Michigan DNR

STATE OF MICHIGAN
DEPARTMENT OF NATURAL RESOURCES

Number 2049 October 29, 1998

Lake Herring Spawning Grounds of the St. Marys River with Potential Effects of Early Spring Navigation

David G. Fielder

FISHERIES DIVISION
RESEARCH REPORT

MICHIGAN DEPARTMENT OF NATURAL RESOURCES
FISHERIES DIVISION

Fisheries Research Report 2049
October 29, 1998

LAKE HERRING SPAWNING GROUNDS OF THE ST. MARYS RIVER WITH POTENTIAL EFFECTS OF EARLY SPRING NAVIGATION

David G. Fielder

DNR
Printed under authority of Michigan Department of Natural Resources
Total number of copies printed 200 — Total cost $348.23 — Cost per copy $1.74

Michigan Department of Natural Resources
Fisheries Research Report No. 2049, 1998

Lake Herring Spawning Grounds of the St. Marys River with Potential Effects of Early Spring Navigation

David G. Fielder

Michigan Department of Natural Resources
Alpena Great Lakes Fisheries Research Station
160 East Fletcher
Alpena, MI 49707-2344

Abstract.–The St. Marys River, which connects Lakes Superior and Huron, is one of the few strongholds of lake herring (*Coregonus artedi*) in Lake Huron. The river is also a thoroughfare for international shipping. Proposals to extend navigation by one week into the early spring raised concerns over the effects on lake herring hatch. Fundamental to assessing the risk is knowledge on location of lake herring spawning grounds. Variable mesh gill nets were fished late October to mid November 1993 through 1996 (128 net sets in all) in the study area between Izaak Walton Bay (above the locks) to lower Lake Munuscong. Lake herring were inspected for sex and maturity levels with the presence of ripe, partially spent and spent females as indicators of spawning activity. Catch rates of female lake herring in spawning condition were compiled in a geographic information system database (GIS) and expressed on 3-D graphic plots for visual inspection of important spawning grounds. A hydraulic flow model was used to predict the dispersion of the eggs from spawning grounds. Stranding of fish on the spring ice shelf by passing vessels was also monitored. Spawning lake herring were detected throughout most of the study area, however, three locations emerged as being of greater relative importance. They were Baie de Wasai vicinity of upper Lake Nicolet, Garden River vicinity, and upper Lake George. Multiple regression analysis failed to clearly link lake herring catch rate to physical characteristics of water velocity, depth, distance to the navigational channel and temperature. The flow model indicated that some areas of relative importance had less distance traveled by drifting eggs, however, there were exceptions and regression analysis of importance and distance traveled detected no significant relationship. The areas of least usage by spawning lake herring were the navigation channel and locks vicinity. Stranded fish on the spring ice shelf were documented from only two locations; the Dunbar area of Lake Nicolet and below the Rock Cut. During the two years of monitoring, strandings averaged only 0.5 fish per 100 m per vessel passage and occurred during a narrow time span. This study documented lake herring spawning grounds while a companion study examined the effect of vessel traffic on lake herring egg incubation in the field. Collectively, the results indicate that lake herring can achieve some successful spawning in St. Marys River despite navigation and ice-breaking operations as conducted during the study period which included a 25 March Soo Locks opener. Recommendations include making permanent the temporary speed limit reduction on the river as well as prohibiting any further channelization of the river.

St. Marys River is a connecting channel between lakes Superior and Huron. It is also a major thoroughfare for international shipping. The history of navigation and a description of the river's ecosystem can be found in Duffy et al (1987), Edsall and Gannon (1993), and Liston et al (1986). The fish community is described by Fielder and Waybrant (1998). Ships traversing the river must pass through locks located at Sault Ste. Marie, Michigan. The season for shipping on the upper Great Lakes is largely determined by extent of ice breaking operations and seasonal operation of the locks (U.S. Army Corps of Engineers 1989, U. S. Coast Guard 1996). Recently, it has been proposed to advance the navigation season in the spring by opening the locks on 25 March instead of 1 April (U.S. Army Corps of Engineers 1989).

It is well established that navigation by large vessels in a river environment can cause resuspension and drift of sediment (Gleason et al 1979a, Poe et al 1980, Bhowmik et al 1981, Poe and Edsall 1982, Hodek et al 1986, Holland 1986, Duffy et al 1987, U. S. Army Corps of Engineers 1989, Zabilansky et al 1992, Bhowmik et al 1994). Suspended sediments have the potential to affect a wide variety of aquatic organisms (Newcombe and MacDonald 1991). In the St. Marys River, the principle concern regarding resuspension of sediment due to spring navigation is its potential effect on reproduction of lake herring *Coregonus artedi*.

Another possible problem with early spring navigation is the phenomenon of fish strandings. The wakes of passing vessels and the subsequent back wash of water is known to strand fish on the shoreline ice shelf (Gleason et al 1979a, U.S. Army Corps of Engineers 1973). Stranded fish observed in the St. Marys River died due to either dehydration or bird predation. Fish strandings may be exacerbated by an earlier navigation season opener.

In response to concern over potential impacts of the proposed earlier opening date of navigation season, the U.S. Coast Guard implemented a 3.2 km/h vessel speed limit for a portion of the river (National Oceanic and Atmospheric Administration 1993). The speed limit reduction was specifically intended to minimize impacts on lake herring egg incubation and hatch, and on damage to shoreline wetland habitat.

Lake herring are classified as a state threatened species in Michigan (Latta 1995) although they are still abundant in most of Lake Superior. Their numbers have also declined throughout much of Lake Huron (Christie 1974). However, lake herring have persisted in the St. Marys River (Goodyear et al 1982, Liston et al 1986, Duffy et al 1987) and provide substantial sport (Rakoczy 1992) and commercial (Mohr and Gile 1996) fisheries. While lake herring use of the St. Marys River for spawning has been documented (MacDonald 1977, U.S. Fish and Wildlife Service 1977, Liston et al 1986), little is known about location of spawning grounds (Organ et al 1979, Goodyear et al 1982). Behmer et al (1979) and Gleason et al (1979b) attempted to identify spawning grounds in the river. Those studies used interviews with local anglers and some egg sampling to locate important areas. Behmer et al (1979) concluded that lake herring were spawning over a variety of substrate types in the river and documented the inherent difficulty in identifying lake herring spawning grounds in the St. Marys River.

In order to assess the potential impacts of the earlier navigation season, information was needed on where lake herring were spawning in the river and what effects vessel traffic had on incubating and hatching eggs (Liston et al 1986, U. S. Army Corps of Engineers 1989, Kavetsky 1993, Savino et al 1994). The objectives of this study were to identify important lake herring spawning grounds in St. Marys River, document and quantify the extent of fish strandings on the ice shelf, and describe the potential impacts of the proposed earlier start of the navigation season.

Methods

Spawning Ground Location

To locate lake herring spawning grounds, St. Marys River was sampled with gill nets during the spawning period in 1993 through 1996 (Table

1). In all, 128 overnight net sets were made during the study. Catch-per-unit-effort (CPUE) was standardized as number of lake herring per 91.4 m of net per night. Although mesh sizes were not entirely uniform among years, they did capture mature lake herring. All lake herring were evaluated for maturity. Females were scored as immature, gravid, ripe, partially spent, or spent. Males were scored as either immature or ripe. Catch-per-unit-effort of females was calculated according to the different maturity levels and also summarized into pooled categories such as all females or partially spent and spent females combined. Spawning activity was defined by the presence of ripe, partially spent and spent females.

The study area spanned from Isaak Walton Bay, above the locks to Rocky Point in Munuscong Bay (Figure 1). The actual vicinity sampled within the study area varied by year. Sampling in 1993 included the area from above the locks through Lake Nicolet to Munuscong Bay. Sampling in 1994 was limited to the area between the locks and Rocky Point. Sampling in 1995 covered the same area as 1994, but included areas around Sugar Island including Lake George. Finally, sampling in 1996 was again limited to the area between the locks and Rocky Point. Sampling in 1994 also included five net sets off of Peck Island in Potagannissing Bay. These sets were performed to collect specimens for comparison of biological data to the collections from the study area. Peck Island is effectively removed from the influence of navigation and was sampled to provide a comparison to biological data from those spawning congregations believed to be exposed to navigation. These comparisons were limited to 1994 data.

CPUE, calculated for both male and female lake herring, was organized into a C-Map Geographic Information System database (Center for Remote Sensing 1991). CPUE of female lake herring was further categorized by maturity level (gravid, ripe, partially spent, or spent). Gravid was defined as eggs still amassed and could not be emitted from the fish by squeezing. Ripe was defined as still possessing full ovaries but with eggs free running. Partially spent were females that upon internal inspection still possessed some free running eggs but were less voluminous than expected for full ovaries. Spent were mature females that no longer contained eggs. The fundamental assumption was made that the presence of ripe, partially spent and spent female lake herring indicated spawning activity and collection in close proximity to spawning grounds.

CPUE of the different sexes and maturity levels was then plotted on three dimensional abundance contour plots for visual interpretation of the relative importance of spawning areas. Determination of importance was limited to CPUE of ripe, partially spent and spent females. Relative importance or unimportance was assigned to portions of the study area based on the relative height of the peaks of the three dimensional plots. These peaks in most cases were amalgamations of the adjacent CPUE values. Thus, importance (or lack there of) was determined relative to all areas sampled within the study area during the four years of sampling. The label "important" was limited to the top three vicinities of spawning activity, moderate to the next three vicinities, and all others were labeled “low”. Three dimensional abundance plots were limited to 1994 through 1996 data for some groups.

To confirm that congregations of ripe, partially spent and spent female lake herring were in fact indicators of local spawning activity, egg sampling was performed in Baie de Wasai area of Lake Nicolet, below the Rock Cut, and in Munuscong Bay. Sampling in 1995 consisted of six tows with a 1-meter larval fish net (500 um) mesh towed near the bottom. Sampling in 1996 was conducted with an egg pump (Stauffer 1981). In all, six tows were performed in 1995 and 19 pumping samples in 1996.

The relationship of female CPUE to water depth, water velocity, distance to the navigation channel, and surface water temperature was analyzed by multiple regression. Temperature and depth were measured in the field. Distance to the channel was determined from National Oceanic and Atmospheric Administration navigation charts and water velocity from Shen et al (1998). Significance of certain variables in predicting lake herring CPUE was determined via multiple regression (Neter et al 1985) and performed using SPSS 8.0 software.

