# EFFECTS OF EUTROPHICATION ON THE FISH COMMUNITIES OF FLORIDA LAKES

RANDY S. KAUTZ, Office of Environmental Services, Florida Game and Fresh Water Fish Commission, Tallahassee, FL 32301

*Abstract:* From an analysis of the trophic status and fish populations of 22 Florida lakes, total fish biomass is low in oligotrophic lakes, increases to a maximum in mesotrophic-eutrophic lakes, and fluctuates around the maximum value in hypereutrophic lakes. Total fish density likewise is low in oligotrophic lakes and increases to a maximum in mesotrophic-eutrophic lakes; but unlike biomass, fish density declines as lakes become hypereutrophic and gizzard shad becomes the dominant species of fish. Sport fishes reach maximum biomass and optimum densities in mesotrophic-eutrophic lakes with a total nitrogen concentration of 1.2 mg/l and a chlorophyll *a* concentration of 11.0 ug/l, but suffer adverse effects with further enrichment.

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Eutrophication, the progressive nutrient enrichment of surface waters, is a natural process that can be accelerated by man's activities. The eutrophication process has been observed to effect undesirable changes in water quality (Brezonik and Shannon 1971) and biota (Jonasson 1969). Probably due to the ease of data collection, most investigations of the eutrophication process have focused on specific chemical and biological parameters, particularly dissolved oxygen, phosphorus, nitrogen, chlorophyll *a* and benthic invertebrates; however, few definitive studies have been made of the effects of nutrient enrichment on the fish community. As a consequence, agencies reponsible for water quality management plan and implement nutrient control programs with an incomplete picture of how the biota of aquatic systems respond to the eutrophication process. This is unfortunate since the laws, rules and regulations enacted to protect water quality have as a basis the conservation of fishery resources.

The notion that fish biomass and yield respond directly to nutrient supplies and primary production is adequately supported in the literature from studies of both experimental ponds (Goodyear et al. 1972) and natural lakes (Matuzek 1978). What is not so clear, however, is whether fish biomass and yield continue to increase as nutrient supplies become excessive and whether the composition of species in the fish community is adversely affected by the eutrophication process.

Jenkins (1967) demonstrated that the total standing crop of fish in American reservoirs increases, reaches a maximum and declines as the morphoedaphic index, an indicator of nutrient concentration, increases; however, he suggested that the observed decline was the result of high salt concentrations rather than an effect of nutrient enrichment. Melack (1976) and Oglesby (1977) have observed that commercial fish yields increase logarithmically with arithmetic increases in primary production in both tropical and temperate lakes; however, their data apparently do not include lakes suffering from excessive nutrient enrichment. Henderson et al. (1973) nonetheless present a set of hypothetical curves that suggest that yield, like standing crop, increases to a maximum and then declines as the morphoedaphic index increases.

With respect to the effects of eutrophication on species composition, Larkin and Northcote (1969) cite several authors who have documented that rough fish populations increase and commercial fish populations decrease as eutrophication progresses in certain lakes. In other systems, in particular the Great Lakes, changes in the relative abundance of species have been attributed at least partially to the effects of eutrophication.

One approach to ascertaining the response of Florida's lake fisheries to the eutrophication process would be to study the fish community of one or several lakes undergoing nutrient enrichment over a long period of time. Unfortunately no such study has been undertaken in Florida nor is there data available for a single lake over a long period of time. A second approach, and the one used in this study, is to compare data on the fish communities of Florida lakes in different stages of eutrophication. It is hoped that the results of this study will provide guidance to the agencies responsible for permitting nutrient-laden effluents from point and non-point sources.

