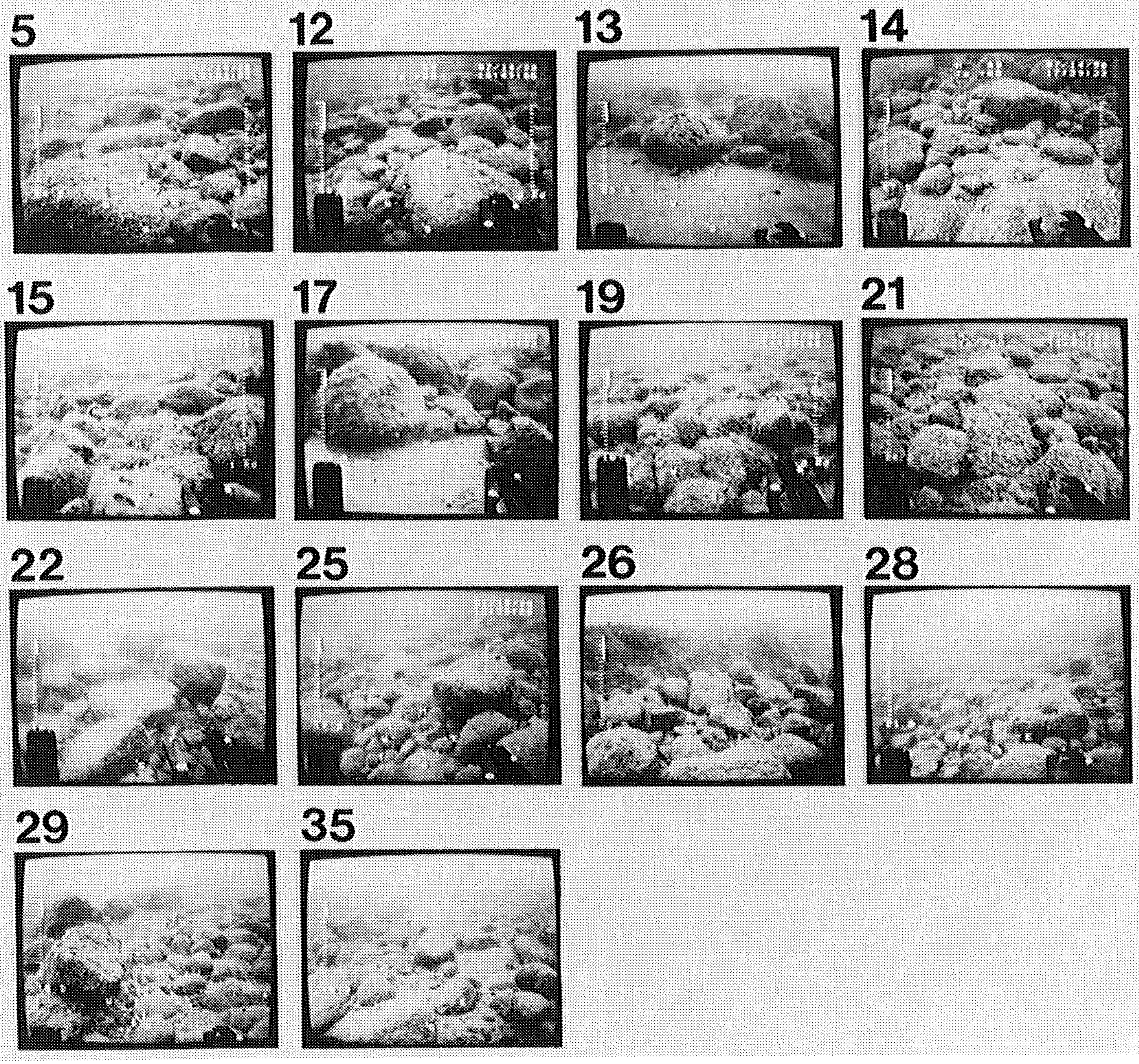


Figure 4. Photographs of the lake bed at 14 ROV sites in the rubble and bedrock substrate portion of the study area. The skids of the ROV, which appear in some of the photographs, are 18 cm apart and provide scale. The ROV site number is given on each photograph. ROV site locations are given in Figure 3.