Transport of released eggs was predicted via a hydraulic flow model (Shen et al 1998). The model was an adaptation of the River Oil Spill Simulation (ROSS) Model (Shen et al 1986). This model predicts the transport and dispersion of liquids and particulates in a river and was specifically adapted to the St. Marys River. Twelve different prediction scenarios were conducted. All scenarios were based on 77,300 cfs total river discharge, which is considered typical for the St. Marys River (Qing Xu, Clarkson University, New York, personal communication). Output of model runs were graphic predictions of egg movement. Each case included water velocity and depth plots, which were necessary to interpret ending point. The model did not directly consider settling rates of fertilized, water hardened eggs and knowledge of the velocity, depth and substrate was necessary to interpret model predictions (H. T. Shen, Clarkson University, personal communication). Model runs (cases) were 20,000 eggs over 6-h scenarios. Six scenarios predicted egg transport from areas deemed as moderately important to important spawning sites. Six scenarios also predicted egg transport in areas of low importance as spawning sites. Starting location was selected based on results of gill netting and predictions of possible areas of importance (Figure 2). Graphics were visually inspected for ending point, distance traveled.

Lake Herring Biological Data

Lake herring collected by gill nets were measured for total length and weight and scales were collected for age analysis. Lake herring were internally inspected for maturity as described above, and were scored for visceral fat index (VFI) according to Goede (1989). Relative weight (Wr) was calculated according to Fisher and Fielder (in press). Means of biological data were compared between the study area samples and the samples from Peck Island in Potagannissing Bay (1994 data only) including length at age, age distributions, and sex ratios. Comparisons of means for biological data were performed with T-tests or Mann-Whitney U tests (Sokal and Rohlf 1981). Sex ratios were tested for association by area by Chi-square 2x2 contingency table analysis (Sokal and Rohlf 1981). All statistical tests were performed at $P\alpha=0.05$ and were conducted with SPSS 8.0 software.

Ice Shelf Strandings

The stranding of fish on the ice shelf was measured by monitoring shoreline stations at the beginning of the navigation season in 1995 and 1996. Five stations were monitored in 1995; Riverside Park, Nine Mile Point, Dunbar, Field Point and Rocky Point. Three stations were monitored in 1996; Riverside Park, Dunbar and below the Rock Cut. The stations were varying distances from the navigation channel allowing some measurement of the influence of the proximity to the channel on fish stranding. Vessel passage was monitored for speed, direction, length, load, and hull design. Also recorded was distance to the channel, ice shelf width and number and species of fish stranded. A total length of 100 m of ice shelf was monitored for stranded fish. The average number of fish stranded per 100 m of ice per vessel passage was calculated.

Results

Spawning Ground Location

A total of 2,927 lake herring were collected between 1993 and 1996. Ripe female CPUE is depicted in Figure 3 and partially spent and spent females in Figure 4. From these figures, it is apparent that the vicinities of upper Lake Nicolet (specifically the Baie de Wasai), Garden River, upper Lake George and immediately below the Rock Cut had the greatest concentration of spawning lake herring. Eggs were collected in Baie de Wasai (Lake Nicolet), below the Rock

Cut, and in central Lake Munuscong. In each case fewer than six eggs were collected. These eggs resembled lake herring eggs but were not hatched for confirmation. Presence of these eggs suggest that lake herring were spawning at the above sites. CPUE of all lake herring indicate larger distribution than spawning fish (Appendix 1) and female lake herring (Appendix 2).

Areas with a notable lack of spawning include the vicinity above the Locks, the river arm north of Sugar Island, east Neebish channel and the Lake George outlet. Southern Lake George was not sampled and can not be inferred to be insignificant. Southern Lake George, like some other areas of the river, was too shallow to be sampled with gill nets.

There was evidence of a spawning migration of lake herring in the study area. Sampling in 1994 spanned a longer period of time, allowing some examination of prespawn behavior. By examining female CPUE by week, a progression is apparent from south to north up the river (Figure 5). Gravid female CPUE in 1994 and again in 1995 reflected an abundance of lake herring in central Lake Munuscong (Figure 6) although abundance of spawning females was low in the area (Figures 3 and 4).

There were no significant relationships between lake herring CPUE and water depth, water velocity, distance to channel, or temperature. Problems with collinearity eliminated some variables. Of the independent variables examined, only depth provided a regression slope that was significantly different from zero. Analysis revealed an inverse relationship between depth and female herring CPUE.

Figure 7 summarizes the egg transport model prediction for Baie de Wasai, a spawning area of high importance. By contrast, Figure 8 summarizes the model prediction for the channel below the locks, a spawning area of low importance. Distance of transport varied between areas from a high of 9,000 m to a low of 200 m. Distance transported is summarized in Table 2 with relative importance also indicated. A regression of distance traveled versus relative importance found no significant relationship.

Lake Herring Biological Data

Lake herring collected in the river and those from Potagannissing Bay differed significantly only in VFI and sex ratio (Table 3). The lake herring populations in St. Marys River and Potagannissing Bay have experienced at least some recruitment each year since 1979 (Table 4). Age distributions for both locations are similar suggesting comparable production and recruitment patterns (Table 4). Significant differences in mean length at age between the river and Potagannissing Bay were found for five ages. In each instance, mean length at age was greater in the river than in Potagannissing Bay. Length at age was greater than the state average (Merna et al 1981) for most ages. Sex ratios of spawning lake herring varied significantly from 0.8 males per female (1995) to 2.8 males per female (week 3, 1994) (Table 5).

Ice Shelf Standings

A total of 17 vessel passages were monitored in 1995 and 11 in 1996 (Table 6). Average speed of the vessels were within speed limits except for up bound traffic at Riverside Park in 1995 and traffic below Rock Cut in 1996. Stranded fish were only observed at Dunbar and below the Rock Cut. An average of 0.5 fish per passage was stranded along 100 m of ice shelf during 1995-96 (Table 6). Five different species of fish were stranded. They were minnows (Cyprinidae) (50%), yellow perch *Perca flavescens* (25%), white sucker *Catostomas commersoni* (12%), rockbass *Amblopites rupestris*, and sculpins *Cottus* sp. each at 6%. No under-ice mortality was observed.

Discussion

Lake herring spawn in a variety of locations throughout the St. Marys River, but four emerged as the most widely used; Baie de Wasai, Garden River, upper Lake George and below the Rock Cut. Despite the collection of eggs in central Lake Munuscong and the abundance of male and gravid females there, that location appears only to be important as a staging area or migration route with minimal spawning. However, this and other less widely used areas of the river may collectively produce significant numbers of lake herring larvae. As concluded by Behmer et al (1979), the presence of spawning lake herring throughout the study area reflects their lack of preference for any particular bottom substrate. The failure of regression analysis to identify relationships between CPUE of spawning fish and various physical characteristics is attributed to the wide dispersion of spawning lake herring and their broadcast spawning behavior.

Examination of egg movement based on model predictions indicates that lake herring eggs are potentially widely dispersed by flows of the St. Marys River. The vicinity immediately below Baie de Wasai was the most consistently important spawning ground documented. That area was predicted to have eggs move slowly in a relatively tight mass along the western shoreline of Sugar Island. By comparison, one of the least used areas was the swift navigation channel area immediately below the locks. Simulation of that area showed eggs to move quickly and a long distance (9 km). Even after six hours, eggs from that scenario were still in the navigation channel. Such movement could leave lake herring eggs more vulnerable to predation and physical damage. However, there were other areas of importance and moderate importance for spawning that had long transport distances such as the Garden River (6 km) and below the Rock Cut (4 km). Regression analysis failed to reveal a significant relationship between distance traveled and relative importance. One factor determining successful reproduction may be substrate that eggs finally settle upon.

Previous work has also suggested the Baie de Wasai area or upper Lake Nicolet to be important to spawning lake herring (Behmer et al 1979, Gleason et al 1979b, Jude et al 1988). That vicinity was sufficiently distant from the navigation channel as to have no observable effect from passing vessel traffic. Upper Lake George, likewise, was effectively removed from the influence of vessel traffic. The lower Rock Cut area, however, is in close proximity to the navigation channel. That area is comprised of large cobble (spoils from the cut) and the resulting large interstitial spaces may allow the retention of lake herring eggs despite the possible effects of passing vessels.

Comparisons of biological data between the study area and Potagannissing Bay indicate that spawning populations in the St. Marys River are similar to those far removed from the effects of navigation. Although mean VFI and sex ratios were significantly different statistically, their significance does not appear to indicate substantial difference in the overall status of each population. The higher VFI in the river population may indicate they are below some adult carrying capacity. Mean Wr, another expression of condition, however, was not significantly different. Growth, as indicated by mean length at age was significantly greater for lake herring spawning in the river compared to those in Potagannissing Bay. Although both growth rates exceeded the state average, their existence below some adult carrying capacity, may be more pronounced in the river. Fielder and Waybrant (1997) also examined lake herring growth and condition of lake herring from both locations and similarly found them to be above average and at excellent levels, respectively.

Skewed sex ratios can be indicative of a lake herring population in decline or under stress (Bowen et al 1990, Clady 1967). Neither the St. Marys River nor Potagannissing Bay lake herring sex ratios were exactly 1:1 and neither were characteristic of populations near collapse (Bowen et al 1990, Smith 1956). Lake herring sex ratios can vary with several different factors related to sampling including timing and gear selection (Hoff and Serns 1983, Smith 1956). The minor deviations from 1:1 observed in this study were likely due to differences between the sexes in staging and timing of arrival on the spawning grounds.

Biological similarity of the populations in the river and the bay is demonstrated further by the age structure of the spawning lake herring. The age frequency indicates that both areas have experienced at least some recruitment since 1979. The age structure was very similar in pattern between both locations indicating that the presence of navigation (as conducted since 1979) has not prevented recruitment to the St. Marys River.

