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# Evaluation of the Effects of the Herbicide Sonar on Sport Fish Populations in Michigan Lakes

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*Abstract.*–The effects of applications of Sonar A.S.® on populations of bluegill *Lepomis macrochirus* and other species of fish were monitored at nine Michigan lakes for up to six years. Monitored population attributes included trap net catch per effort of larger size fish, average length, size composition, growth, and year class strength. Two additional lakes were surveyed less intensively, and four unaltered lakes served as reference sites. Most Sonar treatments eliminated nearly all Eurasian milfoil and other macrophytes for approximately a year, but often the loss of fish cover was partially ameliorated by increases in *Chara* or *Vallisneria*. Modest responses occurred in most fish populations, many of which were statistically meaningful. From a fisheries perspective, all lake responses except one were improvements because all treatment lakes except one had a history of small-size, slow-growing, over-abundant bluegills. Bluegill size and growth characteristics significantly ($P<0.25$) improved for 29 comparisons, remained the same for 3 comparisons, and declined for 3 comparisons. The composite bluegill size score improved from poor to average at five lakes but remained poor at three severely stunted lakes. Bluegills as large as 7 inches total length increased in abundance, but bluegills as large as 8 inches remained sparse. Improvements in size of pumpkinseed *Lepomis gibbosus* and black crappie *Pomoxis nigromaculatus* were also noted for most lakes. Year class strength in the treatment year(s) may have been slightly reduced for a few lakes. Results demonstrated the resiliency of sport fish population dynamics over a broad range of habitat perturbations. Fish populations with normal or good growth and lower density and recruitment may not respond favorably to macrophyte alteration.

Beginning in 1987, a new herbicide named Sonar A.S.® (hereafter referred to as Sonar) was permitted for control of nuisance growths of aquatic macrophytes in Michigan lakes (Kenaga 1992). Nuisance plants of primary concern were two species that are not native to the state, Eurasian water milfoil *Myriophyllum spictatum* and curlyleaf pondweed *Potomogeton crispus*. Both form dense beds which may canopy on the surface of the lake, hindering boating and other recreational uses and crowding out desirable native plants. In shallow, clear-water lakes, these exotics may choke large areas 3 to 15 feet deep.

Early treatments with Sonar devastated all types of rooted aquatic plants – not only submerged macrophytes, but also floating and emergent macrophytes – for two or more years (Kenaga 1992). These treatments, at concentrations over 20 ppb, were at much lower levels than the label-recommended rate of 150 ppb. Biologists, naturalists, and even many boaters were alarmed by Sonar's powerful effect on plants and its potentially harmful effect on fish and wildlife of all types.

Although Sonar is not known to be directly toxic to fish at ordinary dosages (Hamelink et al. 1986) excessive reduction of aquatic plants could have a strong indirect effect on fish populations (Engel 1995). Macrophytes support many types of aquatic invertebrates that are eaten by fish. Thus, fish growth could be reduced. Macrophytes also shelter small fish from predators. Thus, fish survival could be reduced. On the other hand, lakes with excessive densities of macrophytes often have poor quality fish populations (Schneider 1981 and 1989; Theiling 1990). Bluegill *Lepomis macrochirus* populations are often stunted in lakes with extensive amounts of macrophytes. This is a condition in which fish grow so slowly that few of them live long enough to reach 7 inches in length. Consequently, angling is poor. Some reduction in plant density might improve predator-prey balance, population characteristics, and fishing (Engel 1995).

In 1993, intensive research studies were proposed to (a) measure effects of Sonar treatments on macrophyte communities, bluegill populations, fishing, and waterfowl usage; (b) determine optimal levels of treatment to attain healthy ecosystems; and (c) develop guidelines for balancing the need for nuisance plant control against ecosystem considerations. These proposals were not funded. Consequently, to obtain at least some information on Sonar effects, the scope of the investigation was greatly reduced and divided into two parts that could be handled by existing operations and personnel.

The Land and Water Management Division (LWMD) varied application rates, through their permitting process, to determine appropriate dosages for selective plant control. A committee (Quality Action Team) comprised of representatives from LWMD, Fisheries Division, Wildlife Division, licensed chemical applicators, academicians, and conservation groups served as a forum from 1994 until LWMD was split off from the Department of Natural Resources (DNR) into the Michigan Department of Environmental Quality (MDEQ). Extensive observations were made on plant responses (Kenaga 1992 and 1995; MDEQ 1997).

The Fisheries Division, under my scheduling and the field sampling of fisheries managers and technicians, monitored apparent effects of vegetation modification with Sonar on the abundance, growth, size structure, and recruitment of bluegill and other sport fish populations. The fish evaluation is the subject of this report.

Issues not addressed in the combined evaluation included Sonar effects on water quality parameters, phytoplankton, zooplankton, benthic invertebrates, amphibians, reptiles, and waterfowl.

## Methods

The fish evaluation was conducted primarily at nine lakes treated with Sonar once or twice between 1991 and 1996 (Table 1). These nine lakes were selected because their fish populations had been surveyed by the Fisheries Division before Sonar treatment, between 1983 and the treatment date. These lakes were re-sampled 1-6 years after Sonar treatment. The number of before and after samples varied from one to three per lake. Similar methods were used for before and after sampling to facilitate comparisons. Limited additional information was obtained from two other lakes, Rush and Shannon (Table 1).

Four similar lakes were selected as reference lakes (Table 1). These same waters were used as reference lakes for another bluegill study (Schneider and Lockwood 1997). Reference lakes were not treated with Sonar and any management of fish and vegetation had been relatively constant through time. Sampling, primarily targeted at bluegill, was conducted annually from 1988 through 1996 or 1998. Plant populations in the reference lakes were not specifically monitored, but no changes were noted during the fish surveys.

The 15 study lakes were similar in size and type (Table 1). All were hard-water lakes, ranging from 103 to 585 acres, with extensive shallow areas (mean depths mostly less than 10 feet) perceived by MDEQ to have nuisance amounts of Eurasian milfoil, curlyleaf pondweed, or other macrohytes. Only two lakes (Turk and Joslin – both reference) did not have a history of attempts to modify submerged plants by mechanical harvesting or chemicals such as 2,4-D. Therefore, the critical question for the fish study was whether Sonar treatment had a much more severe effect on the ecosystem than prior plant management; i.e., was there a significant change in plant density and amount of food and cover afforded to fish? It was anticipated that lakes with the most extensive and prolonged changes in amount or type of cover would be most likely to show changes in fish population characteristics.

Study lakes had typical warmwater fish communities. Bluegill were abundant in all lakes except Shannon, and were slow-growing and small-sized in all lakes except Shannon and Lansing. Pumpkinseed *Lepomis gibbosus* and black crappie *Pomoxis nigromaculatus* were common, and yellow perch *Perca flavescens* were sparse except in Lake Shannon. Largemouth bass *Micropterus salmoides* was the primary piscivore in all lakes. Most lakes contained low numbers of northern pike *Esox lucius*.

Changes in fish habitat due to Sonar treatment were inferred from MDEQ (1997) observations on shifts in plant species and relative densities. Plant attributes considered to be important for evaluating fish habitat included architectural types (low, intermediate, or high growing), stem density, area of lake covered, and duration of effect. Often, decreases in high-growing, mat-forming architectural types (such as milfoil or curlyleaf pondweed) were countered (with a time lag) by increases in low- and mid-growing architectural types, such as *Chara* and *Vallisneria*, which are less sensitive to Sonar and flourish when competing plants are reduced. To provide a common basis for interpreting fish habitat changes, I ranked the apparent effects of Sonar treatments on macrophyte cover as severe (nearly all macrophytes eliminated for one or more years), moderate (some reduction in abundance), or slight (little or no reduction). I also noted if abundance of *Chara* appeared to change.

Bluegill populations were targeted for fish sampling. This species predominates in most warmwater lakes, is important to sport fisheries, and is readily sampled (Schneider 1981, 1990). Sampling methods for bluegill also provided adequate data on pumpkinseed and black crappie population characteristics. Samples of yellow perch, largemouth bass and northern pike were less adequate but provided some information about growth and recruitment.

Trap nets were the primary fish sampling gear. These were 3 feet high, 5 feet wide, and 8 feet long with 1.5-inch stretched mesh in the single pots. Associated leads and wings had 2.5-inch stretched mesh. These nets sample bluegills (and similar-shaped centrachids) greater than 7 inches total length very well, but catch a few bluegill as small as 4 inches. Smaller sizes were sampled with 220-v boom shocker. Fyke nets were used in two lakes and gillnets in two others.

All fish collected were tabulated by species and measured for total length in inches. Scale samples were taken from as many as 30 fish per inch group for age and growth analysis. In the laboratory, scales were impressed on clear plastic and projected, then annuli were counted.

Population indices determined for each sample date were relative abundance of larger fish, size structure, growth, and recruitment. Abundance of larger fish was indexed by average catch per lift (CPE) in trap or fyke nets for bluegill ≥7.0 inches, pumpkinseed ≥7.0 inches, and black crappie ≥8.0 inches. This index also reflects changes in size structure from year to year.

