THESIS

MICHIGAN STATE UNIVERSITY LIBRARIES
3 1293 10696 2016

LIBRARY
Michigan State
University

This is to certify that the

dissertation entitled

THE FIRST ARTIFICIAL REEF IN THE GREAT LAKES:
AN EVALUATION

presented by

STEPHEN ROSS VANDERLAAN

has been accepted towards fulfillment
of the requirements for

Master degree in Fish & Wildlife

Niles R. Kevern
Major professor

Date February 6, 1984

MSU is an Affirmative Action/Equal Opportunity Institution

O-12771

MSU
LIBRARIES

RETURNING MATERIALS:
Place in book drop to remove this checkout from your record. FINES will be charged if book is returned after the date stamped below.

DEC 1 0 1987

JAN 27 3

THE FIRST ARTIFICIAL REEF IN THE GREAT LAKES: AN EVALUATION

By

STEPHEN ROSS VANDERLAAN

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Fisheries and Wildlife

1983

ABSTRACT

THE FIRST ARTIFICIAL REEF IN THE GREAT LAKES:
AN EVALUATION

By

STEPHEN ROSS VANDERLAAN

The Hamilton Reef was evaluated for fish reproduction and attraction using various gear types including SCUBA. SCUBA observations provided evidence of yellow perch spawning on the reef. Egg pumping, egg trays, emergent fry traps, and larval fish trawls provided no evidence that lake trout had spawned on the reef. Analysis of gill netting data showed no reef attraction over a sand reference area for perch or other species. Emergent fry trap data showed a statistically larger number of fish utilized the shallow rather than the deep end of the reef. Reef light measurements indicate greater periphyton production at the shallow reef site which may cause this attraction. Light measurements and SCUBA observations on the reef disclose a low periphyton production potential because of its depth, nutrient availability, and small size. Comparison to the nearby Muskegon breakwall reveals a high periphyton production, nutrient availability, warmer water temperatures and large size that out competes the reef as a fish attractor.

This thesis is dedicated to my parents, James and Jean VanDerLaan, for their understanding and support.

ACKNOWLEDGEMENTS

The Michigan State University study of the Hamilton Artificial Reef was affected in a very positive way by many organizations, groups, and individuals who contributed financially or with their time and interest to this project. First I would like to recognize the efforts of several Michigan State University staff members. Dr. Niles R. Kevern, effectively coordinated and secured funding for the reef project under difficult economic conditions. He, along with the two other members of my guidance committee, Dr. Darrell King and Dr. Richard Snider, provided counseling and support throughout the project. All of their efforts were invaluable and very much appreciated. Statistical consultation was provided by Dr. John Gill. I am grateful to him for the patience and expertise he expended in behalf of myself and this project.

A special thanks to the Michigan Department of Natural Resources, specifically, Dave Weaver, John Trimberger, Dave Smith, Russell Lincoln, and Doug Kort. They demonstrated interest in the project many times by providing needed manpower, use of facilities, and essential equipment during the entire project.

In the Muskegon area, the Muskegon Sportfishing Association generously contributed both time and money toward the project. The efforts of John Mercer, Dick McEwen, and Tom Hamilton were appreciated. Thanks also to commercial fisherman, Richard Mac Nab, for use of his docks and other fishing facilities.

I am greatly indebted to my fellow coworkers, Scott Cornelius and Bill Biener, who served as research associates, diving partners, and boat hands.

Thanks to Nancy J. Smith for her contributions toward the editing of this manuscript.

Financial support for this study was provided by the following: the Michigan Sea Grant College Program (grant number R/GLF/3, funds from the Office of Sea Grant, National Oceanic and Atmospheric Administration, U.S. Dept. of Commerce and the State of Michigan); the Michigan Agricultural Experiment Station; the Sport Fishery Research Foundation; and the Coastal Management Program, MDNR.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Artificial reefs are a significant tool for both freshwater and marine fisheries management. The significance of artificial reefs has been stated by Prince et.al.(1977) "Artificial reefs whether built in freshwater or saltwater are used when lack of underwater structures has been identified as a potentially limiting factor for fishes". In the past, artificial reef building has been predominantly a marine phenomenon, however,in recent years their introduction to freshwater lakes and reservoirs has been increasing. One of the first artificial structures in freshwater was a brush shelter reported by Hubbs and Hubbs (1933). The shelter was located in Crystal Lake, Michigan and reportedly yielded 6,491 fish from a single seine haul. This illustrates an important characteristic common to most artificial reef structures; they attract large numbers of fish. This unique quality has also been reported by other researchers. Prince (1978) states, "The consensus is that fish are more abundant near reefs and that nearly all lacustrine fishes at least occasionally occupy reef areas...". In essence, fish that live in an environment containing little variation, or bottom structure, are attracted to an artificially structured habitat. One reason for this attraction to underwater structures is food. Reef structures, if located shallow enough, will provide the substrate and environment vital to a wide variety of food organisms. Plants and organisms such as colonial bryozoans, periphytic algae, freshwater sponges, gastropods, and a variety of other food organisms will accumulate on the reef. Because of this food concentration, detritivorous, herbivorous, and carnivorous fish will be attracted to the reef. According to Wilbur (1973), who refers to anything that concentrates fish as a fish attractor, "This type of feeding interrelationship is called a food chain by ecologists and is one of the reasons a fish attractor works".

In addition to providing food for fishes, artificial reef structures also furnish shelter. Artificial reefs can provide shelter because they define vertical space and change wave and current patterns (Mottet,1981). By defining vertical space, artificial reefs provide a location where young game fish, as well as forage fishes, are able to escape predators. This according to Hubbs and Eschmeyer (1937) is an essential requirement for maintaining a large yield of fish in inland waters.

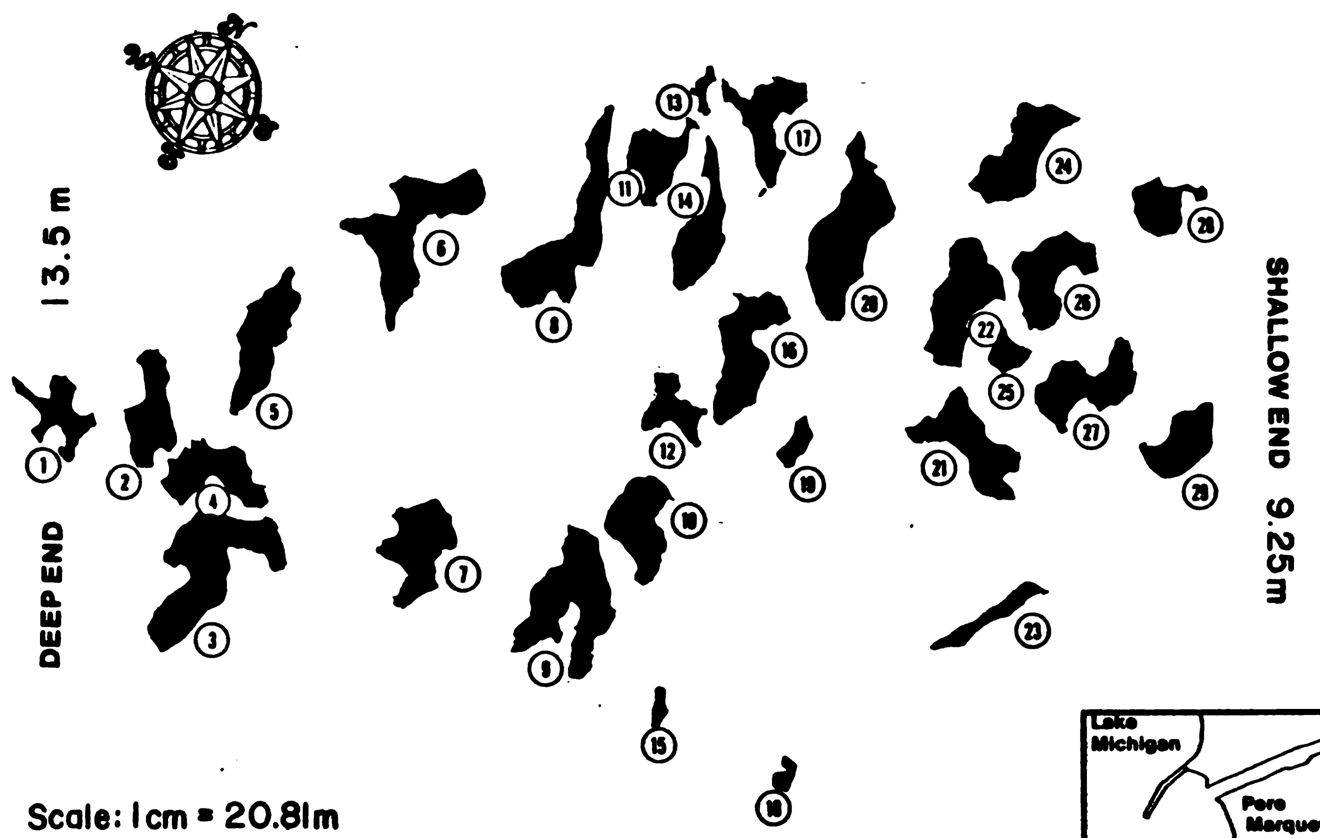
A third essential requirement of fish, in addition to food and shelter, is spawning substrate. The need for spawning substrate is especially acute in underwater areas where little natural cover structure exists. Such areas are common in many of our freshwater lakes and reservoirs. The success of artificial structures as spawning substrate has been well documented in a variety of geographic locations and for a variety of fish species (Peck,1981, Dorr and Jude,1980, Wagner,1980, Prince and Maughan,1979, Wilbur and Crumpton,1974, Rodeheffer,1938).

In the summer of 1979, the Michigan Department of Natural Resources began construction of the first artificial reef in the Great Lakes. The reef was intended to improve the fishing success in Lake Michigan, specifically in an area offshore of Muskegon, Michigan (Muskegon County). Building the reef at this site was viewed as a direct means of providing artificial structure in an area with little or no existing natural structure and thereby supplying food, shelter, and spawning substrate where these had previously been deficient or nonexistent. This study is an investigation of fish reproduction, fish attraction, and potential food production on the Hamilton Reef. Research will be conducted using several types of surface and underwater sampling gear. The reef will be compared to a similar reef structure in Lake Michigan to evaluate its impact and suggestions for future reef construction will be included.

STUDY AREA

In July of 1979, construction of the first artificial reef in Lake Michigan was begun. It was named the Hamilton Reef after a member of the Muskegon Sport Fishing Association, Thomas Hamilton. The lake bottom in the reef area is flat, hard-packed sand void of any permanent reef-like structure. Consequently, there are few locations for fish to congregate along the local shoreline. The reef is located one kilometer offshore from the city of Muskegon (Figure 1.) and is oriented in a southwesterly direction. Composed of dolomite limestone ranging in size from cobble to two meter boulders, the reef comprises 3,636 metric tons with an estimated surface area of 8,471 square meters. The reef is made up of a series of rock piles which vary in both size and elevation above the bottom substrate. These reef piles range in depth from 9.25 meters at the shallowest end to 13.5 meters at the deepest end. Each extremity of the Hamilton Reef is marked with a permanent buoy identifying it as the Michigan Department of Natural Resources Fishing Reef. This enables fishermen to easily locate and use the reef.

Environmental conditions in the reef area can be rigorous, changing frequently with wind direction. South-



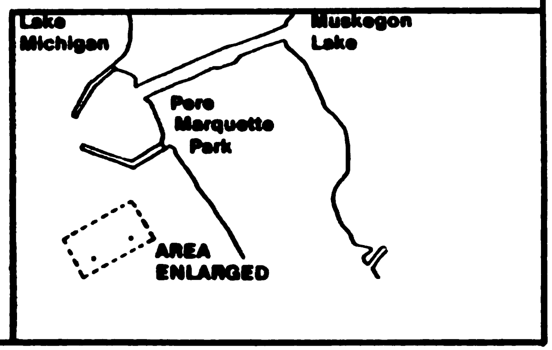


Figure 1. Side-scan sonar sounding map of the Hamilton Reef

westerly winds predominate summer season, pushing warm water into the reef area and commonly causing water temperatures to reach or exceed 21 C. In the fall months northwesterly winds are the rule, pushing cold northern waters into the reef area and commonly reducing temperatures to 7 C or lower (Figure A6.). During the spring and summer months easterly winds play an important role because of the rapid water temperature changes they can cause. In the spring, and especially during the summer months, the unpredictable appearance of easterly winds causes upwelling of cold subthermocline water to replace warm surface waters blown off shore. An example of this phenomenon was documented on July 22, 1981 when water temperatures dipped to 3.3 C. Concurrently on this date, a dense fog bank formed where the Muskegon River entered into Lake Michigan, further illustrating the significant temperature difference that existed.

The Hamilton Reef is influenced significantly by currents and surface wave action. Rapid movement of these currents bring large amounts of drifting material to the reef. Drift such as entire trees, seawall planking, balls of loose vegetation, and various articles of discarded refuse are common. Over time these materials tend to be water-logged and incorporated into the reef structure, increasing its size and enhancing its character. In addition to deposition, currents also have affected the substrate upon which the reef itself is situated. Currents, and possibly wave action, have removed a significant amount of sand from around each rock pile. The result is that they now appear to sit in depressions in the sand.

Lake currents near the mouth of the Muskegon River determine, to a large degree, water clarity surrounding the reef. Just south of the river's mouth, the reef receives river discharge and particulates on a regular basis. This outflow is distinctive due to its brown, mud-like appearance. Water samples in this outflow have been observed to contain large quantities of blue-green algae, specifically Aphanizomenon flos-aquae (L.) Ralfs, Anabaena spp., Coelosphaerium spp., Lyngbya spp., and Microcystis spp. (Spencer, Personal Communication). Suspended particulates and bluegreen algae discharged by the river caused reduced diver visibility (Figure A5.). This was especially so when lake currents pushed river outflow southward over the reef.

During winter ice build up is extensive, making conditions on the Hamilton Reef especially harsh. Indirect evidence such as rock pile movement and flattening and destruction of sampling devices indicate ice damage may be extensive. The effects of ice build up may be intensified by water currents acting in the area as well.

METHODS

To evaluate fish reproduction occurring on the Hamilton Artificial Reef, it was necessary to establish where sampling activities would be performed. This was accomplished by establishing four sampling sites, two on the reef and two located over sand substrate. Maintaining temporary buoys on the reef was difficult. Therefore, existing reef buoys served as underwater sampling area markers. For similar reasons, surface buoys could not be used to mark the sand control areas north of the reef. A system of nylon transect lines was constructed. On one end the transect lines were attached to the anchors of the permanent reef buoys and on the other end they were attached directly to the control sampling areas (Figure 2.). The sampling areas were identical in size. The boundary of each was established by four reinforcing rods serving as corner stakes. Nylon rope was attached to each corner stake forming a square perimeter equaling 30.1 square meters. All perimeter and transect lines were composed of 0.95 centimeter braided nylon to prevent breakage from chafing on rocks.

One of the primary objectives for constructing the Hamilton Reef was to improve habitat conditions for desir-

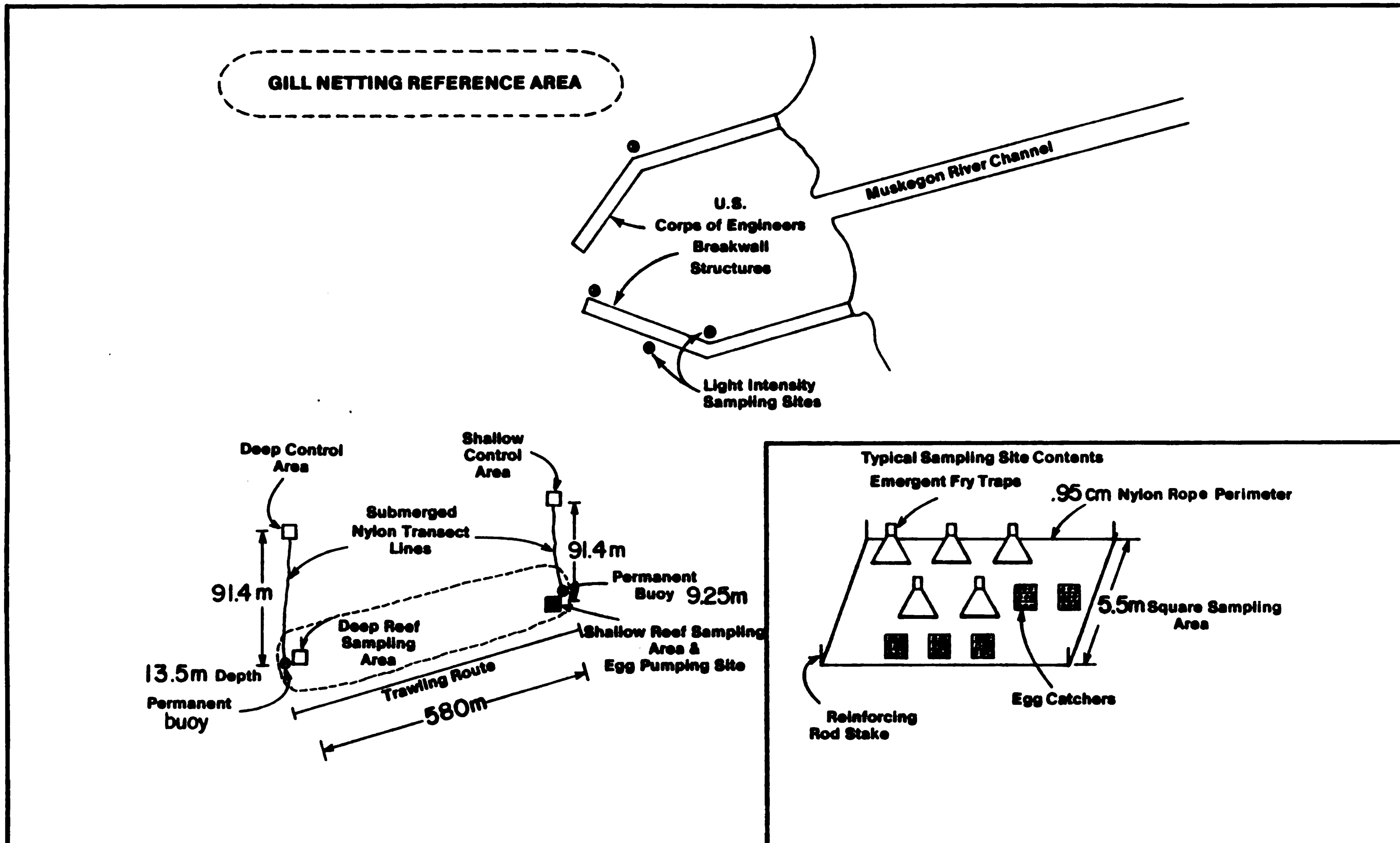


Figure 2. Hamilton Reef sampling site locations

able gamefish. In Lake Michigan one of the most desirable gamefish is the yellow perch (Perca flavescens Mitchill). Since yellow perch commonly spawn in rocky areas like the reef, they were an important study species. To thoroughly evaluate yellow perch spawning activity, observations of all four sampling areas were necessary. The observation process involved swimming around the sampling area perimeter as well as making several cross-area swims. These observations were repeated until the divers were confident the entire sampling area had been inspected and all of the accordian-shaped perch egg masses had been counted. Egg mass counts were committed to memory until the divers could conveniently record the information on the surface.

The lake trout (Salvelinus namaycush Walbaum) was selected as another study species since considerable effort has been expended to its reestablishment. To evaluate lake trout spawning activity, an egg pump was constructed (Figure 3.). The basic system, modeled after Stauffer's 8 cm centrifugal trash pump, was altered to allow enough freedom for SCUBA divers to employ a suction probe (Stauffer,1980). The flexibility of this system enabled divers to probe reef interstices for spawned eggs and slow moving fry. Reef vacuuming was performed on a purely qualitative basis and no

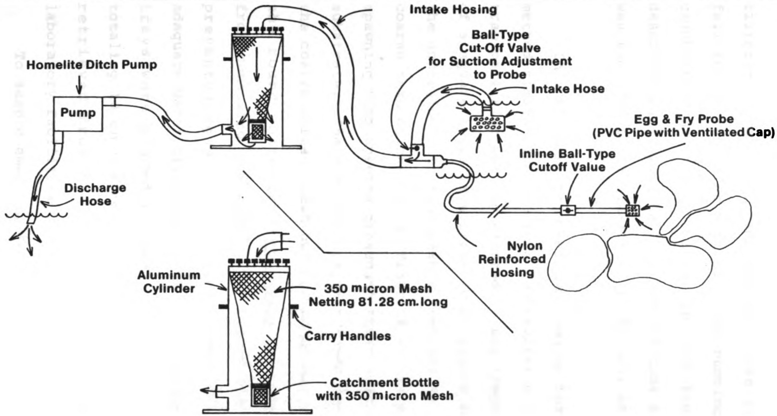


Figure 3. Pumping system for fish egg and fry sampling

attempt was made to quantify the amount of reef water filtered through the pump system. Lake trout spawn in the fall and early winter months. Egg pumping activities were conducted at these times in the four sampling areas described earlier. The location and time spent at each site was recorded for inclusion in later data analysis.

In addition to reef vacuuming for spawned eggs, a method similar in principle to Stauffer's (1980) egg and fry trap pail also was implemented. Egg trays were constructed of a square angle iron frame (0.37 square meters) covered on the underside with fine mesh screen and on the top side with coarse mesh chicken wire (Figure 4.). In principle, scatter spawning fish species broadcast their eggs over the spawning substrate. The egg tray design allowed eggs to pass through the coarse surface mesh but prevented egg predators, such as the round whitefish (Prosopium cylindraceum Richardson), from consuming the eggs. The bottom surface of fine mesh prevented eggs from falling through while still allowing adequate water circulation for any entrapped eggs. Five egg trays were placed at each of the four sampling sites, totaling 10 on the reef and 10 in the control areas. Eggs retrieved from the trays were collected and returned to laboratory facilities for hatching.