Stranding of fish on the ice shelf does not appear to be a substantial source of mortality for fish in the St. Marys River, and not at all for lake herring. While monitoring was able to directly attribute fish loss to ice strandings from vessel passage, the phenomenon appears limited to a relatively small geographic area and a narrow window of time. Spring conditions varied between study years with 1995 an unseasonably warm and fast ice-out, while 1996 was cold and slow ice-out. In each year, however, shoreline ice in the Dunbar area receded suddenly, typically fragmenting with ice flows transported downstream. Vessel passage in the Dunbar area, and to a lesser extent below the Rock Cut area, has a pronounced effect even in the absence of ice. In the Dunbar vicinity, large areas of shoreline were completely dewatered by the draw down effect of passing freighters and then quickly flooded again by the following wash-back. Apparently the morphology of the shallow river bottom in the Dunbar area, in close proximity to the navigation channel, combine to make this area particularly vulnerable to stranding. Poe et al (1980) examined the effects of ship induced waves in an ice environment in St. Marys River, although increased turbidity and drift was documented, no strandings or under ice crushing was observed. Hodek et al (1986) reported that the draw down effect is extremely sensitive to vessel speed, position in the channel and to a lesser degree, ice thickness.

For lake herring, the best measure of impact by early spring shipping may be the direct field measurements of lake herring egg survival and hatch in close proximity to the navigation channel done by Savino et al (1994) and Blouin et al (1996). Both studies documented good hatch rates for lake herring eggs in incubators left in most locations over winter. These studies reported the best hatch in areas free of fine sediment or areas removed from the resuspension effect of passing vessels. These studies included exposure to not only vessel traffic, but ice breaking operations as well. Kavetsky (1993), however, complained that Savino et al (1994) placed incubators in unlikely locations of high flows, keeping them sediment free. Incubators may have also prevented resuspension and transport of eggs to areas of higher sedimentation. However, Savino et al (1994) illustrated via lab studies that lake herring eggs could incubate, hatch and feed at levels of turbidity measured in the river. Similarly, Swenson and Matson (1976) documented good survival of lake herring larvae in varying degrees of turbidity. Given the results of these studies and that lake herring were not spawning in channelized portions of the river except where substrate was comprised of rock cobble, it is concluded that successful lake herring spawning could occur in the presence of navigation and ice breaking operations, as conducted during the study period of 1993 through 1996.

It is important to acknowledge, however, that these findings do not indicate that the lake herring population or the aquatic community in general in St. Marys River has been free of diminishment as a result of historic alterations and navigation in general. Little data exists as to historic lake herring abundance in the St. Marys River, however, whitefish supported a substantial fishery (Duffy et al 1987, Edsall and Gannon 1993). The construction of the Soo locks and dockage in Sault Ste. Marie has greatly reduced historic fish spawning and nursery habitats (Koshinsky and Edwards 1983, Kauss 1991). Channelization has also affected the aquatic community of the St. Marys River (Edwards et al 1989, Bray 1993) as well as dredging (Liston et al 1980). Lake herring growth rate comparisons of this study and those reported by Fielder and Waybrant (1997) indicate the lake herring population size may exist below the adult carrying capacity. Winter and early spring navigation and ice breaking operations may also have serious impacts on large land mammals (Robinson and Fuller 1980, U.S. Army Corps of Engineers 1989), waterfowl and raptors (Robinson and Jensen 1980, Davis and Erwin 1982), wetlands (Williams and Lyon 1991) and shoreline structures (U.S. Army Corps of Engineers 1989).

Recommendations

(1) Because it is not fully clear what habitat characteristics are most desirable to spawning lake herring in the St. Marys River, the effects of further alteration of river habitat on lake herring reproduction would be difficult to predict. Therefore, it would be prudent to discourage further alterations of the river habitat. This includes further water diversion, channel construction, and any dredging beyond channel maintenance. Because the deposition of dredge spoils have the ability to alter hydraulic flows in the St. Marys River, future maintenance dredging should deposit spoils on land as opposed to in the water.

(2) These findings are specific to the time period of the study and can only be inferred for the conditions in place at that time. This includes the speed limit reductions of 3.2 km/h as described by U.S. Coast Guard (1994). Speed limits also are the best means to minimize the stranding of fish on the ice shelf. Consequently, it is recommended that the speed limit reductions in place during the study be institutionalized and enforced.

Acknowledgments

The author wishes to express his appreciation to the following individuals and organizations. Kenneth Gebhardt and other fisheries staff of Bay Mills Indian Community assisted with the field work. Tom Gorenflo, Mark Ebener and the other staff at the Chippewa/Ottawa Treaty Fishery Management Authority provided storage, lab space and other assistance. The U.S. Coast Guard and the U.S. Army Corps of Engineers provided dockage and other support. Dr. Hung Tao Shen and Dr. Qing Xu of the Department of Civil and Environmental Engineering at Clarkson University performed the egg transport model predictions based on their St. Marys River flow model. Yung-Tsung Kang and the other staff of the Center for Remote Sensing, Michigan State University compiled the C-Map GIS database and produced the 3-D plots. Jim Diana of The University of Michigan and Jim Peck of the MDNR provided editorial services. The author also wishes to specifically acknowledge the contributions of MDNR fisheries staff at the Institute for Fisheries Research (Roger Lockwood), Newberry (Steve Scott, Jim Waybrant, Chuck Payment, Frank Kolson), and the Alpena Great Lakes Fisheries Research Station (James Johnson, Bill Cross, Clarence Cross, Steve Dewitt, Jeff Diemond, and Debby MacConnell).

Report approved Richard D. Clark, Jr.
James S. Diana, Editor
Alan D. Sutton, Graphics
Barbara A. Diana, Word Processor
Ellen S. Grove, Desktop Publishing

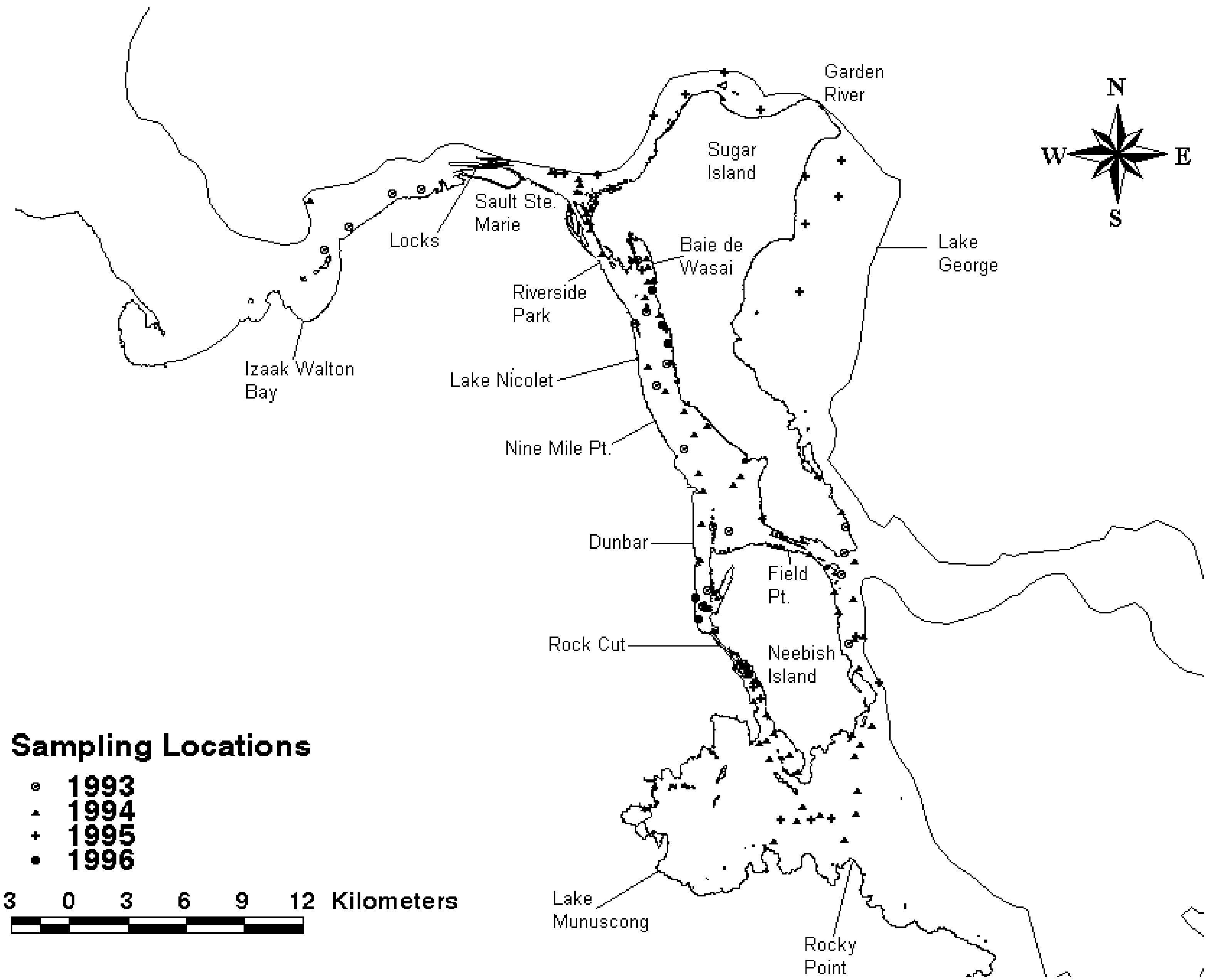


Figure 1.-Gill net sampling locations for St. Marys River 1993 through 1996.