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## METHODS

The responses of the fish communities of Florida lakes to the eutrophication process were determined by plotting biomass and abundance estimates of fish populations along an increasing trophic gradient. Twenty-two Florida lakes were used to establish the trophic gradient based on an 8-year study of water quality by the Florida Game and Fresh Water Fish Commission. Each lake had been sampled twice for water quality from 1971 to 1973 and had been ranked by trophic status on the basis of chlorophyll *a* concentrations, particulate organic nitrogen concentrations, and the difference between unfiltered and filtered turbidity (Holcomb and Starling 1973, Table 1). Data on total nitrogen, total phosphate and chlorophyll *a* from the study were plotted by lake along the established trophic gradient, and the resulting curves were smoothed using an averaging technique to make trends more discernable. Brezonik and Shannon (1971) and the U.S. Environmental Protection Agency (1977) have referred to several of the lakes in the study as being oligotrophic, mesotrophic, eutrophic or hypereutrophic (Table 1). A sufficient number of oligotrophic and hypereutrophic lakes are represented to allow the analysis of the data for these lakes as separate and distinct groups; however, the number of lakes representing both mesotrophic and eutrophic lakes is so small that it has been necessary to combine the data from these 2 lake groups into the single category of mesotrophic-eutrophic lakes for analysis.

Data on the fish populations of each of the 22 lakes were collected by the Florida Game and Fresh Water Fish Commission using standard 0.4 ha block nets and rotenone during the period from 1969 to 1978. Each lake was sampled from 1 to 57 times by various investigators in the course of routine population monitoring or in connection with special projects. Fish population data obtained using the block net technique in Florida lakes is highly variable yielding coefficients of variation ranging from 65 percent to 96 percent for biomass and 90 percent to 115 percent for density. Nonetheless the number of block net samples needed to adequately estimate the mean is rather small. For example, one of the lakes was sampled 8 times in a single year and another lake was sampled 11 times over a 3-year period. In each case, 2 to 3 samples provided a close estimate of the mean biomass, and 2 to 5 samples closely estimated mean density. Thus, since all lakes but one (i.e., Lake Koon) were sampled 2 or more times, it is assumed that the block net data used in this study are close estimates of the actual mean biomass and density of fish in each lake.

For the purposes of the study, the species of fishes present in each lake were placed into the categories of sport, commercial, rough and forage fishes according to the scheme shown in Table 2, and biomass and density estimates were calculated for each group. The placement of a species into a particular group was on the basis of its value to man, or size in the case of forage fishes, rather than on a strict ecological basis such as feeding habits. The biomass and density estimates of each group were plotted by lake along the established trophic gradient, and the resulting curves were smoothed to facilitate analysis. It should

Table 1. Trophic status, size and water quality of lakes used in this study (Holcomb and Starling 1973).

| Lake | Surface Area (ha) | Trophic Status[1] | Chlorophyll *a* (ug/l) | Total Nitrogen (mg/l) | Total Phosphate (mg/l) |
|---|---|---|---|---|---|
| Santa Fe | 1,911 | 0 | 0.6 | 0.48 | 0.03 |
| Ocean Pond | 718 | 0 | 1.5 | 0.42 | 0.05 |
| Jackson | 1,620 | 0 | 2.2 | 0.71 | 0.14 |
| Tsala Apopka (H)[2] | 7,734 | - | 3.7 | 0.46 | 0.03 |
| Tsala Apopka (I) | 7,734 | - | 4.6 | 0.75 | 0.13 |
| Tsala Apopka (F) | 7,734 | - | 10.4 | 0.60 | 0.08 |
| Koon | 45 | 0 | 16.4 | 0.68 | 0.06 |
| South | 446 | E | 4.8 | 1.02 | 0.11 |
| Panasoffkee | 1,805 | M | 11.8 | 0.84 | 0.12 |
| Orange | 5,142 | M | 6.4 | 1.06 | 0.14 |
| Kissimmee | 14,143 | M-E | 9.6 | 1.15 | 0.17 |
| Tohopekaliga | 7,612 | E | 18.5 | 1.47 | 1.25 |
| Lochloosa | 2,309 | M | 13.7 | 1.65 | 0.16 |
| Newnans | 3,006 | E | 27.8 | 2.06 | 0.43 |
| Dora | 1,811 | H | 36.1 | 2.63 | 0.36 |
| Carlton | 155 | - | 35.2 | 2.97 | 0.34 |
| Griffin | 6,680 | H | 36.1 | 3.01 | 0.43 |
| Parker | 919 | - | 61.5 | 3.25 | 0.76 |
| Lulu | 122 | - | 62.2 | 2.92 | 4.75 |
| Hancock | 1,829 | - | 92.2 | 3.37 | 1.60 |
| Scott | 115 | - | 128.3 | 4.64 | 1.15 |
| Apopka | 12,413 | H | 80.2 | 5.78 | 1.12 |

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[1] O=oligotrophic, M=mesotrophic, E=eutrophic, H=hypereutrophic.

