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Identification of Actively Used Near-Shore Lake Trout Spawning Sites in South-Western Lake Michigan

Final Report to
Illinois-Indiana Sea Grant Program

Center for Aquatic Ecology

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ABSTRACT

Restoration of self-sustaining populations of lake trout in the Great Lakes has been a goal of state, provincial, and federal agencies for over three decades. Juvenile lake trout have been stocked into Lake Michigan since 1965, but to date there has been limited evidence of spawning by adult feral fish on natural reefs. Although the restoration effort has focused on deep spawning reefs in the last decade, the only study of spawning on a deep reef in Lake Michigan failed to find any evidence of egg deposition. Working on the hypothesis that stocked lake trout may be spawning on shallow reefs, the nearshore area of south-western Lake Michigan was surveyed to locate areas of cobble substrate. The few areas of cobble substrate which were found appeared to be marginal for overwinter egg incubation, due to the lack of interstitial depth. Egg nets and traps were set on several reefs in the fall; eggs were recovered from four of six sites in 1991 and from three of four sites in 1992. Eggs were also found in high densities by divers on a breakwall in Indiana. All sites where eggs were found were less than 12 m deep and within 4 km of shore. Egg collection rates were considerably lower than those found at an intensively used site in eastern Lake Ontario. The possible reasons for shallow spawning by lake trout on marginal substrate are discussed in regard to their implications for the stocking program.

INTRODUCTION

Lake trout (*Salvelinus namaycush*) thrived in Lake Michigan prior to the arrival of Europeans and the sea lamprey (*Petromyzon marinus*). By the late 1950's native lake trout populations were completely extirpated, in large part due to overfishing and the negative impacts of exotic species. The goal of federal and state agencies involved in lake trout management is to reestablish naturally reproducing lake trout populations (Lake Michigan Lake Trout Technical Committee 1985). To achieve this goal in Lake Michigan, lake trout from Lake Superior (Marquette, Gull Island Shoal, and Isle Royale), Seneca Lake, Lewis Lake, and Green Lake 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 marinas. In order to make further progress toward the goal of restoration, the factors that affect lake trout reproduction must be better understood. However, to study lake trout spawning success, sites where lake trout spawn must first be identified.

The task of finding lake trout spawning sites is best conducted by gradually narrowing the scope of the search from broad-scale, indirect evidence of spawning (e.g., observations of adult aggregations during the fall) to direct evidence of spawning (observation or collection of eggs in the substrate). Much of the historic data about lake trout spawning sites in Lake Michigan comes from commercial fishermen who netted 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. Eggs found in the stomachs of fish such as burbot (*Lota lota*), yellow perch (*Perca flavescens*), and sculpin (*Myoxocephalus* spp., *Cottus* spp.) indicate that spawning has occurred, but the exact location of spawning is not certain unless the movement of the egg predator prior to capture is known. 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 frequently observed; 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). 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. Such evidence can be difficult to obtain due to the small size of the eggs, their rapid disappearance into interstitial spaces in the substrate, the paucity of techniques to find eggs without using scuba, and the difficult working conditions due to weather which occur during the lake trout spawning season in fall.

The purpose of this study was to find sites where lake trout spawn along the southwestern shore of Lake Michigan. Our 'model' of a good spawning site was derived from studies on Stony Island Reef in Lake Ontario (Marsden et al. 1988, Marsden and Krueger 1991), data on lake trout spawning in inland lakes (Martin and Olver 1980), and observations of a number of lake trout spawning reefs by John Fitzsimons (personal communication). These studies indicated that cobble substrate with deep interstitial spaces (> 0.5 m) appears to be ideal for egg incubation and overwinter protection. Many heavily used spawning areas are also characterized by the presence of a steep contour, which may serve either to concentrate lake trout at a natural focal point, or to increase local current velocities which reduce siltation on the eggs, or both. Observations from Lake Ontario and elsewhere in the Great Lakes also indicate that lake trout often spawn in water as shallow as 5 m. This latter point, together with data from commercial gill net collections of ripe lake trout in shallow water in Illinois (Coberly and Horrall 1982), prompted us to focus our search along the near-shore area of Lake Michigan.

METHODS

In 1991, 16 sites along the Illinois and southern Wisconsin shorelines of Lake Michigan were surveyed using sonar and visual examinations by scuba divers (Table 1, Figure 1). Individual sites are described in detail in the Appendix. In 1992 some of these sites were examined more intensively and an additional eight sites were surveyed. Sites were selected for examination on the basis of contours on bathymetric charts of Lake Michigan, recent bathymetric surveys by the Illinois Geological Survey (Collinson et al. 1979, Norby and Collinson 1977), and historic records of commercial fishermen who captured ripe lake trout in the fall at nearshore sites (Goodyear et al. 1982; Thibodeau and Kelso 1990, Coberly and Horrall 1980, 1982). The objective of the visual surveys was to find areas which had contours (>1:10 slope) and accumulations of cobble with interstitial spaces at least 30 cm deep. All sites were located for future reference using Loran coordinates.

