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MACROINVERTEBRATE COLONIZATION OF THE
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MACROINVERTEBRATE COLONIZATION OF THE MUSKEGON FRESHWATER ARTIFICIAL REEF

By

Scott D. Cornelius

A THESIS

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

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ABSTRACT

MACROINVERTEBRATE COLONIZATION OF
THE MUSKEGON FRESHWATER
ARTIFICIAL REEF

By

Scott D. Cornelius

A benthological investigation of the Muskegon Artificial Reef was conducted during the summers of 1981 and 1982 as part of the overall evaluation of the artificial reef's fisheries management potential in the Great Lakes. The objective of this study was to determine the impact of the Muskegon Artificial Reef on the macroinvertebrate population composition and relative abundance. Comparison between the artificial reef's macroinvertebrate population and that found in a reference area was used to determine the impact.

Six macroinvertebrate groups were present in the artificial reef and reference area: amphipoda, diptera, gastropoda, isopoda, oligochaeta, and pelecypoda. Chironomid larvae was the dominant group in the reef area, and *Pontoporeia hovi* was the most abundant group in the reference area. Ephemeroptera, porifera, trichoptera, and turbellaria were four macroinvertebrate groups found only on the artificial reef.

DEDICATION

This thesis is dedicated to my wife, Denice, in appreciation of her understanding, encouragement, and assistance throughout my Masters of Science program.

ACKNOWLEDGMENTS

I wish to express great personal appreciation to the following people. First to Dr. Niles R. Kevern, chairperson of the Department of Fisheries and Wildlife at Michigan State University, for providing me with this research opportunity. Dr. Kevern secured funding for this research throughout the economically troubled years of 1980-1982.

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Special thanks are due to my fellow graduate students Steve VanDerLaan and Bill Biener for their participation as boatman, Scuba diving team members and helpers in the collection of samples. Without their determination and participation this research could not have been completed.

Thanks is extended to Dr. Snider, Walt Duffy, and Dr. Jack Hiltunen for instruction and verification as to the identification of the macroinvertebrates sampled.

The staff of the Michigan Department of Natural Resources provided manpower, equipment and encouragement for the duration of this project for which thanks is given to Dave Weaver, John Trimberger, Doug Kort, Dave Smith and Russell Lincoln.

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TABLE OF CONTENTS

LIST OF TABLES

TABLE | Page

LIST OF FIGURES

FIGURE | Page

INTRODUCTION

With Michigan's automobile industry faltering in 1979-80, alternatives to enhance economic stability and reduce unemployment are being sought. Many believe that one such alternative is tourism. Enhancement and promotion of sports fishing in the Great Lakes could be part of the solution to Michigan's unemployment and economic instability.

The fisheries divison of the Michigan Department of Natural Resources (DNR), has been involed in several enhnacement programs. Two very successful programs were the planting of Coho salmon, *Oncorhynchus kisutch*, (Walbaum) in 1966 followed by the Chinook salmon, *Oncorhynchus tahawytscha*, (Walbaum) planting one year later into Lake Michigan. These success stories are well known and are providing Michigan with an excellent cold water fishery. The estimated income to the state from this fishery is $71,000,000 annually (Talhelm, 1981).

During the summer of 1980 another landmark project was launched. The Michigan DNR fisheries division constructed the first freshwater dolomite limestone artificial reef in the Great Lakes at a site off the coast of Muskegon County, Michigan in Lake Michigan. This reef will provide new fishing opportunities and income to an economically depressed section of Michigan. Preconstruction estimates of this new income was $74,500 per season (Trimberger, 1979).

Saltwater artificial reef fish productivity has been well documented in the Florida Keys (Stone et al.,1979), Puget Sound area

(Walton, 1979) and off the coast of Pinellas County, Florida (Wilbur, 1973). Successful fish productivity has also been reported with freshwater artificial reefs in Florida (Wilbur, 1973) and in Smith Mountain Lake, Virginia (Prince, 1979).

Construction of artificial reefs for the purpose of enhancing a declining fishery is by no means a new idea. Employment of artificial reefs has been traced back to the Japanese in the year 1794. Early reefs such as these consisted simply of wooden frameworks filled with sandbags and tree trunks, which were sunk off the coast of Kobe to rejuvenate a declining fishery (Ino, 1974). In 1845, South Carolina became one of the first states in the U.S. to experiment with artificial reefs. These reefs were similar to those of the Japanese and were placed around estuarine islands to attract Sheephead (Elliot, 1847). Although artificial reefs had their birth in salt water, the concept behind them seems to lend itself well to freshwater environments. The Michigan Department of Conservation during the mid-1930's introduced small artificial reefs constructed of rocks and tree limbs for the purpose of concentrating fish and improving spawning habitat (Hazzard, 1937). Construction of artificial reefs in the 1950's increased dramatically and continues to be a widespread and popular concept. Today at least 15 states possess progressive artificial reef programs. The term "artificial reef" was defined during the 1981 Florida Sea Grant College Conference as: any man-made structure deployed on ocean, lake, or estuarine floors for the purpose of concentrating fish (Ranasinghe, 1981).

When the major limiting factor to a fish population is determined to be lack of suitable habitat, as it was for the area of Lake

Michigan off the coast of Muskegon County, Michigan, an artificial reef is warranted. An artificial reef has the capability of concentrating fish by providing shelter, spawning habitat, and production of food organisms. Introduction of the Muskegon Artificial Reef, also known as the Hamilton Reef, is an attempt to concentrate yellow perch, Perca flavescens, (Mitchill) in an area assessible to sports fishing, thereby enhancing a relatively unproductive area of Lake Michigan. The reef was also intended as a new spawning habitat for lake trout, Salvelinus namaycush, (Wilbaum). Yellow perch and lake trout populations have been declining since 1964 (Wetzel, 1983) and 1945 (Berst et al., 1972), respectively. Today the Lake Michigan lake trout population is sustained only by planting programs. The addition of structural relief to the flat, firm sandy topography of Lake Michigan provides both species with protection from waves and predators, new spawning habitats, and increased production of food organisms (i.e. macroinvertebrates and forage fish).

Cost of materials and construction of this reef were approximately $80,000 (Trimberger, 1979). One-fourth of this money was provided by the State of Michigan and the other three-fourths was received from the Dingell-Johnson Fund (Reynolds, 1984).

The three research projects conducted on the Muskegon Artificial Reef as part of the overall evaluation were: fish colonization, fish reproduction, and benthic macroinvertebrate colonization. Fish colonization was examined by Bill Biener employing experimental gill net and Scuba transect observations. Biener concluded from his research that the artificial reef attracted significantly more yellow perch than the control area (Muskegon Channel breakwall) on greater than 50% of the sampling dates (Biener, 1982). Steve VanDerLaan investigated the utilization of the artificial reef by fish as spawning habitat. Egg pump, egg trays, and emergent fry traps were all used to investigate fish reproduction. VanDerLaan's research findings showed that yellow perch were the only game species to utilize the reef as spawning habitat (VanDerLaan, 1983).

The focus of this research was the benthological investigation into the macroinvertebrate colonization of the Muskegon Artificial Reef. Many food organisms of freshwater fish (i.e. macroinvertebrates) are dependent on substrate for their existence in the aquatic ecosystem requiring a firm attachment surface for completion of their life cycles (Pieczynska et al., 1966). Artificial reefs provide firm attachment substrate and thereby increase the abundance and change the composition of the macroinvertebrate population of an area (Prince et al., 1975 and Maughan et al., 1976).

The benthic fauna of Lake Michigan has been investigated both directly and indirectly for over 100 years. In this span of time, Stimpson (1870) and Eggleton (1936 and 1937) have described and enumerated the profauna collected in bottom samples. More recently, Merna (1960) attempted to relate the number of benthic organisms collected by an orange peel dredge to their geographical and topographical distribution. Throughout the 1960's and 1970's researchers (Powers and Robertson, 1965; Robertson and Alley, 1966; Alley and Anderson, 1968; Powers and Robertson, 1968; Henson, 1970; and Mozley and Garcia, 1972) have conducted studies examining the distribution of the macroinvertebrates of Lake Michigan. Information about the composition and abundance of macrobenthos populations has also evolved from studies (Cook and Powers, 1964; Alley and Powers, 1970; Mozley and Alley, 1973; Olson, 1974; Jude et al., 1978; and Winnell and Jude, 1980) utilizing the benthic faunal community as indicators of eutrophication, perturbation, and/or degradation of an area due to human activity.

This study investigates two areas of research that have been neglected in the past. The first is the macroinvertebrate populations inhabiting the coastal waters of Lake Michigan which have received attention only when an indicator of environmental degradation is desired. The placement of the reef and reference area in shallow waters provides an opportunity to study this macroinvertebrate community. The second is the area of macroinvertebrate colonization of freshwater artificial reefs. The basic understanding of artificial reef development remains greatly impaired due to researchers' tendency to focus on fish colonization when evaluating the success or failure of an artificial reef. This approach is incomplete because it fails to investigate the community interactions of plants and animals comprising the lower levels of the trophic pyramid and their impact on an artificial reef's success.

OBJECTIVE OF THE STUDY

The major objective of this study is to determine what effect the construction of the Muskegon Artificial Reef has on the existing macroinvertebrate population and how their composition and abundance relates to the success of the reef in attracting fish. To accomplish this objective it was necessary to quantify what macroinvertebrate species were present and to assess if these groups are among those known to be utilized by yellow perch as food items.

Diet studies on yellow perch inhabiting the Great Lakes have revealed that they feed on chironomid larvae, amphipods, isopods, ephemeroptera, trichoptera, gastropods, crayfish and small fish (Dodge, 1968; Tharatt, 1959). Brazo determined from stomach samples that the major food items of Lake Michigan yellow perch were amphipods, crayfish and small fish (Brazo, 1973). These studies suggest that macroinvertebrates are the most important food items in the diet of Great Lakes yellow perch and, as such, are one of the key factors affecting the success of the Muskegon Artificial Reef.

DESCRIPTION OF THE STUDY AREA

The Muskegon Artificial Reef is located in Lake Michigan at the coordinates of 43°13'10" north latitude and 86°20'19" west longitude (Figure 1). The reef is one kilometer off the shore of Muskegon County, Michigan and eight-tenths of a kilometer south of the Muskegon Lake Channel (Figure 2). The reference area is located eight-tenths of a kilometer north of the Muskegon Lake Channel and one kilometer offshore of Muskegon County (Figure 2). Scuba surveys conducted in 1979 found the proposed study area to be lacking in suitable habitat for yellow perch, devoid of aquatic plants and relatively unproductive in terms of fish and macroinvertebrates (Dorr et al., 1979).

The artificial reef is contained in a rectangular area 579 by 91.4 meters, and lies perpendicular to the shore. The reef covers an estimated area of 8,500 square meters. Shallow and deep ends of the artificial reef are situated in 8.2 and 13.7 meters of water, respectively. Sampling areas on the reef and in the reference area were located at a water depth of 9.8 meters (Figure 3).

Three barges were required to transport 3,636 metric tons of dolomite limestone quarried in Manitowoc, Wisconsin to the reef site. Construction material ranged in size from 15.2 by 15.2 centimeters up to 3.0 by 2.0 meters. During a three month period in the summer of 1980, Baltema Dock and Dredge of Muskegon, Michigan placed the rocks in piles averaging 6.0 meters in diameter by 1.5 meters high and

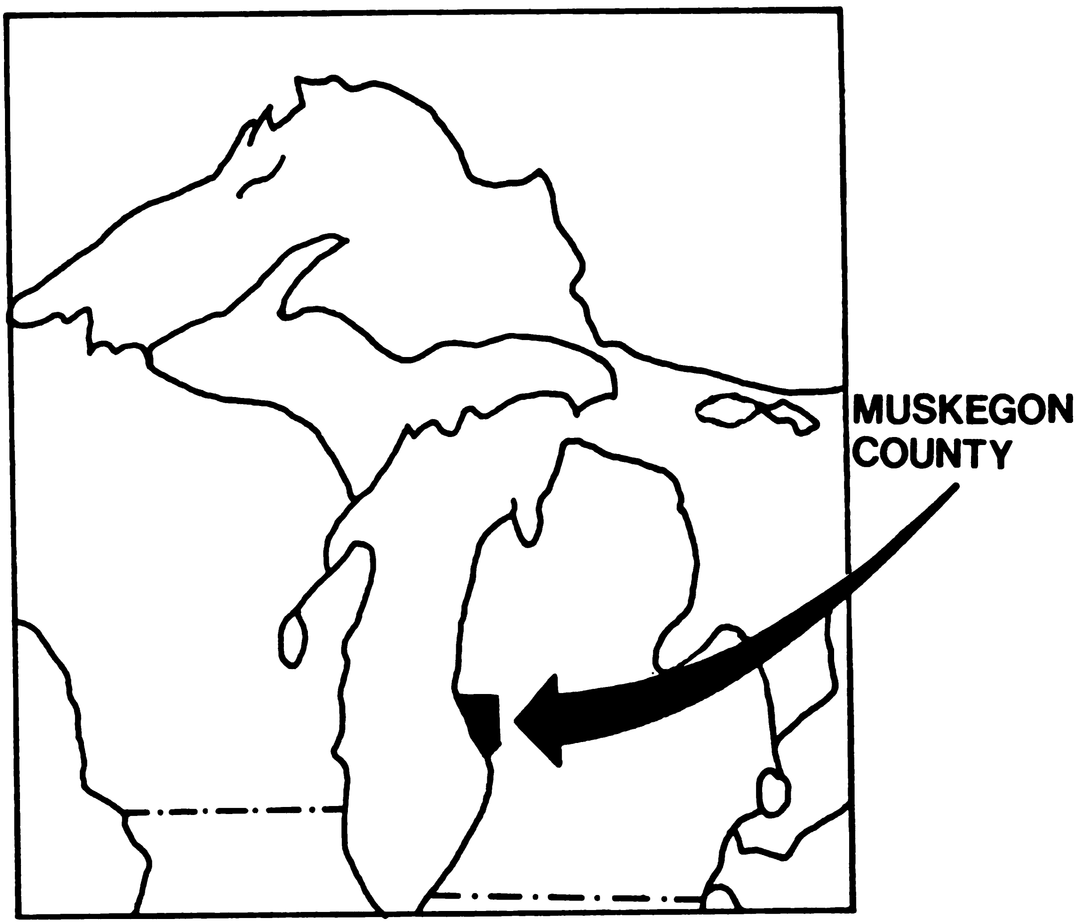


Figure 1. Location map of Muskegon County, Michigan

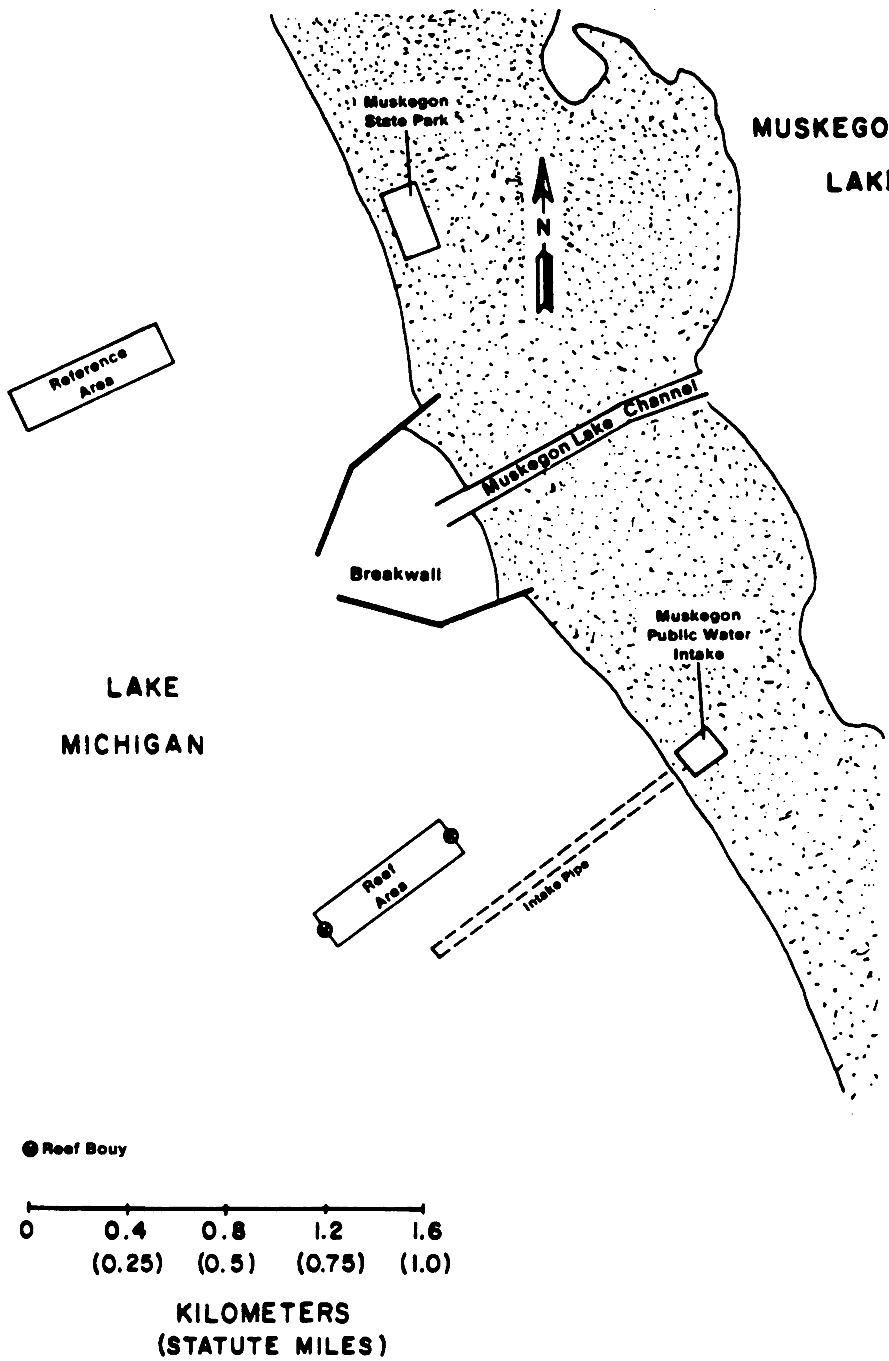


Figure 2. Local map of the Muskegon Artificial Reef and reference area

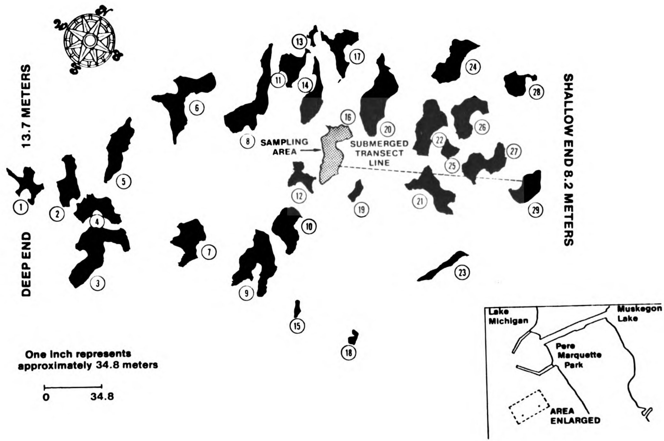


Figure 3. Side sonar sounding map of the Muskegon Artificial Reef

15 meters apart. After the construction was completed, identification buoys reading "Michigan Department of Natural Resources Fishing Reef" were attached to both ends to aid fisherman in locating the reef.

The entire study area comprising the artificial reef and reference site is located on the eastern side of the central basin of Lake Michigan adjacent to the Muskegon Lake Channel breakwall and the shoreline of Muskegon County, Michigan. The topography of this section of Lake Michigan is characterized as a flat, firm, medium grained sandy bottom, lacking any physical structural relief. Water depth increases gradually as the distance from shore increases obtaining a depth of 17.4 meters at a distance of 2.4 kilometers offshore.

Bottom temperature recordings show rapid fluctuation during the field season. Temperatures range from 4.4° to 22.7°C and are strongly influenced by wind direction. During the summer months the prevailing winds are from the southwest. Winds from this direction push warm water into the research area causing bottom temperatures to reach 22.7°C. Fall brings northwest winds which move cold water in replacing the warm water. Bottom temperatures during this time are likely to drop to 4.4°C. Occasionally, through the spring and summer, strong easterly winds prevail causing warm water to move offshore and cold water (4.4°C) to upwell in its place. The harshest conditions predominate during the winter when storm winds produce waves that scour the rocks of the reef. Evidence of scouring by ice and debris at depths down to 9.8 meters has been observed on the reef. Changes in wind direction also influences the direction of currents, waves and flow of the plume from the Muskegon Lake Channel.