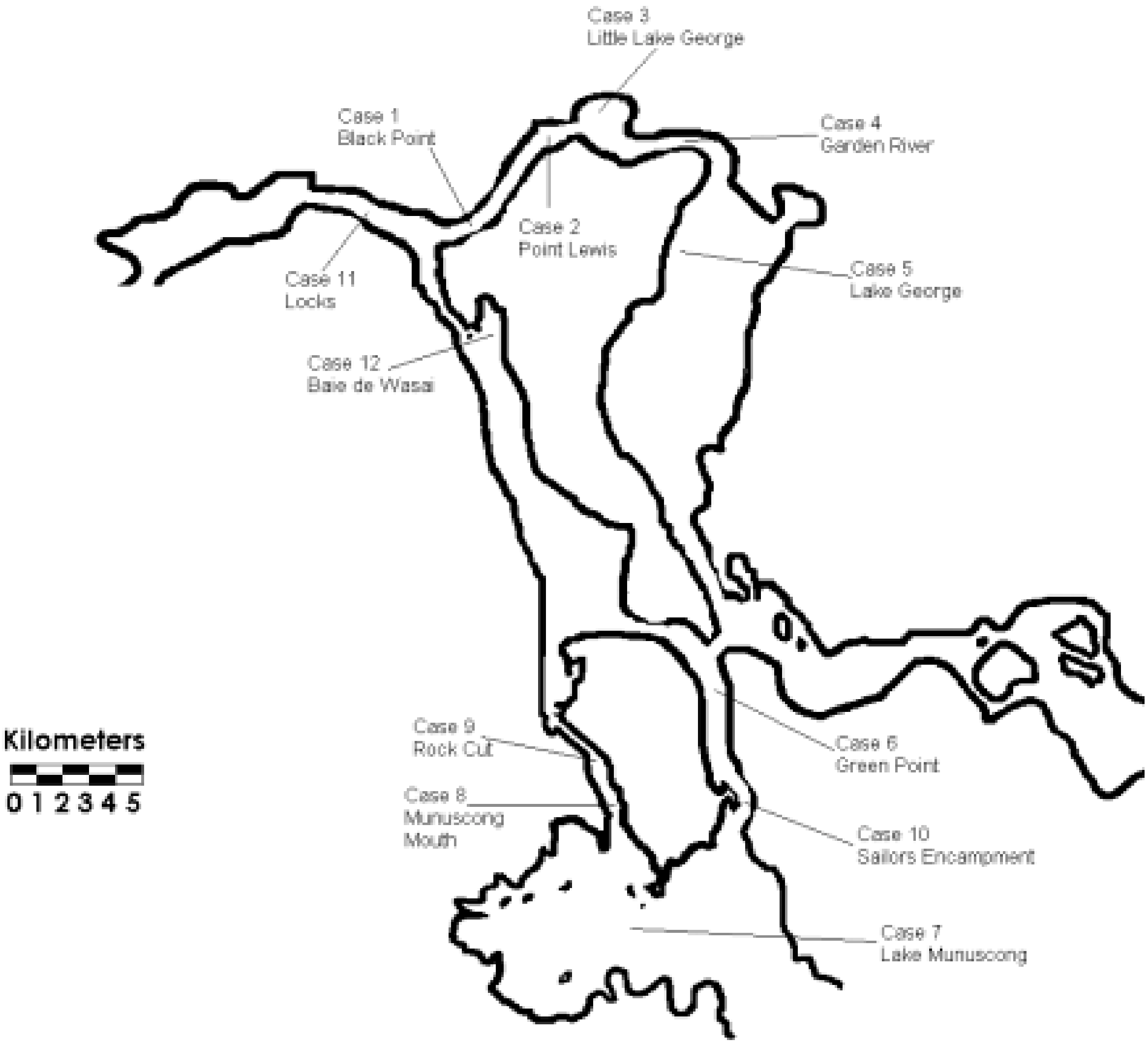


Figure 2.–Locations of egg transport model predictions. Cases 4, 5, & 12 are high importance areas, cases 1, 7 & 8 are moderate importance, and all others are low importance.

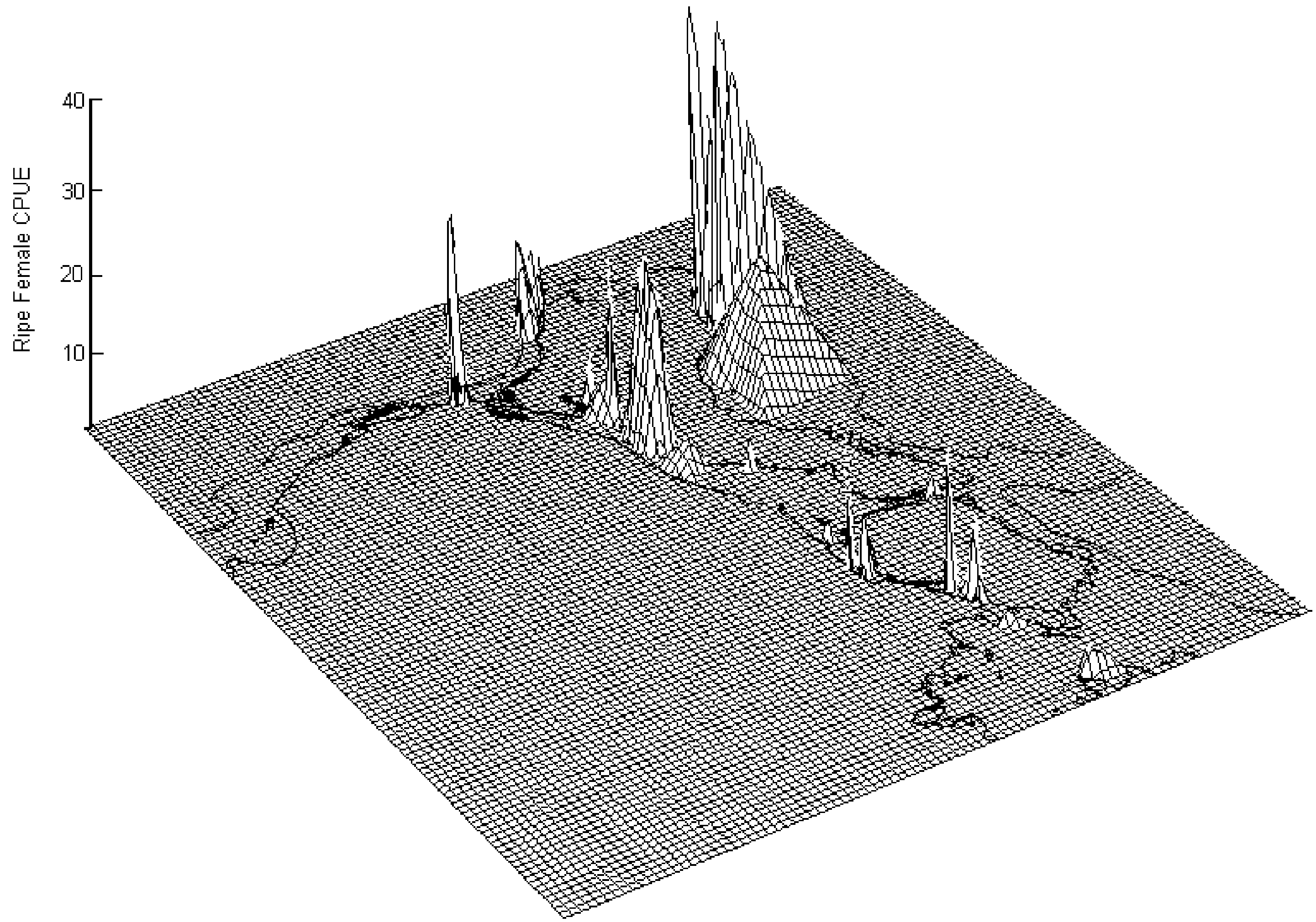


Figure 3.-Number of ripe female lake herring per 91.4 m of gill net (CPUE) captured at sampling locations in St. Marys River, 1994 through 1996.

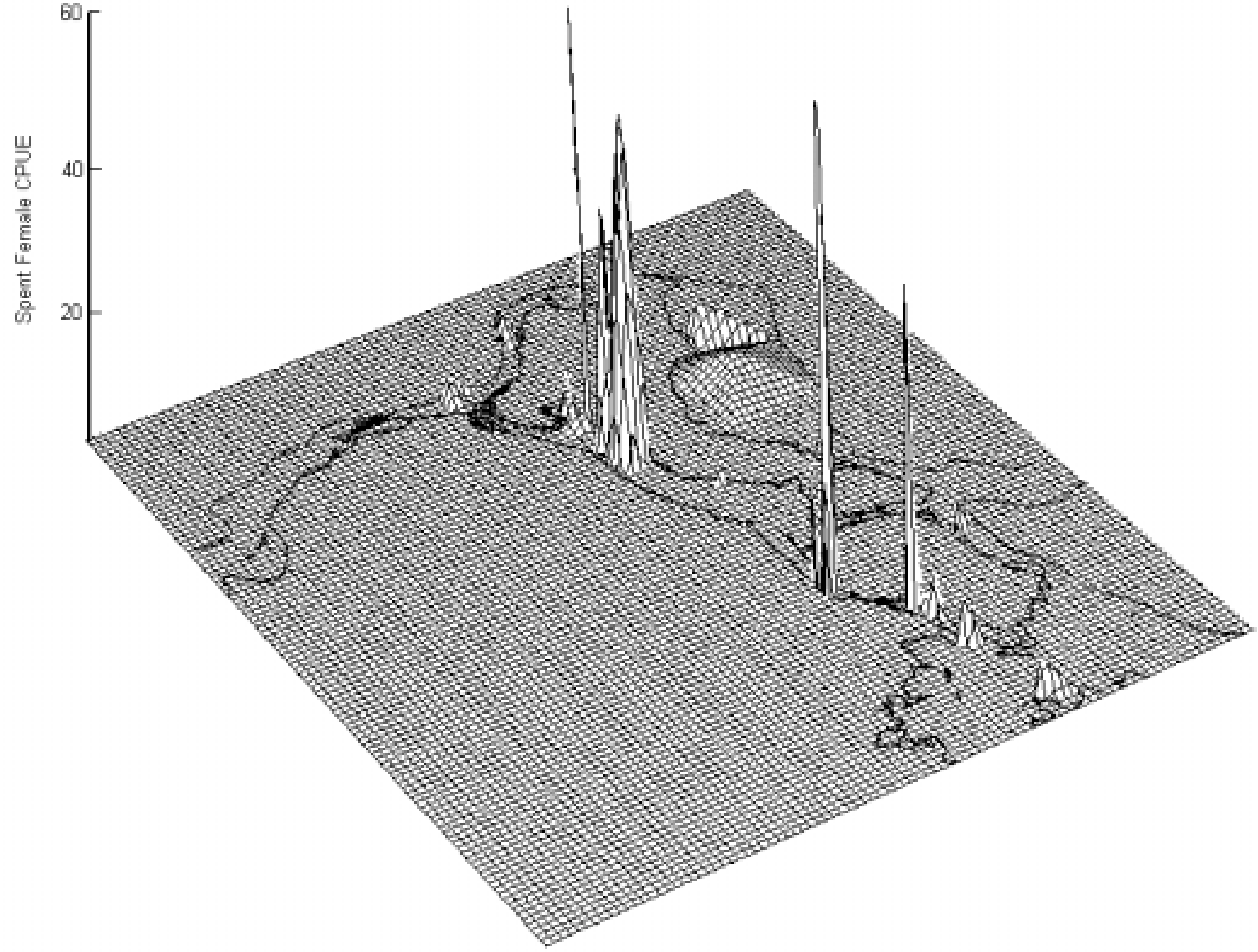


Figure 4.-Number of partially spent and spent female lake herring per 91.4 m of gill net (CPUE) captured at sampling locations in St. Marys River, 1994 through 1996.

