SURFICIAL SUBSTRATES AND BATHYMETRY OF FIVE HISTORICAL LAKE TROUT SPAWNING REEFS IN NEAR-SHORE WATERS OF THE GREAT LAKES

Great Lakes Fishery Commission

TECHNICAL REPORT 58

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October 1992

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ABSTRACT. The reestablishment of self-sustaining stocks of lake trout *(Salvelinus namaycush)* in the lower four Great Lakes has been substantially impeded because planted fish do not produce enough progeny that survive to reproduce. The causes for this failure are unknown, but many historical spawning sites of lake trout have been degraded by human activities and can no longer produce viable swim-up fry. In this study, we used side-scan sonar and an underwater video camera to survey, map, and evaluate the suitability of one reef in each of the five Great Lakes for lake trout spawning and fry production. At four of the reef sites, we found good-to-excellent substrate for spawning and fry production by the shallow-water strains of lake trout that are now being planted. These substrates were in water 6-22 m deep and were composed largely of piles of rounded or angular rubble and cobble. Interstitial spaces in these substrates were 20 cm or deeper and would protect naturally spawned eggs and fry from predators, ice scour, and buffeting by waves and currents. Subsequent studies of egg survival by

other researchers confirmed our evaluation that the best substrates at two of these sites still have the potential to produce viable swim-up fry.

INTRODUCTION

Reestablishment of self-sustaining stocks of lake trout *(Salvelinus namaycush)* in the lower four Great Lakes is substantially impeded because planted fish do not produce enough progeny that grow to 120 mm, the size at which planted hatchery fish show satisfactory survival. The causes for this failure to produce fish of an adequate size are unknown. Researchers at a conference sponsored by the Great Lakes Fishery Commission (GLFC) on lake trout rehabilitation (Eshenroder et al. 1984) examined an extended list of hypotheses and strategies to resolve the problem. Researchers concluded that:

1) habitat degradation might prevent natural reproduction by planted fish in many near-shore waters of the lower four Great Lakes, and

2) better descriptions of the microhabitats on historical spawning reefs were needed to facilitate rehabilitation in the lower four Great Lakes.

In 1985, an ad hoc committee[1] of the GLFC (Eshenroder 1988) designed a field bioassay (Manny et al. 1989) to evaluate the effects of cultural eutrophication on the spawning habitat and reproduction of lake trout. The committee also selected one bioassay site in each Great Lake (Fig. 1) and recommended that side-scan sonar be used to survey the sites, describe their physical features, and identify the best substrates and microhabitats for the bioassays. The New York State Department of Environmental Conservation assisted with site selections in Lakes Erie and Ontario. This paper describes the side-scan sonar and video-camera surveys that were performed on five sites in 1986-87 and evaluates the suitability of those sites as habitat for eggs, developing embryos, and fry of shallow-water or lean-strain lake trout.

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[1] Members of the committee: T. A. Edsall, R. L. Eshenroder (Chair), D. J. Jude, J. R. M. Kelso, J. A. McLean, and J. W. Peck.

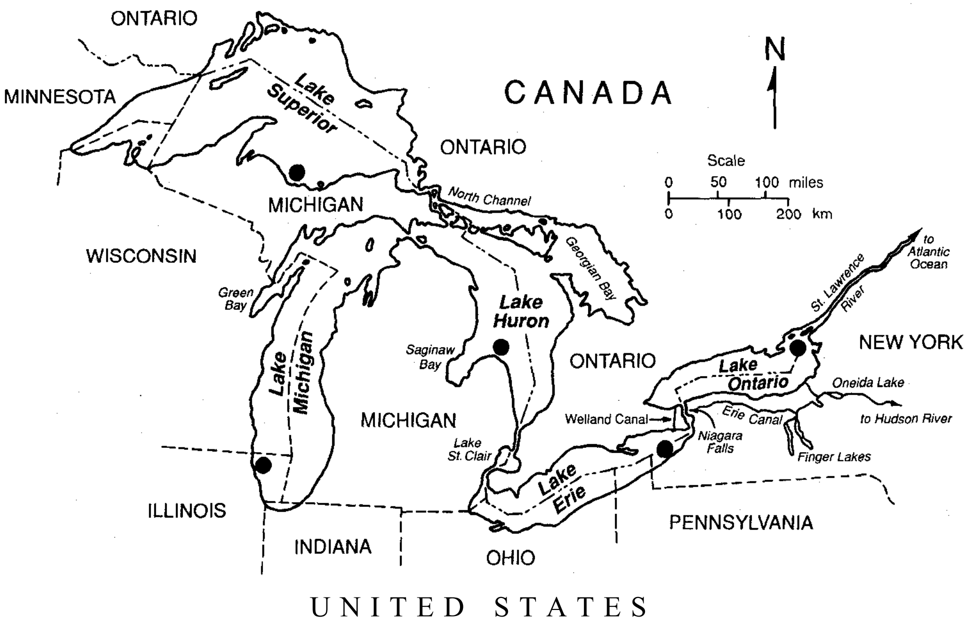

Fig. 1. Locations ● of side-scan sonar surveys.

METHODS

The lake bed was surveyed and mapped with an EG&G (217 Middlesex Turnpike, Burlington, MA 10803, U.S.A.) side-scan sonar system, which included a Model 260 microprocessor, Model 360 digital tape, and Model 272-T 100-kHz towfish with time-varied gain. Survey and mapping methods were similar to those used in studies of lake trout spawning grounds in northern Lake Michigan (Edsall et al. 1989) and central Lake Huron (Edsall et al. 1992). The towfish was deployed from a cable and davit over the side of the survey vessel. The length of the cable was adjusted so that the towfish ran 2-4 m beneath the surface of the water and 5-40 m above the lake bed as the vessel cruised at approximately 7.4 km/h. The towfish directed an acoustic signal to the lake bed, received and amplified the echo from the lake bed, and transmitted it to the microprocessor. The microprocessor converted the signal into a continuous strip-chart record showing the physical features of the surface of a 200-m-wide strip of lake bed beneath the towfish. We pulled the towfish along a series of parallel transects that covered the area to be surveyed and mapped. To facilitate navigation, these transects followed Loran C isograms. Transect spacing was approximately 120 m to allow overlapping representation of the lake bed on strip-chart records for adjacent transects.

The lake bed was examined at selected locations within the survey area with a Mini-ROVER Mk II (Benthos, Inc., 47 Egerton Drive, North Falmouth, MA 02556, U.S.A.) to facilitate interpretation of the side-scan records. The Mini-ROVER Mk II is a remotely operated submersible vehicle (ROV) equipped with a color video camera. An operator aboard the survey vessel guided the movements of the ROV (deployed on a tether) with joystick controls while monitoring the video-camera images transmitted to a closed-circuit video monitor aboard the survey vessel. An alphanumeric display of the depth at which the ROV was operating, and the compass heading it was following, were superimposed on the images of the lake bed. The entire screen display was videotaped to provide a permanent record.

The ROV rested on skids when it was on the bottom of the lake. The skids extended forward into the video-camera field of view and the distance between the skids (18 cm) provided a scale to estimate the size of rocks and other lake-bed objects recorded on the videotapes. The substrate interstitial depth (the vertical distance into loose rock substrates into which lake trout eggs and fry can gravitate) was estimated from the size composition and amount of piling of the loose rock and the degree to which sand or other fine sediments infiltrated the loose rock substrate. A Ponar grab was occasionally used to confirm the identity of soft sediments (sand, silt, clay) registered on the strip charts. The Ponar grab also collected small rocks that helped identify the bedrock or loose-rock components of the substrate.

In the laboratory, a 1:1000-scale mosaic map of each surveyed area was assembled from the strip charts. A regression technique (Edsall et al. 1989) accurately aligned the strip charts forming the mosaic. Substrate area1 distributions were delineated manually on the mosaic as polygons. The substrate within a polygon was classified according to Wentworth (1922) as:

1) sand (<2 mm in diameter),

2) gravel (2-64 mm),

3) rubble (65-256 mm),

4) cobble (257-999 mm), or

5) boulder (>999 mm).

A substrate mixture was classified by the two components that covered the largest- and second-largest amounts of lake bed within the polygon.

A bathymetric overlay was also constructed for each mosaic map from the water-depth information displayed on the margin or profile section of each strip chart in the mosaic (Edsall et al. 1989). The mosaic maps and bathymetric overlays were digitized and entered into a geographic information system. Computer-drawn maps were then produced at a scale of 1:4000, 1:6000, or 1:8000 showing the distribution of major substrates and the bathymetry of each surveyed area. These maps are on file at the National Fisheries Research Center--Great Lakes and copies are available from the GLFC. Evaluation of the lake bed as spawning and try-production habitat was based on recent studies (Wagner 1982, Peck 1986, Nester and Poe 1987, Marsden et al. 1988, Marsden and Krueger 1990) suggesting that angular or round rock (approximately 5-50 cm in diameter with interstitial depths of 30 cm or more) is suitable for planted lake trout in the Great Lakes.

RESULTS AND DISCUSSION

Partridge Island Reef

Partridge Island Reef is between Granite Point and Larus Island near the southern shore of Lake Superior and is separated from the mainland shore by water 20 m deep (Fig. 2). Approximately 366 ha of lake bed around the crest of the reef were mapped (Fig. 3). Water depth ranged from 14 m on the crest of the reef to more than 32 m at the northern end of the mapped area. At depths of 14-20 m, the reef was roughly oval in shape with regular bathymetry. Substrates at the crest of the reef were smooth bedrock, broken bedrock with scattered rubble, and rubble layers with cobble piles (Fig. 4). The southern and western borders of the reef were rubble layers with cobble piles. To the north and east, smooth bedrock and broken bedrock with scattered rubble were the major substrates to a depth of approximately 23 m.

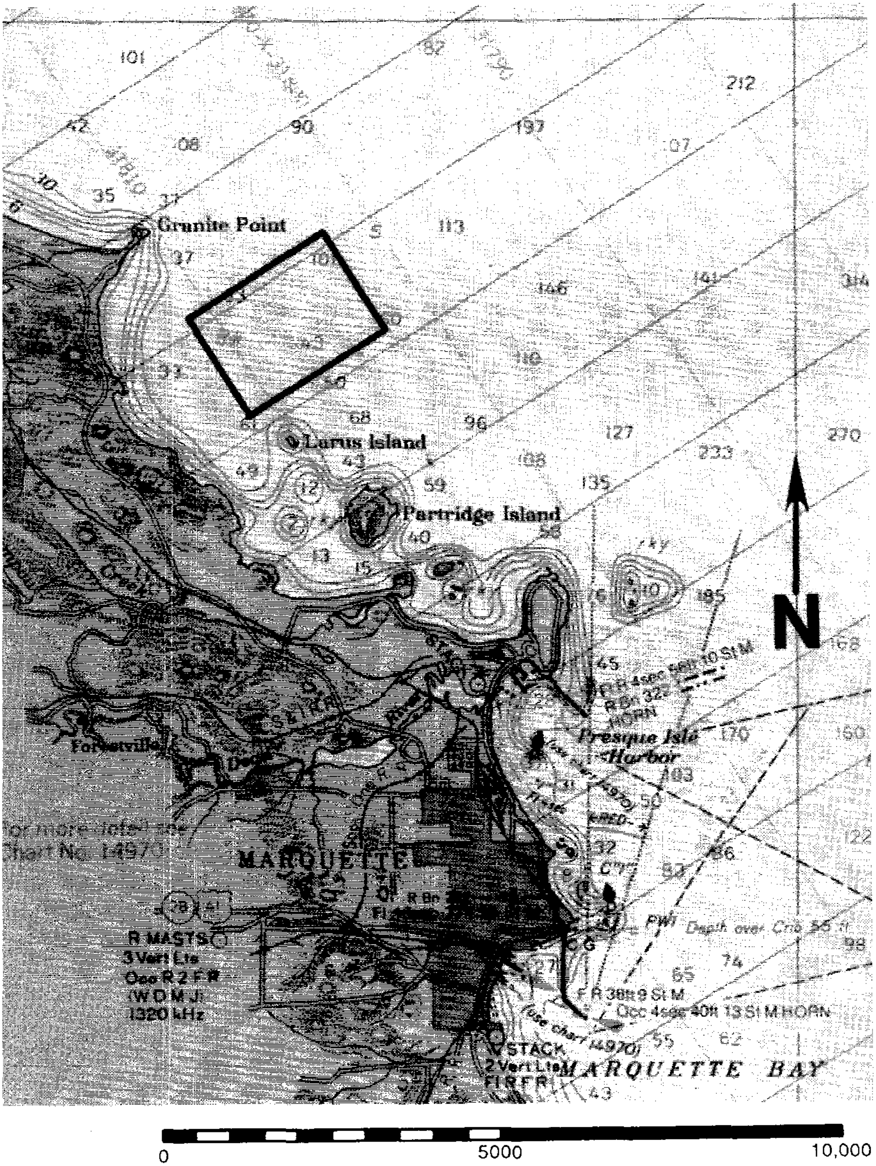

Fig. 2. Location of side-scan sonar survey on Partridge Island Reef, Lake Superior. Plotted on NOAA chart 14963, October 1981. Water depths are in feet.

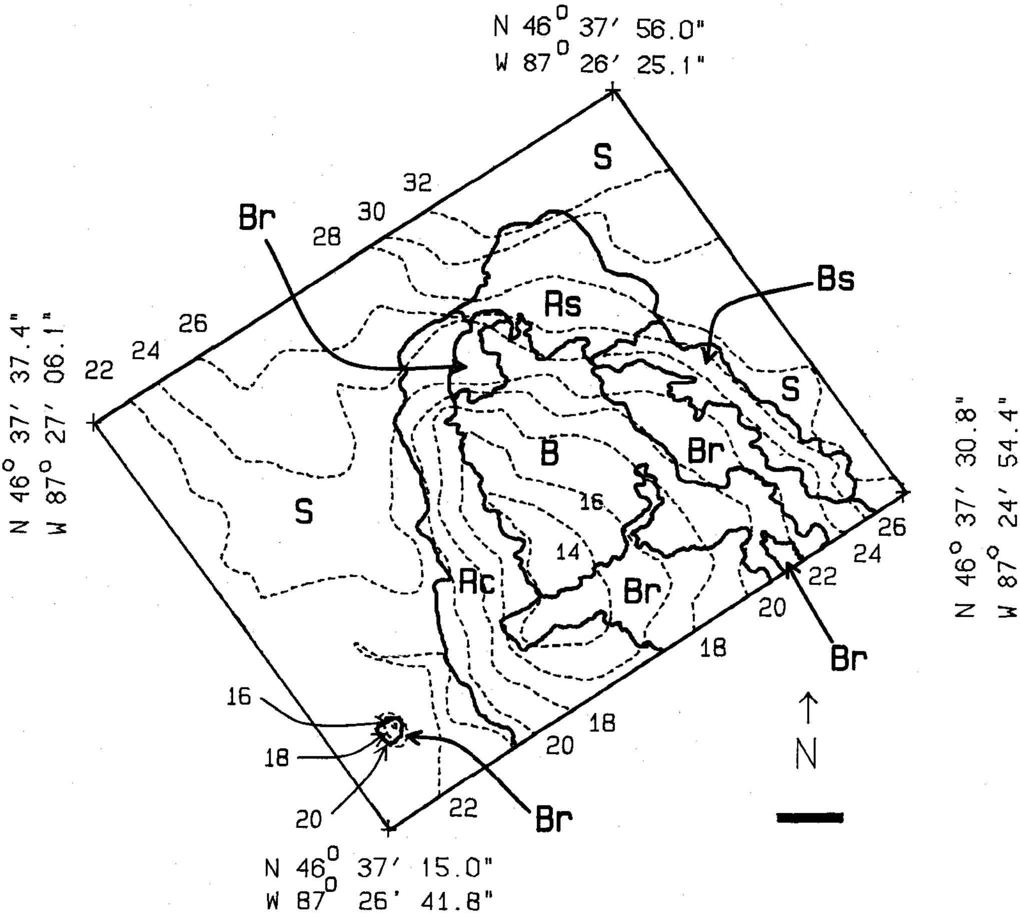

Fig 3. Partridge Island Reef substrates and bathymetry. Water depths (dashed lines) are in meters. The black bar in the lower right corner represents 0.2 km.