Currents running north and south along the coast occur regularly and determine which direction the Muskegon Channel plume flows. The direction of the currents change daily and with it the flow of the plume. Contained in this plume is organic detritus, macroinvertebrates, and the major nutrient input into the area. Wave action usually prevents the accumulation of organic detritus on the bottom of Lake Michigan. However, the reef acts like a retention area trapping organic matter between the crevices of the rocks.

Baseline benthological data for the Muskegon Artificial Reef area was almost non-existent prior to the artificial reef's installation in 1980. The only documented study of this area was conducted by John Dorr, III and David Jude, of the University of Michigan, Great Lakes Research Division, in 1979 to aid the State of Michigan's artificial reef project with site selection. Underwater Scuba observations were performed to document existing physical and biological conditions in this area of Lake Michigan including any unique fish spawning areas or substrates, irregular lake bottom terrain, areas of locally increased turbidity or silt, and presence of aquatic macrophytes (Dorr et al., 1980). The above study surveyed the area containing both the artificial reef and the reference area. It is assumed that the artificial reef and the reference areas were identical before the introduction of the reef and that construction of the reef is the only difference between the two areas.

METHODS AND MATERIALS

Sampling Methods

Benthological investigation of the macroinvertebrate population composition and abundance inhabiting the Muskegon Artificial Reef and the reference area was conducted utilizing the petite ponar grab sampler, rock basket sampler, and multiple plate sampler. Benthic macroinvertebrate samples were collected from the artificial reef using the above three samplers in an attempt to analyze all of the artificial reef's different habitats. The homogenous habitat (i.e. flat, firm sand) of the north reference area required the use of a petite ponar grab sampler alone.

Multiple plate samplers were constructed of four 0.5 x 20 x 20 centimeter hard board plates spaced vertically along a 1.2 centimeter steel spike 37 centimeters long. A 10 centimeter hook was attached at the lower portion of the spike for connecting the sampler to the steel cable woven between the rocks of the reef. This was a modification of the apparatus described by F.E. Hester and J.S. Dendy in 1962, to better fit the sampling requirements. The surface area of one plate is 800 cm^2 and the combined four plate total surface area is 3200 cm^2 (Figure 4). Twenty-four multiple plate samplers were positioned on the artificial reef and connected to the one-half inch braided steel cable by Scuba divers on June 4, 1981. Multiple plate samplers remained for two weeks to colonize, after which triplicate samplers were removed every other week and new multiple plate samplers replaced

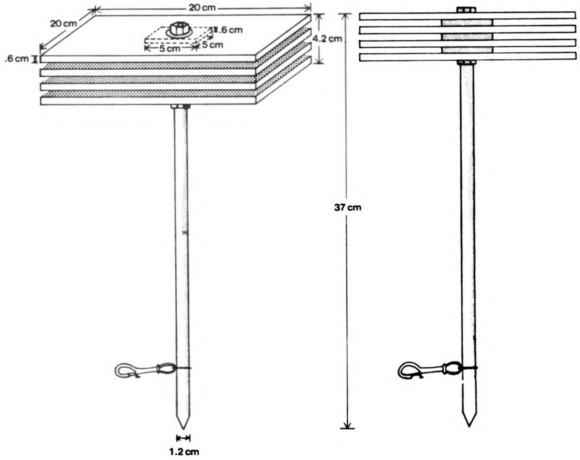


Figure 4. Dimensional drawing of the multiple plate sampler used to sample macroinvertebrates from the Muskegon Artificial Reef

the ones taken.

Rock basket samplers were constructed of one-half inch steel rod welded together to form a rectangular box frame with dimensions of 20 x 20 x 50 cm with a hinged door at one end. The frame was enclosed on all sides by soldered wire mesh with dimensions of 5 x 10 cm (Figure 5). Artificial substrate placed inside the baskets consisted of concrete cones poured in sixteen ounce cups, used as molds. The surface area of a single cone is 252.77 cm^2 and eighteen cones per basket were employed, having a total surface area of 4549.86 cm^2. During the 1982 field season, dolomite rock replaced cones which had been crushed and deteriorated during the previous winter. The approximate weight of a basket sampler filled with concrete cones or rocks is 35 pounds. Thirty-six rock basket samplers were positioned on the artificial reef by Scuba divers and connected to a one-half inch braided steel cable on June 4, 1981. Basket samplers were left to colonize two weeks, after which triplicate samplers were removed every other week and new basket samplers replaced the ones taken.

The procedure for lifting the rock basket and multiple plate samplers was as follows: a team of Scuba divers would descend with three pieces of rope and three pillow cases rolled up in a mesh dive bag. Upon arrival at the samplers each would be covered as far as possible without moving the sampler. When no more could be covered the divers would gently move the basket sampler so that the whole sampler was covered except for one end. The sampler was then unhooked from the steel cable and slowly inverted by one diver while the other closed the pillow case over the open end. The pillow case was tied

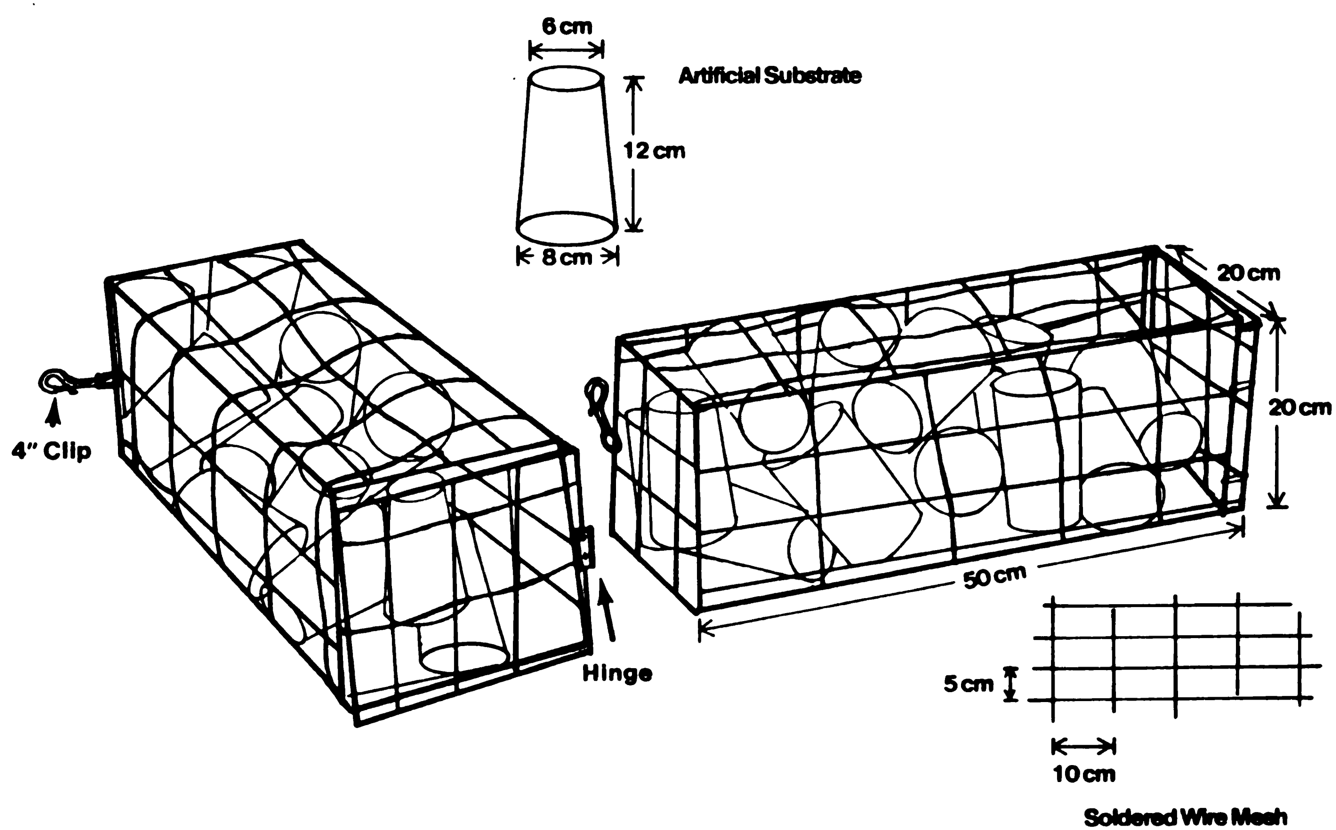


Figure 5. Dimensional drawing of the rock basket sampler used to sample macroinvertebrates from the Muskegon Artificial Reef

closed with rope and each was attached to a buoy. Samplers were then lifted 9.8 meters to the boat.

These two samplers were employed only on the artificial reef. Utilizing these samplers in the reference area would duplicate the effects of the artificial reef producing false data, leading to erroneous conclusions.

Triplicate petite ponar grab samples were collected from the sand substrate of the artificial reef and reference area on a biweekly basis. Jaw dimensions on the petite ponar grab sampler are 15.5 x 16.5 cm and, on an average, collects one and one-half quarts of sediment per set. The petite ponar sampler was selected for its small size, which lends itself well to manipulation by Scuba divers and sampling in confined areas between rocks on the artificial reef (Figure 6). Operating procedures were modified to produce a consistent sample and allow sampling close to the rocks on the reef. A petite ponar sampler was lowered to Scuba divers who would set the sampler from a suspended position just above the bottom and signal the boatman to retrieve the sampler. On board the boat the sample was emptied into a labeled five gallon pail and sealed with a cover.

Triplicate samples of each sampler type were transported back to the laboratory where the artificial substrate was washed and scrubbed into a tub removing all macroinvertebrates. The entire sample was poured through a No. 120 (125 microns) U.S. Standard sieve to remove the water used for washing and placed the sieve contents into quart jars with 70 percent ethanol for storage and sorting after the field season. Labels containing information about the type of sampler used, area sampled, date sampled, and an identification number for the sample were

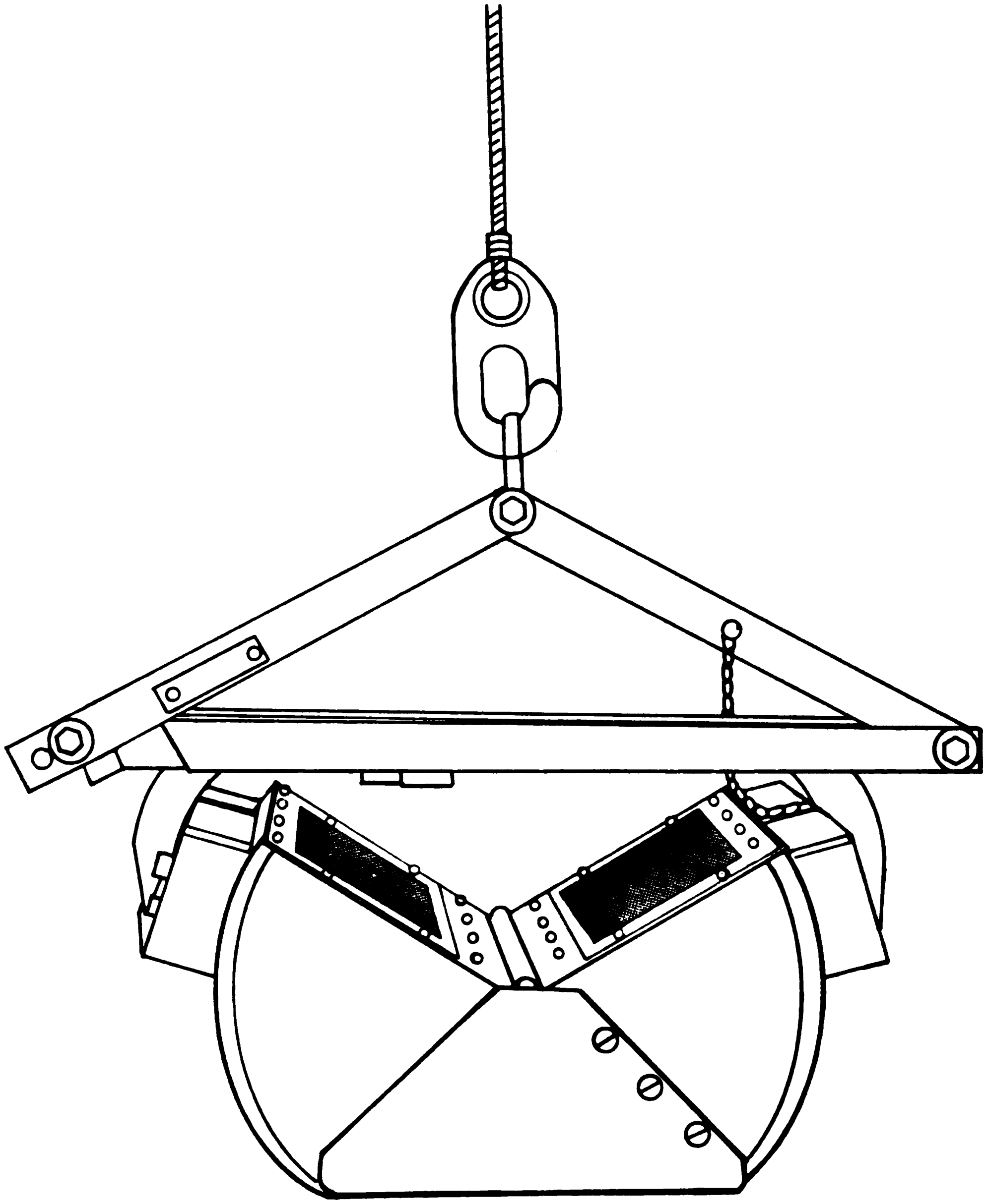


Figure 6. Drawing of the petite ponar grab sampler used to sample macroinvertebrates from the Muskegon Artificial Reef and the reference area

attached to the outside of each quart jar. This information was also entered into a log book.

After the field season the benthic macroinvertebrates were separated from the substrate by passing the entire sample through a U.S. Standard seive series composed of seives No. 20 (833 microns), No. 30 (593 microns), No. 60 (250 microns), and No. 120 (125 microns), listed in order from bottom to top. The contents of each seive were placed in an enamel pan, examined under a magnifying lens, and the organisms removed and segregated by order. Organisms were then identified and counted under a (10X) binocular dissecting microscope, except for oligochaetes and chironomids. Chironomids were temporarily mounted on slides and oligochaetes were mounted and cleared in Ammann's lactophenol. Both of these groups were identified using a binocular compound microscope at a minimum magnification of 100X. All organisms were preserved in 70 percent ethanol, and expressed in numbers of individuals/m^2 using the appropriate conversion factors for each sampler type. The data was multiplied by the conversion factors as follows: petite ponar grab sampler is 3.1250, multiple plate sampler is 39.100, and rock basket sampler is 2.1978.

Identification of the benthic macroinvertebrates was made to the lowest positive taxon using several taxonomic keys: amphipods, isopods, gastropods, pelecypods (Pennak, 1978); turbellaria (Pennak, 1978; Kent, 1976; Ward and Wipple, 1959); trichoptera (Wiggins, 1978); ephemeroptera (Hilsenhoff, 1975); diptera (Hilsenhoff, 1975 and Oliver et al., 1978); porifera (Eddy, 1970); oligochaeta (Stimpen et al., 1982 and Hiltunen et al., 1980) and crayfish (Lippson, 1975).

Physical Measurements

Temperature

Twenty-four hour averaged bottom temperature readings were obtained from the City of Muskegon Water Filtration Plant. The plant's water intake pipe is located in 10.5 meters of water, less than four-tenths of a kilometer south of the artificial reef site. Temperature data for the months of May through November 1980, 1981 and 1982 were collected.

Light

Measurements of light intensity were taken using a Li-Cor, Li-188B Integrating Quantum Meter fitted with a Li-1925B Underwater Quantum Meter Sensor. Light intensity readings were recorded in microeinsteins per square meter per second ($\mu Em^{-2}sec^{-1}$) at one meter intervals from surface to bottom. Readings were taken on July 11, 1983 at eight stations and on August 24, 1983 at four of the eight stations (Figure 7). These two dates provide estimates of above and below average light transmission, respectively.

Linear regression analysis of the natural logarithm of the light measurement versus water depth provided the extinction coefficient ($-\eta$), using the equation given in Wetzel (1983)

$$I_z = I_0 e^{-\eta z}$$

where: I_0 = irradiance at the lake surface,

I_z = irradiance at depth z,

η = the log of the negative extinction coefficient, and

z = depth distance in meters.

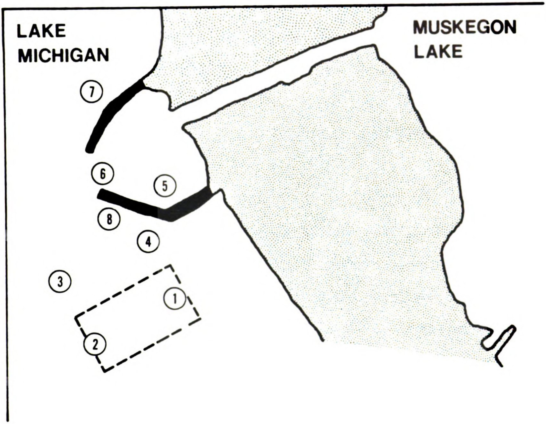


Figure 7. Location map of light measurement stations

Light transmission to depths of 9.5 meters (shallow end of reef) and 13.5 meters (deep end of reef) were calculated using the extinction coefficient for each light measurement station.

It should be mentioned that the above equation does not account for backscattering or surface reflection. Wetzel (1983) reports that when the angle of incident light is greater than 60° the surface reflection and backscatter is less than 2%. Measurements on both dates were taken between 11 A.M. and 3 P.M. when the angle of incident light was greater than 60° and these losses were considered negligible.

Reef Depth

Concern about the stability of the substrate on which the reef was constructed, coupled with the development of small depressions around the edges of some piles, promoted the development of a procedure to measure the reef's depth. Inside the Muskegon Lake Channel breakwall's south arm a permanent benchmark was created by chiseling a small mark into the concrete. This benchmark was used to detect changes in the water level of Lake Michigan. Depth measurements were taken from the water's surface to the base of the anchors securing the permanent buoys on the shallow and deep ends of the reef.

Sampling Schedule

Selection of the artificial reef sampling station equal distance from the shallow and deep ends of the reef was designed to optimize both time and effort during the research period. This sampling station and the reference area sampling station were situated in similar areas south and north of the Muskegon Lake Channel as seen in Figure 2 at a depth of 9.8 meters of water.

Often the presence of strong winds and high waves on Lake Michigan made the sampling stations inaccessible. These conditions occurred often enough to make adherence to the alternate week sampling schedule difficult. Wave conditions less than three feet were required for the retrival of the samplers by Scuba divers. Sampling was resumed as soon as suitable conditions prevailed. Table 1 shows the time table for this study and includes the relationship and duration of the different sampling schedules for each sampling method during the 1981 and 1982 field seasons.

During the winter of 1981, some of the rock basket and multiple plate samplers that were left on the artificial reef incurred damage or were lost. Equipment damage resulted from ice or debris scouring. The artificial substrates, both cement cones and hardboard plates, were often crushed. Ice blocks or debris were also responsible for ripping the samplers from the steel cable and transporting them away from the reef area. Such incidents hindered the sampling of the macroinvertebrates from the reef.

Table 1. Benthic macroinvertebrate sampling schedule for the Muskegon Artificial Reef and reference area indicating the number of samples collected on each date

	Petite Ponar Sampler		Multiple Plate Samplers	Rock Basket Samplers
	Muskegon Artificial Reef	Reference Area		
June 4, 1981			placement	placement
July 20, 1981		3		3
July 29, 1981	3	3		3
Aug. 5, 1981	3	3		3
Aug. 10, 1981	3	3	3	3
Aug. 18, 1981	3	3	3	
Aug. 20, 1981				3
July 19, 1982	3	3		3
Aug. 16, 1982				3
Aug. 30, 1982	3	3	3	3
Sept. 22, 1982	3	3	3	3
Nov. 18, 1982			3	3

Data Analysis

The data collected by this research revealed that the macroinvertebrate distribution met the criteria ($\sigma^2 > \mu$) for contagious distribution, which is common for benthic macroinvertebrate samples. Elliot (1971) has recommended that data with heterogenicity of variance, such as is the case here, be subjected to the log transformation, log (x + 1). After the data were transformed, a one-way analysis of variance and an F-test were performed to determine whether there were significant differences in the major macroinvertebrate groups between sampling areas, between areas for the same field season, between years for the same area, and between sampler type utilized.

RESULTS AND DISCUSSION

Taxa of the reference and reef area-benthic macroinvertebrates as collected by the different sampling gear are presented in Tables 2 through 5.