In the fall of 1991 and 1992, egg nets (Horns et al. 1989) and egg traps (Marsden et al. 1991) were set on the sites which appeared to have the highest potential to attract spawning lake trout (Table 2, Figure 2). Each gang of nets and traps consisted of an 80m line to which 25 nets and 25 traps were attached alternately at 1.6 m intervals. The gangs were held in place using a fyke net anchor at one end and two to three cinder blocks chained together at the other end. Both ends of each gang were marked with a buoy. Ten gangs were set in 1991, and 17 were set in 1992. Gangs were set so that they crossed the steepest contours in the area. At Bullshit Shoal, for example, sites where gangs were set comprised small humps rising 2-3 m off the bottom which were approximately 30-100 m across at the top. Due to damage of egg traps in 1991, the traps were modified in 1992 by fastening a nylon bolt and wing nut through the center of each trap, thus holding both removable sides of the trap together. The nets and traps were set in early fall and retrieved after gillnetting assessments by the Illinois Department of Conservation (IDOC) and Wisconsin Department of Natural Resources indicated that the peak of spawning had occurred (Table 2). In 1992, traps and nets on Bullshit Shoal were checked for eggs three weeks after they were set; the devices were then re-set at the same location. After retrieval, egg collection devices were examined minutely for lake trout eggs or traces of eggs, as egg nets and traps will retain broken eggs as a recognizable chorion.

We used a remotely operated underwater video (ROV; Hydrobotics, Canada) in 1992 to examine Bullshit Shoal and Black Can Reef while the nets and traps were in place. We also examined an area outside the west breakwall of the Port of Indiana using scuba during the 1992 spawning season to look for eggs in the substrate. This site had been indicated to us by local fishermen, who have noted large aggregations of lake trout in the area for several years.

In the spring of 1993, we deployed 30 fry traps along the outside of the west wall of the Port of Indiana breakwall, within 20m of the wall, and 20 traps at the Wilmette WR2 reef site. The traps, described by Marsden et al. (1988), consist of open-based pyramids mde of angle iron and metal screening with a plastic bottle fastened over a hole at the top. The individually-buoyed traps rest on the substrate, so that any fry which emerge from the substrate underneath a trap are likely to swim into the bottle as they rise to the surface to fill their air bladder. Fry enter the bottle through an inverted funnel, making escape from the bottle unlikely. Traps were set at the Port of Indiana on April 7, and were checked on April 23, 29, May 4,17, and June 2. Traps were set at Wilmette on April 22, and checked on April 28, May 5, 10, and June 10. On the first day that traps were checked, many had lost their capture bottles and had to be modified to retain the new bottles. All traps were retrieved on the last day they were checked; three traps were not recovered at the Port of Indiana site due to their becoming wedged between boulders.

RESULTS

Diving surveys indicated that the majority of substrate south of the Wisconsin border consists of hard-pan clay, sand, and small gravel, with scattered areas of bedrock (Table 1). Some of the reefs which are marked on bathymetric charts, notably Highland Park Reef, Glencoe Reef, and the contours marked by green and black buoys at Waukegan, are solid bedrock masses. Portions of Bullshit Shoal are composed of 1-2 m high clay ridges and hummocks, which may have inspired the colloquial name of this area when it was used by commercial fishermen. These substrates were considered poor for lake trout spawning, as there were no deep interstitial spaces. Areas with single or double layers of cobbles from 12 to 75 cm in diameter were found at Black Can, Bullshit Shoal, and South Wind Point in Wisconsin, and near Fort Sheridan, Wilmette, and Evanston in Illinois. These sites had the highest potential for use by spawning lake trout.

Considerable damage to the egg traps was incurred during storms, especially duc to loss of one side of some traps before the traps were modified in 1992. Most of the egg nets were retrieved intact, though many had lost their lead weights. In 1991 a total of 59 lake trout eggs or egg chorions were retrieved; nine eggs were alive (translucent) upon retrieval. In 1992 a total of 3 live eggs plus 83 eggs and chorions were collected (Table 2, Figure 2). The highest collection rate (0.01 eggs/net/day) occurred at Bullshit Shoal in both years. A similar capture rate occurred at Black Can Reef in 1991, but in 1992 all but 29 of the nets and traps were lost and no eggs were collected. The true collection rate is somewhat higher than the numbers indicate because some of the egg nets were probably upside-down and therefore were not fishing for unknown periods of time (Horns et al. 1989).

The Port of Indiana site was not surveyed or fished using egg nets or traps, but was examined by divers on 1 Dec 92. At the base of the breakwall forming the western side of the Harbor, on the outer side, divers found a flat substrate composed of irregular cobbles, 15-40 cm in diameter. Interstitial spaces appeared to be quite deep, though the actual depth was not measured. Numerous lake trout eggs were observed when cobbles were lifted. A single, large lake trout was seen to swim slowly in close proximity to one diver; low visibility due to silt and low light reduced the probability of seeing additional fish. Only two eggs (both viable) were brought to the surface by the divers. Several large echoes which probably indicated lake trout were noted on the sonar while approaching the site. All of these echoes were approximately 0.5m off the bottom and they tended to occur near small rises in the bottom contour. Lake trout were also observed at the Bullshit Shoal site using the ROV. Four lake trout were seen during five minutes of observation; no lake trout were seen during 5 minutes of ROV deployment at Black Can Reef.

