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Evaluation of an Man-Made Walleye Spawning Reef

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Abstract.—I assessed walleye egg deposition and juvenile production from a man-made spawning reef installed in Six Mile Lake, Michigan, in which no walleye reproduction had previously been found. In 1981-86 night observations were made at the reef and along the entire shoreline to determine the number of spawners using the reef. The maximum number of spawners per observation seen on the reef each year ranged from 20 (1983 and 1986) to 38 (1984). Walleyes also were seen on a nearby sand-detritus area, where the maximum number per observation seen each year ranged from 11 (1982) to 39 (1984). Overall, approximately equal numbers of spawners were seen at the two areas. Estimated egg deposition on the reef ranged from 22,000 (1985) to 1,082,000 (1982) and averaged 501,000. Eggs were deposited on the sand-detritus area, but no estimate was made of the total number. Juvenile walleye production was assessed by estimating the number of age-1 walleye present in the lake the following year. To assess production on the sand-detritus area in 1985 and 1986, walleyes were allowed to spawn on the reef, then the eggs were killed with Antimycin. The mean estimated number of age-1 walleyes was 2.3 times higher during years without Antimycin treatment compared to years with treatment. But the difference between non-treatment and treatment years was not statistically significant at the 95% level. Degradation of the reef by siltation was slight during its first 7 years; no settling into the sand occurred nearshore. Also estimated were the number and mean lengths of walleyes, bluegills, pumpkinseeds, and bullheads in June 1980-87; depth distribution of walleyes in June as determined by fyke nets; and changes in benthos due to the change in substrate when the reef was installed.

The walleye *Stizostedion vitreum* is one of the most desirable coolwater sport fishes. However, relatively few Michigan inland lakes support good walleye populations due to inadequate natural reproduction and recruitment (Schneider 1975). Walleye populations have been established and maintained in many lakes by planting fry or small fingerlings. Although stocking provides satisfactory fishing in some of these lakes, hatchery production is limited and expensive. If unsuitable spawning habitat is the limiting factor for self-sustaining populations, man-made spawning reefs may be beneficial.

By 1979, fisheries managers had constructed spawning reefs in six inland lakes in Michigan's Upper Peninsula and more were contemplated. However, it was unknown if walleye spawned on these reefs or if worthwhile numbers of fry were produced. Three studies that evaluated man-made reefs for walleyes in other states have been published.

Newburg (1975) installed a reef in a 2,540-hectare Minnesota Lake and estimated fry production based on the number of live eggs found during late stages of incubation on the reef (1,394 m^2) and also on adjacent natural reefs (2,004 m^2). He estimated that only 10% of the potential fry produced came from the man-made reef. He concluded that it would be cheaper to plant fry than to produce fry on a man-made reef.

Weber and Imler (1974) installed two reefs in 1971 in a 200-hectare Colorado irrigation impoundment that was subject to severe drawdown. The area of man-made reefs was 929 m^2 and the area of existing spawning substrate (apparently marginal) was 5,574 m^2. Prior to man-made reef installation, the population of walleyes age 2 and older averaged two per hectare. Production from the man-made reef was evaluated by estimating young-of-year (YOY) walleye populations in the fall. Population estimates were 500 (1970), 1,100 (1972), and 5,500 (1973). They concluded that the fall YOY walleye populations were increased twofold to tenfold by the two man-made reefs. However, given the notoriously wide fluctuations in hatching success of walleyes, this conclusion may be somewhat premature.

McKnight (1975) installed three reefs in a 98-hectare lake in Wisconsin. Natural spawning area was sparse and the small walleye population had not reproduced for 7 consecutive years. After reef installation, McKnight assessed reproduction for 4 years by sampling eggs with dip nets, fry with meter nets, and fingerlings with electrofishing gear. Although eggs on the reef developed to the eyed stage, there was no evidence of subsequent survival. McKnight recommended further study.

In this report, I present findings of a 1980-87 study to assess walleye egg deposition and fry production on a man-made reef and to determine survival of walleyes to older ages. I also conducted measurements of effective reef life, deposition of walleye eggs on sand-detritus substrate, changes in benthos due to reef installation, distribution of walleyes in early June, and abundance of other species of fish in the lake.

Study Area

Six Mile Lake was selected for this study. It is in the western Upper Peninsula of Michigan on the Houghton-Ontonagon County line but most of it lies in Ontonagon County at T.50 N, R.37 W, Sec. 4. Fisheries Division records show the lake has a methyl orange alkalinity of 13 to 20 ppm and a pH of 6.0 to 7.0. This soft-water lake covers an area of 29 hectares, has a maximum depth of 5 m, and does not winterkill. The bottom is predominantly flocculent silt but small areas of sand occur along shore on the south to southeast side. The shoreline is mostly encroaching overhanging bog mats. Aquatic vegetation, primarily white and yellow water lilies (*Nymphaea* sp.), is very abundant along the west and southwest shores, but some vegetation is present along the entire shoreline. Fisheries Division records show that minnows have always been rare and that no walleyes were present until they were stocked in 1973.

To determine if the abundance of walleyes in Six Mile Lake was adequate to utilize a proposed man-made spawning reef, a mark-and-recapture population estimate of walleyes was made in June 1979 by personnel from the U. S. Forest Service and the Michigan Department of Natural Resources (R. P. Juetten, MDNR, personal communication). The estimate was made in conjunction with a manual removal, with fyke nets, of small bluegills *Lepomis macrochirus*, pumpkinseeds *L. gibbosus*, and black bullheads *Ictalurus melas*. The lake had a population of about 200 walleyes in ages 2 through 6. These walleye were from annual plants of 100,000 to 500,000 fry in 1973-77.

