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OHSU-TB-078

# SUBSTRATE DISTRIBUTION ON WESTERN BASIN REEFS WITH DEPTH AND STORM IMPACTS ON WALLEYE REPRODUCTIVE HABITAT

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March 2005

Text for fulfillment of
Ohio Sea Grant Project R/ZM-28: SUBSTRATE AND ZEBRA MUSSELS: CONTROLS AND IMPACTS ON FISH REPRODUCTIVE HABITAT-WESTERN BASIN REEFS

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MICHIGAN STATE UNIVERSITY

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## ABSTRACT

The project, "SUBSTRATE AND ZEBRA MUSSELS: CONTROLS AND IMPACTS ON FISH REPRODUCTIVE HABITAT- WESTERN BASIN REEFS," funded by the Ohio Sea Grant, was developed with the principal goal of initiating detailed studies of how variability in the physical structure of selected reefs within the Western Basin of Lake Erie might influence the quality of fish habitats on these reefs. To achieve this goal the following primary objectives were to:

1. Develop detailed substrate maps of six reefs within the Western Basin of Lake Erie: Locust Point, Cone, Toussaint, Crib, Round, and Niagara Reefs.
2. Determine patterns of zebra mussel coverage of substrate surfaces within and among the six reefs.
3. Assess the possible effects of variation in substrate on zebra mussel coverage and habitat use by walleye for spawning and reproduction.
4. Assess potential impacts of the exotic round goby on zebra mussels and habitat use by walleye for spawning and reproduction.

The original goal also would give an enhanced understanding of how fish respond to heterogeneity or diversity in the physical environment of these particular reefs. The report also was to enhance understanding of habitat availability and habitat usage.

The Principal Investigators were Dr. S.D. Mackey (formerly Ohio DNR, Division of Geological Survey) and Dr. Kenneth Baker (Heidelberg College), both ofwhom left the project prematurely for various reasons. Prior to their leaving, a significant effort was made toward these objectives.

This report is in partial fulfillment of the original goals and provides a form of placeholder for future studies with similar goals. This report assembles the studies conducted to that end by at least two agencies involved in the project and offers conclusions unrelated to the original objectives. Detailed substrate maps were constructed from the side-scan data in 1998, 1999, and 2000. These indicated that there was less exposed bedrock area than was previously indicated with more area of exposed hard cohesive clay. Generally, the sequence of deposits relative to depth was bedrock in the shallowest depths, followed by high-relief cohesive clay, lower-relief cohesive clay, muddy sand, and sometimes mud in the deepest of the areas. Visual observations provided a trend in Dreissenid (zebra mussel) density that ranged from relatively high on exposed bedrock to low on the mud substrates. The exception was in depths less than 3 meters where the mussel population was much lower. Walleye spawning generally began in late March, peaked in mid-April and was over by early May. Egg densities were highest on the reef tops early in the period but the eggs were later moved into deeper water by wind and wave action. The deeper cohesive clay areas of the reef retained the eggs as they were being moved off the shallow reef tops. This area of reduced wave energy provided the best area for egg incubation.

## PURPOSE

The project, "SUBSTRATE AND ZEBRA MUSSELS: CONTROLS AND IMPACTS ON FISH REPRODUCTIVE HABITAT- WESTERN BASIN REEFS R/ZM-28", funded by the Ohio Sea Grant, was developed with the following primary objectives:

1. Develop detailed substrate maps of six reefs within the Western Basin of Lake Erie: Cone, Crib, Locust Point, Niagara, Round, and Toussaint Reefs;
2. Determine patterns of zebra mussel coverage on substrate surfaces within and among the six reefs;
3. Assess the possible effects of variation in substrate on Dreissenid (zebra and quagga) mussel coverage and habitat use by walleye *Sander vitreus* for spawning and egg incubation;
4. Evaluate potential impacts of the exotic round goby on Dreissenid mussels; and
5. Appraise habitat use by walleye for spawning and egg incubation.

Because of changes in employment, the principal investigators for the grant, Dr. S.D. Mackey (formerly Ohio Department of Natural Resources, Division of Geological Survey) and Dr. Kenneth Baker (Heidelberg College) left the project prematurely. Therefore, this report will summarize what was accomplished, although the results do not meet all the original objectives stated above. This project has:

1. Assembled the work conducted by the staffs of ODNR Divisions of Geological Survey and Wildlife relative to the project and offers conclusions relating to some of the original objectives;
2. Developed substrate maps from side scan sonar and ground-truth data for each of the 6 reefs;
3. Prepared a limited quantification of Dreissenid mussel coverage, with no differentiation of the types of exotic mussels;
4. Noted changes in the temporal distribution of Dreissenid mussels but the magnitude of the changes were not quantified;
5. Added additional knowledge of habitat availability and habitat usage in the reef areas;
6. Estimated walleye egg abundance, relative densities and egg viability data relative to reef, depth, and time;
7. Provided an enhanced understanding of how fish respond to heterogeneity in the physical environment of these particular reefs; and
8. Presented data relative to fish egg response to a major storm event.

**ACKNOWLEDGMENTS**

We would like to thank the Ohio Sea Grant organization for partial funding this project. Dr. Scudder Mackey provided the initial concept and a significant effort in the original planning and execution of the preliminary phase of the project. In addition, we would like to thank Thomas Berg, State Geologist for Ohio, and Constance J. Livchak, Geologist and Group Supervisor, Division of Geological Survey, Lake Erie Geology Group for their review of the text and for providing support and the time to work on this project. The use of Stone Lab's remotely operated vehicle (ROV) and operator Matt Thomas is greatly appreciated. Also, thanks go to Michael Bur, USGS, Lake Erie Biological Station, and Dr. Kenneth Baker, Department of Biology, Heidelberg College for assistance in collecting data.

## SUBSTRATE DISTRIBUTION

### PREVIOUS WORK

Hough (1958) presents a good description of the general physical setting for the Great Lakes, which is still very valid. J. L. Verber (The Ohio Division of Shore Erosion 1957) described the reef area in an overview of the Western Basin. Herdendorf and Braidech (1972) collected detailed bathymetry over the reefs and characterized them as having a central rock area (ranging in size from 0.2 to 0.6 square kilometers) surrounded by gravelly sand. Bolsenga and Herdendorf (1993) summarized a portion of the data presented in the earlier Herdendorf and Braidech (1972) work.