Population size structure was primarily indexed by average length of bluegill, pumpkinseed, and black crappie caught in trap nets. Bluegill size structure was also evaluated using size score (Schneider 1990), which averages the ranks of four metrics: average length and percent of catch ≥6, ≥7 and ≥8 inches. Size scores can range from 1 to 7. Size scores of 3-4 are typical for Michigan bluegill populations, 1 is severely stunted, and 7 indicate exceptionally high proportions of bluegills over 8 inches in length.

Growth rate for all species was expressed as the Michigan growth index (Schneider et al. 1981). For this index, observed length at each age is compared to the appropriate seasonal State of Michigan average. Deviations (inches) are then averaged across all age groups to obtain a single growth index for each species in each lake. A growth index close to 0 indicates the observed growth rate is close to the state average; growth indices less than -1 inch indicate exceptionally poor growth (Schneider et al. 1981).

Recruitment effects were evaluated by relative year class strength in the year of treatment. The premise was that Sonar treatment might inhibit spawning success or reduce survival of young either directly or indirectly by increasing predation on them. In addition, recruitment in 1992 was evaluated for all lakes because that was a cool summer (apparently due to the eruption of Mount Pinatubo in the Philippines) and weak year classes of bluegill occurred in other Michigan lakes (Schneider and Lockwood 1997). The cool summer could confound analysis of Sonar treatments made during 1992. Evaluation of year class strength was based on age-frequencies of scale samples. The expected progression was more age-3 fish would be sampled than age-4, than age-5, etc. Interpretation was tempered with size/age selectivity of the sample gear used and if the pattern of weakness was consistent in subsequent samples. Sometimes apparent year class weakness, determined by several sequential years when younger age classes were not more abundant than older ones based on electrofishing fish ages 1-4, would not be considered weak when estimated by trap net samples of age 5 and older fish. Recruitment was classified as either acceptable (within expected variation), low (decidedly lower than normal), or insufficient data. No year classes appeared to be exceptionally strong. In southern Michigan lakes like those studied, totally missing year classes rarely occur and recruitment of centrachids and yellow perch is expected to be quite uniform. Northern pike recruitment is more likely to be irregular.

To better identify broad patterns, interpretations of year class strength in the years of Sonar treatments were pooled for bluegill, pumpkinseed, and black crappie. Similarly, interpretations were pooled for yellow perch, largemouth bass, and northern pike. The data were also grouped according to three possible effects: Sonar-only (year class strength in treatment year, 1992 excepted), cool summer only (1992 year class and no treatment), and cool summer+Sonar (1992 year class and treatment combined).

For analysis, population characteristics were compared in before and after periods. For the reference lakes, 1988-1992 samples were designated the before period and 1993-1997 samples were taken as representative of the after period. For each lake, percentage change in indices of CPE, size, and growth was computed and evaluated with the Kruskal-Wallis test (SPSS version 9.0). Probabilities $<0.25$ were accepted as indicating meaningful trends. A higher probability, $P<0.1$, was also calculated and is shown in the appendices. Overall trends in each index were summarized as number of lakes with apparent increase (+), no change (0), decrease (-) or insufficient data.

My choice of $P<0.25$ is a less rigorous than the conventional research standard of $P<0.05$. A lower P increases the chance of finding a treatment effect when none actually exists but is not biased towards either positive or negative results. The $P<0.25$ provided a uniform standard for ranking the magnitude of trends that maybe helpful to managers who must make timely decisions and to researchers contemplating additional research.

## Results

*Vegetation Changes*

Sonar treatments at the fish study lakes had less drastic effects on plants than some earlier treatments at higher dosages (Kenaga 1992, 1995; MDEQ 1997). Out of 13 applications during 1991-96, I ranked 8 as severe, 4 as moderate, and 1 as light (Table 1). In lakes ranked as severely affected, nearly all macrophytes were eliminated for a year. However, the density of *Chara* or other plants increased in most lakes, so the lakes were not barren for long and potential effects of macrophyte removal on fish were tempered.

*Effects on Fish Size and Growth*

Index data were first summarized by lake (Appendices 1-15). Below is a synopsis by species.

*Bluegill*.–Population size characteristics improved slightly at all nine treatment lakes sampled for those characteristics (Table 2 and Appendices 1-15). Catch rate of bluegill ≥7 inches, average length, and size score increased significantly for 23 before-after comparisons, were unchanged for 1, decreased for 1, and for 8 comparisons there were insufficient data to make a judgement of trend. The single decrease was for Crooked Lake, where the effect of Sonar treatment on plants was rated as light. Improvements were mostly restricted to the 7.0- to 7.9-inch size group; bluegills as large as 8.0 inches continued to be absent or rare in lakes with slow growth. Changes in bluegill growth index roughly paralleled changes in size indices. Growth index increased at six treatment lakes, was unchanged at two lakes, decreased at two lakes, and for one lake there was insufficient data (Table 2). The reference lakes did not show the increasing trend evident for treatment lakes (Table 2).

*Pumpkinseed*.–Population size characteristics improved slightly at all nine treatment lakes sampled for those characteristics (Table 2 and Appendices 1-15). Catch rate of pumpkinseed ≥7 inches and average length improved for 13 before-after comparisons, were unchanged for 3, and declined for 1 comparison. Changes in pumpkinseed growth index also were favorable. Growth index increased at six lakes, was unchanged at two lakes, and decreased at none. At three out of four reference lakes there was some improvement in average length, but not the improvement in CPE ≥7" that occurred in most Sonar lakes (Table 2).

*Black crappie*.–Population size characteristics generally improved in treatment lakes (Table 2 and Appendices 1-15). Catch rate of crappie ≥8 inches and average length index increased for 11 before-after comparisons, did not change for 5, and decreased for 1 comparison. Likewise, growth tended to improve. Size of black crappie in reference lakes also tended to improve, but not as consistently (Table 2).

*Yellow perch*.–The lakes contained relative few large perch. Consequently, samples were inadequate to evaluate changes in size structure or growth.

*Largemouth bass*.–Sample sizes were too small to evaluate size trends but growth indices could be calculated for seven lakes (Table 2). No clear trend was evident. Growth apparently increased at one lake, was unchanged at four lakes, and decreased at one lake.

*Northern pike*.–Sample sizes were small. Growth index appeared to remain the same or to decline at the two lakes with limited data (Table 2).

### *Effects on Fish Recruitment*

First, number of sampled fish in various year classes was summarized by species and lake (Appendices 16-21). Then, interpretations of year class strength were pooled and summarized (Table 3).

Recruitment appears to have been slightly reduced by Sonar treatment, but affected more by the cool summer of 1992. For cool summer-only year classes, 35% of the strength rankings for bluegill, pumpkinseed, and black crappie combined were low (Table 3). For Sonar-only year classes, 22% were low; and for cool summer+Sonar year classes 55% were low. This pattern is less apparent in the combined data for yellow perch, largemouth bass, and northern pike: only 5% of the year classes during Sonar-only years were low (Table 3). While some year classes appeared to be weak, none were totally missing if an adequate sample size was taken. For the reference lakes, recruitment showed no trend, but all four lakes had weak bluegill year classes in 1992 (Schneider and Lockwood 1997).

## Discussion

Results suggest Sonar treatments had no direct effect on fish. If any direct mortality of juvenile or adults occurred, it was not great enough to be detected at the population level by my techniques. This deduction is supported by laboratory and field studies that indicate Sonar is not toxic to fish at concentrations used for plant management (Hamelink et al. 1986). Similarly, zooplankton and benthos do not appear to be sensitive to concentrations of Sonar used in treatments (Hamelink et al. 1986; Navqvi and Hawkins 1989).

Sonar treatment had modest indirect effects on fish. Most likely mechanisms were modified food chains and predator-prey relationships due to plant reduction. Observed effects on fish population characteristics were relatively slight, considering how much habitat was altered. For the fish study, low dosage rates of 5-22 ppb were used. Fish study lakes already had a history of light to medium control of nuisance plants, so additive effects of Sonar on overall fish cover were probably minor. Plants died gradually and were partially replaced with macrophytes or *Chara* in a year or less. Devegetation was not abrupt, total, or prolonged. Greater effects on fish may have resulted if very high dosages of Sonar had been applied.

From the perspective of sportfishery management, the observed trends in fish population characteristics were beneficial rather than harmful because most study lakes initially contained stunted or poor populations of bluegill and other panfish. Density and average size of larger bluegill, pumpkinseed, and black crappie generally improved following vegetation changes. In most cases this could be attributed to improved growth rates. Recruitment may have declined slightly. Improvements in bluegill populations at five lakes were sufficient to raise size scores above the stunted or poor range (size score <3). However, bluegills as large as 8 inches remained uncommon. Size scores at three severely stunted lakes (Woodland, Pontiac, and Tipsico) improved slightly but remained below satisfactory.

The improvements in fish populations due to Sonar treatments are not likely to persist indefinitely if fish populations or habitat conditions are allowed to revert. Lakes with large amounts of vegetative cover can produce good bluegill populations if piscivore populations are maximal and fishing harvest is low (Schneider 1993). Higher size limits on largemouth bass and northern pike, initiated statewide in 1993, may help. Stocking of walleye is also a promising technique for improving stunted bluegill populations (Schneider and Lockwood 1997).