To sample emerging fry and juvenile fish on or near the Hamilton Reef emergent fry traps were used (Figure 5.). Construction of these traps was based on a design by Collins

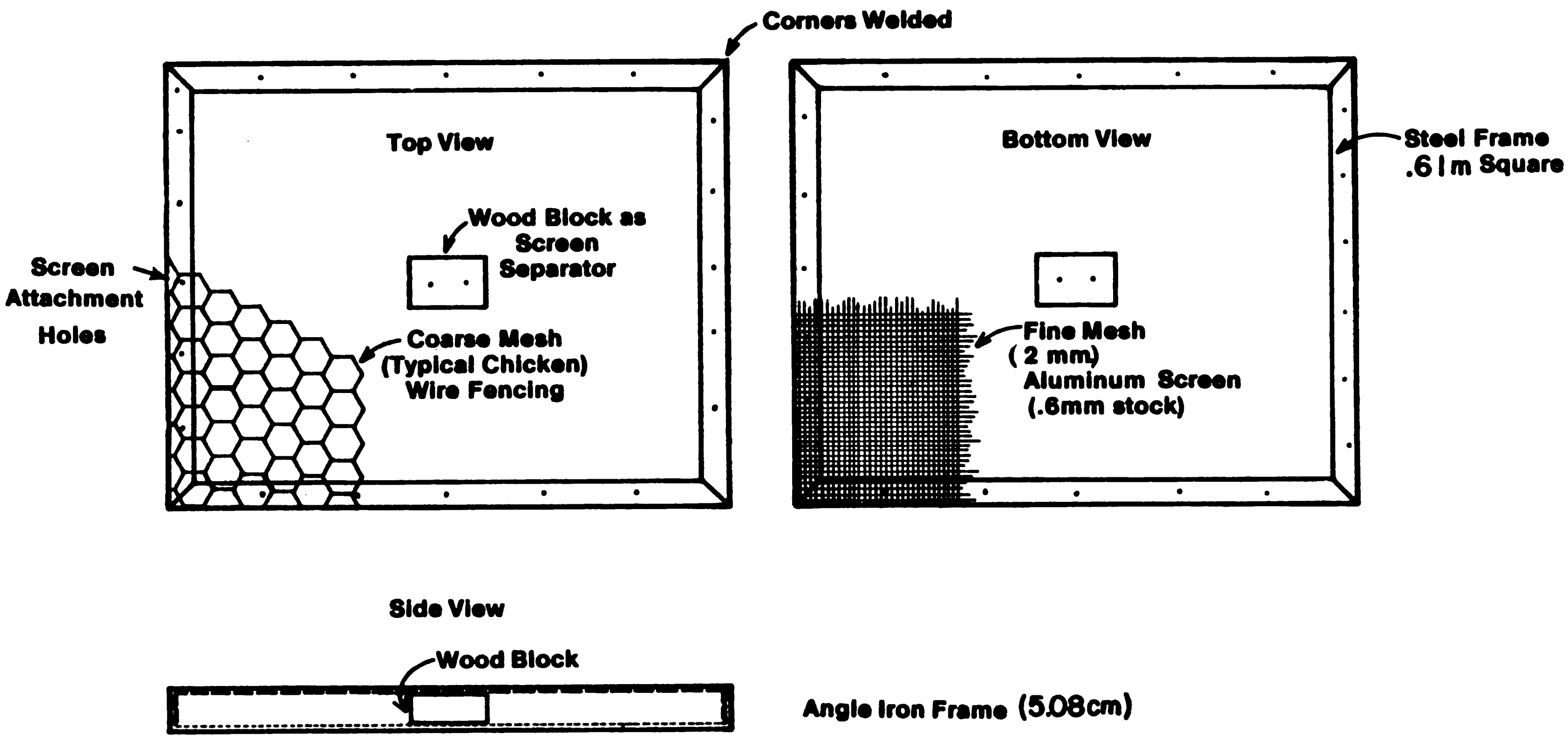


Figure 4. Design of a fish egg sampling tray

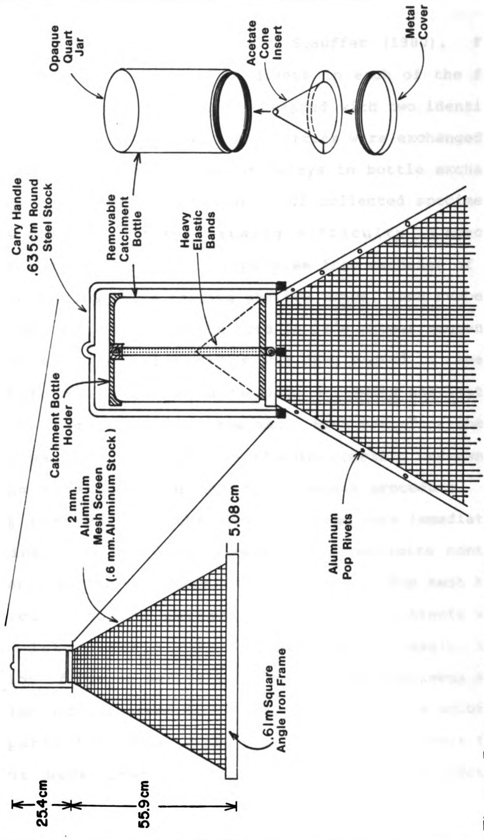


Figure 5. Design of emergent fry traps used on the Hamilton Reef

(1975) and a later modification by Stauffer (1980). Five fry traps were placed by SCUBA divers in each of the four sampling areas, each trap being equipped with two identical catchment bottles. Trap catchment bottles were exchanged at least one time per week. Longer delays in bottle exchange led to problems with the integrity of collected specimens, such as death or decay, causing difficulty in species identification. To ensure problem free exchange of the catchment bottles while tending the fry traps, each numbered bottle was tied with nylon cord in it's proper sequence. The tied sequence of bottles was then packed in reverse order into a nylon mesh dive bag, allowing the initial bottle to remain outside the bag. Each bag of catchment bottles was then brought to the appropriate underwater sampling site to begin the replacement procedure. The bottles removed from the sampling sites were immediately placed inside an empty nylon mesh bag to minimize content disturbance during transport to the surface. The mesh bags were brought to the surface where their contents were emptied into plastic tubs on the research vessel. Upon completion of diving activities all captured specimens were identified and preserved for stomach analysis in a solution of 70 percent ethanol and 30 percent water. Adult fish stomachs were examined under a binocular dissecting microscope to detect fry cannibalism, if it occurred in the catchment bottles.

To insure that the Hamilton Reef was adequately sampled for fry and juvenile fish, larval fish trawls were utilized to supplement information obtained from emergent fry traps. On two occasions in the spring of 1982 trawling was conducted using the University of Michigan vessel 'Mysis'. Trawls from the 'Mysis' were performed with an otter trawl and were conducted parallel to the reef.

In the spring of 1983 trawling was again conducted on the Hamilton Reef. Unlike the previous year, trawling was conducted solely by Michigan State University and was performed with a beam trawl (Figure 6.), parallel to the reef in a straight line south of the permanent buoys. This prevented any chance of entanglement in the transect lines on the north side of the reef (Figure 2.). Trawling, like egg pumping, was performed on a qualitative basis with no attempt to quantify the data. Fish trawls were conducted in equal numbers from an easterly and westerly direction.

One primary reason for building the Hamilton Reef was to attract desirable gamefish for fishermen. To determine whether the reef was attracting game fish, experimental gill nets were set over the reef and reference area on a 24 hour basis. Each net was composed of 5, 7 meter mesh panels, each successive panel being comprised of a finer mesh than its predecessor. Mesh sizes included 102, 76, 64, 51, and 38 millimeter stretched nylon mesh. Adult fish were netted by setting four gill nets, two over the reef and two in the northern control station (Figure 2.). No attempt was made

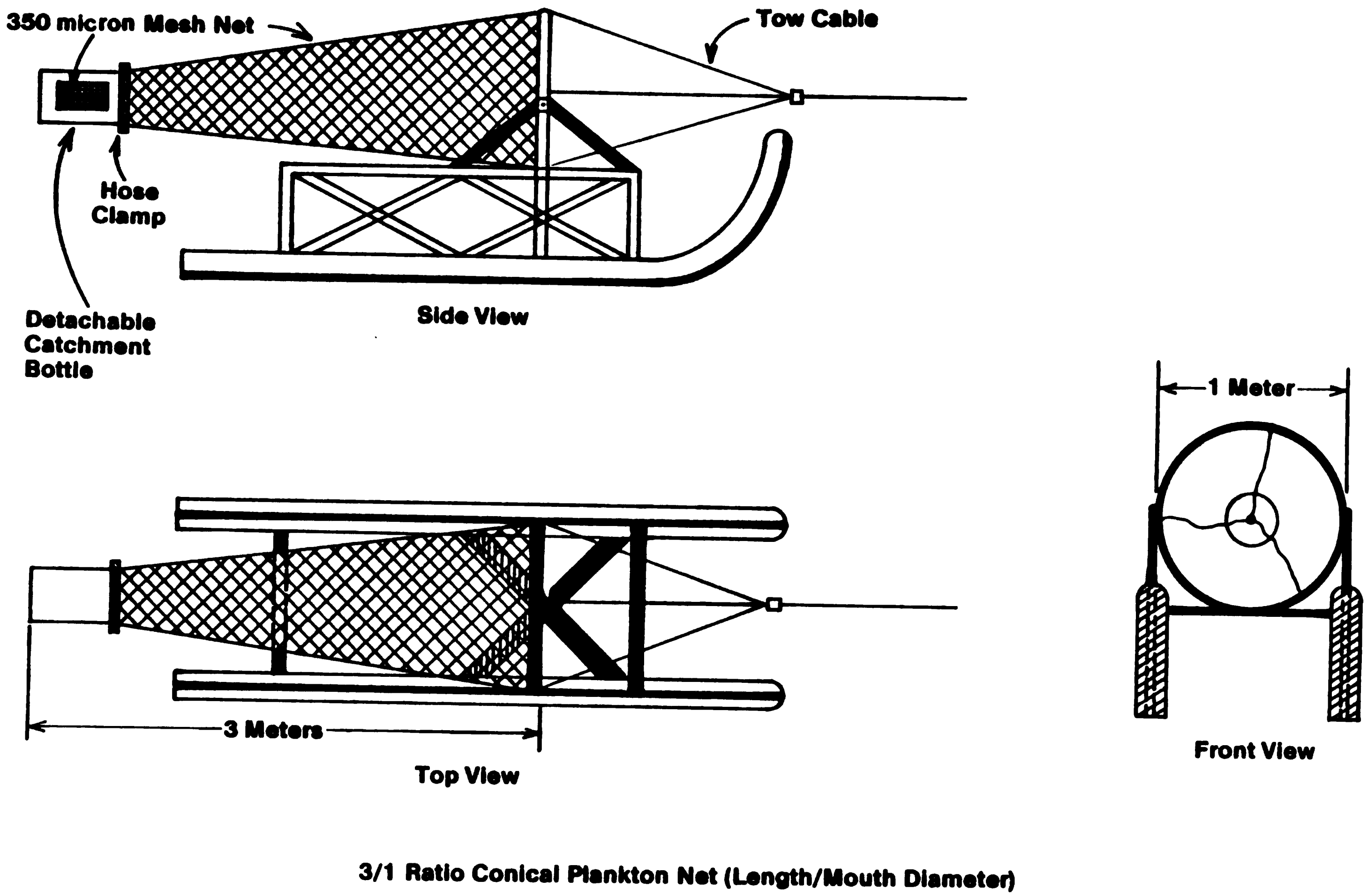


Figure 6. Design of larval fish beam trawl used on the Hamilton Reef

to divide the reef into deep or shallow zones however, nets on either the reef or reference area were set at the same depth. Gill netting was conducted at both areas in July and August, 1982. August netting was conducted on a 12 hour basis rather than 24 hour because of boat traffic in the sampling areas.

All late fall (October through January) netting was conducted solely over the Hamilton Reef to determine sexual maturity of lake trout. Two nets used during the fall netting period were composed of nongraduated nylon mesh. The first net had 99.06 meters of 6.67 centimeter mesh and 56.4 meters of 12.7 centimeter mesh. The second had 121.9 meters of 6.67 centimeter mesh and 45.72 meters of 10.16 centimeter mesh. The stomachs of all fish obtained from these nets were checked to determine if any egg predation had occurred.

Shortly after reef construction the appearance of dish-like depressions around each rock pile caused some concern. Outwardly, it appeared as though the reef was settling into the substrate and would eventually be completely covered by sand. A procedure was developed to detect any vertical movements in the reef rock piles. A small permanent benchmark was chiseled into the finished concrete portion of the south breakwall, providing a permanent reference point to which all reef depth measurements could be related (Figure 7.). Measurements were taken from the base of each permanent buoy anchor to

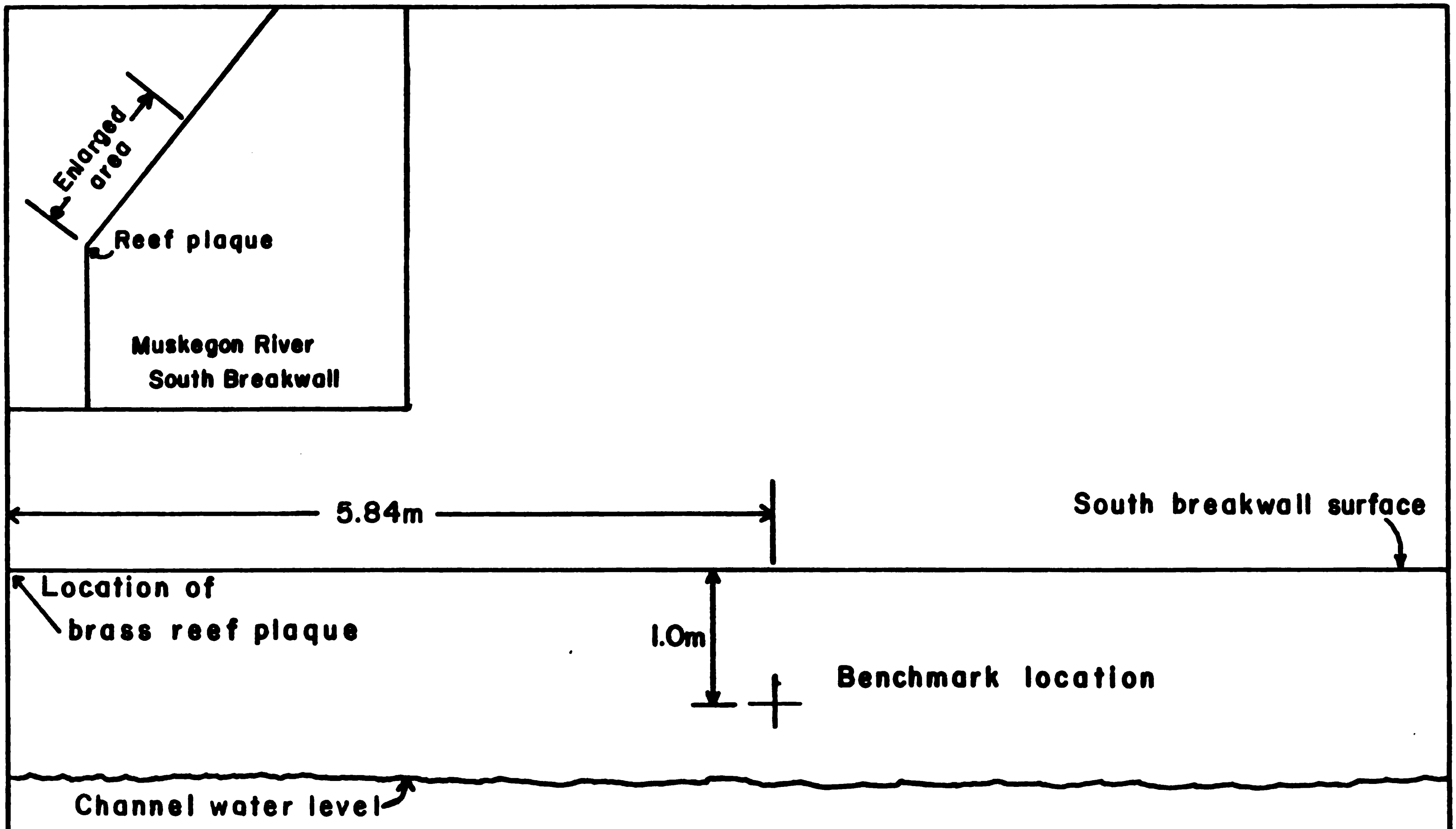


Figure 7. Location of the Hamilton Reef depth benchmark on the South Muskegon River Breakwall

water surface. Next, the distance from benchmark to water surface was recorded to account for any seiche caused water level changes.

The Hamilton Reef is the base of a new ecological community. By its nature it provides new attachment sites for autotrophic periphytic algae. In addition to planktonic algae fallout, periphyton production is the only other significant food source for this new ecological reef community. Potential periphyton production was evaluated by measuring light intensity. Measurements were taken with a digital Li Cor quantum light recorder at one meter intervals from surface to bottom. All light readings, in microeinsteins per square meter per second ($\mu E/m^2/sec$), were recorded twice for each depth with the average serving as the light reading for that particular depth. The extinction coefficient (slope) was calculated for the resulting light data by regression analysis of the natural logarithm of the light reading versus water depth. With the resulting coefficient (- K), light penetration could then be determined for both the shallow and deep ends of the reef. Calculations were performed according to the following equation based on Lamberts Law :

$$I(d) = I(o)\ e^{(-K)(d)}$$

(Reid and Wood,1976)

where:

I(d) = measurement of light intensity incident at depth d

I(o) = original intensity of the entering light

e = base of natural logarithms (2.7)

K = extinction coefficient

d = depth of measurement

Because the reef varies in depth, it was necessary to estimate the amount of square surface area found at each respective light intensity. Reef side-scan sonar soundings were used as the basis of all calculations. Using a Keuffel and Esser polar planimeter, area estimates for each of the 29 rock piles were obtained (Table A4.). For ease of calculation, the measured area of each rock pile was used to calculate a circle of equal area. This yielded an imaginary reef composed of circular rock piles with an area equal to the Hamilton Reef. However, because the reef is three dimensional rather than two, it was necessary to estimate reef height. This was a difficult estimate to obtain because of the reefs scattered nature and the lakes inherently poor underwater visibility conditions. On the basis of diving records over three years an average height of 2.1 meters was determined. By representing the entire reef as a series of cones with base circumference equal to actual (planimeter measured) pile area, and an average height estimated at 2.1 meters, it was possible to calculate the surface, or lateral area of each rock pile cone. Total lateral area of the reef was then divided into seven depth ranges, 0-.3, .3-.6, .6-.9, .9-1.2, 1.2-1.5, 1.5-1.8, and 1.8-2.1 meters off the bottom. Lateral area for each depth range was determined by subtracting the calculated surface area estimate for each depth range from the total lateral area of the cone. By incorporating light data it was possible to calculate light intensity at the midpoint of each depth range on the reef (Figure A4.). Total light for each reef section was determined by multiplication of the section midpoint light intensity by the area found in that depth section. Light intensity for the reef was calculated by summation of the 7 reef section intensities yielding one total value.

RESULTS

Observation of Yellow Perch Egg Masses

Lake Michigan yellow perch are known to spawn during May and June (Dorr and Jude,1980). Research on the Hamilton Artificial Reef supported these findings during 1981 and 1982 field seasons. The second spring (June, 1981) after reef construction, SCUBA divers observed, on two separate occasions, the characteristic gelatinous egg masses spawned by yellow perch. On June 2, divers observed 3 egg masses on the reef, and 3 days later another. The latter was not lying loosely on the reef as the previous eggs had been but was wound around the top of an emergent fry trap. Subsequent dives during the months of June and July produced no additional egg masses in the reef sampling areas. Observations during summer of 1981 were limited to the reef, because no control stations were established. These observations provide qualitative evidence of yellow perch spawning activity on the Hamilton Reef.

During May and June of the 1982 field season yellow perch spawning was again observed on the reef (Table 1.).

Table 1. Observed yellow perch egg mass counts on the Hamilton Reef in 1981 and 1982.

Observation Period	Reef	Shallow Reef	Deep Reef	Reference Area
6/2/81	3	n/a	n/a	0
6/5/81	1	n/a	n/a	0
5/26/82	1	1	0	0
6/9/82	2	0	2	0
6/29/82	2	2	0	0
6/30/82	1*	0	0	0

* One egg mass was observed on the reef but outside the deep reef sampling area.

All observations in 1982 were conducted within the confines of the established sampling areas. Yellow perch eggs were observed in reef sampling areas on 3 different occasions May 26, June 9, and June 29. On May 26 and June 29, 1 and 2 egg masses respectively were observed in the shallow reef sampling area, while on June 9, two more were observed in the deep reef sampling area. On June 30 one egg mass was observed outside of the deep reef sampling area but at no time were perch eggs seen elsewhere on the reef or in any of the sand reference areas.

To establish the viability of yellow perch eggs spawned on the Hamilton Reef divers removed an egg mass from the reef on May 26, 1982. After an incubation period of 13 days the eggs began to hatch, proving that viable yellow perch eggs were spawned on the Hamilton Reef.

Another method to determine the amount of yellow perch spawning activity on the reef was estimation of fish fecundity. A common method to estimate fish fecundity utilizes the linear or curvilinear relation between fish length and number of eggs produced per adult female fish. By constructing a graph of fish length versus eggs produced future estimation of fish fecundity can be determined with fish length data alone. However, no diving observations conducted on the Hamilton Reef provided any female perch length data to construct the above relation. As a method of estimating yellow perch fecundity on the reef the scientific fisheries literature provided the necessary information. By utilizing the yellow perch length-fecundity relationship found in other areas of the Great Lakes it was possible to conservatively estimate the number of eggs spawned on the Hamilton Reef. Sztramko and Teleki (1977), found Lake Erie age III yellow perch contained 12,641 eggs. Brazo, et.al. (1975), reported that Lake Michigan age II yellow perch contained 10,654 eggs per female. Lake conditions at Ludington and Muskegon are very similar and thus for purposes of estimation, all yellow perch egg masses were assumed to be from mature age II fish. Multiplying the number of egg masses observed on the reef by 10,654 eggs per fish, an estimate was calculated. The number of yellow perch eggs spawned on the Hamilton Reef in the established sampling areas for 1981 was 42,616 and in 1982 was 63,924, yielding a total of 106,540 eggs spawned over that period.

Because of time and physical limitations encountered by SCUBA divers, it was impossible to observe the entire reef for perch egg masses in any single observation period.

However, to estimate the number of eggs spawned on the entire reef, observations were conducted in the two established sampling areas that enclosed 60.2 square meters. On 3 separate occasions during the months of May and June 1982, a total of 5 egg masses were observed (Table 1.). The number of egg masses per square meter per spawning season equaled 5 divided by 60.2 or 0.083 egg masses per square meter per season. From planimeter calculations the total reef size was estimated at 8,471 square meters, and by multiplication the total number of egg masses spawned on the reef per season equals 704. Estimated fecundity was obtained by using 10,654 eggs per mature age II female (Brazo et.al.,1975) multiplied by 704 egg masses and equaled 7,500,416 eggs per reef per season.

These estimates seem reasonable when related to diver observations over 3 successive field seasons and are low when compared to similar substrates such as the riprap field of the Donald C. Cook Nuclear Power Plant in Berrien County Michigan. Dorr and Jude (1975) reported riprap egg mass densities of 6 ± 3 per 1000 square meters. Estimated egg mass density on the Hamilton Reef was calculated to be 1.36 egg masses per 1000 square meters which is less than that observed at the Cook Nuclear Power Plant.

Egg Pumping

Egg pumping over the Hamilton Reef was attempted a total of 6 times in 1980 and 1982. Inclement weather and mechanical difficulties during the fall months hampered pumping efforts on 4 occasions. No evidence of spawning was discovered on either of the 2 successful pumping trips.

Egg Trays

During August 1982, egg trays were set on the reef. Five egg trays were placed at each sampling site to collect eggs from scatter spawning species. These were observed routinely at each of the 4 sampling sites until regular scheduled diving was terminated in late September of 1982. Between September (1982) and March 25 (1983) some significant structural changes occurred on the reef and reference areas altering the original placement of the egg trays. In March several of the trays which had been resting horizontally, directly on the reef, were wedged vertically between reef boulders while other trays were flipped over and were lying nearby. All egg catchers in the reference areas were gone.