### FIELD WORK

Research vessels used for this project were the ODNR Division of Geological Survey research vessels *R/V GS-1 and R/V GS-3*; the U.S. Geological Survey Biological Research Division research vessel *R/V Musky*; Michigan State University's *R/V Osmerid*; and Dr. Baker's personal boat.

The Lake Erie Geology Group's (LEGG) main task in this project was to develop detailed, geo referenced substrate base maps of six reefs offshore of Locust Point, Ohio (Figure 1). The six reefs are: Cone, Crib, Locust, Niagara, Round, and Toussaint

Reefs. With an emphasis on walleye, the substrate maps were to be used for detecting the spawning and hatchery needs of sport fishes utilizing the reefs. One intent of this project was to develop a specialized geologic/biologic substrate classificationthat would combine sediment grain size and biologic characteristics, but this never came to fruition. Instead, detailed substrate maps of the reefs are provided.

Numerous visits to each of the reefs in the study area between 1998 and 2000 were undertaken by the LEGG. The primary side scan sonar (SSS) mosaics (see mosaic

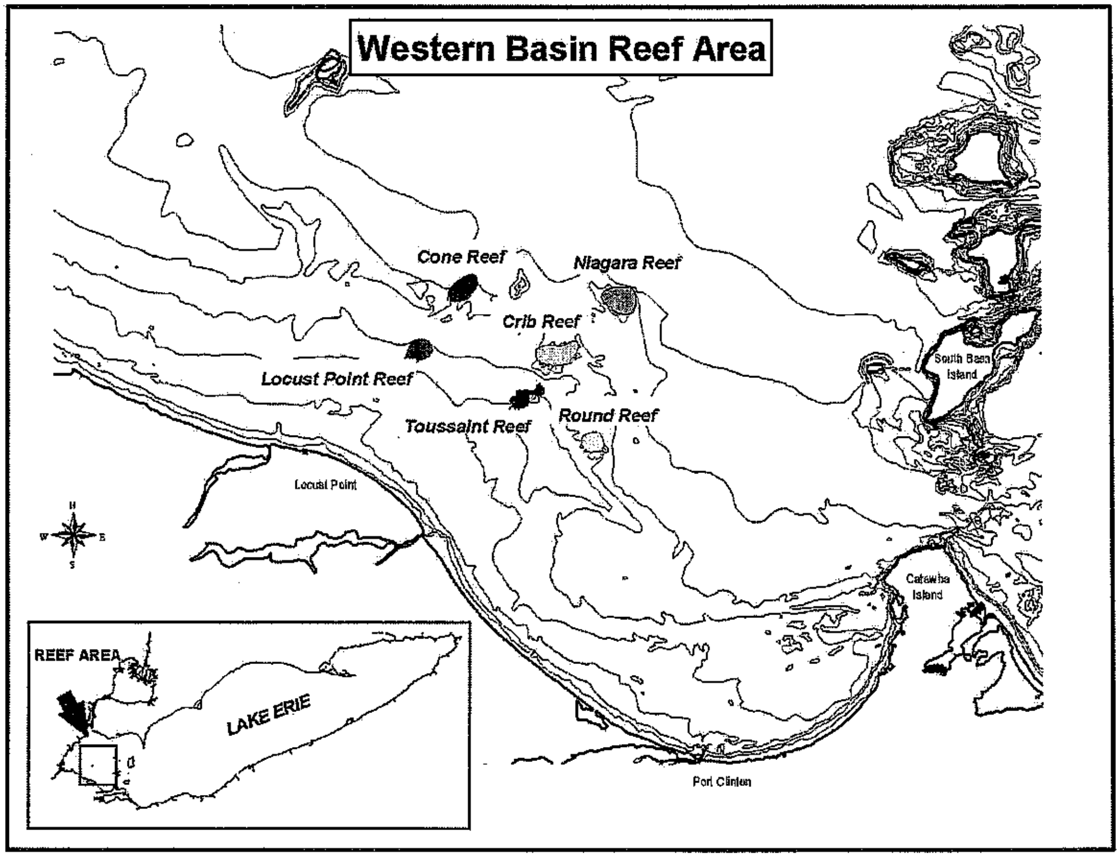


Figure 1. Reef location map.

Plates 1-12) were produced in 1998 with subsequent visits used to obtain groundtruth data. Data-collection efforts were hampered by environmental conditions, which required multiple site visits. Problems affecting data collection were caused by the rapid changes in the depth over the reefs creating an enhanced effect of waves on the reef tops resulting in excessive interference. Thermoclines were a problem on days when the shallower water over the reef top warmed preferentially relative to the deeper areas. This jump from warmer to colder temperatures produced an acoustic layer which sound could not penetrate causing a restriction in achievable range. Also, in 1998, the SSS system technology and proficiency were immature compared to present. Since 1998, a significant suite of additional hardware and software has been added to the system, which greatly enhances the data capturing and processing abilites. Some of the improved processing was used to enhance the data presentation in this report.

The major electronic data equipment used to characterize the reef substrates are: a Klein® Model 595 side scan sonar and a Triton Elics® Data Acquisition System. These were georeferenced with a Trimble® real-time differential global positioning system (D-GPS) navigation unit with sub-meter resolution.

The SSS tracklines were run approximately East and West, which was generally along the long dimension of each reef, using a 25% overlap with adjacent lines. The 75-meter range was used on all reefs and was selected to best balance the need for detail, while not overwhelming the data-collection system (Table 1). A Raytheon DE-719 Fathometer® was used in an attempt to both locate the top of each reef and to link some of the historic bathymetry data (Herdendorf and Braidech, 1972) to this study. This link never materialized due to a number of factors including changes in navigation precision, mapping assumptions made in the interpretation of the historic data, and the need for additional new data to effectively match archived records.

Ground-truth data, used to aid in the SSS backscatter interpretations, were collected using a variety of methods. Visual methods included SCUBA diving at pre-selected sites, a towed video camera, and an ROV with a video camera. Diving included both 3 meter circle dives around a single anchor point and along 40-meter transect lines. Both video and still pictures were taken during many of the dives. The towed camera was used both as a drop camera at specific locations and towed by the boat which was located to drift across the target area with the wind and positioned with DGPS. The ROV traversed along pre-selected 90-meter transect lines. In addition to the video ground-truthing, grab samples were collected with an Eckman® sampler, a rod was used to probe the bottom, anchor fluke sediment samples were examined, and bottom samples were described at egg sampling sites.