Manipulation of excessive macrophytes may sometimes benefit fish populations but it does not seem to be cost-effective if justified solely as a fishery management tool. Using harvesting machines to cut channels in dense macrophytes sometimes benefits fish growth (Trebitz et. al. 1997; Olson et al. 1998) and allows largemouth bass to hunt bluegill more effectively (Savino and Stein 1989; Smith 1993, 1995). Sonar and other herbicides are sometimes used to enhance fish or fishing opportunities (Andrews 1989). On the other hand, Radomski et al. (1995) and Cross et al. (1992) were unable to detect significant improvements in stunted bluegill and other fish in two Minnesota lakes following either herbicide application or harvesting. Both of these were short-term (two-year) studies. Many Michigan lakes have a long history of poor fish populations despite moderately intensive attempts at vegetation control with conventional methods (Schneider 1989).

One of the study lakes, Lake Lansing, is an interesting example of linkage between habitat and fish population characteristics. For decades, Lake Lansing contained dense macrophytes and stunted bluegill (size score approximately 2.5; growth index -0.6 to -1.1 inch). Partial dredging in the late 1970s-early 1980s removed some soft sediments and plants, and the bluegill population was better from 1985 to 1991 (size score 3.8 to 5.0; growth index -0.3 to +0.9 inch). But by 1995, vegetation had increased and bluegills were reverting (size score 2.5; growth index -0.3 inch). Three years after the 1995 Sonar treatment, bluegill were again improved (size score 6.0 and growth index +0.1 inch).

Excessive vegetation control could have negative effects on fish populations and fisheries. Sparse, fast-growing populations are probably the most vulnerable. These already have modest rates of recruitment, so added predation caused by reduction in cover may reduce survival of small fish enough that the biological potential of the habitat is not realized. Shannon Lake may be an example where extensive and prolonged vegetation control has depressed bluegill abundance (Schneider 1998). Species of fish that are closely associated with vegetation, such as grass pickerel *Esox americanus vermiculatus* and spawning northern pike, are also likely to be sensitive to excessive plant management by either chemicals or shoreline alteration such as filling or bulk-heading. Generally, fish species diversity is high in areas where macrophytes are abundant, diverse, and patchy (Weaver et al. 1997).

Another negative consequence of excessive macrophyte control is the risk for over harvest of fish. Anglers often comment that fish become easier to catch after macrophytes are reduced. Excessive harvest of largemouth bass, northern pike, and large panfish could cause fish community imbalance and poorer angling in the long run (Schneider 1981, 1993; Schneider and Lockwood 1997).

From a fisheries perspective, optimal composition of fish communities and fish harvest occurs at intermediate plant density. While total fish and invertebrate production tend to increase as macrophyte density increases (Schneider 1978; Crowder and Cooper 1982; Wiley et al. 1984), that benefit can be completely negated by reduced growth (Crowder and Cooper 1982) and increased stunting of panfish at high plant densities (Schneider 1981, 1989; Theiling 1990). Trebitz et al. (1997) calculated that the best bluegill growth occurred when about 30% of the milfoil was removed by cutting narrow strips. Since macrophytes covered about 50% of their study lake's surface, the optimum macrophyte coverage was about 35% of the total lake area. Trebitz et al. (1997) also calculated that an intermediate level of cutting enhanced largemouth bass growth and abundance. In support, Theiling (1990) found poorest bluegill growth was usually associated with macrophyte coverage of more than 33% of the total area for Michigan lakes. For largemouth bass, Durocher et al. (1984) observed standing crop of bass and numbers of bass >10 inches were positively related to macrophyte coverage up to 20% of total reservoir area, the highest plant coverage studied. Wiley et al. (1984) estimated optimal bass production in ponds occurred at 36% macrophyte coverage. Engel (1987) noted largemouth bass growth was poor in a lake where macrophytes covered approximately 50% of the area.

The Fisheries Division position statement on aquatic vegetation management in inland waters includes these important elements (Anonymous 1993):

- No (or minimal) manipulation should be permitted in waters where good fish communities exist in conjunction with native aquatic vegetation;
- In eutrophic lakes, it is preferred to have native aquatic macrophytes in 20-40% of the littoral zone;
- A minimum of 5-8 species of macrophytes is preferred, with representatives from each of the architectural groups.

These recommendations are still are appropriate. However, the preceding review of literature suggests that 25-36% coverage on a total area basis would be optimal for both bluegill and largemouth bass. This means, for optimal fisheries values, that macrophyte removal should not be permitted below the level of 25% of total lake area. No macrophytes should be removed from lakes naturally containing less than 25% coverage. Likewise, macrophytes should not be altered in lakes already containing a good fish community.

Beyond the fisheries issues, manipulation of aquatic plants should be minimized to maintain natural ecosystems to the fullest extent possible. Diverse and even overly abundant macrophytes are part of the natural system of shallow, nutrient-rich lakes. These plants support diverse populations of invertebrates, amphibians, turtles, and waterfowl in addition to fish. All are part of the resource heritage of Michigan.

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Table 1.–Physical characteristics of study lakes, Sonar treatment data, and relative effects of treatments on submerged macrophyte abundance.

| | | | Mean | Sonar treatment | | Treatment effect[2] | |
|---|---|---|---|---|---|---|---|
| Lake | County | Area (acres) | depth (ft) | Year | Dose (ppb)[1] | Submergents | *Chara* |
| | | | | **Treatment Lakes** | | | |
| Crooked | Clare | 260 | 15.1 | 1995 | 5 | Light | Dense |
| Lansing | Ingham | 452 | 7.5 | 1995 | 6 | Severe | Dense |
| Lobdell | Genessee | 545 | 7.6 | 1991 & 92 | 11-14 | Severe | Dense |
| Pliness | Mason | 103 | … | 1993 | 5 | Severe | Dense |
| Pontiac | Oakland | 585 | 5.1 | 1992 | 18 | Severe | Dense |
| | | | | 1996 | 4 | Moderate | Dense |
| Rush | Livingston | 139 | 5.2 | 1992 | 15 | Severe | Dense |
| Shannon | Livingston | 262 | 9.7 | 1993 | 3-8 | Moderate[3] | None |
| Tipsico | Oakland | 261 | 9.7 | 1993 | 10 | Severe | Same |
| White[4] | Oakland | 540 | 12.3 | 1992 | 14 | Severe | Dense |
| | | | | 1995 | 5 | Moderate | Same |
| Wolverine | Oakland | 241 | 8.1 | 1993 | 12 | Severe | Dense |
| Woodland | Livingston | 290 | 7.6 | 1993 | 10-20 | Severe[3] | Same |
| | | | | **Reference Lakes** | | | |
| Big Seven | Oakland | 170 | 10.9 | none | … | … | … |
| Joslin | Washtenaw | 187 | 3.6 | none | … | … | … |
| Saddle | Van Buren | 292 | 8.9 | none | … | … | … |
| Turk | Montcalm | 151 | 9.9 | none | … | … | … |

[1] Computed Sonar concentration based on total volume of lake; no *in situ* measurements were made.

[2] Effect on submerged macrophytes ranked as severe (nearly all eliminated for 1 or more years), moderate (some reduction in abundance), or slight (little or no reduction in abundance). Change in *Chara* abundance noted as: became dense, remained same (initially sparse or common), or none present either before or after treatment. Interpretation of effects is based on data and comments by Kenaga (1997).

[3] Light dosages in east arms of Lake Shannon and Woodland Lake were flushed out and had little effect; heavier dosages in other arms had severe effect on macrophytes for over 2 years in Lake Shannon and for 1-2 years in Woodland Lake.

[4] Spot treatment also attempted at White Lake in 1989.

Table 2.–Synopsis of apparent responses of fish population indices to Sonar treatments at 11 lakes. Also shown are changes in four reference lakes for 1988-92 compared to 1993-98. + = significant increase; 0 = no change; - = significant decrease; ? = insufficient data

| | | Number of Sonar lakes | | | | | Number of reference lakes | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | Index | + | 0 | - | ? | Total | + | 0 | - | ? | Total |
| Bluegill | | | | | | | | | | | |
| | CPE>7" | 7 | 1 | 1 | 2 | 11 | 2 | 1 | 1 | 0 | 4 |
| | Size score | 8 | 0 | 0 | 3 | 11 | 1 | 2 | 1 | 0 | 4 |
| | Avg. length | 8 | 0 | 0 | 3 | 11 | 2 | 1 | 1 | 0 | 4 |
| | Growth index | 6 | 2 | 2 | 1 | 11 | 1 | 1 | 2 | 0 | 4 |
| | Recruitment | 0 | 7 | 4 | 0 | 11 | 0 | 4 | 0 | 0 | 4 |
| Pumpkinseed | | | | | | | | | | | |
| | CPE>7" | 7 | 2 | 0 | 2 | 11 | 0 | 2 | 2 | 0 | 4 |
| | Avg. length | 6 | 1 | 1 | 3 | 11 | 3 | 1 | 0 | 0 | 4 |
| | Growth index | 6 | 2 | 0 | 3 | 11 | … | … | … | 4 | 4 |
| | Recruitment | 0 | 8 | 2 | 1 | 11 | … | … | … | 4 | 4 |
| Black crappie | | | | | | | | | | | |
| | CPE>8" | 6 | 3 | 0 | 2 | 11 | 2 | 2 | 0 | 0 | 4 |
| | Avg. length | 5 | 2 | 1 | 3 | 11 | 2 | 2 | 0 | 0 | 4 |
| | Growth index | 4 | 5 | 1 | 1 | 11 | … | … | … | 4 | 4 |
| | Recruitment | 0 | 9 | 2 | 0 | 11 | … | … | … | 4 | 4 |
| Yellow perch | | | | | | | | | | | |
| | Growth index | 0 | 2 | 0 | 9 | 11 | … | … | … | 4 | 4 |
| | Recruitment | 0 | 7 | 2 | 2 | 11 | … | … | … | 4 | 4 |
| Largemouth bass | | | | | | | | | | | |
| | Growth index | 1 | 4 | 1 | 5 | 11 | … | … | … | 4 | 4 |
| | Recruitment | 0 | 7 | 0 | 4 | 11 | … | … | … | 4 | 4 |
| Northern pike | | | | | | | | | | | |
| | Growth index | 0 | 1 | 1 | 9 | 11 | … | … | … | 4 | 4 |
| | Recruitment | 0 | 6 | 0 | 5 | 11 | … | … | … | 4 | 4 |