Substrate		Hectares
S - Sand		195.75
Rc - Rubble layers with cobble piles		41.98
Rs - Rubble patches on sand		19.87
Bs - Bedrock covered by sand patches		13.31
Br - Broken bedrock with scattered rubble		42.07
B - Smooth bedrock		5283
	Total	365.81

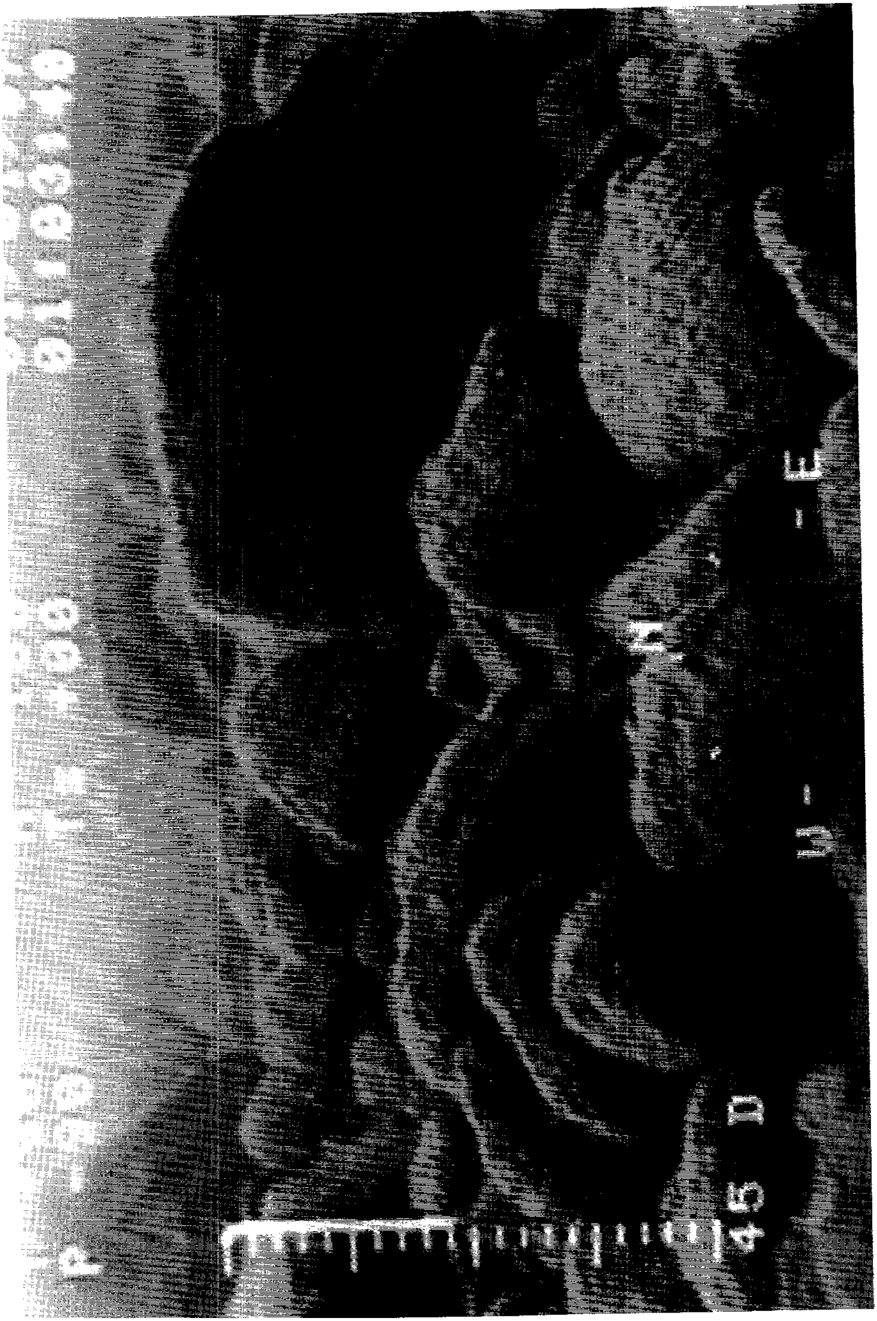

Fig. 4. Rubble layers with cobble piles substrate on Partridge Island Reef, Lake Superior.

The northern and eastern borders of the reef were bedrock covered by sand patches and rubble patches on sand at depths of approximately 23-32 m. Sand surrounded the reef on three sides in the mapped area and depths were as shallow as 20 m on the western side of the reef. Large sand ripples with crest-to-crest distances of 3-4 m were apparent on the mosaic map adjacent to the northern end of the rubble layers with cobble piles substrate (Fig. 5).

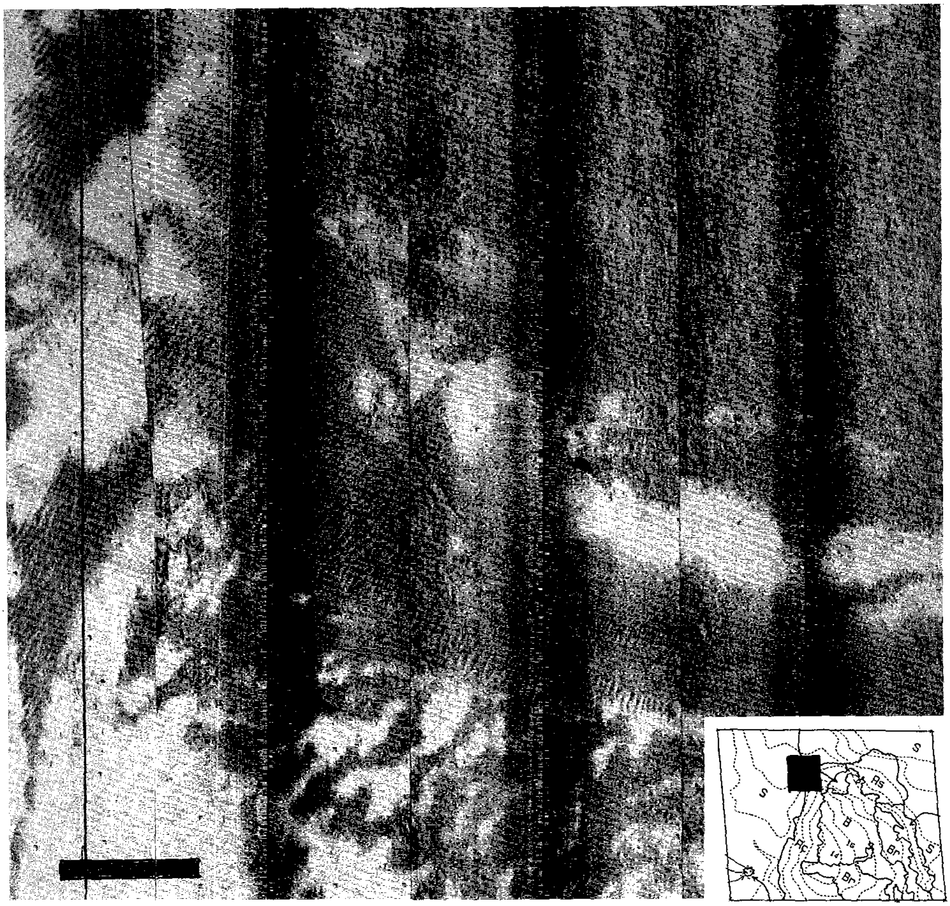

Fig. 5. Large sand ripples at the northern end of Partridge Island Reef, Lake Superior. The black bar in the lower left corner represents 50 m.

The best habitat on Partridge Island Reef for lake trout spawning and fry production was the rubble layers with cobble piles that covered approximately 42 ha on the western side of the reef at depths of 14-22 m. Videotapes of this substrate revealed interstitial depths of 30 cm or more and little or no periphyton growth. The absence of fine sediments on this part of the reef and the presence of large sand ripples immediately adjacent to the reef in water 22-26 m deep indicated the rubble layers with cobble piles substrate was periodically scoured by strong littoral currents. The broken bedrock with scattered rubble substrate that covered approximately 42 ha on the reef was also a suitable substrate in patches where the interstitial depth exceeded 20 cm. Both the rubble layers with cobble piles substrate and the broken bedrock with scattered rubble substrate extended beyond the southeastern border of the mapped area. No other substrates that were mapped provided sufficient interstitial depth to serve as spawning or fry-production habitat.

Wilmette Reef

Wilmette Reef is a small bedrock outcrop approximately 10 km northeast of Wilmette, Illinois, in southern Lake Michigan (Fig. 6). The reef is in water 15-18 m deep on the lakeward edge of a broad, gently sloping plateau of Silurian dolomite bedrock (Collinson et al. 1979). East of the reef, the lake bed drops quickly to depths of at least 30 m. Approximately 322 ha of lake bed surrounding the reef crest were mapped (Fig. 7). Water depth ranged from approximately 12 m on the reef crest to 28 m in the southeastern corner of the mapped area. The reef was roughly oval in shape at depths of 12-16 m and was composed mostly of bedrock ridges (Fig. 8). This central portion of the reef was surrounded by a narrow band of rubble piles with sand patches (Fig. 9) and sand with scattered rubble (Fig. 10) mostly at depths of 20-22 m. Rubble with sand was the major substrate on most of the rest of the mapped area at depths of approximately 20-27 m. Small areas of sand, sand with scattered rubble, and gravel with scattered rubble were present at depths of approximately 23-28 m in the southeastern portion of the mapped area.

None of the lake bed that we mapped on Wilmette Reef seemed suitable for spawning or fry production by lake trout. The bedrock ridges that were the major bathymetric feature of the reef lacked the loose rock overburden needed for successful lake trout spawning and fry-production habitat. Only scattered patches of widely spaced rubble and a patchy veneer of sand were present on top of the bedrock ridges substrate and there were no substrate interstices that could hold eggs or fry. The rubble piles with sand patches substrate had interstitial depths up to 5 cm in places, but extensive sand infilling rendered this substrate unsuitable for fry production. The other substrates in the surveyed area had no interstitial depth.

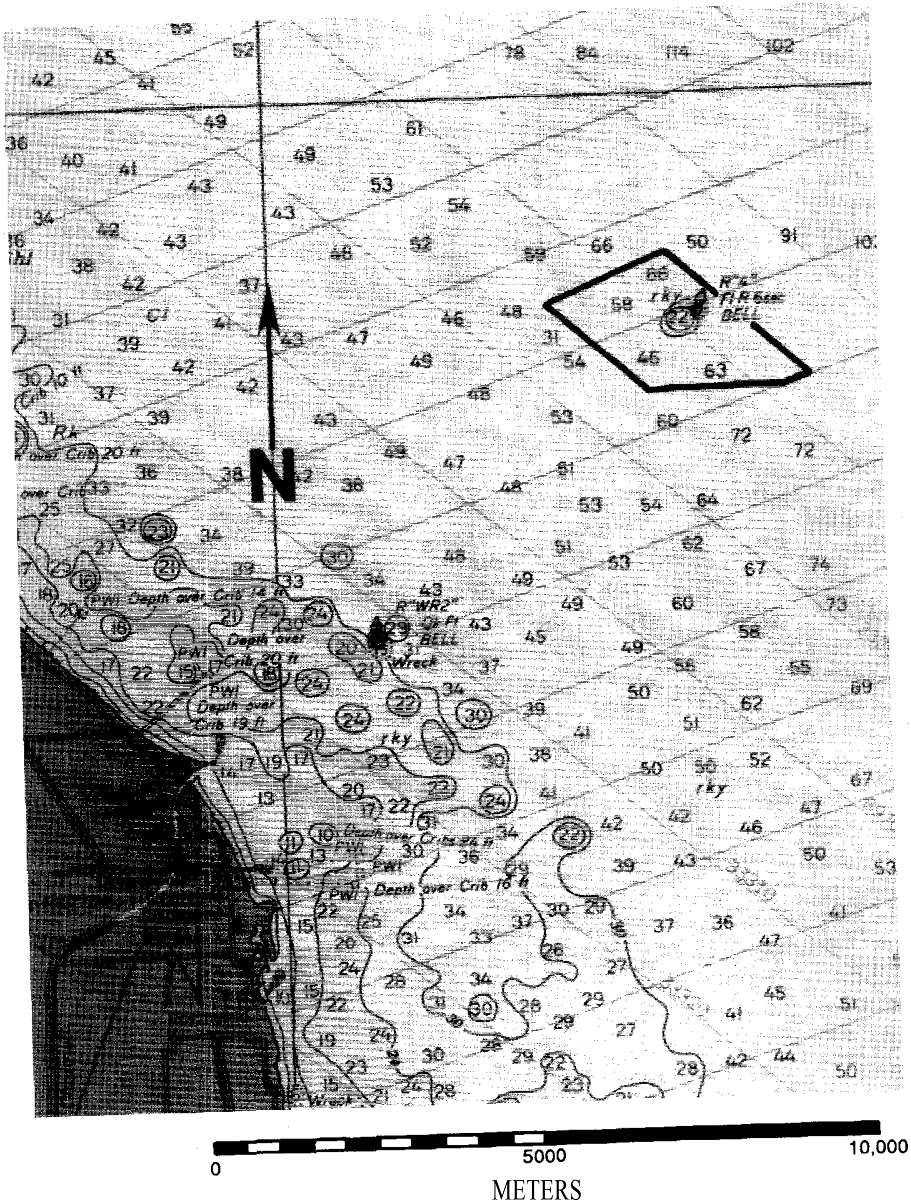

Fig. 6. Location of side-scan sonar survey on Wilmette Reef, Lake Michigan. Plotted on NOAA chart 14905, November 1981. Water depths are in feet.

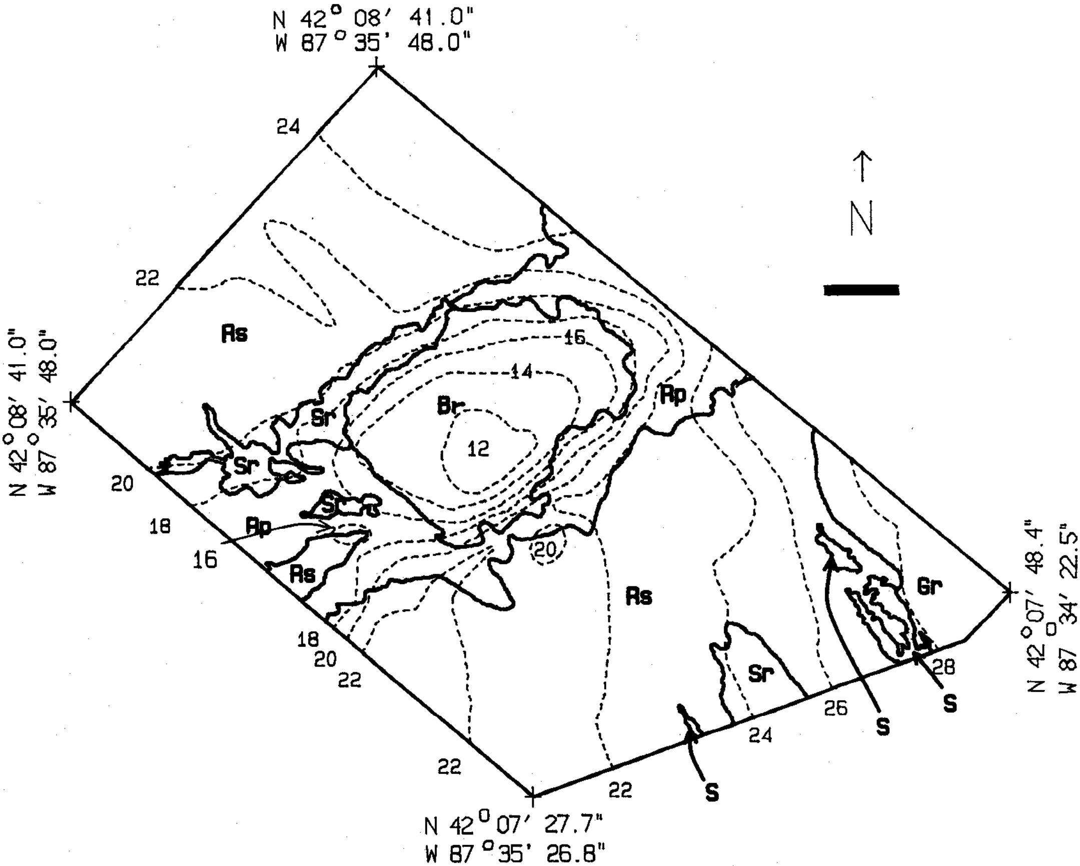

Fig. 7. Wilmette Reef substrates and bathymetry. Water depths (dashed lines) are in meters. The black bar in the top right corner represents 0.2 km.