Table 1. Side scan sonar field visits. Primary records used for mosaics were run August 27 and 28, 1998.

| Reef name | # of lines | Field Date | Line Length (km) | Reef total km | Comments |
|---|---|---|---|---|---|
| Locust | | Aug 27, 97 | | 22.0 | too rough |
| Locust | 8 | May 14, 98 | 1.2 | 9.8 | thermocline |
| Cone | 8 | | 1.1 | 8.9 | thermocline |
| Niagara | 10 | May 27, 98 | 1.8 | 18.5 | thermocline |
| Crib | 10 | | 1.7 | 16.7 | thermocline |
| Toussaint | 10 | | 1.7 | 16.7 | thermocline |
| Round | 9 | | 1.2 | 10.7 | thermocline |
| Toussaint | 9 | Aug 27, 98 | 1.7 | 15.0 | waves |
| Round | 8 | | 1.7 | 11.9 | good, scale 75 meters |
| Niagara | 8 | | 1.7 | 11.9 | good, scale 75 meters |
| Crib | 10 | Aug 28, 98 | 2.0 | 20.4 | good, scale 75 meters |
| Cone | 7 | | 1.1 | 7.8 | good, scale 75 meters |
| Locust | 8 | | 1.1 | 8.9 | good, scale 75 meters |
| Toussaint | 9 | | 1.7 | 15.0 | good, scale 75 meters |
| Niagara | 7 | Oct 27, 98 | 1.5 | 10.4 | fill in, good N-S |
| Round | 1 | | 1.3 | 1.3 | fill in, good |
| | | | | | |
| | | | Total | 205.9 | Kilometers of record |

## DATA COMPILATION

Ground-truth data were catalogued by location, type of data, and description of the bottom. All available videotapes were viewed, and relative bottom firmness, bottom description, and estimated percent of Dreissenid mussel coverage were entered onto a form to assure consistency of notation through the hours of tape that were viewed.

The raw field SSS data was post-processed in the office by performing a number of corrections. These corrections included slant range correction to observe true distance to targets, a beam angle and grazing angle correction to remove abnormalities, and smoothing of navigation. The records were then processed into a mosaic with adjacent records in Delphmap® to produce a single spatial side scan sonar mosaic representation of each reef. The mosaics were exported to geographic information system (GIS) software where the data was further processed. Maps showing ground truth type and location were produced. (Mosaic Plates 1-6). Areas of similar SSS backscatter were outlined using both the mosaicked data and the raw analog (both 100 and 500 kHz) and digital records. Using the ground-truth data, a bottom substrate map was created by correlating and modifying the areas of similar backscatter with the ground-truth data. The substrate map was then digitized into a polygon layer in the GIS software to overlay onto the SSS mosaic (see 6 substrate Plates).

The historical depth data was evaluated, both from the printed report (Herdendorf and Braidech, 1972) and from a reevaluation of the original field data. General trends could be seen in reef area shapes when the bathymetry data were visually compared to the SSS mosaics; but the data sets could not be linked to the georeferenced SSS data with acceptable accuracy for detailed depth analysis without collecting new data. For this reason, the depth data are not included as a GIS overlay for the SSS mosaics.

**RESULTS**

The substrate units mapped in this project were mud, sandy mud/muddy sand, cohesive clay (flat), cohesive clay (with relief), and bedrock (Table 2). Each of the reefs included in this project can be summarized as a single or series of small bedrock outcrops (0.1 square kilometer or less) surrounded by cohesive clay deposits that are in turn surrounded by sandy mud/muddy sand. At the outer edge of some of the reefs the fluid mud, which dominates the modern western basin, can be seen on the six substrate Plates.

The limited depth data that was collected does suggest that the expected relationship of depth and substrate type holds true. The bedrock provides the high point on the reef and depths slope off from the bedrock high through the high relief cohesive clay. The low-relief cohesive clay can be found in slightly deeper water. As the depth continues to increase, the low-relief cohesive clay transitions to the sandy mud/muddy sand and finally to the mud which dominates the majority of the western basin.

In a preliminary interpretation, it was believed that the high-relief cohesive clay unit was also bedrock. This interpretation was based on areas showing similar relief to the

Table 2. Substrates mapped in the Locust Point Reef Area

| **Substrate Unit Description** | **Backscatter Characteristics** |
|---|---|
| Mud | Little backscatter and few shadows |
| Sandy mud / muddy sand | Even backscatter low intensity generally lacking relief |
| Cohesive Clay, relatively flat | Even backscatter with some point and ridge shadows, some lines and possible ice scour marks present |
| Cohesive Clay, with relief, may have ledges, cobbles and boulders | Rhythmic lines with hard edges and common shadows indicating relief, possible ice scour marks |
| Bedrock with boulders and cobbles | Complex and more detailed backscatter a bit more random including depressions, also may have a cliff associated, no ice scours |

bedrock areas and having nearly 100 percent coverage by Dreissenid mussels(zebra mussels). Visual records from the 2000 ground-truth video data clearly demonstrated areas where the mussels had been plucked from a cohesive clay surface. The exposed surface of the cohesive clay looked like the mussels had burrowed into the clay. Further refinement of the interpretation suggested that the areas with moderate relief and rhythmic lines were another cohesive clay unit. This is supported by the presence of possible ice scour marks within the areas.

Dreissenid mussels do not appear to have a distinct acoustic signature on the SSS records when they are on a relatively hard surface, so their distribution could not be mapped. However, the density of the mussels can mask the bottom substrate as seen on the videotapes. For these reasons, only generalizations of the substrate can be determined by using the percent coverage of Dreissenid mussels. Dreissenid mussel coverage was effectively 0 percent in the one mud area that was sampled. Conversely, Dreissenid mussel coverage averaged about 80 percent over the bedrock areas that were greater than 3 meters deep (survey water depth). Bedrock areas wih less than 3 meters of water had reduced coverage. The other substrates, lowrelief and high-relief clay, had intermediate values for Dreissenid mussel coverage (65 and 70 percent respectively, see Table 3).