A reef was installed in Six Mile Lake by the U. S. Forest Service in winter 1980. Rounded fieldstone was placed on the ice above a hard sand bottom in the southeast corner of the lake. The rock was piled from shore out to a depth of 60 cm. The rocks were 5 to 30 cm in diameter and were piled to a thickness of about 30 cm over an area of 375 m^2. In the spring the rocks settled onto the sand. The reef was shaped like a trapezoid with a 29-m long side along shore, a 24-m long side offshore, and extended out 14 m into the lake.

Methods

Spawning Observations

Observations were made each year, 1981-86, to determine where and when walleyes spawned. The number of walleyes that spawned on the reef and at other shoreline locations was determined by making nighttime observations using a boat and spotlights. Because walleye eyes reflect light, it was easy to locate the fish in the shoal water. Observations were made no sooner then 1 hour after sunset and were completed within 3 hours. Shoal areas were checked every 2 to 4 days from ice-out until no or very few walleyes were seen. Observations were made on the reef by approaching from deep water; two observers counted only those walleyes visible on their side of the boat. On the rest of the lake, observations were made by slowly cruising along the shoreline in depths of about 1 m; one person looked for walleyes and the other operated the boat. The reef and a nearby sand-detritus area were usually checked twice each night but the rest of the shoreline was checked only one to three times a season.

Observers estimated the age (maturity) of walleyes they saw. Age-1 walleyes could be distinguished from older walleyes by their small eyes, but age-2 walleyes could only be separated from older fish by observing their body size. I did not determine age at maturity, but age-2 walleyes undoubtedly were not yet mature because at Little Cut Foot Sioux Lake, Minnesota, a few precocious males matured as early as age 3 and occasionally females were mature as early as age 5 (Johnson 1971).

The spawning act was not observed, because the fish could not be watched without the spotlight. As soon as the light shined on them they moved to deeper water. Walleye occurring in pairs or groups suggested that they were in the shoal areas to spawn, however the presence of eggs in the vicinity was taken as evidence of spawning.

Egg Deposition and Fry Production

The number of eggs deposited on the reef (1980-86) and subsequent fry production (1980-82) were estimated by extrapolation of the number of eggs and fry recovered from steel pails buried in the reef. The pails were 26 cm high and 28 cm in diameter; the area of the opening at the top was 616 cm^2. The bottoms were cut out and replaced with wire screen. Openings equal to 30% of the side area were cut in the sides and replaced with wire screen to facilitate circulation. The pails had been used previously to collect lake trout eggs and were described by Stauffer (1980). However, the openings in the wire mesh were too large to retain walleye eggs and fry, so a liner made of HC3-600 nitex was placed in the pails. The reef was divided into 20 equal-sized areas and one to three pails were set at the center of each of these areas during 1980-84.

Prior to spawning, holes were dug into the rock reef and the pails were placed in the holes so their tops were flush with the substrate. The excavated material was placed in the pails. After spawning was completed, some pails were lifted to estimate egg deposition; other pails were fitted with fry traps (Stauffer 1980) or flat metal covers to retain the fry, so fry production could be estimated. Pails were set after ice-out in 1980 and 1981, but pails for 1982-84 samples were set the previous fall so that no spawning would be missed. The fry pails were lifted when it was assumed that the eggs had sufficient time to hatch. When the pails were lifted, the rocks were rinsed to remove eggs and fry, and then replaced in the depressions. The remaining eggs, fry, and debris were preserved in 5% formalin for later examination. In the laboratory, eggs and fry were picked from the debris, classified as alive or dead, and counted. Total egg deposition on the reef was calculated by multiplying the mean number of live and dead eggs and fry found per pail by the ratio of the area of a pail to the area of the reef. Ninety-five percent confidence limits were also calculated. Fry production was calculated as the number of live eggs plus the number of fry. Johnson (1961) used eyed and pre-eyed eggs to estimate fry production because there was little mortality between the pre-eyed egg and fry stages in hatcheries. He defined pre-eyed as the stage when eyes are visible only with magnification.

To determine if eggs had been deposited at the sand-detritus area I sampled for eggs and fry in areas where walleyes had been seen by agitating the substrate with my feet then passing a dip net through the roiled water. The net had a 23 x 39 cm opening and the metal-mesh bag had apertures of 1.1 x 1.8 mm. The number of passes were recorded so an index of the number of eggs per pass could be calculated. However, no attempt was made to estimate the total number in the area. The samples were preserved in 10% formalin. In the laboratory the eggs were picked from the copious amounts of sticks, leaves, and other debris.

In 1983-87, the number of recruits produced from the sand-detritus area was indirectly estimated by attempting to prevent any walleye recruitment from the reef. Consequently, any yearling or older walleye belonging to those year classes should have been produced from the sand-detritus area. Two methods to prevent recruitment were tried. First, immediately after ice-out in 1983 and 1984, a barrier net was set around the rock reef in an attempt to prevent walleye from spawning there. Second, in 1985 and 1986, walleye were allowed to spawn on the rock reef, then the eggs were killed with Antimycin. Prior to the application of Antimycin, plastic sheeting was hung around the reef to reduce water exchange between the reef and the lake during the treatment. The reef was treated at a concentration of 0.5 ppb in 1985; in 1986 the reef was treated twice, first at 2.0 ppb, then 3 days later at 4.5 ppb. In fall, 1984 and 1985, 20 and 13 pails, respectively, were installed on the reef to assess egg development and to evaluate the Antimycin treatments in 1985 and 1986.