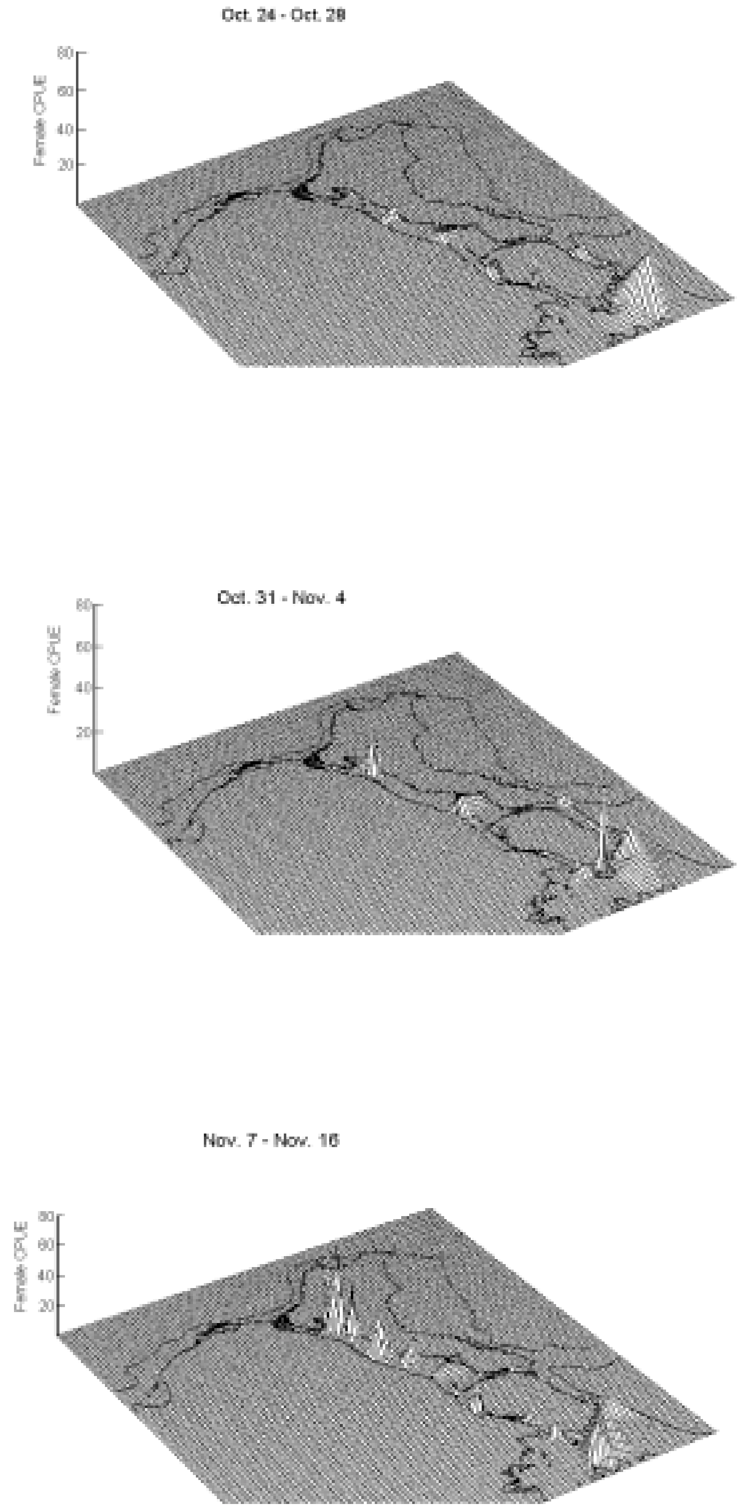


Figure 5.-Number of female lake herring (maturity levels combined) per 91.4 m of gill net (CPUE) captured at sampling locations by week in St. Marys River, 1994.

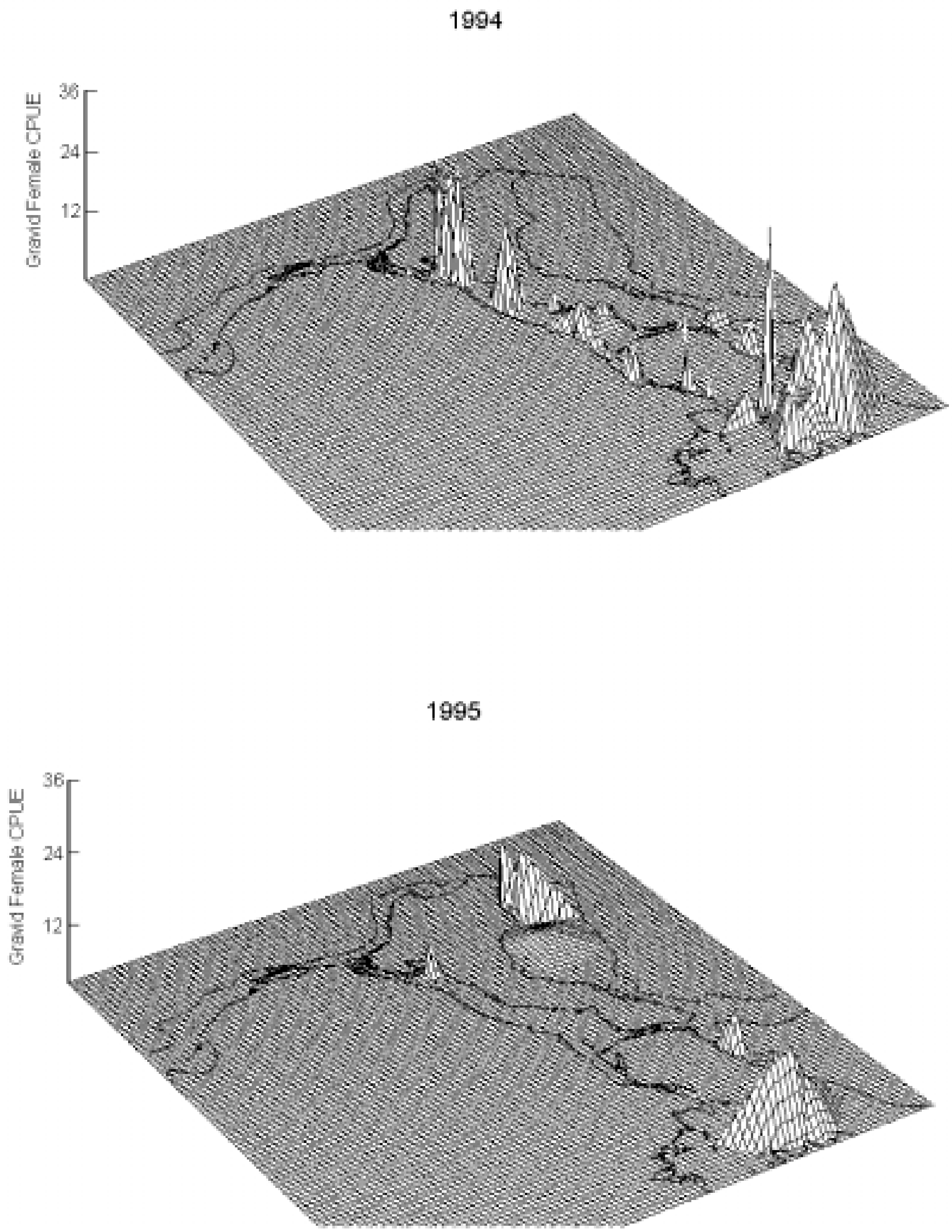


Figure 6.-Number of gravid female lake herring per 91.4 m of gill net (CPUE) captured at sampling locations in St. Marys River, 1994 and 1995.

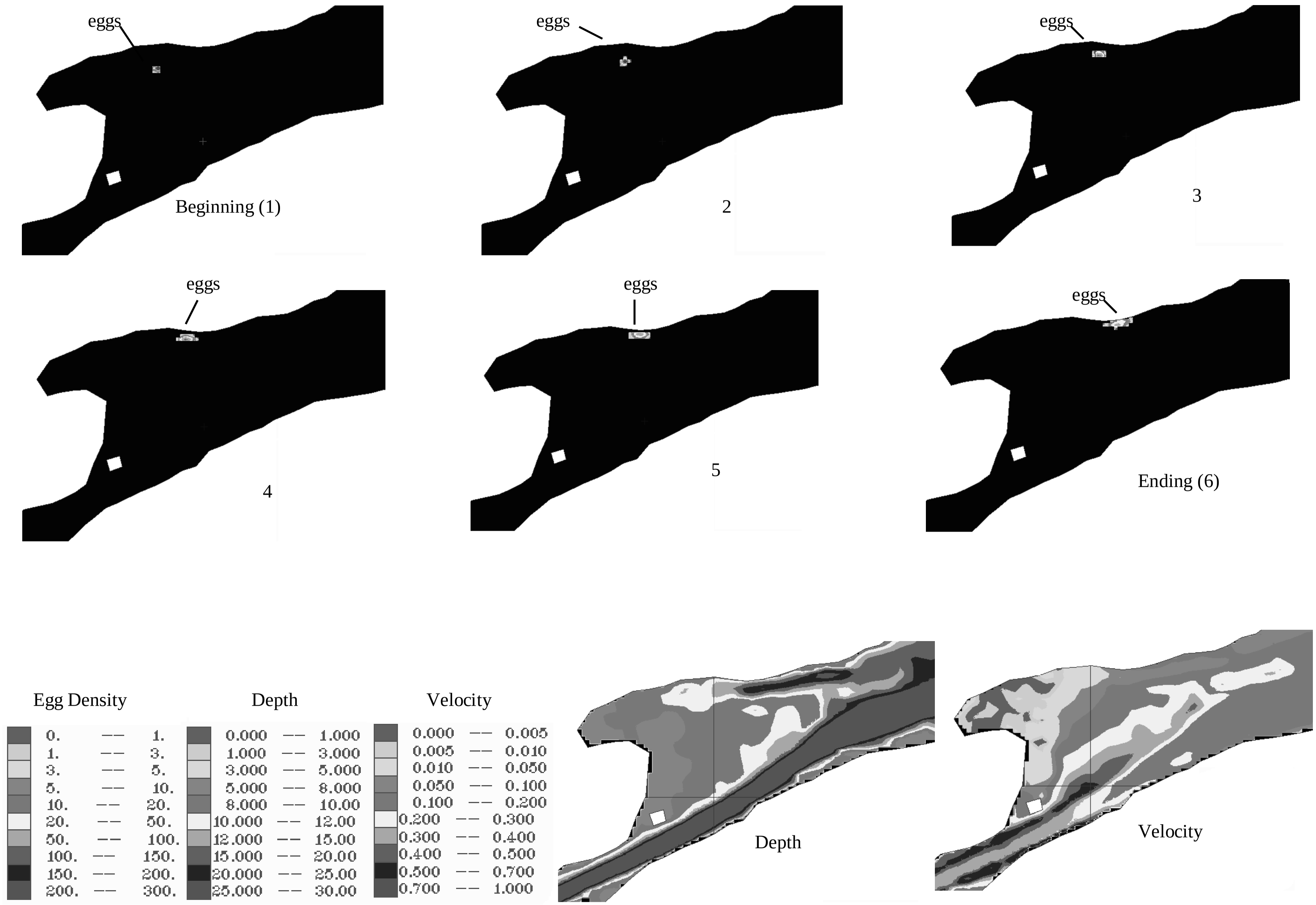


Figure 7. Six hour egg transport prediction for the Baie de Wasai vicinity (a high importance area). Distance traveled by egg mass was 1,200 m. Egg density is in eggs/m^2, velocity in m/s, and depth in m.