Table 2. **Taxa of reference area benthic macroinvertebrates as collected in the 1981 and 1982 petite ponar grab samples**

- Arthropoda
  - Eucrustacea
    - Malacostraca
      - Isopoda
        - Asellidae
          - *Asellus* sp.
      - Amphipoda
        - Gammaridae
          - *Gammarus pseudolimnaeus*
        - Haustoriidae
          - *Pontoporeia hoyi*
- Mollusca
  - Gastropoda
    - Pulmonata
      - Physidae
        - *Physa* sp.
      - Planorbidae
        - *Gyraulus* sp.
- Insecta
  - Diptera
    - Chironomidae
      - *Chironomus* sp.
      - *Cryptochironomus* sp.
      - *Polypedilum* sp.
      - *Dicrotendipes* sp.
      - *Tanytarsus* sp.
    - Diamesinae
      - *Potthastia* sp.
      - *Monodiamesa* sp.
    - Orthocladiinae
      - *Cardiocladius* sp.
      - *Psectrocladius* sp.
      - *Heterotrissocladius* sp.
- Annelida
  - Oligochaeta
    - Haplotaxida
      - Naididae
        - *Uncinais uncinata*
      - Tubificidae
        - *Limnodrilus hoffmeisteri*

Table 3. Taxa of artificial reef benthic macroinvertebrates as collected in the 1981 and 1982 multiple plate samplers

- Arthropoda
  - Eucrustacea
    - Malacostraca
      - Isopoda
        - Asellidae
          - *Asellus* sp.
      - Amphipoda
        - Gammaridae
          - *Gammarus* *pseudolimnaeus*
        - Haustoriidae
          - *Pontoporeia* *hoyi*
- Mollusca
  - Gastropoda
    - Pulmonata
      - Bithyniidae
        - *Bithynia* *tentaculata*
      - Physidae
        - *Physa* sp.
      - Planorbidae
        - *Gyraulus* sp.
  - Pelecypoda
    - Heterodonta
      - Sphaeriidae
        - *Pisidium* sp.
- Insecta
  - Ephemeroptera
    - Heptageniidae
      - *Stenonema* sp.
  - Trichoptera
    - Hydropsychidae
      - *Hydropsyche* sp.
    - Hydroptilidae
      - *Hydroptila* sp.
      - *Orthotrichia* sp.
    - Leptoceridae
      - *Ceraclea* sp.

Table 3. Continued

Insecta					
	Diptera				
		Chironomidae			
			Chironomus sp.		
			Cryptochironomus sp.		
			Dicrotendipes sp.		
			Glyptotendipes sp.		
			Parachironomus sp.		
			Polypedilum sp.		
			Tanytarsus sp.		
		Diamesinae			
			Monodiamesa sp.		
			Potthastia sp.		
		Orthocladiinae			
			Cardiocladius sp.		
			Heterotrissocladius sp.		
			Orthocladius sp.		
			Psectrocladius sp.		
			Thienemanniella sp.		
		Tanypodinae			
			Larsia sp.		
Annelida					
	Oligochaeta				
		Haplotaxida			
			Tubificidae		
				Limnodrilus hoffmeisteri	
Platyhelminthes					
	Turbellaria				
		Tricladia			
			Planariidae		
				Dugesia tigrina	

Table 4. Taxa of artificial reef benthic macroinvertebrates as collected in the 1981 and 1982 basket samplers

Arthropoda
- Eucrustacea
  - Malacostraca
    - Isopoda
      - Asellidae
        - _Asellus_ sp.
    - Amphipoda
      - Gammaridae
        - _Gammarus pseudolimnaeus_
      - Haustoriidae
        - _Pontoporeia hoyi_

Mollusca
- Gastropoda
  - Pulmonata
    - Bithyniidae
      - _Bithynia tentaculata_
    - Physidae
      - _Physa_ sp.
    - Planorbidae
      - _Gyraulus_ sp.
- Pelecypoda
  - Heterodonta
    - Sphaeriidae
      - _Pisidium_ sp.

Insecta
- Ephemeroptera
  - Heptageniidae
    - _Stenonema_ sp.
- Trichoptera
  - Hydropsychidae
    - _Hydropsyche_ sp.
  - Hydroptilidae
    - _Hydroptila_ sp.
    - _Orthotrichia_ sp.
  - Leptoceridae
    - _Ceraclea_ sp.
    - _Nectopsyche_ sp.

Table 4. Continued

- Insecta
  - Diptera
    - Chironomidae
      - *Chironomus* sp.
      - *Cryptochironomus* sp.
      - *Glyptotendipes* sp.
      - *Parachironomus* sp.
      - *Polypedilum* sp.
      - *Dicrotendipes* sp.
      - *Tanytarsus* sp.
    - Tanypodinae
      - *Larsia* sp.
    - Diamesinae
      - *Potthastia* sp.
      - *Monodiamesa* sp.
    - Orthocladiinae
      - *Cardiocladius* sp.
      - *Heterotrissocladius* sp.
      - *Orthocladius* sp.
      - *Psectrocladius* sp.
      - *Thienemanniella* sp.
- Annelida
  - Oligochaeta
    - Haplotaxida
      - Naididae
        - *Nais varibilis*
        - *Ophidonais serpentina*
        - *Stylaria lactistris*
- Platyhelminthes
  - Turbellaria
    - Tricladia
      - Planariidae
        - *Dugesia tigrina*

Table 5. Taxa of artificial reef benthic macroinvertebrates as collected in the 1981 and 1982 petite ponar grab samples

- Arthropoda
  - Eucrustacea
    - Malacostraca
      - Isopoda
        - Asellidae
          - *Asellus* sp.
      - Amphipoda
        - Gammaridae
          - *Gammarus pseudolimnaeus*
        - Haustoriidae
          - *Pontoporeia hoyi*
- Mollusca
  - Gastropoda
    - Pulmonata
      - Physidae
        - *Physa* sp.
      - Planorbidae
        - *Gyraulus* sp.
  - Pelecypoda
    - Heterodonta
      - Spheriidae
        - *Pisidium* sp.
- Insecta
  - Diptera
    - Chironomidae
      - Chironominae
        - *Chironomus* sp.
        - *Cryptochironomus* sp.
        - *Tanytarsus* sp.
      - Orthocladiinae
        - *Psectrocladius* sp.
      - Diamesinae
        - *Monodiamesa* sp.
- Annelida
  - Oligochaeta
    - Haplotaxida
      - Naididae
        - *Uncinais uncinata*
        - *Stylaria lactistris*
        - *Nais varibilis*
        - *Piguetiella michiganensis*
      - Tubificidae
        - *Potamothrix moldaviensis*
        - *Limnodrilus angustipenis*
        - *Limnodrilus profundicola*

Chironomidae

Samples were collected from the sand substrate of the artificial reef and reference area by the petite ponar grab sampler. The chironomid larvae collected from the sand of the artificial reef were dominated by Chironomus sp. and Cryptochironomus sp. from the family Chironominae. The abundance of these two genera were 70.6% and 18.2%, respectively. Less numerous genera also present were: Monodiamesa sp. at 5.6%; Dicrotendipes sp. at 3.7%; Heterotrissocladius sp. at 1.1%; Psectrocladius sp. at 0.16%; and Cardiocladius sp. at 0.03% (Figure 8).

The dominant chironomid larvae in the reference area were also Chironomus sp. and Cryptochironomus sp. The abundance of these two genera were found to be somewhat lower than that of the reef, 64.3% and 12.3%, respectively. Less abundant genera found in this area were: Monodiamesa sp. 10.8%; Tanytarsus sp. 5.8%; Psectrocladius sp. 2.9%; Heterotrissocladius sp. 1.4%; Dicrotendipes sp. 1.0%; and Orthocladius sp. 1.0% (Figure 9).

Multiple plate and rock basket samplers collected a number of genera not found in the sand substrate of either sampling site. Psectrocladius sp. and Glyptotendipes sp. were the most abundant chironomid larvae in the multiple plate samples. Their abundance was shown to be 29.9% and 23.4%, respectively. Glyptotendipes sp. was absent from the sand substrate samples from both areas, while Psectrocladius sp. was very scarce in the petite ponar grab samples collected from the sands of the above two areas. Eleven other genera were also collected by the multiple plate sampler with less regularity than the above two. These genera and their abundances are as follows: Tanytarsus sp. 10.2%; Larsia sp. 9.6%; Cryptochironomus sp. 6.9%;

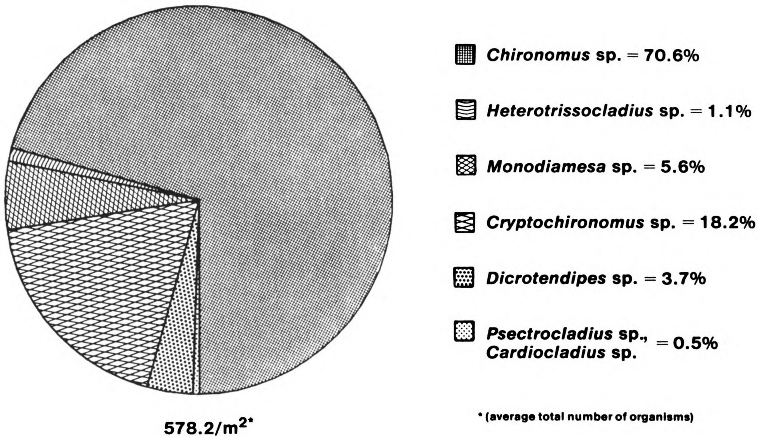


Figure 8. Composition and relative abundance of the family Chironomidae as sampled in 1981 and 1982 from the Muskegon Artificial Reef by the petite ponar grab sampler (macroinvertebrates/m^2)

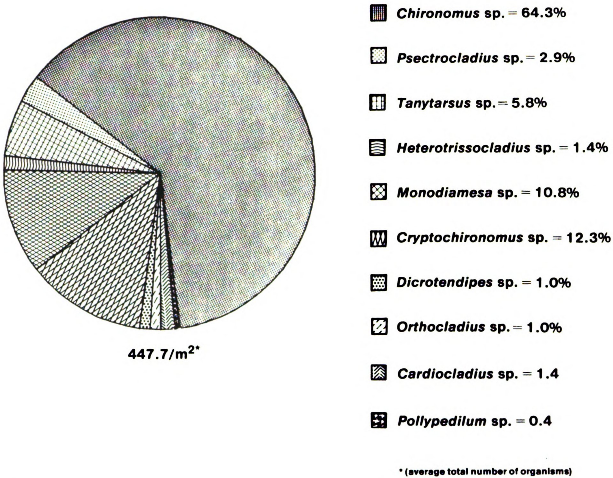


Figure 9 . Composition and relative abundance of the family Chironomidae as sampled in 1981 and 1982 from the reference area by the petite ponar grab sampler (macroinvertebrates/m^2)

Parachironomus sp. 5.4%; and Chironomus sp. 4.9%, all of intermediate abundance. The remaining genera were present but sparse in the samples: Monodiamesa sp. 2.4%; Dicrotendipes sp. 1.8%; Cardiocladius sp. 0.8%; Thienemanniella sp. 0.5% (Figure 10).

Abundances of 33.6% for Psectrocladius sp. and 20.3% for Chironomus sp. made these the dominant genera in the rock basket samples. Genera present in intermediate abundance were: Parachironomus sp. 11.9%; Glyptotendipes sp. 9.3%; Tanytarsus sp. 6.6%; and Cardiocladius sp. 5.8%. The following genera were present but rare in comparison: Larsia sp. 3.6%; Heterotrissocladius sp. 2.4%; Orthocladius sp. 2.1%; Polypedilum sp. 2.2%; Dicrotendipes sp. 0.8% and Potthastia sp. 0.8% (Figure 11).

The dominant chironomid larvae in the coastal zone of southeastern Lake Michigan was reported to be Chironomus, Cryptochironomus and Procladius (Mozley and Garcia, 1972). These genera were also found to be the dominant chironomid larvae in the coastal areas of central Lake Michigan (Olson, 1974). Chironomus and Cryptochironomus were the most abundant genera found in the reference and reef areas sampled by the petite ponar samplers. However, in the Muskegon area Procladius was absent, possibly due to the increased depth at which the samples were taken.

Chironomid larvae are reported to be important food items in the diet of yellow perch (Brazo, 1973) and round whitefish (Armstrong, 1973). Several trophic levels are occupied by the chironomid larvae inhabiting the reef area. The subfamily Chironominae includes the following genera found on the reef: Chironomus sp., Cryptochironomus sp., Glyptotendipes sp., Parachironomus sp., Polypedilum sp. and

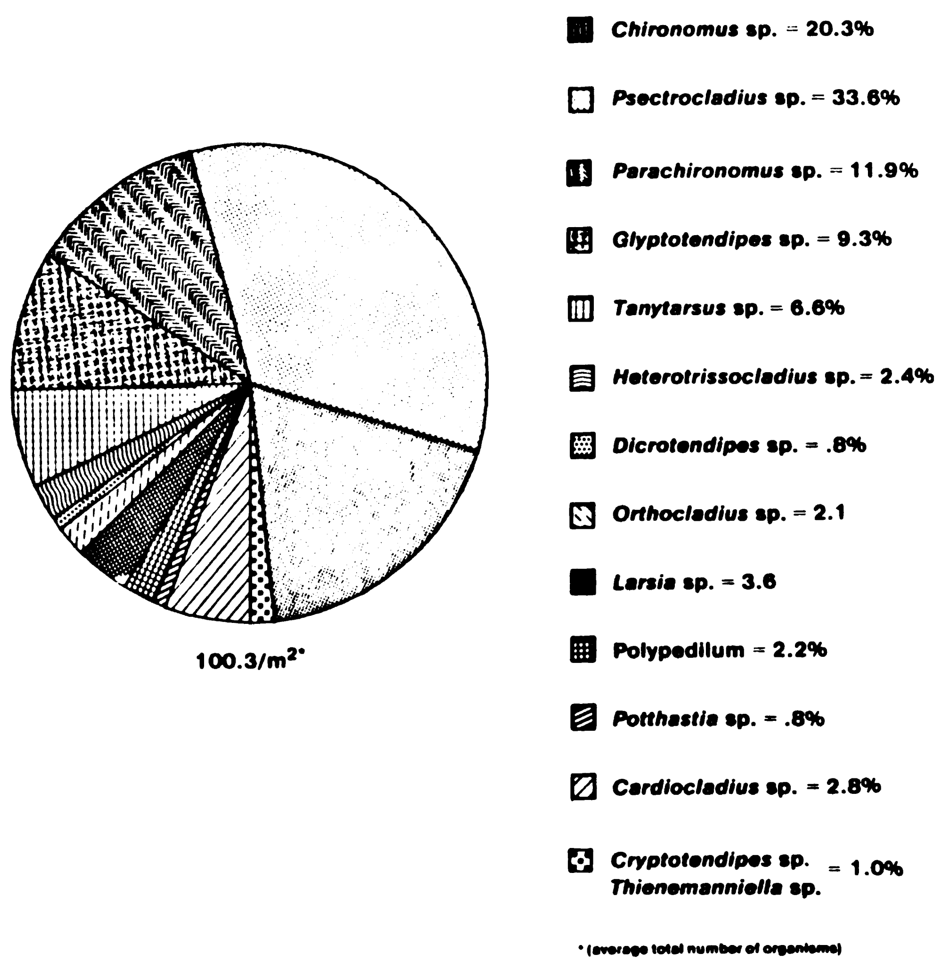


Figure 10. Composition and relative abundance of the family Chironomidae as sampled in 1981 and 1982 from the Muskegon Artificial Reef by multiple plate samplers (macroinvertebrates/m^2)

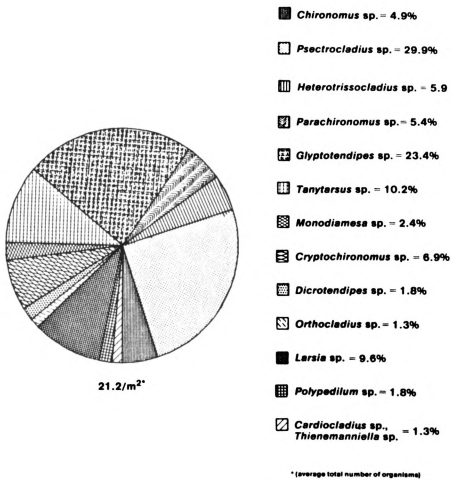


Figure 11. Composition and relative abundance of the family Chironomidae as sampled in 1981 and 1982 from the Muskegon Artificial Reef by rock basket samplers (macroinvertebrates/m^2)

Dicrotendipes sp. Larvae from these genera are herbivores and detritivores (Pennak, 1978). The genera Cryptochironomus sp. (Ward, 1974), Chironomus sp., and Glyptotendipes sp. (Bryce et al., 1972) scrape algae and detritus off surfaces with their labial plates. This feeding habit may have limited Glyptotendipes sp. to the rock substrate, explaining why this genus was not collected from the sand in either area.

Orthocladiinae larvae feed by scraping algae off the surfaces of rocks (Bryce et al., 1972). Collection of a small number of individuals from the genera Cardiocladius sp., Heterotrissocladius sp., Orthocladius sp., Psectrocladius sp. and Thienemanniella sp. was made on the reef. Comparing the basket and multiple plate samplers to the petite ponar samplers, it is evident that these genera are more abundant on the reef than in the sand.

Tanypodinae larvae, of which Larsia sp. was the only genera present inhabiting the rock substrate of the reef, is reported to be predaceous and feeds on small invertebrates (Bryce et al., 1972).

Gastropoda

Three families of gastropods belonging to the suborder Pulmonata were collected from the artificial reef by rock basket and multiple plate samplers. Rock basket samples contained *Physa* sp. representing the family Physidae. This genus was the most numerous gastropod with an abundance of 7.5%. *Gyraulus* sp. of the family Planorbidae and *Bithynia tentaculata* of the family Bithyniidae were present at an abundance of 0.65% each (Figure 12).

The multiple plate samplers collected the same three genera, but in much greater abundance. *Physa* sp. was still the dominant gastropod with an abundance of 32.1%. While the abundance of *Gyraulus* sp. and *B. tentaculata* were 2.2% and 1.6%, respectively (Figure 13).

Petite ponar grab samples collected from both areas showed *Gyraulus* sp. to be most abundant. In the reference area its abundance was 0.7% and at the reef site it was 2.4%. *Physa* sp. was the next most abundant at 0.22% and 1.0%, respectively. However, the third group *Bithynia tentaculata* was absent from the petite ponar samples of both areas (Figures 14 and 15). Sampling results indicate that *B. tentaculata* is dependent on rock substrate and for some reason could not survive on sand substrate.