Table 3. Dreissenid mussel carpet coverage by substrate

| **Substrate type** | **Range % cover** | **Cone Reef** | **Crib Reef** | **Locust Reef** | **Niagara Reef** | **Round Reef** | **Toussaint Reef** |
|---|---|---|---|---|---|---|---|
| Mud | 0 | ND | ND | ND | X | ND | ND |
| Sandy mud/muddy sand | 30-60 | X | ND | ND | ND | X | ND |
| Low relief cohesive clay | 40-90 | X | X | X | X | X | X |
| High relief cohesive clay | 50-90 | X | X | X | X | X | X |
| Rock, except on shallow reef top, < 3 meters deep | 60-100 | X | X | X | X | ND | X |

X = substrate sample present on reef   ND = no data

# FISH HABITAT

## INTRODUCTION

On western Lake Erie reefs, walleye begin spawning shortly after iceout, and peak spawning typically occurs by mid-to-late April (Roseman and others, 1997). Eggs are broadcast over hard substrates (gravel/rock) in shallow areas of tributaries and midlake reefs. Eggs require oxygen levels above 35% saturation for survival and incubation is temperature dependant, lasting up to 2 weeks (Siefert and Spoor, 1974). Because of the east-west orientation of the lake, the western basin is very susceptible to the effects of storm generated waves and currents, especially those originating from eastely direction which have long fetches and carry high wave energy (Gedney and Lick, 1972).

Storm events on large lakes like Lake Erie can create strong wind-driven currents and strong wave action (Gedney and Lick, 1972; Hamblin, 1979) and some studies have inferred that such processes cause mortality during the early life history stages of fish thereby reducing year-class strength and limiting recruitment (Busch and others,1975, Houde, 1989).

Because walleye are broadcast spawners, their eggs are vulnerable to mortality caused by dislodging from severe wind and wave action during spawning and incubation periods (Johnson, 1961; Serns, 1982). Prolonged strong wind events create wave and current conditions that can transport fish large distances (Martin and others, 1992) and sediment deposited on incubating eggs can reduce oxygen levels and suffocate eggs (Ventling-Schwank and Livingstone, 1994).

The purpose of the egg-sampling portion of this project was to determine the relative abundance and distribution of walleye eggs on the six reefs in western Lake Erie. The objectives included determining the spatial and temporal patterns in walleye egg relative density on reefs and how egg density is related to substrate and lacustrine processes.

**Methods**

Walleye egg sampling on reefs began in late March 1998 shortly after ice-out and continued through to mid-May when spawning ceased and catches of walleye eggs were negligible. Eggs were collected at least once per week on Cone, Crib, Locust, Niagara, Round and Toussaint reefs (Figure 2). Egg sampling was stratified by depth to examine egg deposition density; depths of 0-5 m, and 5-7 m were sampled. These depth strata encompass the range of depths where walleye eggs were collected in previous studies (Baker & Manz, 1971, Roseman and others, 1996, Roseman 1997). Three samples were taken at each depth on each sampling day. Sample sites were located by GPS coordinates and marked with an anchored buoy. A 39kg iron sled (Stauffer 1981) attached to a diaphragm pump atthe surface by a flexible hose 5 cm in diameter was used for egg collections. For each sample, the sled was towed for 2 minutes at about 0.5 m/s.

Eggs and benthic debris (Dreissenid mussels and shells, sand, benthic organisms) were deposited from the pump apparatus into a 0.5 $m^3$ basket lined with 0.5 mm square mesh netting. The net liner containing the sample was then removed and placed in a labeled plastic bag. Samples were acclimated and refrigerated at 5°C until they could be sorted at the laboratory, which typically was within 2.5 to 24 hours (h). We found no indication that delays in processing of up to 24 h influenced egg viability.

At the laboratory, samples were weighed then rinsed through a galvanized steel wire screen (6 mm bar mesh) to separate large debris from finer particles and eggs. The small particulate matter was then examined for walleye eggs, which were counted entirely or sub-sampled. A single sub-sample was taken when there appeared to be more than 1,000 eggs in the total sample. Sub-samples were typically 10% of the mass of the drained fine particulate matter. Identification of eggs was based on egg diameter (mm), egg color, and subsequent hatching of eggs. Three sizes of eggs were found on the reefs during this study; 3 mm, 2 mm, and 1.5 mm. Several eggs of each size category were acclimated in aquaria with aerated lake water and incubated at 15°C. Hatched larvae were identified according to Auer (1982). Collected eggs were examined with 10X magnification for viability and measured (nearest 0.1 mm). All eggs that were ruptured or showed signs of opaqueness or fungal growth were classified as dead eggs. All clear or eyed eggs were classified as viable eggs.