Emergent Fry Traps

To evaluate the emergence of forage fish and fry spawned on the reef, emergent fry traps were utilized during the summer of 1982. Four sampling sites were designated with 5 traps per site and each site was trapped for a total of 10 weeks. All data were combined into one of two groups, early or late summer sampling periods. To obtain a normal distribution of fry data it was transformed to logarithm (Y + 1) where Y equals the number of fry caught in each fry trap. This transformation assured compliance with the assumptions of a normal distribution. Statistical comparisons of each fish species proved to be impractical because of the low numbers of each obtained (Tables 2.,3.,and 4.). All emergent fry trap data, therefore, were placed into one of three possible categories: fry or juvenile fish, adult fish, and all fish captured combined (Tables 5.,6.,and 7.). A three factor model with bottom substrate, water depth, and sampling period as fixed effects was examined via split-plot analysis of variance (ANOVA) applied to the three data groups:

$$Y = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + T(ij)K + \gamma_l + (\alpha\gamma)_{il} + (\beta\gamma)_{jl} + (\alpha\beta\gamma)_{ijl} + E(ijKl)$$

(i = 1,2; j = 1,2; k = 1,2,...5; l=1,2.)

Table 2. Larval and juvenile fish captured in emergent fry traps on the Hamilton Reef and sand reference areas in 1982.

Hamilton Reef	Sampling Period									
Species	A	B	C	D	E	F	G	H	I	J
Sculpin* (*Cottus* spp.)	14	4	3	2	4	0	2	8	2	2
Rainbow smelt (*Osmerus mordax* Mitchill)	0	0	0	0	0	10	5	3	3	24
Burbot (*Lota lota* Linnaeus)	0	0	0	2	0	0	0	1	0	1
Yellow perch (*Perca flavescens* Mitchill)	1	0	0	0	0	0	0	0	1	1
Trout perch (*Percopsis omiscomaycus* Walbaum)	0	0	0	0	0	1	0	0	0	0
Cyprinidae spp. (Unidentified)	0	0	0	0	0	0	0	0	0	0
Sand Reference Area										
Species										
Sculpin* (*Cottus* spp.)	n/a**	2	3	10	8	4	3	1	2	2
Rainbow smelt (*Osmerus mordax* Mitchill)	n/a	0	0	1	0	0	0	1	0	4
Burbot (*Lota lota* Linnaeus)	n/a	0	1	0	0	1	1	0	1	0
Yellow perch (*Perca flavescens* Mitchill)	n/a	0	0	0	0	0	0	0	0	0
Trout perch (*Percopsis omiscomaycus* Walbaum)	n/a	0	0	0	0	0	0	0	0	0
Cyprinidae spp. (Unidentified)	n/a	9	1	0	0	0	0	0	0	0

**Cottus bairdi* Girard and *Cottus cognatus* Richardson combined.
**Data unavailable due to incomplete sampling area construction.

Table 3. Adult fish captured in emergent fry traps on the Hamilton Reef and sand reference areas in 1982.

Hamilton Reef	Sampling Period									
Species	A	B	C	D	E	F	G	H	I	J
Johnny darter (*Etheostoma nigrum* Rafinesque)	17	29	46	11	19	15	6	3	3	3
Spottail shiner (Notropis hudsonius Clinton)	2	9	2	1	0	0	0	0	0	0
Sculpin* (Cottus spp.)	6	1	1	1	0	1	0	1	0	0
Ninespine stickleback (*Pungitius pungitius* Linnaeus)	3	1	0	0	0	0	0	0	0	0
Sand Reference Area										
Species										
Johnny darter (*Etheostoma nigrum* Rafinesque)	n/a**	7	12	4	6	11	2	0	2	2
Spottail shiner (*Notropis hudsonius* Clinton)	n/a	0	0	0	0	0	0	0	0	0
Sculpin* (Cottus spp.)	n/a	0	0	0	0	1	0	0	0	0
Ninespine stickleback (*Pungitius pungitius* Linnaeus)	n/a	0	0	0	0	0	0	0	0	0

**Cottus bairdi* Girard and *Cottus cognatus* Richardson combined.
**Data unavailable due to incomplete sampling area construction.

Table 4. All fish captured in emergent fry traps on the Hamilton Reef and reference areas in 1982.

Hamilton Reef

Species	Sampling Period A	B	C	D	E	F	G	H	I	J
Johnny darter	17	29	46	11	19	15	6	3	3	3
Sculpin spp.	20	5	4	3	4	1	2	9	2	2
Spottail shiner	2	9	2	1	0	0	0	0	0	0
Ninespine stickleback	3	1	0	0	0	0	0	0	0	0
Rainbow smelt	0	0	0	0	0	10	5	3	3	24
Yellow perch	1	0	0	0	0	0	0	0	1	1
Trout perch	0	0	0	0	0	1	0	0	0	0
Cyprinidae spp.	0	0	0	0	0	0	0	0	0	0
Burbot	0	0	0	2	0	0	0	1	0	1

Sand Reference Area

Species	A	B	C	D	E	F	G	H	I	J
Johnny darter	n/a*	7	12	4	6	11	2	0	2	2
Sculpin spp.	n/a	2	3	10	8	5	3	1	2	2
Spottail shiner	n/a	0	0	0	0	0	0	0	0	0
Ninespine stickleback	n/a	0	0	0	0	0	0	0	0	0
Rainbow smelt	n/a	0	0	1	0	0	0	1	0	4
Yellow perch	n/a	0	0	0	0	0	0	0	0	0
Trout perch	n/a	0	0	0	0	0	0	0	0	0
Cyprinidae spp.	n/a	9	1	0	0	0	0	0	0	0
Burbot	n/a	0	1	0	0	1	1	0	1	0

*Data unavailable due to incomplete sampling area construction.

Table 5. Emergent fry trap data on juvenile fish presented by trap, substrate, and sampling period.

Hamilton Reef	Shallow Fry Traps					Deep Fry Traps				
Sampling Period	1	2	3	4	5	1	2	3	4	5
Period I	0	0	1	2	3	0	0	3	2	4
Transformed data*	0	0	.3	.48	.6	0	0	.6	.48	.7
Period II	8	4	5	9	7	2	1	16	2	4
Transformed data	.95	.7	.78	1	.9	.48	.3	1.23	.48	.7
Sand Reference Area										
Sampling Period										
Period I	0	1	4	2	4	5	6	7	6	0
Transformed data	0	.3	.7	.48	.7	.78	.84	.9	.84	0
Period II	0	1	1	0	0	2	5	4	4	0
Transformed data	0	.3	.3	0	0	.48	.78	.7	.7	0

* Data has been transformed to Log(Y+1) where Y equals the mean number of fry caught. Statistical analyses have been performed on thusly transformed data.

Table 6. Emergent fry trap data on adult fish presented by trap, substrate, and sampling period.

	Shallow Fry Traps					Deep Fry Traps				
Hamilton Reef										
Sampling Period	1	2	3	4	5	1	2	3	4	5
Period I	8	18	20	19	9	9	10	8	10	10
Transformed data	.95	1.28	1.32	1.3	1	1	1.04	.95	1.04	1.04
Period II	2	2	5	3	7	0	3	1	4	2
Transformed data	.48	.48	.78	.6	.9	0	.6	.3	.7	.48
Sand Reference Area										
Sampling Period										
Period I	1	2	1	0	3	5	5	6	0	6
Transformed data	.3	.48	.3	0	.6	.78	.78	.85	0	.85
Period II	0	0	0	0	0	2	0	7	3	4
Transformed data	0	0	0	0	0	.48	0	.9	.6	.7

Table 7. Emergent fry trap data on all fish captured presented by trap, substrate, and sampling period.

Hamilton Reef	Shallow Fry Traps					Deep Fry Traps				
Sampling Period	1	2	3	4	5	1	2	3	4	5
Period I	8	18	21	21	12	9	10	11	12	14
Transformed data	.95	1.28	1.34	1.34	1.11	1	1.04	1.08	1.11	1.18
Period II	10	6	10	12	14	2	4	17	6	6
Transformed data	1.04	.85	1.04	1.11	1.18	.48	.7	1.26	.85	.85
Sand Reference Area										
Sampling Period										
Period I	1	3	5	2	7	10	11	13	6	6
Transformed data	.3	.6	.78	.48	.9	1.04	1.08	1.15	.85	.85
Period II	0	1	1	0	0	4	5	11	7	4
Transformed data	0	.3	.3	0	0	.7	.78	1.08	.9	.7

where: μ = overall mean number of fish

α_i = effect of "i"th bottom substrate

β_j = effect of "j"th water depth

$(\alpha\beta)_{ij}$ = effect of interaction between bottom substrate and water depth

$T(ij)K$ = experimental error peculiar to the "k"th fry trap on the "i"th bottom substrate and the "j"th water depth (error for testing effects of substrate and depth.)

γ_l = effect of "l"th sampling period

$(\alpha\gamma)_{il}$ = effect of interaction between bottom substrate and sampling periods.

$(\beta\gamma)_{jl}$ = effect of interaction between water depth and sampling periods.

$(\alpha\beta\gamma)_{ijl}$ = effect of interaction between bottom substrates, water depths, and sampling periods

$E(ijKl)$ = experimental error associated with the "i"th bottom substrate at the "j"th water depth for the "k"th fry trap at the "l"th sampling period (error for testing all effects associated with sampling periods.)

The hypotheses examined were:

H_1 : no difference between bottom substrates

H_2 : no difference between water depths

H_3 : no interaction between bottom substrate and water depth

H_4 : no difference between sampling periods

H_5 : no interaction between bottom substrate and sampling period.

H_6 : no interaction between water depth and sampling period

H_7 : no interaction between bottom substrate, water depth, and sampling period.

All F-ratios from the analysis of variance were compared to their appropriate critical values (Gill,1978) and the results are presented in Tables 8,9, and 10.

For juvenile fish the average effects of periods and their interaction with substrate and substrate-depth combined were significant.

For adults, average effects of substrate, depth, and periods were significant as well as the interactions of substrate with depth and periods.

For all fish combined, average effects of substrate, depth, and periods were significant, as well as the interaction of substrate with depth.

Plotting the transformed mean numbers of fish caught for each sampling site versus both sampling periods, it can be seen that the reference area attracted more juvenile fish than the reef in sampling period I (Figure 8.). In sampling period II, however, the reef was seen to attract more

Table 10. Significance of abundance of all fish captured by substrate, depth, and sampling period using three-way analysis of variance.

Source of Variation	df	ss	ms	f-ratio Significance
Bottom Substrate	1	1.6	1.6	$P < .001$
Water Depth	1	.36	.36	$P < .01$
Bottom Substrate, Water Depth Interaction	1	1.28	1.28	$P < .001$
Experimental Error	16	.62	.04	
Sampling Period	1	.71	.71	$P < .001$
Bottom Substrate, Sampling Period Interaction	1	.04	.04	$P < .5$
Water Depth, Sampling Period Interaction	1	.04	.04	$P < .5$
Bottom Substrate, Water Depth, Sampling Period Interaction	1	.11	.11	$P < .08$
Experimental Error	16	.41	.03	

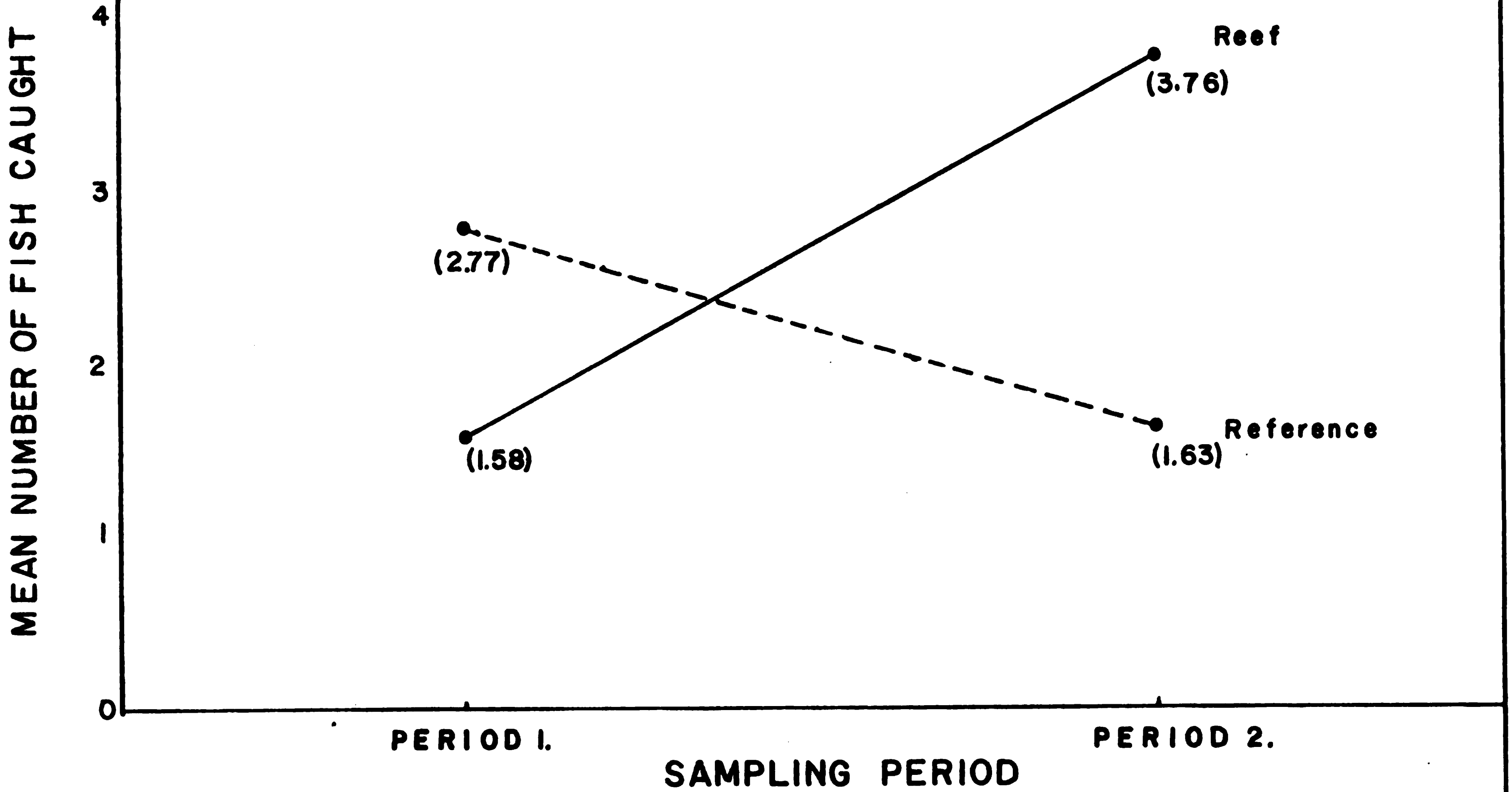


Figure 8. The effects of bottom substrate and sampling period on the distribution of juvenile fish caught in emergent fry traps

juvenile fish than the reference areas. One interpretation of these results is that juvenile young of the year fish are more mobile during the late spring and early summer months in attempts to locate cover structure for protection. Later in the season after locating the available cover structures juvenile fish concentrate near them. In addition, SCUBA observations in the reef area have revealed schools of unidentified fry with greater frequency in the mid and late summer than in the early summer. The difference between sampling period I and II suggests that the reef attracts more juvenile fish species later in the year than earlier in the year.

A highly significant three-way interaction between bottom substrate, water depth, and sampling period was also observed to affect the distribution of juvenile fish (Figure 9.). This interaction suggests, during period I, the reef attracted significantly fewer juvenile fish than the reference area. The converse was observed in period II where the reef attracted significantly more juvenile fish than the reference area. The magnitude difference in the number of juvenile fish captured during the two sampling periods favors the shallow reef sampling site as being more attractive to juvenile fish. These results would also indicate that in the later months of the summer shallow underwater structures would attract comparatively more juvenile fish than comparable deep water structures during the same time period.

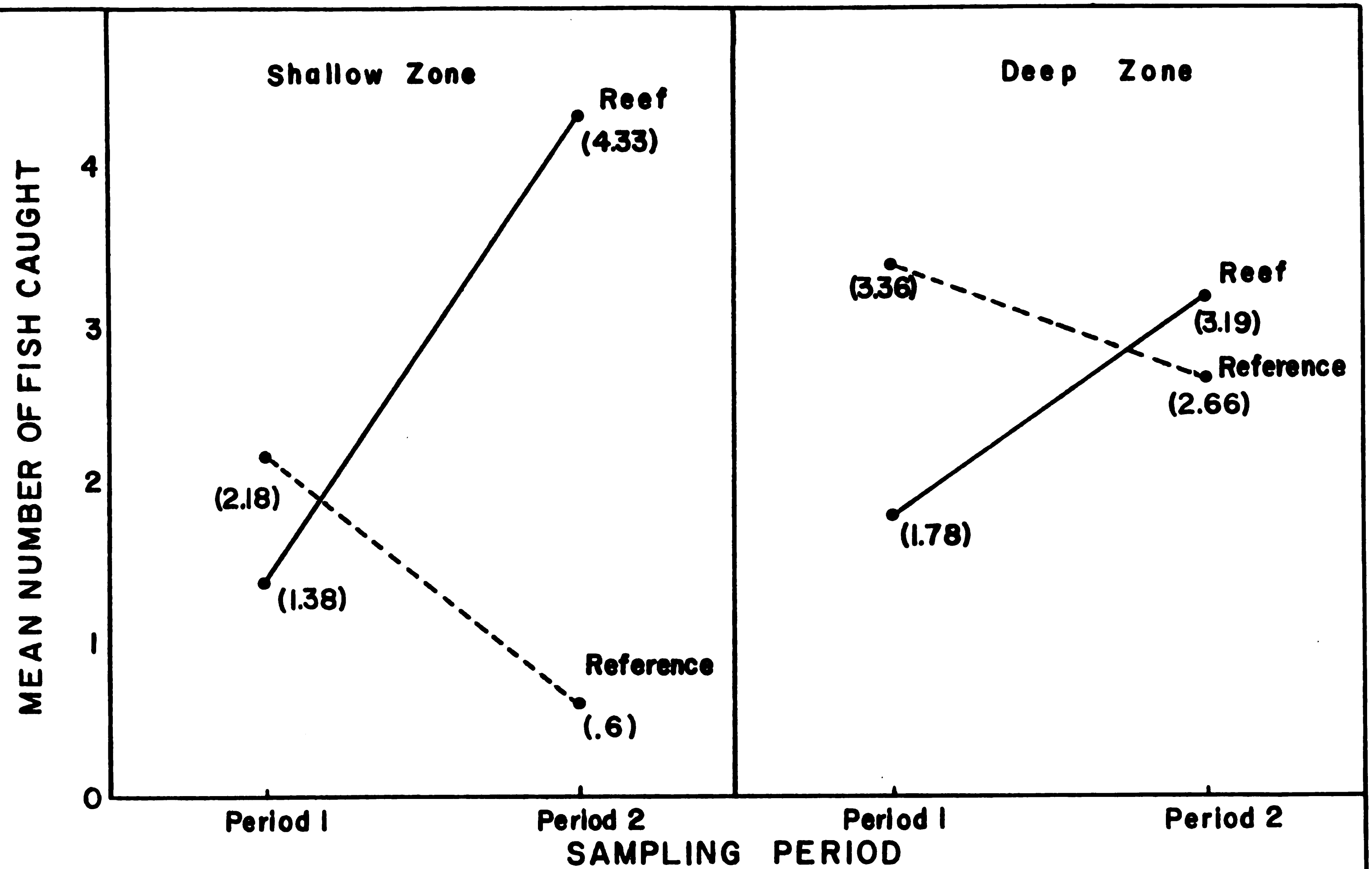


Figure 9. The effects of bottom substrate, water depth, and sampling period on the distribution of juvenile fish caught in emergent fry traps

The second major group analyzed with ANOVA techniques was the adult fish captured in the emergent fry traps. The first interaction found to be significant was that between bottom substrate and water depth (Figure 10.). In this case, at both water depths the mean number of fish caught on the reef was larger than that for the reference area. The number of fish caught at each site was similar to the pattern seen in prior interactions; a larger number of adult fish were captured on the shallow end of the reef. The conclusion infered from this is that adult fish prefer the reef to the reference area at any depth but prefer shallower depths if available.

The two-way interaction between bottom substrate and sampling period was also found to be significant for adult fish captured in emergent fry traps. As in the prior interaction (Figure 10.), the reef attracted more adult fish during both sampling periods but a decline in the number of adult fish was observed from sampling period I to II. This may be explained by a predominance of spawning fish on the reef during sampling period I. A similar event was observed during the summer of 1981 while performing preliminary fry trap work and was especially noticeable in numbers of johnny darters and ninespine sticklebacks (Figures A1.and A2.).