Physa sp. was found on both substrate types but seems to do better on rock substrate. *Physa* sp. has been reported to reproduce easily throughout the year with temperature, light and food changes stimulating egg deposition (Pennak, 1978). Changes in temperature and light occur almost daily on the reef which could lead to an increase in *Physa* sp. reproduction. Eggs attached to the rocks may also have a better survival rate than those deposited in the sand. *Gyraulus* sp. was also

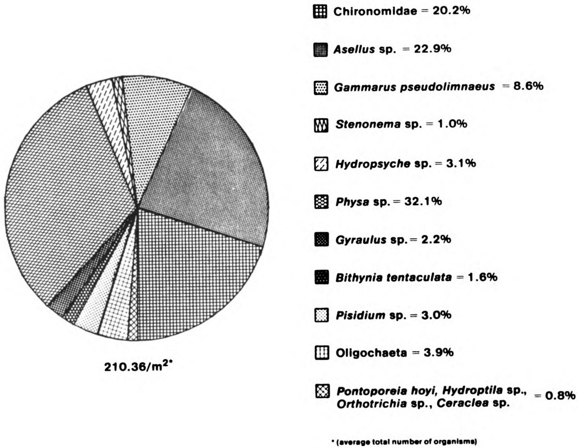


Figure 12. Macroinvertebrate composition and relative abundance as sampled in 1981 and 1982 from the Muskegon Artificial Reef by rock basket samplers (macroinvertebrates/m^2)

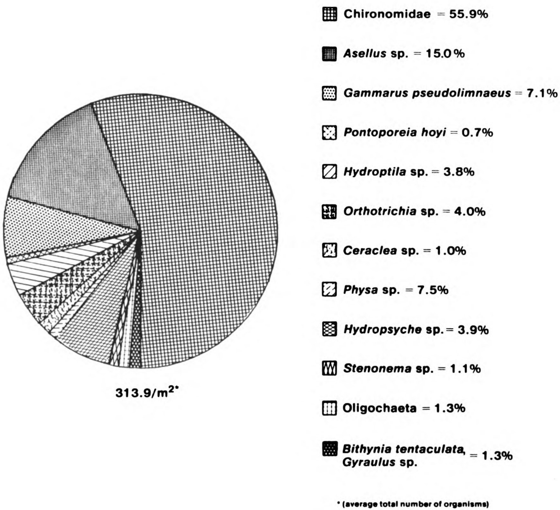
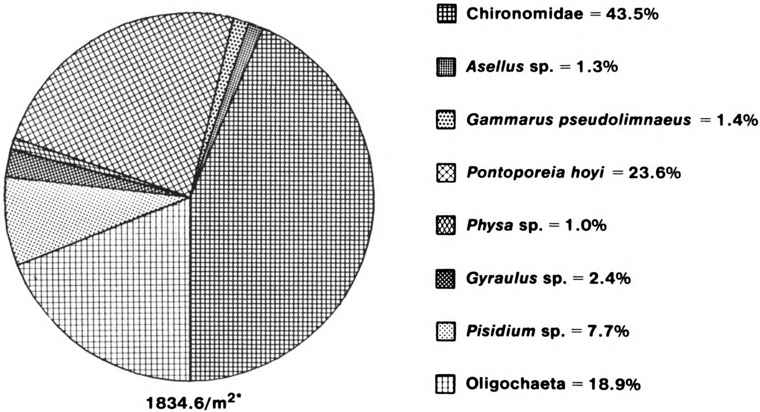


Figure 13. Macroinvertebrate composition and relative abundance as sampled in 1981 and 1982 from the Muskegon Artificial Reef by the multiple plate samplers (macroinvertebrates/m^2)



* (average total number of organisms)

Figure 14. Macroinvertebrate composition and relative abundance as sampled in 1981 and 1982 from the Muskegon Artificial Reef by the petite ponar grab sampler (macroinvertebrates/m^2)

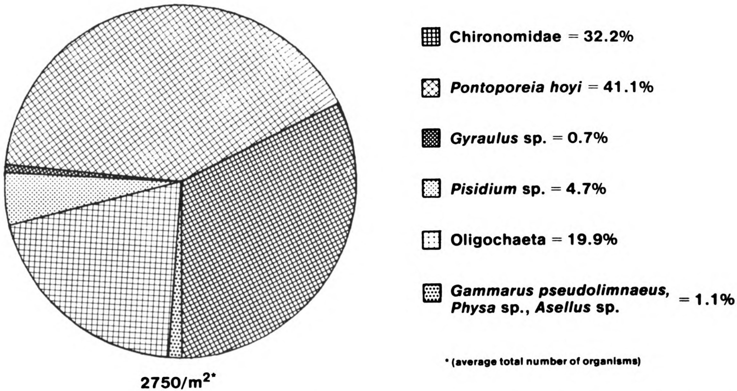


Figure 15. Macroinvertebrate composition and relative abundance as sampled in 1981 and 1982 from the reference area by the petite ponar grab sampler (macroinvertebrates/m^2)

found on both substrates. This gastropod occurred in low numbers on the sand but was still more dominant than Physa sp. Both Gyraulus sp. and Physa sp. were found to be the major gastropods on the dolomite jetties at Ludington (Olson, 1974), again demonstrating their preference for rock substrate. Gyraulus sp. and Physa sp. have been reported to be primarily periphyton feeders (Lenat et al., 1973). Periphyton is more abundant on the hard substrate provided by the reef, explaining the greater abundance of these two gastrops on rock substrate rather than sand substrate.

Oligochaeta

Oligochaeta was the third most abundant group sampled by the petite ponar sampler from the reference area. The abundance was 18.9% for this area and contained the following: Isochaetides frevi, Limnodrilus hoffmeisteri, Piguetiella michiganensis, Uncinais uncinata, and several immature tubificids (Figure 15).

Similar total oligochaete abundance, 19.9%, was found to occur in the sand substrate of the reef. Species identified were: Limnodrilus angustipenis, Stylaria lactistris, Nais variabilis, Potamothrix moldaviensis, Limnodrilus profundicola, Piguetiella michiganensis, Uncinais uncinata, and several immature tubificids (Figure 14).

Multiple plate samplers found oligochaetes to have an abundance of 3.9% on the dolomite (Figure 13). Limnodrilus hoffmeisteri and immature tubificids were present in these samples. However, the rock basket samplers sampling the dolomite substrate collected Ophidonais serpentina, Nais variabilis, and Stylaria sp. The combined abundance of these three speices was 1.3% (Figure 12).

Trichoptera

Four genera of trichoptera were collected solely from the dolomite rock substrate of the artificial reef by the rock basket and multiple plate samplers. The genera collected by the samplers were: Ceraclea sp., Hydropsyche sp., Hydroptila sp., and Orthotrichia sp. The last two genera mentioned construct purse-shaped cases out of silk and are the smallest in size of the four larvae. Both of these trichopterians are commonly found in submerged beds of aquatic plants or in slowly flowing waters (Wiggins, 1977) where they feed on filamentous algae by piercing the cell wall and eating the contents (Nielsen, 1948).

Ceraclea sp. was the next largest trichoptera collected from the reef. Larvae of this genus occur in both lentic and lotic waters (Wiggins, 1977). Investigators have reported the larvae to feed on detritus (Resh, 1976) and freshwater sponges (Wallace, 1976). Detritus is carried to the reef site by the Muskegon Lake Channel plume and becomes trapped between the rocks, while the freshwater sponge, Eunapius fragilis, is an extremely abundant food source on the reef.

The largest trichoptera found on the reef was Hydropsyche sp. This genus uses a net spun of silk to trap food and does not build a case. Larvae of this group are found to inhabit rivers, streams and the edges of large lakes such as Lake Michigan (Wiggins, 1977). Food items of this genus are algae, detritus and very small invertebrates (Coffman et al., 1971).

The compiled abundance of each genus as collected by the rock basket samplers was: 4.0% Orthotrichia sp., 3.9% Hydropsyche sp., 3.8% Hydroptila sp., and 1.0% Ceraclea sp. (Figure 12). Abundance for the same groups collected by the multiple plate samplers was 0.13% Orthotrichia sp., 3.1% Hydropsyche sp., 0.06% Hydroptila sp., and 0.39% Ceraclea (Figure 13).

Isopoda

The isopod, sometimes referred to as the aquatic sow bug, was represented by only one genus, Asellus sp. Asellus sp. is a member of the family Asellidae and of the suborder Asellota. The feeding habits of isopods are as scavengers. They have been observed eating dead and injured animals of all kinds, in addition to both green and decaying aquatic vegetation (Pennak, 1978).

Multiple plate samplers collected Asellus sp. at its greatest abundance of 22.0% (Figure 13). The rock basket samplers showed an abundance of 15.0% (Figure 12), and the petite ponar grab samples from the reef site showed an abundance of only 1.3% (Figure 14). The reference area was determined to have an abundance of 0.15% which was the lowest of all samples (Figure 15).

This trend was also shown in the Ludington Pump Storage Plant study. Asellus sp. was collected in greatest abundance from the rock jetties by multiple plate samplers. Freshwater isopods seldom venture into open water but remain secured under rocks, vegetation, and debris (Pennak, 1978) which explains their greater abundance in the multiple plate samplers on the reef. Barton and Hynes (1976) stated that Asellidae as a group appeared to be restricted to the sheltered areas of rocky substrate. Their requirement for shelter makes the multiple plate samplers preferred over the rock basket sampler.

Amphipoda

Two species of amphipods were collected from the artificial reef and reference area. The family Gammaridae was represented by *Gammarus pseudolimnaeus* (Bousifeld), *Pontoporeia hoyi* (Smith) represented the family Haustoriidae. *P. hoyi* was more abundant in the petite ponar grab samples from the reference area representing 41.1% and only 1.4% in the reef area. The reverse was true for *G. pseudolimnaeus*, having an abundance of 0.07% in the reference area and 23.6% in the reef area (Figure 15 and 14).

Multiple plate samples contained *G. pseudolimnaeus* at 8.6%, and *P. hoyi* at o.26% (Figure 13). Similar abundance was evident from the rock basket samples, with *G. pseudolimnaeus* and *P. hoyi* at an abundance of 7.1% and 0.7%, respectively (Figure 12).

These two species are both bottom dwelling amphipods but exhibit different activity patterns. *P. hoyi's* vertical migration in Lake Michigan has been documented by Wells (1960), Marzolf (1965) and Wells (1968). This latter article determined the movement of *P. hoyi* during the daytime as well as at night. Locomotion involves both swimming and drifting with currents (Pennak, 1978) which may explain the low numbers of *P. hoyi* found on the reef rocks. The literature strongly suggests that substrate preference is the determining factor in the abundance of these two species. Barton and Hynes (1976) found *P. hoyi* to inhabit sandy areas and *G. pseudolimnaeus* to inhabit rocky substrate in great abundance. Olson (1975) reported that *G. pseudolimnaeus* associates closely with the rock jetties of the Ludington Power Plant, which are constructed of dolomite similar to the reef. *Pontoporeia hoyi* is a burrowing amphipod and would not be expected to be abundant in the rock basket and multiple plate samples or on the reef. However, G. pseudolimnaeus would be expected to be abudant in both samplers and on the reef as it has been reported to be most abundant on firm rocky substrate (Barton and Hynes, 1976; Menon, 1969; and Duffy, 1979).

Ephemeroptera

The genus Stenonema sp. of the family Heptageniidae was the only mayfly naiad collected from the dolomite rock substrate of the artificial reef. Stenonema sp. inhabit flowing water or wave-swept shores clinging tightly to stones. The greatest abundance is usually found in crevices and under rocks (Pennak, 1978). This tendency to cling to stones may explain their absence from sand substrate samples from the reef and reference areas. Abundance for both the rock basket and multiple plate samplers were small, 1.1% and 1.0%, respectively (Figures 12 and 13).

This group of aquatic insects was considered a minor item in the diets of both the roung whitefish (Koezl, 1929; Armstrong, 1973) and yellow perch (Brazo, 1973). The fact that it was not determined to be a major food item may stem directly from lack of suitable habitat in Lake Michigan, keeping its abundance low. This habitat limitation was also apparent from the Ludington Pump Storage Plant study which collected Stenonema sp. along man-made jetties in multiple plate samplers but not from the surrounding sand substrate (Olson, 1973).

Pelecypoda

Pisidium sp. of the family Sphaeriidae was the only pelecypod collected from either area. The majority of these were collected in the petite ponar grab sampler. This sampler showed the relative abundance in the reference area to be 4.7% and 7.7% at the artificial reef site (Figure 14 and 15). Basket and multiple plate samplers that came in contact with the sand substrate also collected *Pisidium* sp. suggesting that they were on the dolomite rocks. However, Scuba diving observation and scrapings contradict this finding. Both samplers had a lower relative abundance than the petite ponar samplers (Figure 12 and 13).

Turbellaria

Dugesia tigrina (Girard) of the family Planariidae was found to be the only turbellaria present at the artificial reef site. Turbellaria were completely absent from the reference area. The multiple plate samplers collected 27 specimens of *D. tigrina*, except for five collected by the basket samplers and those collected in periodical suction samples taken by Scuba divers. Scuba divers also collected wood debris containing greater numbers of individuals than the multiple plate samplers. These observations indicated that the sampling gear were not sampling the turbellaria reliably and, therefore, they were excluded from the analysis.

Acari and Hirudinea

Water mites were collected rarely in any sample, while leeches were collected by Scuba divers twice on wood debris. Therefore, these groups were considered to be incidental and not major colonizing groups.

Porifera

Twenty-four samples of freshwater sponge were collected by Scuba divers over the two year period. These samples were all identified from their spicules and gemmules as Eunapius fragilis (Leidy) of the family Spongillidae, class Demospongiae. The three methods of sampling were not designed to collect sponges and, as a consequence, no sponges were included in the samples. Scuba observations revealed that sponges colonized only the upper portions of the rocks facing the water surface. Sponge colonies were not observed on vertical sides or undercut edges of rocks. Competition occurred between sponges and algae for attachment substrate. When this situation arose the sponges would out grow the algae. The average diameter of a colony was approximately 15 centimeters. However, a few reached a diameter of one meter. Eunapius fragilis was abundant by the end of the 1982 field season on the shallow end of the reef with decreasing abundanc as water depth increased. This decrease in abundance was probably due to colder water temperatures at the deep end of the reef.

Decapoda

The complete absence of crayfish on the artificial reef was unexpected. Originally, it was thought that crayfish from the Muskegon Lake Channel breakwall would colonize the reef. Crayfish collected by Scuba divers from the breakwall were identified as *Orconectes propinquus* (Girard) which is the most abundant crayfish in Michigan (Lippson, 1975). They seemed to inhabit an area very similar to that of the reef. However, Scuba surveys revealed that these crayfish inhabited the inside of the breakwall rather than the Lake Michigan side of the breakwall. *O. propinquus* typically inhabit rocky substrate of rivers, lakes and ponds (Lippson, 1975). These waters have warmer temperatures than those found on the outside of the breakwall or on the reef. The literature and Scuba observations suggest that cold water temperatures prevented *O. propinquus* from colonizing the reef.

Due to the lack of crayfish colonization of the reef, seeding of the reef with crayfish was proposed. Samples of crayfish from the Wolf Lake Fish Hatchery ponds were collected and identified as *Orconectes virilis* (Hagen). This species inhabits deep (30 m) cold areas in Lake Michigan (Pennak, 1978) and has also been taken in nets set at 32 meters in Green Bay, Lake Michigan (Creasar, 1934). *O. virilis* is reported to be the only species of crayfish inhabiting the waters of Alberta, Canada, where it survives the winters by moving into deep water (Aiken, 1967). *O. virilis* is the second in distribution only to *O. propinquus* in Michigan and also congregates among rocks (Lippson, 1975). From the information presented above, *O. virilis* seemed an excellent choice for seeding the reef.

However, the MDNR provided approximately 2,500 crayfish from the Belmont Pond instead of the Wolf Lake Hatchery as originally planned because of their immediate availability. At the time of planting, July 23, 1982, crayfish specimens were collected for identification. Later these crayfish were identified as *Orconectes rusticus* (Girard).

These crayfish were placed in five gallon pails with lids, given to Scuba divers and placed on the deep buoy pile, the shallow buoy pile, and a pile with basket samplers on it in the middle of the reef. The crayfish were allowed to acclimate to the change in temperature and pressure prior to release from the pails. Judging from their body orientation and flight response when confronted, they appeared well adjusted.

While diving August 5, 1982, we observed three living crayfish on the shallow pile and two alive on the middle pile. On August 11, 1982, we observed two alive on the shallow pile and four alive on the middle pile. On both occasions several dead crayfish were observed. After August 11, 1982, Scuba divers could find no evidence that crayfish, *Orconectes rusticus*, has survived. Typically *O. rusticus* inhabit rivers and make shallow excavations under rocks (Lippson, 1975). According to the literature, *O. rusticus* would not be able to survive the cold water temperatures found on the reef.

The original plan to seed the reef with *O. virilis* from the Wolf Lake Hatchery is still strongly encouraged. The addition of this major food item could have a positive effect on yellow perch utilization of the reef.

Forage Fish

The benthic macroinvertebrates inhabiting the Muskegon Artificial Reef support eight species of forage fish. Johnny darters, Etheostoma nigrum, (Refinesque); mottled sculpin, Cottus bairdi, (Girard) and slimy sculpin, Cottus cognatus, (Richardson) are the most abundant forage fish. These three bottom dwelling species are permanent residents of the reef. The other five species found frequently on the reef are spottail shiners, Notropis hudsonius, (Clinton); ninespine stickleback, Pungitius pungitius, (Linnaeus); rainbow smelt, Osmerus mordax, (Mitchill); trout perch, Percopsis omiscomaycus, (Walbaum) and a representative of Cyprinidae sp. According to Scott (1979), all of these species feed primarily on macroinvertebrates and they, in turn, are preyed upon by yellow perch. Brazo (1973) reported that yellow perch, greater than 235 mm in length, feed mainly on crayfish and small forage fish. The presence of these forage fish on the reef gains importance due to the absence of crayfish.

Sampler Type Preference

Although the number of individuals per meter square for most of the macroinvertebrates, with the exception of chironomids, look sparse; these individuals comprise a significant food source. The high relative abundance of a few groups gives the misrepresentation that the remaining groups are insignificant due to their low relative abundance. However, examination of Table 6 shows that most groups were consistently collected by the samplers. This indicates that although they may not be as abundant as the chironomid larvae, they are present in sufficient numbers to be an important food source for the target fish. As stated previously, Brazo's 1973 Ludington Pump Station study of yellow perch stomach contents indicates that amphipods, chironomid larvae, isopods, ephemeroptera, trichoptera, gastropods, crayfish and small fish are primary food items in the diet of yellow perch.

Comparison of Figures 16, 17, 18 and 19 shows that macroinvertebrates have a preference for habitat which was manifested as sampler type preference. The four dominant macroinvertebrate groups found on the sand substrate of the reef and reference areas were amphipoda, chironomid, *Pisidium* sp. and oligochaeta. The composition of major macroinvertebrate groups changed as substrate changed from sand to dolomite limestone with both *Pisidium* sp. and oligochaeta becoming less abundant. The multiple plate samplers contained gastropoda, isopoda, chironomid and amphipoda as the major groups in order of decreasing abundance. The basket samplers' major groups, listed in decreasing order of abundance, were chironomid, isopoda, trichoptera, amphipoda and gastropoda.

Tables 6. The percent occurrence of macroinvertebrates in each type of sampler for the areas during 1981 and 1982

Genus	Reef: Basket sampler (%)	Reef: Multiple plate sampler (%)	Reef: Petite ponar sampler (%)	Reference: Petite ponar sampler (%)
Gammarus pseudolimnaeus	100	71.4	4.8	4.2
Pontoporeia hoyi	33.3	14.3	85.7	100
Asellus sp.	96.3	85.7	9.5	4.2
Physa sp.	77.7	95.2	23.8	14.3
Gyraulus sp.	48.1	57.1	42.9	33.3
Bithynia tentaculata	44.4	38.1	0	0
Pisidium sp.	14.8	47.6	61.9	54.2
Hydropsyche sp.	44.4	42.9	0	0
Hydroptila sp.	88.8	4.8	0	0
Orthotrichia sp.	85.2	9.5	0	0
Ceraclea sp.	63.0	14.2	0	0
Stenonema sp.	59.3	42.8	0	0
Chironomidae	100	95.2	95.2	100
Oligochaeta	18.5	23.8	66.7	70.8

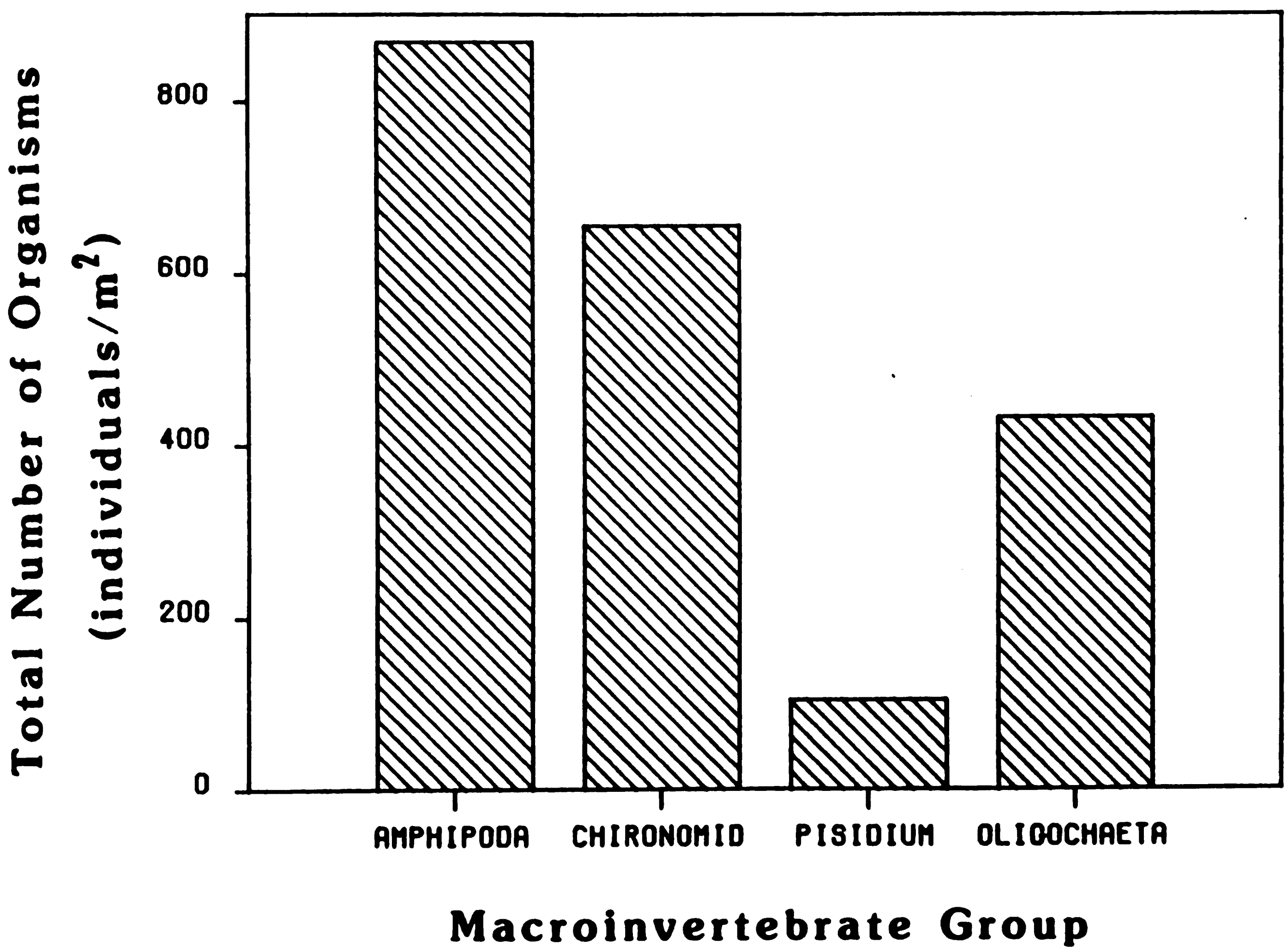


Figure 16. Total number of organisms (individuals/m^2) of the major macroinvertebrate groups collected by the petite ponar grab sampler from the reference area