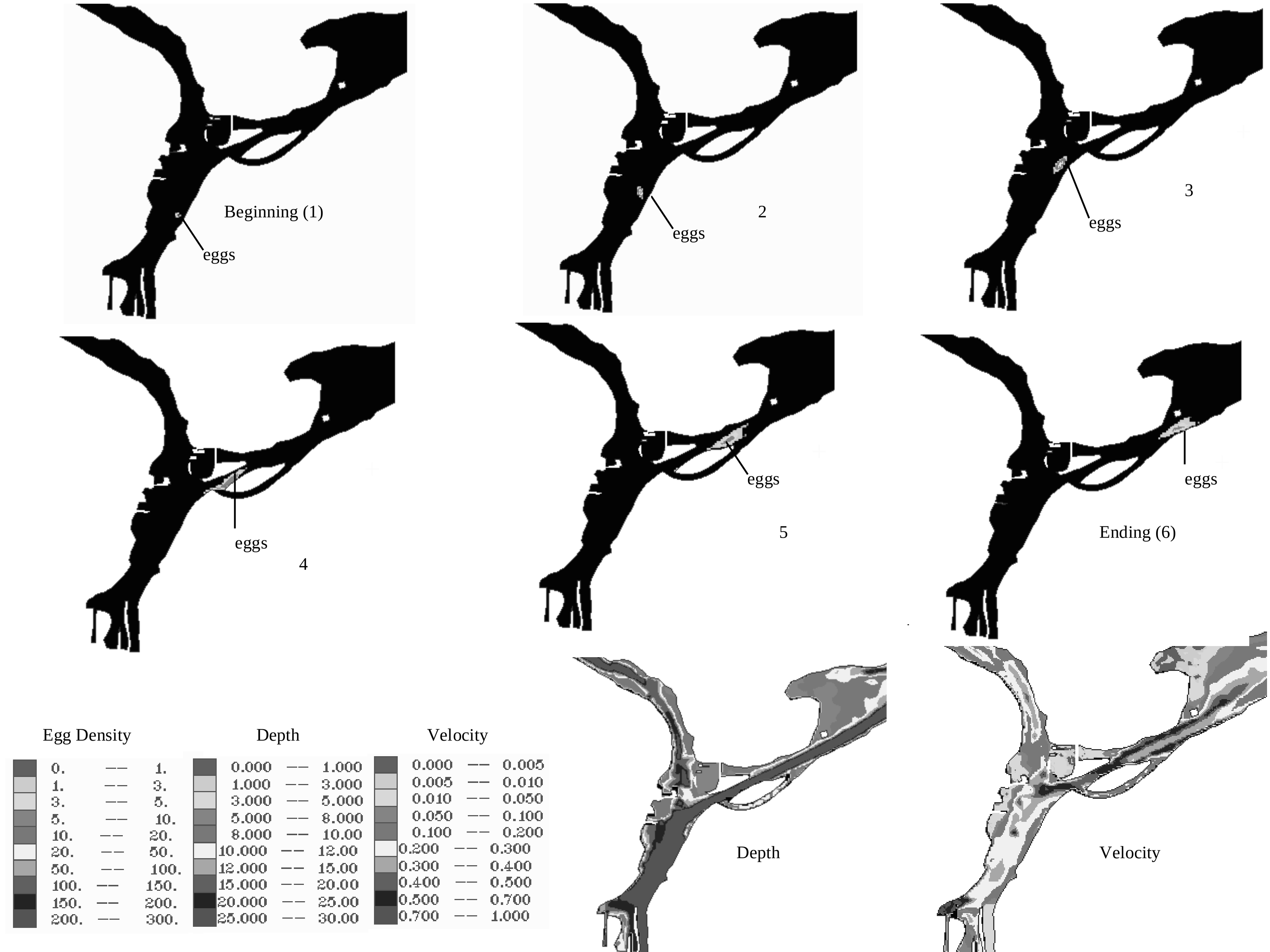


Figure 8.–Six hour egg transport prediction for the Locks area (a low importance area). Distances traveled by egg mass was 9,000 m. Egg density is in eggs/m^2, velocity in m/s, and depth in m.

Table 1.–Gill net effort summary for upper St. Marys River (Isaak Walton Bay to Rocky Point, Lake Munuscong) 1993 through 1996, with Potagannissing Bay (1994) included for comparison of some parameters. Mesh sizes are stretch measure. Net sets each year did not necessarily include all mesh sizes listed.

Year	Location	Sampling period	N	Mesh sizes (mm)	Panel lengths (m)
1993	River	Nov. 10 - Nov. 19	20	57, 64, 76, 114	91.4
1994	River	Oct. 24 - Nov. 15	75	51, 64, 76, 89	15.2
1994	Potagannissing Bay	Oct. 24 - Nov. 15	5	51, 64, 76, 89	30.5
1995	River	Nov. 6 - Nov. 10	22	51, 64, 76, 89	30.5
1996	River	Nov. 6 - Nov. 12	6	64, 76, 89	15.2
Total			128		

Table 2.–Egg transport model predictions of distance traveled and relative importance as a lake herring spawning ground for each simulation site in St. Marys River.

Location	Case number	Distance traveled (m)	Relative importance
Black Point	1	5,400	moderate
Point Lewis	2	4,400	low
Little Lake George	3	200	low
Garden River	4	6,000	high
Lake George	5	200	high
Green Point	6	2,800	low
Central Lake Munuscong	7	1,600	low
Lower West Neebish	8	2,400	moderate
Below Rock Cut	9	4,000	moderate
Sailor’s Encampment	10	3,600	low
Below Locks	11	9,000	low
Baie de Wasai	12	1,200	high

Table 3.–Means (SE) for various biological statistics measured for lake herring from St. Marys River study area (Issak Walton Bay to Rocky Point, Lake Munuscong) and Potagannissing Bay, 1994. An asterisk (*) indicates statistics are significantly different between sites ($P\alpha \leq 0.05$).

	Upper St. Marys River		Potagannissing Bay	
Statistic	N	Mean (SE)	N	Mean (SE)
Age (yr.)	338	7.9 (0.2)	246	8.2 (0.2)
Length (mm)	1,122	367 (1)	407	370 (2)
Weight (g)	998	545 (6)	393	552 (9)
Relative weight	998	91.9 (0.4)	393	91.4 (0.4)
Visceral fat index*	993	1.89 (0.04)	403	1.46 (0.07)
Male:female ratio*	1,442	1.9:1.0	392	1.2:1.0

Table 4.–Mean length (SE) in mm and percent frequency at age for lake herring sampled from the study area (upper St. Marys River) and Potagannissing Bay, October through November 1994. An asterisk (*) after the age indicates mean lengths are significantly different between sites (Pα≤0.05).

	St. Marys River			Potagannissing Bay			
Age	N	%	Length	N	%	Length	State average length
2	2	0.6		3	1.2		
3	57	16.9	321 (4)	24	9.8	314 (4)	274
4	14	4.1	333 (10)	36	14.6	336 (3)	300
5	14	4.1	350 (7)	22	8.9	348 (4)	328
6	23	6.8	367 (5)	11	4.5	357 (4)	353
7*	32	9.5	386 (4)	14	5.7	358 (7)	381
8*	42	12.4	380 (4)	16	6.5	363 (6)	406
9*	38	11.2	392 (2)	20	8.1	381 (3)	
10	38	11.2	398 (3)	21	8.5	388 (3)	
11	22	6.5	396 (6)	26	10.6	390 (4)	
12*	28	8.3	417 (2)	24	9.8	404 (4)	
13*	19	5.6	411 (4)	10	4.1	396 (6)	
14	5	1.5	407 (4)	6	2.4	388 (8)	
15	2	0.6		6	2.4	414 (7)	
16	0	0.0		4	1.6		
17	2	0.6		2	0.8		
18	0	0.0		1	0.4		
Total	338	100.0		246	100.0		

Table 5.–Sex ratio (male:female) of lake herring from St. Marys River study area (Issak Walton Bay to Rocky Point, Lake Munuscong) 1994-96. Week 1 was Oct. 24-28, week 2 was Oct. 31-Nov. 4, week 3 was Nov. 7-11, and week 4 was Nov. 14-16.

Year or week	N	Sex ratio
1994 week 1	187	1.2:1.0
week 2	435	1.8:1.0
week 3	637	2.8:1.0
week 4	183	0.9:1.0
1994 total	1,442	1.9:1.0
1995 total	504	0.8:1.0
1996 total	234	1.4:1.0

Table 6.–Summary of ice shelf strandings of fish resulting from vessel passage in St. Marys River study area during the beginning of navigation in 1995 and 1996.