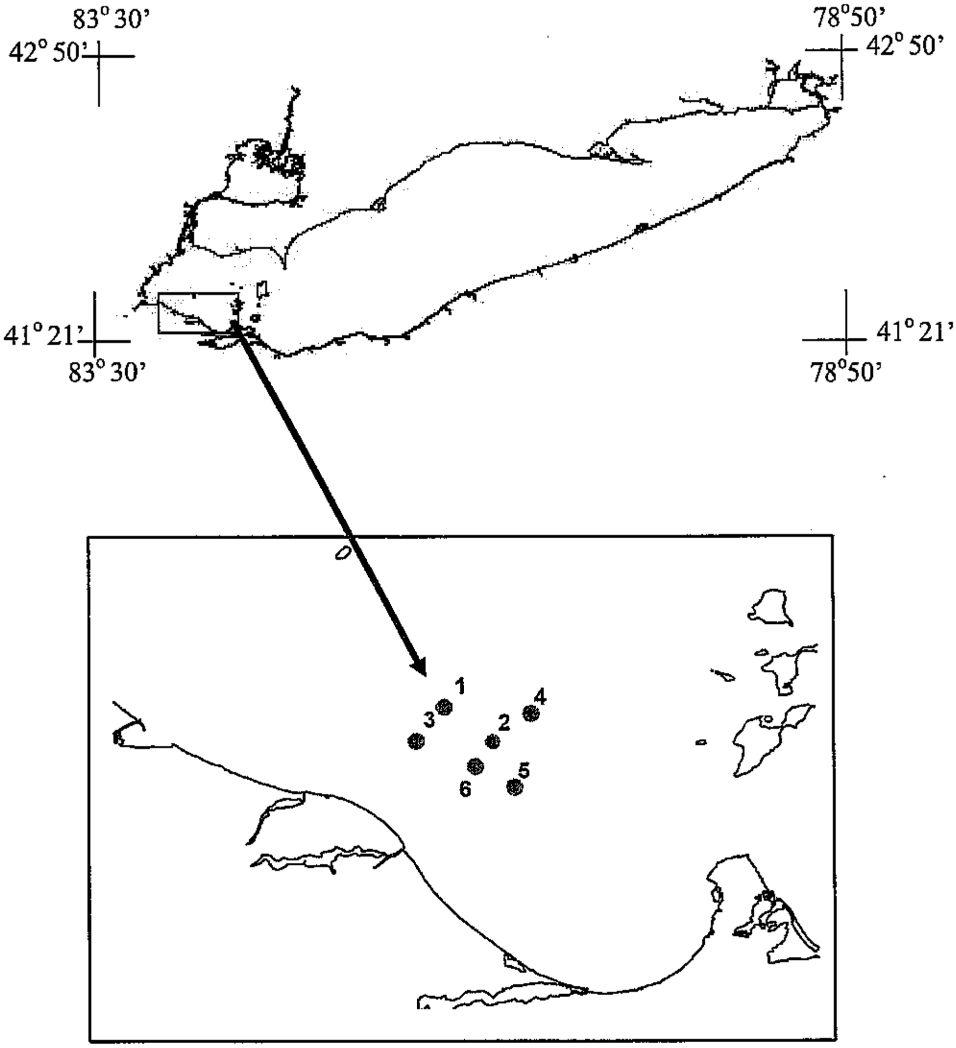


Figure 2. Western Lake Erie study area. Numbers indicate reef locations: 1- Cone reef, 2 - Crib reef, 3 - Locust reef, 4 - Niagara reef, 5 - Round reef, 6 - Toussaint reef

To compare relative egg density between reefs, a calculation of the weighted averages of numbers of walleye eggs collected per 2 minute tow on each reef was performed. The proportion of the reef surface area contributing to depth strata as weighting factors for each reef was used. Surface area proportions were estimated from bathymetric maps of the reefs (Herdendorf and Braidech, 1972). To examine the effects of a severe storm event that occurred during the egg incubation period in 1998, an analysis of variance was used in the form of a general linear model to assess the significance of differences in egg relative density between sampling dates, between reefs, and between depths before and after the storm occurred. Percent loss of eggs was used as the dependent variable and depth and reef were the interacting class variables. A significance level of 0.05 was used for all statistical tests.

Wind velocity and direction data recorded at South Bass Island in western Lake Erie were obtained from the National Climatic Data Center Web site (National Climatic Data Center (NCDC), 2000). South Bass Island is approximately 20 km east of the reef complex. The number of days between April 1 and May 15 when wind events having velocities between 25 - 50 km/h and > 50 km/h was determined. This time period typically covers the walleye egg incubation period on reefs in western Lake Erie (Baker and Manz, 1971; Roseman and others, 1996; Roseman, 1997). Busch and others, (1975) determined that winds exceeding 25 km/h were sufficient to remove incubating eggs from reefs. Wind events exceeding 50 km/h were separated from the first category because storm events of this magnitude were rare during the study period (NCDC 2000) and it was observed that they had a different impact on incubating eggs than storms of a lesser magnitude. Additionally, only winds originating from directions with fetches > 10 km (260° – 110°) were considered because wave energy increases with fetch (Gedney and Lick, 1972). Southerly offshore winds with shorter fetches produced smaller wave amplitudes and had minimal effects on the abundance of incubating eggs on reefs.

## RESULTS

Walleye egg relative abundance (number of eggs collected per two-minute tow) for years 1994 through 1999 are presented in Figures 3 and 4. In 1998 the first walleye eggs were collected on March 23 from Locust and Toussaint reefs. Eggs were present on all reefs on March 29. Egg relative abundance peaked on Toussaint reef on April 3 when an average of 2,747 eggs was collected per 2-minute tow. Egg relative abundance peaked on Crib, Locust, Niagara, and Round reefs on April 6 when an average of 540, 1,063, 1,340, and 562 eggs were collected per 2-minute tow. Egg abundance peaked on Cone reef on April 15 when 1,164 eggs were collected per 2 minute tow. Viable walleye eggs were collected from all reefs through April 28 while eggs were found on only Locust and Niagara reefs on May 3 (Figure 3).

Eggs were sampled only three times during 1999 due to equipment failure. Eggs first appeared in samples collected on March 31. Egg abundance averaged 932, 1,928, 674, 1,281 3,437, and 581 on Cone, Crib, Locust, Niagara, Round and Toussaint reefs respectively on April 8. Eggs were still present in low numbers on all reefs on May 5 (Figure 4).

In general, more eggs were found at shallow sites on reefs than deep sites early in the spawning season of each year. This trend reversed later in the egg incubation period as eggs were removed from shallow sites and displaced to deeper sites on the reefs (Figure 5).

Similar increasing trends in egg viability were observed in both years. Walleye egg viability did not differ substantially between reefs or depths. Egg viability increased from values around 20% on all reefs in early April to about 60% by early May (Figure 6). The observed increasing trend in egg viability is likely due to dead eggs becoming buoyant and drifting off the reefs (Johnson, 1961).