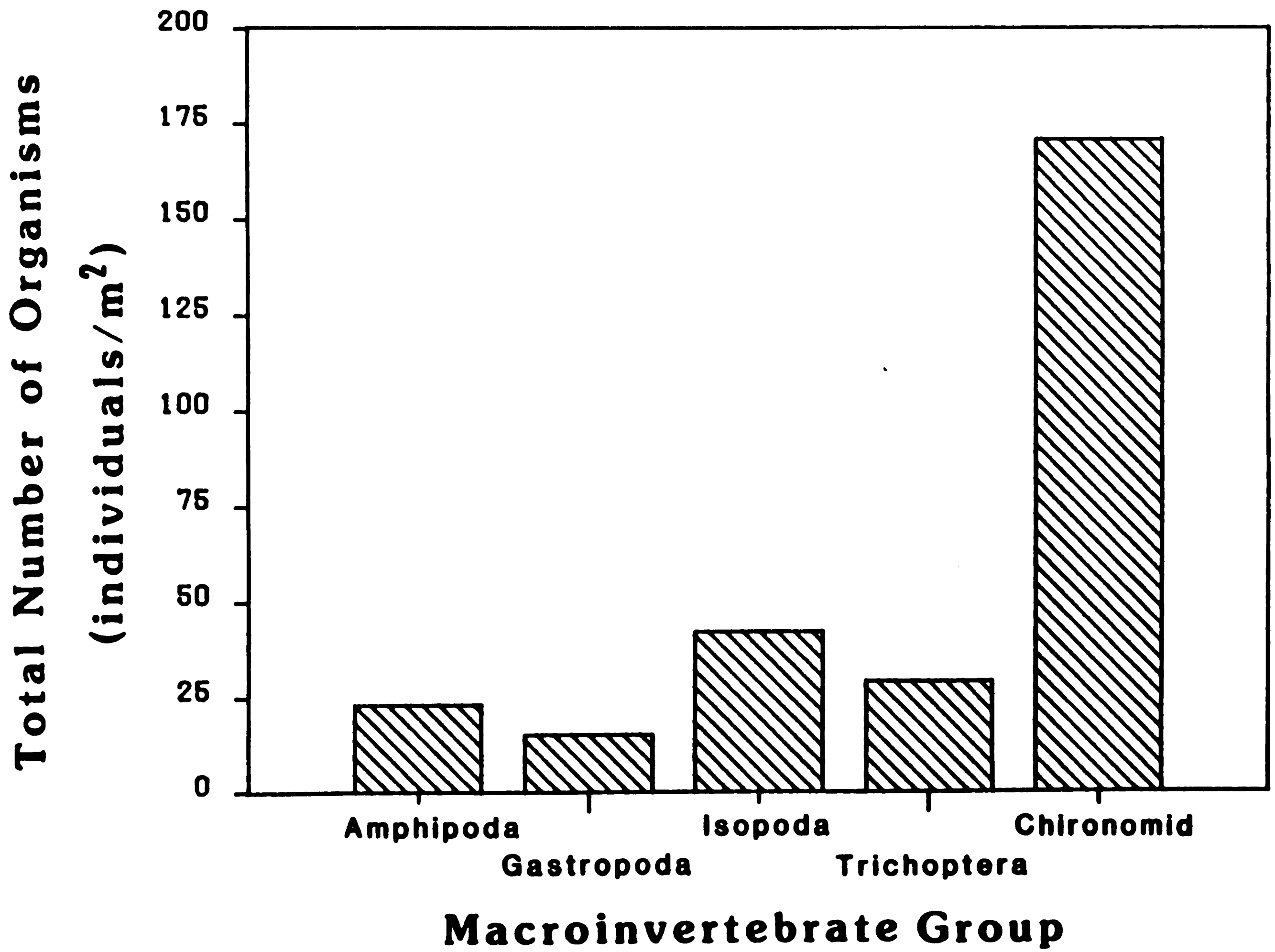


Figure 17. Total number of organisms (individuals/m^2) of the major macroinvertebrate groups collected by the rock basket sampler from the Muskegon Artificial Reef

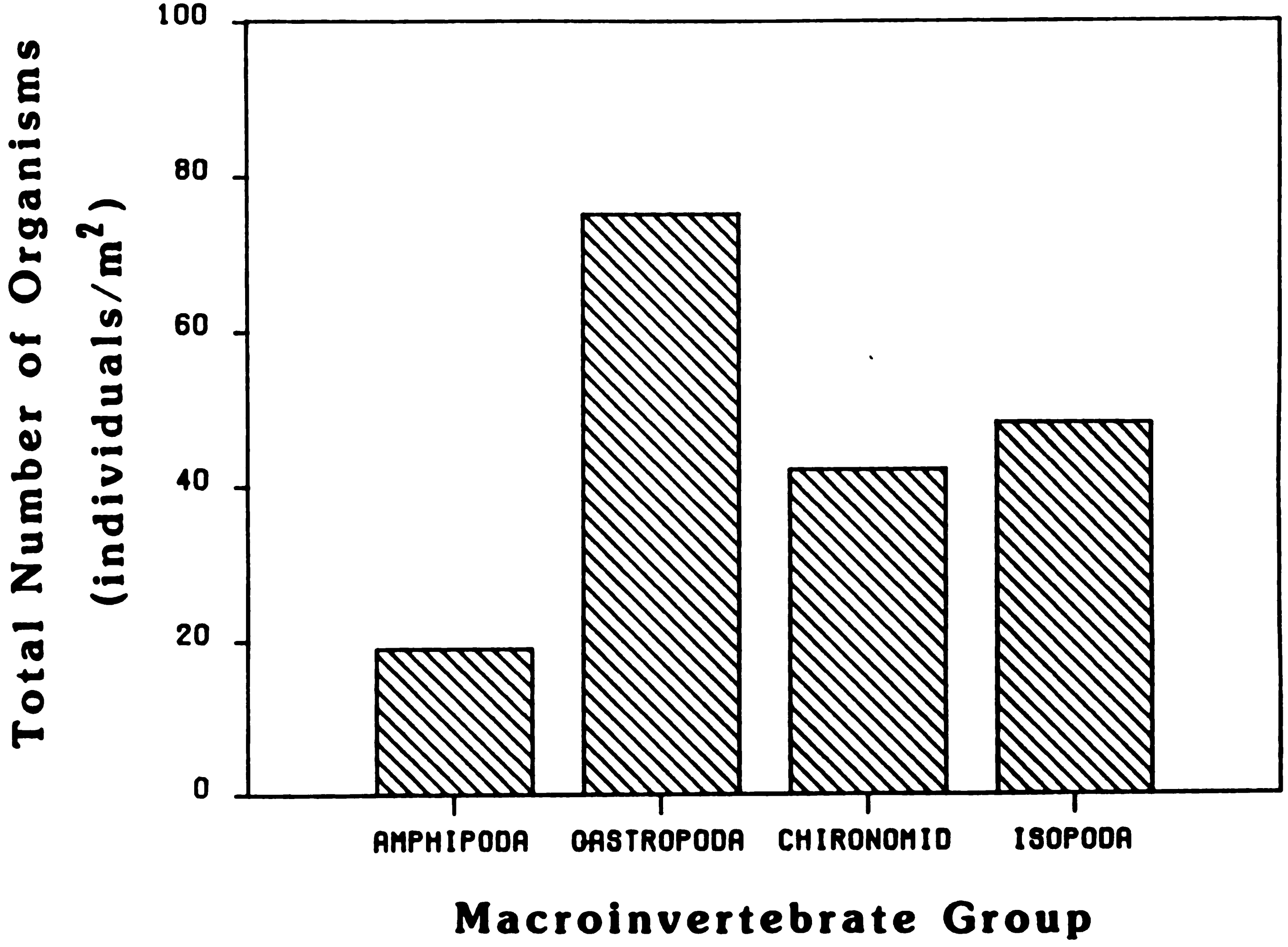


Figure 18. Total number of organisms (individuals/m^2) of the major macroinvertebrate groups collected by the multiple plate sampler from the Muskegon Artificial Reef

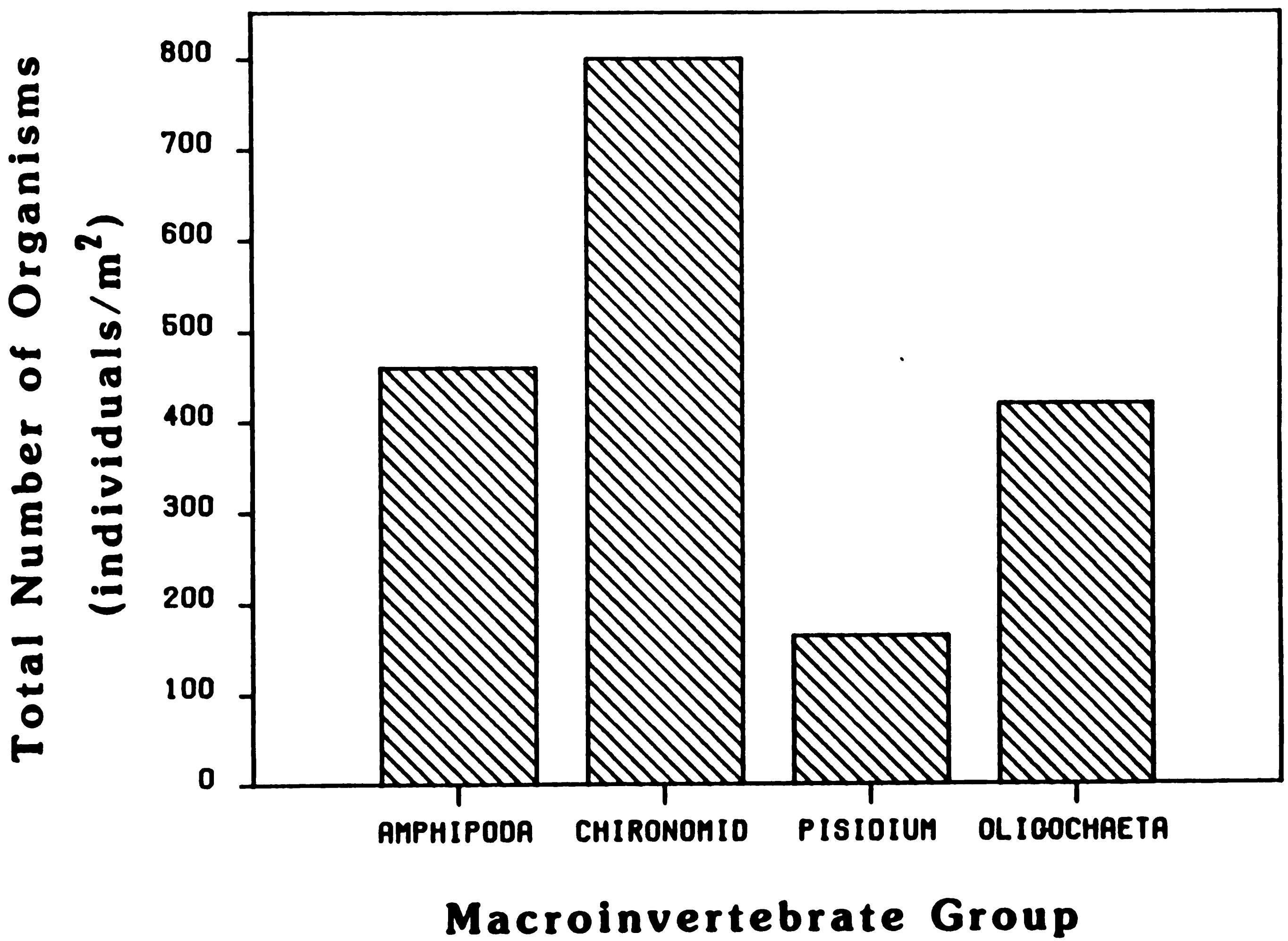


Figure 19. Total number of organisms (individuals/m^2) of the major macroinvertebrate groups collected by the petite ponar grab sampler from the Muskegon Artificial Reef

Statistical Analysis

The Muskegon Artificial Reef has been successfully colonized by several macroinvertebrate groups. Major macroinvertebrate group variances for comparisons between sampling areas, between areas for the same field season, between years for the same area, and between sampler type utilized, was analyzed. A one-way analysis was performed on each comparison, with the null hypothesis being that the macroinvertebrate samples were taken from the same population. The F-test in Sokal and Rohlf (1969) and Elliot (1971) was performed to determine whether a significant difference existed between the samples.

The results from the one-way analysis of variance and the F-test are compiled into Tables 7 through 18. Tables 19 through 22 demonstrate the mean ($\bar{X}$) and standard error of the mean ($s/\sqrt{n}$) for the major groups. These tables are the basis for the following discussion.

Many of the macroinvertebrate groups that colonized the reef are found to inhabit only the dolomite limestone substrate and, therefore, are dependent on the attachment substrate for their existence in Lake Michigan. For this reason the discussion of the macroinvertebrate colonization necessitates the division of the reef into sand and dolomite limestone substrates.

With the exception of amphipoda and thus the total number of macroinvertebrates, the composition and abundance of the macroinvertebrates inhabiting the sand substrate of the reef did not differ significantly ($\alpha = 0.05$) from those found inhabiting the reference area. Statistically, it was determined that these two exceptions were restricted to the 1981 field season. Petite ponar samples from both sampling areas contained almost exclusively _P. hoyi_. This species of amphipod

Table 7. Significance of abundance of amphipoda by area using one-way analysis of variance

Source of Variation	df	ss	ms	f-ratio significance
Area (Reef vs Reference)	1	18.032	18.032	$p < 0.01$
Experimental Error	40	82.112	2.052	
Total	41	100.145		

Table 8. Significance of abundance of macroinvertebrates by area using one-way analysis of variance

Source of Variation	df	ss	ms	f-ratio significance
Area (Reef vs Reference)	1	2.750	2.750	$p < 0.05$
Experimental Error	40	18.637	0.465	
Total	41	21.387		

Table 9. Significance of abundance of amphipoda by field season using one-way analysis of variance

Source of Variation	df	ss	ms	f-ratio significance
Area (Reef '81 vs Reference '81)	1	12.992	12.992	$p < 0.05$
Experimental Error	21	40.666	1.936	
Total	22	53.658		

Table 10. Significance of abundance of amphipoda by field season using one-way analysis of variance

Source of Variation	df	ss	ms	f-ratio significance
Field Season (Reference '81 vs Reference '82)	1	3.140	3.140	$p < 0.01$
Experimental Error	20	4.922	0.246	
Total	21	8.063		

Table 11. Significance of abundance of chironomid larvae by field season using one-way analysis of variance

Source of Variation	df	ss	ms	f-ratio significance
Field Season (Reference '81 vs Reference '82)	1	8.205	8.205	$p < 0.05$
Experimental Error	20	6.562	0.328	
Total	21	14.768		

Table 12. Significance of abundance of *Pisidium* sp. by field season using one-way analysis of variance

Source of Variation	df	ss	ms	f-ratio significance
Field Season (Reference '81 vs Reference '82)	1	35.764	35.764	$p < 0.05$
Experimental Error	20	111.419	5.570	
Total	21	147.184		

Table 13. Significance of abundance of trichoptera by field season using one-way analysis of variance

Source of Variation	df	ss	ms	f-ratio significance
Field Season (Rock Basket '81 vs Rock Basket '82)	1	10.936	10.936	$p < 0.01$
Experimental Error	25	6.300	0.252	
Total	26	17.237		

Table 14. Significance of abundance of amphipoda by sampler type using one-way analysis of variance

Source of Variation	df	ss	ms	f-ratio significance
Sampler Type (Multiple Plate vs Petite Ponar)	1	112.635	112.635	$p < 0.01$
Experimental Error	40	120.156	3.003	
Total	41	232.791		

Table 15. Significance of abundance of chironomid larvae by sampler type using one-way analysis of variance

Source of Variation	df	ss	ms	f-ratio significance
Sampler Type (Multiple Plate vs Petite Ponar)	1	50.919	50.919	$p < 0.01$
Experimental Error	40	86.844	2.171	
Total	41	137.763		

Table 16. Significance of abundance of chironomid larvae by sampler type using one-way analysis of variance

Source of Variation	df	ss	ms	f-ratio significance
Sampler Type (Multiple Plate vs Rock Basket)	1	25.262	25.262	$p < 0.05$
Experimental Error	46	36.461	0.792	
Total	47	61.724		

Table 17. Significance of abundance of gastropoda by sampler type using one-way analysis of variance

Source of Variation	df	ss	ms	f-ratio significance
Sampler Type (Rock Basket vs Multiple Plate)	1	17.073	17.073	$p < 0.01$
Experimental Error	46	70.529	1.533	
Total	47	87.602		

Table 18. Significance of abundance of amphipoda by sampler type using one-way analysis of variance

Source of Variation	df	ss	ms	f-ratio significance
Sampler Type (Rock Basket vs Petite Ponar)	1	76.351	76.351	$p < 0.01$
Experimental Error	46	92.315	2.006	
Total	47	168.666		

Table 19. Mean ($\bar{X}$) and standard error for the major macroinvertebrate groups collected from the reference area by the petite ponar sampler

Macroinvertebrate Group	$\bar{X}$	$s_{\bar{X}}$
Amphipoda	821	± 0.137
Chironomid	545	± 0.185
Pisidium sp.	19	± 0.576
Oligochaeta	67	± 0.684
Total macroinvertebrates	2,276	± 1.361

Table 20. Mean ($\bar{X}$) and standard error for the major macroinvertebrate groups collected from the Muskegon Artificial Reef by the petite ponar sampler

Macroinvertebrate Group	$\bar{X}$	$s_{\bar{X}}$
Amphipoda	140	± 0.458
Chironomid	150	± 0.404
Pisidium sp.	22	± 0.571
Oligochaeta	37	± 0.552
Total macroinvertebrates	1,033	± 0.256

Table 21. Mean ($\overline{X}$) and standard error for the major macroinvertebrate groups collected from the Muskegon Artificial Reef by the multiple plate samplers

Macroinvertebrate Group	$\overline{X}$	$s_{\overline{X}}$
Amphipoda	9	± 0.328
Gastropoda	44	± 0.278
Chironomid	22	± 0.365
Isopoda	30	± 0.228
Total macroinvertebrates	132	± 0.277

Table 22. Mean ($\overline{X}$) and standard error for the major macroinvertebrate groups collected from the Muskegon Artificial Reef by the rock basket samplers

Macroinvertebrate Group	$\overline{X}$	$s_{\overline{X}}$
Amphipoda	18	± 0.157
Gastropoda	19	± 0.233
Isopoda	27	± 0.209
Trichoptera	22	± 0.157
Chironomid	129	± 0.144
Total macroinvertebrates	252	± 0.097

is a burrower and, as such, their reduced abundance on the reef may be related to their preference for the sand substrate over the rock-sand mixture found on the reef. This difference may also have resulted from the petite ponar's inability to sample close to rock bases and, therefore, underestimates P. hoyi's abundance.

Comparison of the two field seasons, 1981 versus 1982, for each sampler was investigated to determine if any difference existed. A significant difference ($\alpha = 0.05$) between the two field seasons existed for amphipoda, chironomids and Pisidium sp. in the reference area only. The reef area was found to have no significant differences due to field seasons. Differences between the two years for chironomids and Pisidium sp. in the reference area may have been due to warmer water temperatures in 1982, causing increased reproduction. As previously mentioned, P. hoyi was the dominant amphipod species in the reference area. Pennak (1978) reported that temperature was largely responsible for initiating reproduction. Figure 9 shows that temperature fluctuated dramatically and could account for an increase in numbers. Effects of field season was examined for the rock basket and multiple plate samplers also. The only comparison to show a significant difference ($\alpha = 0.01$) was the group trichoptera collected by the rock basket samplers. This group was most abundant in 1981.