Location	Number. of passages	Speed limit (km/h)	Average speed (km/h)	Ice shelf width (m)	Average stranded (fish/passage)
1995					
Riverside Park	4	12.9 up	20.6 up	6.1	0.0
		16.1 down	13.2 down		
Nine Mile	7	19.3	15.0	86.6	0.0
Dunbar	4	12.9	10.6	12.5	0.5
Field Point	1	12.9	10.3	4.6	0.0
Rocky Point	1	none	14.6	3.0	0.0
Total	17				0.1
1996					
Riverside Park	2	12.9 up	15.3 down	6.1	0.0
		16.1 down			
Dunbar	5	12.9	10.6	5.9	0.6
Below Rock Cut	4	12.9	15.1	8.0	0.5
Total	11				0.4

References

Behmer, D. J., G. R. Gleason, and T. Gorenflo. 1979. Identification and evaluation of lake whitefish and herring spawning grounds in the St. Marys River area. U. S. Army Corps of Engineers Contract No. DACW35-80-M-0193, Detroit.

Bhowmik, N. G., J. R. Adams, A. P. Bonini, C. Guo, D. J. Kisser, and M. A. Sexton. 1981. Resuspension and lateral movement of sediment by tow traffic on the upper Mississippi and Illinois rivers. Illinois Institute of Natural Resources, State Water Survey Division, Contract Report 269, Champaign.

Bhowmik, N. G., T. Soong, and R. Xia. 1994. Hydrodynamic effects of navigation traffic in large rivers. Pages 439-447 *in* H. Cheong, N. J. Shankar, E. Chan, and W. Ng, editors. Proceedings of the Ninth Congress of the Asian and Pacific Division of the International Association for Hydraulic Research, Developments in hydraulic engineering and their impact on the environment, Volume 2. Reprinted by the National Biological Survey, Environmental Management Technical Center, LTRMP 94-R012, Onalaska.

Blouin, M. A., M. J. Kostich, T. N. Todd, and J. F. Savino. 1996. The reproductive success of lake herring in habitats near shipping channels and ice-breaking operations. National Biological Service, Completion Report, Ann Arbor.

Bowen, S. H., D. J. D'Angelo, S. H. Arnold, M. J. Keniry and R. J. Albrecht. 1990. Density-dependent maturation, growth, and female dominance in lake superior lake herring (*Coregonus artedii*). Canadian Journal of Fisheries and Aquatic Sciences 48:569-576.

Bray, K. 1993. Preliminary inventory and evaluation of littoral habitat in the St. Marys River area of concern. Ontario Ministry of Natural Resources, Owen Sound.

Center for Remote Sensing. 1991. C-MAP computer mapping, display, and analysis version 2.1 user's manual. Michigan State University, East Lansing.

Christie, W. J. 1974. Changes in the fish species composition of the Great Lakes. Journal of the Fisheries Research Board of Canada 31:827-854.

Clady, M. D. 1967. Changes in an exploited population of the cisco, *Coregonus artedii* Le Sueur. Papers of the Michigan Academy of Science, Arts, and Letters, Vol. LII: 85-99.

Davis, T. E., and R. M. Erwin. 1982. Potential impacts of extended winter navigation upon migratory birds of the upper U. S. Great Lakes. FWS/OBS-82/51 and U. S. Army Corps of Engineers Contract No. NCE-IS-78-31.

Duffy, W. G., T. R. Batterson, and C. D. McNabb. 1987. The St. Marys River, Michigan: an ecological profile. U. S. Fish and Wildlife Service, Biological Report 85.

Edsall, T. A. and J. E. Gannon. 1993. Profile of the St. Marys River. MICHU-SG-93-700, Michigan Sea Grant College Program, Ann Arbor.

Fielder, D. G., and J. R. Waybrant. 1998. Fish population surveys of St. Marys River, 1975-1995, and recommendations for management. Michigan Department of Natural Resources, Fish-eries Research Report 2048, Ann Arbor.

Fisher, S. J., and D. G. Fielder. In press. A standard weight evaluation to assess the condition of North American lake herring (*Coregonus artedi*). Journal of Freshwater Ecology.

Gleason, G. R., D. J. Behmer, and K. L. Vincent. 1979a. Evaluation of benthic dislocation due to pressure waves initiated by vessel passage in the St. Marys River. Unpublished Report, Lake Superior State College, Sault Ste. Marie.

Gleason, G. R., D. J. Behmer, and R. Hook. 1979b. Evaluation of lake whitefish and herring spawning grounds as they may be affected by excessive sedimentation induced by vessel entrapment due to the ice environment within the St. Marys River system. U. S. Army Corps of Engineers Contract No. DACW-35-79-M-0561.

Goede, R. W. 1989. Fish health/condition assessment procedures, part 1. Utah Division of Wildlife Resources, Fisheries Experiment Station, Logan.

Goodyear, C. D., T. A. Edsall, D. M. Ormsby Dempsey, G. D. Moss, and P. E. Polanski. 1982. Atlas of the spawning and nursery areas of Great Lakes fishes: volume III, St. Marys River. U. S. Fish and Wildlife Service, FWS/OBS-82/52.

Hodek, R. J., M. D. Annable, G. R. Alger, and H. S. Santeford. 1986. Development of a predictive model to assess the effects of extended season navigation on Great Lakes connecting waters. Final Report for U. S. Army Corps of Engineers Contract No. DACA89-85-k-0001.

Holland, L. E. 1986. Effects of barge traffic on distribution and survival of ichthyoplankton and small fishes in the upper Mississippi River. Transactions of the American Fisheries Society 115:162-165.

Jude, D. J., M. Winnell, M. S. Evans, F. J. Tesar, and R. Futyma. 1988. Drift of zooplankton, benthos, and larval fish and distribution of macrophytes and larval fish in the St. Marys River, Michigan, during winter and summer, 1985. The University of Michigan, Great Lakes Research Division, Special Report No. 124, Ann Arbor.

Kauss, P. B. 1991. Biota of the St. Marys River: habitat evaluation and environmental assessment. Hydrobiologia 219:1-35.

Kavetsky, R. T. 1993. Biological resources at risk from the proposed opening, prior to 1 April, of the locks at Sault Ste. Marie, Michigan. U. S. Fish and Wildlife Service. Final fish and wildlife coordination act report, East Lansing.

Koshinsky, G. D., and C. J. Edwards. 1983. The fish and fisheries of the St. Marys Rapids: an analysis of status with reference to water discharge, and with particular reference to "condition 1.(b)". International Joint Commission, Great Lakes Region, Detroit.

Latta, W. C. 1995. Distribution and abundance of lake herring (*Coregonus artedi*) in Michigan. Michigan Depart-ment of Natural Resources, Fisheries Research Report 2014, Ann Arbor.

Liston, C. R., C. D. McNabb, D. Brazo, J. Bohr, J. Craig, W. Duffy, G. Fleischer, G. Knoecklein, F. Koehler, R. Ligman, R. O'Neal, M. Siami, and P. Roettger. 1986. Limnological and fisheries studies of the St. Marys River, Michigan, in relation to proposed extension of the navigation season, 1982 and 1983. Office of Biological Services, U. S. Fish and Wildlife Service, U. S. Department of Interior, Biological Report 85(2), Twin Cities, Minnesota.

Liston, C. R., W. G. Duffy, D. E. Ashton, C. D. McNabb, and F. E. Koehler. 1980. Environmental baseline and evaluation of the St. Marys River Dredging. U. S. Fish and Wildlife Service, FWS/ OBS 80/62.

MacDonald, G. A. 1977. The Saulteur-Ojibwa fishery at Sault Ste. Marie, 1640-1920 M. A. Thesis, University of Waterloo, Waterloo, Ontario.

Merna, J. W., J. C. Schneider, G. R. Alexander, W. D. Alward, and R. L. Eshenroder. 1981. Manual of fisheries survey methods. Michigan Department of Natural Resources. Fisheries Management Report Number 9, Lansing.

Mohr, L. C., and S. R. Gile. 1996. Status and outlook for the major commercial fish species of Lake Huron, 1996. Ontario Ministry of Natural Resources, Lake Huron Management Unit, Report 3-96, Owen Sound.

National Oceanic and Atmospheric Administration. 1993. United States Coast Pilot 6, Great Lakes: lakes Ontario, Erie, Huron, Michigan, and Superior and St. Lawrence River. U. S. Department of Commerce, Silver Springs, Maryland.

Neter, J., W. Wasserman, and M. H. Kutner. 1985. Applied linear statistical models, Second edition. Richard D. Irwin, Inc., Homewood, Illinois.

Newcombe, C. P., and D. D. MacDonald. 1991. Effects of suspended sediments on aquatic ecosystems. North American Journal of Fisheries Management 11:72-82.

Organ, W. L., G. L. Towns, M. O. Walter, R. B. Pelletier, and D. A. Riege. 1979. Past and presently known spawning grounds of fishes in the Michigan coastal waters of the Great Lakes. Michigan Department of Natural Resources, Fisheries Technical Report 79-1, Ann Arbor.

Poe, T. P., and T. A. Edsall. 1982. Effects of vessel-induced waves on the composition and amount of drift in an ice environment in the St. Marys River. U. S. Fish and Wildlife Service, Great Lakes Fishery Laboratory, Administrative Report No. 82-6, Ann Arbor.

Poe, T. P., T. A. Edsall, and J. K. Hiltunen. 1980. Effects of ship-induced waves in an ice environment on the St. Marys River ecosystem. U. S. Fish and Wildlife service, Great Lakes Fishery Laboratory Administrative Report 80-6, Ann Arbor.

Rakoczy, G. P. 1992. Sport fishing catch and effort from the Michigan waters of lakes Michigan, Huron, Erie, and Superior, and their important tributary streams, April 1 1991 - March 31, 1992. Michigan Department of Natural Resources Fisheries Technical Report 92-11, Ann Arbor.

Robinson, W. L., and T. K. Fuller. 1980. Potential effects of winter navigation on movements of large land mammals in the eastern Lake Superior and St. Mary's River area. U. S. Army Corps of Engineers Contract No. 14-16-0009-79-053.

Robinson, W. L., and R. W. Jensen. 1980. Effects of winter navigation on waterfowl and raptors in the St. Mary's River area. U. S. Army Corps of Engineers Contract No. DACW-35-30-X-0194.

Savino, J. F., M. A. Blouin, B. M. Davis, P. L. Hudson, T. N. Todd, and G. W. Fleischer. 1994. Effects of pulsed turbidity and vessel traffic on lake herring eggs and larvae. Journal of Great Lakes Research 20:366-376.

Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Fisheries Research Board of Canada, Bulletin 184, Ottawa.

Shen, H. T., P. D. Yapa, and M. E. Petroski. 1986. Simulation of oil slick transport in Great Lakes connecting channels: volume II: user's manual for the river oil spill simulation model (ROSS). Department of Civil and Environmental Engineering, Clarkson University, Report No. 86-2, Potsdam, New York.