Substrate	Hectares
S - Sand	3.29
Sr - Sand with scattered rubble	15.99
Gr - Gravel with scattered rubble	14.63
Rs - Rubble evenly distributed on sand	196.42
Rp - Rubble piles with sand patches	50.01
Br - Bedrock ridges	4192
Total	322.26

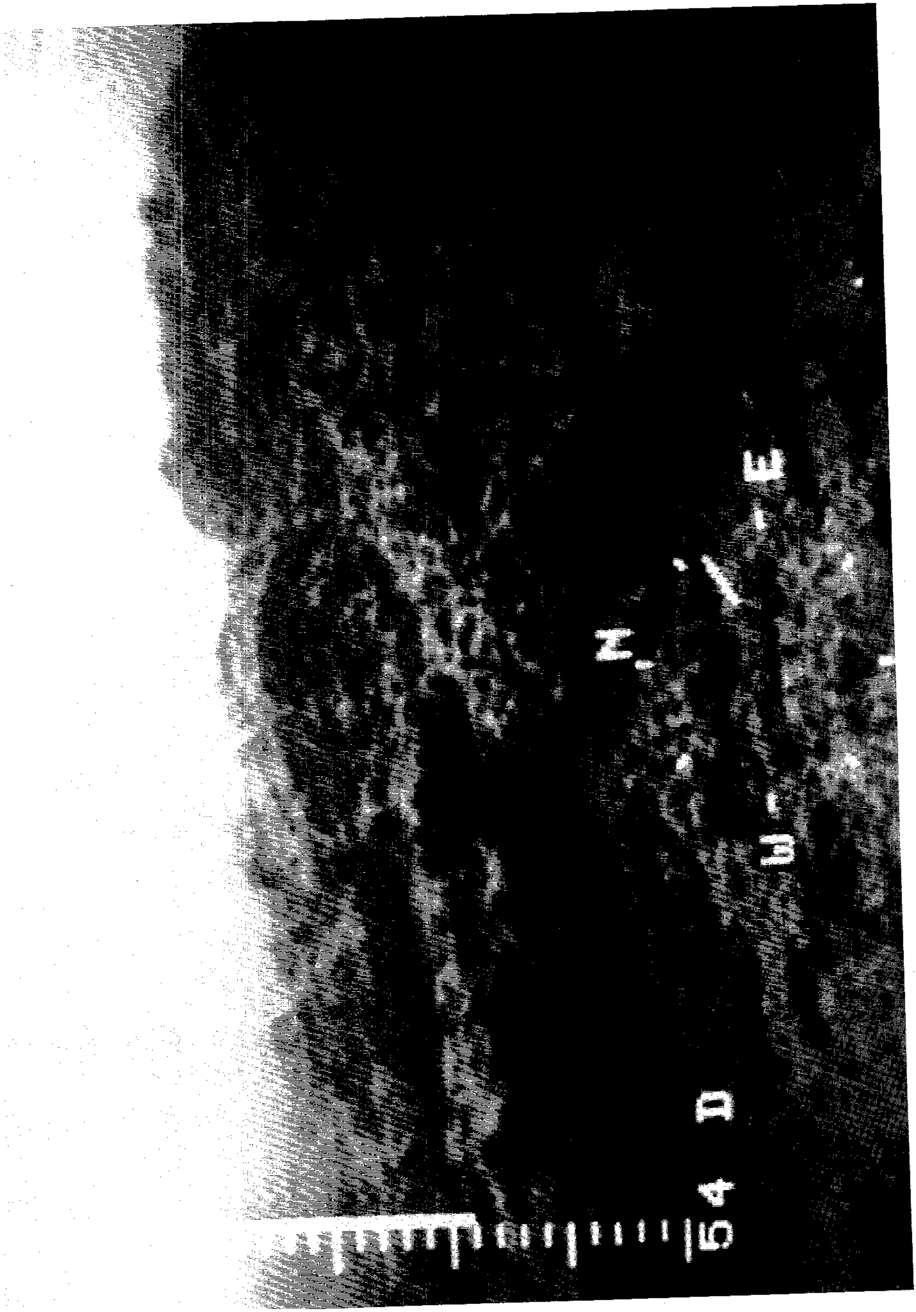

Fig. 8. Bedrock ridges substrate on Wilmette Reef, Lake Michigan.

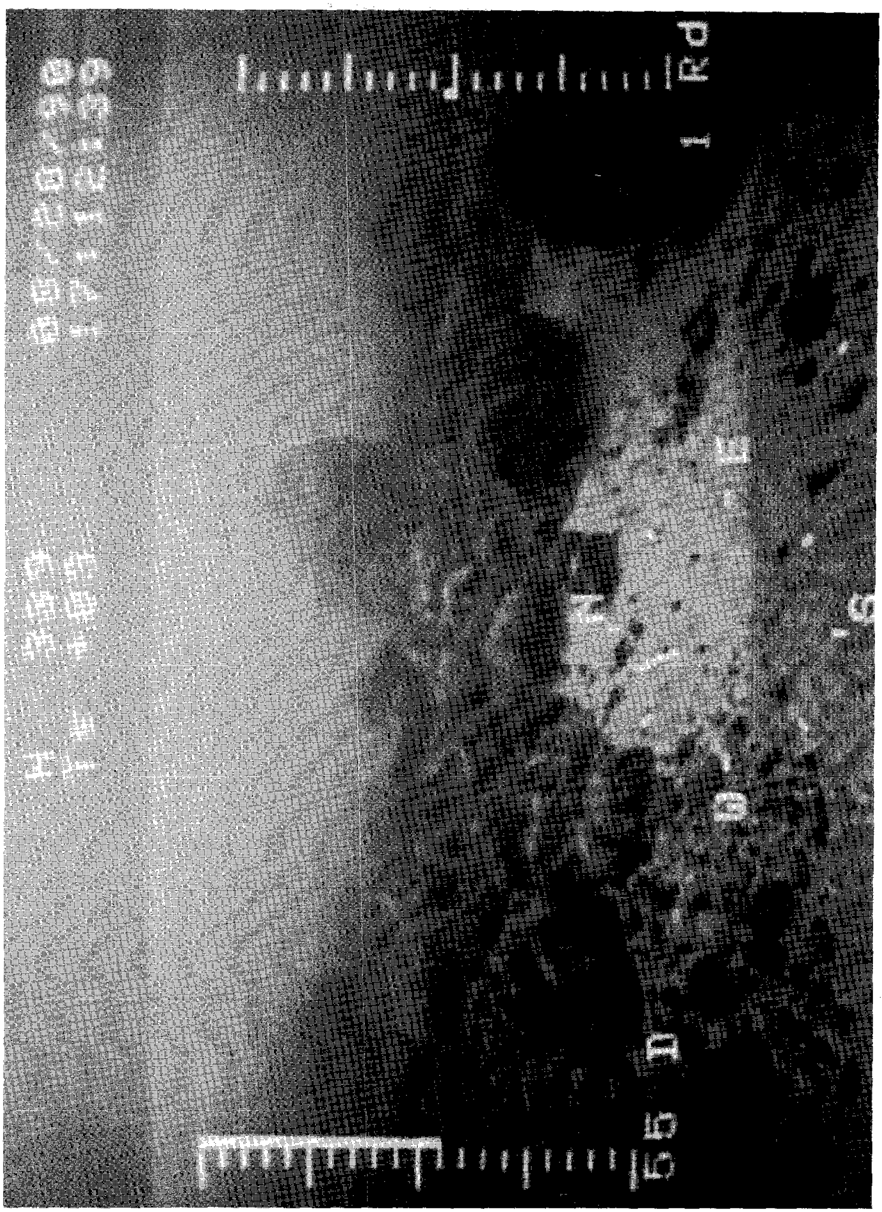

Fig. 9. Rubble piles with sand patches substrate on Wilmette Reef, I Michigan.

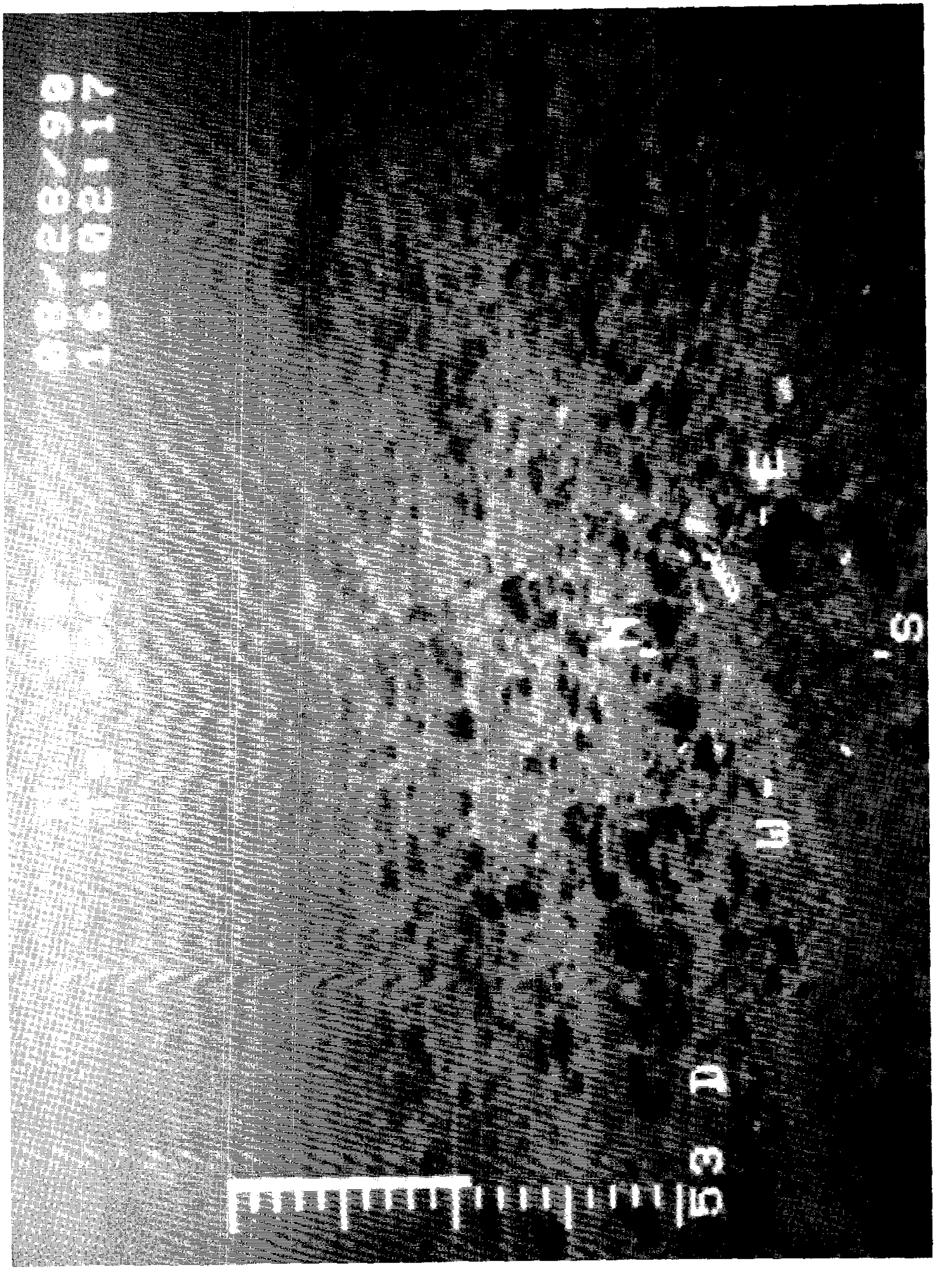

Fig. 10. Sand with scattered rubble substrate on Wilmette Reef, Lake Michigan.

Port Austin Reef

Port Austin Reef occupies the lakeward end of a submerged, rocky point that extends 3-4 km into southeastern Lake Huron near the mouth of Saginaw Bay at Port Austin, Michigan (Fig. 11). The general stratigraphy and composition of the surficial sediments of southern Lake Huron, including the Port Austin Reef area, are described by Cvancara and Melik (1961) and Thomas et al. (1973). Bedrock strata form exposed ridges on the lake bed near Port Austin and include Mississippian shales of the Napoleon-Marshall and Coldwater formations; unconsolidated glacial deposits are also found along the shoreline (Cvancara and Melik 1961). Other major surficial sediments composing the lake bed near Port Austin include sand from sources in Saginaw Bay, glaciolacustrine clays from the Canadian shield, and glacial tills (Thomas et al. 1973). The glaciolacustrine clays occur between the glacial tills deposited in inshore waters and the muds deposited in the deeper offshore waters. Both the glaciolacustrine clays and glacial tills vary in color from gray to reddish brown and both may occur as outcrops on the lake bed. The glaciolacustrine clays are moderately stiff in composition and may contain ice-rafted pebbles and display colored laminations. The tills are composed of cobbles and pebbles in a stiff sand, silt, and clay matrix and are usually covered with complex lag gravels (pebble- to cobble-sized rocks that remain after the finer materials are washed away), sands, or both, especially near the mouth of Saginaw Bay.

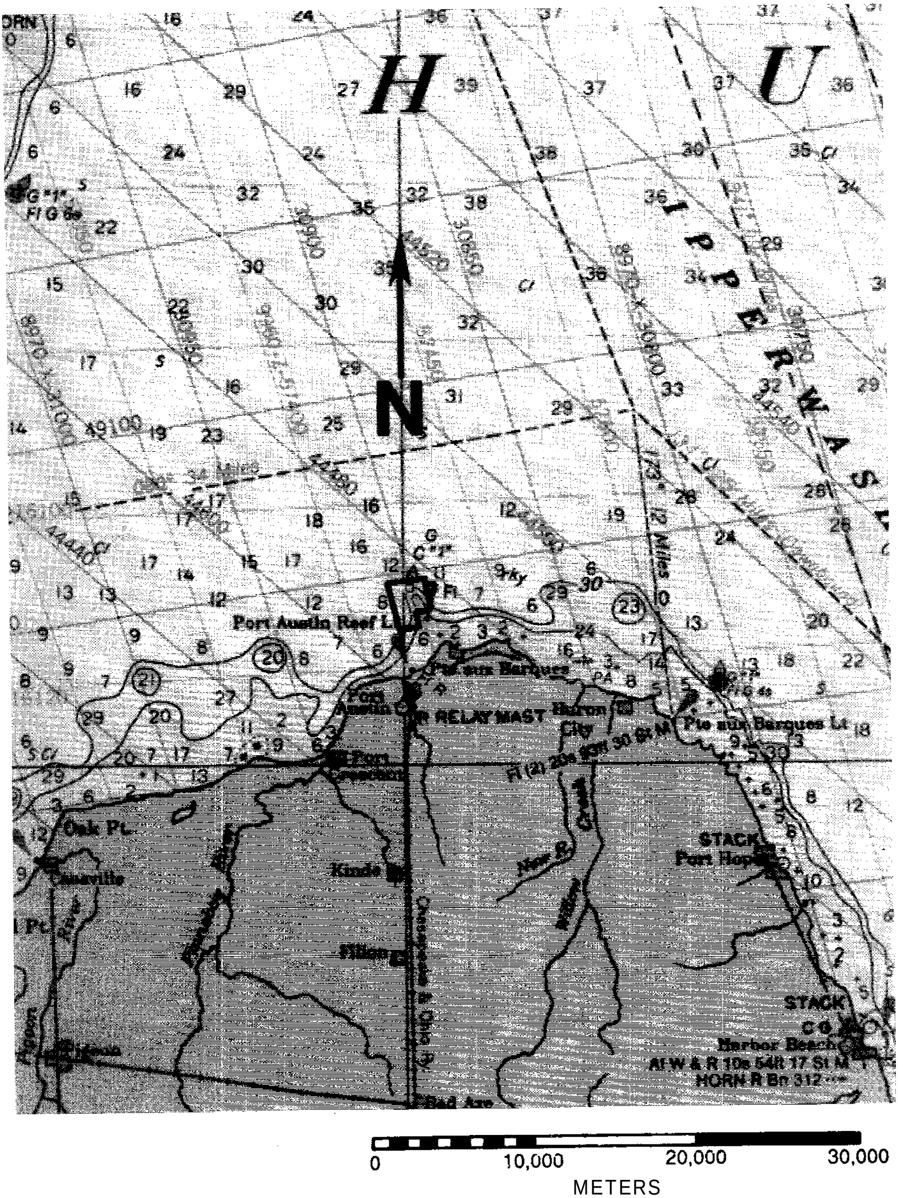

Fig. 11. Location of side-scan sonar survey on Port Austin Reef, Lake Huron. Plotted on NOAA chart 14860, October 1987. Water depths are in feet and fathoms.

Approximately 430 ha surrounding the crest of Port Austin Reef (Fig. 12) were mapped. Water depth was approximately 6 m at the crest of the reef and the reef was basically oval in shape at depths of 6-12 m. The reef sloped quickly into deep water (20 m or more) to the north and was separated from the shoreline to the south by a narrow band of water approximately 13 m deep. Substrate distribution on the mapped portion of the reef was complex. The reef crest at depths of 6-12 m was mostly smooth bedrock (Fig. 13) and bedrock with cobble patches (Fig. 14). A small intrusion of cobble on bedrock (Fig. 15) was present on the southern side of the crest and cobble evenly distributed on sand (Fig. 16) bordered the crest on the southwest. The smooth bedrock, cobble on bedrock, and cobble patches on sand were all extensions of substrates present in shallow water along the shoreline to the south. Bedrock with cobble patches substrate surrounded the reef crest on three sides and extended shoreward in a narrow finger to a depth of approximately 12 m. The same substrate also extended northeast to a depth greater than 20 m. Clay ridges with sand (Fig. 17) bordered the eastern and western sides of the mapped area at depths less than 18 m. These ridges were conspicuous features on the mosaic. They were approximately l-2 m high, 5 m wide, up to 100 m long, and were oriented roughly north to south (Fig. 18). The ridges were composed of stiff clay with inclusions of gravel- to rubble-sized rock, suggesting they were glacial till. At depths greater than 18 m, the substrate was sand with scattered rubble, sand with cobble patches, sand on broken bedrock (Fig. 19), and cobble patches on sand.

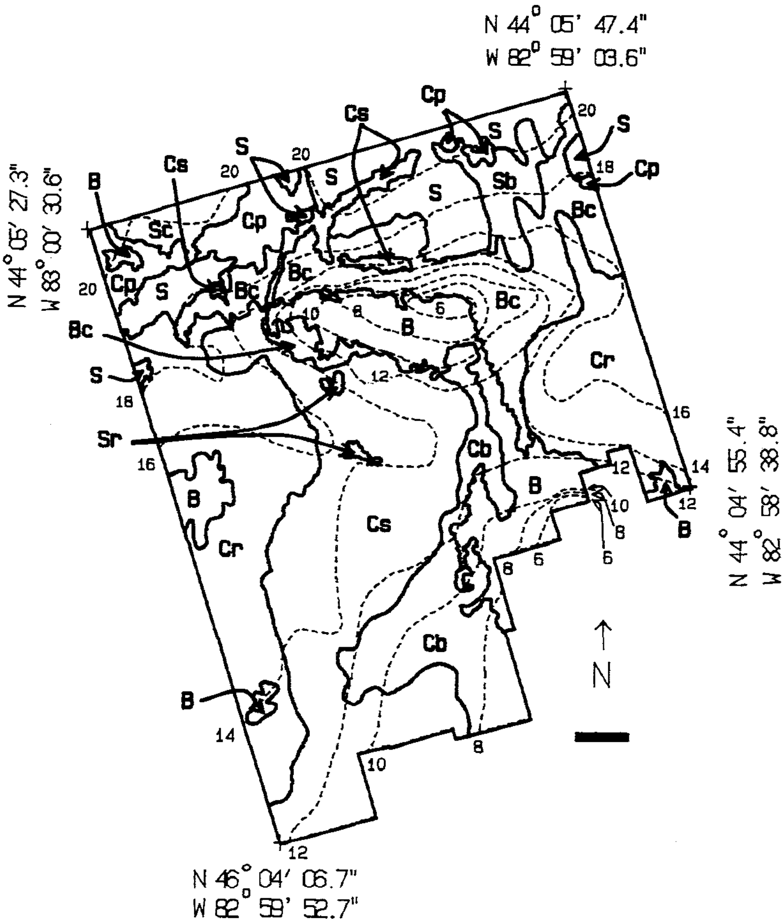

Fig. 12. Port Austin Reef substrates and bathymetry. Water depths (dashed lines) are in meters. The black bar in the lower right corner represents 0.2 km.