The live eggs collected were reared in the laboratory at the Lake Michigan Biological Station. Of the nine eggs reared in 1991, three eyed up and one hatched. In 1992, all of the 5 live eggs eyed up and 4 hatched. The other eggs apparently died due to leakage of the chorion, presumably resulting from abrasion during capture rather than developmental abnormalities. This sample size was too small to determine whether egg mortality is sufficiently high to cause concern.

Two lake trout sac fry were captured at the Port of Indiana on April 29. Empty chorions were frequently recovered in the bottles or on the outside of the traps at this site, but no evidence of lake trout eggs or fry was seen at the Wilmette site. Sculpins were frequently seen in traps at both sites.

DISCUSSION

The results of our egg collections show that despite a paucity of good spawning substrate, stocked lake trout deposit eggs on multiple shallow, near-shore reefs in south-western Lake Michigan. The density of deposited eggs was low compared with egg collections at other sites using the same equipment: a maximum of 0.024 eggs per net-day and 0.059 eggs per trap-day were collected, versus maximums of 7.2 eggs per net-day and 2.33 eggs per trap-day at Stony Island Reef, Lake Ontario (Horns et al. 1989, Marsden and Krueger 1991). The exception is the Port of Indiana, the one site at which we did not quantify egg deposition with nets or traps. Egg densities at this site, as noted by divers, appeared to be comparable to or higher than densities seen during dives on Stony Island Reef. Of interest is the fact that this was the only site where we looked for eggs which was artificially constructed, albeit of natural materials. Spawning on man-made 'reefs' such as breakwalls and intake lines has been noted previously, and is often sizeable (Peck 1986, Stauffer 1981, Wagner 1981). The capture of fry at the Port of Indiana indicates that the breakwall substrate was suitable for overwinter egg incubation. Absence of fry at the Wilmette WR2 site is likely due to the extremely low density of eggs found at that site relative to the Port of Indiana.

Our low egg captures may have been due to equipment problems, low egg deposition rates, or our failure to find the epicenter of egg deposition at each site. Both the egg collection devices and the eggs suffered much higher damage than similar devices deployed in Lake Ontario (Marsden et al. 1989, Marsden and Krueger 1991). Stony Island Reef is partially protected from storms by the proximity of Stony Island less than 0.5 km away to the south-west, whereas all of the Lake Michigan sites except the Port of Indiana were at least 2.5 km from shore. Nets and traps which were damaged but not destroyed may have spilled unknown numbers of eggs. Future egg collections in Lake Michigan will require either modified use of the traps and nets with heavy chain in place of line, or use of new methods (e.g., Perkins et al. in review). It is unlikely that we missed the epicenter of egg deposition at all sites, because in 1992 we focused additional effort in areas where eggs were caught in 1991. Despite increasing the area covered by nets and traps at each site, the catch per unit effort at each site did not increase from 1991 to 1992. We could have missed the period of highest spawning activity; however, the collection devices were in place for a considerable period of time which included the period when high aggregations of adults were seen in gill-net assessments. Thus, the low egg collection rates were likely due to a combination of equipment inefficiency and low egg deposition rates.

Why are stocked lake trout spawning in shallow water on less than ideal substrate? Several explanations are possible: (1) hatchery-reared fish 'home' to their stocking sites to spawn, (2) stocked fish seek conditions experienced during their hatchery residence for spawning, i.e., shallow water, (3) the stocked fish are shallow-water spawning strains, (4) because they did not receive imprinting cues in the hatchery, or possibly because the species lacks a strong homing instinct, stocked lake trout spawn in areas where they recognize good spawning substrate, and/or (5) spawning substrate is less important than we hypothesize as a cue for spawning, allowing the possibility that the areas where we found eggs (barring the Port of Indiana) were actually historic spawning sites which were recognized by stocked fish . Each of these possibilities has consequences for the future management of the lake trout rehabilitation program in Lake Michigan.

The original population of lake trout in Lake Michigan was apparently composed of multiple strains which commercial fishermen distinguished by body shape, fat content, coloration, and the areas in which the fish spawned (Coberly and Horrall 1982). Some of these strains may have spawned in shallow, near-shore waters. Many of the fish which were caught in spawning condition on deep reefs may have actually deposited their eggs on shallow reefs. Certainly the Seneca and Superior strains, which are presumed to be deep water strains in their native habitat, spawn successfully in 5 m depth in Lake Ontario (Marsden and Krueger 1991). Thus, assumptions about where stocked strains 'should' spawn may not be valid. The results of this study demonstrate that stocked lake trout in Lake Michigan do spawn on shallow reefs within a few kilometers of shore. Clearly, additional information about where strains of lake trout used for broodstocks spawn in their native habitat, and their behavioral plasticity, would enhance our understanding of their behavior after stocking.