Shen, H. T., P. D. Yapa, and Q. Xu. 1998. Numerical simulation of lampricide transport in the upper St. Marys River. Department of Civil and Environmental Engineering, Clarkson University, Potsdam, New York.

Smith, S. H. 1956. Life history of lake herring of Green Bay, Lake Michigan. U. S. Fish and Wildlife Service, Fishery Bulletin 109.

Sokal, R. R., and F. J. Rohlf. 1981. Biometry. Second edition. W. H. Freeman and Company, San Francisco.

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

Swenson, W. A., and M. L. Matson. 1976. Influence of trubidity on survival, growth and distribution of larval lake herring (*Coregonous artedii*). Transactions of the American Fisheries Society 105:541-545.

United States Coast Guard. 1994. Vessel traffic service manual, edition 1. U. S. Coast Guard, Cleveland.

United States Coast Guard. 1996. Draft environmental impact statement Great Lakes icebreaking. U. S. Coast Guard, Cleveland.

United States Army Corps of Engineers. 1973. Phase I report, Mississippi River year-round navigation. North Central Corps of Engineers, Chicago.

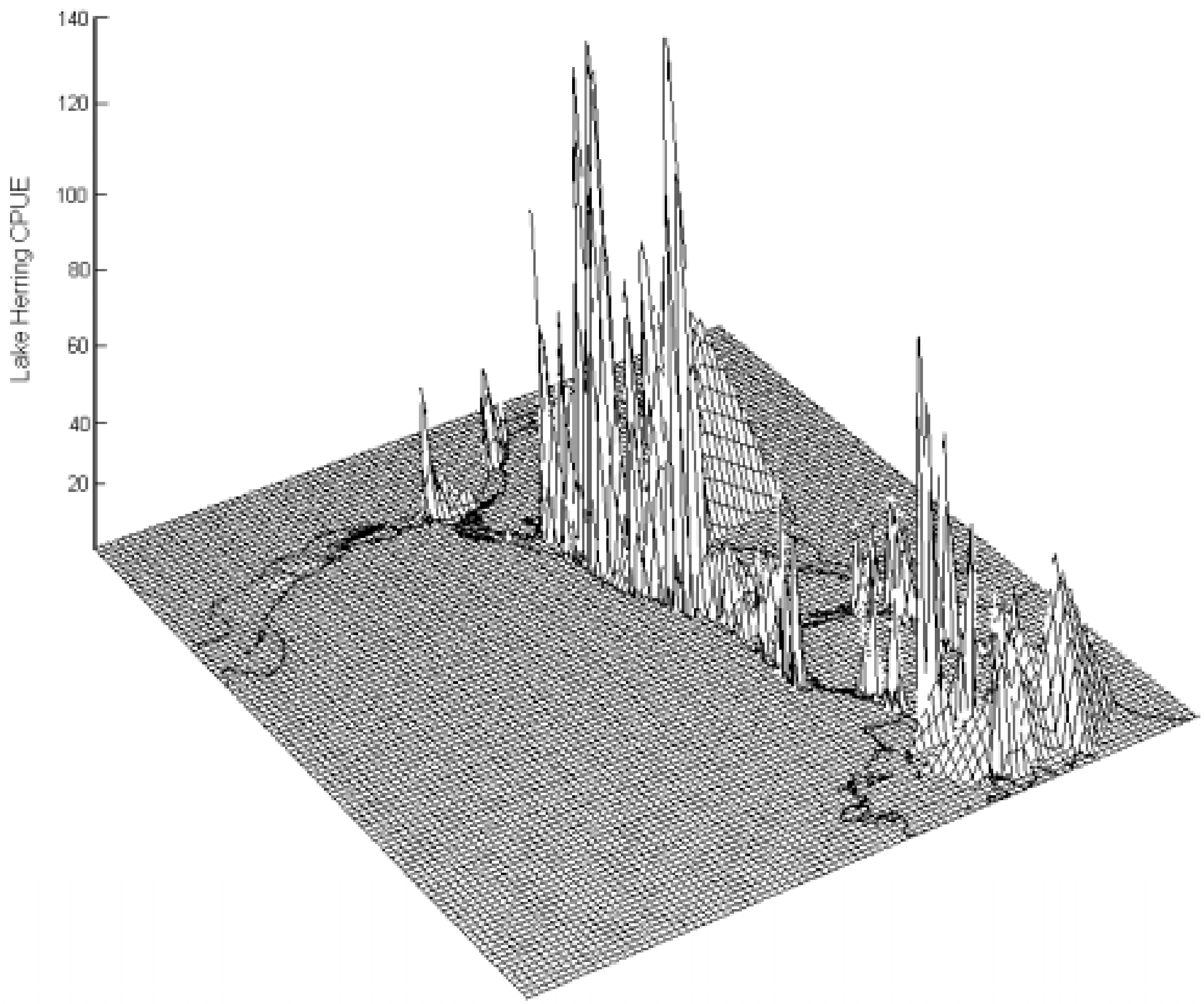
United States Army Corps of Engineers. 1989. Final Environmental Impact Statement, Supplement II, To the final environmental impact statement operations, maintenance, and minor improvements of the federal facilities at Sault Ste. Marie, Michigan (July 1977), Operation of the lock facilities to 31 January ± 2 weeks. U. S. Army Corps of Engineers, Sault Ste. Marie.

United States Fish and Wildlife Service. 1977. Great Lakes connecting channels follow-up study. Great Lakes Region, Twin Cities, Minnesota.

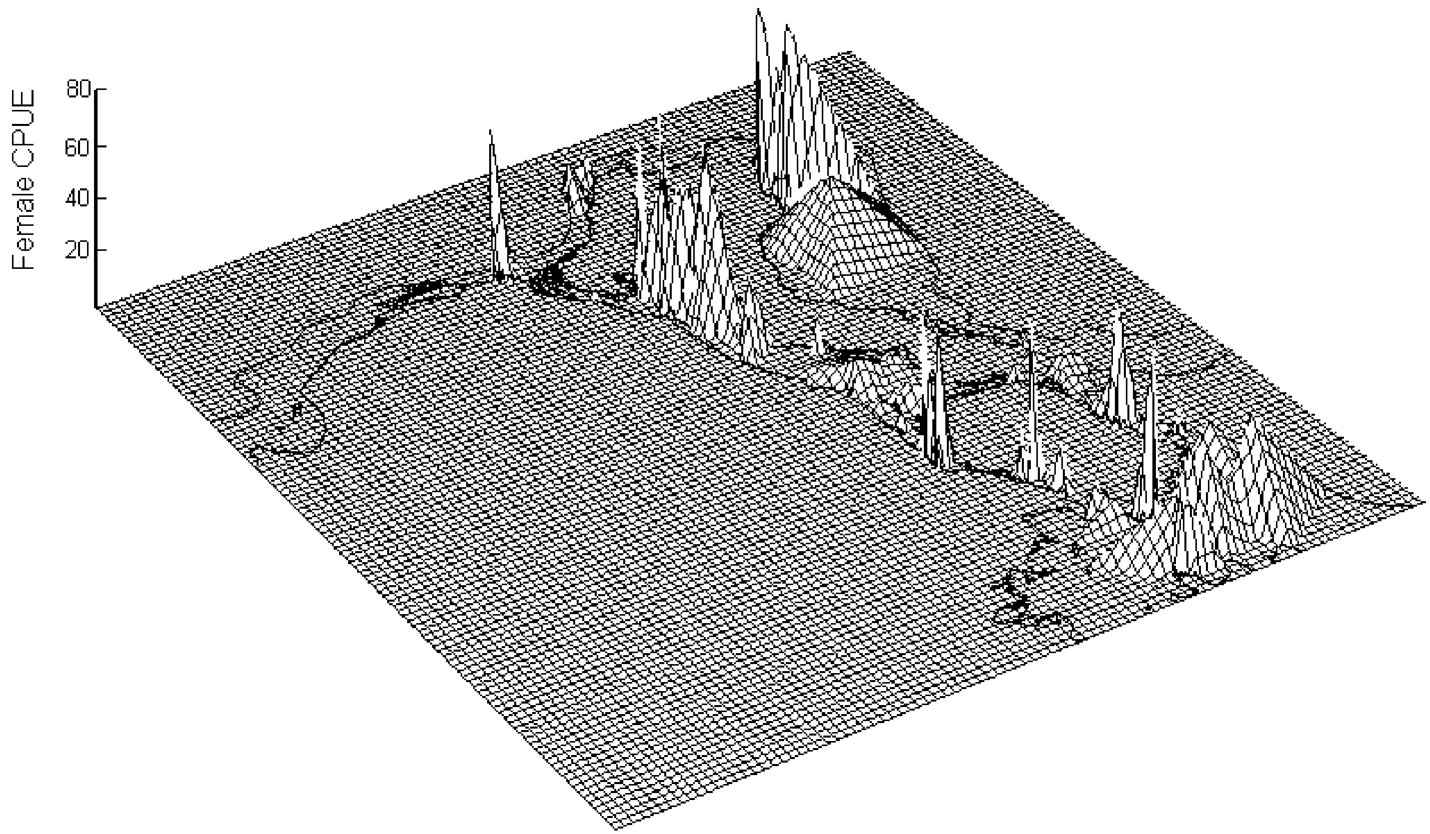
Van Den Avyle, M. J. 1993. Dynamics of exploited fish populations. Pages 105-135 in C. C. Kohler and W. A. Hubert, editors. Inland fisheries management in North America. American Fisheries Society, Bethesda, Maryland.

Williams, D. C., and J. G. Lyon. 1991. Use of a geographic information system data base to measure and evaluate wetland changes in the St. Marys River, Michigan. Hydrobiologia 219:83-95.

Zabilansky, L. J., G. E. Frankenstein, and A. M. Tuthill. 1992. Observations and measurement of ice movement and sediment transport on the St. Marys River during early opening of navigation 15-31 March 1992. Cold Regions Research and Engineering Laboratory Report to Detroit District U. S. Army Corps of Engineers, Agreement CENCE-IA-92-0043.



Appendix 1.–Number of all lake herring (sexes and maturity levels combined) per 91.4 m of gill net (CPUE) captured at sampling locations in 1993 through 1996, St. Marys River.



Appendix 2.-Number of female lake herring (maturity levels combined) per 91.4 m of gill net (CPUE) captured at sampling locations in St. Marys River, 1993 through 1996.