Substrate	Hectares
S - Sand	37.74
Sr - Sand with scattered rubble	1.09
Sc - Sand with cobble patches	7.36
Sb - Sand on broken bedrock	10.48
Cb - Cobble on bedrock	39.12
Cs - Cobble evenly distributed on sand	113.54
Cp - Cobble patches on sand	17.32
Cr - Clay ridges with sand	99.62
Bc - Bedrock with cobble patches	55.54
B - Smooth bedrock	48 26
Total	430.07

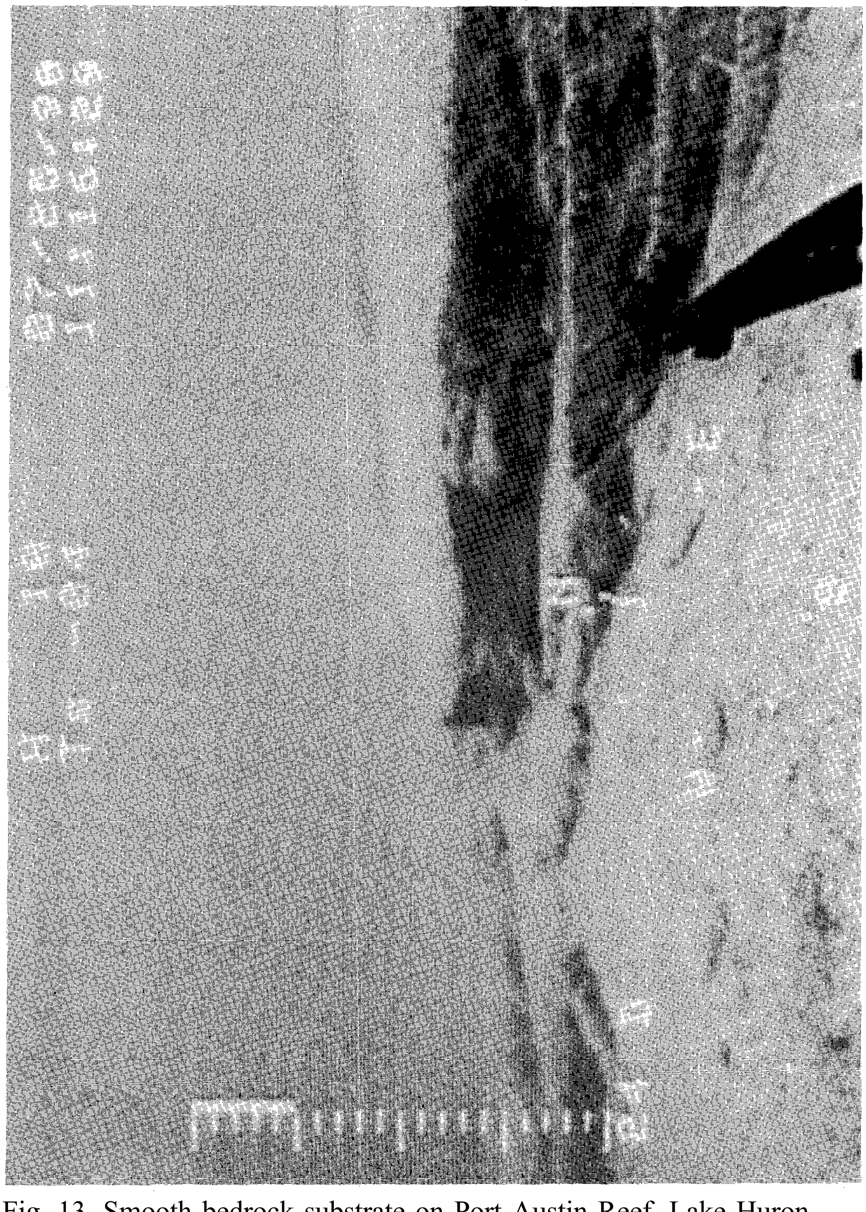

Fig. 13. Smooth bedrock substrate on Port Austin Reef, Lake Huron.

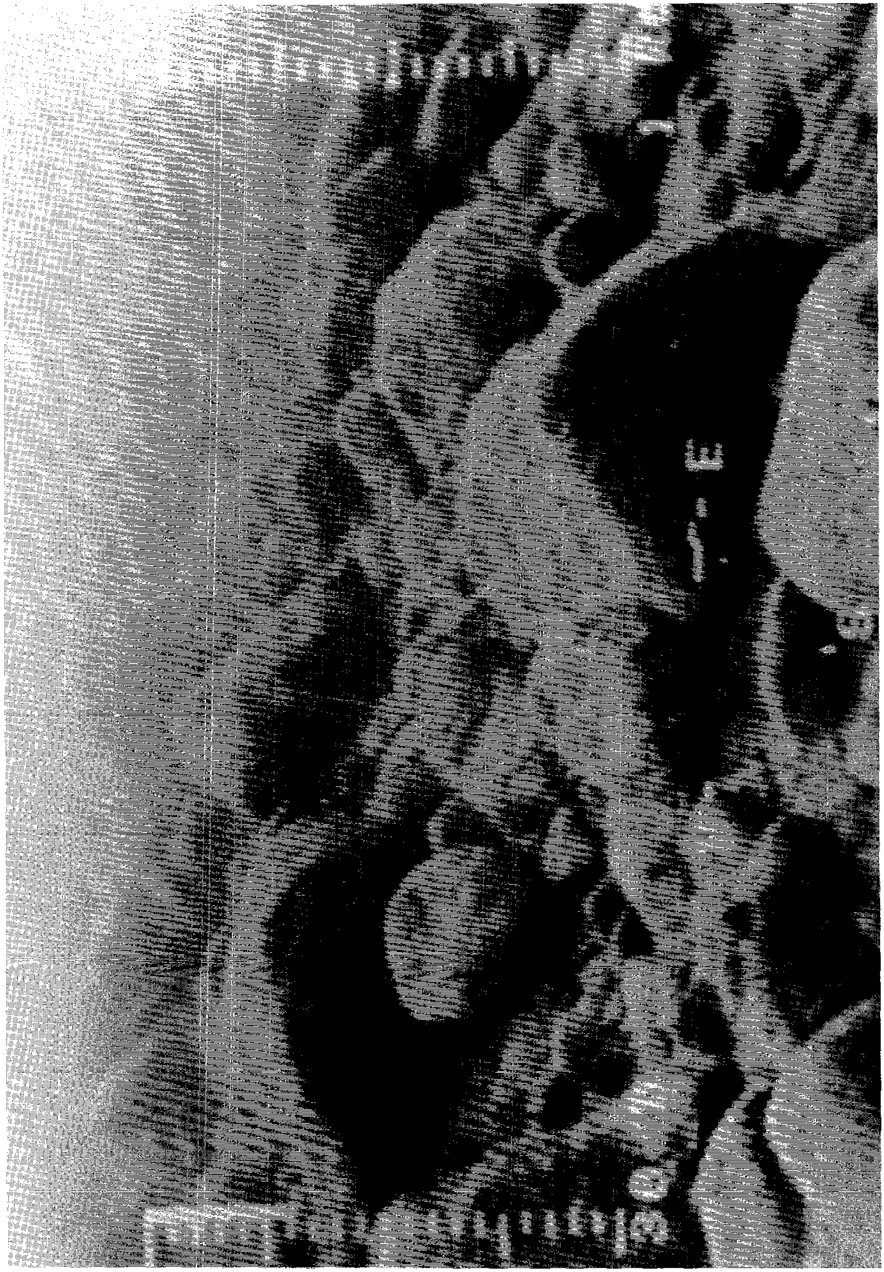

Fig. 14. Bedrock with cobble patches substrate on Port Austin Reef, Lake Huron.

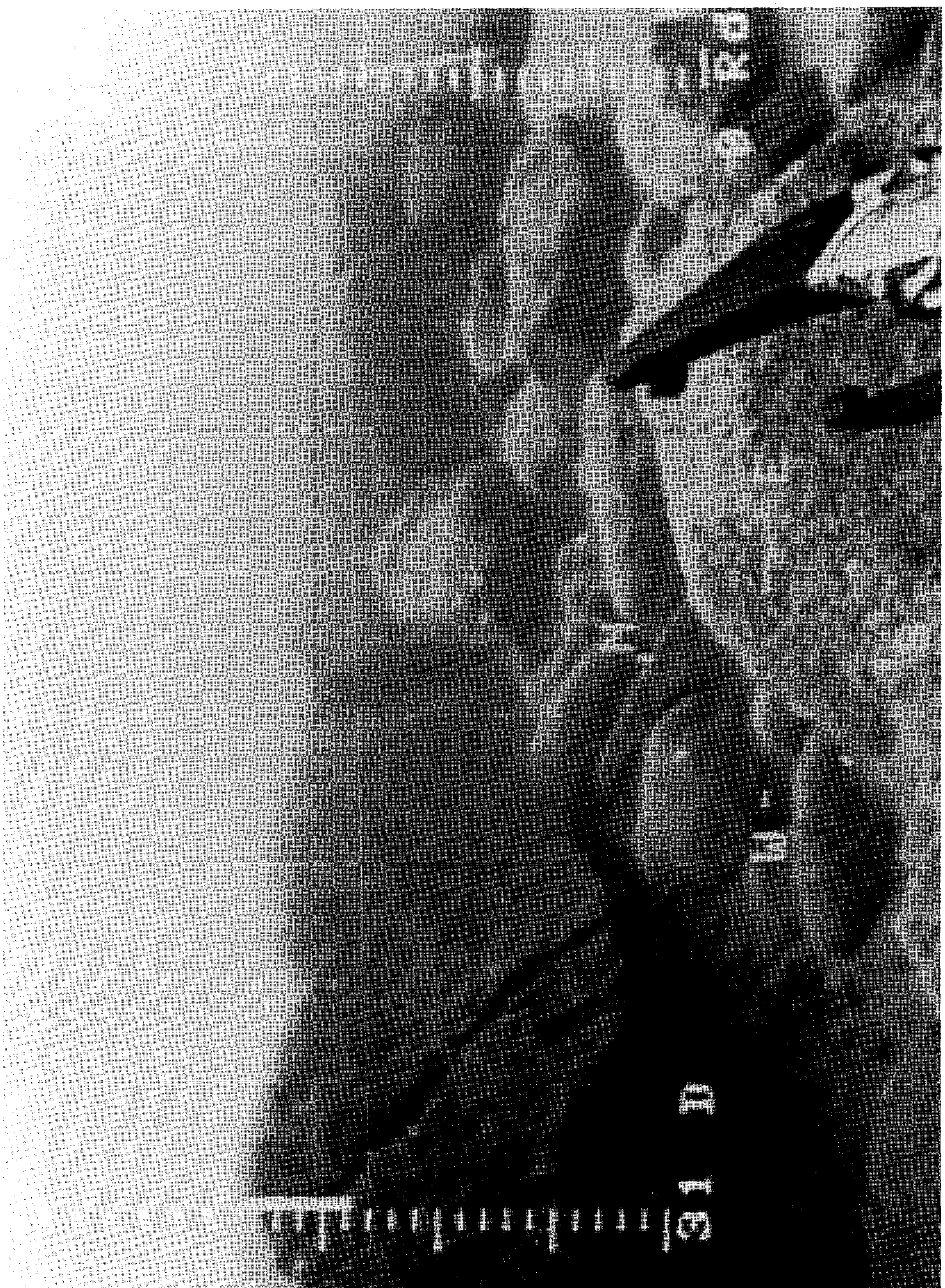

Fig. 15. Cobble on bedrock substrate on Port Austin Reef, Lake Huron.

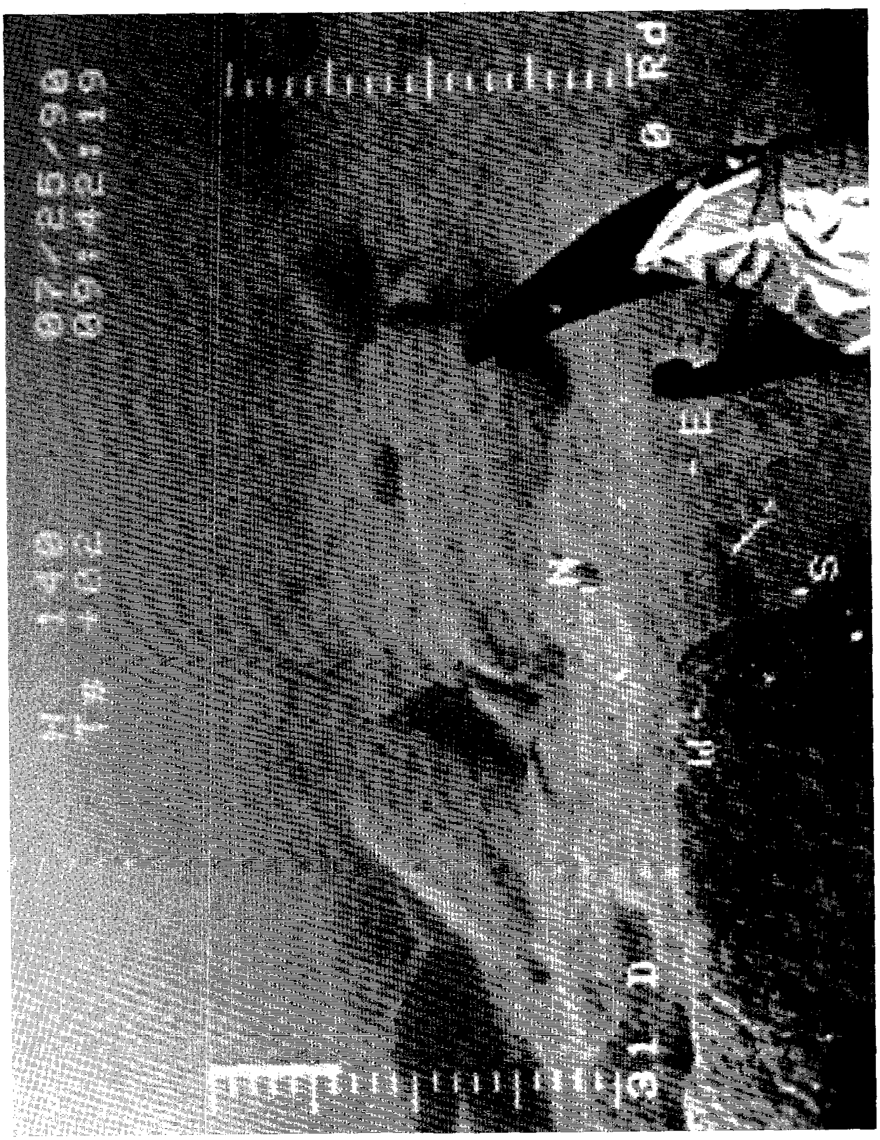

Fig. 16. Cobble evenly distributed on sand substrate on Port Austin Reef, Lake Huron.