[2] H=Hernando pool, I=Inverness pool, and F=Floral City pool.

Table 2. Species of fish which were classified as sport, commercial, rough and forage fishes for the purpose of this study.

*Sport Fishes*

Largemouth bass *(Micropterus salmoides)*
Bluegill *(Lepomis macrochirus)*
Redear sunfish *(Lepomis microlophus)*
Warmouth *(Lepomis gulosus)*
Black crappie *(Pomoxis nigromaculatus)*
Chain pickerel *(Esox niger)*
Redbreast sunfish *(Lepomis auritus)*
Striped bass *(Morone saxatilis)*
Spotted sunfish *(Lepomis punctatus)*

*Commercial Fishes*

Brown bullhead *(Ictalurus nebulosus)*
Channel catfish *(Ictalurus punctatus)*
White catfish *(Ictalurus catus)*
Yellow bullhead *(Ictalurus natalis)*
American eel *(Anguilla rostrata)*

*Rough Fishes*

Gizzard shad *(Dorosoma cepedianum)*
Florida gar *(Lepisosteus platyrhincus)*
Longnose gar *(Lepisosteus osseus)*
Bowfin *(Amia calva)*
Blue tilapia *(Tilapia aurea)*

*Forage Fishes*

Threadfin shad *(Dorosoma petenense)*
Lake chubsucker *(Erimyzon succetta)*
Golden shiner *(Notemigonus crysoleucas)*
Atlantic needlefish *(Strongylura marina)*
Seminole killifish *(Fundulus seminolis)*
Taillight shiner *(Notropis maculatus)*
Bluespotted sunfish *(Enneacanthus gloriosus)*
Golden topminnow *(Fundulus chrysotus)*
Brook silverside *(Labidesthes sicculus)*
Swamp darter *(Etheostoma fusiforme)*
Madtom *(Noturus gyrinus)*
Bluefin killifish *(Lucania goodei)*
Flagfish *(Jordanella floridae)*
Least killifish *(Heterandria formosa)*
Dollar sunfish *(Lepomis marginatus)*
Sailfin molly *(Poecilia latipinna)*
Mosquitofish *(Gambusia affinis)*
Everglades pygmy sunfish *(Elassoma evergladei)*
Banded pygmy sunfish *(Elassoma zonatum)*
Pugnose shiner *(Notropis anogenus)*
Sheepshead minnow *(Cyprinodon variegatus)*
Pirate perch *(Aphredoderus sayanus)*
Orange spotted sunfish *(Lepomis humilis)*
Redfin pickerel *(Esox americanus)*

be noted that the biomass and density curves were plotted on the same relative scale in each figure so that the effects of eutrophication on the average weight of a fish in the group could be discerned.

The species diversity of the fish community of each lake was calculated using the Shannon-Weaver index (Shannon and Weaver 1963), and the resulting values were plotted along the trophic gradient and smoothed in the manner described for nutrients, chlorophyll *a* and fish. (Some reviewers have criticized the application of the species diversity index to fish abundance data collected with block nets because of the difficulty of obtaining a complete sample of small-sized fishes. However, it is assumed for the purpose of this analysis that all workers in the field sampled small-sized fishes with equal efficiency making the comparison of the relative species diversity indices a valid exercise.) The data on species diversity were taken from Buntz and Manooch (1970), Buntz and Chapman (1971), Vaughn et al. (1973, 1974, 1976), Wegener et al. (1973), Holcomb and Barwick (1974), Schneider et al. (1974), Wegener and Williams (1974), Wilbur and Crumpton (1974), Chapman et al. (1975), Babcock and Rousseau (1976) and McKinney et al. (1976).