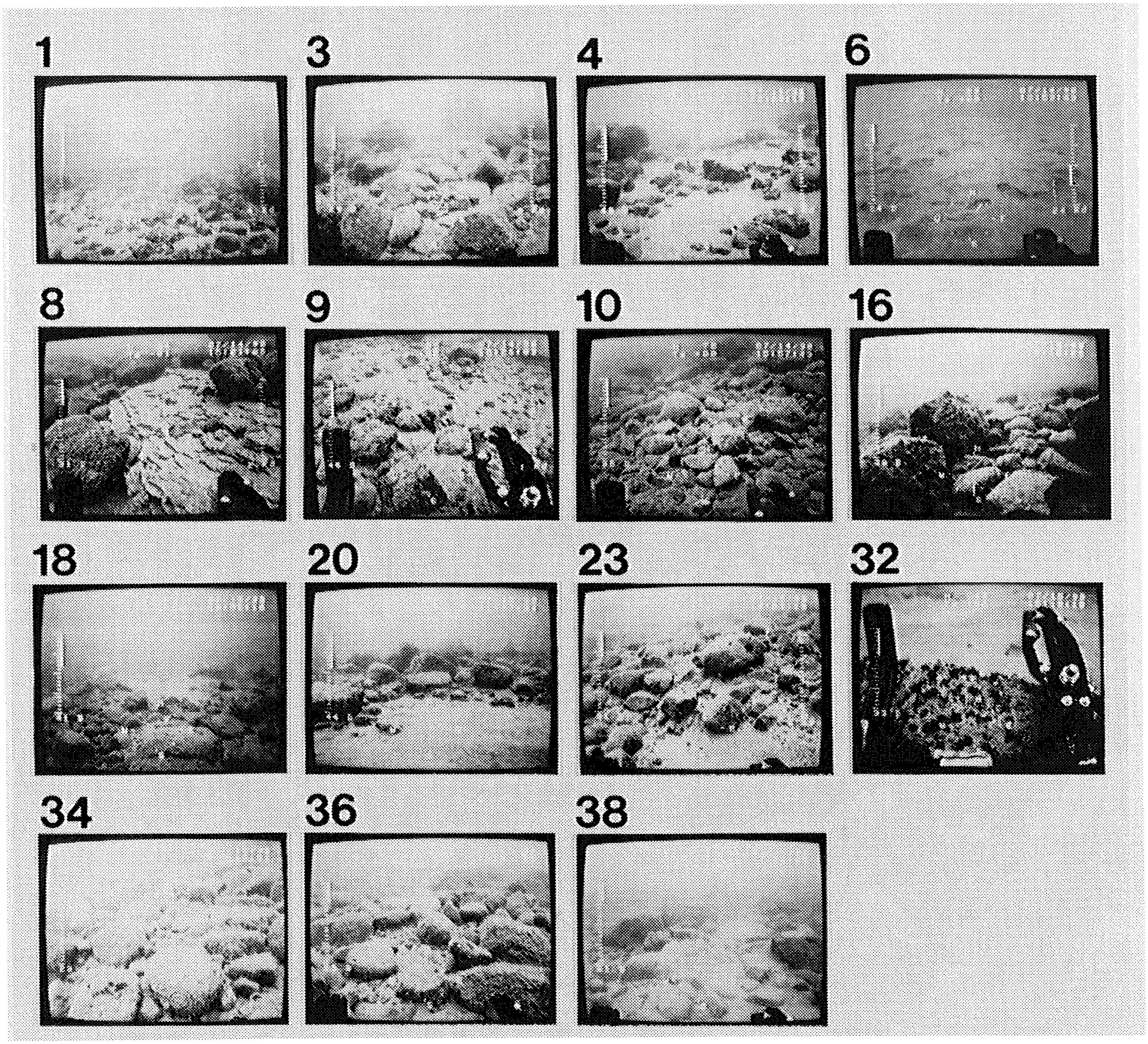