Sampler types (rock basket, multiple plate and ponar) were compared to determine if a preference for substrate type existed among those macroinvertebrates that the study encountered. The comparison between multiple plate and petite ponar samples was conducted on the only two major macroinvertebrate groups they had in common: amphipods and chironomids. Both groups showed a significant difference (α = 0.01) between the samplers. From Figures 15 through 18 it is clear that the genera of the group chironomid were different between sampler types. The dominant chironomid larvae collected by the ponar sampler was *Chironomus* sp. and *Cryptochironomus* sp. while the multiple plate samplers determined the dominant genera to be *Psectrocladius* sp. and *Glyptotendipes* sp. Rock basket samplers had *Psectrocladius* sp. and *Chironomus* sp. as the dominant genera, and were found to be significantly different (α = 0.05) from multiple plate samplers for the group chironomids. Similar sampler preference, reflecting habitat preference, was seen throughout the chironomid assemblage.

Gastropods were collected in much greater numbers by the multiple plate samplers than by the rock basket samplers with a significant difference (α = 0.05) between samplers. The petite ponar samples contained few snails and never included any representative of *Bithynis tentaculata*.

For the group amphipoda the comparison of petite ponar samples versus rock basket samplers and petite ponar samples versus multiple plate samplers was determined to have a significant difference (α = 0.05). As noted in the results, the group amphipoda is represented by *Gammarus pseudolimnaeus* on the dolomite and *Pontoporeia hoyi* in the sand substrate. The rock basket and multiple plate samplers collected predominantly *G. pseudolimnaeus* from the dolomite substrate while the petite ponar sampler collected almost exclusively *P. hoyi* from the sand of the reef. The difference is due to the sampling of two separate populations.

Temperature Impact

Water temperatures for the research area range from 4.4° - 27.7°C from May through November (Table 23). Rapid temperature fluctuations are common with variations being as large as 19°C in a 24-hour period. According to Pennak (1978), these sudden changes in temperature can bring on reproduction in many macroinvertebrate groups inhabiting the reef. This seems to be reflected best with Pisidium sp. and chironomid larvae during 1982.

Crayfish, Orconectes propinquus, inhabiting the inside of the Muskegon Lake Channel breakwall were unable to colonize the reef because of the colder temperatures that exist on the reef. This was confirmed by Scuba observations that these crayfish were absent from the Lake Michigan side of the breakwall. Temperature also seems to have led to the demise of the seeded crayfish, Orconectes rusticus, in less than two months.

Water temperature influences metabolism, feeding activities, growth and distribution of yellow perch and is considered a very important environmental parameter for fish. From laboratory studies assessing the preferred temperature of several species of fish, Ferguson (1958) reported that yellow perch have a preferred temperature of 24.2°C. Summer field observations of yellow perch in several temperate region lakes showed a preferred temperature range of 12.2° - 21.0°C (Ferguson, 1958 and Hile et al., 1941). The seasonal vertical movements of the perch suggest that they follow the 20°C isotherm (Scott et al., 1979). Scuba observations and gill netting results on the reef support this suggestion.

Figure 23. Average bottom water temperature of the Muskegon Artificial Reef area in Lake Michigan

Month of:	May 1980	June 1980	July 1980	August 1980	September 1980	October 1980	November 1980
Date	Temp. (°C)	Temp. (°C)	Temp. (°C)	Temp. (°C)	Temp. (°C)	Temp. (°C)	Temp. (°C)
1	4.4	13.3	14.4	11.6	21.6	14.4	9.9
2	4.4	13.8	14.9	14.9	21.6	14.4	9.4
3	4.9	11.6	11.6	13.8	22.2	12.2	9.9
4	4.9	7.2	11.1	13.3	22.7	10.5	9.9
5	6.1	8.3	11.1	19.4	22.7	8.3	9.9
6	7.2	12.2	9.9	21.6	22.7	8.8	9.9
7	6.6	12.7	12.2	21.6	21.6	10.5	9.9
8	6.1	8.8	11.1	22.2	22.2	12.7	9.9
9	6.1	7.7	12.7	22.2	17.2	13.3	9.9
10	6.1	6.6	13.3	20.5	8.8	13.8	9.9
11	6.6	6.1	13.8	19.4	8.8	13.8	9.9
12	6.6	7.2	15.5	13.8	7.7	11.6	8.8
13	6.6	10.5	15.5	8.3	13.8	8.8	9.4
14	6.6	12.7	16.6	11.6	15.5	8.3	8.8
15	6.1	12.2	19.4	11.6	12.2	8.3	8.8
16	6.1	8.8	19.9	8.8	14.9	9.9	8.8
17	6.6	6.6	18.3	11.1	15.5	12.2	8.8
18	7.2	9.4	16.1	16.6	14.4	12.7	8.8
19	6.1	11.1	19.9	14.9	15.5	12.2	8.8
20	5.5	6.6	19.9	16.6	17.2	12.2	8.3
21	5.5	6.1	19.9	15.5	17.2	12.2	8.3
22	5.5	9.4	9.4	10.5	17.2	11.6	7.7
23	5.5	13.8	9.4	7.7	14.4	11.1	7.7
24	5.5	14.4	7.2	7.2	11.6	11.6	7.7
25	6.1	14.9	7.2	7.2	13.3	11.6	7.7
26	5.5	14.9	8.3	12.2	9.9	11.1	7.2
27	4.9	13.8	8.8	14.4	8.3	9.9	7.2
28	5.5	13.8	7.2	13.8	9.9	9.9	7.2
29	6.6	14.9	6.6	14.9	11.1	9.4	7.2
30	11.6	14.4	6.6	20.5	12.7	9.4	6.6
31	14.4		8.3	21.6		9.9	
Monthly Average	6.6	11.1	12.7	14.9	15.5	11.1	8.8

Figure 23. Average bottom water temperature of the Muskegon Artificial Reef area in Lake Michigan

Month of:	May 1981	June 1981	July 1981	August 1981	September 1981	October 1981	November 1981
Date	Temp. (°C)	Temp. (°C)	Temp. (°C)	Temp. (°C)	Temp. (°C)	Temp. (°C)	Temp. (°C)
1	6.1	6.6	8.8	7.7	21.1	15.5	11.1
2	6.6	7.7	13.3	11.1	21.1	13.3	11.6
3	6.6	8.8	13.8	15.5	19.9	8.8	11.6
4	6.6	8.8	12.7	18.3	12.7	8.8	11.6
5	7.2	7.2	11.1	19.4	8.3	11.6	11.6
6	7.7	8.8	8.3	18.8	7.7	12.7	9.4
7	8.3	9.9	9.4	20.5	7.7	9.9	9.9
8	8.3	14.4	11.6	19.9	8.3	8.3	9.4
9	7.2	13.8	12.2	13.8	10.5	6.6	8.8
10	7.2	16.1	8.3	14.9	16.1	7.7	8.3
11	7.2	15.5	9.4	21.1	18.8	8.8	8.3
12	7.2	16.6	11.6	21.6	19.4	9.4	8.3
13	7.2	16.6	12.7	22.7	19.4	9.9	8.3
14	7.2	17.2	10.5	22.7	19.9	11.6	8.3
15	7.2	17.2	12.2	22.7	19.4	12.2	8.3
16	7.7	17.7	13.3	21.1	17.2	12.2	8.3
17	7.2	17.2	11.6	16.6	11.1	12.2	8.3
18	6.6	18.3	12.2	10.5	8.3	12.2	8.3
19	7.2	17.2	11.6	8.3	8.3	12.2	8.3
20	7.7	16.6	11.6	8.8	8.8	11.6	8.3
21	6.6	14.9	8.3	7.7	13.3	11.6	7.2
22	6.1	12.2	6.1	8.3	14.4	12.2	6.1
23	7.7	8.8	6.1	9.4	13.8	12.2	6.1
24	8.3	11.1	6.6	11.6	14.4	12.2	5.5
25	11.6	12.7	7.2	13.3	15.5	11.6	6.1
26	12.2	7.7	7.2	17.7	15.5	11.6	6.1
27	11.6	7.2	5.5	19.4	16.1	11.6	6.1
28	10.5	9.9	6.1	20.5	15.5	11.6	5.5
29	7.7	14.9	6.6	20.5	15.5	11.6	5.5
30	8.8	15.5	7.2	21.1	15.5	11.2	4.9
31	6.6		7.2	21.1		11.2	
Monthly Average	7.7	11.6	9.4	16.1	14.4	11.2	8.3

Figure 23. Average bottom water temperature of the Muskegon Artificial Reef area in Lake Michigan

Month of:	May 1982	June 1982	July 1982	August 1982	September 1982	October 1982	November 1982
Date	Temp. (°C)	Temp. (°C)	Temp. (°C)	Temp. (°C)	Temp. (°C)	Temp. (°C)	Temp. (°C)
1	5.5	7.2	7.2	10.5	17.2	17.2	12.7
2	4.9	7.2	7.2	18.3	17.7	17.7	12.7
3	5.5	6.6	7.2	20.5	9.9	17.7	12.7
4	7.2	6.6	7.2	21.6	8.3	17.7	12.2
5	8.3	6.1	7.2	22.7	11.1	17.7	11.6
6	8.3	6.1	7.2	21.6	17.2	17.7	11.1
7	8.8	5.5	15.5	19.9	17.2	18.3	9.9
8	8.8	7.2	18.8	20.5	17.2	18.3	9.9
9	7.2	6.6	18.8	14.4	17.2	18.3	9.9
10	7.7	6.6	18.3	7.7	19.4	17.7	9.9
11	8.8	6.6	18.8	7.2	19.9	17.2	9.9
12	8.3	8.3	19.9	7.2	19.4	17.2	9.9
13	8.3	8.8	20.5	8.3	12.2	17.2	9.9
14	8.8	11.1	20.5	13.8	10.5	16.6	9.4
15	9.9	13.3	20.5	16.6	10.5	16.1	8.8
16	10.5	9.4	21.1	18.3	12.2	14.1	8.3
17	9.9	7.2	21.6	16.1	13.8	11.1	7.7
18	11.1	7.7	22.2	7.2	10.5	12.7	7.7
19	12.2	9.9	22.7	16.6	8.8	13.8	7.7
20	12.2	10.5	22.2	19.4	13.8	14.4	8.3
21	6.6	12.7	20.5	18.3	8.8	13.8	8.3
22	7.2	13.8	19.4	18.3	6.6	12.7	8.8
23	6.6	11.1	18.8	19.4	6.6	12.7	8.8
24	7.7	11.6	12.7	19.9	9.4	12.7	8.3
25	7.7	14.9	7.7	18.8	13.8	12.7	8.3
26	7.7	15.5	10.5	18.8	14.9	12.7	7.2
27	8.3	13.8	13.8	19.4	16.1	12.7	7.2
28	8.8	13.8	14.9	14.4	16.1	13.3	6.1
29	8.8	14.4	9.9	12.2	17.2	13.3	7.2
30	7.7	9.9	6.6	17.2	17.2	13.3	6.6
31	7.7		7.7	17.7			
Monthly Average	8.8	9.9	17.7	16.1	13.3	14.9	9.4

Tables 24 through 30 show that yellow perch are more abundant on the reef when the temperature is above 13.8°C. Referring back to Figures 21, 22 and 23, it becomes apparent that the temperature on the reef during the three years of research has risen above 13.8°C less than 18% of the time. The calculated average number of angler days that would be favorable for perch is 62 days per year. Figure 20 is a graphic representation of the number of days that the temperature rose above 13.8°C on a monthly basis for 1980, 1981 and 1982.

This preference for temperature is widely excepted for warm water sports fish. It is reported that fish start to move into reef areas as temperatures exceed 10°C in the spring. The numbers of species and individuals increase through spring and remain at stable levels through summer and fall. When temperatures start declining in the fall the fish move off the reef (Prince et al., 1977). The situation in Lake Michigan is much different than in warm waters. Temperatures on the reef (Figures 21, 22 and 23) fluctuate rapidly, decreasing to force yellow perch into the warmer shallow areas.

The effects of temperature were not confined only to aquatic animals. Temperature dictates the species of diatoms and algae; their distribution (Wetzel, 1983) and rate of photosynthesis (Nielsen, 1974). For the above reasons the comparison between the reef and the inside of the Muskegon Lake Channel was unrealistic. The temperature differences combined with the increased nutrient content in the channel water gives this area a distinct advantage over the reef in primary production. Scuba observations on the Lake Michigan side of the breakwall have shown this area to be intermediate between the inside of the breakwall and the reef in terms of primary production.

Table 24. Scuba observations of yellow perch abundance on the Muskegon Artificial Reef during 1980

Date	Temp. °C	Number of Yellow Perch
*7/2/80	14.9	0
*7/8/80	11.1	0
*7/9/80	12.7	0
*7/30/80	6.6	0
*7/31/80	8.3	0
*8/4/80	13.3	0
*8/6/80	21.6	0
8/11/80	19.4	0
8/12/80	13.8	0
8/13/80	8.3	0
8/14/80	11.6	0
8/15/80	11.6	0
8/21/80	15.5	200
8/22/80	10.5	0
8/25/80	7.2	0
8/26/80	12.2	0
8/27/80	14.4	50
8/28/80	13.8	8
8/29/80	14.9	9
9/9/80	17.2	0
9/12/80	7.7	0

*Scuba observations in Muskegon Artificial Reef area before its introduction

Table 25. Scuba observations of yellow perch abundance on the Muskegon Artificial Reef during 1981

Date	Temp. °C	Number of Yellow Perch
5/20/81	7.7	0
5/21/81	6.6	0
5/22/81	6.1	2
5/28/81	10.5	0
5/29/81	7.7	0
6/2/81	7.7	0
6/3/81	8.8	0
6/11/81	15.5	100
6/12/81	16.6	12
6/23/81	8.8	0
7/2/81	13.3	120
7/6/81	8.3	0
7/7/81	9.4	0
7/10/81	8.3	0
7/16/81	13.3	3
7/17/81	11.6	1
7/19/81	11.6	4
7/20/81	11.6	0
7/21/81	8.3	8
7/22/81	6.1	0
7/23/81	6.1	0
7/29/81	6.6	0
7/30/81	7.2	0
8/5/81	19.4	4
8/6/81	18.8	75
8/10/81	14.9	50
8/17/81	16.6	0
8/20/81	8.8	0
8/21/81	7.7	0
8/24/81	11.6	0
8/27/81	19.4	5

Table 26. Scuba observations of yellow perch abundance on the Muskegon Artificial Reef during 1982

Date	Temp. °C	Number of Yellow Perch
7/15/82	20.5	0
8/2/82	18.3	15
8/5/82	22.7	17

Table 27. Number of yellow perch taken by the gill nets on the Muskegon Artificial Reef during 1980

Date	Temp. °C	Number of Yellow Perch
6/16/80	8.8	3
7/2/80	14.9	138
7/21/80	19.9	310
7/28/80	7.2	2
8/18/80	16.6	348
9/8/80	22.2	2

Table 28. Number of yellow perch taken by the gill nets on the Muskegon Artificial Reef during 1981

Date	Temp. °C	Number of Yellow Perch
5/13/81	7.2	40
5/26/81	12.2	169
6/17/81	17.2	90
6/30/81	15.5	90
7/13/81	12.7	80
7/26/81	7.2	19
8/25/81	13.3	18

Table 29. Number of yellow perch taken by the gill nets on the Muskegon Artificial Reef during 1982

Date	Temp. °C	Number of Yellow Perch
7/6/82	7.2	3
7/13/82	20.5	0
7/27/82	13.8	0
8/24/82	19.9	0
8/31/82	17.7	0

Table 30. Number of yellow perch taken by the gill nets on the Muskegon Artificial Reef during 1983

Date	Temp. °C	Number of Yellow Perch
5/27/83	7.5	203
6/23/83	8.0	26
7/26/83	7.0	31
8/19/83	21.0	122
10/31/83	9.0	263

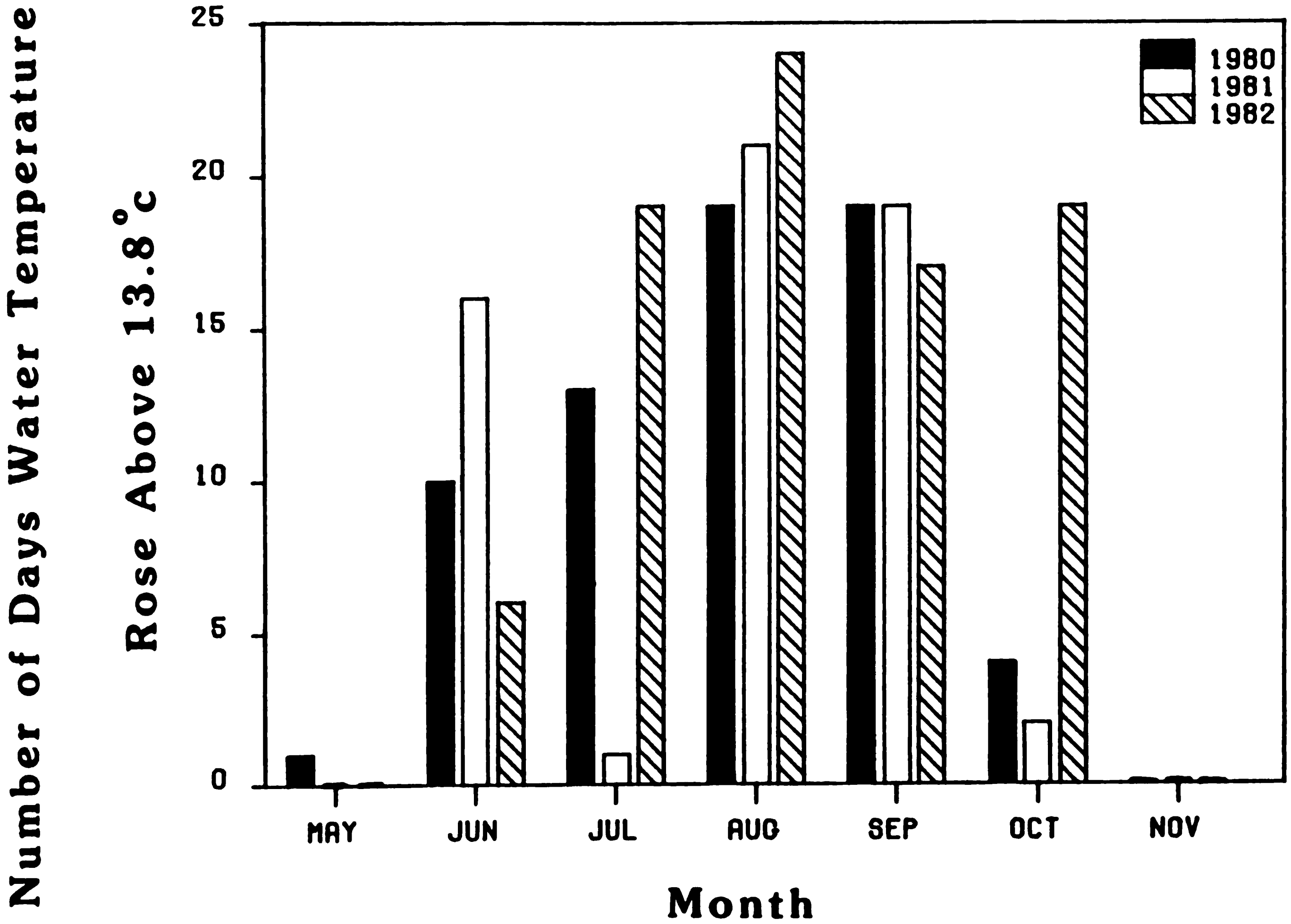


Figure 20. Graph illustrating the total number of days per month that water temperature in research area rose above 13.8°C