Stocked lake trout may have returned to their stocking area because they imprinted to it when they were stocked, or because they imprinted on shallow, flowing water in their natal hatchery. The extent to which lake trout return to their natal areas to spawn is still in question; different studies either support the homing hypothesis (Eschmeyer 1955, Martin 1960) or suggest that spawning fish wander widely (MacLean et al. 1981, McCrimmon 1958). The indication that lake trout home less in inland lakes than in the Great Lakes suggests that homing may not be a general trait of the species, but instead varies among strains. During the first 15 years of the lake trout stocking program in Lake Michigan, fish were stocked from the shore. Many stocked lake trout returned as adults in fall to the area where they were stocked, but many also strayed to traditional spawning areas (Eschmeyer 1955, Peck 1979, Coberly and Horrall 1982). The number of fish returning to near-shore stocking sites in the 1970's prompted a reevaluation of the stocking plan, and in 1980 Wisconsin and Illinois began to alter the focus of stocking fish to deep, offshore reefs for which there was historic evidence of spawning. This focus relied upon two implicit assumptions: at least some native lake trout in Lake Michigan spawned on deep, offshore reefs, and stocked lake trout from 'deepwater' strains will also spawn on deep, offshore reefs (e.g., Krueger et al. 1983). Since 1981, the majority of fish stocked by Illinois have been planted on Julian's Reef, a deep reef 23 km due east of Fort Sheridan, IL. Fall gill-net assessments since 1984 have shown that stocked lake trout have returned to this area as adults. However, an intensive five-year effort to capture eggs using egg nets and traps on Julian's Reef failed to yield any evidence of egg deposition (Horns et al. 1989, unpublished data). While it is virtually impossible to provide conclusive evidence that lake trout do not spawn at a given site, the results of the current study provide strong circumstantial evidence against the occurrence of spawning at Julian's Reef. Given the low effort used in this study to collect a number of eggs at each of several sites, the high effort used at Julian's Reef each year should certainly have yielded eggs. In the fall of 1992, the IDOC conducted gill-net assessments along the shore at Lake Forest, Fort Sheridan, and Wilmette Reef (Figure 1) in conjunction with their assessments at Julian's Reef. Ripe lake trout were caught at all of the near-shore sites, though the catch per unit effort was half that found at Julian's Reef. These data indicate that despite their aggregating behavior on deep reefs, a large proportion of stocked lake trout move inshore in the fall to spawn. Therefore stocked lake trout do not necessarily home to the area where they were stocked, but may try to spawn in the conditions in which they were reared. Rearing fry in deep water is logistically infeasible for a production facility. However, if homing to shallow water is indeed a problem, the recent experimental stocking of lake trout as eggs or early fry in lakes Michigan and Superior may prove to be a viable solution.

Finally, it is possible that the shallow sites where we collected eggs were, in fact, traditional spawning sites. Certainly there is ample historic evidence of inshore movements and aggregations of lake trout in the fall in the Great Lakes (Goodyear et al. 1982, Thibodeau and Kelso 1990). Stocked lake trout appear to be able to recognize traditional spawning sites in Lake Ontario, even ones that are more than 6km from the nearest stocking site (Marsden et al. 1988, Marsden and Krueger 1991, John Fitzsimons personal communication). If the sites we examined are 'correct' places for lake trout to spawn, then we must revise our concept of good lake trout spawning substrate. The next critical step is to determine whether this spawning behavior is successful in producing hatched fry. Our continuing work on the reefs in south-western Lake Michigan will resolve whether man or lake trout is best able to recognize a spawning site which can successfully incubate eggs.

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Table 1. Sites along the southwestern shore of Lake Michigan surveyed for potential lake trout spawning areas.

	Year of Survey	Site	Loran Coordinates.	Depth (m)	Substrate	Potential as Spawning site
1	1991	Milwaukee breakwall	33005.0/49287.0	3	cobble and gravel	poor
2	1991	Black Can Reef site 1	32999.0/49306.8	8	infilled cobble and gravel	poor
3	1991	Black Can Reef site 2	33001.8/49303.5	6	cobble, infilled gravel, bedrock	moderate
4	1992	Black Can Reef site 3	33002.4/49307.2	7	large cobbles to boulders	mod/good
5	1991	Bullshit Shoal site 1	33015.9/49339.3	7	areas of deep cobble	good
6	1991	Bullshit Shoal site 2	33013.6/49335.0	6	deep cobble layers, good contour	very good
7	1991	Bullshit Shoal site 3	33013.7/49334.3	7	tiny area of cobble on infill	moderate
8	1991	Bullshit Shoal site 4	33014.4/49336.9	7-10	single layer of cobble w. contour	moderate
9	1991	Wind Point S. Shoal	33058.6/49469.4	7-8	cobble boulders	moderate
10	1991	Waukegan intake	33251.0/49749.0	3-10	infilled cobble, sand	poor
11	1991	Waukegan black can reef	33241.0/49736.0	7	flat, smooth bedrock	none
12	1991	Waukegan green buoy reef	33241.0/49733.0	7	flat, smooth bedrock	none
13	1992	Lake Forest	33277.0/49793.0	7	cobble slope, then sand	poor
14	1991	Fort Sheridan NE reef	33285.8/49823.1	6	infilled cobble, gravel	poor
15	1991	Fort Sheridan SW reef	33290.3/49829.3	12	sand, infilled gravel, clay	poor
16	1991	Fort Sheridan middle reef	33295.9/49829.6	5	thin cobble layer, good contour	moderate
17	1991,2	Highland Park Reef	33287.0/49860.0	7	solid, smooth bedrock	none
18	1991,2	Glencoe	33311.4/49887.9	2.5	bedrock; sand, infilled cobble	poor
19	1992	Wilmette Reef WR4 buoy	33280.0/49920.0	10-20	bedrock ridges, cobble at base	poor
20	1991,2	Wilmette Reef WR2 buoy	33283.0/49923.0	6-11	cobble, w/o deep interstices	visually good
21	1992	Wilmette nearshore (WR2)	33315.0/49942.0	6-11	infilled cobble	moderate/poor
22	1992	Bahai Temple	33326.0/49945.0	5	cobble, with sand inshore	moderate/poor
23	1992	Evanston, nearshore	33338.0/49987.0	5	gravel, infilled cobble	poor
24	1991	Montrose Harbor	33363.0/50030.0	3	broken rock, sand, silt	poor
25	1991	Burnham Harbor	33398.0/50100.0	3	cobble and broken rock on sand	poor
26	1991	Calumet Harbor	33432.0/50199.0	3	mud, silt, broken rock	poor
27	1992	Port of Indiana	33370.0/50315.0	12	deep layers of irregular cobble	excellent