The third category of fry trap contents examined statistically was all fish combined. The first significant interaction for all fish combined was that between bottom substrate and water depth (Figure 11.). Inspection of the

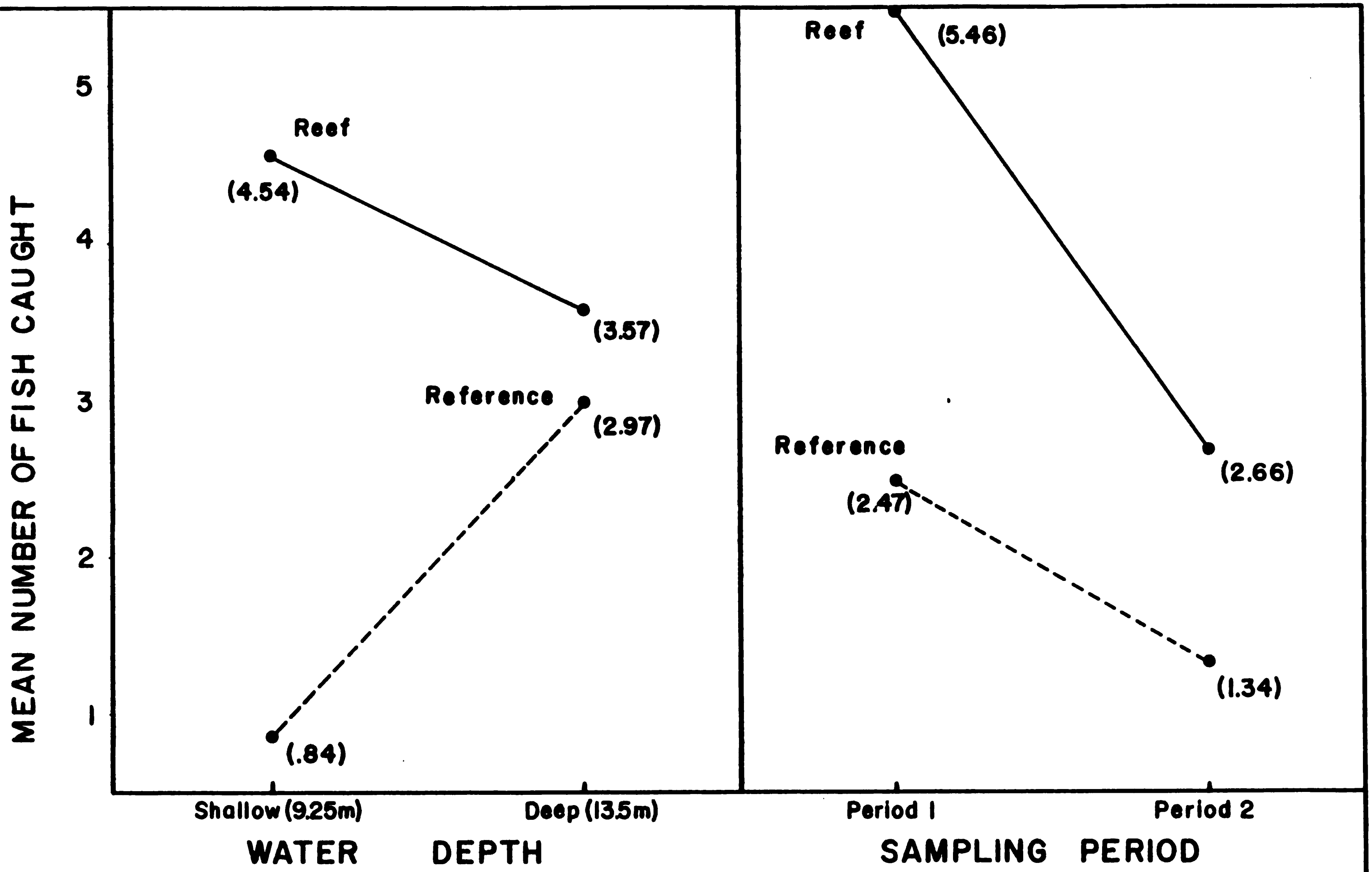


Figure 10. The effects of bottom substrate, water depth and bottom substrate, sampling period on the distribution of adult fish species captured in emergent fry traps

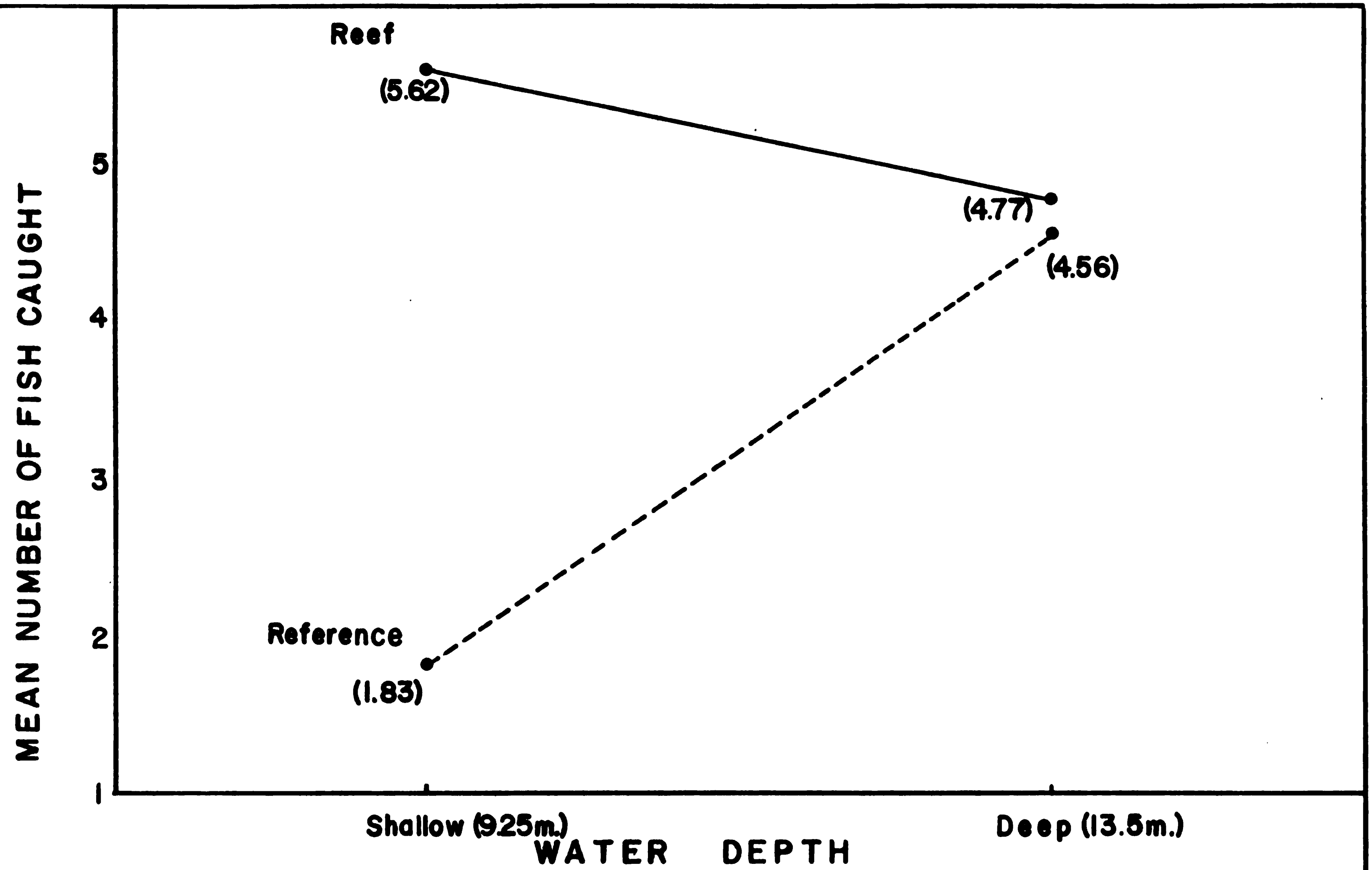


Figure 11. The effects of bottom substrate and water depth on the distribution of all fish caught in emergent fry traps

graph suggests that the reef has attracted more fish than the reference area at both depths. As in previous interactions, the shallow reef sampling site attracted more fish overall than the other three sites. Cover, food and light penetration are possible reasons for this difference.

Another statistically significant interaction for all fish combined was bottom substrate, water depth, and sampling period (Figure 12.). As in figures 10. and 11., the shallow reef site attracted the largest numbers of fish overall. However, the numbers of fish on the reef declined in both depth zones from the first to the second sampling periods. The decline in adult fish caught may be the result of spent adults dispersing from the reef as observed in 1981 (Figures A1. and A2.)

The design of emergent fry traps used on the Hamilton Reef permitted a potential cannibalism problem. Because the contents of individual catchment bottles were not kept separate, numbers of fry or juvenile fish may have been underestimated. Stomach dissections were performed to evaluate adult cannibals. Observations were made under a variable 10-20 power binocular dissecting microscope. The results of the analysis are presented in Table 11. and show that no cannibalism had occurred. Stomach contents were distinctive and contained primarily insect parts, empty fish-egg casings, acanthocephalan parasites, isopods, and gastropods.

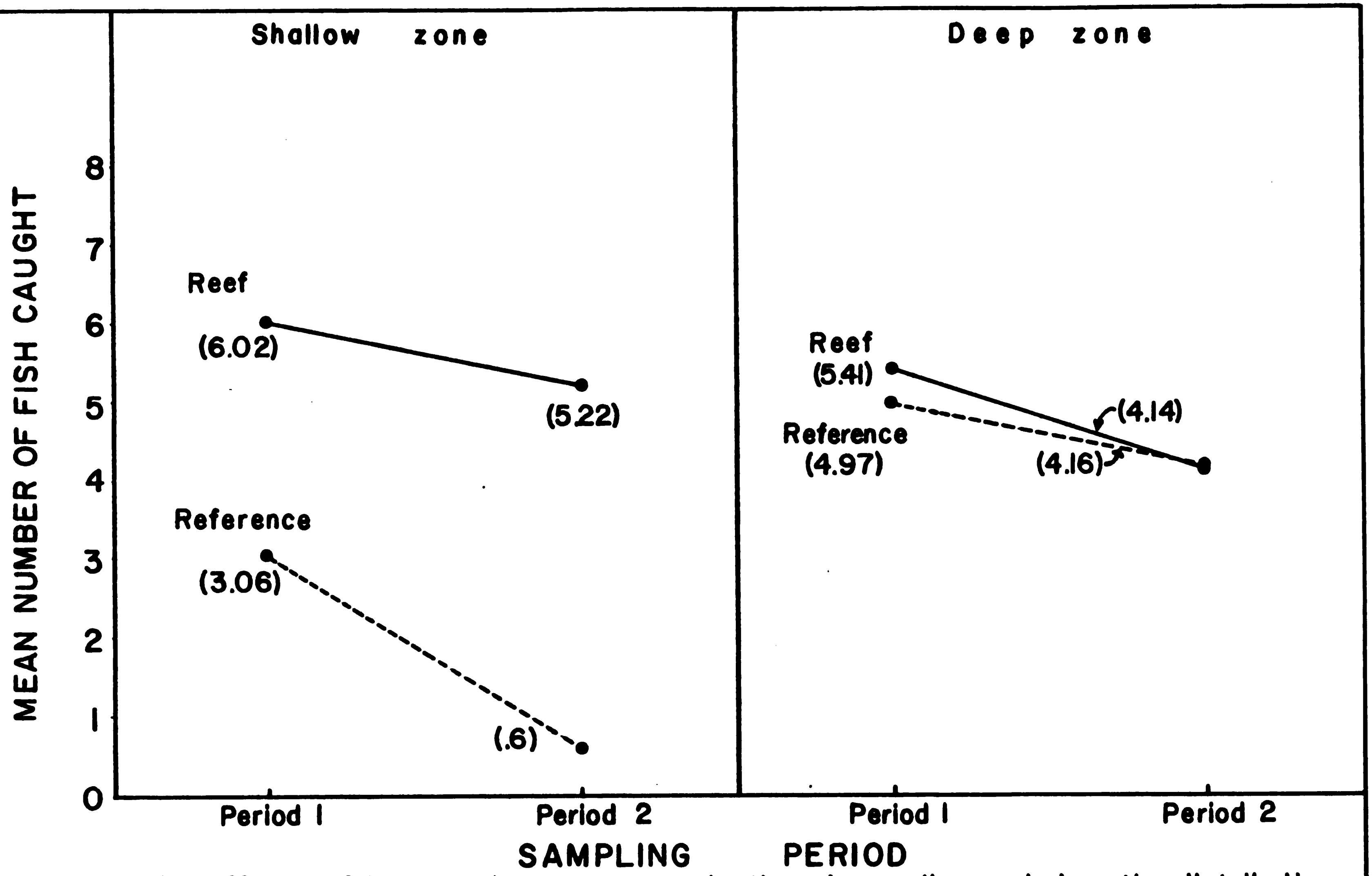


Figure 12. The effects of bottom substrate, water depth and sampling period on the distribution of all fish caught in emergent fry traps

Table 11. Results of stomach analysis on emergent fry trap adult fish species.

Fish Species	Number Dissected	Observed Stomach Contents
Johnny darter	146	1) Empty 2) Chironomidae*1 and Insect Parts 3) Unidentified Material 4) Fish Egg Casings 5) *Gammarus* spp.
Ninespine stickleback	4	1) Empty 2) Unidentified Material 3) Fish Egg Casings 4) Acanthocephalan Invertebrates*2
Sculpin spp. (*Cottus bairdi* and *Cottus cognatus*)	11	1) Empty 2) Insect Parts 3) Small Stones 4) Fish Egg Casings 5) Isopods, Gastropods 6) Detritus 7) Unidentified Material 8) Acanthocephalan Invertebrates
Spottail shiner	6	1) Empty
Yellow perch	3	1) *Daphnia* spp. *Cyclops* spp. Invertebrates 2) Empty
Burbot	3	1) Empty 2) *Gammarus* spp.

*1 For additional information see Merritt, p.345-76.
*2 For additional information see Barnes, p.309.

To ensure that emergent fry were adequately sampled during the early months of the year, emergent fry traps were placed on the reef and reference areas during April of 1983. On April 5 all preliminary work was completed and fry traps were placed in their respective sampling areas. The same sampling scheme was utilized as in the previous year. Inclement weather conditions on Lake Michigan prohibited diving until April 26. An examination of the reef sites on the 26th revealed that the emergent fry traps were destroyed and at the sand reference areas they were gone. Traps that were located on the reef were in poor condition, smashed flat with the sampling apparatus destroyed. In one instance a trap was torn from it's steel base, leaving the base as the only evidence that a fry trap had existed. Because of time constraints and the poor condition of the remaining fry traps, no further attempt was made to collect fry trap data. The cause of the fry trap destruction could not be resolved but it was speculated that water currents, probably in conjunction with underwater debris, were the major force behind these losses.

Larval Fish Trawling

Trawling for larval fish was performed 4 times on the Hamilton Reef during the spring months of 1982 and 1983 (Table 12.). Contents of the otter trawls made on April 23 and May 21 of 1982 included trout perch, rainbow smelt, sculpins, alewifes (<u>Alosa pseudoharengus</u> Wilson), and spottail shiners but no lake trout were captured.

Table 12. Summary of larval fish trawling on the Hamilton Reef in 1982 and 1983.

Trawling Date	Trawl Type	Sampling Organization	Results
4/23/82	otter	University of Michigan	trout perch rainbow smelt sculpin spp. spottail shiner alewife
5/21/82	otter	University of Michigan	trout perch rainbow smelt sculpin spp. spottail shiner alewife
5/5/83	beam	Michigan State University	No Fish Larvae Microcrustacea
5/18/83	beam	Michigan State University	Poor Weather Conditions

Larval fish trawling during spring of 1983 was performed with a beam trawl. On May 5 trawl contents contained microcrustacea and planktonic algae; no larvae were captured. Inclement weather conditions aborted a subsequent attempt on May 18.

Experimental Gill Netting

Experimental gill netting was conducted on the Hamilton Artificial Reef to determine if fish species were using the reef and to monitor the sexual condition of adult game fish. All fall gill netting was conducted over the reef to determine the sexual condition of adult lake trout in the area. A summary of fall netting data is presented in Table 13. Fall gill netting also was important for coordination of egg pumping activities on the reef. Gill netting, and subsequent stomach analysis, made it possible to coordinate egg pumping times with lake trout sexual maturity and presence on the reef. A summary of this data is presented in Table 14.

Table 14. Summary of lake trout sexual condition for 1980, 1981, and 1982.

		Sampling Date				
		1980			1981	1982
Sex	Condition	10/23	10/28	11/7	11/14	10/26
Male	Green	0	0	0	0	0
	Ripe	10	3	2	0	0
	Immature	0	0	0	0	0
Female	Green	13	7	5	1	0
	Ripe	0	1	2	0	2
	Spent	0	0	3	0	0
	Immature	0	0	1	0	0

Lake trout were captured at all stages of sexual maturity during 1980 with results indicating mature lake trout were in the reef area.

Stomach analysis were conducted on all possible lake trout egg predators caught in the 1980 and 1981 fall nettings. These analyses provided little evidence that lake trout spawning was occurring on or near the reef. The only

Table 13. Summary of fall gill netting on the Hamilton Reef in 1980, 1981, and 1982.

Fish Species	Sampling Date					
	10/23/80	10/28/80	11/7/80	12/11/80	11/14/81	10/26/82
Lake trout (*Salvelinus namaycush* Walbaum)	23	11	13		1	2
Brown trout (*Salmo trutta* Linnaeus)			2		4	
Rainbow trout (*Salmo gairdnerii* Richardson)					1	
Chinook salmon (*Oncorhynchus tshawytscha* Walbaum)			1		4	
Coho salmon (*Oncorhynchus kisutch* Walbaum)		1				
Lake whitefish (*Coregonus clupeaformis* Mitchill)		2	3			
Round whitefish (*Prosopium cylindraceum* Pallas)				27	23	
Burbot (*Lota lota* Linnaeus)				3	5	
Yellow perch (*Perca flavescens* Mitchill)				13	11	
Walleye (*Stizostedion vitreum* Mitchill)					16	6
Redhorse sucker (*Moxostoma macrolepidotum* Lesueur)		9	12			2
White sucker (*Catostomus commersonnii* Lacepede)		7		1		2
Longnose sucker (*Catostomus catostomus* Forster)		4				1
Gizzard shad (*Dorosoma cepedianum* Lesueur)					5	4
Northern pike (*Esox lucius* Linnaeus)		1				
Rainbow smelt (*Osmerus mordax* Mitchill)					2	
Channel catfish (*Ictalurus punctatus* Rafinesque)						1

evidence that spawning of any kind occurred was found in November of 1981 when several round whitefish stomachs were found to contain unidentified outer fish egg casings.

Further gill netting data was obtained in the summer of 1982. These data were used to compare statistically the numbers of yellow perch and all fish species combined found over the reef and north reference area (Tables 15. and 16.).

A two-way analysis of variance (ANOVA) was conducted on the data utilizing a transformation of logarithm (Y + 1) where Y equals the number of fish caught per hour. This transformation assured that the assumption of normal distribution was not violated. Netting was conducted 6 times from July to October during the 1982 field season. Unfortunately, on two occasions, August 11 and October 11, research gill nets were stolen leaving a total of 4 sampling dates for the ANOVA analysis. ANOVA was applied to the data from the four gill netting dates according to the following model:

$$Y = \mu + \alpha_i + \beta_j + \left[(\alpha\beta)_{ij} + E(ijk)\right]$$

(i = 1, 2; j = 1, 2...4; k =1)

where: μ = overall mean number of fish caught per hour

α_i = main effect of the "i"th bottom substrate

β_j = main effect of the "j"th sampling data

Table 15. Catch per effort of yellow perch caught by gill net in 1982.

Sampling Date	Hamilton Reef		North Reference Area	
7/13/82	2.7	(.57)*	1.54	(.40)
7/27/82	1.04	(.31)	3.54	(.66)
8/24/82	.58	(.20)	1.67	(.43)
8/31/82	4.5	(.74)	2.75	(.57)

*Parenthesis indicate data have been transformed to log(Y+1) where Y equals the number of yellow perch caught per hour.

Table 16. Catch per effort of all fish caught by gill net in 1982.

Sampling Date	Hamilton Reef		North Reference Area	
7/13/82	11.17	(1.09)	13.38	(1.16)
7/27/82	2.33	(.52)	8.13	(.96)
8/24/82	3.17	(.62)	2.75	(.57)
8/31/82	7.33	(.92)	3.83	(.68)

$\left[(\alpha\beta)_{ij} + E_{(ijK)}\right]$ = confounded interaction and error term because of no net replication *1

*1 Note: Data represent the combined catch per hour of two nets instead of each individual net's contents. As a result, the interaction of bottom substrate and sampling date is confounded with experimental error. This confounded error term acts as a fail-safe error term in that any main effects found to be significant, in spite of the inflated error term, can be considered truly significant.

The hypotheses of the ANOVA were as follows:

H_1: no difference between bottom substrates

H_2: no difference among sampling dates

F-ratios for yellow perch and all fish combined support the hypotheses presented of no difference between bottom substrates and among sampling dates (Tables 17 and 18). However, it is possible that a substrate period interaction biased the tests so that observed differences appeared to be insignificant statistically. A graphic presentation of the transformed number of fish caught per hour versus netting period is presented in Figures 13 and 14. Figure 13 shows the reef to have attracted more perch than the reference area during netting periods I and IV but comparatively less

Table 17. Significance of yellow perch abundance by bottom substrate and sampling date using two-way analysis of variance.

Source of Variation	df	ss	ms	f-ratio Significance
Bottom Substrate	1	.01	.01	P < .5
Sampling Date	3	.12	.04	P < .5
Confounded Error	3	.1	.03	

Table 18. Significance of all fish abundance by bottom substrate and sampling date using two-way analysis of variance.

Source of Variation	df	ss	ms	f-ratio Significance
Bottom Substrate	1	.01	.01	P < .5
Sampling Date	3	.28	.093	P < .25
Confounded Error	3	.14	.046	

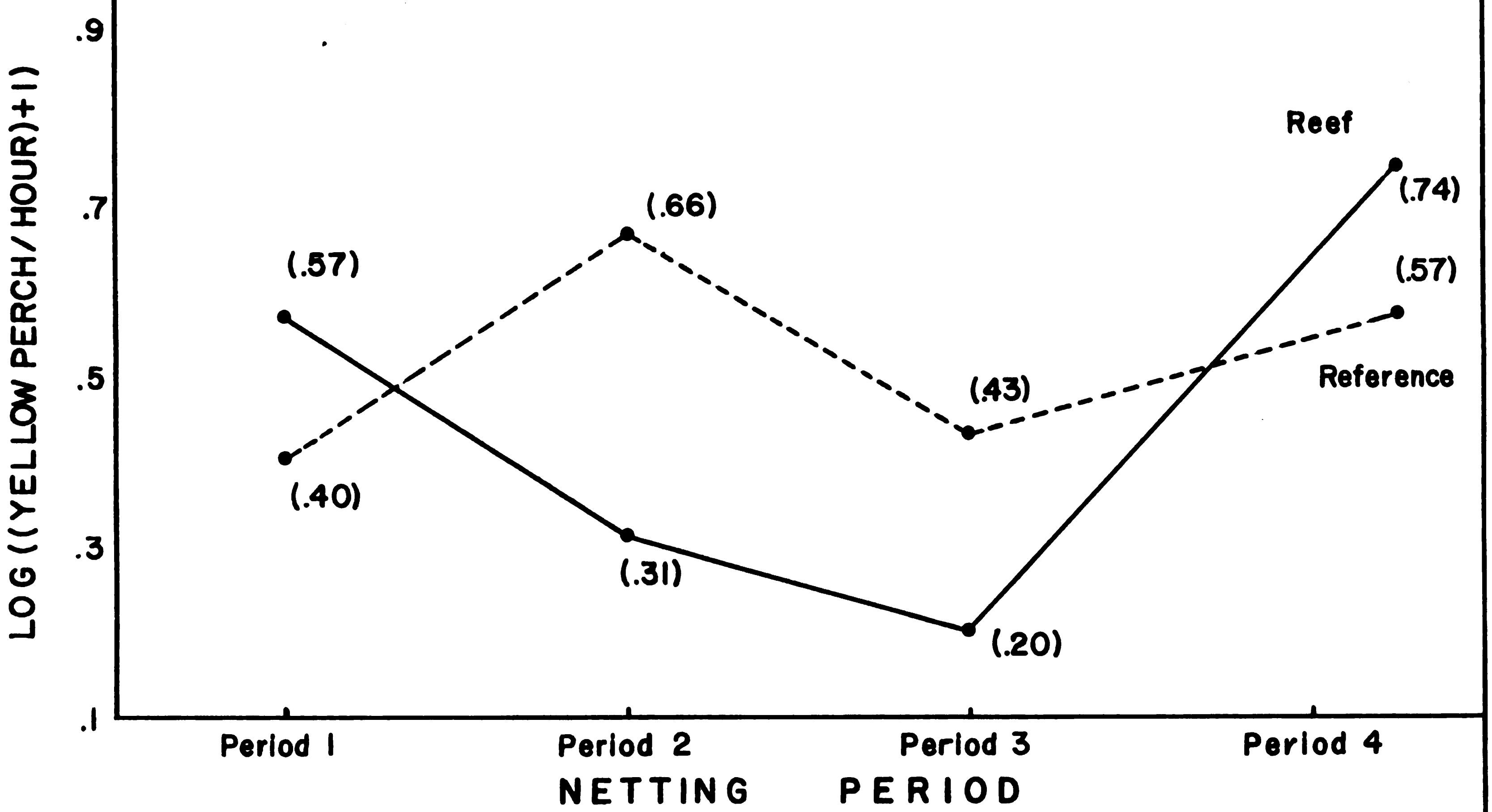


Figure 13. Results of gill netting for yellow perch

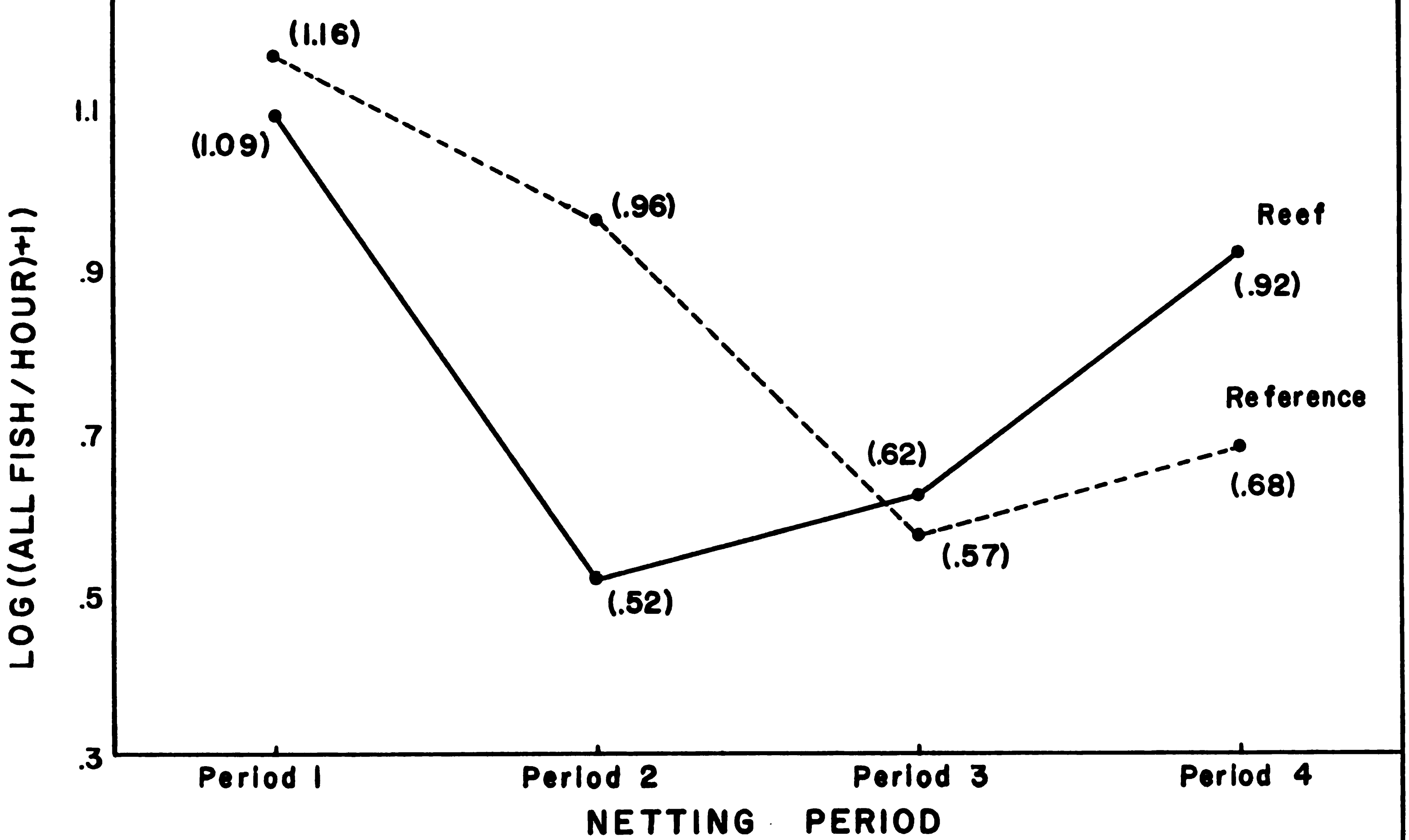


Figure 14. Results of gill netting for all fish species combined

during periods II and III. Despite possible bias from interaction, it appears that there is no significant attraction to the reef over the reference area for yellow perch.