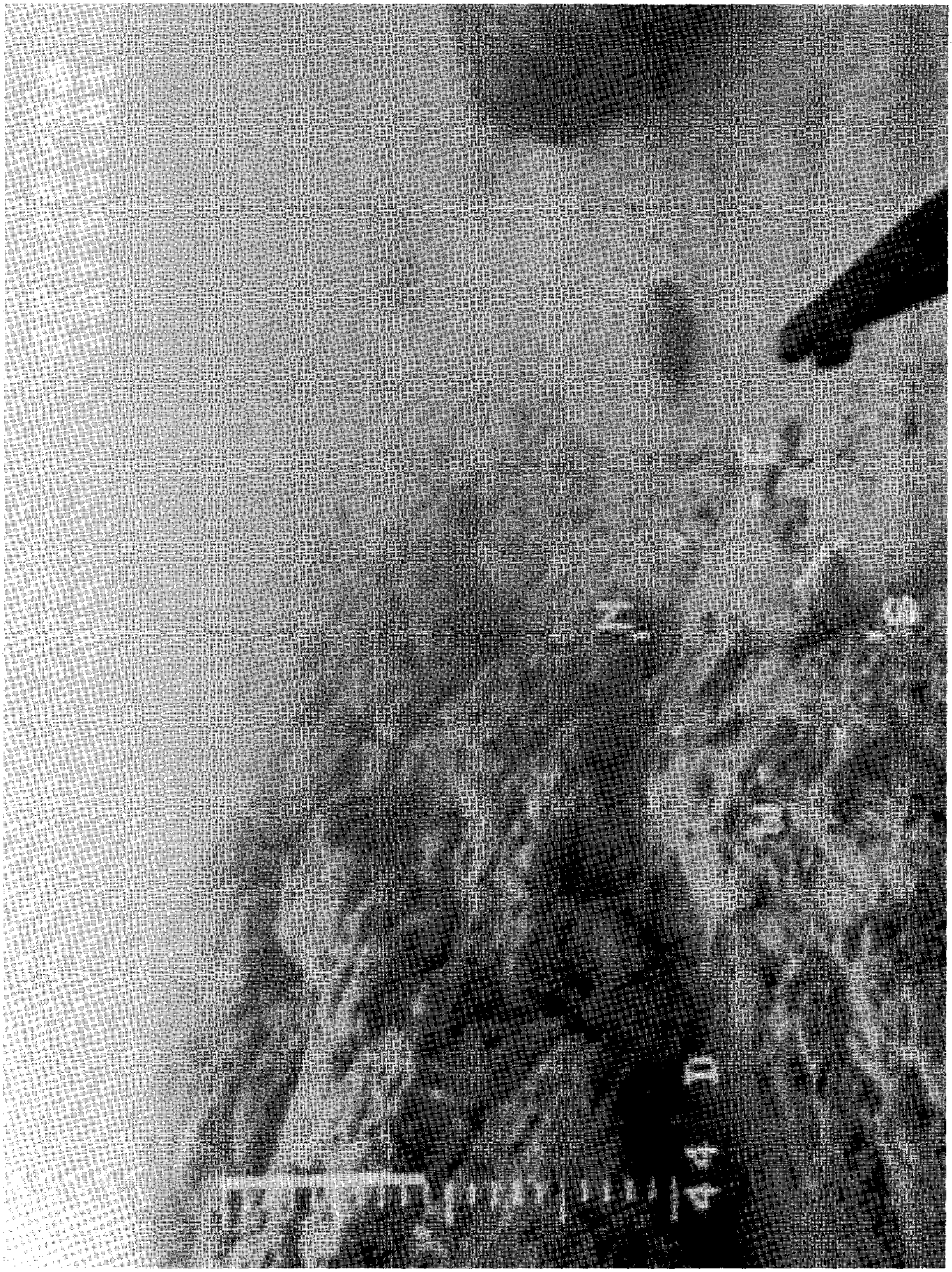

Fig. 17. Clay ridges with sand substrate on Port Austin Reef, Lake Huron.

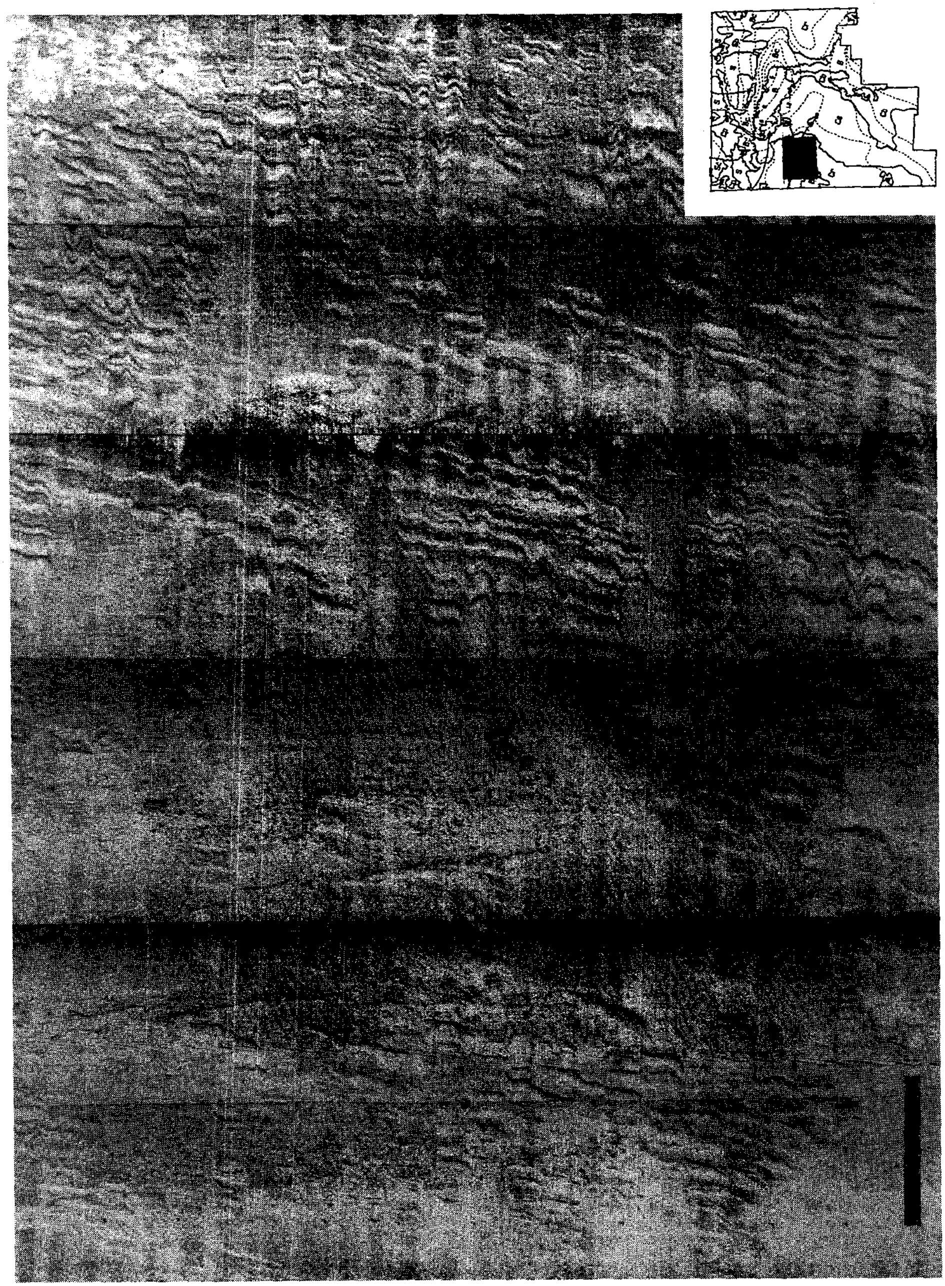

Fig. 18. Port Austin Reef, Lake Huron, mosaic element showing clay ridges on sand substrate. Inset shows location of mosaic element on Fig. 12. The black bar represents 50 m.

Fig. 19. Sand on broken bedrock substrate on Port Austin Reef, Lake Huron.

The best substrate on Port Austin Reef for lake trout spawning and fry production was the bedrock with cobble patches that covered approximately 56 ha on the northern, eastern, and western sides of the crest of the reef. Interstitial depth exceeded 20 cm on most of this substrate. Also suitable for spawning and fry production were scattered patches of cobble in the cobble on bedrock substrate that covered approximately 39 ha between the crest of the reef and the southern boundary of the mapped area. Interstitial depth exceeded 20 cm in these patches, which were several meters in diameter. The other substrates in the mapped area were unsuitable because their interstitial depth was less than 5 cm.

Brocton Shoal

Brocton Shoal is a bedrock outcrop approximately 4-8 km offshore in eastern Lake Erie near Brocton, New York (Fig. 20). The shoal spans the 20-m depth contour and appears to be an underwater extension of Van Buren Point. Water depth between the shoal and the shoreline exceeds 15 m. The lake bed slopes sharply downward north of the shoal and somewhat less sharply to the west. The bedrock substrate along the New York shore of Lake Erie is composed of Devonian shales that dip gradually to the east and are covered in places by glacial till or glaciolacustrine clay; rocky headlands (where present) are younger shales and sandstones (Hall 1843, Carter 1977, Sly and Thomas 1974).

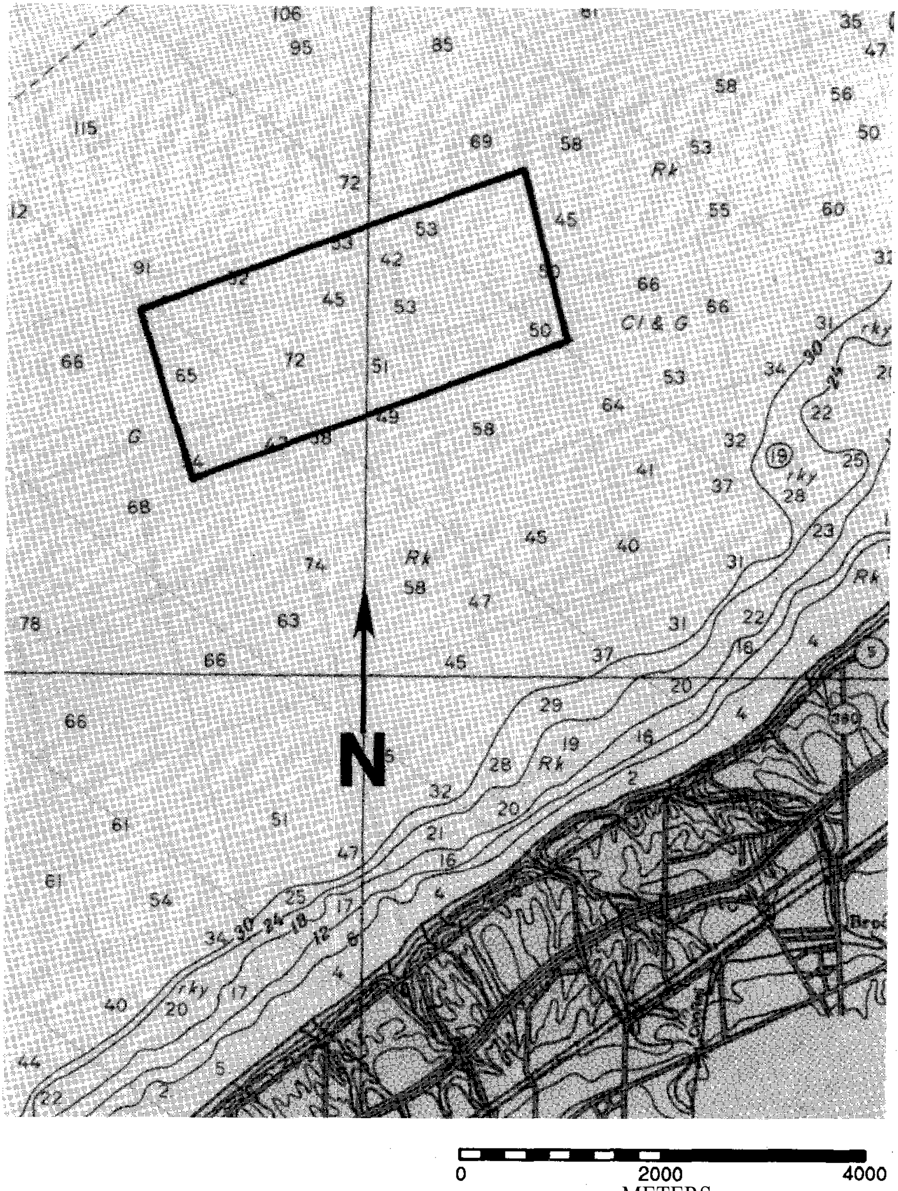

Fig. 20. Location of side-scan sonar survey on Brocton Shoal, Lake Erie. Plotted on NOAA chart 14823, September 1987. Water depths are in feet. A portion of the submerged lakeward extension of Van Buren Point is shown by the 24- and 30-foot depth contours east of the surveyed area.

Approximately 753 ha of lake bed were mapped on the shoal (Fig. 21). Three shoal crests were present in the mapped area. Water depth ranged from 16 m on the central crest and 18 m on the eastern and western crests, to 26 m in the northwestern corner of the mapped area. The eastern crest, which was only partly mapped, was composed of worn bedrock at 18-22 m and was bordered on the west by sand with scattered rubble, and broken bedrock covered by sand. The central crest was mostly worn bedrock at depths of 16-22 m (Fig. 22). It was bordered on the south and west by broken bedrock covered by sand (Fig. 23) and cobble ridges scattered on sand (Figs. 24, 25, 26) at 18-20 m, and on the east and north by sand with scattered rubble at 18-22 m. The western crest was worn bedrock, broken bedrock with scattered boulders, and broken bedrock covered by sand at 18-22 m. This crest was surrounded by sand except on the northwestern corner where broken bedrock covered by sand bordered the worn bedrock at 26 m. Broken bedrock covered by sand occupied part of the southwestern corner of the mapped area at 18-22 m.

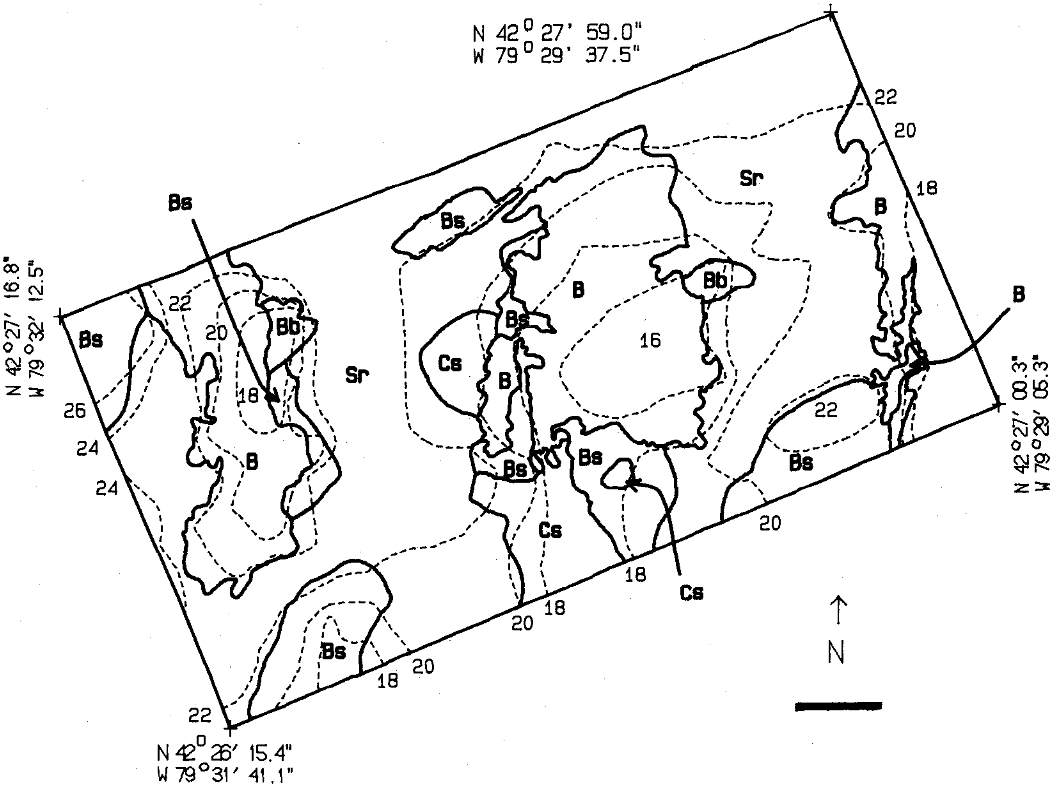

Fig. 21. Brocton Shoal substrates and bathymetry. Water depths (dashed lines) are in meters. The black bar represents 0.4 km.

Substrate		Hectares
Sr - Sand with scattered rubble		392.19
Cs - Cobble ridges on sand		37.51
B - Worn bedrock		204.74
Bb - Broken bedrock with scattered boulders		9.01
Bs - Broken bedrock covered by sand		109 49
	Total	752.94

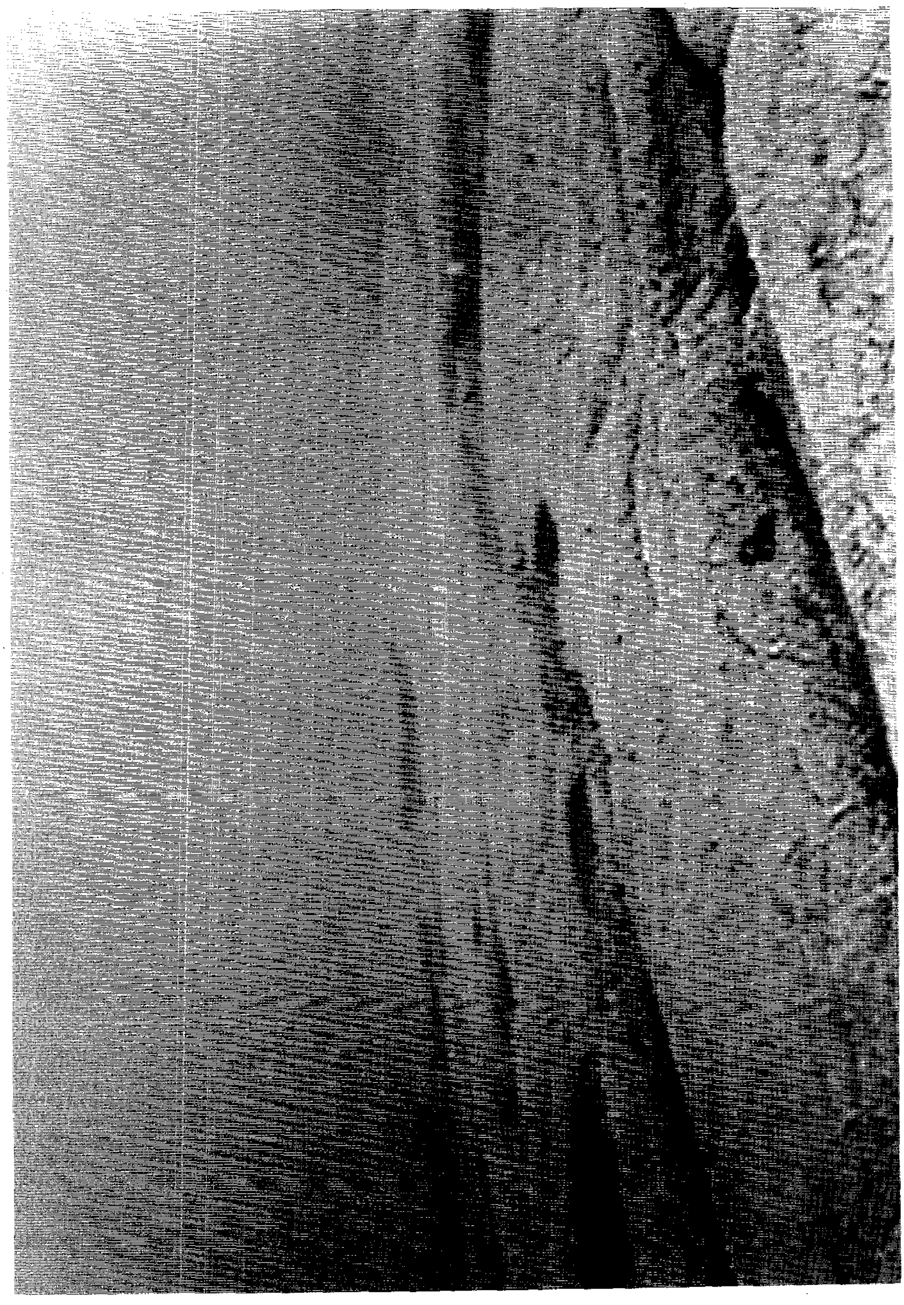

Fig. 22. Worn bedrock substrate on Brocton Shoal, Lake Erie.