Table 2 Collections of lake trout eggs in southwestern Lake Michigan, 1991 - 1992. Site locations, depths, and substrate types are given in Table 1.

Location	Date set	Date lifted	Intact traps	Intact eggs	chor.	CPUE	Intact nets	Intact eggs	chor.	CPUE	Total eggs
1991											
Black Can Reef 2	9-Oct	12-Nov	3	0	0	0.0000	50	2	15	0.0100	17
Bullshit Shoal 1, 2, 3	8-Oct	12-Nov	37	2	0	0.0016	74	13	23	0.0143	38
Wind Point S Shoal	8-Oct	12-Nov	1	2	0	0.0588	25	0	1	0.0012	3
Ft Sheridan mid. reef	2-Oct	15-Nov	13	0	0	0.0000	25	0	0	0.0000	0
Glencoe	2-Oct	15-Nov	0	0	0	0.0000	3	0	0	0.0000	0
Wilmette nearshore	2-Oct	15-Nov	12	0	0	0.0000	25	0	1	0.0011	1
1992											
Black Can Reef 2	1-Oct	11-Nov	9	0	0	0.0000	20	0	0	0.0000	0
Bullshit Shoal 2	1-Oct	21-Oct	94	1	0	0.0005	93	1	4	0.0026	6
Bullshit Shoal 2	21-Oct	11-Nov	51	1	0	0.0009	93	20	27	0.0241	48
Ft Sheridan mid. reef	19-Oct	9-Nov	48	0	3	0.0030	50	3	5	0.0076	11
Wilmette nearshore	19-Oct	9-Nov	50	1	4	0.0048	50	0	16	0.0152	21
Wilmette Reef	19-Oct	9-Nov	50	0	0	0.0000	50	0	0	0.0000	0