Table 3.–Year class rank (low or acceptable) in relation to the cool summer of 1992, the Sonar treatment effect, and a combination of the two effects.

| Combined species | Sample size and rank[1] | Cool summer -only | Sonar -only | Cool summer +Sonar |
|---|---|---|---|---|
| Bluegill, Pumpkinseed, Black crappie | N | 17 | 27 | 11 |
| | acceptable | 65% | 78% | 45% |
| | low | 35% | 22% | 55% |
| | Total | 100% | 100% | 100% |
| Yellow perch, Largemouth bass, Northern pike | N | 10 | 22 | 10 |
| | acceptable | 80% | 95% | 90% |
| | low | 20% | 5% | 10% |
| | Total | 100% | 100% | 100% |

[1] N is number of year x species x lake combinations for which year class (recruitment) strength was ranked. Ranks were ok or low (no year classes were ranked as high, and insufficient data were excluded from N).

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James E. Breck, Editorial Board Reviewer
Barbara A. Diana, Word Processor

Appendix 1.–Indices of population density (CPE), size structure (size score and average length), growth (growth index) and recruitment (acceptable (ok) or low) for fish species collected from Big Seven Lake. Density and size structure indices are based on trap net catches. This was a reference lake in which no Sonar treatment occurred.

| | | May | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | Index | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1998 | Change |
| Bluegill | | | | | | | | | | | | |
| | CPE>7" | 0.1 | 0.3 | 1.0 | 0.3 | 0.6 | 0.5 | 0.1 | 0.3 | 0.0 | 0.1 | -57%* |
| | Size score | 1.5 | 2.0 | 2.5 | 2.0 | 1.8 | 1.8 | 1.8 | 1.3 | 1.3 | 1.5 | -22%** |
| | Avg. length | 5.4 | 5.6 | 5.7 | 5.5 | 5.4 | 5.2 | 5.0 | 4.9 | 4.8 | 5.0 | -10%** |
| | Growth index | -1.1 | -1.1 | -1.3 | -1.2 | -0.7 | -0.9 | -1.6 | -1.7 | -1.7 | -1.2 | -31%* |
| | Recruitment | ok | ok | ok | ok | low | ok | ok | ok | ok | … | no |
| Pumpkinseed | | | | | | | | | | | | |
| | CPE>7" | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 0.3 | +33% |
| | Avg. length | 4.3 | 5.1 | 4.8 | 5.5 | 4.8 | 4.6 | 4.7 | 4.8 | 4.6 | 5.3 | -2% |
| Black crappie | | | | | | | | | | | | |
| | CPE>8" | 0.0 | 0.2 | 0.0 | 0.8 | 1.4 | 1.0 | 0.5 | 3.8 | 0.8 | 0.5 | +172%* |
| | Avg. length | 6.8 | 6.9 | 6.5 | 7.5 | 8.2 | 8.4 | 8.1 | 8.0 | 6.8 | 6.8 | +6% |

*Significant change between before and after averages at P<0.25.
**Significant change between before and after averages at P<0.1.

Appendix 2.–Indices of population density, size structure (CPE), growth (growth index) and recruitment (acceptable (ok) or low) for fish species collected from Crooked Lake. Density and size structure indices are based on catches in all types of nets. Shading indicates when Sonar treatment occurred.

| | | Pre-years | | | | Post-years | |
|---|---|---|---|---|---|---|---|
| Species | Index | May 1991 | 1992 | May 1995 | 1995 | May 1998 | Change |
| Bluegill | | | | | | | |
| | CPE>7" | 0.8 | | 0.3 | | 0.2 | -66%* |
| | Growth index | -0.7 | | -0.4 | | -0.7 | -27% |
| | Recruitment | | ok | | ok | | no |
| Pumpkinseed | | | | | | | |
| | CPE>7" | 0.3 | | 0.4 | | 0.7 | +100%* |
| | Growth index | -0.8 | | -1.0 | | -0.1 | +89%* |
| | Recruitment | | ok | | ok | | no |
| Black crappie | | | | | | | |
| | CPE>8" | 3.5 | | 4.4 | | 4.7 | +19%* |
| | Growth index | -1.7 | | -2.1 | | -0.9 | +53% |
| | Recruitment | | ok | | ok | | no |
| Largemouth bass | | | | | | | |
| | Growth index | 0.7 | | -1.4 | | -0.9 | -160% |
| | Recruitment | | | | ? | | ? |
| Northern pike | | | | | | | |
| | Growth index | -1.3 | | -3.4 | | -2.5 | -6% |
| | Recruitment | | ok | | ok | | no |

Appendix 3.–Indices of population density (CPE), size structure (size score and average length), growth (growth index) and recruitment (acceptable (ok) or low) for fish species collected from Joslin Lake. Density and size structure indices are based on trap net catches. This was a reference lake in which no Sonar treatment occurred.

| Species | Index | 1988 | 1989 | 1990 | 1991 | May 1992 | 1993 | 1994 | 1996 | 1997 | Change |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bluegill | | | | | | | | | | | |
| | CPE>7" | 20.5 | 6.5 | 15.0 | 56.5 | 11.8 | 5.6 | 20.0 | 13.5 | 31.8 | -25% |
| | Size score | 5.0 | 4.3 | 5.0 | 5.7 | 4.7 | 3.5 | 4.3 | 4.2 | 6.0 | -10% |
| | Avg. length | 6.8 | 6.6 | 6.8 | 7.0 | 6.6 | 6.4 | 6.6 | 6.6 | 7.0 | -2% |
| | Growth index | -0.8 | -1.0 | -1.0 | -0.9 | -0.9 | -1.2 | -1.3 | -1.1 | -1.0 | -25%** |
| | Recruitment | ok | ok | ok | ok | weak | ok | ok | ? | … | no |
| Pumpkinseed | | | | | | | | | | | |
| | CPE>7" | 6.0 | 4.3 | 4.8 | 32.3 | 7.8 | 4.8 | 3.3 | 20.8 | 1.1 | -48%* |
| | Avg. length | 6.5 | 6.5 | 6.8 | 6.7 | 6.5 | 6.6 | 6.7 | 6.9 | 7.2 | +4%* |
| | Growth index | 0.1 | … | … | … | … | -0.3 | … | 0.1 | 0.3 | +200% |
| | Recruitment | … | ok | ok | ok | weak | ok | ? | ? | … | no? |
| Black crappie | | | | | | | | | | | |
| | CPE>8" | 0.8 | 3.5 | 1.0 | 0.3 | 4.4 | 0.0 | 0.0 | 2.5 | 2.2 | -68% |
| | Avg. length | … | 9.0 | 9.2 | 6.8 | 9.4 | … | … | 9.9 | 10.4 | +15%** |

Appendix 4.–Indices of population density (CPE), size structure (size score and average length), growth (growth index) and recruitment (acceptable (ok) or low) for fish species collected from Lake Lansing. Density and size structure indices are based on trap net catches. Shading indicates when Sonar treatment occurred.

| | | Pre-years | | | | | Post-years | |
|---|---|---|---|---|---|---|---|---|
| | | June | May | | May | | May | |
| Species | Index | 1987 | 1991 | 1992 | 1995 | 1995 | 1998 | Change |
| Bluegill | | | | | | | | |
| | CPE>7" | 10.0 | 21.0 | | 4.0 | | 27.0 | +130%* |
| | Size score | 4.3 | 4.3 | | 2.5 | | 6.0 | +64%* |
| | Avg. length | 6.7 | 6.1 | | 5.1 | | 7.0 | +18%* |
| | Growth index | 0.7 | 0.9 | | -0.3 | | 0.1 | -77% |
| | Recruitment | | | ok | | ok | | no |
| Pumpkinseed | | | | | | | | |
| | CPE>7" | 0.2 | 0.8 | | 0.8 | | 3.6 | +500%* |
| | Avg. length | 5.8 | 5.5 | | 5.8 | | 6.8 | +19%* |
| | Growth index | 0.5 | … | | -0.4 | | 0.6 | +1100%* |
| | Recruitment | | | ok | | ok | | no |
| Black crappie | | | | | | | | |
| | CPE>8" | 0.2 | 27.7 | | 9.9 | | 1.4 | -89% |
| | Avg. length | 7.3 | 7.7 | | 8.8 | | 9.8 | +24%* |
| | Growth index | -1.4 | 0.4 | | -0.9 | | 0.7 | +200%* |
| | Recruitment | | | … | | ok? | | no? |