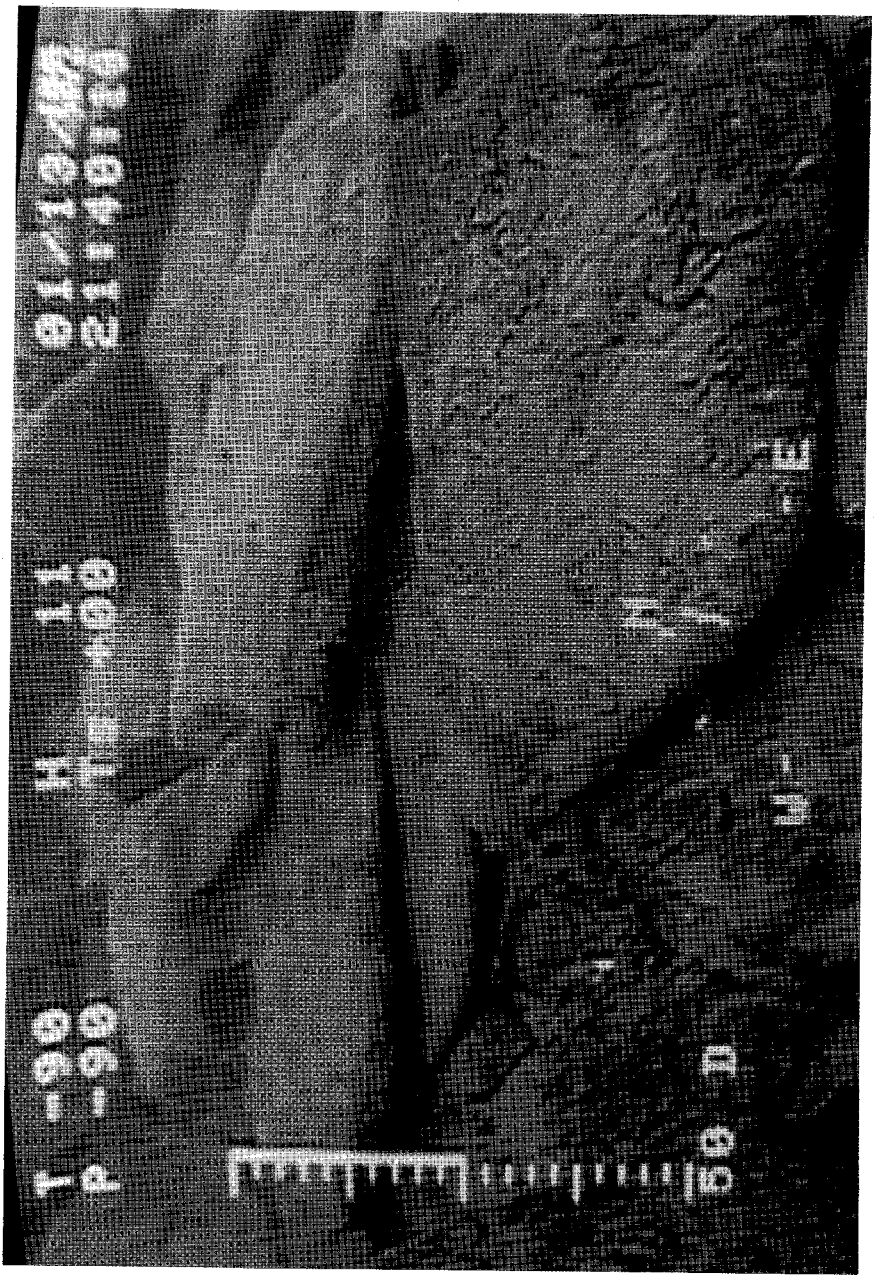

Fig. 23. Broken bedrock covered by sand substrate on Brocton Shoal, Lake Erie.

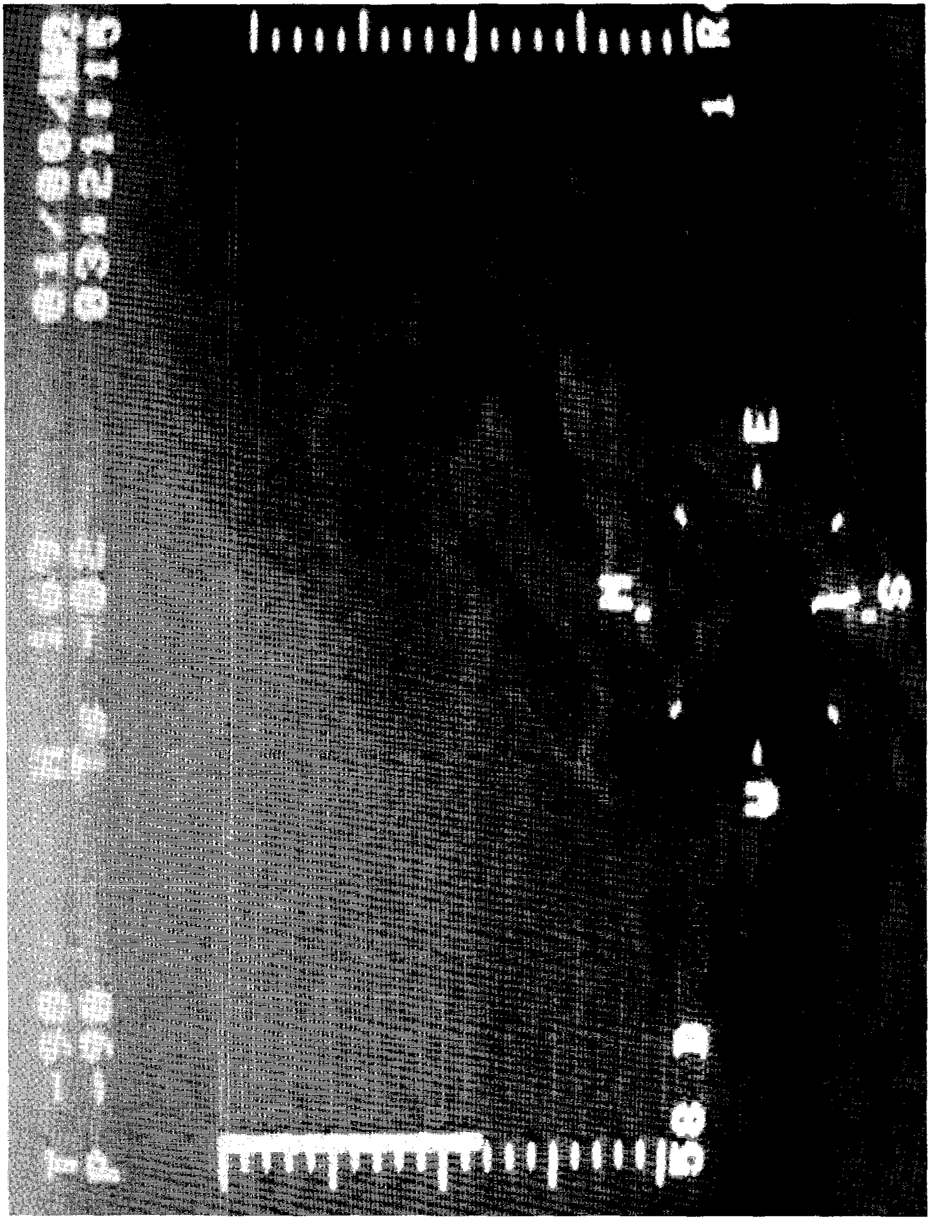

Fig. 24. Cobble ridges scattered on sand substrate on Brocton Shoal, Lake Erie. View of side of ridge.

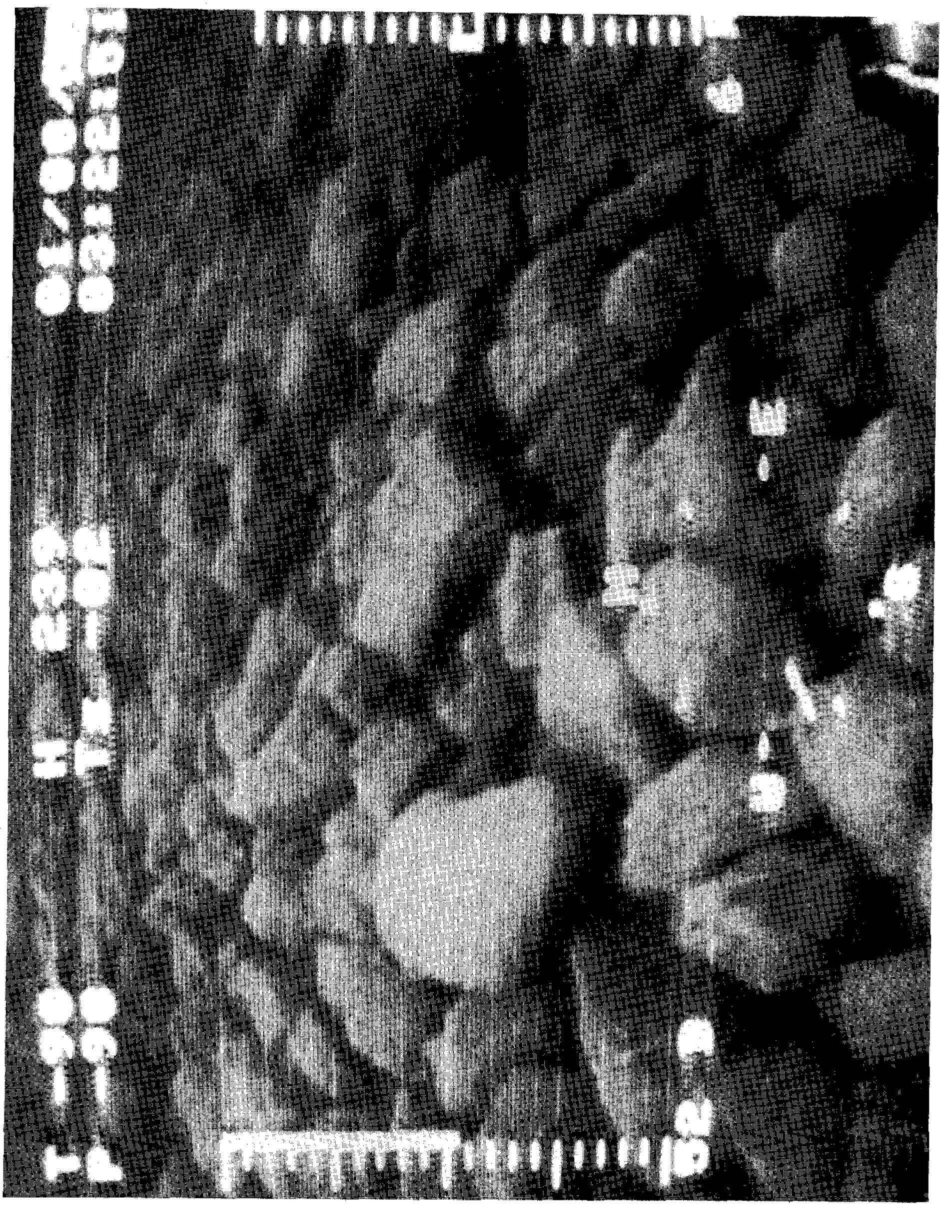

Fig. 25. Cobble ridges scattered on sand substrate on Brocton Shoal, Lake Erie. View of top of ridge.

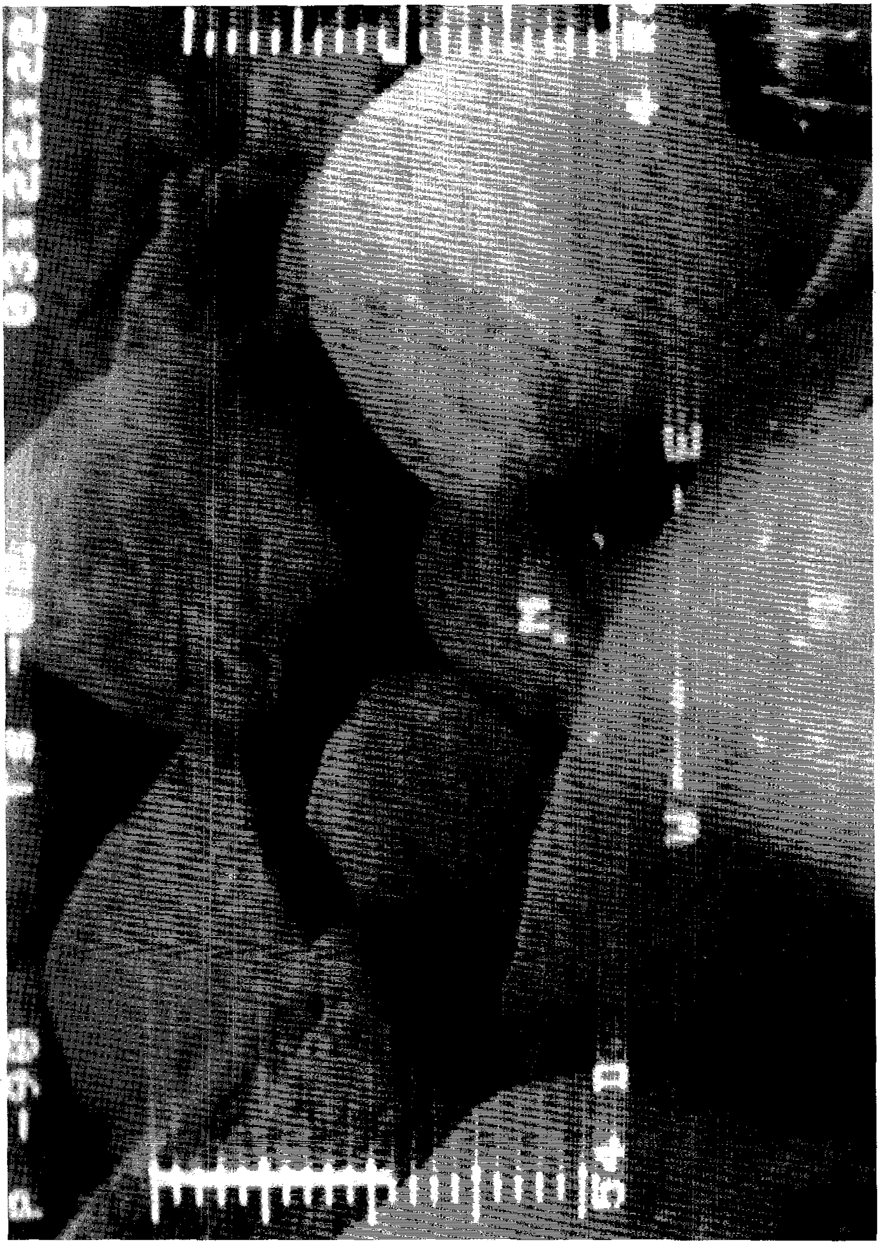

Fig. 26. Close-up of cobble shown in Fig. 25. Note the clean surface of the rocks.

The best substrate for spawning and fry production on Brocton Shoal was the 38 ha of cobble ridges on sand on the southern and western edges of the central reef crest. These ridges were readily apparent on the mosaic as sinuous features approximately 5-10 m wide, 100 m or more long (Fig. 27), and approximately 2 m high (shown by the depths recorded on Figs. 24 and 25). The rock comprising the ridges was clean when it was photographed in July (Fig. 26) and interstitial depth appeared to exceed 30 cm. The sand ripples at the base of some of the ridges (Figs. 28, 29) indicated there was considerable hydraulic action at the bottom in this area. The broken bedrock with scattered boulders substrate that covered 9 ha on the eastern slopes of the central and western crests was marginal for lake trout spawning and fry production. In this substrate, interstitial depths were less than 10 cm and the spaces between the loose rocks were wide enough to allow small fish to prey on eggs and fry resting there. None of the other substrates on Brocton Shoal was suitable for lake trout spawning and fry production.