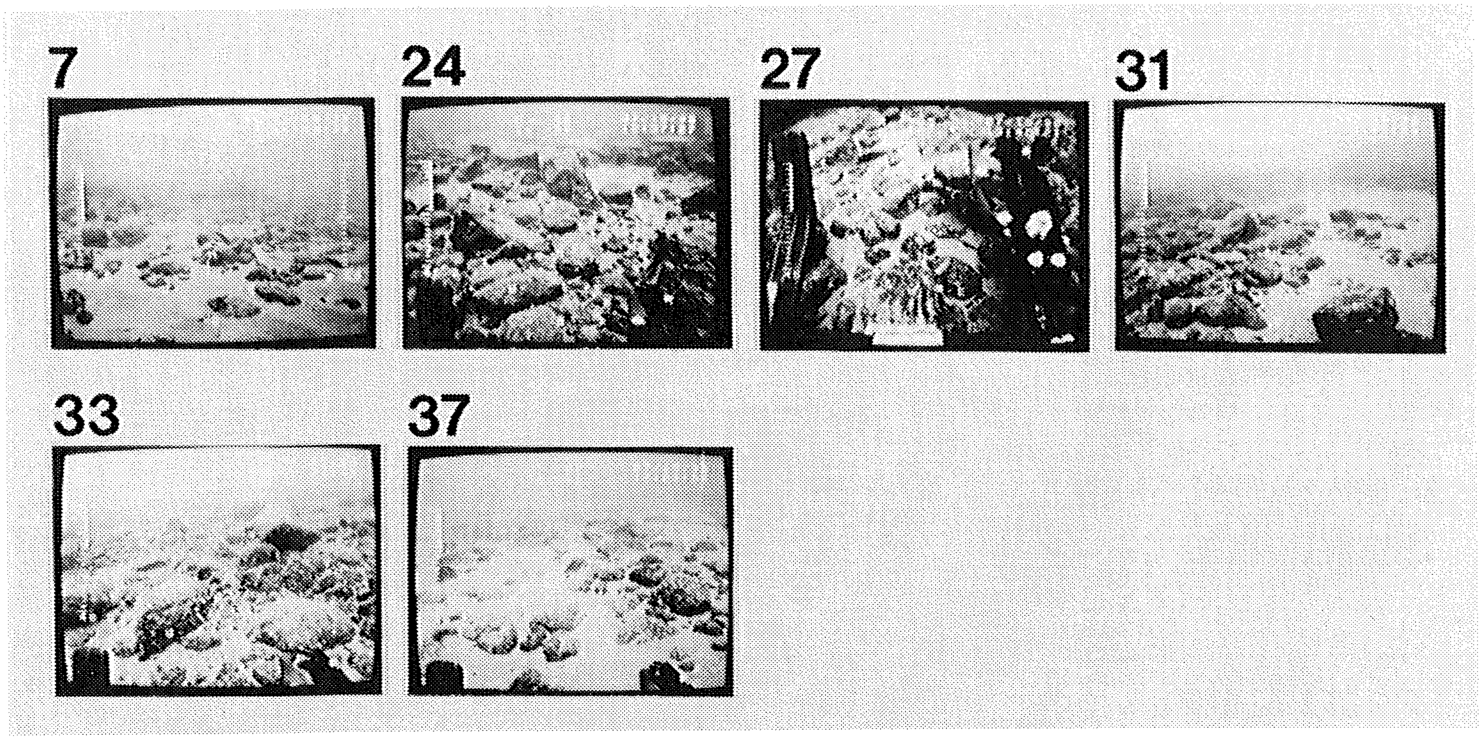