In addition to the trend analyses, means were calculated for nutrients, chlorophyll *a*, and fish biomass and density for each of the three lake groups. The means were then tested for significant differences using analysis of variance, Duncan's new multiple range test and a 5 percent level of significance.

## RESULTS

Since nitrogen was used as a parameter for establishing the trophic gradient for Florida lakes, the resulting curve for total nitrogen shows a fairly smooth increasing trend along the trophic gradient with minimum values occurring in Florida's most oligotrophic lakes and maximum values in the most hypereutrophic lakes (Fig. 1). The mean total nitrogen concentrations of the 3 lake groups are as follows: oligotrophic—0.59 mg/l; mesotrophic-eutrophic—1.32 mg/l; and hypereutrophic—3.57 mg/l. The mean total nitrogen concentrations of hypereutrophic lakes is significantly greater than the other lake groups, but no significant difference exists between the mean total nitrogen concentrations of oligotrophic and mesotrophic-eutrophic lakes.

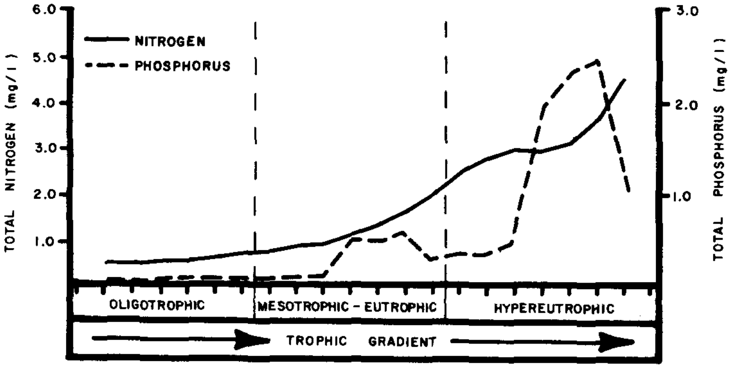

Fig. 1. Responses of total nitrogen and total phosphate concentrations to increasing levels of eutrophication in Florida lakes.

Total phosphate generally follows the same trend as total nitrogen, but the curve is much more variable since phosphate was not one of the parameters used in the trophic ranking of the lakes. The mean total phosphate concentrations of the 3 lake groups are as follows: oligotrophic—0.07 mg/l; mesotrophic-eutrophic—0.34 mg/l; and hypereutrophic—1.31 mg/l. No significant differences exist between the mean total phosphate concentrations of oligotrophic and mesotrophic-eutrophic lakes or between mesotrophic-eutrophic and hypereutrophic lakes; however the mean total phosphate concentration of hypereutrophic lakes is significantly greater than that of oligotrophic lakes.

Chlorophyll *a*, the principal biotic variable used in the trophic ranking, follows a smooth increasing trend along the trophic gradient similar to that of total nitrogen (Fig. 2). The mean chlorophyll *a* concentrations of the 3 lake groups are as follows: oligotrophic—5.6 ug/l; mesotrophic-eutrophic—13.2 ug/l; and hypereutrophic—66.5 ug/l. The mean chlorophyll *a* concentration of hypereutrophic lakes is significantly greater than those of oligotrophic and mesotrophic-eutrophic lakes, but no significant difference was observed between the latter 2 lake groups.

With regard to the fish communities, as the eutrophication process progresses through the range of oligotrophic lakes, the biomass and density of sport fishes show little or no apparent increase even though total nitrogen and chlorophyll *a* concentrations are increasing slightly (Fig. 3). However, as eutrophication progresses to the middle of the mesotrophic-eutrophic group of lakes, a phenomenal increase in both biomass and numbers occurs, and maximum biomass of sport fishes is reached. Up to the middle of the mesotrophic-eutrophic group of lakes, the biomass and density curves track one another fairly well, suggesting a stable ratio of number of fish per unit of biomass. As the degree of