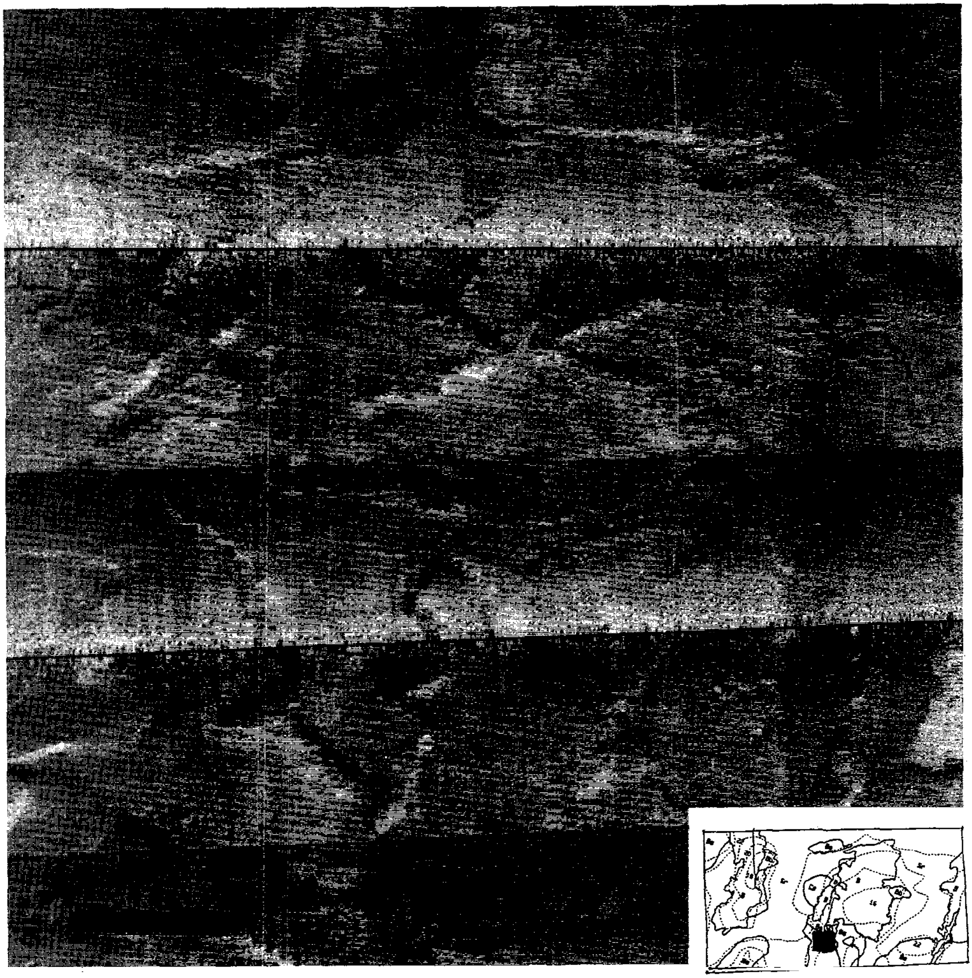

Fig. 27. Brocton Shoal mosaic element showing cobble ridges scattered on sand. Inset shows location of mosaic element on Fig. 18. The black bar in the lower left corner represents 50 m.

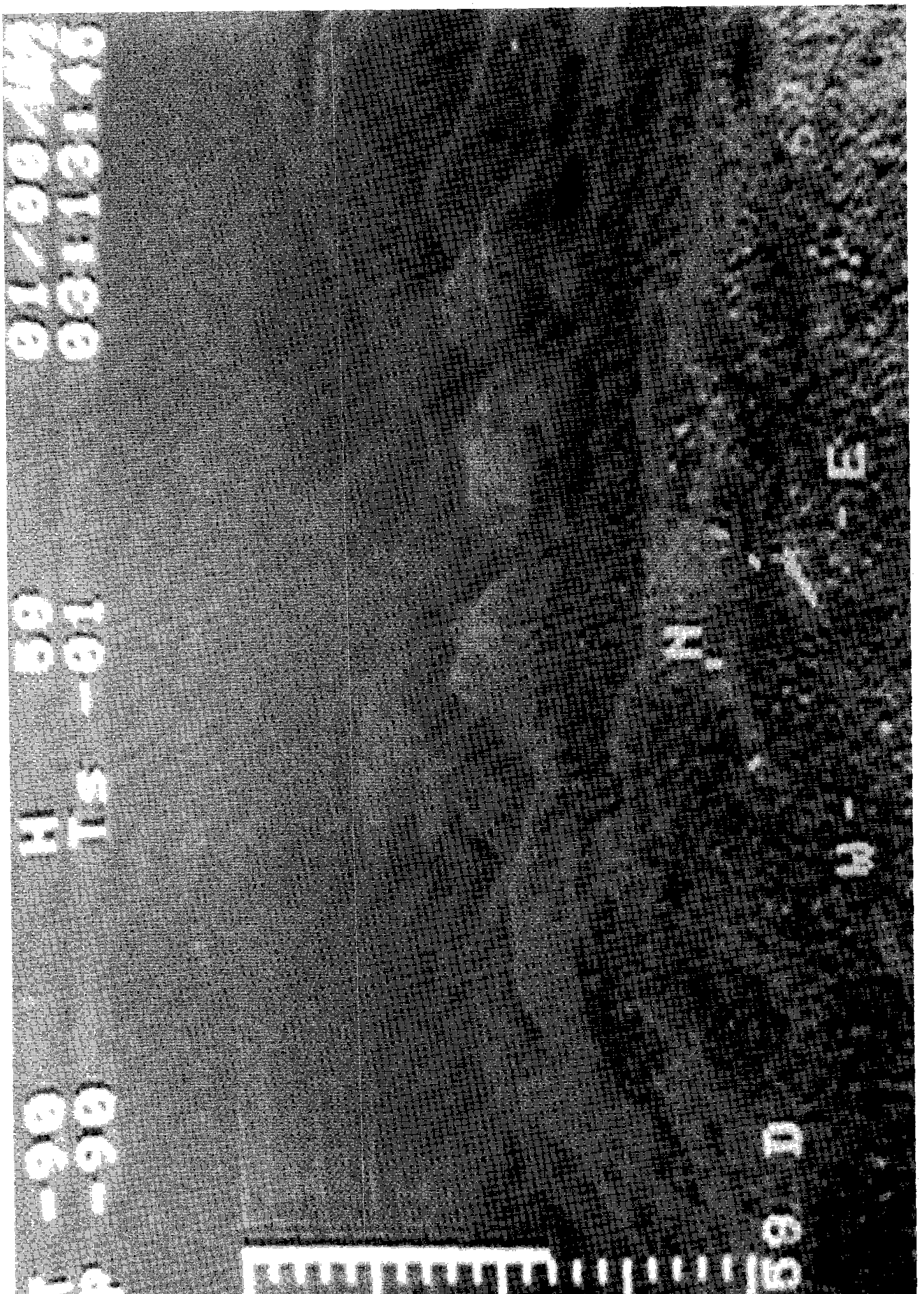

Fig. 28. Sand ripples at the base of a cobble ridge on Brocton Shoal, Lake Erie.

ERRATA: Technical Report 58, p.41
Surficial Substrates and Bathymetry of Five Historical Lake Trout Spawning Reefs in Near-shore Waters of the Great Lakes

Charity Shoal Complex

The Charity Shoal complex in eastern Lake Ontario is a bedrock outcrop composed of Charity Shoal, East Charity Shoal, and South Charity Shoal. This shoal complex straddles the international border approximately 8 km south of Bear Point on Wolf Island at the head of the St. Lawrence River (Fig. 30). East Charity Shoal Light occupies a small, rocky island at the north end of the shoal. Water 18 m or more deep surrounds the shoal complex. The bedromck forming the lake bed in eastern Lake Ontario is Ordovician limestone and the strata dip gently to the south (Hough 1958).

An irregularly shaped area of lake bed covering approximately 1,000 ha was mapped (Fig. 31). The shoal within the mapped area was a ring-like formation with a tail that extended to the southwest. A pocket of water with depths to 18 m occupied the area within the ring of shoal water. Water depth elsewhere in the mapped area, excluding the small portion of East Charity Shoal occupied by the lighthouse, ranged from approximately 6 m to slightly more than 22 m.

A Ponar grab sample revealed that the substrate in the deepwater area in the center of the shoal was stiff, varved clay covered with a layer of course brown sand approximately 1-2 cm thick. A ring of broken bedrock evenly distributed on bedrock (Fig. 32) surrounded the sand, mostly at 10-14 m and was surrounded, in turn, by worn bedrock ridges with patches of broken bedrock at approximately 6-14 m (Figs. 33, 34). The worn bedrock ridges were conspicuous features on the mosaic (Fig. 35). They were bordered by rubble with broken bedrock (Fig. 36), two small areas of broken bedrock, and on the southeastern edge of the shoal at 14-18 m, by sand with scattered cobble. Some of the cobble was extensively pitted (Fig. 37). Sand with scattered cobble was also present on the northeastern end of the shoal, mostly at depths greater than 14 m, and at the southern end of the shoal at depths greater than 20 m.

The best substrate for lake trout spawning and fry production on the Charity Shoal complex was the rubble with broken bedrock that bordered most of the mapped area. Interstitial depths of 30 cm or more occurred in patches in this substrate on about the 20-m depth contour in the northeastern corner of the mapped area and at 14 m on the western side of the mapped area.

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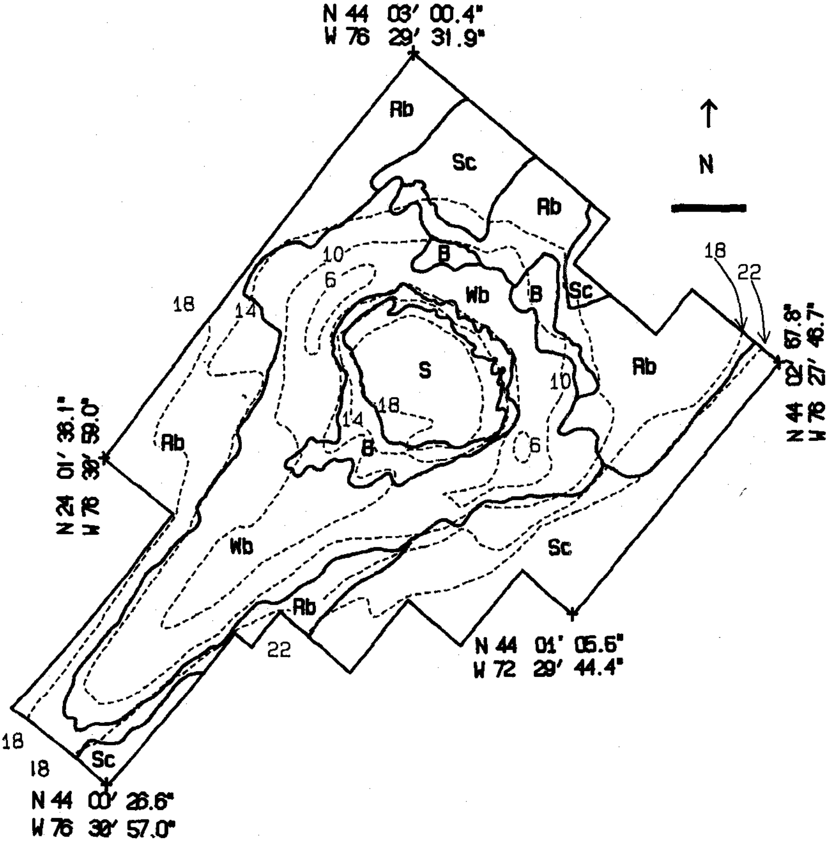

Fig. 31. Charity Shoal complex substrates and bathymetry. Water depths (dashed lines) are in meters. The black bar in the upper right corner represents 0.4 km.

Substrate		Hectares
S - Sand		66.22
SC - Sand with scattered cobble		199.98
Rb - Rubble with broken bedrock		319.18
Wb - Worn bedrock ridges with broken bedrock patches		341.14
B - Broken bedrock evenly distributed on bedrock		69.17
	Total	995.69

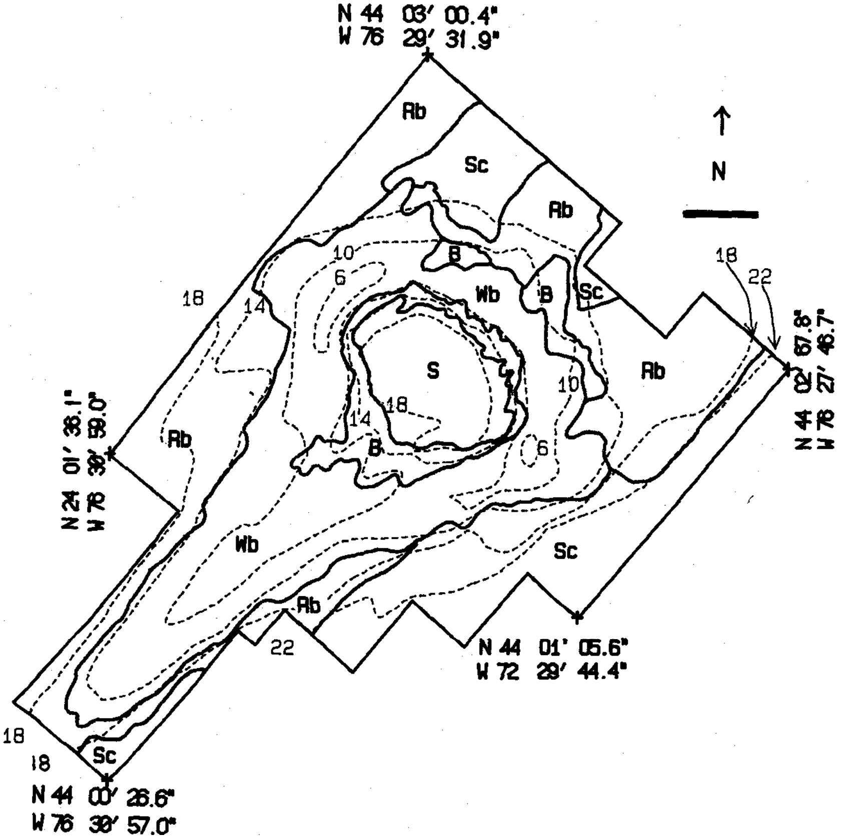

Fig. 31. Charity Shoal complex substrates and bathymetry. Water depths (dashed lines) are in meters. The black bar in the upper right corner represents 0.4 km.

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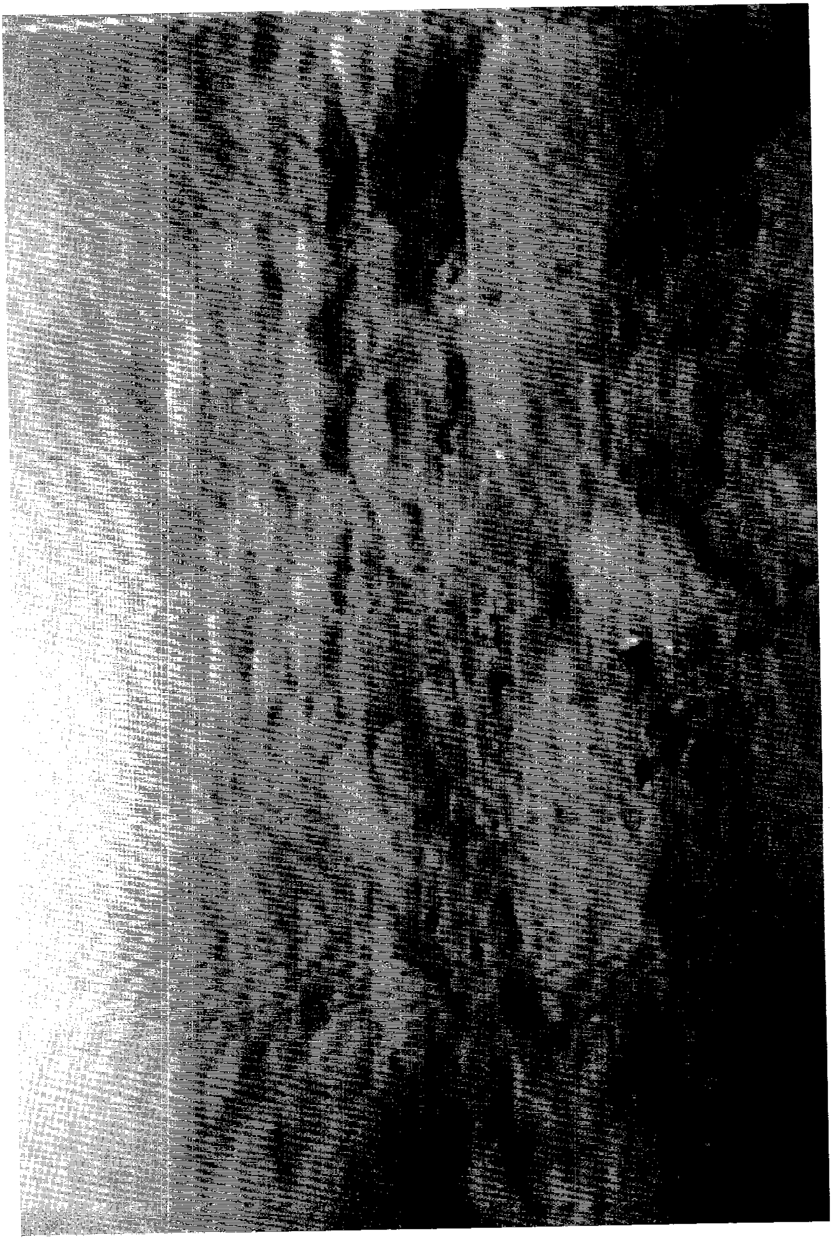

Fig. 32. Broken bedrock evenly distributed on bedrock substrate on Charity Shoal complex, Lake Ontario.