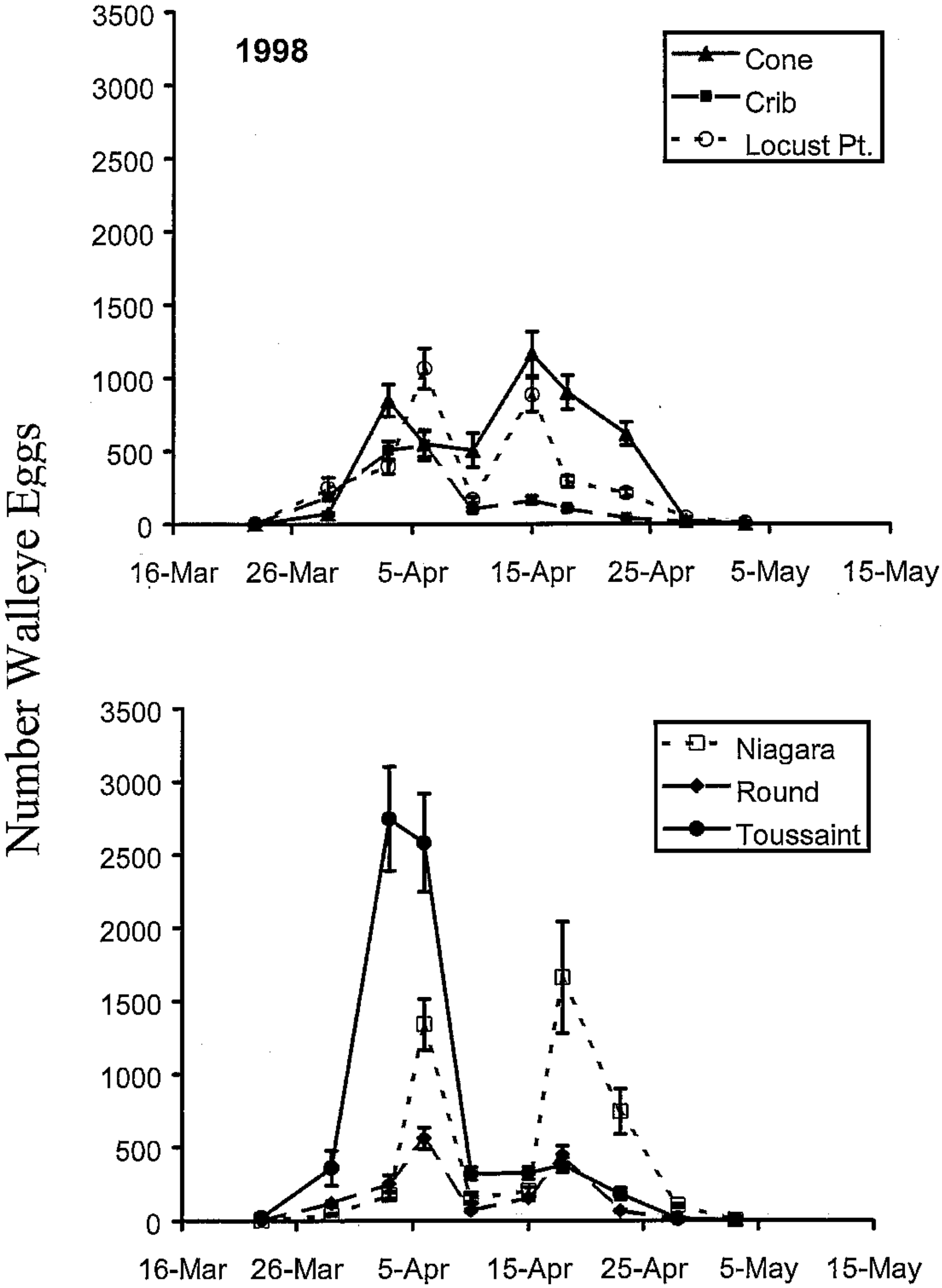


Figure 3. Walleye egg relative abundance (± 1 standard deviation) on reefs in western Lake Erie, 1998.

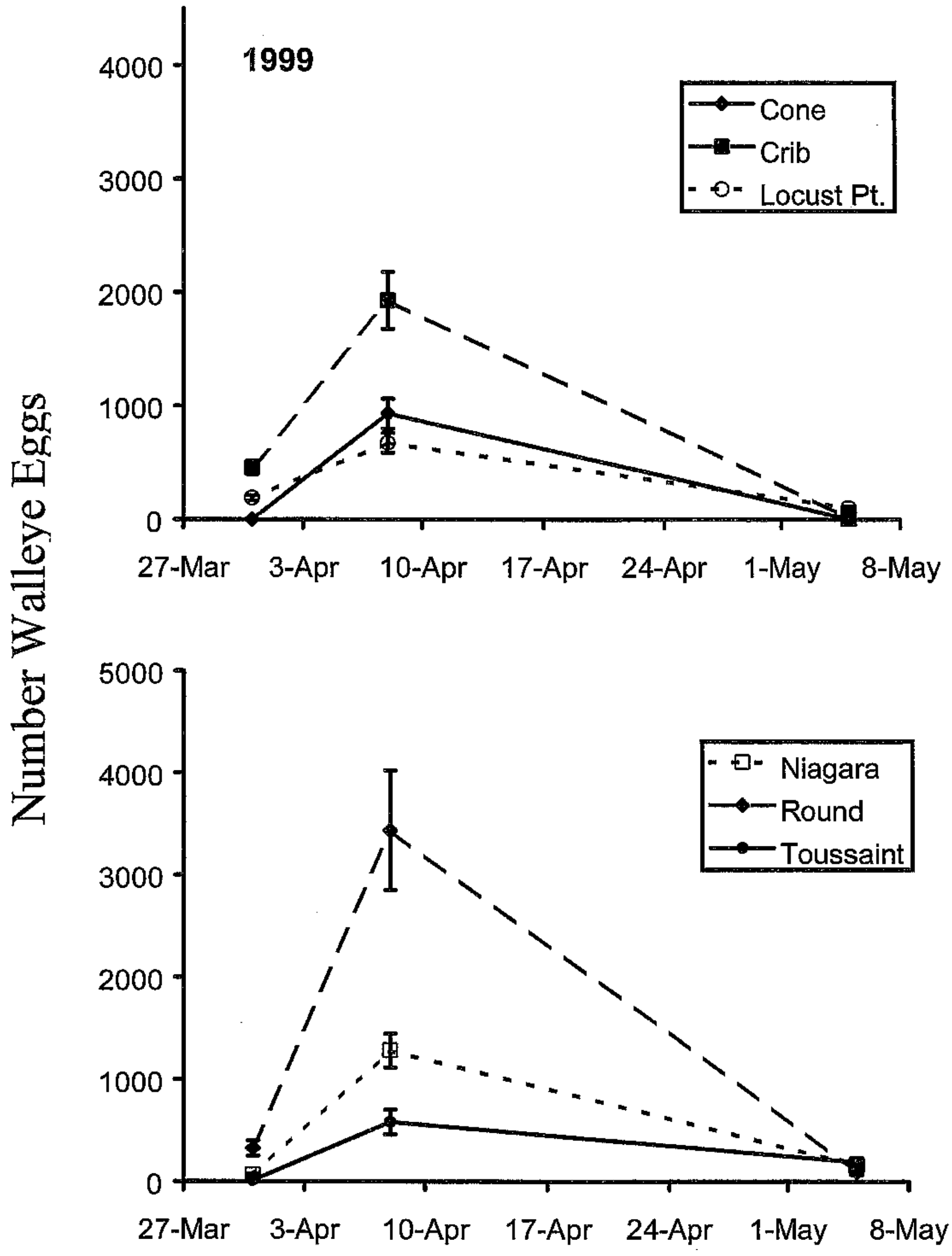


Figure 4. Walleye egg relative abundance (± 1 standard deviation) on reefs in western Lake Erie, 1999.