Figure 14 shows the reef to have attracted more total fish than the reference area during netting periods I and II. Again it appears that there is no significant difference in attraction between the reef and reference area. Although the mean number of fish caught per hour during each sampling period does not differ significantly, the possibility of a significant time interaction may exist. Additional netting would have been required to demonstrate this with any degree of certainty.

Light Measurements

Regression analysis of the natural logarithms of light versus water depth yielded an extinction coefficient of .156 for the Hamilton Reef. This coefficient was used to calculate light penetration on the reef (Figure 15.) at each depth required. Lateral surface area calculations and calculated light intensities are presented in Table 19 and equal a total light intensity of 40,592.5 μE/sec for the entire reef.

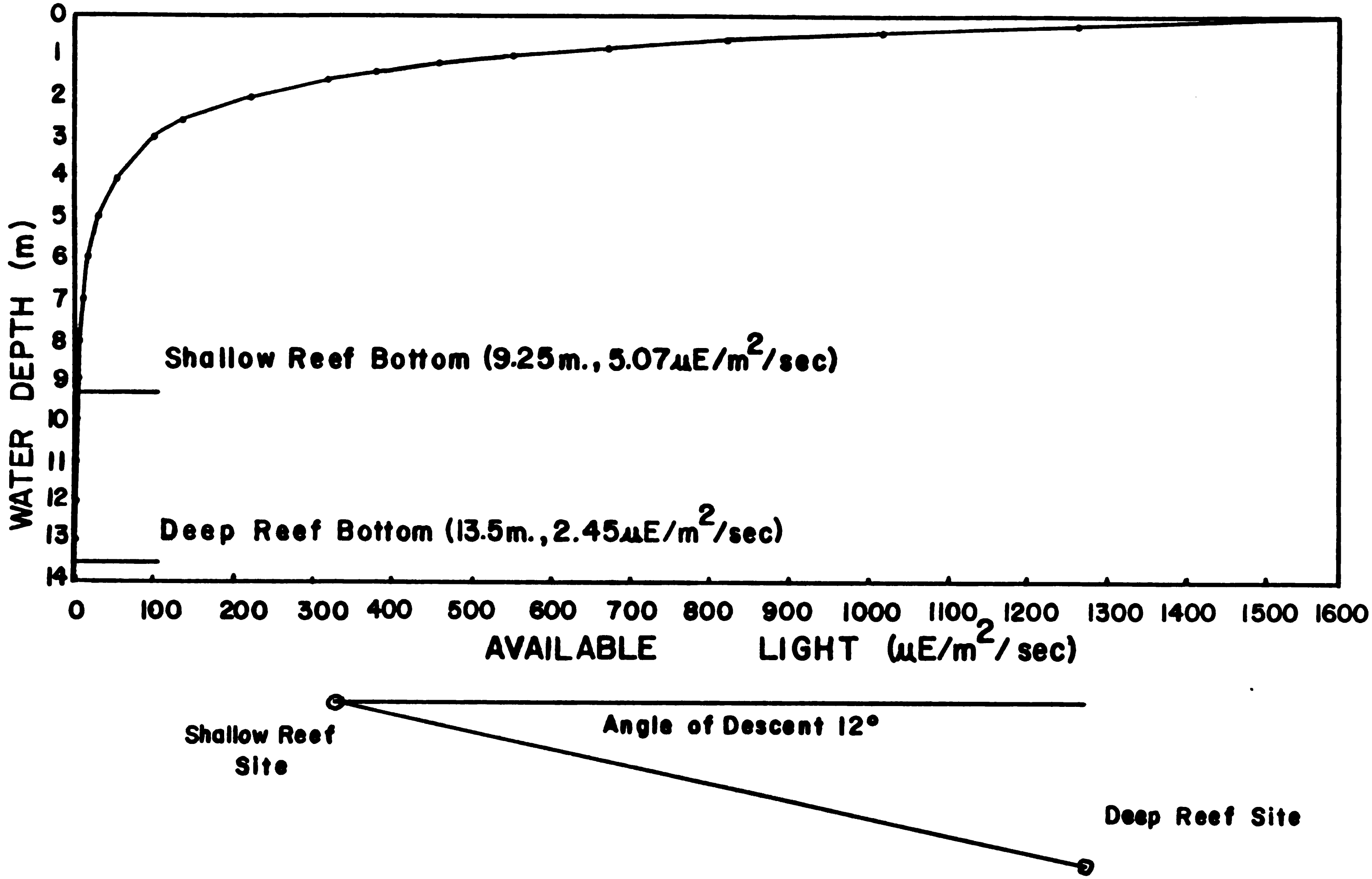


Figure 15. A calculated light curve for the Hamilton Artificial Reef

Table 19. Estimated lateral area and available light for the deep and shallow zones* of the Hamilton Reef.

Water Depth (m) Shallow & Deep Reef	Estimated Lateral Area: Shallow Piles 16-29 (m^2)	Estimated Lateral Area: Deep Piles 1-15 (m^2)	Available Light: Shallow Piles ($uE/m^2/sec$)	Available Light: Deep Piles ($uE/m^2/sec$)	Calculated Available Light: Shallow Piles (uE/sec)	Calculated Available Light: Deep Piles (uE/sec)	Total Calculated Available Light: Reef (uE/sec)
7.3 11.55	97.82	78.29	10.61	3.38	1037.87	264.62	1302.49
7.6 11.85	294.71	234.68	9.52	3.19	2805.64	748.63	3554.27
7.9 12.15	492.25	391.52	8.59	3.03	4228.43	1186.30	5414.73
8.2 12.45	687.52	549.43	7.78	2.88	5348.90	1582.36	6932.26
8.5 12.75	883.60	706.72	7.09	2.74	6264.72	1936.41	8201.13
8.8 13.05	1080.96	861.94	6.48	2.62	7004.62	2258.30	9262.92
9.1 13.35	1284.47	1020.88	5.95	2.51	7643.00	2562.41	10205.41
				Totals:	34333.18	10539.03	44872.21

*The Hamilton Reef was arbitrarily divided into deep and shallow zones. Piles numbered 1-15 and 16-29 represent the deep and shallow zones repectively. All available light readings were obtained from measured light intensities on the reef.

Reef Depth Measurements

Reef depth measurements were taken on August 4, 1982, July 11, 1983, and August 24, 1983. The results of these three measurements are given in Table 20. Observation of the single valid measurement reveals the reef to have settled approximately 1.2 meters on the shallow end and 0.62 meters on the deep end from August of 1982 to July of 1983.

One important factor should be considered before any conclusions on reef settling are drawn. Given the constantly changing nature of the reef rock piles and the repeated covering and uncovering of the permanent buoy anchors, it is difficult to determine a permanent reference point on the reef and, therefore, difficult to state conclusively what is happening to the reef. Obtaining repetitive depth measurements on the reef was made difficult because there are no stationary points from which to do so. All measurements taken thus far were obtained as near the base of the permanent buoys as possible. Given the amount of anchor movement that has been observed during two field seasons of SCUBA observation the reef seems to be settling. The degree to which this is occurring is debatable. In any event this phenomenon should be studied in greater detail to establish the actual degree of settling.

Table 20. Depth measurements of the Hamilton Reef.

Measurement Location	Measurement Date	Current Conditions	Measured* Depth (m)	Change in Depth (m)	Benchmark Height above Water (cm)
Shallow Reef	8/4/82	None	9.28		47
Deep Reef	8/4/82	None	13.17		47
Shallow Reef	7/11/83	None	10.47	1.19	15.24
Deep Reef	7/11/83	None	13.79	.62	15.24

*Distance from base of permanent buoy to the surface.

DISCUSSION

To appraise the Hamilton Reef objectively it must be evaluated on the basis of recorded data. The following discussion will evaluate the Hamilton Reef on the basis of its fish reproduction, fish attraction, and a comparison to a similar reef structure.

Game fish reproduction on the Hamilton Reef was limited to one species. SCUBA observations, gill netting, egg trays, and egg pumping revealed yellow perch to be the only species spawning on the reef. Lake trout spawning was not detected, although fish in all stages of sexual maturity were captured over the reef. To date, the calculated sport fish reproduction generated by the Hamilton Reef has been 704 yellow perch egg masses.

Fish attraction to the Hamilton Reef was evaluated in terms of adult game fish species and forage fish species captured over the reef and reference areas. Forage fish attraction to the Hamilton Reef was studied in three categories: juvenile fish, adult fish, and a category of all fish combined. Examination of Figures 8, 9, 10, 11, and 12 show the reef has attracted more fish than the sand reference areas. These figures also show that of reef sampling sites the shallow site consistently attracts more forage species than the deep. The one exception being a second sampling period preference for the reef by juvenile forage species. The attraction for the sand reference area during sampling period I may be the result of juvenile forage fish attempting to locate suitable cover structures. Later in the season after locating cover structures like the Hamilton Reef, juveniles concentrate near these for protection. Adult forage species and the category of all fish combined show no sampling period preference in their attraction to the Hamilton Reef. Both groups preferred the reef and more specifically, the shallow end.

A variety of factors may be responsible for the observed forage fish attraction to the Hamilton Reef. However, the cover that the reef provides forage fish species is certainly one of the more important factors. The Hamilton Reef, because of its rock substrate, provides needed refuge for forage fish species unlike the reference area sand substrate. In addition to prefering the rock substrate of the reef, forage fish exhibited a greater attraction to the shallow over the deep sampling site. This attraction may be explained in terms of bottom illumination at the specific reef sampling site. At greater depths illumination is low and consequently forage fish species find it easier to conceal themselves on both the deep reef and sand reference areas (Figure 12.). Because forage species can be concealed easier at deeper depths any attraction to the deep end of the reef, for refuge or cover purposes, is reduced. Conversely, the shallow reef site attracts more forage species because of the cover it provides at higher bottom light intensities. The shallow sand reference area, under similar shallow water illumination, cannot provide the protection found on the reef and as a result fish numbers caught there were less.

Water depth is another factor that may influence fish attraction to the Hamilton Reef. Figures 8, 9, 10, 11, and 12 illustrate increased forage fish capture at a corresponding decrease in water depth. Assuming that reef bottom cover is constant from shallow to deep sampling sites, it is plausable that light penetration also is involved in fish attraction to the reef. Light penetration is inversely related to water depth and directly related to periphyton or food production on the reef. Since underwater light intensity is related to the water extinction coefficient and depth, the deeper the reef is located the less light that can reach it, resulting in a low potential for periphyton production (Figure 15.). If periphyton production, based on available light, is a contributing factor to forage fish attraction, then it should be detectable by plotting mean forage fish numbers caught versus light intensity. Figures 16. and 17. show lower light intensities correspond to lower fish numbers while at

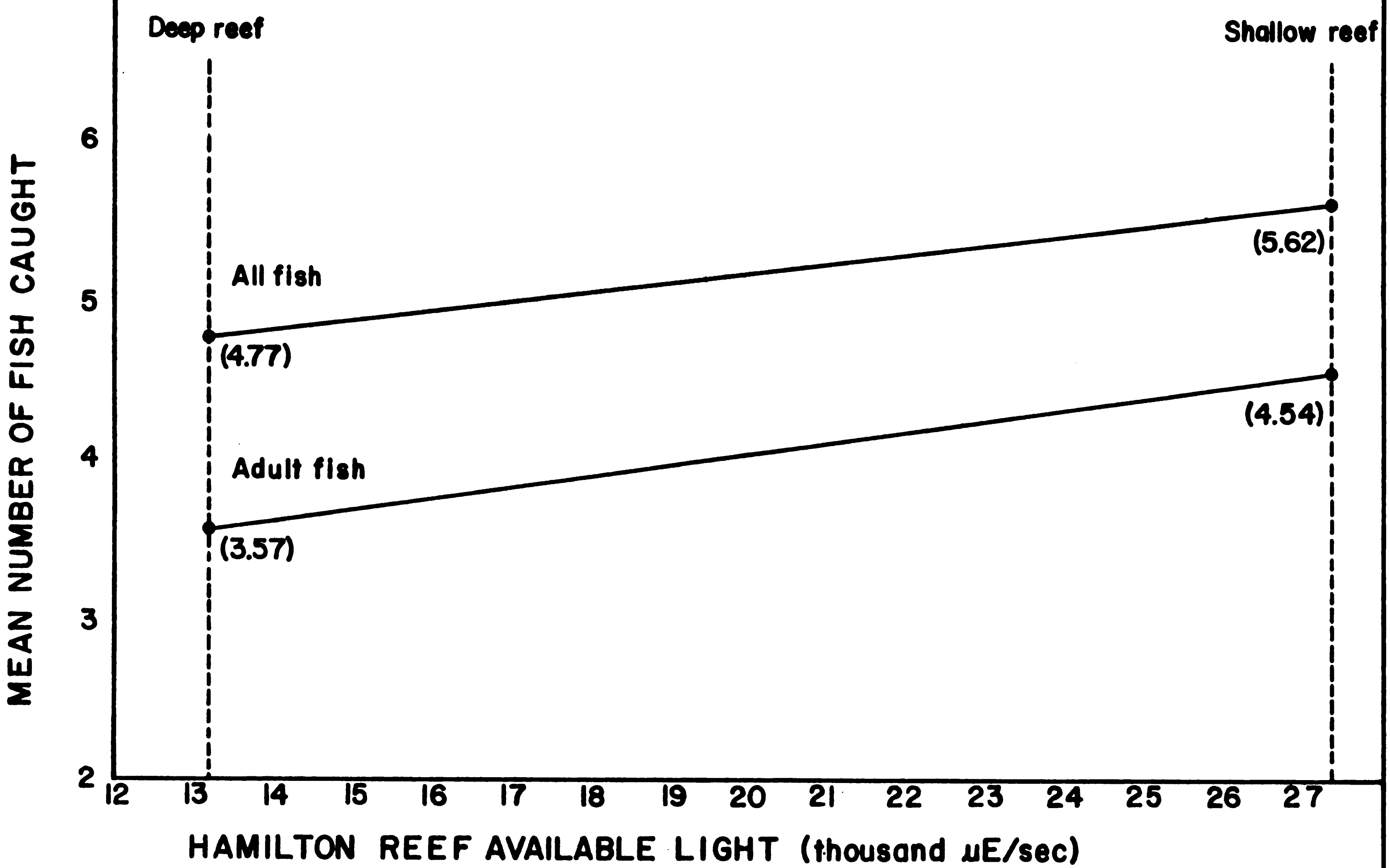


Figure 16. Captured total fish and adult fish from emergent fry traps in relation to available reef light

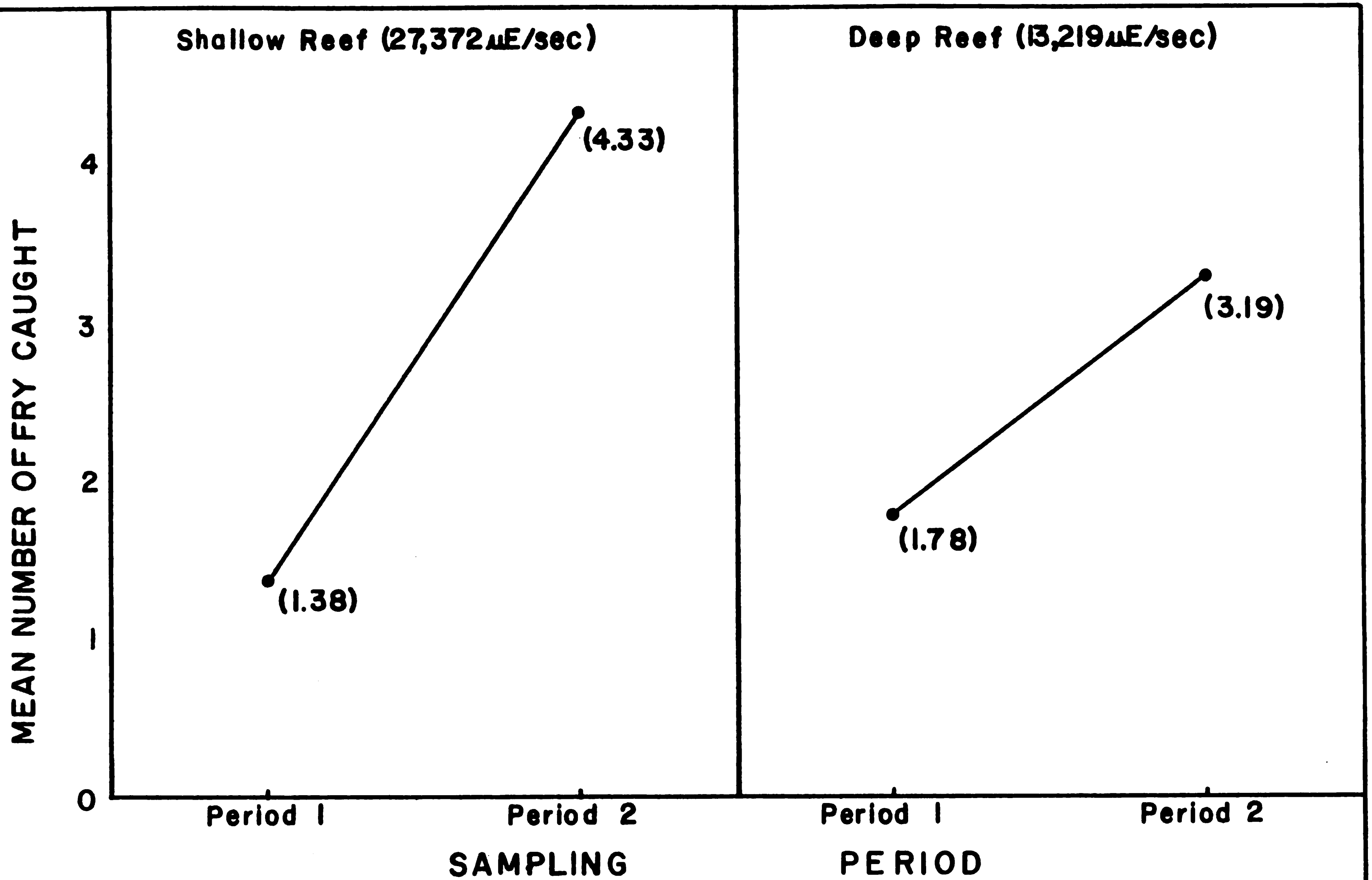


Figure 17. Captured juvenile fish or fry from emergent fry traps in relation to available reef light

higher intensities higher fish numbers are observed. In all examined categories, adult fish, all fish combined, and juvenile fish (during the second sampling period), there was a definite preference for higher light intensity areas where higher periphyton production probably was a contributing factor. SCUBA observations supported this in that attached periphyton were noticeably more abundant on the shallow reef sampling site than its deep-water counterpart.

Water temperatures in addition to cover and periphyton production also may influence forage fish attraction to the Hamilton Reef. SCUBA observation on the reef and reference areas during periods of warm and cold water temperatures verified this. When reef temperatures were warm forage species such as johnny darters, slimey sculpins, and mottled sculpins were commonly observed, however, when reef water temperatures were low fish were few or absent from the reef. Reef temperatures were generally uniform from end to end allowing accurate predictions of fish presence or absence prior to SCUBA observations on any given dive. This relationship between temperature and fish presence or absence was observed in many instances on the Hamilton Reef and Muskegon breakwall.

Attraction of adult game fish species to the Hamilton Reef was evaluated through the use of gill nets. Gill netting data for yellow perch and all captured species combined showed no statistical evidence of an attraction to the reef over the sand reference area (Figures 13. and 14.). In a similar yellow perch gill netting study Biener (1982) netted over the Hamilton Reef and over north and south reference areas. Biener found the reef to have attracted significantly more perch than the reference areas on 50% of the dates sampled. Overall, 6 of 11 statistical contrasts favored the reef as having attracted more perch than the reference areas north and south of the reef, although, sample means were higher for the reef in three of the five non-significant statistical contrasts. Gill netting data shown in figures 13 and 14 revealed similar results for yellow perch and all fish combined. The results of this study, supported by Biener's data, indicate the reef has an attraction for perch and other species, however, the attraction is only moderately strong.