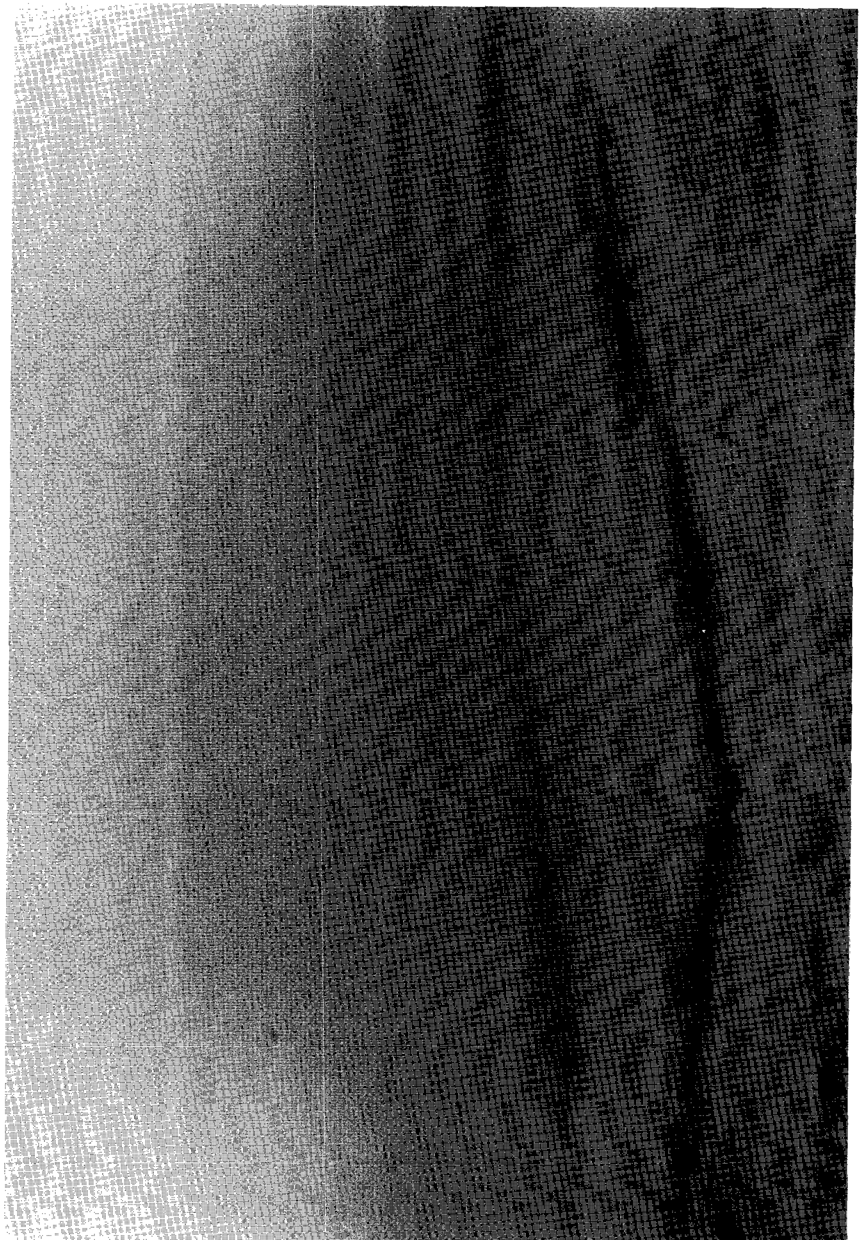

Fig. 33. Worn bedrock ridges **substrate** on Charity Shoal complex, Lake Ontario.

Fig. 34. Broken bedrock patches substrate on Charity Shoal complex, Lake Ontario.

The worn bedrock ridges with patches of broken bedrock substrate provided only small, widely spaced patches of marginal habitat for spawning and fry production. Little piling of loose rock occurred, interstitial depth was generally less than 10 cm, and most of the interstitial spaces were large enough to allow small fish to prey on eggs and fry resting there. The other three substrates that were mapped were unsuitable for lake trout spawning and fry production because they had interstitial depths of less than 5 cm.

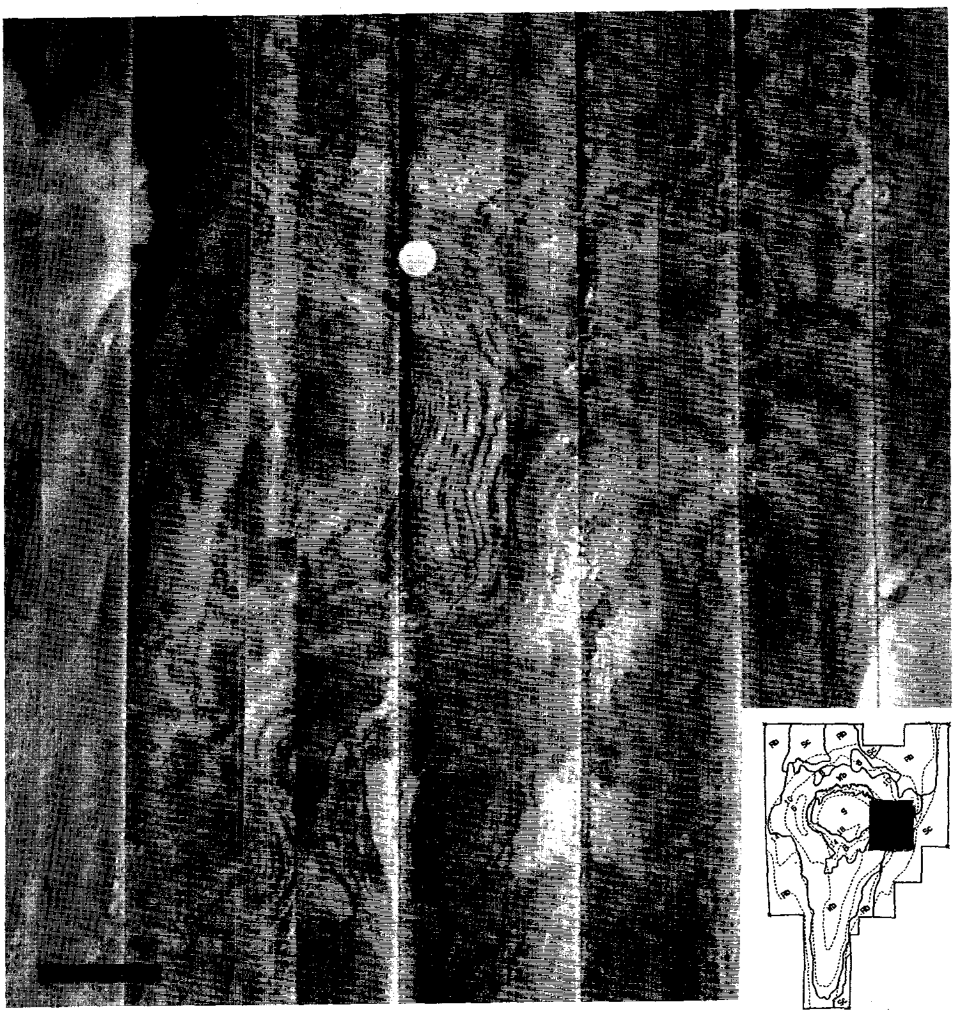

Fig. 35. Charity Shoal mosaic showing worn bedrock ridges. Dot shows the approximate location of the East Charity Shoal Light. The black bar in the lower left corner represents 100 m.

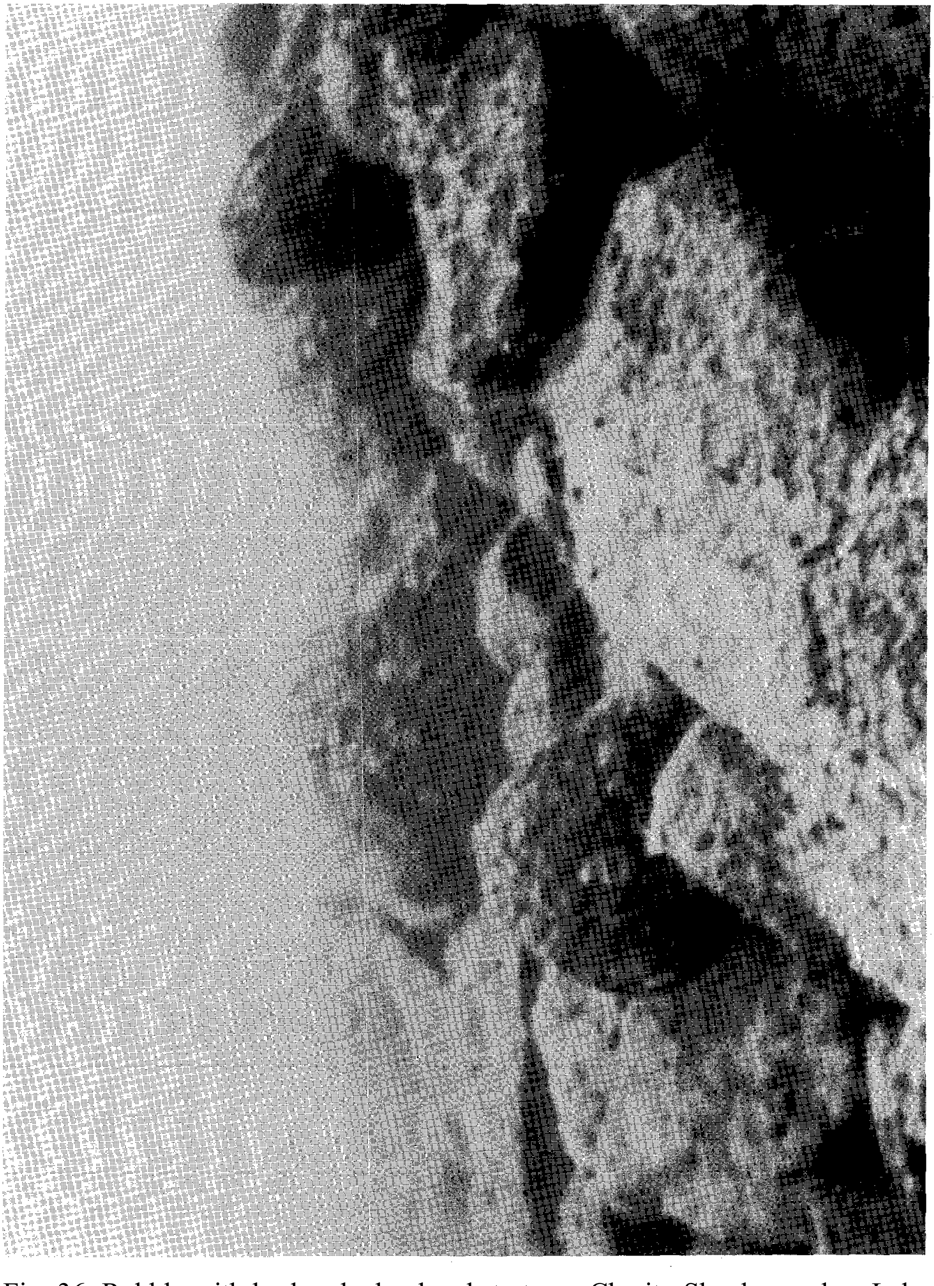

Fig. 36. Rubble with broken bedrock substrate on Charity Shoal complex, Lake Ontario.

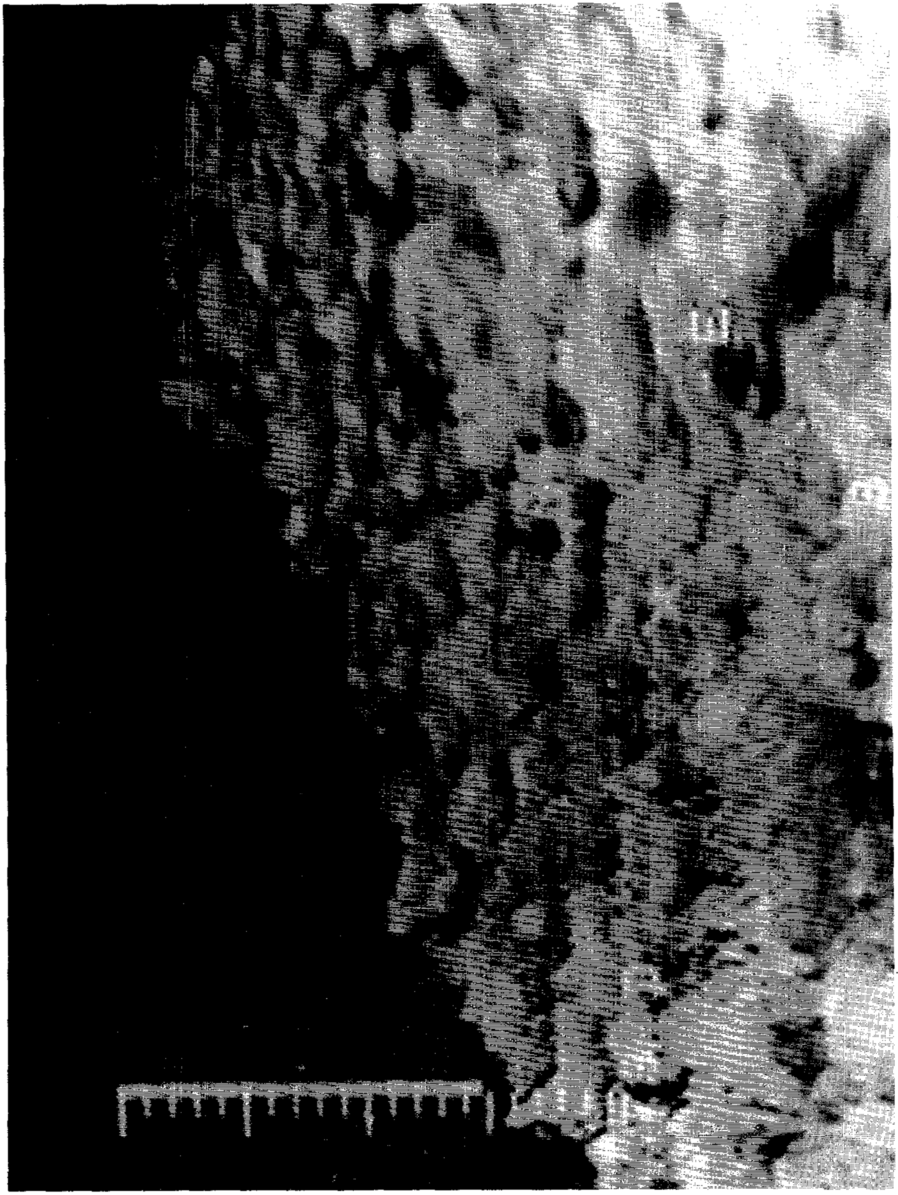

Fig. 37. Pitted cobble substrate on Charity Shoal complex, Lake Ontario.

SUMMARY AND CONCLUSIONS

Partridge Island Reef, Port Austin Reef, Brocton Shoal, and the Charity Shoal complex contained what seemed to be good-to-excellent substrates for spawning and fry production by shallow-water strains of lake trout that are planted in the Great Lakes. These substrates were in water 6-22 m deep where natural illumination reached the lake bed. They consisted largely of piled, rounded, or angular rubble and cobble and had interstitial spaces that were 20 cm or more deep and narrow enough to protect lake trout eggs and fry from predators, ice scour, and buffeting by waves and currents.

Results of the side-scan sonar surveys at Partridge Island Reef, Lake Superior, and Port Austin Reef, Lake Huron, helped Great Lakes Fishery Commission cooperators plan and conduct egg survival field bioassays at those sites (Manny et al. 1989). These bioassays (B. Manny, U.S. Fish & Wildlife Service, pers. commun.) confirmed that the best substrates on both reefs can support the production of viable, swim-up fry. Among the three other sites that we surveyed, Brocton Shoal in Lake Erie probably offers the best habitat for spawning and fry production. The best Brocton Shoal substrate is clean, deep, and reasonably contiguous. The Charity Shoal complex also contains suitable substrate, but it is distributed in relatively small, isolated patches and exhibits a light to moderately thick covering of periphyton and silt. No suitable substrate was found on Wilmette Reef; periphyton covered most rock surfaces and interstitial depth was 5 cm or less. Wilmette Reef is not recommended as a site for egg survival studies.

The present study reaffirms the utility of side-scan sonar and underwater video-camera surveys for mapping and evaluating till-derived substrates (Edsall et al. 1989) and demonstrates that the approach can also be effectively applied on bedrock dominated substrates. Till-derived and bedrock dominated substrates are the two major types that Goodyear et al. (1982) indicated were used historically for spawning by lake trout in the Great Lakes.

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