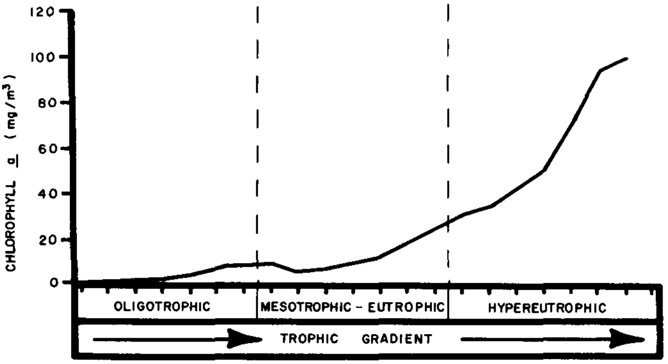

Fig. 2. Response of chlorophyll *a* concentrations to increasing levels of eutrophication in Florida lakes.

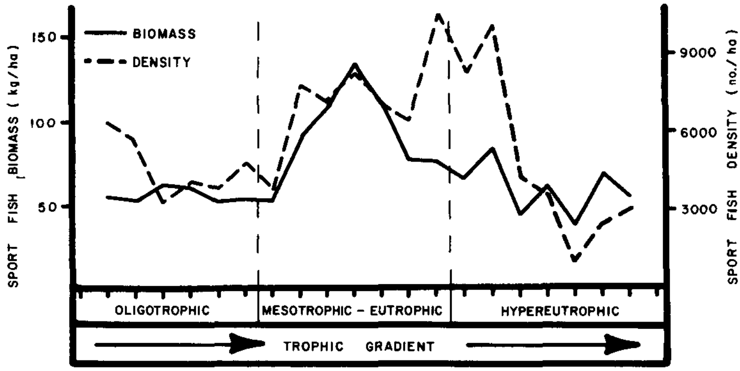

Fig. 3. Responses of biomass and density of sport fishes to increasing levels of eutrophication in Florida lakes.

eutrophication increases from the middle of the mesotrophic-eutrophic group of lakes to the middle of the hypereutrophic group of lakes, the density of sport fishes increases to maximum values while biomass is declining. These lakes are generally characterized by large numbers of small sunfish (i.e., *Lepomis* sp.), and the indication is that the community of sport fishes at this level of nutrient loading is in a state of disequilibrium. Finally, in Florida's most hypereutrophic lakes, numbers and biomass of sport fishes decline to reach the lowest values observed over the entire trophic gradient.

While these trends are clearly suggested by the curves, differences between the sport fish populations of the 3 lake groups can not be demonstrated statistically, presumably due to the small sample size. Mean biomass and density estimates for sport fishes in the 3 lake groups are as follows: oligotrophic—51.85 kg/ha and 5,032/ha; mesotrophic-eutrophic—88.99 kg/ha and 6,775/ha; and hypereutrophic—65.31 kg/ha and 5,522/ha.

Commercial fishes, comprised almost exclusively of catfishes, show a generally increasing trend along the trophic gradient in terms of biomass and density (Fig. 4). Whereas few commercial fishes are present in any lakes up to the middle of the mesotrophic-eutrophic group of lakes, dramatic increases occur beyond that point. Maximum biomass and density values are reached in the middle of the hypereutrophic group of lakes. The curves

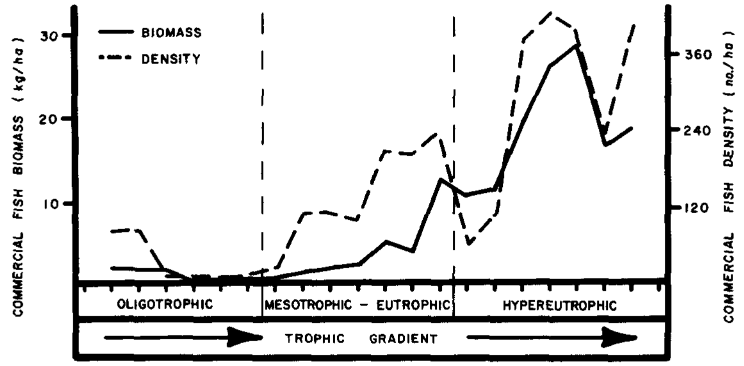

Fig. 4. Responses of biomass and density of commercial fishes to increasing levels of eutrophication in Florida lakes.

suggest that the biomass and density of commercial fishes decrease with extreme hypereutrophy, but it is difficult to decide whether or not the decreasing trends are real because of the variability apparent in the other portions of the curve.