In 1998, there was a unique opportunity to observe the strong effects of a single gale force storm event on the relative density, distribution, and survival ofwalleye eggs on reefs in western Lake Erie. The storm occurred between April 8 and the morning of April 10, well after spawning had begun that year (Figure 3). This storm brought gale force winds in excess of 80 km/h from the east-northeast and persisted for over 36 h (Table 4; NCDC, 2000). Resulting waves (some > 4 m in height) scoured western basin reefs. We found about 80% fewer eggs in samples collected on April 10 than on April 6 and this difference was significant (ANOVA, $p < 0.001$). All reefs except Cone experienced a significant decrease in egg relative density between April 6 and April 10. Shallow sites (< 5 m) on reefs lost significantly more eggs (87%) than deep sites (50%) (ANOVA, $p < 0.0001$; Table 4; Figure 5). Cone reef is a deep reef having no area with depth less than 6 m as noted during the 1998 investigation. There was an observed difference in egg relative density of only 8% between April 6 and April 10 on Cone reef and this difference was not statistically significant ($p = 0.08$).

On average, over 80% of the eggs were collected from shallow sites on the reefs before the storm while only 19% of the eggs were collected from shallow sites after the storm (Table 4; Figure 5). Egg survival for the period that includes the storm (March 26 – April 10) was quite low ranging from 0.001– 0.010 on reefs with shallow sampling sites, but noticeably higher on Cone reef at 0.185. Walleye continued to spawn on the reefs after the storm as evidenced by increasing egg relative abundance in mid-April (Figure 3).

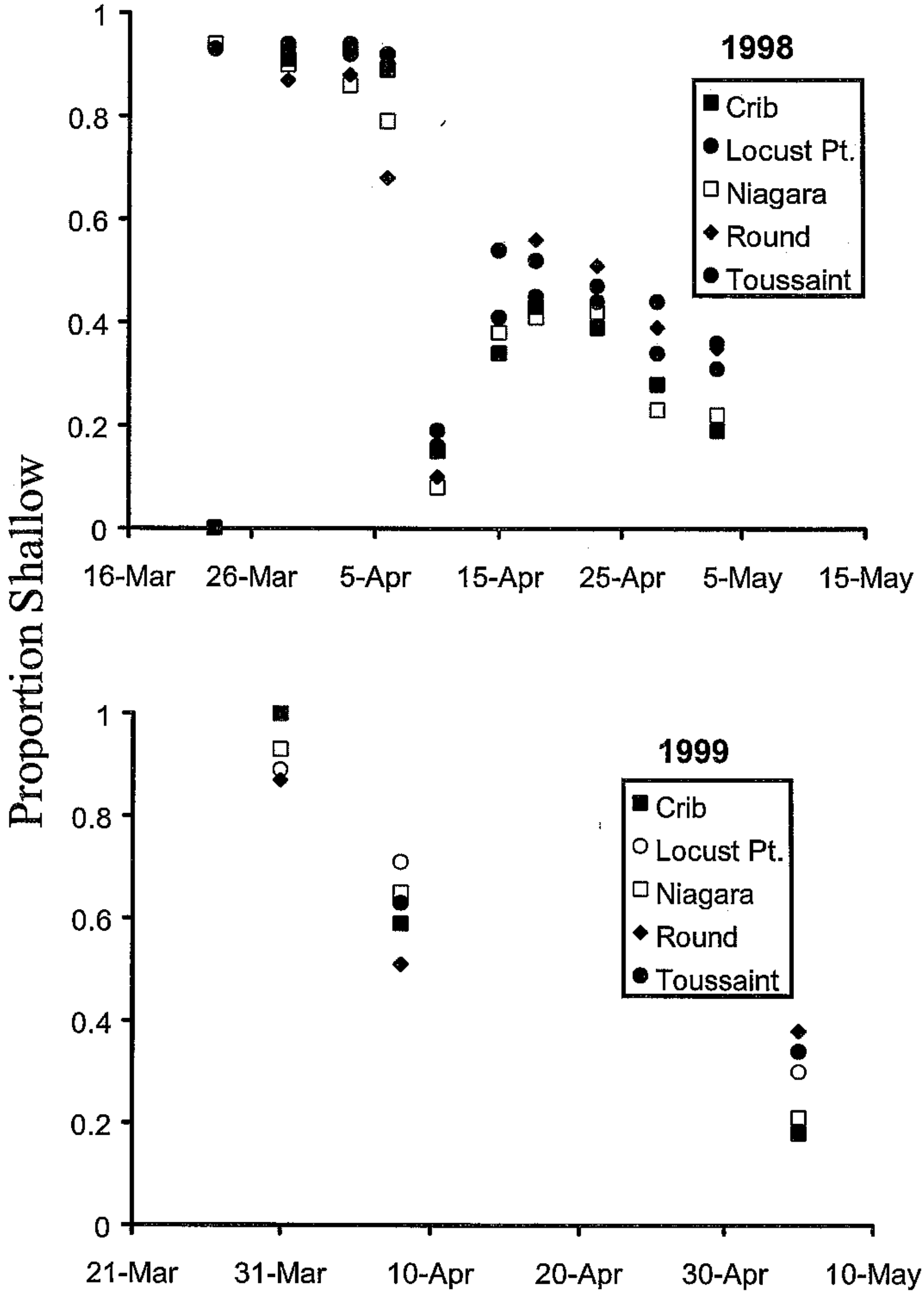


Figure 5. Proportion of eggs collected from shallow sites (< 5m) on reefs in western Lake Erie, 1998 and 1999.