During most years, water temperatures were monitored with a maximum-minimum thermometer placed on the reef at ice-out and removed after all work on the reef was completed for the year. The thermometer was read and reset each time the reef was visited. In 1986, a recording thermograph was installed on the reef prior to any spawning so the hatching date and the best treatment date could be predicted more accurately. The temperatures at 0600 hours and 1800 hours, which usually were the minimum or maximum for the day, were averaged and used to calculate degree-days. The number of degree-days required for walleye eggs to hatch was found in the literature (Allbough and Manz 1964; Koenst and Smith 1976).

Fish Population Estimates

I made Schumacher and Eschmeyer population estimates (Ricker 1975) each year in June 1980-87, to determine the number of age-1, age-2, and age-3 and older walleyes in Six Mile Lake. Bluegills, pumpkinseeds, and black bullheads longer than 9 cm in 1980 and 4 cm thereafter, were also estimated. Four-foot fyke nets were used to collect the fish. In 1980, eight nets were fished; in other years 12 nets were fished. The nets used in 1980 were constructed of 19 mm (square measure) mesh. In 1981, six 19-mm nets and six 13-mm nets were used. Thereafter, only 13-mm nets were fished.

A grid was drawn on a map of the lake which divided it into 50 x 50 m squares. The squares were numbered and randomly selected for netting, except that equal numbers of nets were set in each quadrant each day. The lake was marked with floats at 100-m intervals to guide placement of the nets. Squares that included shoreline were used as sampling locations if they contained at least one half the area of a full square. The pot of the net was set at the center of the selected square with the lead toward shore. In squares that bordered the shore, the leads started at the waters edge and ran perpendicular to the shoreline. Water depth at the pot was measured to 0.1 m during 1981-85. Nets were emptied and moved each day for 14 days.

Total lengths of fish were measured to nearest cm, given an upper caudal clip, and returned to the lake at the netting site. In 1980, walleyes were also weighed and scale sampled. Larger walleyes were weighed to nearest 10 g on a spring scale with a capacity of 15 kg. A length-weight relationship was calculated for walleyes greater than 40 cm long. Age was determined from the scale samples.

Benthos

Bottom samples were collected in early November 1979 from the area where the reef was to be constructed and again on October 18, 1982 from the reef. These were used to measure the change in benthos due to the change in substrate type from sand and vegetation to rock. A 0.5 x 0.5 m enclosure with screened sides was placed over the substrate area to be sampled. A foam rubber skirt was added to the lower edge of the enclosure when the rock reef was sampled to fill the crevices between rocks and prevent organisms from leaving or entering the enclosure. A 4-cm centrifugal water pump was used to suck water, substrate, and organisms from the enclosure. The pump discharged into a box made of metal screening with 1.1 x 1.8 mm apertures. In 1979, a layer of substrate about 6 cm thick was sucked up by the pump, thus most of the organisms in the area sampled were collected. In 1982, the end of the suction hose was wielded to probe the interstices between the rocks and to vacuum organisms off the rocks. Material retained by the screening box was preserved in 5% formalin. Organisms were later picked from the debris without magnification, classified to family or higher taxonomic group and counted.

Effective Reef Life

The rock reef was constructed over a firm sand substrate, but there was a possibility that it might settle into the sand. It was also possible that sand, silt, and organic debris carried over the reef by currents during storms could settle into the interstices. Devices were installed in the reef in August 1980 to measure the amount of settling and siltation that would occur. The measuring device was a 2.5-cm wire mesh square prism, with a 5 x 5 cm base which was set into a concrete disk that was 15 cm in diameter and rounded on the bottom to resemble the rock in the reef. After the measuring device was set into the reef the top was cut off so it was 10 cm below the top of the reef.

A measuring device was set near the center of each of 20 equal-sized areas of the reef. At each location, rock was removed to the sand base, the concrete disk was set on the sand, and the rock was replaced around and over the screen. A painted rock was placed directly over the screen to mark its location. I assumed that if settling occurred, the concrete disks would settle at the same rate as the surrounding rocks. The vertical difference between each concrete disk and an onshore bench mark was measured to nearest cm with a transit. I also assumed that silt would accumulate in the prisms and in the interstices at similar rates. The devices were examined in August 1981 and 1982, October 1984, and July 1987. A metal detector was needed to locate the devices in 1987.

Results

Spawning Observations

Walleyes spawned in Six Mile Lake during late April to early May in 1981-86. Both mature and immature walleye were seen in the shoal areas and a few age-2 walleyes could have been mistakenly included in the older group. In 1981, the entire shoreline was checked each night that observations were made. Nearly all of the age-3 and older walleyes seen were either on the man-made reef or on a 200-m long sand-detritus area that began 100 m to the right of the reef. In later years, the entire shoreline was only checked occasionally to assure that walleyes were only spawning on the reef or the sand-detritus area. Walleyes seen on the reef and on the sand-detritus area were frequently in pairs or small groups, but those seen at other areas of the lake were never in pairs or groups. Dates that observations were made and the number of age-3 and older walleyes seen are shown in Table 1. The maximum number of walleyes seen on the reef each year during one observation ranged from 20 (1983 and 1986) to 38 (1984). The maximum number seen on the sand-detritus area ranged from 11 (1982) to 39 (1984). A few age-1 and age-2 walleyes were seen around the entire shoreline but were most abundant along the east shore.