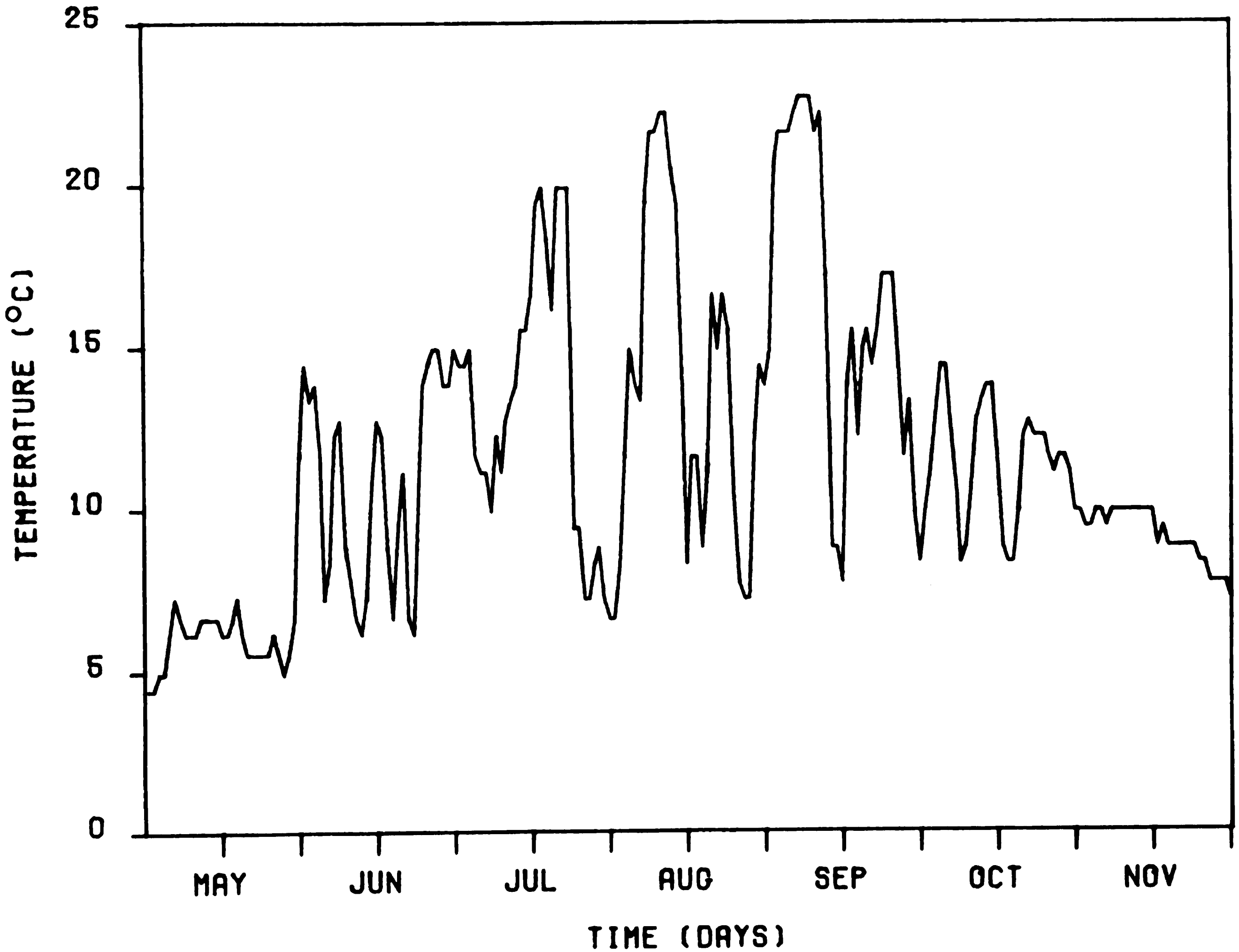


Figure 21. Graph of the bottom water temperature for the Muskegon Artificial Reef area in Lake Michigan during 1980

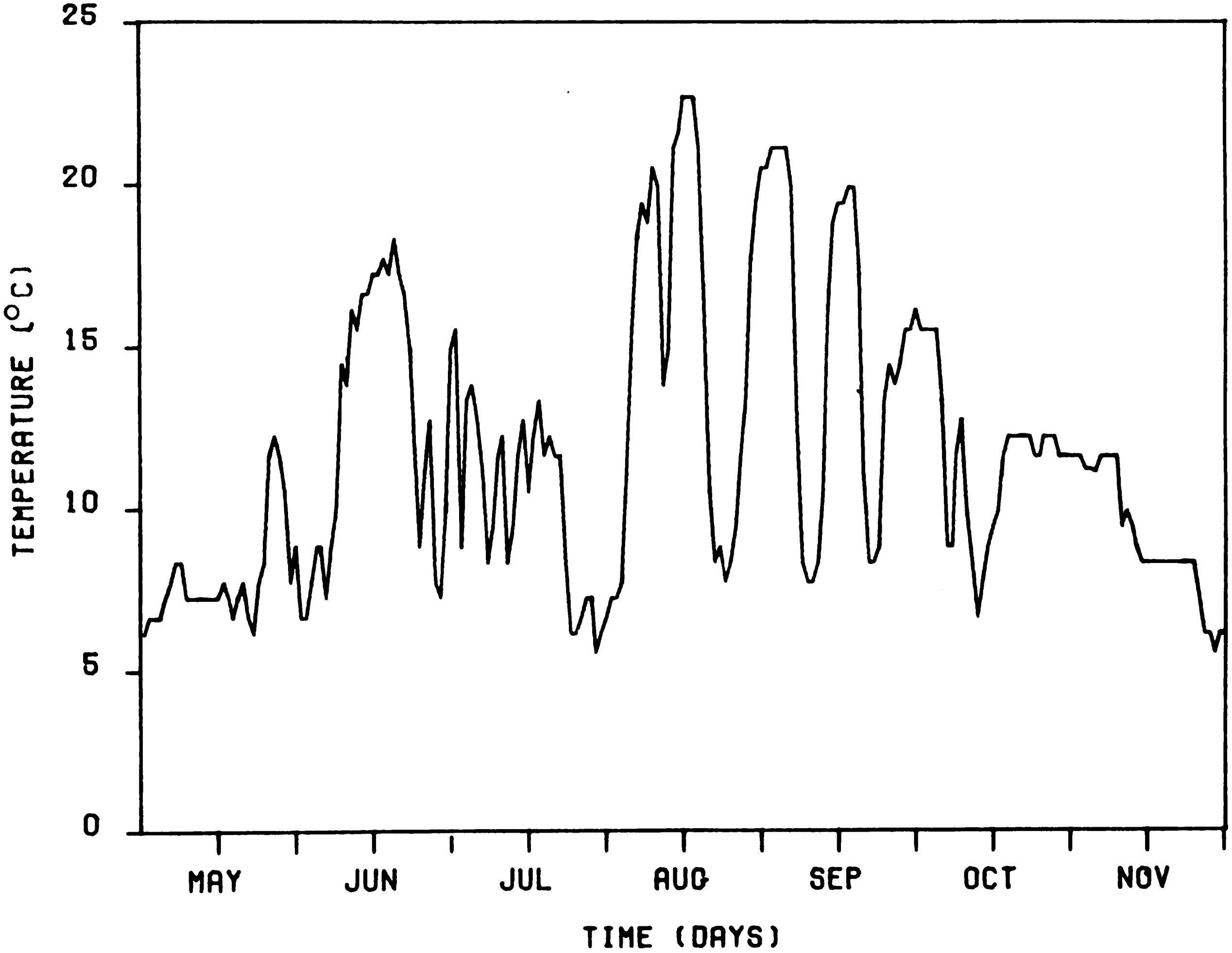


Figure 22. Graph of the bottom water temperature for the Muskegon Artificial Reef area in Lake Michigan during 1981

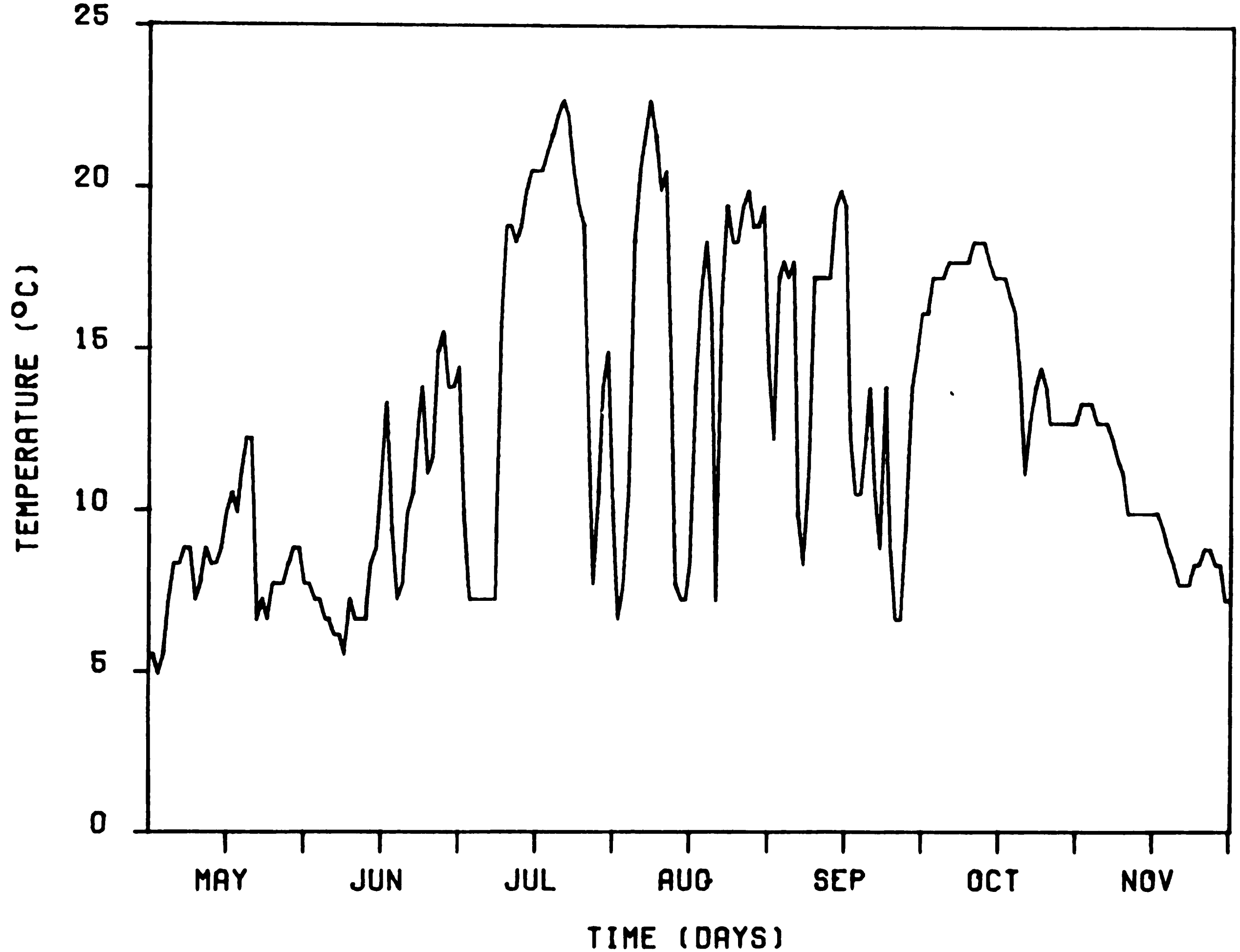


Figure 23. Graph of the bottom water temperature for the Muskegon Artificial Reef area in Lake Michigan during 1982

Studies conducted with alga in the laboratory have shown them to be capable of growing over a range of water temperatures. However, alga grown at low temperatures (below 15.0°C) have lower rates of photosynthesis and growth rates than those grown at high temperatures (Keith et al., 1979 and Gordon et al., 1980). This would account for the difference in primary production between the Muskegon Lake Channel and the Muskegon Artificial Reef. The water temperature in the channel is usually above 15.0°C, but the water temperature in the reef area is below 15.0°C, 82% of the time (Figures 21, 22 and 23).

Light Impact

Construction of the Muskegon Artificial Reef introduced a hard attachment substrate to an area where none had previously existed. Several macroinvertebrate groups and attached algae are dependent on this attachment substrate for their existence at the reef site. Autotrophic epiphytic periphyton represents the primary producers of the reef's ecosystem and is a major food source for many of the macroinvertebrate groups inhabiting the dolomite of the reef. The rate of primary production of epiphytic periphyton is obviously dependent upon the substrate area available for colonization within the zone of adequate light (Wetzel, 1983). Light measurements were taken to determine if light intensity reaching the reef was adequate for primary production to occur. Eight stations (Figure 7) on and off the reef were measured. Stations inside the Muckegon Lake Channel breakwall were chosen because of the vast amounts of periphyton observed growing on the rocks to a depth of 1.5 meters by Scuba divers. However, below this depth the rocks were barren. The extinction coefficients for the eight stations were used to calculate the transmission of light to a depth of 13.5 meters and 9.5 meters correcponding the depths of the deep and shallow ends of the reef, respectively (Table 31). Figures 24, 25, 26 and 27 are graphic representations of these calculations. They illustrate that the differences in primary production between the inside of the Muskegon Lake Channel breakwall and the reef is not due to the difference in transmission of light. Although light intensity at the shallow and deep ends of the reef are 59.8 $\mu Em^{-2}sec^{-1}$ and 16.8 $\mu Em^{-2}sec^{-1}$ respectively, under the worst conditions there would still be enough light for photosynthesis. However, light in combination with other factors may

Table 31. Values of irradiance light to depth of 9.8m and 13.5m calculated from light measurements at eight stations and corresponding correlation coefficient r^2

Station	I_z at 9.8m($\mu Em^{-2}sec^{-1}$) 7/11/83	8/24/83	I_z at 13.5m($\mu Em^{-2}sec^{-1}$) 7/11/83	8/24/83	r^2 for 7/11/83	r^2 for 8/24/83
1	250.5	59.8	123.6	16.8	0.96608	0.99682
2	231.7	83.8	103.5	23.3	0.96446	0.99281
3	234.0	71.9	105.8	23.1	0.99598	0.98372
4	212.4	66.3	99.6	18.5	0.98454	0.99248
5	2.4		0.2		0.93804	
6	1.6		0.2		0.96444	
7	22.4		4.4		0.95713	
8	16.3		2.8		0.98882	

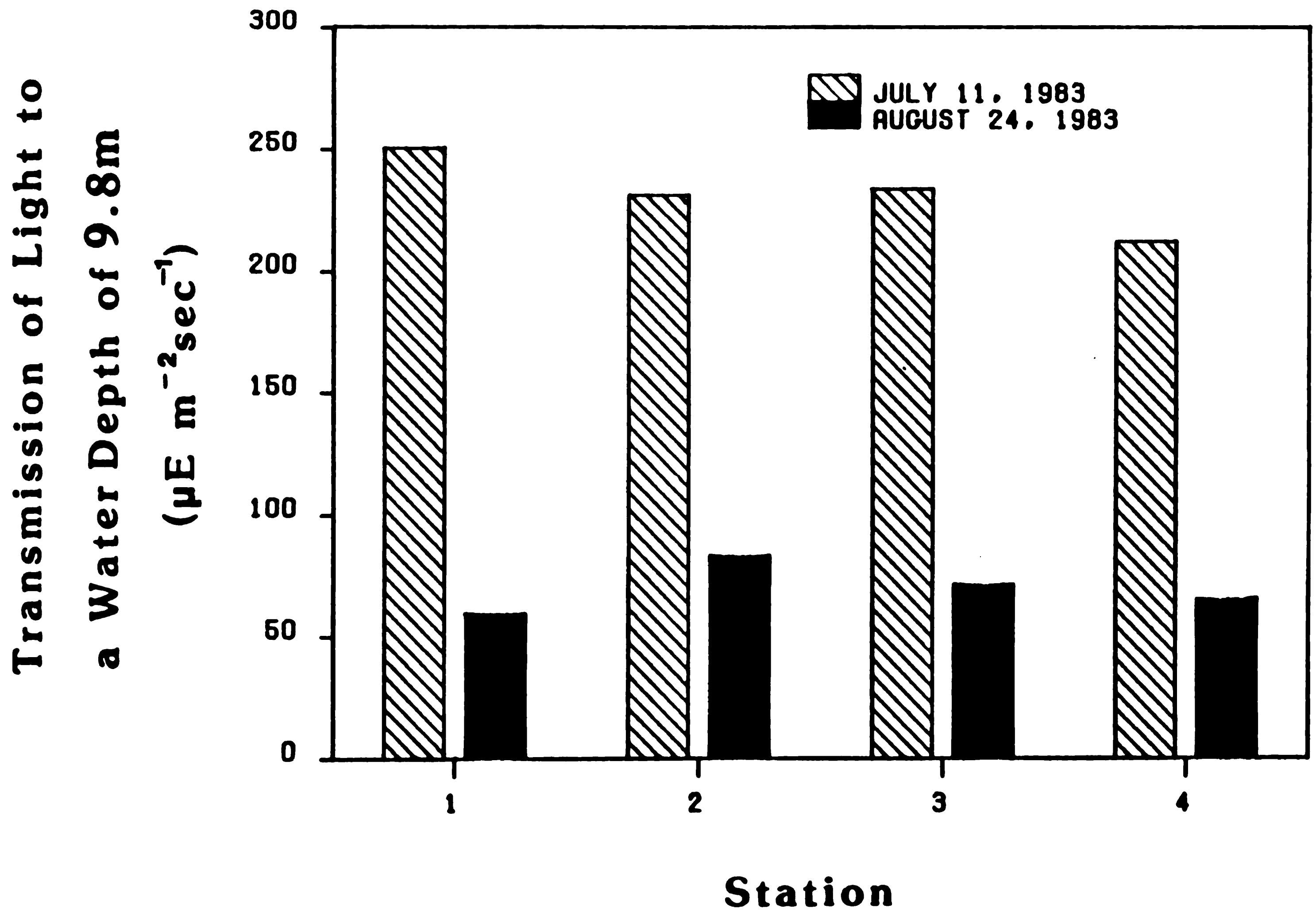


Figure 24. Light transmission given a depth of 9.8 meters as calculated using the extinction coefficient for each light measurement station

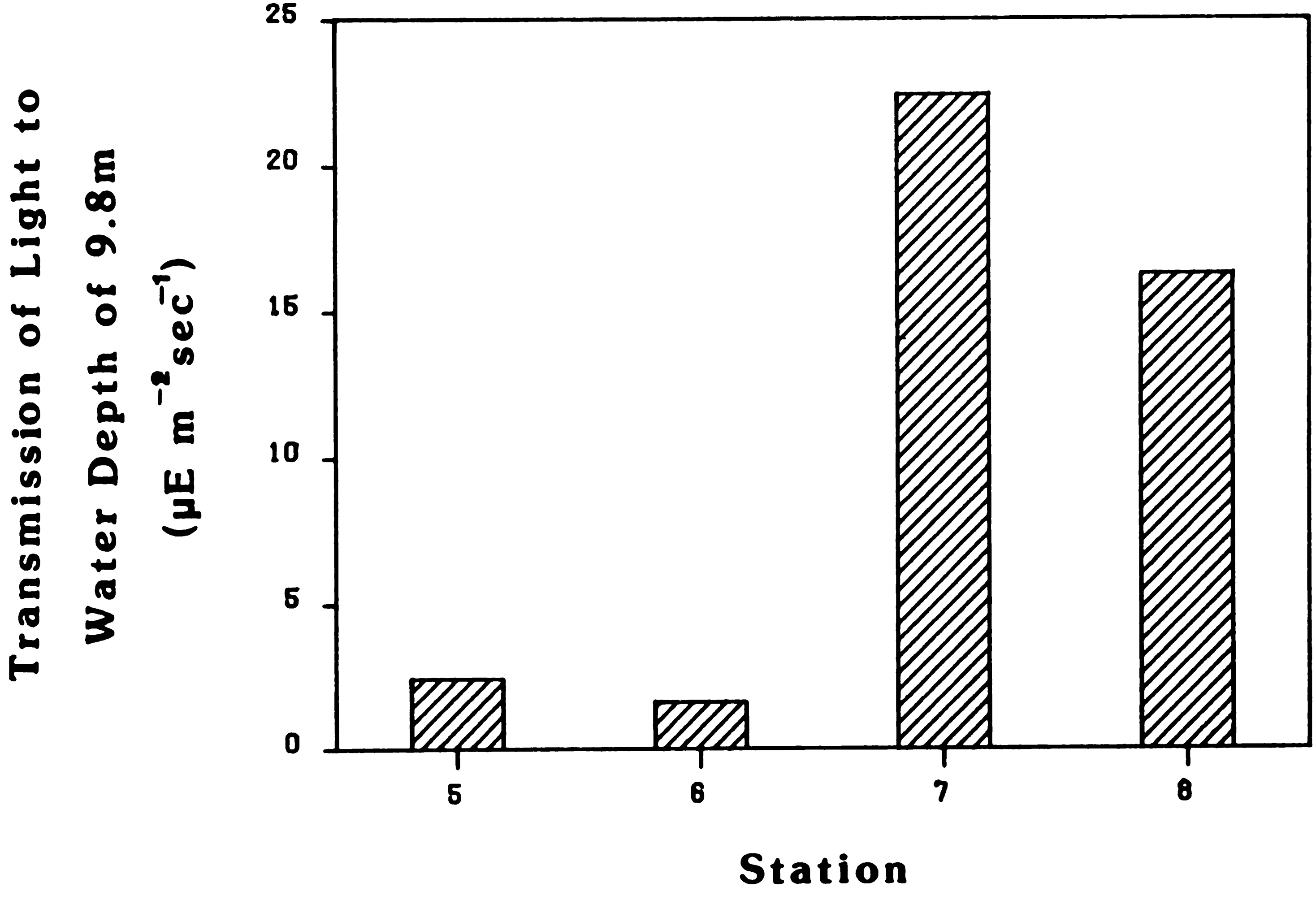


Figure 25. Light transmission given a depth of 9.8 meters as calculated using the extinction coefficient for each light measurement station