Table 4. Surface area of reefs ($km^2$) in western Lake Erie sampled for walleye eggs (area shallower than 5 m is shown in parentheses), average numbers of walleye eggs collected per 2 minute tow on reefs before storm, % of eggs collected from shallow sites (< 5 m) before storm (standard error in parentheses), average numbers of walleye eggs collected per 2 minute tow on reefs afer storm, (standard error in parentheses), % of eggs collected from shallow sites after storm, and % loss of eggs from reefs due to storm.

| Reef | Area ($km^2$) | # Eggs Before | % Shallow | # Eggs After | % Shallow | % Loss |
|---|---|---|---|---|---|---|
| Cone | 0.67 (0.00) | 549 (88) | --- | 506 (84) | ---- | 8 |
| Crib | 0.85 (0.65) | 540 (69) | 89 | 100 (21) | 15 | 81 |
| Locust | 0.93 (0.80) | 1063 (72) | 90 | 166 (31) | 19 | 84 |
| Niagara | 2.49(1.50) | 1340 (51) | 79 | 153 (42) | 8 | 89 |
| Round | 0.88 (0.79) | 562 (100) | 68 | 69 (21) | 10 | 88 |
| Toussaint | 1.23 (1.02) | 2582 (141) | 92 | 321 (81) | 16 | 88 |

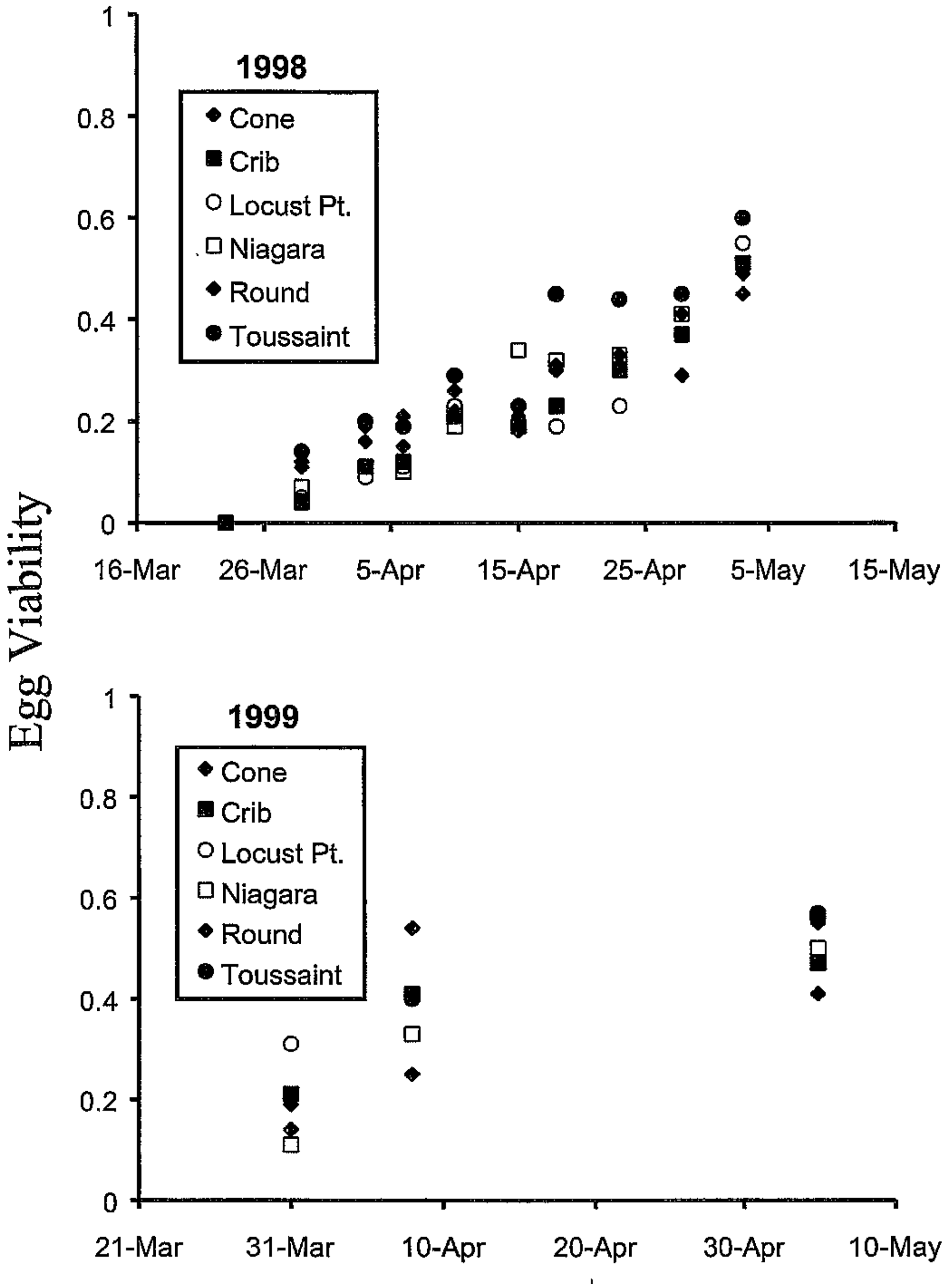


Figure 6. Walleye egg viability on reefs in western Lake Erie, 1998 and 1999.

# CONCLUSIONS

- The bedrock exposure areas of the reefs are smaller in area than was anticipated as indicated by the published literature (Herdendorf and Braidech, 1972).
- The morphology of each reef includes a small outcrop or group of outcrops of bedrock surrounded by high-relief cohesive clay that is often in turn surrounded by lower-relief cohesive clay. Usually the cohesive clay units are surrounded by a sandy mud/muddy sand unit, which is surrounded by a soft mud. The mud unit may not be seen if the coverage did not extend far enough from the reef center, or if mud was excluded between two reefs.
- The above sequence of substrates generally folows the pattern with increasing depth (bedrock is the shallowest).
- The bedrock acted as a boss for the glacier and the compressed glacial till has proved to be relatively resistant to erosion.
- Side scan sonar imagery was not adequate to estimate the distribution of Dreissenid mussels in areas of hard substrate.
- Dreissenid mussel coverage of the bottom can make visual substrate mapping difficult.
- Dreissenid mussel density trends range from high on the bedrock substrates to low on mud substrates. The exception was that in bedrock areas that were less than 3 meters deep, the mussel population was much lower.
- Dreissenid mussel density and trends are not constant from year to year.
- Walleye began spawning on mid-lake reefs in late March and early April and egg relative density on reefs typically peaked in mid-April. Spawning was concluded by early May.
- Spawning took place over the shallowest areas of reefs where substrates were composed of bedrock.
- Egg relative densities were highest on the tops of reefs earlyin the spawning period, but decreased due to wind and wave action that displaced eggs to deeper areas.

- The proportion of viable eggs on reefs increased over the incubation period as dead eggs were removed from reefs.
- Strong wind events and associated waves removed eggs from reefs.
- Deep areas of reefs better retained eggs due to reduced wave energy and more complex substrate morphology than shallow tops of reefs.

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