Appendix 5.–Indices of population density (CPE), size structure (size score and average length), growth (growth index) and recruitment (acceptable (ok) or low) for fish species collected from Lobdell Lake. Density and size structure indices are based on trap net catches. Shading indicates when Sonar treatment occurred.

| | | Pre-years | | | | Post-years | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | May | Sep | | | May | | | |
| Species | Index | 1984 | 1987 | 1991 | 1992 | 1994 | 1995 | 1997 | Change |
| Bluegill | | | | | | | | | |
| | CPE>7" | 8.0 | 3.8 | | | 31.0 | 6.5 | 11.3 | +176%* |
| | Size score | 3.3 | 2.8 | | | 4.8 | 4.0 | 4.3 | +44%** |
| | Avg. length | 5.7 | 5.3 | | | 6.7 | 6.0 | 6.2 | +15%** |
| | Growth index | -1.3 | -0.7 | | | -0.3 | -0.8 | -0.6 | +43%* |
| | Recruitment | | | ok | low? | | | | no |
| Pumpkinseed | | | | | | | | | |
| | CPE>7" | 5.7 | 0.0 | | | 0.0 | 2.5 | 1.2 | -57% |
| | Avg. length | 6.0 | 5.4 | | | 5.9 | 6.3 | 6.2 | +8%* |
| | Growth index | … | -0.6 | | | -0.5 | … | -0.7 | 0% |
| | Recruitment | | | ok | ok | | | | no |
| Black crappie | | | | | | | | | |
| | CPE>8" | 87.3 | 1.7 | | | 17.2 | 14.8 | 3.5 | -73% |
| | Avg. length | 9.0 | 7.3 | | | 8.5 | 8.2 | 7.5 | -1% |
| | Growth index | -0.5 | 0.2 | | | 0.7 | … | -0.2 | +270% |
| | Recruitment | | | ok | ok | | | | no |
| Yellow perch | | | | | | | | | |
| | Recruitment | | | ok | ok | | | | no |
| Largemouth bass | | | | | | | | | |
| | Growth index | -2.2 | -0.6 | | | -1.3 | … | -2.2 | -25% |
| | Recruitment | | | ok | ok | | | | no |
| Northern pike | | | | | | | | | |
| | Recruitment | | | ? | ok | | | | ? |

Appendix 6.–Indices of population density (CPE), size structure (size score and average length), growth (growth index) and recruitment (acceptable (ok) or low) for fish species collected from Pliness Lake. Density and size structure indices are based on combined trap and fyke net catches. Shading indicates when Sonar treatment occurred.

| | | Pre-years | | | Post-years | | |
|---|---|---|---|---|---|---|---|
| | | May | | | June | Aug | |
| Species | Index | 1989 | 1992 | 1993 | 1995 | 1997 | Change |
| Bluegill | | | | | | | |
| | CPE>7" | 0.2 | | | 4.5 | 7.0 | +28%* |
| | Size score | 2.5 | | | 3.3 | 5.0 | +65%* |
| | Avg. length | 6.0 | | | 6.2 | 6.6 | +7%* |
| | Growth index | -1.5 | | | -1.2 | -1.1 | +23%* |
| | Recruitment | | low? | ok | | | no |
| Pumpkinseed | | | | | | | |
| | CPE>7" | 0.2 | | | 1.3 | 0.7 | +500%* |
| | Avg. length | 5.9 | | | 6.5 | 5.7 | +3% |
| | Growth index | -0.3 | | | 0.4 | 0.3 | +200%* |
| | Recruitment | | low | low | | | down |
| Black crappie | | | | | | | |
| | CPE>8" | 0.4 | | | 5.3 | 4.8 | +1000%* |
| | Avg. length | 7.4 | | | 8.2 | 8.7 | +14%* |
| | Growth index | -2.8 | | | -2.8 | -1.1 | +30% |
| | Recruitment | | ok | ok | | | no |
| Yellow perch | | | | | | | |
| | Recruitment | | ok | ok | | | no |

Appendix 7.–Indices of population density (CPE), size structure (size score and average length), growth (growth index) and recruitment (acceptable (ok) or low) for fish species collected from Pontiac Lake. Density and size structure indices are based on trap net catches. Shading indicates when Sonar treatments occurred.

| | | Pre-year | | Post-years | | | | |
|---|---|---|---|---|---|---|---|---|
| | | June | | Oct | | | May | |
| Species | Index | 1992 | 1992 | 1993 | 1994 | 1996 | 1997 | Change[1] |
| Bluegill | | | | | | | | |
| | CPE>7" | 0.2 | | 0.0 | 0.3 | | 0.9 | +500%* |
| | Size score | 1.5 | | 1.2 | 2.2 | | 2.8 | +82%* |
| | Avg. length | 5.2 | | 4.9 | 5.8 | | 5.9 | +14%* |
| | Growth index | -1.3 | | -1.5 | -1.2 | | -1.0 | +21%* |
| | Recruitment | | low | | | ok | | no |
| Pumpkinseed | | | | | | | | |
| | CPE>7" | 0.0 | | 0.0 | 0.0 | | 0.0 | 0% |
| | Avg. length | 6.1 | | 5.4 | 5.5 | | 5.8 | -9%* |
| | Growth index | -0.8 | | -0.6 | … | | -0.3 | +44%* |
| | Recruitment | | low? | | | ok? | | no? |
| Black crappie | | | | | | | | |
| | CPE>8" | 0.3 | | 1.1 | 0.5 | | 9.5 | +1200%* |
| | Avg. length | 7.0 | | 7.3 | 6.5 | | 7.3 | 0% |
| | Growth index | -1.7 | | -1.6 | -1.3 | | -1.0 | +15%* |
| | Recruitment | | low? | | | ? | | no? |
| Yellow perch | | | | | | | | |
| | Growth index | -1.0 | | … | … | | -1.2 | -20% |
| | Recruitment | | ok | | | ok | | no |
| Largemouth bass | | | | | | | | |
| | Growth index | -1.2 | | -1.0 | -1.6 | | -0.9 | +3% |
| | Recruitment | | ok | | | ok | | no |

[1] For bluegill, before period designated as 1992-93 and after period 1994-97 due to delayed response.

Appendix 8.–Indices of recruitment (acceptable (ok) or low) for fish species collected from Rush Lake. Shading indicates when Sonar treatment occurred.

| Species | Index | 1992 |
|---|---|---|
| Bluegill | Recruitment | low? |
| Pumpkinseed | Recruitment | low |
| Black crappie | Recruitment | ok |
| Yellow perch | Recruitment | low? |
| Largemouth bass | Recruitment | ok |
| Northern pike | Recruitment | ok |

Appendix 9.–Indices of population density (CPE), size structure (size score and average length), growth (growth index) and recruitment (acceptable (ok) or low) for fish species collected from Saddle Lake. Density and size structure indices are based on trap net catches. This was a reference lake in which no Sonar treatment occurred.

| | | May | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | Index | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | Change |
| Bluegill | | | | | | | | | | | |
| | CPE>7" | 0.8 | 2.7 | 0.0 | 0.3 | 0.7 | 1.0 | 1.0 | 2.8 | 2.8 | +10%* |
| | Size score | 1.8 | 2.8 | 3.0 | 2.0 | 3.0 | 3.3 | 2.3 | 2.8 | 2.8 | +10% |
| | Avg. length | 5.4 | 5.7 | 5.7 | 5.6 | 5.8 | 6.2 | 5.7 | 5.9 | 6.1 | +6%** |
| | Growth index | -1.7 | -1.0 | -1.2 | -1.1 | -1.0 | -0.8 | -1.7 | -1.2 | -1.3 | +3% |
| | Recruitment | ok | ok | ok | ok | low | ok | ok | ok | … | no |
| Pumpkinseed | | | | | | | | | | | |
| | CPE>7" | 0.0 | 1.5 | 0.0 | 0 | 0.7 | 0.0 | 0.0 | 0.5 | 1.3 | +1% |
| | Avg. length | 5.2 | 5.5 | 5.4 | 5.1 | 5.8 | 5.8 | 5.4 | 5.8 | 6.2 | +7%* |
| Black crappie | | | | | | | | | | | |
| | CPE>8" | 1.8 | 3.8 | … | 1.7 | 5.0 | 1.2 | 1.0 | 12.8 | 4.3 | +57% |
| | Avg. length | 9.8 | 9.3 | … | 10.0 | 9.8 | 9.4 | 11.0 | 9.8 | 9.2 | +1% |