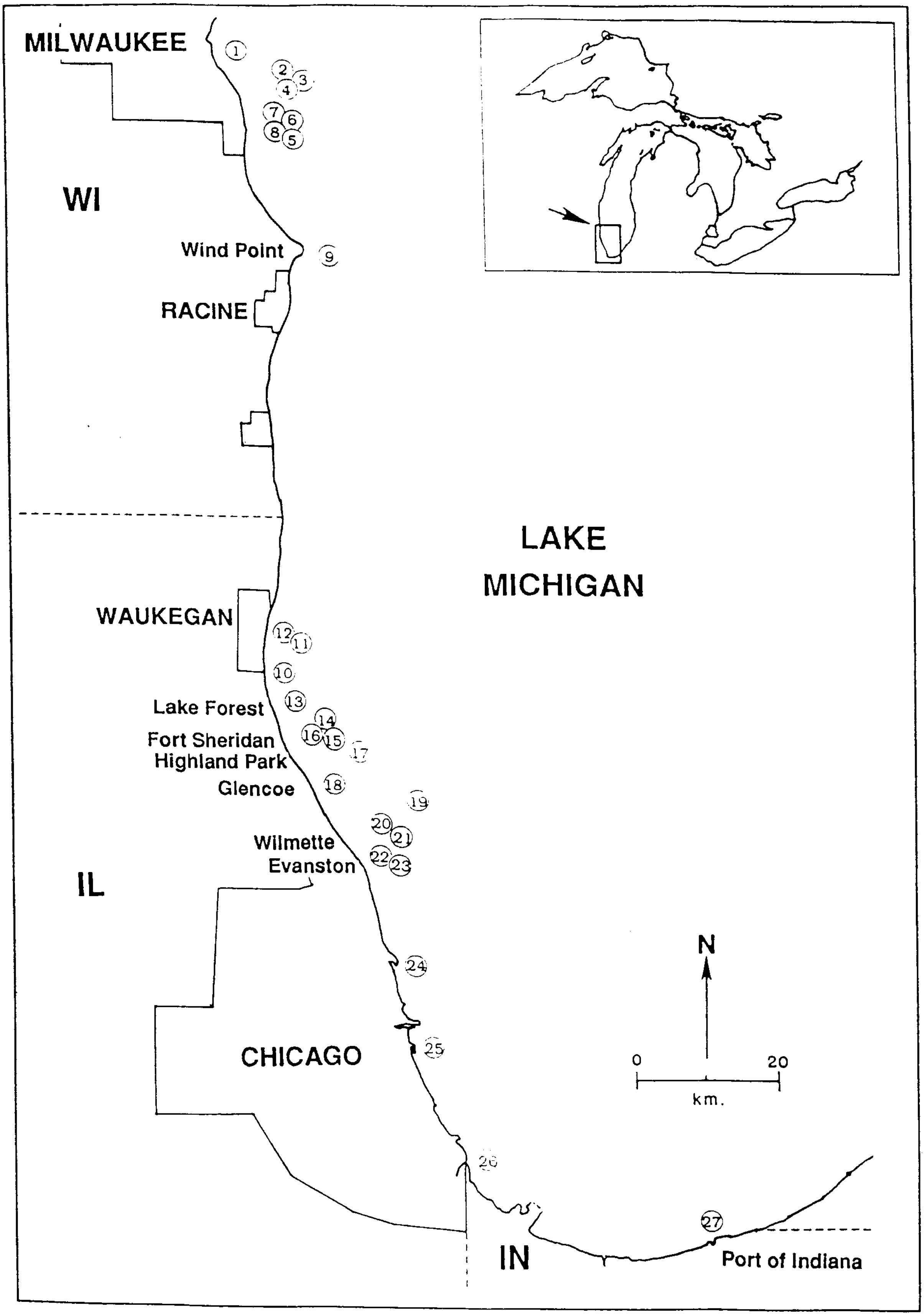

Figure 1. Locations surveyed by divers for potential lake trout spawning sites in south-western Lake Michigan, 1991-1992. Numbers correspond to locations in Table 1.