Egg Deposition and Fry Production

Dates when sampling pails were lifted from the man-made reef and the number of eggs and fry found in the pails are shown in Table 2. The estimated number of eggs deposited on the reef are shown in Table 3. The mean estimated egg deposition was 501,000 per year; it ranged from 22,000 to 1,082,000. In 1980, the majority of the eggs had already hatched when the pails were lifted so some fry may have swum out of the pails. If that happened egg deposition and fry production would have been underestimated. In 1981, hatching had begun when the pails were lifted, so again, egg deposition and fry production may have been underestimated. The pails that were fitted with fry traps could not be used, because many had been broken by wave action or exposed by falling water levels. The pails that were fitted with solid covers during 1980-82 also could not be used to estimate fry production, because nearly all eggs were dead when the pails were lifted. No further attempts were made to estimate fry production.

The number of walleye eggs collected with a dip net from the sand-detritus area are shown in Table 4. Abundance ranged from 1.4 to 103.7 eggs per net pass. Collections were made on three dates in 1981 and on four dates in 1986. There was a general decrease in the number of eggs collected per pass as the dates progressed. This showed that the number of eggs collected is greatly influenced by the length of time from deposition to collection. The 1981 collections probably were made too long after deposition, because no live eggs were collected. In the first collection made in 1986, 57% of the eggs were alive, but within 11 days all eggs collected were dead. The number of dead eggs collected during the 11 days decreased from 44 to 4 per pass which suggests that the dead eggs rapidly decomposed. The greater number of eggs per pass collected during the later years could have been influenced by better collecting techniques due to experience.

Each year during 1983-86 walleye production on the sand-detritus area was to be evaluated by preventing walleye production from the man-made reef. Attempts at this were unsuccessful in 1983 and 1984. In 1983, walleye got past the small-mesh blocking seine within 2 days after it was installed. In 1984, the reef became ice-free on April 22. On April 23 three pails were lifted while the blocking seine was being set and walleye eggs were found (Table 2). Walleye had already spawned on the reef.

Walleye production was successfully prevented in 1985 and 1986 by treating the reef with Antimycin to kill the eggs. In 1985, just prior to treating the reef, 10 pails were lifted and the contents were preserved. Later examination of the preserved contents showed that all eggs were dead when the pails were lifted. If the condition of the eggs in the pails indicated the condition of the eggs on the reef, then all eggs were already dead, and the treatment of the reef was unnecessary. In 1986, many live fry were found in some pails that were lifted just prior to reef treatment (Table 2). Unlike previous years, these samples were not preserved but were examined for eggs immediately. When the eggs were being picked from the rocks many shells were broken and swimming fry were released. Two days after the reef was treated, live eggs and fry were found in pails that were left on the reef during the treatment. Consequently, the reef was treated again. No live eggs were found in pails lifted after the second treatment.

Sporadic temperature readings of the maximum-minimum thermometer indicated that the average water temperature during early May was about 10°C. Calculations from the thermograph readings showed that in 1986 there were 145 degree-days from the time the first spawners were seen on the reef until the reef was treated the first time.

Walleye Population Estimates

The estimated number of the age-1, age-2, and age-3 and older walleyes in Six Mile Lake during 1980-87 are shown in Table 5. No fry were planted after 1977 so the age-1 and age-2 walleyes collected in 1980 indicate that reproduction occurred prior to the installation of the reef.

Mean number and 95% confidence interval of age-1 walleyes in 1980 (prior to reef installation) and in 1986 and 1987 (when eggs on the man-made reef were killed the previous year) was 204±214. During 1981-85, when walleyes were produced on the reef, the mean number was 464±109. The confidence limits overlap indicating the means are not significantly different at the 95% confidence level.

Walleye Growth

In June, age-1 walleyes averaged 15.1 (1985) to 19.3 (1982) cm long (Table 5). However, size estimates were affected by net size selectivity. A comparison of the number of walleyes in each size group caught in the 19-mm mesh nets and in the 13-mm mesh nets in 1981 indicated that many walleyes less than 18 cm long were able to pass through the 19-mm mesh and escape (Table 6). Since the mesh size influences the size and number of age-1 walleyes caught, the catch in 13- and 19-mm mesh nets cannot be compared. The mortality rate in 1981 was 37% in the 19-mm mesh nets and 2% in the 13-mm mesh nets. Most of the mortality in the larger mesh nets was due to gilling in the mesh. Only 13-mm mesh nets were used in later years, and this greatly reduce the mortality and the escapement of small walleyes.

Length at age for age-2 through age-7 walleyes collected in June 1980 is compared to the state averages in Table 7. The growth index, as defined by Laarman et al. (1981), was +1.5 cm, indicating that walleyes grow at an above average rate in Six Mile Lake.

The length-weight relationship for all walleyes greater than 40 cm long collected in June 1980 from Six Mile Lake was

$$log_{10} W = -5.774 + 3.256\ log_{10} L.$$

Where L was length in mm and W was weight in grams.

Walleye Survival

Estimates were made of the number of eggs deposited on the man-made reef and the subsequent number of age-1 and age-2 walleyes in Six Mile Lake for year classes 1980-84 (Table 8). The egg estimates exclude eggs deposited off the reef. Consequently, the estimate of survival to age-1 is a maximum estimate. The mean survival was 0.08% from deposited egg to age-1 and 23% from age-1 to age-2.