To evaluate the Hamilton Reef it is helpful to compare it to a similar existing structure. Approximately one kilometer north of the reef the United States Army Corps of Engineers maintains a large navigation structure, the Muskegon breakwall (Figure 18.). This structure is very similar in composition to the reef. For comparative purposes, the Muskegon River breakwall will be used here as a reference for the Hamilton Reef.

Food energy input for both the Hamilton Reef and the Muskegon River breakwall comes from two primary sources, planktonic fallout and periphyton growth. Planktonic fall-

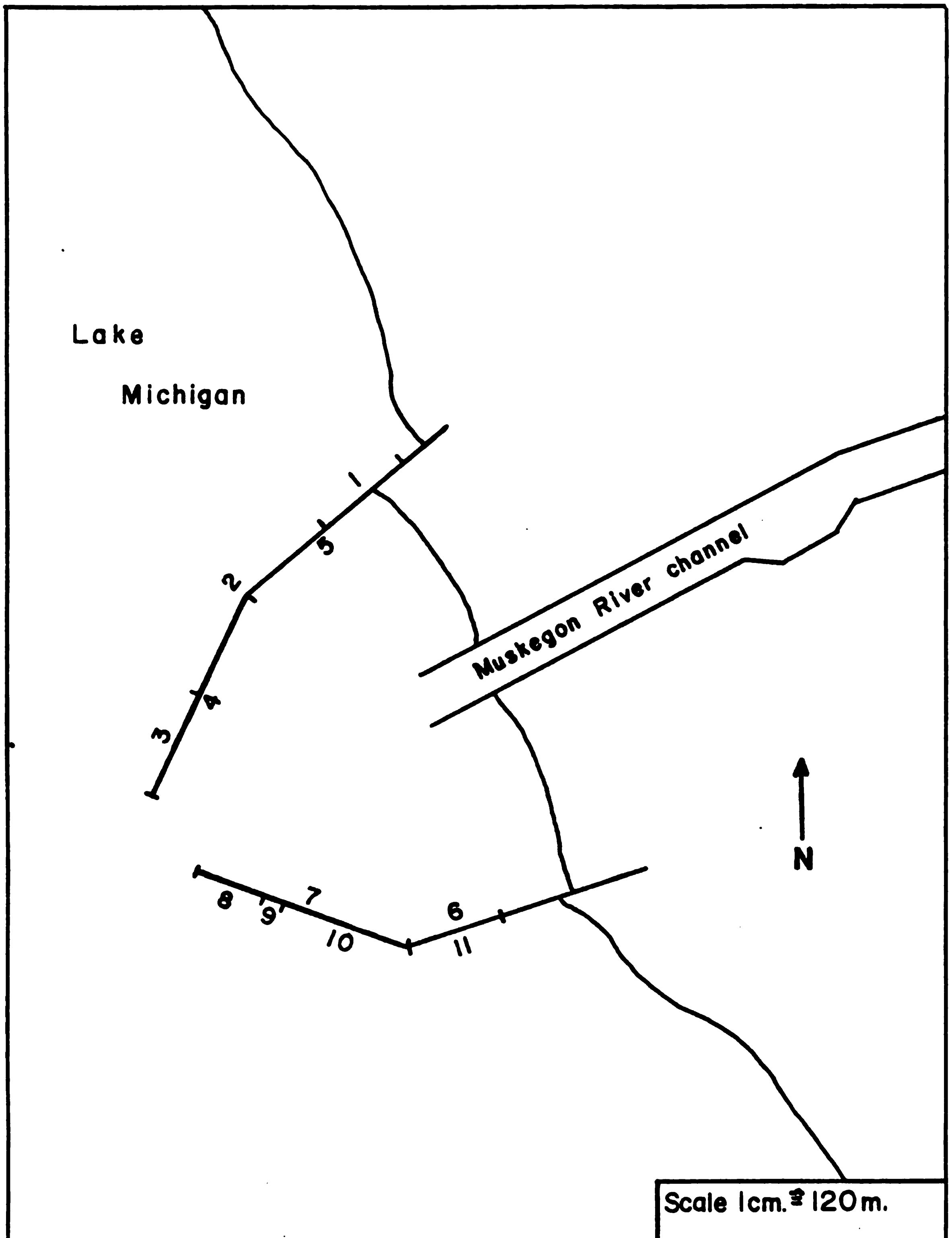


Figure 18. Muskegon River Breakwall sections used for lateral area estimates

out from the Muskegon River-Lake system is a continuous process. The process of planktonic fallout slows and finally stops as river water is dispersed into Lake Michigan. Light measurements taken inside and outside the breakwall and on the reef reveal a decreasing light extinction coefficient as distance from the river mouth increases. To determine if inside breakwall (.686), outside breakwall (.406), and reef (.156) extinction coefficients differed significantly from each other, they were compared using a Students "t" statistical test for comparing regression slopes (Table A2.) This comparison disclosed that coefficients for each of the sampling sites were significantly different (Table 21.).

Table 21. Summary of students "t" test results

Statistical Comparison	"t" Value	Level of Significance
Reef Extinction Coefficient versus Inside Breakwall Extinction Coefficient	15.3	$P < .00025$
Reef Extinction Coefficient versus Outside Breakwall Extinction Coefficient	4.7	$P < .00025$
Inside Breakwall Extinction Coefficient versus Outside Breakwall Extinction Coefficient	5.4	$P < .00025$

The observed decrease in extinction coefficient is undoubtedly due to a decrease in water turbidity which is probably due largely to plankton. On the reef this translates into less energy from planktonic fallout while on the breakwall it means the opposite, a higher energy input.

The second energy source for the reef and breakwall is attached periphytic algae. Periphyton, because it is attached to submerged substrates, must have a sufficient supply of light from the surface to survive. Extinction coefficients measured for the reef and breakwall reveal water clarity increases with distance from the river mouth. This appears as a benefit to the reef, however, the depth of the water over the reef limits light penetration to low levels. The breakwall appears to be handicapped by high light extinction coefficients, but the large shallow area of the breakwall easily makes up for any reduction in light penetration.

To place the reef and Muskegon River breakwall in perspective each must be considered in terms of size, light received, and depth underwater. Area estimates for the reef were calculated from side-scan sonar soundings (Table A4.and Figure A4.), while breakwall area estimates were determined from Army Corps of Engineers drawings and blueprints (Figure 18.and Tables 22. and A3.). Calculated light per area data has been plotted versus water depth in Figure 19. and reveals the basic differences between these two structures. The breakwall is much larger in size, has large shallow

Table 22. Calculated surface area and available light on the Muskegon River Breakwall.

Depth Below Water Surface (m)	Calculated Surface Area (m^2)	Calculated Available Light (uE/sec)
0.0-0.5	2744.38	853986.41
0.5-1.0	2744.38	104687.50
1.0-1.5	2744.38	28018.16
1.5-2.0	2744.38	12007.30
2.0-2.5	2744.38	7100.99
2.5-3.0	2653.24	4731.33
3.0-3.5	2276.81	3316.89
3.5-4.0	2109.18	2720.39
4.0-4.5	1629.14	1965.69
4.5-5.0	1144.76	1339.25
5.0-5.5	720.22	843.54
5.5-6.0	368.86	410.15
6.0-6.5	222.37	240.07
6.5-7.0	185.17	194.43
7.0-7.5	185.17	192.58
7.5-8.0	154.40	158.93
Totals	25371.12	1033188.20

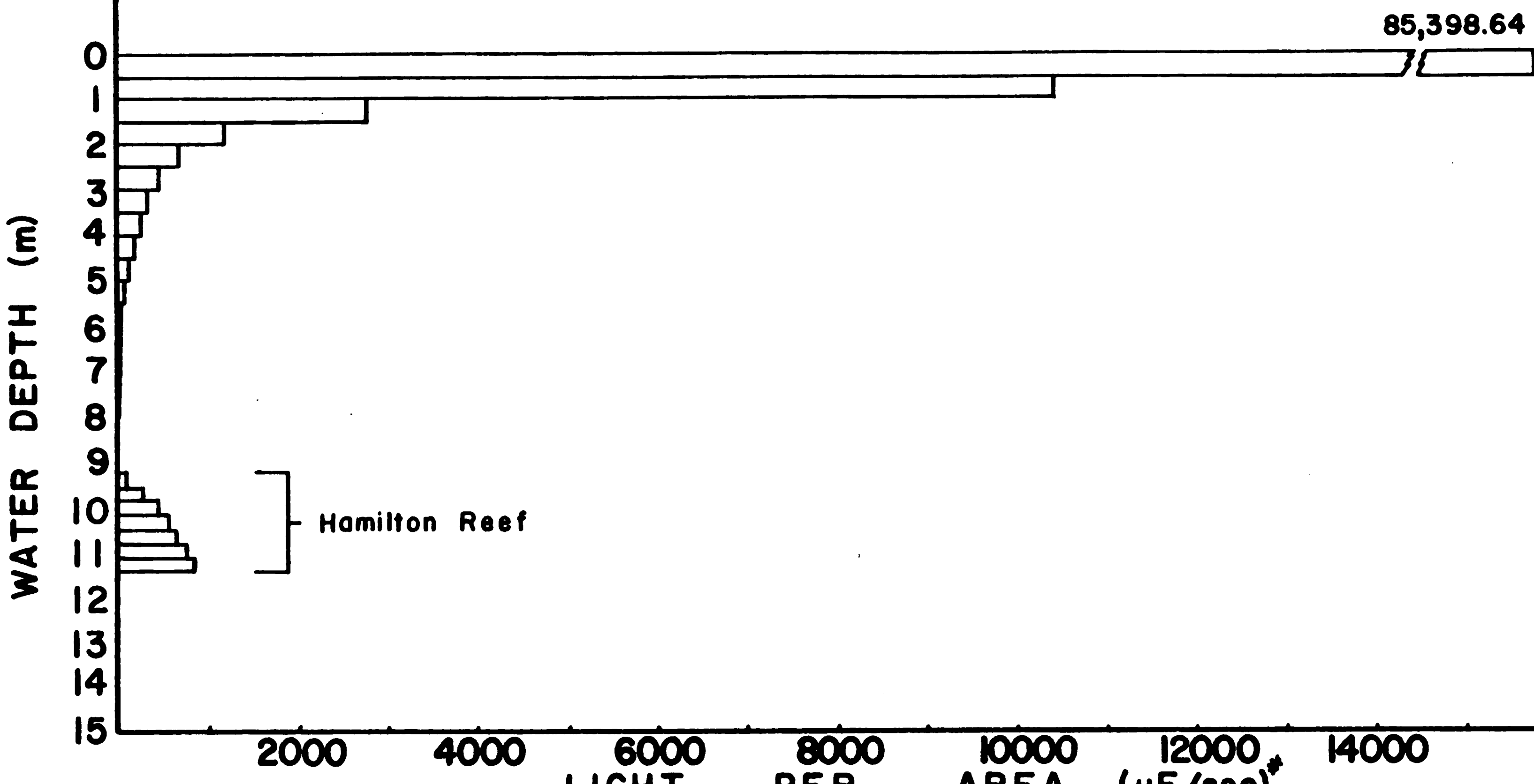


Figure 19. A comparison of the Hamilton Reef to the Muskegon River Breakwall on the basis of light per area versus water depth

*Note: For graphing purposes light per area values have been reduced by a factor of 10 areas, and is continuously being supplied with nutrients from the river. The reef ,however, is relatively small in size, is located relatively deep, and has a much reduced input of nutrients from river outflow.

In addition to being a nutrient source, the Muskegon River also can influence fish attraction and periphyton growth. Consistently warm river water temperatures attract fish to the breakwall while variable water temperatures are a factor that will detract from the reef's effectiveness asa fish attractor (Figure A6.). Rapid temperature changes on the reef are common due to a variety of meteorological conditions. In contrast, the Muskegon River outflow is consistently warm through most of the fishing season. The influence of warm water on fish distribution is dramatic. SCUBA observation of the Hamilton Reef has shown that under cold water conditions game and forage fish numbers are significantly reduced on the reef. Concurrently, large numbers of fish can be observed consistently just inside the Muskegon River breakwall. Periphyton and invertebrates would probably be less tolerant of the temperatures found on the reef as well. Consistently warm water temperatures, high light intensity, nutrient input, and shallow depths translate into a very productive environment on the breakwall. The breakwall is very productive in terms of periphyton, invertebrates and also in the size fish community these food organisms can sustain.

Fish reproduction data, fish attraction data, and a comparison to the Muskegon River breakwall show the beneficial impacts of the Hamilton Reef to be negligible during the study period. Yellow perch reproduction on the reef has been limited to 704 egg masses (estimated) and no evidence of the reef as a lake trout spawning site was observed. Adult and forage fish use of the reef was restricted by unfavorable water temperatures and low food production. When compared to the Muskegon River breakwall the reef is too small, too deep, and too far from the Muskegon River's beneficial impact. In terms of its fish attracting ability, this study has shown that the reef does not compete well with the breakwall as a fish attractor.

Suggestions for Future Reef Building

Several agencies and organizations have expressed interest in the Hamilton Reef research with regards to possible application elsewhere in the Great Lakes. The failure of the Hamilton Reef, as seen by this study, provides evidence that important considerations can be overlooked when constructing an artificial reef. The following suggestions are based on research data and SCUBA observation on both the Hamilton Reef and Muskegon River breakwall and should be considered in planning for any future reefs in the upper Great Lakes.

Because artificial reefs are usually built as a result of some environmental deficiency, the purpose behind its construction may dictate specific things about the reef. For example, the purpose for construction may dictate where the reef is going to be located. A reef built to provide yellow perch spawning substrate would require a shallow, well illuminated location. Research data from the Hamilton Reef also suggests two probable site locations for such a spawning reef. The first site utilizes reef construction as a means of enhancing existing resources, such as breakwalls, jetties, and piers. Binkowski (1983) has utilized this concept through the use of small inshore artificial perch reefs. These structures are easily accessable, shallow, and increase the production of near-shore areas. The second site places the reef in an area where its substrate is unique, compared to other existing structures. This location assures fish attraction to the reef will not be diminished by other nearby substrate. Additional construction considerations such as reef shape and substrate type may also be prescribed by the purpose for building the reef.

Human considerations are another facet of reef building that can affect the success of an artificial fishing reef. Resource managers must ask themselves the question can and, more importantly, will enough people use the reef to justify its creation at a given location? Using the Hamilton Reef as an example, why would people, for other than aesthetic reasons, go out to the reef when fishing from the breakwall has consistently been very good? This does not imply the reef is never a good place to fish, but given the time constraints, economic considerations of boat and motor, and the desire to consistently catch fish, most people would probably choose the breakwall.

Because a reef represents a substantial investment of time and money it is essential that it attract fish as effectively as possible. To insure as many environmental factors work in favor of the reef as possible, it is important to conduct preliminary research at each potential reef site. Research data and SCUBA observations suggest that Great Lakes artificial reef structures should be very large and occupy shallow water depths. Attachment sites, for periphytic organisms, and illumination, for photosynthesis, are two essential ingredients of a successful reef. To satisfy these preconditions the optimum depth for the reef should be determined. To determine this depth artificial substrates, of known area, should be strung together and deployed at each potential reef site. This string of substrates should extend from the surface to lake bottom. After time for sufficient periphyton growth has elapsed all substrates should be removed and growth carefully scraped off. By analyzing the scrapings for chlorophyll A content, the depth at which growth is maximum can be determined and selected for reef placement. Growth measurements of this type are especially useful because they integrate many local environmental factors such as nutrient availability, available light, and possible pollutants.

In addition to growth measurements, local temperature regimes are also very important because of the dramatic influence they can have on fish distribution. Continuous 24 hour temperature recordings taken at different times of the year should be recorded for any potential reef location. Resident fish species, and their preferred temperature ranges, should be reviewed with recorded temperature data as a means of determining their potential reef use. The role water temperature plays in fish distribution was observed many times during this study and should not be underestimated as a factor in reef site selection.

After completion of preliminary site research and all building permits have been secured, reef marking should be considered. To assist accurate placement of the reef and to protect navigation interests it is strongly suggested the reef be marked prior to its actual construction. Buoys placed in advance on the reef site can provide advance warning for commercial and pleasure boaters commonly in the reef area. This procedure will also allow some control over reef placement instead of haphazard substrate dumping. Reef marking is an important consideration and should always be prearranged according to Coast Guard and Corps of Engineers guidelines.

Because water currents and settling can affect the reef in an adverse manner precautions should be taken to minimize their impact. Filter cloth, although costly, should form a stabilizing layer upon which the reef can be placed. This boundary layer will probably retard the loss of cobble sized reef substrate as well. Substrate of this size has all but vanished from the Hamilton Reef.

As a final suggestion for installation, the reef should be mapped with a side-scan sonar unit. This procedure should be considered because it provides a picture of the final reef configuration and it can be used as a reference map for future damage assessment. The action of waves, water currents, ice scour, and underwater debris are accentuated in the shallow waters of all potential reef sites. After several seasons of existence it is suggested that an additional side-scan sonar map of the reef be obtained. Using the initial construction map as a reference it should be possible to determine where and if reef repairs should be made. Regular assessments and reef additions will maintain the structures effective existence for many years.

SUMMARY AND CONCLUSIONS

The study of fish reproduction on the Hamilton Reef utilized several sampling methods. The methods were fish egg observations, egg pumping, use of fish egg trays, emergent fry trapping, larval fish trawling, and experimental gill netting.

Game fish reproduction on the Hamilton Reef was limited to one species, yellow perch. Evidence of lake trout spawning could not be found ,however, sexually mature lake trout were captured on the reef. Gill netting data for yellow perch and all fish species combined showed no statistical preference for the reef. A previous netting study revealed similar results, showing moderate attraction of yellow perch to the reef.

Emergent fry trap data revealed forage fish were attracted to the reef in larger numbers than to sand reference areas nearby. In addition, forage species exhibited an attraction for the shallow over the deep end of the reef. Explanations for this shallow reef attraction were discussed in terms of protective cover and periphyton production on the reef.

A comparison of the Hamilton Reef to the nearby Muskegon River breakwall revealed several differences between these structures. Breakwall area, shallow depth, and potential periphyton production more successfully attracted fish than the reef which has a relatively small size, deep depth, and low periphyton production.

Several suggestions were proposed for future reef construction in the Great Lakes. Artificial reef structures should be very large and located in shallow water. They should ideally be placed in areas where they would suppliment existing fish attracting structures or in areas where they would form a unique substrate far from any other potentially competitive structure.

Preliminary site research is suggested as a means of determining reef location and placememt depth. Preliminary research includes periphyton growth measurements and temperature profiles at each potential location.

Final suggestions for reef construction include side-scan sonar mapping to obtain a picture of the reef and as a future reference to detect deterioration, damage and rock movement. Scheduled additions to the reef should be made on the basis of additional side-scan sonar maps made of the reef. Comparison of the initial sonar map to subsequent versions should reveal when and where reef repairs or additions are needed. Regular assessments will help maintain the reef's existence for many years.

Conclusions

Study of the Hamilton Reef has yielded several conclusions about both the nature and future of artificial reef construction in the Great Lakes:

1. Great Lakes artificial reefs must be very large to effectively attract fish.

2. Great Lakes artificial reefs must be relatively shallow to allow sufficient periphyton production to occur.

3. Artificial reefs in the Great Lakes should be located in areas where they comprise a unique substrate and/or preferably as an addition to an existing structure.

4. Periphyton growth measurements and water temperature impact on fish distribution should be taken into consideration when selecting a potential reef site.

5. Future reef construction in the Great Lakes should be concentrated on supplimenting existing fish attractor structures.

6. Potential reef locations where reef size, depth, and temperature considerations can be satisfied are limited in the Great Lakes. Future Great Lakes reef building should be considered carefully.

LITERATURE CITED

LITERATURE CITED

Biener, W.E. 1982. Evaluation of an Artificial Reef Placed in Southeastern Lake Michigan: Fish Colonization. Thesis for degree of M.S.. Michigan State University. 40pp.

Binkowski, F.P. 1983. Utilization of Artificial Reefs in the Inshore Areas of Lake Michigan. Center for Great Lakes Studies. University of Wisconsin-Milwaukee, Milwaukee, Wisconsin. 10pp.

Brazo, D., Tack, P.I., and C.R. Liston. 1975. Age, growth, and fecundity of yellow perch, *Perca flavescens*, in Lake Michigan near Ludington, Michigan. Trans. Am. Fish. Soc. 104:726-30.

Collins, J.J. 1975. An emergent fry trap for lake spawning salmonines and coregonines. Prog. Fish-Cult. 37(3):140-2.

Dorr, J.A. and D.J. Jude. 1980. SCUBA assessment of abundance spawning, and behavior of fishes in Southeastern Lake Michigan near the Donald C. Cook Nuclear Power Plant. Pap. Mich. Acad. Arts, and Letters. 12:345-64.

Gill, J. 1978. *Design and Analysis of Experiments in the Animal and Medical Sciences*. Iowa: Iowa State University Press. Volume II pp. 197-214., Volume III pp. 19-50.

Hubbs, C.L. and L. Hubbs. 1933. The increased growth, predominant maleness, and apparent infertility of hybrid sunfishes. Pap. Mich. Acad. Sci. Arts, and Letters. 17(1932):613-41.

Hubbs, C.L. and R.W. Eschmeyer. 1937. Providing shelter, food, and spawning facilities for the game fishes of our inland lakes. Trans. 2nd N. Amer. Wildlife Conference. 2:613-19.

Kittleman, R. 1983. Personal Communication. United States Army Corps of Engineers, Grand Haven Projects Office, P.O. Box 629, Grand Haven, Michigan 49417.

Mottet, M.G. 1981. Enhancement of the marine environment for fisheries and aquaculture in Japan. State of Washington Department of Fisheries. Technical Report No. 69. p. 3.

Peck, J.W. 1981. Dispersal of lake trout from an artificial spawning reef in Lake Superior. Mich. Dept. Nat. Res., Fish.Res. Rep. 1892. pp.1-13.

Prince, E.D. and O.E. Maughan. 1978. Freshwater artificial reefs: biology and economics. Fisheries. 3(1):5-9.

________.1979. Attraction of fishes to artificial tire reefs in Smith Mountain Lake, Virginia. Pages 19-25. in D.L. Johnson and R.A. Stein, eds. Response of fish to habitat structure in standing water. North Central Div. Am. Fish. Soc. Spec. Publ. 6.

Prince, E.D., O.E. Maughan, and P. Brouha. 1977. How to build a freshwater artificial reef. Second edition. Va. Polytech. Inst. and St. Univ., Blacksburg, Va. Sea Grant Extension Publ. VPI-S6-77-02. 16pp.

Reid, G.K. and R.D. Wood. 1976. Ecology of Inland Waters and Estuaries. 1976. D. Van Nostrand Company, New York. p.134-5.

Rodeheffer, I.A. 1938. Experiments in the use of brush shelters by fish in Michigan lakes. Pap. Mich. Acad. Sci., Arts, and Letters. 24:183-93.

Robison, J.V. 1970. Modern Trigonometry. McGraw-Hill Book Company, New York. pp. 124-30.

Spencer, C. Personal Communication. 1982. Dept. of Fisheries and Wildlife, Michigan State University, East Lansing, Michigan 48824

Stauffer, T.M. 1980. Collecting gear for lake trout eggs and fry. Mich. Dep. Nat. Resour., Fish. Res. Rep. 1884. pp. 1-23.