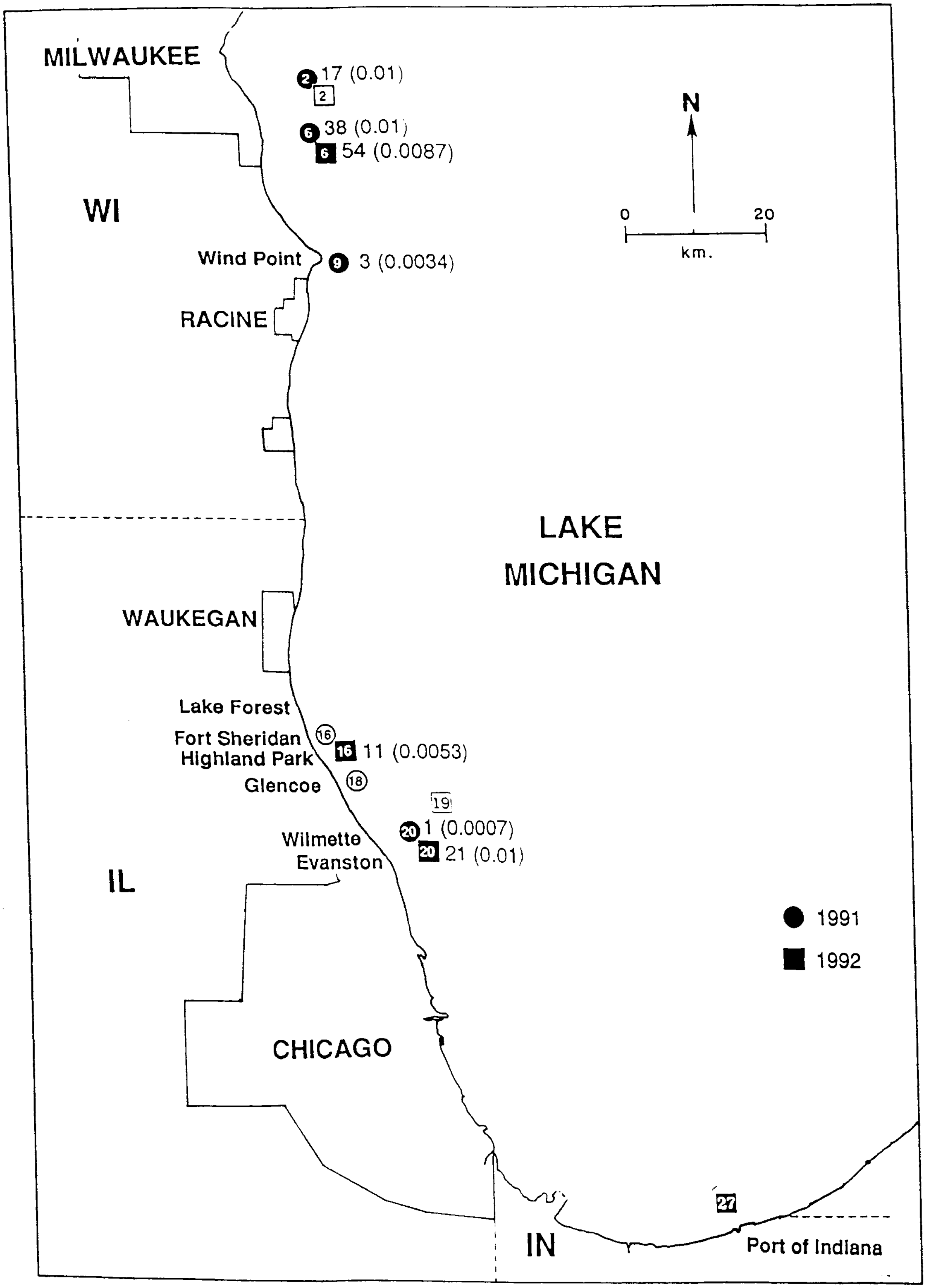

Figure 2. Sites where eggs were collected in southwestern Lake Michigan in the fall of 1991 and 1992. Open symbols indicate sites where collecting gear was deployed but no eggs were found, filled symbols indicate sites where eggs were collected. Numbers of eggs collected at each site are shown with CPUE (number of eggs collected per device per day) in parentheses. Loran coordinates for each site are given in Table 1. Numbers within each symbol correspond to locations in Table 1.

Appendix - reef survey, south-western Lake Michigan

Under each dive site is listed the dates of diving surveys, Loran coordinates of the dive, depth of the dive, water visibility as noted by divers (a somewhat subjective evaluation), and the Secchi disk depth as measured from the boat prior to the dive.

Black Can Reef, Milwaukee

Aug. 15, 1991	Depth: 8m	Visibility: 2m		33002.3/49303.7
Aug. 6, 1992	Depth: 7.5m	Visibility: 5m	Secchi: 4.5m	

Cobble and gravel, infilled with sand, many large boulders up to 3m; some small patches of exposed bedrock. Spawning habitat: Occasional patches of deeper cobble with interstitial spaces up to 25cm (33002.3/49307.2)

Bullshit Shoal

August 14, 1991	Depth: 7m on top	Visibility: 2.2m	Secchi:	33m S of 33015.8/49338.9
August 16, 1991	Depth: 5-10m	Visibility: 3-3.3m	Secchi	33014.1/49335.1
August 3, 1992	Depth: 7-10m	Visibility: 7m+	Secchi: 4.7m	33014.1/49335.1
August 5, 1992	Depth: 10m	Visibility: 10m	Secchi: 7m	33014.9/49337.2
August 5, 1992	Depth: 7-10m	Visibility: 10m	Secchi:	33014.7/49337.7
August 5, 1992	Depth: 5-7m	Visibility:	Secchi:	33013.3/49334.7
August 6, 1992	Depth: 7m	Visibility: 7m	Secchi: 7m	33015.8/49339
August 6, 1992	Depth: 9m	Visibility: 5m	Secchi: 5m	33014.7/49336.7

Hard pan clay with scattered cobble, increasing layers of cobble going south, with maximum of triple layers and 15cm deep interstitial spaces. One area at 5m (33014.1/49335.1) had 1-3m rounded boulders with cobble and large pebbles underneath, interstitial spaces to 10cm below lowest layer of pebbles. Beyond this area, cobbles become more scattered, with more gravel and exposed hard pan clay. To east, clay forms sharply-defined ridges and cliffs.
Spawning habitat: moderate potential, particularly at 33014.1/49335.1

South Bullshit Shoal

August 11, 1992	Depth: 10m	Visibility: 6.6m	Secchi: 5.5m	33020/49357

Flat area of sand, gravel, buried rocks
Spawning habitat: none

Wind Point South Shoal

August 14, 1991 Depth: 8.3m Visibility: 2.2m

Areas of shallow cobble, a few boulders, large areas of bedrock, some of which was deeply sculpted. Some large patches of sand on top of bedrock. Substrate patches were scattered.

Spawning habitat: none

North Point Reef, 330m E of harbor entrance

August 18, 1992 Depth: 7m Visibility: 7.6m Secchi: 4m

Sandy substrate with some hard pan clay, small area of very rounded cobble 15-40cm diameter, up to two layers deep

Spawning habitat: area probably too small, interstitial spaces too shallow

Waukegan Green Can

July 10, 1991 Depth: 7m on top, 10m at base Visibility: 2.2m Secchi: 6m

Dove on SE side. Massive bedrock reef rising vertically from 10 to top at 7m. Some small stretches of cobble and gravel at base.

Spawning habitat: none

Waukegan Black Can Reef

July 10, 1991 Depth: 5.3m on top Visibility: 4m

Bedrock mass with sand at base.

Spawning habitat: none

Intake line S. of Waukegan

June 20, 1991 Depth: Visibility: 5-6.6m Secchi: 6m

N side of line (running E-W) is level with sand substrate, S side drops approx. 3m. Large boulders, 3m diameter, tie down outer edge of intake. Some areas along line have jumbles of 10-20" cobble, about 3 layers thick. Crib at end is filled with cobble..

Spawning habitat: possible spawning area, though not historic

Lake Forest

July 28, 1992 Depth: 7m Visibility: 7m Secchi: 1.2m

Gradual, cobble-covered slope with pure sand substrate at top.