Appendix 10.–Indices of fish growth (growth index) and recruitment (acceptable (ok) or low) for fish species collected from Lake Shannon. Shading indicates when Sonar treatment occurred.

| | | Pre-years | | | Post-years | | |
|---|---|---|---|---|---|---|---|
| | | May | | | July | Oct | |
| Species | Index | 1990 | 1992 | 1993 | 1994 | 1998 | Change |
| Bluegill | | | | | | | |
| | Growth index | 0.9 | | | 1.1 | 1.7 | +56%* |
| | Recruitment | | ? | low? | | | down? |
| Black crappie | | | | | | | |
| | Growth index | 0.2 | | | 0.4 | -0.4 | -100% |
| | Recruitment | | ? | ok | | | no |
| Yellow perch | | | | | | | |
| | Growth index | 0.2 | | | 0.2 | -0.1 | -75% |
| | Recruitment | | ? | ok | | | no |
| Largemouth bass | | | | | | | |
| | Growth index | 4.0 | | | | -0.2 | -105%* |
| | Recruitment | | ? | ? | | | ? |
| Northern pike | | | | | | | |
| | Recruitment | | ok? | ok | | | no |

Appendix 11.–Indices of population density (CPE), size structure (size score and average length), growth (growth index) and recruitment (acceptable (ok) or low) for fish species collected from Tipsico Lake. Density and size structure indices are based on trap net catches. Shading indicates when Sonar treatment occurred.

| | | Pre-years | | | Post-years | | |
|---|---|---|---|---|---|---|---|
| | | Sep | | | May | | |
| Species | Index | 1988 | 1992 | 1993 | 1995 | 1997 | Change |
| Bluegill | | | | | | | |
| | CPE>7" | 0.3 | | | 4.3 | 1.1 | +800%* |
| | Size score | 1.2 | | | 1.5 | 2.5 | +67%* |
| | Avg. length | 4.7 | | | 4.9 | 5.1 | +8%* |
| | Growth index | -1.2 | | | -1.6 | -1.3 | -21%* |
| | Recruitment | | low? | low? | | | down? |
| Pumpkinseed | | | | | | | |
| | CPE>7" | 0.1 | | | 4.9 | 2.0 | +6000%* |
| | Avg. length | 5.3 | | | 6.6 | 5.9 | +18%* |
| | Growth index | -0.8 | | | -0.1 | -0.4 | +69%* |
| | Recruitment | | low? | ok | | | no |
| Black crappie | | | | | | | |
| | CPE>8" | 0.4 | | | 1.6 | 2.7 | +400%* |
| | Avg. length | 5.9 | | | 7.0 | 8.2 | +28%* |
| | Growth index | -2.1 | | | -1.6 | -0.1 | +60%* |
| | Recruitment | | low? | low | | | down? |
| Yellow perch | | | | | | | |
| | Recruitment | | ok | low? | | | down? |
| Largemouth bass | | | | | | | |
| | Growth index | -3.1 | | | -1.0 | | +68% |
| | Recruitment | | low? | ok | | | no |
| Northern pike | | | | | | | |
| | Recruitment | | ok | ok | | | no |

Appendix 12.–Indices of population density (CPE), size structure (size score and average length), growth (growth index) and recruitment (acceptable (ok) or low) for fish species collected from Turk Lake. Density and size structure indices are based on trap net catches. This was a reference lake in which no Sonar treatment occurred.

| Species | Index | 1988 | 1989 | 1990 | 1991 | May 1992 | 1993 | 1994 | 1995 | 1996 | Change |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bluegill | | | | | | | | | | | |
| | CPE>7” | 5.3 | 2.5 | 1.5 | 2.7 | 4.2 | 5.0 | 12.5 | 11.3 | 10.3 | +67%** |
| | Size score | 3.3 | 2.5 | 2.5 | 2.5 | 3.3 | 3.5 | 3.5 | 4.0 | 4.3 | +26%** |
| | Avg. length | 5.8 | 5.8 | 5.7 | 5.7 | 6.2 | 6.3 | 6.3 | 6.3 | 6.6 | +8%** |
| | Growth index | -1.2 | -1.4 | -1.5 | -1.4 | -1.2 | -1.3 | -1.1 | -1.1 | -0.9 | +11%** |
| | Recruitment | ok | ok | ok | ok | low | ok | ok | ok | ok | no |
| Pumpkinseed | | | | | | | | | | | |
| | CPE>7” | 2.0 | 6.0 | 3.8 | 5.7 | 7.6 | 1.0 | 4.3 | 3.0 | 3.5 | -70%* |
| | Avg. length | 6.4 | 6.5 | 6.7 | 5.6 | 6.8 | 7.0 | 7.3 | 7.2 | 7.1 | +10%** |
| Black crappie | | | | | | | | | | | |
| | CPE>8” | 3.3 | 1.0 | 3.3 | 1.0 | 0.4 | 6.8 | 8.5 | 22.0 | 0.5 | +81%* |
| | Avg. length | 8.7 | 8.1 | 7.7 | 7.1 | 8.6 | 9.0 | 9.1 | 9.5 | … | +13%* |

Appendix 13.–Indices of population density (CPE), size structure (size score and average length), growth (growth index) and recruitment (acceptable (ok) or low) for fish species collected from White Lake. Density and size structure indices are based on trap net catches. Shading indicates when Sonar treatments occurred.

| | | Pre-years | | | Post-years | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Sep | May | | May | | | May | |
| Species | Index | 1983 | 1986 | 1992 | 1993 | 1995 | 1995 | 1997 | Change |
| Bluegill | | | | | | | | | |
| | CPE>7" | 0.2 | 0.2 | | 35.2 | 27.5 | | 8.5 | +11000%** |
| | Size score | 1.3 | 1.8 | | 3.0 | 5.2 | | 5.8 | +210%** |
| | Avg. length | 4.8 | 5.4 | | 6.1 | 7.1 | | 7.2 | +33%* |
| | Growth index | -1.1 | -0.9 | | -0.9 | -0.8 | | -0.8 | +17%* |
| | Recruitment | | | ok? | | | ok | | no |
| Pumpkinseed | | | | | | | | | |
| | CPE>7" | 0.1 | 0.3 | | 0.7 | 5.6 | | 0.7 | +1000%** |
| | Avg. length | 5.2 | 6.0 | | 6.3 | 7.2 | | 7.3 | +24%** |
| | Growth index | -0.7 | -0.3 | | -0.5 | -0.2 | | -1.0 | -13% |
| | Recruitment | | | low | | | ok | | no? |
| Black crappie | | | | | | | | | |
| | CPE>8" | 0.1 | 1.3 | | 4.1 | 22.6 | | 14.3 | +1900%** |
| | Avg. length | 6.4 | 6.6 | | 7.1 | 8.5 | | 9.3 | +28%** |
| | Growth index | -1.2 | -1.9 | | -1.7 | -1.5 | | -0.7 | -16% |
| | Recruitment | | | low | | | ok | | no |
| Yellow perch | | | | | | | | | |
| | Recruitment | | | ok? | | | ok | | no? |
| Largemouth bass | | | | | | | | | |
| | Growth index | -0.5 | -0.7 | | 0.3 | -0.5 | | -0.3 | +72%* |
| | Recruitment | | | ok? | | | ok | | no |
| Northern pike | | | | | | | | | |
| | Growth index | -1.0 | -0.9 | | -1.6 | -2.1 | | | -95%* |
| | Recruitment | | | ok | | | ok? | | no |

Appendix14.–Indices of population density (CPE), size structure (size score and average length), growth (growth index) and recruitment (acceptable (ok) or low) for fish species collected from Wolverine Lake. Density and size structure indices are based on trap net catches. Shading indicates when Sonar treatment occurred.

| | | Pre-years | | | | Post-years | | |
|---|---|---|---|---|---|---|---|---|
| | | May | Oct | | | May | | |
| Species | Index | 1988 | 1992 | 1992 | 1993 | 1995 | 1997 | Change |
| Bluegill | | | | | | | | |
| | CPE>7" | 0.1 | 0.0 | | | 17.8 | 4.3 | +22000%* |
| | Size score | 2.0 | 1.2 | | | 4.5 | 4.5 | +181%** |
| | Avg. length | 5.0 | 4.6 | | | 6.3 | 6.5 | +33%* |
| | Growth index | -1.3 | -1.8 | | | -1.1 | -1.0 | +32%* |
| | Recruitment | | | ok | ok | | | no |
| Pumpkinseed | | | | | | | | |
| | CPE>7" | 0.0 | 0.6 | | | 2.5 | 1.6 | +600%* |
| | Avg. length | 5.4 | 5.3 | | | 6.3 | 6.6 | +21%* |
| | Growth index | … | -1.1 | | | -0.4 | -0.2 | +73%* |
| | Recruitment | | | low | ok | | | no |
| Black crappie | | | | | | | | |
| | CPE>8" | 4.2 | 0.7 | | | 9.9 | 12.1 | +355%* |
| | Avg. length | 7.7 | 6.4 | | | 8.5 | 8.7 | +22%* |
| | Growth index | … | -0.9 | | | -0.2 | -0.4 | +67%* |
| | Recruitment | | | ok | ok | | | no |
| Yellow perch | | | | | | | | |
| | Recruitment | | | low | ok | | | no |
| Largemouth bass | | | | | | | | |
| | Growth index | … | -1.3 | | | -2.3 | -0.7 | -15% |
| | Recruitment | | | ok | ok | | | no |
| Northern pike | | | | | | | | |
| | Recruitment | | | ? | ok | | | no |