Figure 5. Photographs of the lake bed at 15 ROV sites in the rubble and sand substrate portion of the study area. The skids of the ROV, which appear in some of the photographs, are 18 cm apart and provide scale. The ROV site number is given on each photograph. ROV site locations are given in Figure 3.



7 24 27 31

33 37

Figure 6. Photographs of the lake bed at five ROV sites in the sand and rubble substrate portion of the study area. The skids of the ROV, which appear in some of the photographs, are 18 cm apart and provide scale. The ROV site number is given on each photograph. ROV site locations are given in Figure 3.

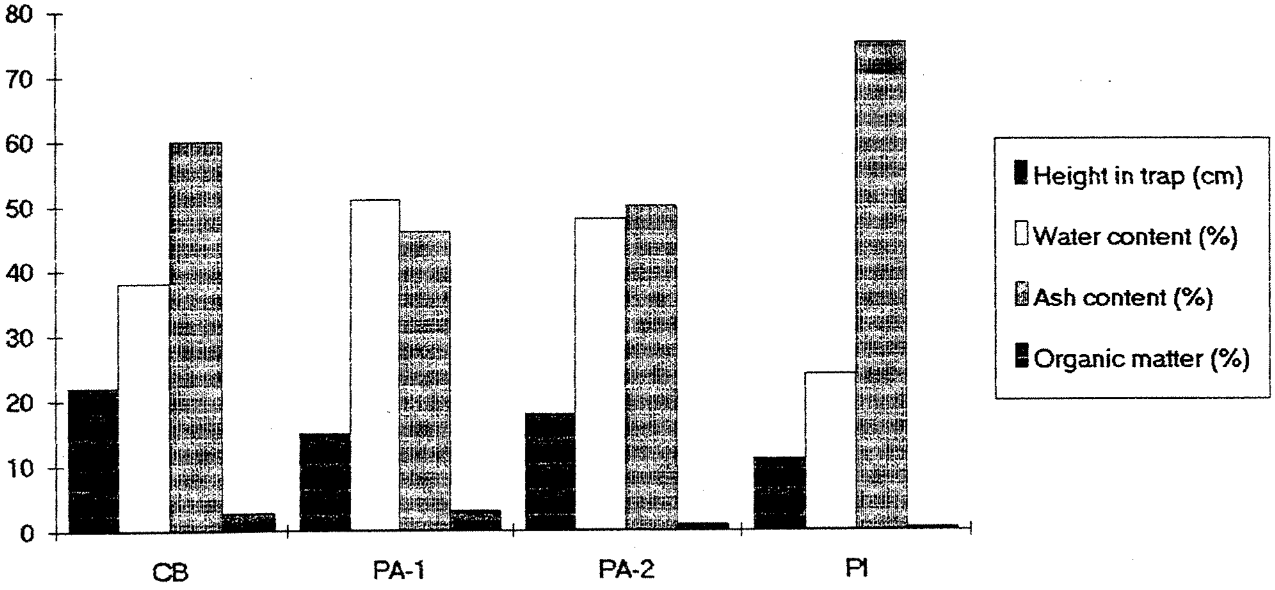


Figure 7. Physical and chemical characteristics of sediment collected over winter in sediment traps on historical lake trout spawning grounds in the Great Lakes. CB= Clay Banks Reef (present study). PA-1= Port Austin Reef, Lake Huron, 1986-87; PA-2= Port Austin Reef, 1987-88; PI= Partridge Island Reef, Lake Superior, 1987-88 (GLFC 1990, 1991).

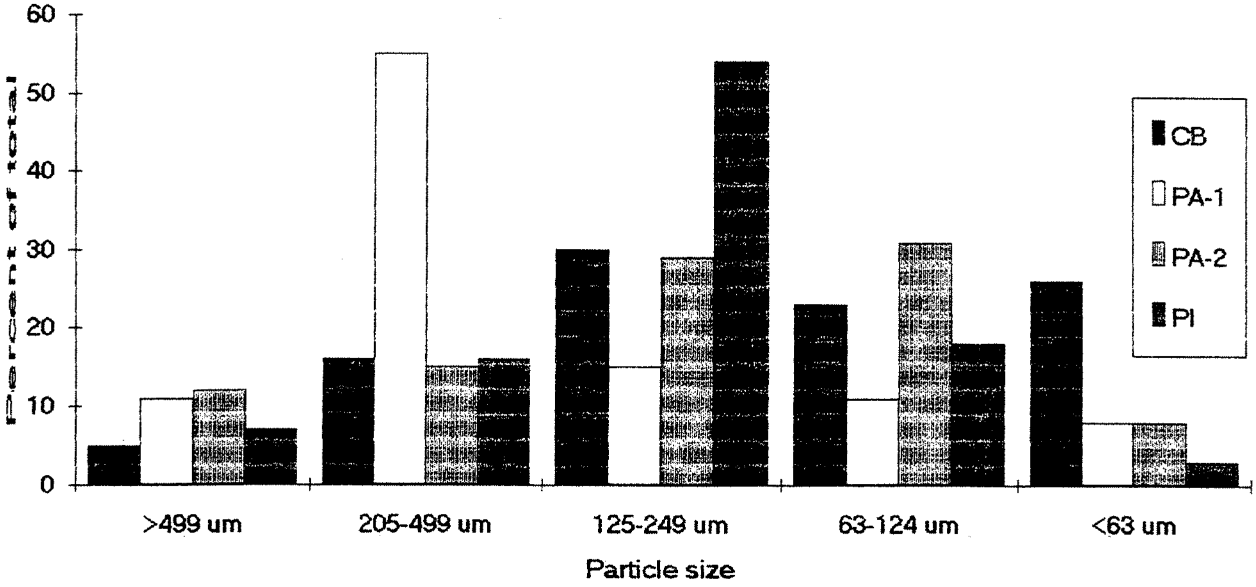


Figure 8. Particle-size distribution of sediment collected over winter in sediment traps on historical lake trout spawning grounds in the Great Lakes. CB= Clay Banks Reef (present study). PA-1= Port Austin Reef, Lake Huron, 1986-87; PA-2= Port Austin Reef, 1987-88; PI= Partridge Island Reef, Lake Superior, 1987-88 (GLFC 1990, 1991).