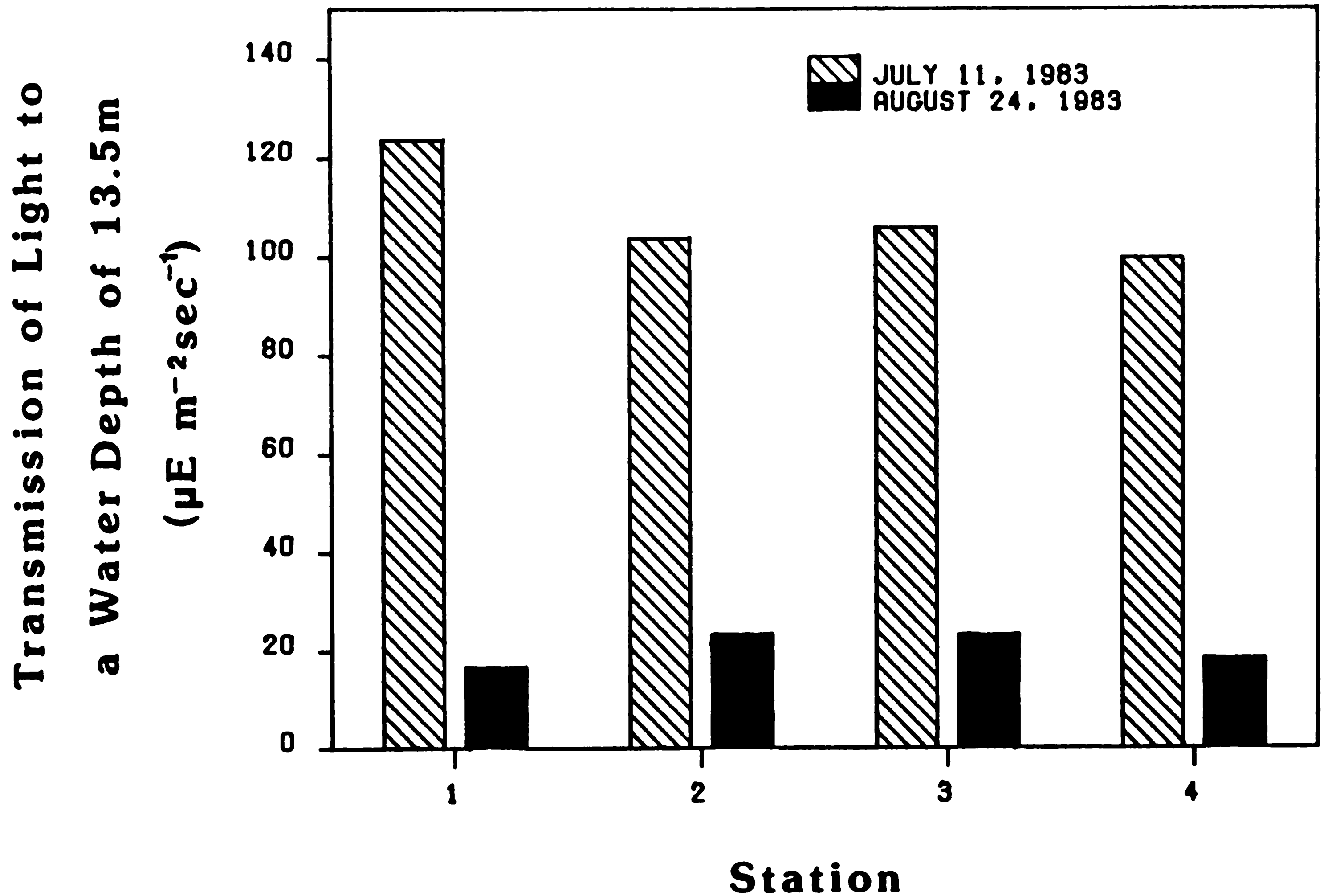


Figure 26. Light transmission given a depth of 13.5 meters as calculated using the extinction coefficient for each light measurement station

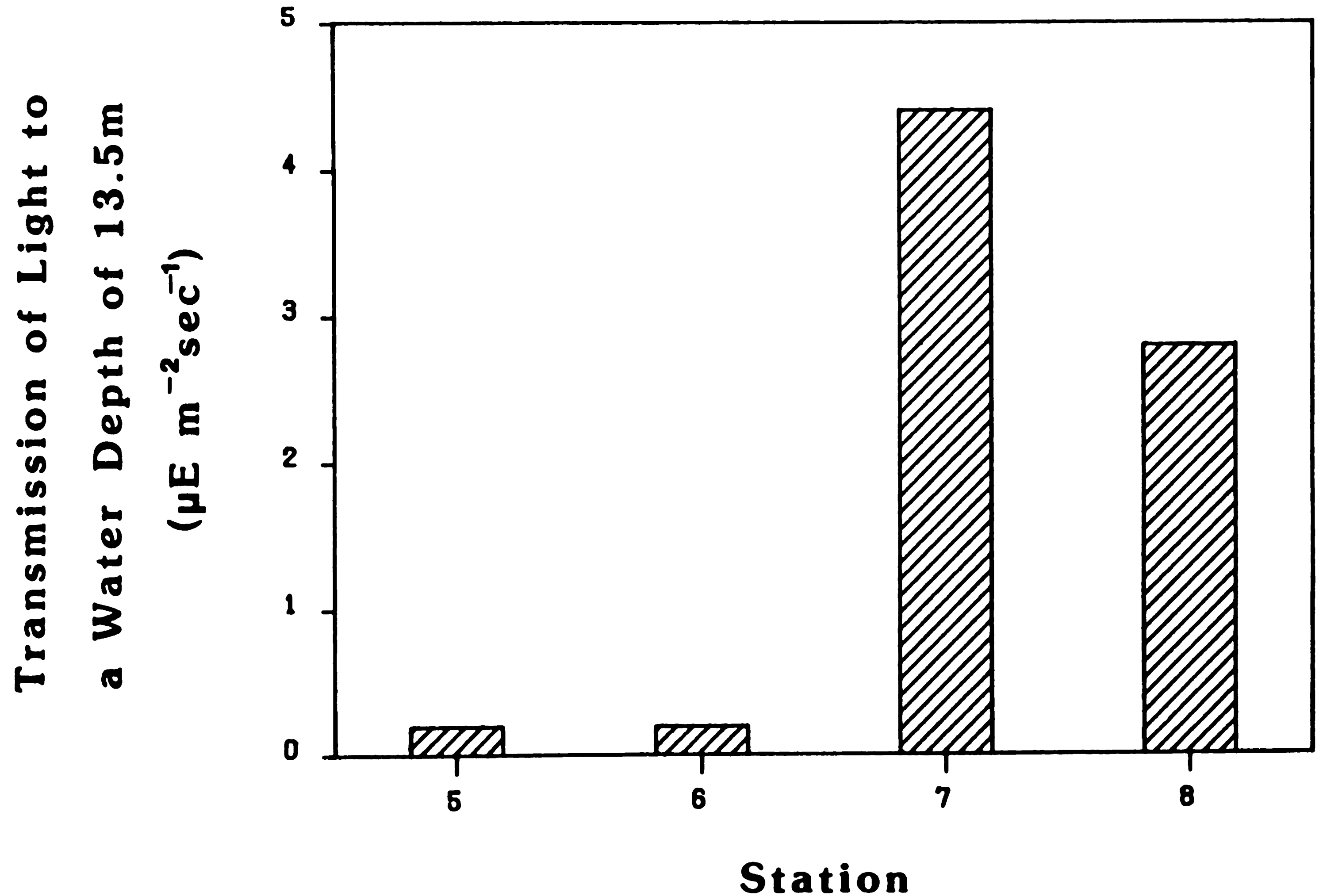


Figure 27. Light transmission given a depth of 13.5 meters as calculated using the extinction coefficient for each light measurement station

be responsible for the low primary productivity observed on the reef. Investigation into the algal grow has shown that grow is affected by the interaction between light intensity, water temperature and nutrient availability (Morgan and Kalff, 1979; Gordon et al., 1980). The reef has low light intensity, cold water temperature and low nutrient availability. The Muskegon Lake Channel also possess low light intensity, but receives rich nutrient input from Muskegon Lake and has warm water temperatures. The later two parameters appear to be responsible for the primary production on the rocks in the upper 1.5 meters of water on the breakwall.

Extinction coefficients for the deep and shallow ends of the reef were calculated to be 0.320 and 0.317, respectively. These extinction coefficients fall in the range (0.2 - 0.4) of extinction coefficients reported by Beeton (1962) for open water of Lake Michigan. The reef extinction coefficients compare favorably to those of Crystal Lake (0.2) reported by Wetzel (1983) to be a very clear lake. These comparisons and the abundance of the macroinvertebrate groups suggests that the epiphytic periphyton colonization is occurring. It appears that the major factors limiting periphyton growth on the reef is the interaction between Low light intensity, cold temperature and lack of nutrients.

Depth Impact

Examination of reef depth was carried out to determine if the reef was sinking and what effects the positioning of the reef had on the colonizing organisms. Depth measurements (Table 32), although crude, would enable one to determine if the reef was sinking. These measurements indicate that the reef is not sinking, and that a normal settling process has taken place. The dish-like depressions at the outer

Table 32. Depth measurement from shallow and deep ends of the Muskegon Artificial Reef

Measurement Date	Location on Reef	Depth (m)	Water Level Below Benchmark (m)	Change in Depth (m)
8/4/82	Shallow end	8.81	0.015	0.56
7/11/83	Shallow end	9.40	0.047	
8/4/82	Deep end	12.68	0.015	0.38
7/11/83	Deep end	13.11	0.047	

edges of a few shallow piles seem to occur sporadically and coincide with the occurrence of strong currents. To better explain these dish-like depressions, the analogy of a fencepost in a snow covered field on a windy day is applicable. The wind is blowing north to south and causes air turbulence which removes the snow from around the pole causing a dish-like depression. On the reef, the water, reef and sand act much like the wind, pole and snow. This process seems to have very little effect on the reef piles as a whole.

Depth of the reef (8.2m - 13.7m) seems to have a indirect negative effect on the colonizing organisms. Generally, as depth increases in Lake Michigan the temperature decreases. The average temperature on the reef during the three years of research was 11.6°C. Low temperatures would reduce macroinvertebrate reproduction (Pennak, 1978) and decrease the growth rate of periphyton (Barko et al.,1984). Examination of the reef's temperature data (Figures 21, 22 and 23) indicates that beyond the depth of 10.5 meters the temperature was below the yellow perch's minimum preferred temperature of 13.8°C more than 85% of the time during the period from May 1 to November 30. Scott (1979) reports that yellow perch are considered shallow water fish because they are not usually found below depths of 9.2 meters (Scott et al.,1979). This suggests that the reef is situated in water that is too deep to contain a temperature range suitable for yellow perch and abundant periphyton. Periphyton would also be effected by the decrease in light intensity with increasing depth.

CONCLUSION

The Muskegon Artificial Reef has been successfully colonized by several different macroinvertebrate groups. These macroinvertebrates have been reported as food items in the diets of yellow perch and round whitefish inhabiting Lake Michigan (Brazo, 1975; Dodge, 1968; Koezl, 1929 and Tharatt, 1959). The sand substrate of the reef and reference area contained amphipoda, chironomids, Pisidium sp. and oligochaeta as the major macroinvertebrate groups. Abundance of these groups are very similar for the two areas (Figures 16 and 19). The addition of the artificial reef has had very little effect on the composition and abundance of these macroinvertebrates. Due to their habitat requirements, these groups were unable to utilize the dolomite limestone substrate of the reef. This inability of the existing macroinvertebrates to utilize the new habitat left an open ecosystem for other macroinvertebrates to exploit.

The rock basket and multiple plate samplers collected these new macroinvertebrates from the dolomite limestone substrate. When these samplers were compared to the ponar samples of sand substrate it was evident that the presence of the dolomite substrate had increased the abundance of Gammarus pseudolumnaeus, Asellus sp., Physa sp. and Psectrocladius sp.

Introduction of the dolomite substrate has also attracted many new macroinvertebrate genera and changed the composition of the area. These new additions were as follows: for the chironomids

Parachironomus sp., Glyptotendipes sp., Larsia sp., Polypedilum sp., Cardiocladius sp., and Thienemanniella sp.; for trichoptera Hydroptila sp., Hydropsyche sp., Orthotrichia sp., and Ceraclea sp.; for ephemeroptera Stenonema sp.; for gastropoda Bithynia tentaculata; for oligochaeta Limnodrilus angustipenis, Limnodrilus profundicola, Nais variabilis, Potamthrix moldaviensis, Piguetiella michiganensis, Stylaria lactistris, Uncinais uncinata, and Ophidonais serpentina. Two abundant new macroinvertebrate groups on the reef sampled by Scuba divers are the sponge, Eunapius fragilis, and to a lesser extent, the turbellaria, Dugesia tigrina.

The majority of the macroinvertebrates that colonized the reef feed on periphyton and detritus (Pennak, 1978). Their presence indicates that periphyton colonization is proceeding, although the production may be low in comparision to the channel breakwall. This was substantiated by the measurements taken on the reef. Extinction coefficients compared favorably with those reported by Wetzel (1983) for a very clear lake and to the open water extinction coefficients of Lake Michigan reported by Beeton (1962). These comparisons suggest that the transmission of light to the depths of the reef is sufficient for periphyton growth.

Periphyton, sponges, and detritus comprise the base of the reef's trophic pyramid. These groups are grazed by the macroinvertebrates, who in turn, are fed on by the eight species of forage fish present on the reef (Table 33). Both the macroinvertebrates and the forage fish are potential food for the yellow perch. The Muskegon Artificial Reef has successfully increased the availability of food organisms to yellow perch in what was previously a biologically unproductive area of Lake Michigan. Scuba observations confirmed that the reef provides shelter to yellow perch, and VanDerLaan (1983) determined that yellow perch did

Table 33. **Taxa list of fish collected on the Muskegon Artificial Reef during 1981 and 1982**

Johnny darter, Etheostoma nigrum (Rafinesque)
Spottail shiner, Notropis hudsonius (Clinton)
Mottled sculpin, Cottus bairdi (Girard)
Slimy sculpin, Cottus cognatus (Richardson)
Ninespin stickleback, Pungitius pungitius (Linnaeus)
Rainbow smelt, Osmerus mordax (Mitchill)
*Trout perch, Percopsis omiscomaycus (Walbaum)
Cyprinidae spp.

*Reported by VanDerLaan, 1983

utilize the reef as spawning habitat.

It was stated that the success of the Muckegon Artificial Reef rested on its ability to provide yellow perch with shelter, spawning habitat and increased availability of food organisms, all of which the reef has accomplished. However, Scuba observations and netting results indicate that yellow perch are absent from the reef the majority of the time. Examination of the reef's physical parameters such as temperature and depth reveals why this occurs.

Water temperature has been shown throughout this research to be the major controlling environmental factor on the Muskegon Artificial Reef. The temperature on the reef ranges from 4.4°C - 27.7°C effecting macroinvertebrate reproduction, photosynthesis and distribution of periphyton, as well as distribution and feeding activities of yellow perch. Both the macroinvertebrates and periphyton seem to do quite well over this range of temperatures. The yellow perch, on the other hand, use their motility to seek their preferred water temperature. Waters in the preferred temperature range prevail most of the year inside the Muskegon Lake Channel and, at times, in the shallow waters close to shore. Employing the minimum preferred temperature (13.8°C) as an arbitrary cutoff for the presence of yellor perch as determined from Scuba diver observations and netting results, it was determined that temperatures favorable to yellow perch occurred on an average of 62 days per year on the reef. Although no area in Lake Michigan possesses the temperature regime of the water from Muskegon Lake, the shallow water areas of Lake Michigan do have significantly warmer temperatures to offer. The major reason for these warmer temperatures is the shallow depth. In the previous discussion, it was shown that the reef's water depth (8.2 m to 13.7 m) was not conducive to the temperatures preferred by the yellow perch.

The introduction stated that the pre-construction estimate of new income to the Muskegon area due to the gross expenditures of anglers using the reef is approximately $74,500 per season. Jordan (1983) estimated from angler interviews that the Muskegon Artificial Reef accounted for 215 angler days and $2,392. Due to the enormous discrepancy between the two estimates, it would have to be concluded that the reef was not a financial success.

The financial success of this or any artificial reef ties in with the ability of anglers to catch fish. Freshwater artificial reef fishing is new to Michigan and, like any other type of fishing, is a combination of art and applied science. The inability of anglers to catch yellow perch stems as much from their lack of knowledge concerning the techniques of fishing an artificial reef as it does from the low frequency of reef utilization by yellow perch. On several occasions Scuba divers observed large schools of yellow perch on the reef. Upon surfacing, the divers inquired of anglers about their catch. To our surprise, most anglers were having no success while a few anglers had good catches. It was determined that anglers not anchored directly over a rock pile would have very little success because the perch would not venture out onto the sand for the bait.

Twenty-five percent of the boat anglers interviewed during Jordan's (1983) study had fished the reef. This, coupled with the fact that 48% of all pier anglers interviewed were primarily fishing for yellow perch which made up 75% of the total catch from the pier, would suggest intense interest in the new fishing opportunity offered by the reef (Jordan, 1983). With angler success, this interest could have grown. However, like any fishing spot it takes time to learn the area, when to fish it, and what baits to use. Until anglers become informed about such things they will continue to fish the areas they know well, such as the Muskegon Lake Channel where the total success rate is 2.9 fish per angler day (Jordan, 1983).

The above conclusions may have shed doubt on the usefulness of artificial reefs as a fisheries enhancement tool in the Great Lakes. The major flaw in the design of this reef lies in its physical positioning. Consideration of the depth versus temperature profile of this area and the preferred temperature of perch may have been overlooked in the planning of the reef. As previously mentioned, the reef's water depth was not often conducive to temperatures above 13.8°C. During the times when these temperatures are present on the reef, anglers utilizing the reef often enjoy impressive catches. However, it has been shown that the occurrence of these temperatures at this depth are not frequent enough to justify its construction.

The fact that the reef does attract perch and that a tight relationship between temperature and the presence of perch on the reef exists, suggests that the concept of the artificial reef in the Great Lakes is sound. The Muskegon Artificial Reef has clearly shown that the planning of future reefs must take into consideration temperature, light and nutrient input as it relates to the organisms that will potentially inhabit the reef. Physical and geological aspects that should also be considered are the substrate composition and movement, siltation rate of the area, wave length as it relates to type and density of reef construction material, depth and placement distance off shore (Mathews, 1981).

Lack of knowledge concerning artificial reefs in the Great Lakes led to the development of unrealistic expectations of the Muskegon Artificial Reef. Contributing to these unfounded expectations, were the comparisons made between the reef and the Muskegon Lake Channel. The channel possesses the ideal water temperature range for yellow perch, receiving high amount of nutrient input directly from Muskegon Lake, and having a shallow depth (1.5 m) where most of the primary production occurs. It would be unrealistic to expect any open water area of Lake Michigan to imitate those conditions found in the channel. In comparison, the open water of Lake Michigan has colder water temperatures and is lacking both shallow depths and nutrients.

Taking into consideration what has been learned from the Muskegon Artificial Reef, the recommendations for future artificial reefs in the Great Lakes are as follows. Artificial reefs should be positioned so that the water depth is conducive to the preferred water temperature range of the target species. If the target species is yellow perch, as it was for the Muskegon Artificial Reef, a relatively shallow area just beyond the high energy wave zone will usually provide the appropriate temperature range. Breakwalls, piers and erosion control areas are associated with the shallow coastal waters. These structures usually act as unintentional artificial reefs and have many advantages over building where no structure exists. The above structures would provide the new artificial reef with a source of existing organisms for rapid colonization, and additional material to increase the scale of the new reef. The scale of an artificial reef is the proportional three-dimensional measurement which takes into account length, width and height. Height of a reef is an important influencing factor of water temperatures and light penetration. As the height of the reef increases and approaches the water surface, temperature and light availability also increase. Both height and length increases the probability that the preferred temperature for the target species of fish (i.e. yellow perch) will exist on the reef. This range of temperatures would enable yellow perch and other organisms to seek their preferred temperatures without leaving the reef.

Artificial reef research conducted by the Japanese has shown that the scale of an artificial reef significantly effects its ability to attract fish. A minimum of 400 - 1000 m^3 was determined to be the lower scale limit, depending on the target species (Sheehy, 1982). Scale of an artificial reef could be drastically increased by incorporation of an existing structure. The above guidelines for reef scale suggest that the scatter pile construction employed on the Muskegon Artificial Reef should be avoided in the future. These piles were not large enough to accommodate the schools of yellow perch that utilized the reef. Future artificial reefs should be constructed to maximize the scale so as to avoid this problem.

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