Appendix 15.–Indices of population density (CPE), size structure (size score and average length), growth (growth index) and recruitment (acceptable (ok) or low) for fish species collected from Woodland Lake. Density and size structure indices are based on trap net catches. Shading indicates when Sonar treatment occurred

| | | Pre-years | | | | Post-years | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Jun | May | | | Jun | May | | |
| Species | Index | 1985 | 1991 | 1992 | 1993 | 1994 | 1995 | 1998 | Change |
| Bluegill | | | | | | | | | |
| | CPE>7" | 0.7 | 0.0 | | | 0.0 | 1.0 | 0.5 | +48% |
| | Size score | 1.5 | 1.3 | | | 1.5 | 1.8 | 2.3 | +33%* |
| | Avg. length | 5.1 | 4.7 | | | 5.3 | 5.0 | 5.6 | +8%* |
| | Growth index | -0.4 | -0.8 | | | -1.6 | -1.5 | -1.1 | -125%** |
| | Recruitment | | | ok? | low? | | | | down? |
| Pumpkinseed | | | | | | | | | |
| | CPE>7" | 0.0 | 0.0 | | | 0.7 | 0.3 | 0.1 | +7000%** |
| | Avg. length | 5.4 | 5.9 | | | 6.0 | 6.1 | 5.7 | +5%* |
| | Growth index | … | … | | | -0.6 | … | -0.4 | ? |
| | Recruitment | | | ok? | ok | | | | no |
| Black crappie | | | | | | | | | |
| | CPE>8" | 2.5 | 4.0 | | | 1.3 | 8.6 | 3.3 | +36% |
| | Avg. length | 8.1 | 8.8 | | | 7.0 | 8.3 | 7.9 | -8%* |
| | Growth index | … | -0.1 | | | -1.2 | … | -0.5 | -750%* |
| | Recruitment | | | ok | low | | | | down |
| Yellow perch | | | | | | | | | |
| | Growth index | …. | … | | | -1.0 | … | -1.1 | ? |
| | Recruitment | | | ok? | ok | | | | no |
| Largemouth bass | | | | | | | | | |
| | Growth index | … | … | | | -2.3 | -1.6 | … | ? |
| | Recruitment | | | low? | ok? | | | | no? |

Appendix 16.–Year class strength of bluegill as reflected by numbers of fish sampled for age analysis. Year of Sonar treatment indicated by shading.

| Lake and sample date | Year of birth | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 |
| Pliness | | | | | | | | | | | | | |
| Jun-95 | | | 10 | 26 | 47 | 25 | 54 | 1 | 1 | 11 | | | |
| Aug-97 | | | | | 2 | 13 | 40 | 10 | 19 | 11 | 34 | 25 | |
| Crooked | | | | | | | | | | | | | |
| May-98 | | | | | 1 | | 1 | 2 | 9 | 14 | 11 | | |
| Wolverine | | | | | | | | | | | | | |
| May-95 | 3 | 11 | 16 | 25 | 18 | 20 | 40 | 2 | 51 | 1 | | | |
| May-97 | | | | | 2 | 1 | 5 | 34 | 31 | 3 | | | |
| Tipsico | | | | | | | | | | | | | |
| May-95 | | 6 | 6 | 26 | 27 | 9 | 46 | 8 | 28 | 39 | | | |
| May-97 | | | | 2 | 4 | 7 | 48 | 15 | 7 | 46 | 19 | 32 | |
| Lansing | | | | | | | | | | | | | |
| May-98 | | | | | | 1 | 6 | 18 | 34 | 15 | 3 | 2 | 1 |
| Lobdell | | | | | | | | | | | | | |
| May-94 | | 3 | 20 | 20 | 10 | 11 | 8 | 1 | | | | | |
| May-95 | | 2 | 2 | 8 | 27 | 25 | 45 | 0 | 33 | 32 | | | |
| May-97 | | | | 1 | 3 | 15 | 27 | 33 | 57 | 39 | 42 | 9 | |
| Pontiac | | | | | | | | | | | | | |
| Oct-93 | | | 10 | 30 | 21 | 27 | 34 | 1 | 28 | | | | |
| Oct-94 | | | 3 | 9 | 21 | 22 | 21 | 0 | 36 | | | | |
| May-97 | | | 1 | | 3 | 18 | 47 | 15 | 21 | 27 | 47 | 28 | |
| White | | | | | | | | | | | | | |
| May-95 | | | | 5 | 24 | 29 | 22 | 25 | 58 | 2 | | | |
| May-97 | | | | | 6 | 12 | 13 | 9 | 57 | 28 | 35 | 1 | |
| Woodland | | | | | | | | | | | | | |
| Jun-94 | | | 4 | 19 | 6 | 3 | 2 | 3 | | | | | |
| May-95 | | | 10 | 24 | 14 | 19 | 42 | 6 | 3 | 43 | | | |
| May-98 | | | | | | 1 | 11 | 18 | 11 | 47 | 29 | 25 | 33 |
| Rush | | | | | | | | | | | | | |
| May-97 | | 1 | 2 | 5 | 5 | 5 | 5 | 2 | 13 | 3 | 16 | 8 | |
| Shannon | | | | | | | | | | | | | |
| Oct-98 | | | | | | | | | | 1 | 5 | 3 | 12 |

Appendix 17.–Year class strength of pumpkinseed as reflected by numbers of fish sampled for age analysis. Year of Sonar treatment indicated by shading.

| Lake and sample date | Year of birth | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 |
| Pliness | | | | | | | | | | | | | |
| Jun-95 | | | 2 | 1 | 4 | 6 | 22 | 3 | 2 | | | | |
| Aug-97 | | | | | | | 7 | 1 | 2 | 54 | 10 | | |
| Crooked | | | | | | | | | | | | | |
| May-98 | | | | | | | 4 | 5 | 12 | 11 | 11 | | |
| Wolverine | | | | | | | | | | | | | |
| May-95 | | 1 | 15 | 10 | 5 | 17 | 28 | 2 | 21 | | | | |
| May-97 | | | 1 | 2 | 8 | 14 | 12 | 2 | 10 | 1 | | | |
| Tipsico | | | | | | | | | | | | | |
| May-95 | | 1 | 6 | 10 | 26 | 11 | 22 | 0 | 26 | | | | |
| May-97 | | | | 1 | 2 | 5 | 23 | 6 | 14 | 20 | 6 | 3 | |
| Lansing | | | | | | | | | | | | | |
| May-98 | | | | | | | 1 | 4 | 13 | 7 | 6 | 1 | |
| Lobdell | | | | | | | | | | | | | |
| May-94 | | | 12 | 11 | 6 | 7 | 3 | | | | | | |
| May-97 | | | | 2 | 4 | 15 | 7 | 16 | 22 | 27 | 9 | | |
| Pontiac | | | | | | | | | | | | | |
| Oct-93 | | | | 1 | 7 | 6 | 1 | | | | | | |
| Oct-94 | | | | 1 | 2 | 2 | 0 | 3 | 6 | | | | |
| May-97 | | | | | | 1 | 2 | 3 | 13 | 1 | 7 | 1 | |
| White | | | | | | | | | | | | | |
| May-95 | 1 | 5 | 9 | 16 | 13 | 7 | 12 | 1 | 18 | | | | |
| May-97 | | 1 | 1 | 2 | 1 | 2 | 3 | 1 | 9 | 10 | 12 | | |
| Woodland | | | | | | | | | | | | | |
| Jun-94 | | 2 | 5 | 7 | 6 | 9 | 5 | | | | | | |
| May-98 | | | | | | 1 | 4 | 10 | 22 | 14 | 5 | 6 | |
| Rush | | | | | | | | | | | | | |
| May-97 | | | | | | 2 | 2 | | 3 | 2 | 5 | 4 | |
| Shannon | | | | | | | | | | | | | |
| Oct-98 | | | | | | | | | | | | | 7 |

Appendix 18.–Year class strength of black crappie as reflected by numbers of fish sampled for age analysis.  Year of Sonar treatment indicated by shading.