There was a non-significant negative correlation ($r = -0.59$) between the number of eggs deposited on the reef and the number of age-1 walleye. The correlation between age-1 and age-2 walleyes was positive but not significant ($r = 0.06$). The imprecision of the estimates probably obscured any relationships between the groups.

Depth at Capture

Few age-1 walleye (0.13 per net) were caught in the nets along the shore or in those set offshore in water 1 m deep. Most (1.67 per net) were caught in nets set in water 3 and 4 m deep (Table 9). On the other hand, the catch of age-3 and older walleyes was highest in the two shallow water areas (0.72) and lowest in the two deep water areas (0.13). The number of age-1 walleye caught in 2 m deep water was intermediate between the shallow and deep areas, but the number of older walleyes caught in the 2 m deep water was similar to the catch in shallow areas. Year-to-year variation in catch per net was fairly small for age-1 and age-3 and older walleye. No relationship between depth and abundance was evident for age-2 walleyes.

Population Estimates of Other Species

The number of bluegills declined rapidly during the first 4 years and the mean length of those caught in the nets increased from 17.8 to 21.2 cm (Table 5). In 1984, large numbers of age-1 bluegills were caught and the estimated total number was the highest of any year during this study. Due to the large number of age-1 bluegills the mean length dropped to 11.2 cm, by far the smallest during the study. During the last 3 years, the estimated numbers and sizes followed a pattern similar to the first 4 years. Estimated numbers and sizes of pumpkinseeds followed a pattern similar to that of bluegills, but mean lengths were more variable. Both size and numbers of bullheads declined slightly during this study, but only the decline in numbers was statistically significant.

Benthos

The sand substrate from which the 1979 benthos samples were collected fell into three general classifications: (1) fine woody debris, (2) coarse woody debris, and (3) vegetation. The 1982 samples were all taken from the rock reef.

There was much variation in the number of organisms per sample in 1979 (Table 10). The number of organisms per sample collected in 1982 was much less than in 1979. Part of the decline in number of organisms and taxonomic groups collected could have been due to reduced sampling efficiency on rock substrate. In 1979, most organisms were probably in the top 6 cm of sandy substrate and that much substrate was pumped up and passed through the screen. Thus, most of the organisms in the sandy substrate were collected. But in 1982, although the rocks were turned over, they were not removed from the enclosures, so only about the top 10 cm of substrate was sampled. Interstices extended down about 30 cm to the sand base. Consequently, some organisms probably were missed. The inefficiency of the pump for collecting organisms from rock substrate was demonstrated when I collected walleye eggs in spring 1980. The pump collected 12 eggs per m^2 compared to 256 eggs per m^2 collected concurrently with egg trapping pails.

Expected Reef Life

In 1981 and 1982, all 20 settling and siltation devices were found and examined. No settling had occurred, and siltation was too small to be measured (0-1 mm). Only seven devices were found in 1984; they were examined for siltation but not for settling. None of them contained more than a trace of silt. In 1987, seven devices were found in a completely usable condition. One of them contained a measurable amount (16 cm) of silt. Three devices no longer were covered with a rock; one had 4 cm of silt and the other two had a trace of silt. The two devices that contained measurable accumulated silt were both in the row closest to shore. No settling by these ten devices was detected. Six devices had disintegrated into a mass of rusty wire, one location was under a 5 x 6 m floating bog mat that had become grounded on the reef, and the remaining three devices could not be found.

Discussion

There was a 2.3-fold increase in the mean estimated number of age-1 walleyes during years in which there was production on the man-made spawning reef compared to years without that production. But, the difference between the two groups was not statistically significant (at the 95% level). Thus, the large year-to-year variation in year class strength and the brevity of this study prohibit the conclusion that the man-made reef increased production of walleyes, but the data at least suggest that walleye production was greater when the man-made reef was used.

Estimated egg deposition was far less than the potential. The maximum number of walleyes seen on the reef at one time each year during the 6 years observations were made ranged from 20 to 38 fish. The sex ratio of these fish was not determined. Other studies have found the percentage of females in spawning runs ranged from 1 to 56%, but usually 17 to 25% (Johnson 1971; Eschmeyer 1950). Generally, the percentage of females was highest at the peak of the run. Many authors suggest males spend many days on the spawning areas and females spend a much shorter time. If the sex ratio at Six Mile Lake was similar, I expect that no more than four or five of the fish seen at one time were females. Based on the number of walleyes observed on the reef and what others have reported, I judge the number of females that spawned there was no more than 12 to 15 each year. Fecundity of walleyes from other northern lakes, reported as number of eggs per kg of body weight, ranged from about 62,000 in Lake Gogebic, Michigan (Eschmeyer 1950) to 65,000 in Little Cut Foot Sioux Lake, Minnesota (Johnson 1971). If the fecundity of walleyes in Six Mile Lake was similar, all of the estimated egg deposition on the reef in 1980 and 1984 could have been produced by the two largest fish in the population. Either most females did not spawn on the reef, or egg deposition was greatly underestimated.

The covered pails used in 1980-82 were unsuitable for estimating fry production. It appears that some unknown factor(s) in the pails killed nearly all the eggs before they hatched and most of the few fry that were produced. Additional evidence that walleye eggs and fry do not survive in confinement was found at Au Train Lake in the early 1980s. Wire-mesh cages were seeded with a known number of fertilized walleye eggs, and when these cages were examined later, only a few dead eggs were found (R. Reichardt, MDNR, personal communication).