Spawning habitat: moderate potential

Fort Sheridan NE reef

July 9, 1991 Depth: 6m at top, 11m at base Visibility: 5m Secchi: 5.25m

Flat-topped 'reef' with cobble/gravel substrate infilled with sand and silt. Rocks mostly <12cm diameter, some with covering of algae. Some rocks had incipient honeycombing formations. Slopes gradually to 10.6m, with areas of sand, or gravel overlying hard pan clay, or exposed clay.

Spawning habitat: none

Fort Sheridan SW reef

July 9, 1991 Depth: 12m Visibility: Secchi: 5.25m

Infilled cobble, sand, patches of gravel, some hard pan clay, a few large rocks up to 0.6m across

Spawning habitat: none

Fort Sheridan middle reef

July 12, 1991 Depth: 5m Visibility: 2m

Dense cobble with some gravel and smaller rocks, sand underlayment. A few 1.6-2.3m boulders. Shallow slope to sand at base of reef.

Spawning habitat: good potential

Highland Park Reef

July 9, 1991 Depth: 7.3m on top Visibility: 6m Secchi: 5.25m

August 20, 1992 Depth: 7m Visibility: 7m

Solid bedrock with small crevices and large crevasses filled with boulders. Some areas with 2cm growth of algae.

Spawning habitat: none

Lake Bluff marina

July 12, 1991 Depth: 5m Visibility: Secchi:

Cobbles infilled with sand and gravel

Spawning habitat: none

Glencoe Shoal

July 10, 1992 Depth: 3.1m Visibility: 10-12m

Large bedrock mass, rising to within 1.5m of surface, silty clay at base, some scattered cobbles at E edge. A few small patches of gravel. Some areas with 10cm deep colonies of algae (Chara?)

Spawning habitat: unlikely

Wilmette Reef (WR4 buoy)

July 16, 1992 Depth: 7.5m at top, slope to 11m Visibility: 10-12m

August 20, 1992 Depth: 20-10m Visibility: 7m Secchi: 5m

Mostly single layer of cobbles on hard pan clay. Very rich biological community. SSW area of steepest slope has infilled cobbles at base, then jagged bedrock, forming ridges and large holes as it rises to 10m. Holes up to 2m deep had layers of cobble at bottom.

Spawning habitat: moderate potential

Evanston shore, 10 from shoreline

July 16, 1992 Depth: 5m Visibility: 7m

Very flat area of gravel and sand, with occasional patches of mostly buried rubble and cobble.

Spawning habitat: unlikely

Bahai Temple, .25mi offshore

July 16, 1992 Depth: 5m Visibility: 3.2m

Single to double layers of cobble on clay. Pure sand within about 70m of shore.

Spawning habitat: moderate potential

Burnham Harbor, Chicago

Aug. 29, 1991 Depth: 3m

Areas of cobble and broken rock approx. 5m off sheet piling wall.

Spawning habitat: none

Montrose Harbor, Chicago

Aug. 29, 1991 Depth: 3m Visibility: 4m

Broken rock, sand, silt.

Spawning habitat: none

Calumet Park, Chicago

Aug. 29, 1991 Depth: 3m Visibility: 5m

Mud, silt, broken rock

Spawning habitat: none

Port of Indiana, west side of west breakwall

December 1, 1992 Depth: 12m Visibility: 1.5m

Breakwall comprised of large, rectangular blocks, approx. 2x1x.3m, jumbled together with large spaces in between. Blocks covered with zebra mussels. Base of breakwall at 12m. At base of breakwall, flat area of irregularly shaped cobbles, 15-30cm diameter, some sculpted. Apparently deep interstitial spaces. Dive was short (15 min), but numerous eggs were found by lifting cobbles. One large (15lb) adult lake trout swam slowly by, within a few inches of one of the dives.

Spawning habitat: cobble underlayment provdides excellent spawning habitat in the form of layers of rounded cobbles with deep, clear interstital spaces.

APPENDIX 1

During winter 1995 we conducted experiments to help clucidate the threat that a new non-indigenous species, the round goby *Neogobius melanostomus* (Pallas), may pose to interstitial deposits of lake trout eggs. Preliminary results suggest that gobies easily penetrate cobble substrate and readily consume lake trout eggs. Further studies directly comparing the performance of round gobies and mottled sculpins are planned for the winter of 1996.

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

APPENDIX 2

The following is an account of the sites we visited during 1994-1995, with comments about the suitability of observed substrate for lake trout spawning.

Buffington Harbor

Burns Harbor. We explored the site on several dives conducted during the fall of 1994 and in May 1995. The breakwall consists of a thick layer of bedding stone, which is cobble, and a thicker top layer of armor stone, each piece of which weighs 2-10 tonnes. The Burns Harbor site offers excellent spawning substrate for lake trout because the bedding stone averages several meters in depth and has fairly open interstitial spaces, and because there are large areas of it to the west of the breakwall that are not covered by armor stonc. We determined that the best potential lake trout spawning areas at the site lie in a strip adjacent to the west face of the breakwall. The strip is 10-30 meters in width, and runs for more than 200m, from just south of the northwest corner of the breakwall to shallow water north of the junction of the stone breakwall and the sheet piling portion of the wall. At the deep end, the strip of bedding stone lies in depths of 5-14 m, while at the shallow end it lies in depths of 3-6 m.

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

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

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

Pastrick Marina

Wilmette Reef R-2

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