| Lake and sample date | Year of birth | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 |
| Pliness | | | | | | | | | | | | | |
| Jun-95 | 3 | 10 | 8 | 5 | | 1 | 14 | 1 | | | | | |
| Aug-97 | | 1 | 3 | 7 | 5 | 5 | 9 | 5 | 12 | 20 | 5 | | |
| Crooked | | | | | | | | | | | | | |
| May-98 | | | | | 1 | | 6 | 9 | 15 | 3 | 22 | 5 | |
| Wolverine | | | | | | | | | | | | | |
| May-95 | | | 2 | 3 | 2 | 10 | 39 | 1 | 2 | 2 | | | |
| May-97 | | | | | | 6 | 24 | 27 | 35 | 24 | | | |
| Tipsico | | | | | | | | | | | | | |
| May-95 | | | 1 | 2 | 12 | 5 | 36 | 0 | 0 | 1 | | | |
| May-97 | | | | | 4 | 4 | 16 | 8 | 2 | 4 | | | |
| Lansing | | | | | | | | | | | | | |
| May-98 | | | | | | | | | 2 | 5 | 1 | | |
| Lobdell | | | | | | | | | | | | | |
| May-94 | | | | 2 | 17 | 10 | 24 | | | | | | |
| May-95 | | | | | | | | | | | | | |
| May-97 | | | | | | 2 | 1 | 5 | 14 | 43 | 3 | 1 | |
| Pontiac | | | | | | | | | | | | | |
| Oct-93 | | | 5 | 13 | 20 | 34 | 12 | 0 | 3 | | | | |
| Oct-94 | | 1 | 1 | 1 | 4 | 11 | 17 | 0 | 29 | 2 | | | |
| May-97 | | | | | | 2 | 8 | 10 | 29 | 42 | 1 | | |
| White | | | | | | | | | | | | | |
| May-93 | 3 | 16 | 20 | 27 | 7 | 13 | 16 | | | | | | |
| May-95 | | 1 | 9 | 18 | 18 | 15 | 16 | 0 | 3 | | | | |
| May-97 | | | | 2 | 7 | 17 | 12 | 1 | 24 | 32 | 17 | | |
| Woodland | | | | | | | | | | | | | |
| Jun-94 | 1 | 0 | 1 | 0 | 3 | 10 | 15 | | | | | | |
| May-95 | | | | | | | | | | | | | |
| May-98 | | | | | | | | 6 | 1 | 20 | 11 | | |
| Rush | | | | | | | | | | | | | |
| May-97 | | | | | | 1 | 1 | 1 | 8 | 6 | 1 | | |
| Shannon | | | | | | | | | | | | | |
| Oct-98 | | | | | | | | | 2 | 8 | 7 | | 2 |

Appendix 19.–Year class strength of yellow perch as reflected by numbers of fish sampled for age analysis. Year of Sonar treatment indicated by shading.

| Lake and sample date | Year of birth | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 |
| Pliness | | | | | | | | | | | | | |
| Jun-95 | | | | | 1 | 1 | 6 | 2 | 2 | | | | |
| Aug-97 | | | | | | | | 3 | 10 | 8 | 15 | 10 | |
| Crooked | | | | | | | | | | | | | |
| May-98 | | | | | | | | 1 | | | | | |
| Wolverine | | | | | | | | | | | | | |
| May-95 | | | 2 | 0 | 0 | 9 | 17 | 0 | 13 | 12 | | | |
| May-97 | | | | | 5 | 4 | 2 | 1 | 1 | | | | |
| Tipsico | | | | | | | | | | | | | |
| May-95 | | | 1 | 6 | 1 | 9 | 31 | 4 | | | | | |
| May-97 | | | | | | 3 | 2 | 3 | | 4 | | 2 | |
| Lansing | | | | | | | | | | | | | |
| May-98 | | | | | | | | | | | | | |
| Lobdell | | | | | | | | | | | | | |
| May-94 | | | 1 | 0 | 3 | 4 | 4 | | | | | | |
| May-95 | | | | | | | | | | | | | |
| May-97 | | | | | | 1 | 4 | 14 | 4 | | | | |
| Pontiac | | | | | | | | | | | | | |
| Oct-93 | | 1 | 1 | 1 | 0 | 0 | 2 | | | | | | |
| Oct-94 | | | | | | | 2 | 0 | 1 | | | | |
| May-97 | | | | | | | 1 | 1 | 2 | 5 | 6 | 6 | |
| White | | | | | | | | | | | | | |
| May-95 | | | | 1 | 0 | 0 | 0 | 2 | 1 | | | | |
| May-97 | | | | | | | 2 | 1 | 1 | 5 | 4 | | |
| Woodland | | | | | | | | | | | | | |
| Jun-94 | | | 2 | 6 | 1 | 1 | 3 | | | | | | |
| May-98 | | | | | | | | | 1 | 6 | 6 | 1 | 2 |
| Rush | | | | | | | | | | | | | |
| May-97 | | | | | | | 3 | | 1 | 6 | | | |
| Shannon | | | | | | | | | | | | | |
| Oct-98 | | | | | | | | | 2 | 9 | 18 | | 1 |

Appendix 20.–Year class strength of largemouth bass as reflected by numbers of fish sampled for age analysis. Year of Sonar treatment indicated by shading.

| Lake and | Year of birth | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| sample date | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 |
| Pliness | | | | | | | | | | | | | |
| Jun-95 | | 2 | 3 | 1 | 3 | 2 | | | | | | | |
| Aug-97 | | | 2 | 4 | 8 | 6 | 8 | 13 | 13 | 28 | 2 | 1 | 4 |
| Crooked | | | | | | | | | | | | | |
| May-98 | | | | | | 1 | 2 | 1 | 4 | 4 | 1 | 14 | |
| Wolverine | | | | | | | | | | | | | |
| May-95 | | | | 8 | 9 | 3 | 4 | 3 | 3 | | | | |
| May-97 | | | 1 | 1 | 4 | 14 | 10 | 12 | 9 | 15 | | | |
| Tipsico | | | | | | | | | | | | | |
| May-95 | | 1 | 4 | 8 | 6 | 1 | 1 | 0 | 5 | 22 | | | |
| May-97 | | | | 1 | | | 1 | 1 | 2 | 2 | 3 | 1 | |
| Lansing | | | | | | | | | | | | | |
| May-98 | | | | | | 1 | | | 1 | 1 | | | |
| Lobdell | | | | | | | | | | | | | |
| May-94 | | | | 2 | 8 | 16 | 10 | 4 | | | | | |
| May-95 | | | 1 | 2 | 2 | 6 | 8 | 11 | 28 | 1 | | | |
| May-97 | | | | | 3 | 7 | 18 | 20 | 14 | 12 | 6 | 2 | |
| Pontiac | | | | | | | | | | | | | |
| Oct-93 | 1 | 1 | 0 | 1 | 3 | 4 | 12 | 3 | | | | | |
| Oct-94 | 1 | 0 | 1 | 3 | 0 | 3 | 2 | 0 | 3 | | | | |
| May-97 | | | | | 1 | 1 | 1 | 5 | 6 | 3 | | 11 | |
| White | | | | | | | | | | | | | |
| May-93 | 1 | 7 | 9 | 8 | 4 | 4 | 7 | | | | | | |
| May-95 | | 3 | 2 | 3 | 14 | 39 | 25 | 10 | 0 | 1 | | | |
| May-97 | | | 1 | 3 | 4 | 11 | 8 | 10 | 13 | 9 | 8 | 2 | |
| Woodland | | | | | | | | | | | | | |
| Jun-94 | 4 | 3 | 10 | 14 | 20 | 19 | 9 | 1 | | | | | |
| May-95 | | 1 | 1 | 3 | 5 | 3 | 2 | 1 | 0 | 15 | | | |
| May-98 | | | | | | | | 1 | 3 | 3 | 3 | 1 | 2 |
| Rush | | | | | | | | | | | | | |
| May-97 | | | | | | 4 | 3 | 2 | 4 | 9 | | | |
| Shannon | | | | | | | | | | | | | |
| Oct-98 | | | | 2 | 1 | | 1 | 2 | | 1 | | 1 | 1 |

Appendix 21.–Year class strength of northern pike as reflected by numbers of fish sampled for age analysis. Year of Sonar treatment indicated by shading.

| Lake and sample date | Year of birth 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pliness | | | | | | | | | | | | | |
| Aug-97 | | | | | 1 | 2 | | 2 | | | | | |
| Crooked | | | | | | | | | | | | | |
| May-98 | | | | | | | | 2 | 5 | 10 | 11 | 6 | |
| Wolverine | | | | | | | | | | | | | |
| May-95 | | | | | 1 | | | | | | | | |
| May-97 | | | | | | | 1 | | 4 | | 2 | 1 | |
| Tipsico | | | | | | | | | | | | | |
| May-95 | | | | 3 | 3 | 1 | 1 | 7 | 5 | | | | |
| May-97 | | | | | 1 | | | | 1 | 4 | | | |
| Lansing | | | | | | | | | | | | | |
| Lobdell | | | | | | | | | | | | | |
| May-97 | | | 1 | | | 1 | 2 | | | | 2 | | |
| Pontiac | | | | | | | | | | | | | |
| Oct-93 | 1 | 1 | 1 | 1 | 1 | | | | | | | | |
| May-97 | | | | 1 | | | 1 | | | | | | |
| White | | | | | | | | | | | | | |
| May-93 | | 1 | 1 | 10 | 13 | 3 | | | | | | | |
| May-95 | | | | | 2 | 11 | 7 | 4 | | | | | |
| May-97 | | | | | | | | 3 | 1 | 2 | 1 | | |
| Woodland | | | | | | | | | | | | | |
| Rush | | | | | | | | | | | | | |
| May-97 | | | | 1 | | | | 5 | 2 | | | | |
| Shannon | | | | | | | | | | | | | |
| Oct-98 | | | | | | | | 1 | 1 | 6 | 2 | | 1 |