It was unlikely that hatching took place before the reef was treated in 1985 and 1986, because insufficient temperature-degree days occurred prior to Antimycin treatment. Allbaugh and Manz (1964) reported that 215 degree-days were needed for walleye eggs to hatch. From data given by Koenst and Smith (1976), I calculated that 144-205 degree-days were required. In 1985, it was 14 days from the time walleyes were first seen on the reef until I lifted the egg pails used to determine stage of maturity. Thus, the eggs were subjected to only about 140 degree-days. Apparently, conditions on the reef killed all the eggs in the pails and probably also killed the eggs on the reef prior to treatment. In 1986, it also was unlikely that any eggs hatched before the reef was treated, because the eggs were exposed to a maximum of 145 degree-days before the reef was treated the first time. If any eggs hatched between the first treatment and the time that all eggs were found dead in the pails, the fry would have been retained by the plastic sheet deployed around the reef and would have been killed by the Antimycin.

Fry production from the sand-detritus area should have produced all the estimated number of age-1 walleyes the year after the Antimycin treatments. If natural mortality killed the eggs on the reef in 1985, mortality on the sand-detritus area should also have been high. The estimated number of age-1 walleyes in 1986 was the lowest found during the 8 years of this study. On the other hand, in 1986 egg survival was high, both on the reef prior to treatment and in the dip-net samples from the sand-detritus area. In 1987, the estimate of age-1 walleyes was the third highest found during this study. This suggests that reproductive success was excellent on the sand-detritus area in 1986.

Walleye depth distribution in June appears to be influenced by age. Fisheries managers in Michigan's Upper Peninsula nearly always set fyke nets with leads starting from shore. Based on my results, this may tend to under sample age-1 walleye. For Six Mile Lake, I calculated that to be 95% sure of catching at least one age-1 walleye, 59 nets would have to be set adjacent to shore. The small chance of catching age-1 walleyes in fyke nets set adjacent to shore is probably the reason that none were caught during the manual removal in June 1979. Age-3 and older walleyes had a 95% chance of being detected with only six nets set along shore.

At Six Mile Lake, catches in along-shore nets were also poor indicators of adult walleye density. There was a nonsignificant negative correlation between the number of age-3 and older walleyes caught per along-shore net and the population estimates for 1981-85 (r = -0.32). Thus, the catch in a few net sets, as is frequently done, probably would not give a true indication of adult walleye abundance.

Eschmeyer (1942) described Six Mile Lake as "not potentially capable of becoming a highly productive lake which will stand up under more than light fishing pressure". He based this on 1937 surveys of chemical and biological conditions. My findings also suggest that Six Mile Lake was infertile. Benthic organisms were scarce in Six Mile Lake. Eschmeyer (1942) reported that the 1937 survey party noted a general scarcity of invertebrates and a single sample taken near the middle of the lake yielded only one midge larvae. I found fairly large numbers of organisms in 1979 in the area where the reef was to be installed. That area was sand with varying amounts of woody debris and vegetation but made up only a very small portion of the bottom type in the lake. Well over 90% of the bottom was mucky (Eschmeyer 1942). Seldom did I see benthic organisms clinging to the nets when the nets were lifted after 24 hours in the lake.

Minnows were rare in Six Mile Lake during this study and historically. They were only seen during 1 year of this study. In 1984, 500 adult golden shiners *Notemigonus crysoleucas* were stocked in Six Mile Lake. Fourteen were caught in nets during the 1984 population estimates but none were seen in subsequent years. In 1937, the survey party seined an area of 1,115 m^2 and caught only one finescale dace *Phoxinus neogaeus*. Their seining technique apparently was effective because they caught 38 YOY yellow perch *Perca flavescens* and 20 YOY largemouth bass *Micropterus salmoides*.

The infertility of Six Mile Lake does not agree with the above average growth of walleyes found at the onset of this study. Much of that growth was attained during the years prior to the manual removal of large numbers of small bluegills, pumpkinseeds, and bullheads in 1979. If the number of walleyes present during this study kept those species from increasing to their former abundance, then it seems that food must be a limiting factor, and it is unlikely that the full potential of the reef will ever be realized in terms of an increased standing crop of walleyes.

After 7 years, there was no evidence that any settling of the rock reef had occurred. Silt was found in two siltation measuring devices but the amount probably would have little effect on the sheltering capability of the interstices on walleye eggs. The greatest degradation of the reef was due to the floating bog mat which covered nearly 10% of the reef.

Recommendations

1. Because of the wide fluctuations of year-class strength of walleyes, a long-term study is needed to evaluate the benefits of a man-made spawning reef. A minimum of 4 years of pre-data is needed to determine the level of reproduction prior to reef installation. Five years of study should follow reef installation.

2. The lake should have the following characteristics:

   a. a fair to good population of adult walleyes that is maintained by stocking fry or fingerlings;

   b. a fair to good walleye fishery;

   c. little or no natural reproduction;

   d. a windswept shoreline area with a firm bottom that will support a man-made reef;

   e. a shoreline where observations of adults can be made during the spawning season and where a boom shocker can be used to collect YOY in the fall;

f. bottom types and depths that can be fished with fyke nets or trap nets;

g. an access where large work boats can be launched.

3. During the pre-data portion of the study the walleye population should be maintained with biennial walleye plants. Walleyes in year classes when plants were not made will be from natural reproduction.

4. Nets should be set in all areas of a lake when sampling for age-1 walleyes.

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Table 1.—Number of adult walleyes observed on the man-made reef and the sand-detritus area, Six Mile Lake, 1981-86.