Sztramko, L. and G.C. Teleki. 1977. Annual variations in the fecundity of yellow perch from Long Point Bay, Lake Erie. Trans. Am. Fish. Soc. 106(6):578-82.

Wagner, W. 1980. Reproduction of planted lake trout in Lake Michigan. Mich. Dep. Nat. Resour., Fish. Res. Rep. 1885. pp.1-15.

Wilbur, R.L. 1973. A preliminary look at fish attractors for Florida's freshwater fishermen. A Contribution of Florida Game and Freshwater Fish Commission Dingell-Johnson Project F-26. pp. 1-15.

Wilbur, R.L. and J.E. Crumpton. 1974. Florida's fish attraçtor program. in L. Colunga and R.B. Stone, eds. Proceedings of an international conference on artificial reefs. Sea Grant Publ. 74-103. Texas A and M Univ., Houston, Texas. pp. 39-46.

GENERAL REFERENCES

Auer, N.A. ed. 1982. Identification of Larval Fishes of the Great Lakes Basin with Emphasis on the Lake Michigan Drainage. Ann Arbor: Great Lakes Fishery Commission, Special Publication 82-3. pp. 146-51, 265-69, 471-76, 607-10, 619-624.

Bagenal, T. 1978. Methods for Assessment of Fish Production in Fresh Waters. Blackwell Scientific Publications. pp. 165-178.

Barnes, R.D. 1980. Invertebrate Zoology. Pennsylvania: Saunders College. p. 309.

Eddy, S. and J.C. Underhill. 1980. How to Know the Freshwater Fishes. 1980. Iowa: Wm. C. Brown Company Publishers. pp. 87-109, 148-9, 151-6, 175-7.

Hubbs, C.L. and K.F. Lagler. 1964. Fishes of the Great Lakes Region. The University of Michigan Press, Ann Arbor, Michigan, pp. 29-34, 57-63, 66-75, 100-105, 116-120.

Lagler, K.F. 1956. Freshwater Fishery Biology. Second edition. Iowa:Wm. C. Brown Publishing Co. p. 131-158.

Lippson, A.J. 1976. Preliminary Pictoral Key to the Distinguishing Family Characteristics Among Great Lakes Fish Larvae. Maryland: Martin Marietta Environmental Technology Center. pp.1-9.

Merritt, R.W. and K.W. Cummins. 1978.An Introduction to the Aquatic Insects of North America. 1978. Iowa: Kendall/Hunt Publishing Company. pp. 345-76.

Scott, W.B., and E.J. Crossman. 1973. Freshwater Fishes of Canada. 1973. Fish. Res. Bd. Can. Bull. 184. p. 459-63, 793-97, 826-35.

APPENDICES

APPENDIX A

Light Data and "t" Statistic Calculations

On two occasions light data were taken on the Hamilton Reef and Muskegon River breakwall. Raw data were converted from microeinsteins per square meter per second ($\mu E/m^2/sec$) to the natural logarithm microeinsteins per square meter per second ($ln(\mu E/m^2/sec)$ (Table A1.). By pairing this transformed light data with it's appropriate depth underwater, a large number of light-depth points resulted. Plotting these points, made it possible to determine the slope (extinction coefficient) of the light intensity versus depth line. To determine if these extinction coefficients differed significantly a students "t" test was employed:

$$t = (b_1^a - b_1^b) / ((SS_e^a + SS_e^b)/(n^a + n^b - 4))((1/SS_x^a) + (1/SS_x^b))$$

(Gill,1978)

where: b_1 = slope of line (extinction coefficient)

SS_e = sum of squared deviations from the mean for error

= SS - SS

SS_r = sum of squared deviations from the mean for regression

= $(b_1)(SP_{xy})$

Table A1. Transformed* light data taken on the Hamilton Reef and both the inside and outside of the Muskegon River Breakwall.

Water Depth (m)	Hamilton Reef 7/11/83		Hamilton Reef 8/24/83		Inside Breakwall 7/11/83		Inside Breakwall 8/24/83		Outside Breakwall 7/11/83		Outside Breakwall 8/24/83	
0	7.47	7.47	7.28	7.28	7.47	7.47	7.28	7.28	7.47	7.47	7.28	7.28
1	6.96	7.02	6.78	6.97	6.2	5.85	6.41	6.48	6.32	6.46	6.93	6.93
2	6.92	6.92	6.51	6.77	6.02	5.10	5.74	5.69	6.34	6.28	6.68	6.55
3	6.76	6.75	6.11	6.43	4.93	4.79	5.41	5.26	5.89	5.67	6.39	6.04
4	6.4	6.54	5.9	6.2	4.42	3.5		4.59	5.38	5.26	6.24	5.77
5	6.3	6.33	5.45	5.91		2.94		4.07	4.93	4.74	5.88	5.42
6	6.17	6.15	5.32	5.67		1.92		3.71	4.42	4.36	5.94	
7	5.95	6.01	4.82	5.38		1.55		2.96				
8	5.8	5.86	4.57	5.05		.92		1.23				
9	5.63	5.65	4.27	4.73		.74						
10		5.49	3.98	4.28		.18						
11		5.3		3.96		0						
12		5.06		3.6								
13		4.74		3.18								
13.5		4.17		3.0								

*Data have been transformed to log(Y) where Y equals recorded light reading. ($\mu E/m^2/sec$).

SS_x = sum of squared deviations from the mean for x

SS_y = sum of squared deviations from the mean for y

SP_{xy} = sum of products of deviations of two variables from their sample means

n = number of data pairs used

Calculated "t" values were compared to the critical value:

$$\pm t_{\alpha/2,\ n^a + n^b - 4}$$

where: α = level of significance chosen

n = number of data pairs used

Three comparisons were made following calculation of the components in the student "t" equation (Table A2.). All comparisons when compared to their appropriate test statistic were significantly different from each other ($P < .00025$).

Table A2. Significance of light data taken from the Muskegon River Breakwall and the Hamilton Reef

Location	b_1	n	ss_x	ss_y	ss_r	ss_e	sp_{xy}	Contrast	"t" value Significance
Reef	.156	51	796.63	63.56	48.59	14.97	-311.76	Reef and Inside Breakwall	$P < .00025$
Outside Breakwall	.406	27	99.80	19.99	16.47	3.52	-40.55	Reef and Outside Breakwall	$P < .00025$
Inside Breakwall	.686	31	345.69	169.57	161.98	7.59	-237.13	Outside Breakwall and Inside Breakwall	$P < .00025$

APPENDIX B

1981 Preliminary Emergent Fry Trap Data

The use of emergent fry traps was conducted during the summer and fall of 1981 and as a result of it's preliminary nature was not used statistically (Figures A1.and A2.). The number of fish captured showed a rather dramatic peak followed by a sharp decline in numbers. This could be interpreted in two ways; the fish are invading a new environment and the decline in numbers indicated the carrying capacity of the reef, or the fish have congregated on the reef for spawning purposes. Analysis of 1982 fry trap data revealed a similar drop in numbers over time, however, the overall numbers of fish caught were lower. This suggested that a combination of initial invasion of the reef occurred and the large decline in numbers was due to emigration of spent and overcrowed adults.

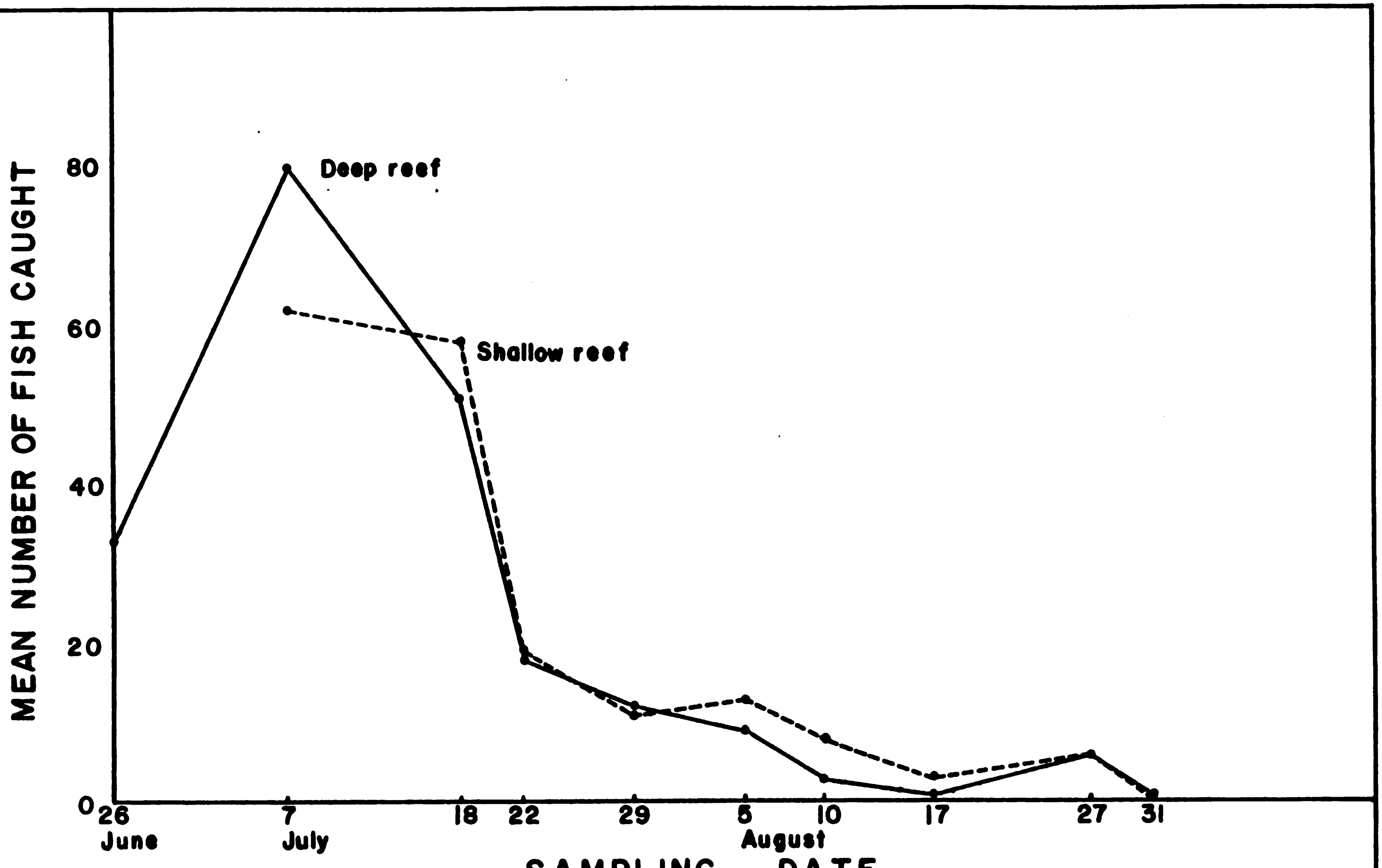


Figure AI. Preliminary johnny darter emergent fry trap catch data for 1981

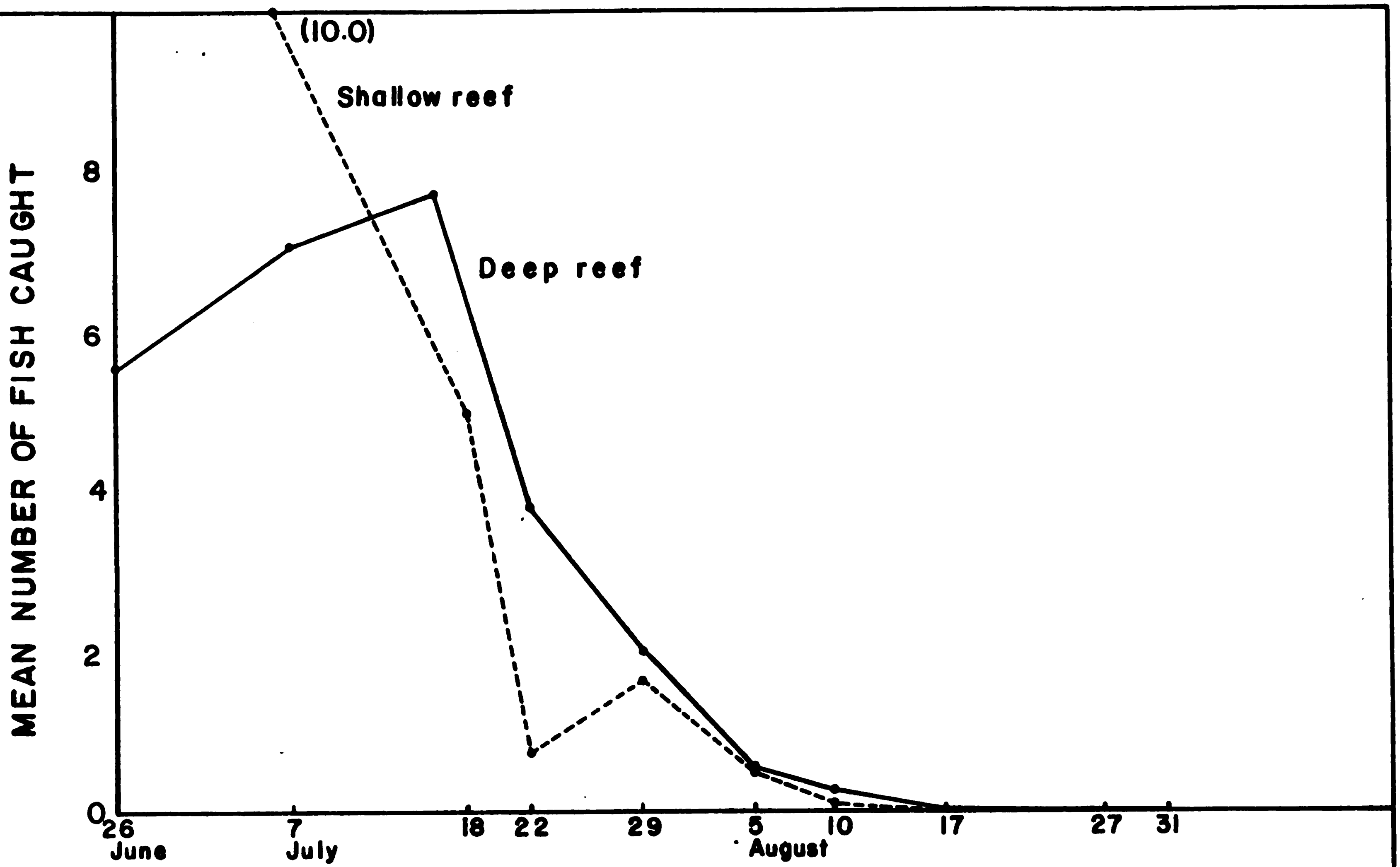


Figure A2. Preliminary ninespine stickleback emergent fry trap catch data for 1981

APPENDIX C

Muskegon Breakwall Area and Light Calculations

Area calculations of the Muskegon River breakwall were based on United States Corps of Engineers scale drawings of the structure (Table A3.)(Kittleman,Personal Communication). The breakwall was divided into sections based on these drawings (Figure 18.). To estimate the surface area of the stone below water level, it was necessary to have the maximum water depth directly in front of each breakwall section and also the angle of descent from the water surface. By the law of sines for right triangles, the length of the hypotenuse (C), or in this case the distance from the water surface at the breakwall angling down to the bottom, is equal to the maximum water depth (A) divided by the sine of the angle of descent (Robison,1970). The water depth at each breakwall section and the angle of descent were obtained from the scale drawings provided by the Army Corps of Engineers. Once the width of each breakwall section was calculated, the length of each section from scale drawings was multiplied by it, resulting in the total square area for that particular section. Each breakwall area was divided into one meter depth zones from the surface to the lake bottom, so that all the various reef zones could be combined on the same basis. To determine the available

Table A3. Muskegon River Breakwall light-area calculation data.

Breakwall Section	A. Maximum Depth (m)	C. Lateral Area (m^2)	Angle of Descent (degrees)	Total Section Length (m)	Extinction Coefficient
1	2.74	4.88	34.16	198.12	.406
2	5.49	9.75	34.27	403.86	.406
3	7.92	14.20	33.90	205.74	.406
4	4.27	7.62	34.08	400.05	.686
5	3.06	5.49	33.87	346.71	.686
6	3.66	7.32	30.00	183.18	.686
7	4.88	11.13	26.00	445.01	.686
8	6.10	10.9	34.03	164.60	.406
9	6.10	13.87	26.09	32.92	.406
10	3.96	8.99	26.13	247.50	.406
11	4.57	10.06	27.02	183.20	.406

light in each depth zone, light meter readings were calculated for the mid-point of each depth zone. This meant that for every meter of descent, the available light was calculated at the half-meter mark and represented the available light found in that particular depth zone. Light intensities were obtained by using the appropriate light extinction equation with the appropriate extinction coefficient. Since light meter readings were necessary at each half-meter along the descending surface of rock, it was necessary to also calculate the depth (A) at each half-meter mark. This depth was determined by manipulating the law of sines from C = A / sine angle of descent to A = (C)(sine angle of descent) where A equals the water depth at each half-meter mark. From this point each meter depth zone from surface to bottom was multiplied by the light at it's mid-point yielding the total amount of light in each depth zone. The following example of breakwall section one illustrates how this procedure was performed for each of the eleven sections.

Section one is approximately 198.12 meters in length and the lateral rock surface descends (into the water) at an angle of 34.16 degrees. The water depth along section one is assumed to be constant for calculation purposes. With this information it is now possible to schematically represent section one (Figure A3.). Since the angle of descent is 34.16 degrees and the maximum water depth is equal to 2.74 meters ,the length of C, or the total width of

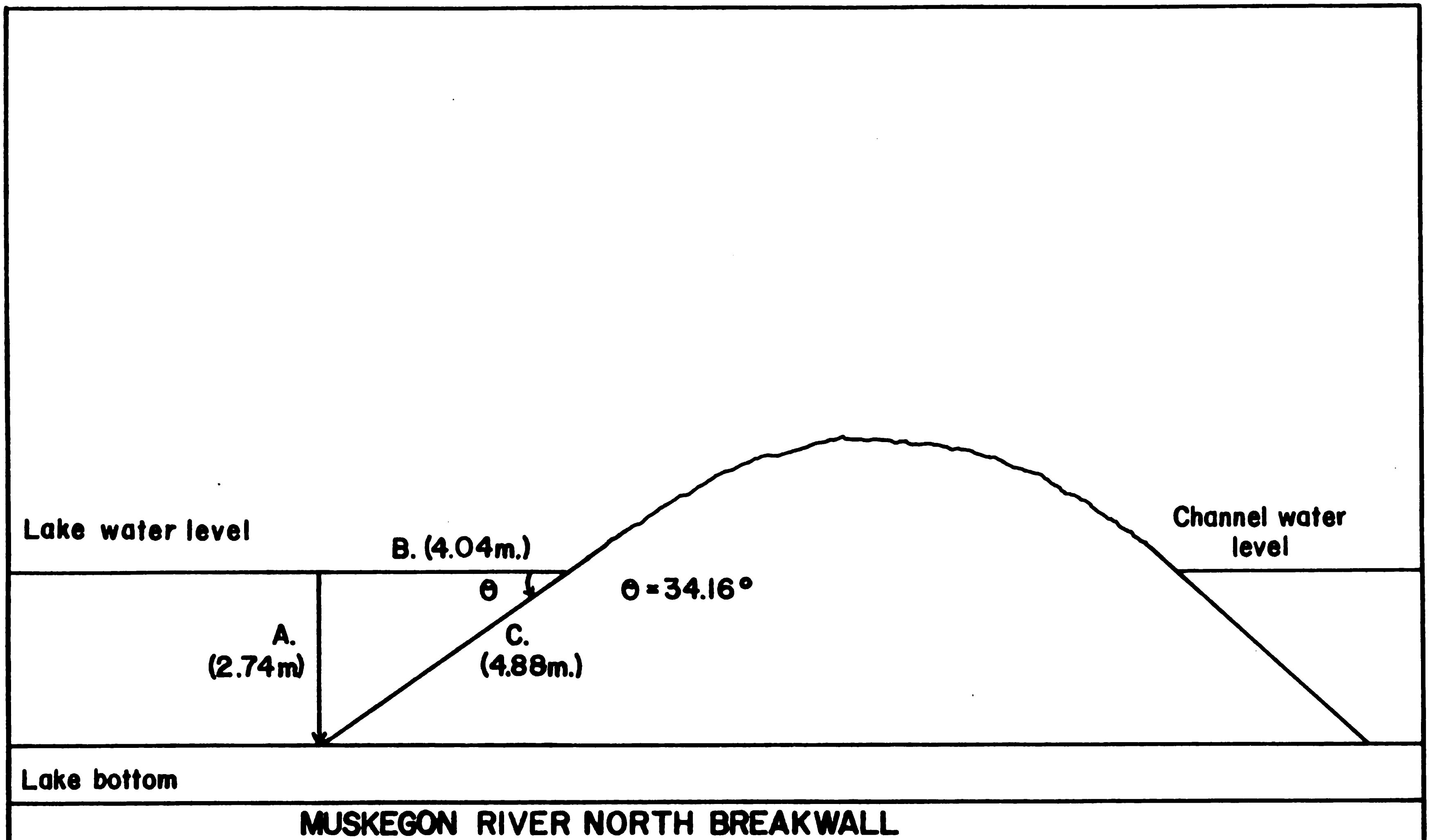


Figure A3. Cross section of Muskegon River Breakwall section one breakwall section one is equal to 2.74 divided by the sine of 34.16 (.5615) which is equal to 4.88 meters. Thus the length of C from the water surface to the lake bottom is equal to 4.88 meters. To estimate the amount of light striking this lateral surface area it was necessary to divide 4.88 into one meter intervals. Obviously in this case, there were four one meter intervals with .88 meters left over. Light intensity for each interval on C was calculated for the midpoint of each interval using the appropriate light extinction coefficient for the given location. For example, in the first one meter interval along C the intensity of light at .5 meters represented the light available in the first interval. To determine the amount of available light at .5 meters on C it was necessary to calculate the depth (A) at that point. Using the law of sines, A is equal to C (.5 meters) times the sine of 34.16 degrees or .28 meters. By utilizing the extinction coefficient for the outside of the Muskegon River Breakwall (.406) the calculated light intensity at .5 meters along C is equal to 722.35 $\mu E/m^2/sec$. To obtain square area for the first meter interval the section length (198.12 meters) was multiplied by the interval width (one meter) yielding an area of 198.12 square meters in breakwall section one. The total estimated light intensity on interval one of breakwall section one was obtained by multiplying the interval area ,198.12 square meters, by the average light intensity (722.35 $\mu E/m^2/sec.$) yielding 143,111.98 $\mu E/sec$/interval one. This procedure was followed for intervals one through four and also for the additional .88 meter interval.

Upon completion of the light intensity calculations, all light intensities were totaled to give the estimate of available light for breakwall section one. Calculations were based on this procedure for breakwall sections one through eleven.