Date	Location: Man-made reef	Location: Sand-detritus area
1981		
Apr 16	12	8
Apr 16	6	—
Apr 18	20	3
Apr 18	10	7
Apr 19	11	9
Apr 19	17	20
Apr 22	10	10
Apr 25	20	25
Apr 25	25	25
Apr 28	23	20
Apr 28	27	14
1982		
May 04	5	10
May 04	28	—
May 07	16	11
May 07	6	—
May 09	2	0
1983		
May 03	0[1]	18
May 03	—	18
May 05	20[2]	20
May 05	20	—
May 09	10[3]	21
May 12	0	0
1984		
Apr 23	0[1]	—
Apr 25	18[3]	36
Apr 25	22	39
May 02	38	20
1985		
Apr 29	22	27
Apr 29	26	—
May 03	18	9
May 09	0	0

Table 1.—Continued:

Date	Location: Man-made reef	Location: Sand-detritus area
1986		
Apr 17	1	1
Apr 20	20	9
Apr 23	19	21
Apr 28	21	11
May 01	3	7
May 03	0	2

[1] Blocking net set prior to observation.

[2] Walleye got past net.

[3] Net removed prior to observation.

Table 2.—Dates sampling pails lifted and number of eggs and fry found in Six Mile Lake, 1980-86.

Date lifted	Number of pails	Live eggs	Dead eggs	Live fry	Dead fry
1980					
May 09	20	200	115	450	0
May 19	20[1]		11		
1981					
May 05	20	1,652	1,610	9	16
May 08	10[2]	87	696	4	16
May 16	10[2]		1,217	3	14
1982					
May 12	20	2,673	879		
May 27	9[3]		255		
Jun 01	8[3]		121		
1983					
May 13	20	938	403		
1984					
Apr 23	3	78	25		
May 04	15	326	61		
1985					
May 13	10		37		
May 18	10		—[4]		
1986					
May 05	8	482	142	167	0
May 07	4	8	41	18	2
May 12	5		—[4]		

[1]Pails covered on May 9, 1980.

[2]Pails covered on May 5, 1981.

[3]Pails covered on May 12, 1982.

[4]Eggs and/or fry were too decomposed to count.

Table 3.—Estimated egg deposition and fry production, with 95% confidence intervals on the man-made reef in Six Mile Lake, 1980-86.

Date pails lifted	Estimated egg deposition	Estimated fry production
May 09, 1980	233,000 ± 139,000	198,000 ± 120,000
May 05, 1981	1,001,000 ± 649,000	511,000 ± 282,000
May 12, 1982	1,082,000 ± 652,000	814,000 ± 538,000
May 13, 1983	408,000 ± 280,000	—
May 08, 1984	158,000 ± 79,000	—
May 13, 1985	22,000 ± 24,000	—
May 05, 1986	602,000 ± 558,000	—

Table 4.— Walleye eggs collected with a scap net from the sand-detritus area in Six Mile Lake, 1981-86.

Date	Total number passes	Number eggs		Eggs per pass
		Live	Dead	
1981				
May 05	75	0	310	4.1
May 08	175	0	237	1.4
May 16	75	0	149	2.0
1982				
May 12	160	592	786	8.6
1983				
May 13	120	420	662	9.0
1984				
May 08	120	1,064	1,997	25.5
1985				
May 14	125	1	1,166	9.3
1986				
May 01	50	2,958	2,227	103.7
May 05	75	181	1,215	18.6
May 08	50	59	762	16.4
May 12	75	0	306	4.1

Table 5.—Population estimates and mean lengths with 95% confidence intervals of walleyes, bluegills, pumpkinseeds, and black bullheads in Six Mile Lake, June 1980-87.

Species and age	Year	Population estimate	Mean length (cm)	Length range (cm)
Walleye				
Age 1	1980	114 ± 39	18.6 ± 0.3	16-20
	1981[1]	433 ± 230	16.9 ± 0.1	14-19
	1982	361 ± 87	19.3 ± 0.1	16-21
	1983	152 ± 45	16.8 ± 0.2	15-19
	1984	187 ± 84	17.4 ± 0.2	15-19
	1985	1,188 ± 330	15.1 ± 0.1	13-18
	1986	85 ± 52	16.2 ± 0.2	14-17
	1987	413 ± 316	16.1 ± 0.2	13-18
Age 2	1980	15 ± 9	30.8 ± 0.9	30-33
	1981	34 ± 16	28.9 ± 0.6	26-31
	1982[1]	136 ± 48	28.5 ± 0.2	26-30
	1983	260 ± 201	26.9 ± 1.1	25-30
	1984	11 ± 8	27.8 ± 1.4	26-30
	1985	42 ± 22	28.4 ± 0.8	25-30
	1986	79 ± 36	24.8 ± 0.4	23-26
	1987	46 ± 27	29.0 ± 1.7	24-33
Age >2	1980	144 ± 30	44.8 ± 1.0	35-60
	1981	113 ± 30	44.2 ± 0.9	35-52
	1982	80 ± 43	45.4 ± 1.7	37-55
	1983[1]	214 ± 92	41.2 ± 1.7	32-57
	1984	104 ± 45	41.6 ± 0.9	33-59
	1985	83 ± 19	43.2 ± 1.6	33-56
	1986	52 ± 27	44.7 ± 1.6	38-56
	1987	69 ± 18	44.2 ± 1.3	35-58
Bluegill[2]				
	1980	13,314 ± 1,480	17.8 ± 0.1	11-24
	1981	8,413 ± 2,101	19.2 ± 0.1	6-22
	1982	3,162 ± 2,781	19.8 ± 0.4	5-23
	1983	946 ± 1,077	21.2 ± 0.6	8-24
	1984	18,224 ± 17,229	11.2 ± 0.5	5-27
	1985	4,752 ± 2,109	18.1 ± 0.7	5-28
	1986	1,188 ± 688	19.6 ± 0.8	9-27
	1987	1,399 ± 547	21.0 ± 0.8	5-28