APPENDIX D

Hamilton Artificial Reef Light and Area Calculations

Area calculations for the Hamilton Reef were based on an actual side-scan sonar representation of the reef. A clean version of the actual sounding map has been presented in Figure 6. where each pile has been assigned a number from one through twenty-nine. Pile area was determined by polar planimeter. Using this area estimate each rock pile was treated as if it's measured perimeter were a perfect circle on the lake bottom. Because of the difficulty in obtaining pile height off the bottom, an estimate of 2.1 meters based on SCUBA observation, was used to represent average rock pile height. With these estimates each rock pile was represented as a cone with a base area equal to the actual planimeter measured rock pile area and height of 2.1 meters off the lake bottom. From these calculations the circumference of each pile and it's slant height were calculated by the following equations:

Radius = pile area / π

Circumference = $(\pi)(2)(\text{radius})$

Slant height = (radius) + (2.1)

The angle of ascent (θ) was calculated according to the law of sines:

angle of ascent(θ) = arcsine (2.1 /slant height)

Having calculated the above information (Table A4.) for piles one through twenty-nine, each pile was divided into seven .3 meter zones of area (Figure A4.). The total area of each zone was calculated by subtraction. For example, on pile number one the total lateral surface area equaled 217.36 square meters. By subtracting the total area above .3 meters, the area remaining was equal to the zone from zero to .3 meters above the bottom. By repeating this process the areas of all seven zones was determined. The area of each zone was calculated exactly as above with the exception that a new radius was calculated for each zone above the bottom. At each increment above the bottom the radius was calculated according to the following:

C = A / sine angle of ascent

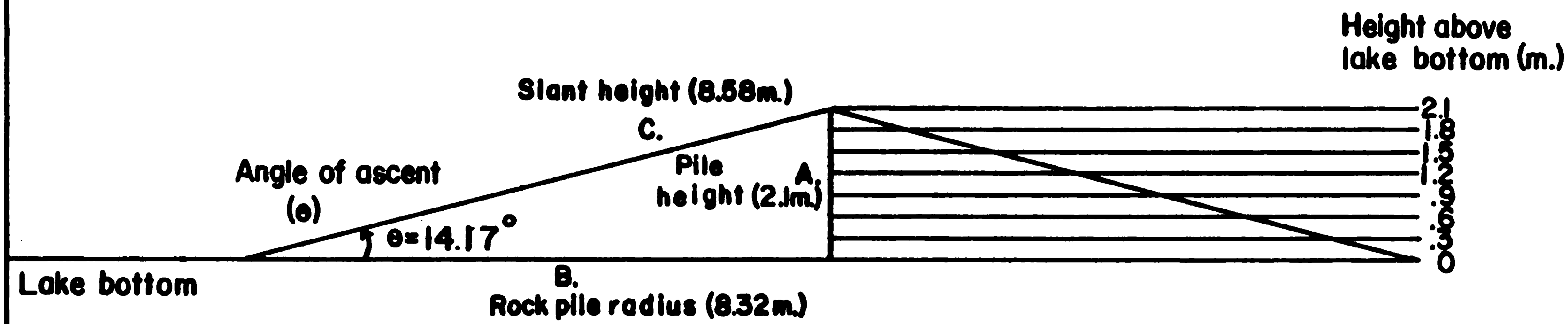
B = (C)(cosine angle of ascent)

This procedure was followed for each of the twenty-nine reef piles resulting in lateral area estimates for each of the seven depth zones and a cumulative reef lateral area estimate (Table 21.).

Table A4. Hamilton Reef calculated rock pile area data

Pile Number	Measured Planimeter Units*	Area (m^2)	Calculated Pile Radius (m)	Calculated Pile Circumference(m)	Pile Slant Height(m)	Pile Lateral Area(m^2)	Pile Angle of Ascent(degrees)
1	.18	217.36	8.32	52.26	8.58	224.24	14.17
2	.19	229.43	8.54	53.69	8.79	235.97	13.82
3	.475	573.56	13.51	84.90	13.67	580.29	8.84
4	.33	398.48	11.26	70.76	11.45	405.1	10.57
5	.265	319.99	10.09	63.14	10.31	325.49	11.76
6	.39	470.93	12.245	76.93	12.42	477.73	9.73
7	.31	374.33	10.915	68.59	11.11	381.02	10.89
8	.42	507.15	12.705	79.83	12.88	514.10	9.38
9	.44	531.30	13.00	81.71	13.17	538.06	9.17
10	.24	289.80	9.60	60.35	9.83	296.62	12.33
11	.195	235.46	8.65	54.40	8.91	242.35	13.63
12	.14	169.05	7.33	46.09	7.63	175.83	15.97
13	.055	66.41	4.60	28.89	5.06	73.09	24.52
14	.24	289.80	9.60	60.35	9.83	296.62	12.33
15	.04	48.30	3.92	24.64	4.45	54.82	28.16
16	.31	374.33	10.91	68.59	11.11	381.02	10.89
17	.255	307.91	9.9	62.2	10.12	314.73	11.98
18	.09	108.68	5.88	36.95	6.24	115.28	19.67
19	.065	78.49	5.0	31.41	5.42	85.12	22.8
20	.475	573.56	13.51	84.90	13.67	580.29	8.84
21	.255	307.91	9.9	62.20	10.12	314.73	11.98
22	.305	368.29	10.82	68.03	11.03	375.18	10.97
23	.14	169.05	7.33	46.09	7.63	175.83	15.97
24	.31	374.33	10.91	68.59	11.11	381.02	10.89
25	.07	84.53	5.18	32.59	5.59	91.09	22.05
26	.255	307.91	9.9	62.20	10.12	314.73	11.98
27	.265	319.99	10.09	63.41	10.30	326.56	11.76
28	.14	169.05	7.33	46.09	7.63	175.83	15.97
29	.17	205.28	8.08	50.79	8.35	212.05	14.57

*One planimeter unit equals 1207.56 square meters.



MUSKEGON REEF ROCK PILE REPRESENTATION

Figure A4. Calculated area data for Hamilton Artificial Reef rock pile number one

An estimation of available light on the reef was calculated at the middepth of the reef (11.375 m). This insured an average estimate of light intensity on the reef. Light intensity readings were calculated using the extinction coefficient obtained from light readings taken on the reef to insure their accuracy. Depth zone light intensity was calculated for the center of each of the seven depth zones which were 9.4, 9.7, 10.0, 10.3, 10.6, 10.9, and 11.2 meters from the surface. With these estimates it was possible to determine both the light found at each depth zone of the reef and also a cumulative total for the entire reef (Table 19.).

APPENDIX E

Estimated Limits of Diver Visibility, 1981-1983

Diving in the Great Lakes can be an exhilarating experience but it can also be sheer drudgery, all depending on the clarity of the water. To illustrate visibility conditions that were commonly encountered on the Hamilton Reef, a bar graph of diver estimated visibility was constructed (Figure A5.). Observation of Figure A5. reveals a maximum visibility of 7.62 meters and a minimum of .3 meters on June 20, 1982 and March 29, 1983 respectively. Typically, visibility conditions in the spring and fall months are the worst, while generally in the summer months they are better and on occasion exceptional.

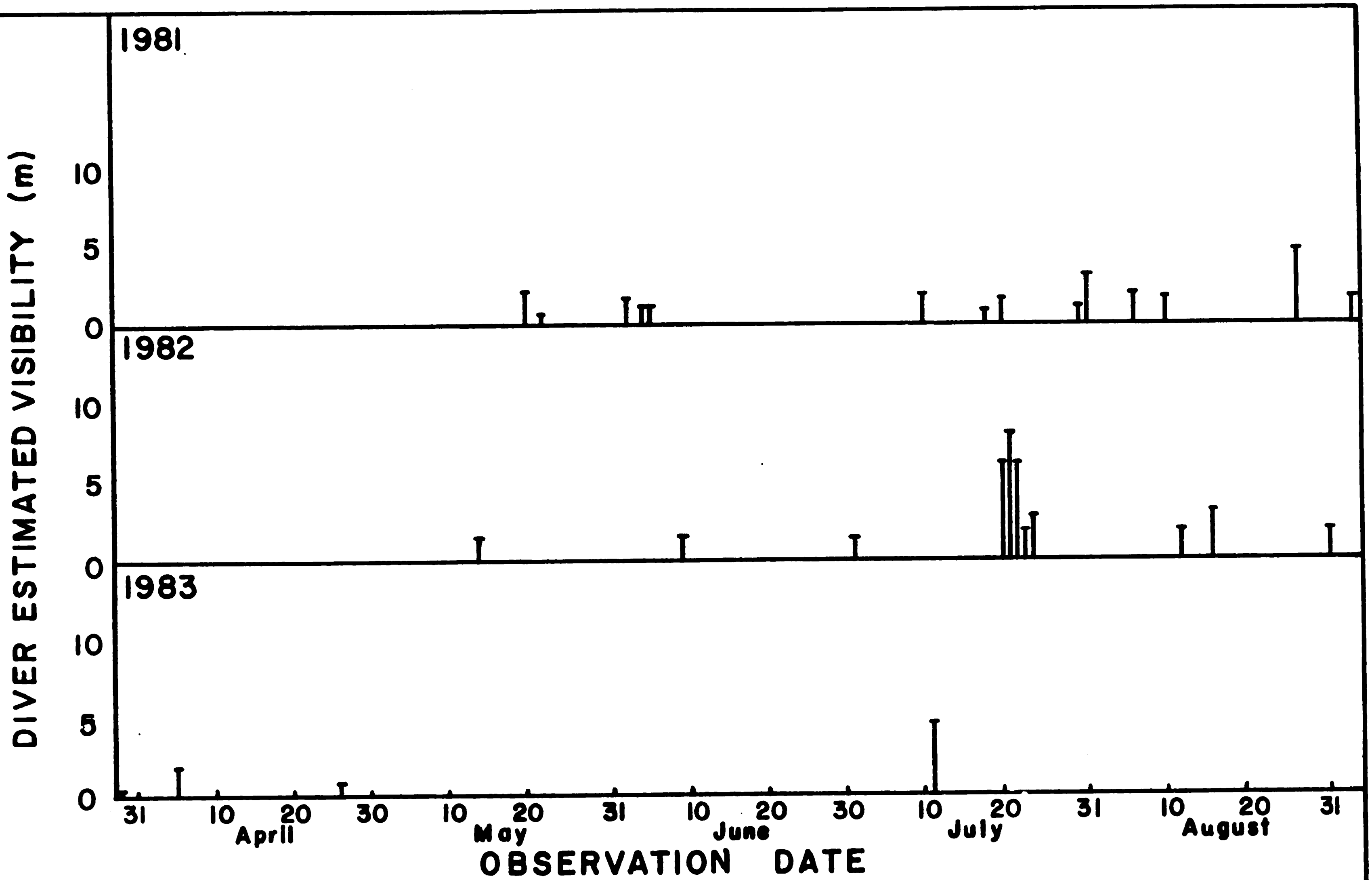


Figure A5. Estimated limits of SCUBA diver visibility on the Hamilton Reef

APPENDIX F

Bottom Temperatures on the Hamilton Reef 1981-1983

Water temperatures on the Hamilton Reef were highly subject to change depending upon wind and weather conditions. Figure A6. shows temperature data recorded on the reef with an electric thermistor-type thermometer. Rapid changes in the bottom temperature can be noticed from day to day. The most drastic temperature changes result from east winds, as on July 22, 1981. The lake water was cooled to 3.3 C or less and warm Muskegon River outflow caused a dense fog bank to form at the contact point of river and lake water. Temperatures, as expected, were seen to be lowest in the spring and fall, but very cold water temperatures in the summer months were not uncommon.

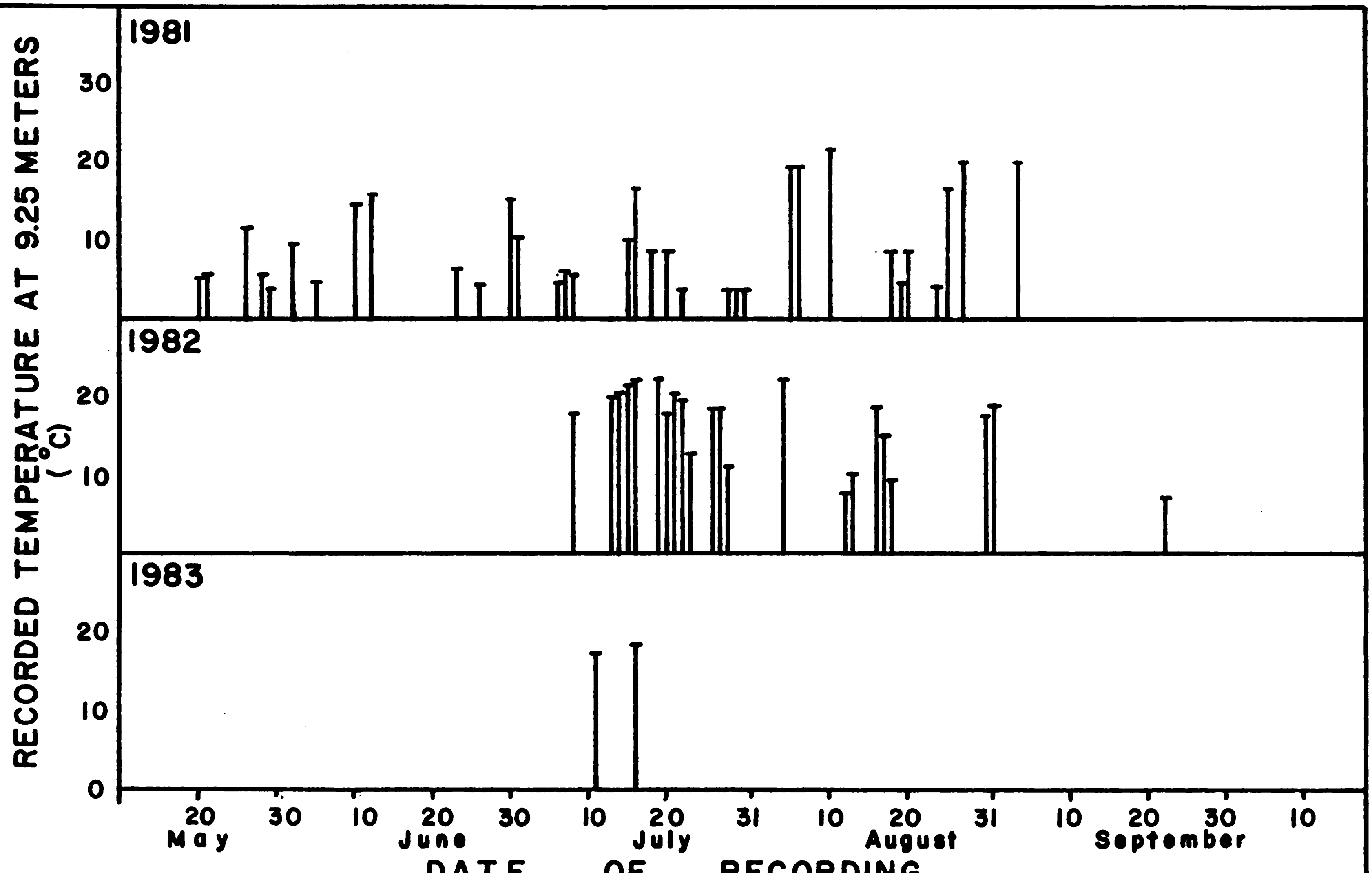


Figure A6. Recorded bottom temperatures on the Hamilton Reef

APPENDIX G

Yellow Perch Length-Weight Relationship

During the summer of 1982 the yellow perch length-weight relationship for gill netted perch was calculated and is represented by the following equation:

$$\log_{10} \text{(fish weight)} = (\log_{10} \text{(fish length)})(2.91) + (-4.69)$$

(Lagler,1956)

In this equation fish weight is measured in grams and fish length in millimeters (Figure A7.). All yellow perch were netted using experimental graduated mesh gill nets.

Yellow perch length-frequency data has been presented in Figure A8. A total of 111 yellow perch were gill netted over the four gill netting periods during the summer of 1982.

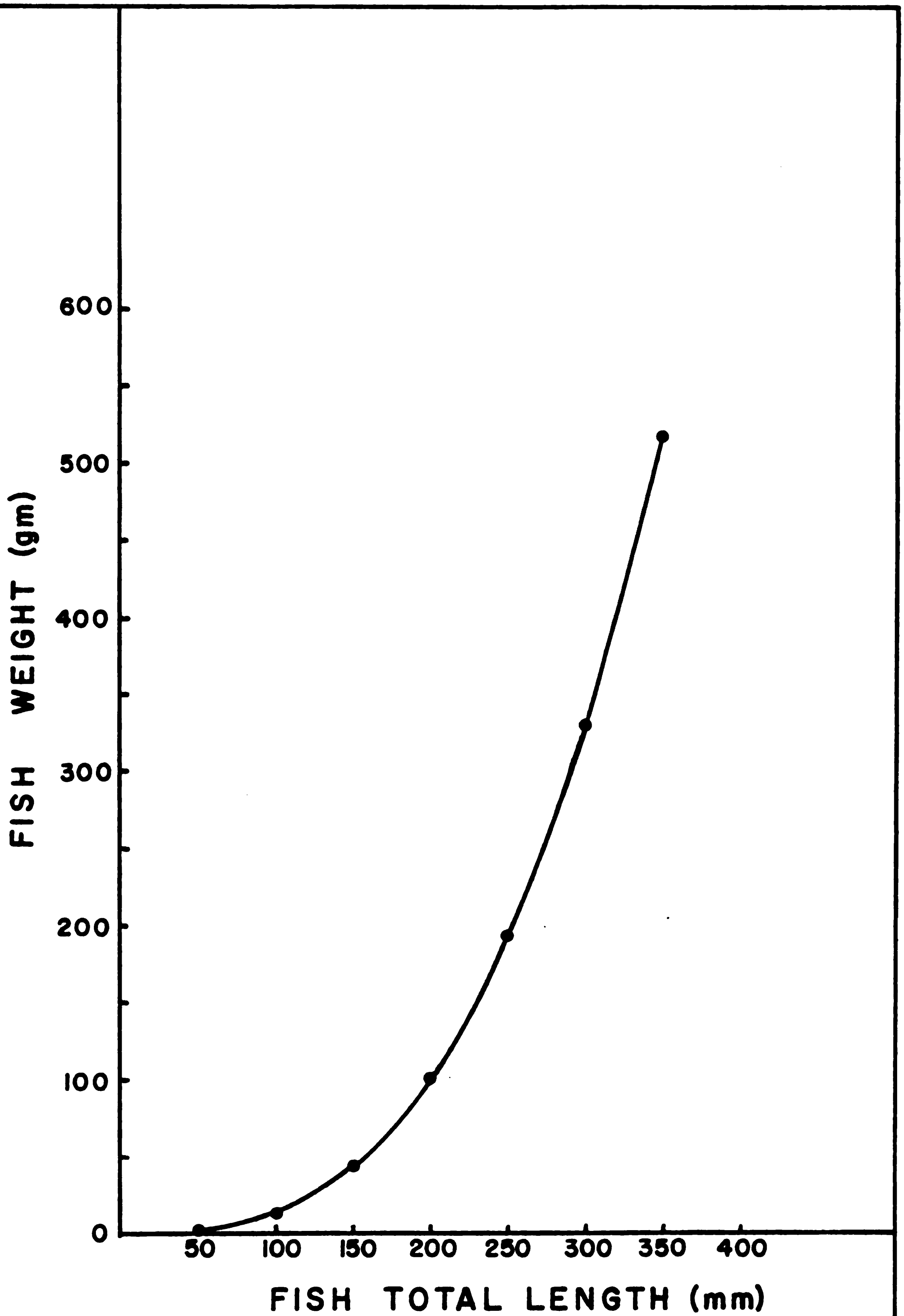


Figure A7. Length-weight relationship for gill netted yellow perch

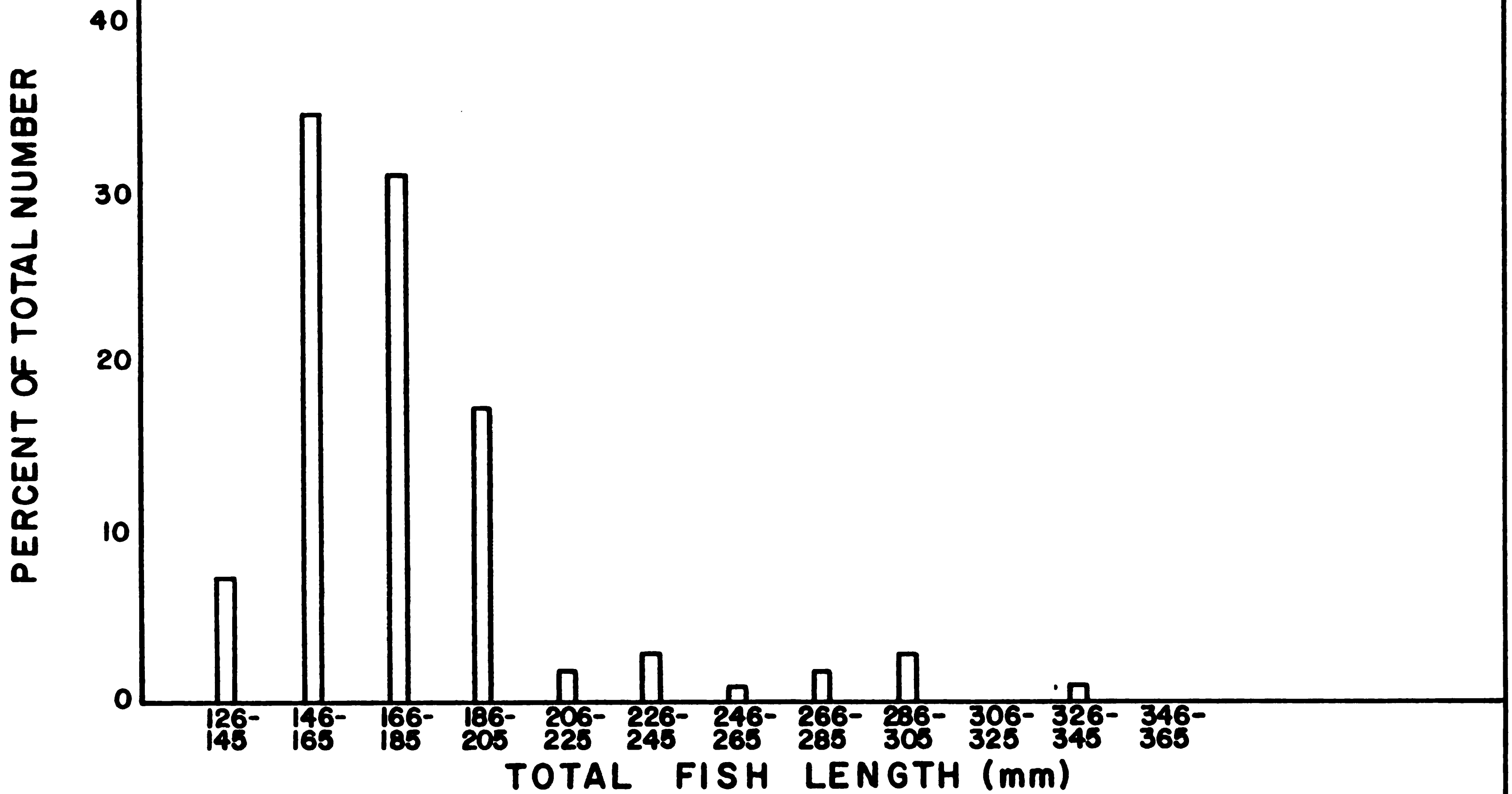


Figure A8. Length-frequency for gill netted yellow perch

MICHIGAN STATE UNIV. LIBRARIES
31293106962016