Table 5.—Continued:

Species and age	Year	Population estimate	Mean length (cm)	Length range (cm)
Pumpkinseed[2]				
	1980	2,269 ± 1,027	16.0 ± 0.1	10-19
	1981	1,551 ± 406	17.2 ± 0.2	9-20
	1982	878 ± 4,346	16.0 ± 0.8	5-21
	1983	423 ± 401	17.6 ± 1.2	8-22
	1984	6,327 ± 3,617	9.6 ± 0.5	5-24
	1985	1,038 ± 667	13.3 ± 0.9	6-25
	1986	525 ± 540	16.9 ± 1.3	8-25
	1987	780 ± 234	13.6 ± 1.1	5-27
Black bullhead[2]				
	1980	577 ± 81	27.2 ± 0.2	13-32
	1981	446 ± 151	29.0 ± 0.6	11-33
	1982	332 ± 122	27.4 ± 1.4	7-36
	1983	464 ± 80	28.0 ± 0.8	9-39
	1984	334 ± 398	22.0 ± 1.5	5-35
	1985	125 ± 55	25.9 ± 1.8	12-37
	1986	335 ± 499	22.4 ± 1.9	8-37
	1987	186 ± 44	25.1 ± 1.3	7-37

[1]First year that walleye could have been produced from the reef.

[2]Estimates of bluegill, pumpkinseed, and black bullhead were for fish longer than 9 cm in 1980 and fish longer than 4 cm in 1981-87.

Table 6.—Length-frequency of age-1 walleyes caught in 13- and 19-mm mesh fyke nets (number dead in parentheses) in Six Mile Lake, June 1981. The number of sets for 13- and 19-mm nets were 84 and 82, respectively.

Length group	Mesh size 13 mm	19 mm
14	1	—
15	3	—
16	21 (1)	3 (1)
17	50 (1)	12 (6)
18	21 —	14 (3)
19	— —	1 (1)
Total	96 (2)	30 (11)

Table 7.—Length (cm) at age for walleye collected at Six Mile Lake in June 1980 compared to State averages.

	Age 2	3	4	5	6	7
Number	8	4	35	23	12	9
Length range	30-33	35-38	37-45	41-51	45-53	47-60
Mean length	31	36	42	46	49	52
State average length	26	35	40	45	49	52

Table 8.—Estimated number of eggs deposited on Six Mile reef and subsequent survival (%) to age 1 and to age 2 for the 1980-84 year class.

Year class	Eggs	Survival[1]	Age 1	Survival	Age 2
1980	233,000	0.18	433	31	136
1981	1,000,000	0.04	361	72	260
1982	1,082,000	0.01	152	7	11
1983	370,000	0.05	187	22	42
1984	158,000	0.75	1,188	7	79
Mean	569,000	0.08	464	23	106

[1]Assumes all age-1 fish were from reef eggs.

Table 9.—Catch per net of age 1, age 2, and age 3 and older walleyes in fyke nets set adjacent to shore and offshore at 1-m depth intervals in Six Mile Lake, June 1981-85.

Location and depth	Age 1	Age 2	Age ≥3	Number of nets
Along shore	0.14	0.21	0.76	179
1 m	0.08	0.12	0.46	24
2 m	0.58	0.22	0.53	281
3 m	1.50	0.19	0.15	243
4 m	2.05	0.15	0.08	109
Total	0.93	0.20	0.40	836

Table 10.—Mean number and 95% confidence intervals of organisms found in 0.25 m^2 samples of substrate in Six Mile Lake. Sand samples were taken in 1979. Rock samples were taken in 1982.

	Year and substrate				
Taxonomic group	Fine woody debris	Course woody debris	Vegetation	Mean	Rock
Oligochaeta	624 ± 4	5 ± 14	18 ± 22	11 ± 8	0
Amphipoda	13 ± 14	18 ± 22	89 ± 40	32 ± 18	2 ± 1
Ephemeroptera	259 ± 252	97 ± 138	591 ± 279	359 ± 164	82 ± 16
Odonata					
Anisoptera	43 ± 47	5 ± 11	62 ± 28	43 ± 21	12 ± 4
Zygoptera	15 ± 15	5 ± 20	38 ± 36	22 ± 14	6 ± 2
Trichoptera					
Psychomyiidae	2 ± 2	<1 ± 1	2 ± 1	2 ± 1	22 ± 4
Leptoceridae	41 ± 40	2 ± 10	44 ± 48	34 ± 22	0
Diptera					
Tendipedidae	902 ± 796	151 ± 452	1,023 ± 647	800 ± 376	14 ± 4
Ceratopogonidae	7 ± 8	<1 ± 1	8 ± 9	6 ± 4	<1 ± <1
Gastropoda	6 ± 7	3 ± 8	12 ± 13	7 ± 5	1 ± 1
Pelecypoda	34 ± 32	1 ± 3	61 ± 53	38 ± 23	<1 ± <1
Number of samples	3	3	6		20

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