The increasing trend of commercial fishes is supported by the statistical analysis of the 3 lake groups. Mean biomass and density estimates for commercial fishes in each lake group are as follows: oligotrophic—1.04 kg/ha and 45/ha; mesotrophic-eutrophic—2.98 kg/ha and 142/ha; and hypereutrophic—20.83 kg/ha and 341/ha. The mean biomass estimate for commercial fishes in hypereutrophic lakes is significantly greater than those for oligotrophic and mesotrophic-eutrophic lakes; however, no significant difference exists between the mean biomass estimates for commercial fishes in oligotrophic and mesotrophic-eutrophic lakes. The only significant difference in the density estimates for commercial fishes exists between oligotrophic and hypereutrophic lakes.

Rough fishes, generally regarded as undesirable competitors of sport and commercial fishes, show a definite increasing trend along the entire trophic gradient, particularly in terms of biomass (Fig. 5). In oligotrophic lakes, rough fishes are generally scarce or even

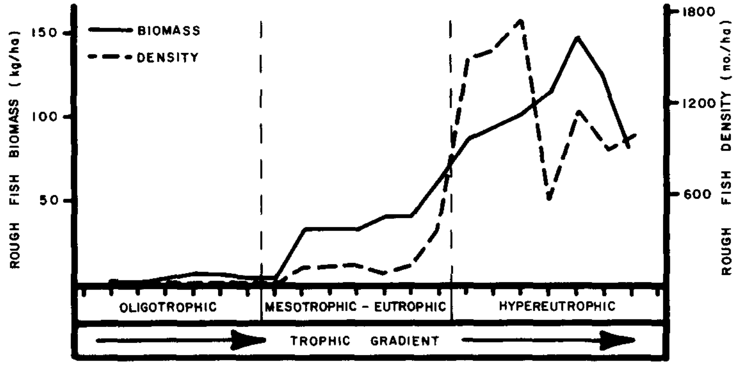

Fig. 5. Responses of biomass and density of rough fishes to increasing levels of eutrophication in Florida lakes.

absent, and numbers remain low through the mesotrophic-eutrophic range of lakes even though biomass increases gradually. However, moving from eutrophic to hypereutrophic lakes, the density of rough fishes increases tremendously, and both biomass and density values reach maxima midway through the hypereutrophic group of lakes. Following the peaks, the populations of rough fishes appear to decline as lakes progress into an advanced state of hypereutrophication.

The increasing trend observed for rough fishes is reinforced by the statistical analysis of the 3 lake groups. Mean biomass and density estimates for rough fishes in the 3 lake groups are as follows: oligotrophic—4.42 kg/ha and 13/ha; mesotrophic-eutrophic—33.30 kg/ha and 131/ha; and hypereutrophic—104.82 kg/ha and 1,123/ha. For both biomass and density, the differences between the populatons of rough fishes in oligotrophic and mesotrophic-eutrophic lakes are not significant, but significant differences do exist between mesotrophic-eutrophic and hypereutrophic lakes.

Forage fishes, which comprise an important source of food for predatory sport fishes and for the aquatic food chain in general, reach highest biomass and density values in the middle of the mesotrophic-eutrophic group of lakes and then fall sharply to their lowest values in the hypereutrophic lakes (Fig. 6). The biomass and density curves for forage fishes in oligotrophic lakes do not show a clear trend, probably due to the inefficiency with which small fish are sampled with block nets (B. Barnett, personal communication). However, it is probable that forage fish populations would show a generally increasing trend through the range of oligotrophic lakes and would make a smooth transition to the mesotrophic-eutrophic group of lakes if the problems with the sampling technique could be resolved.

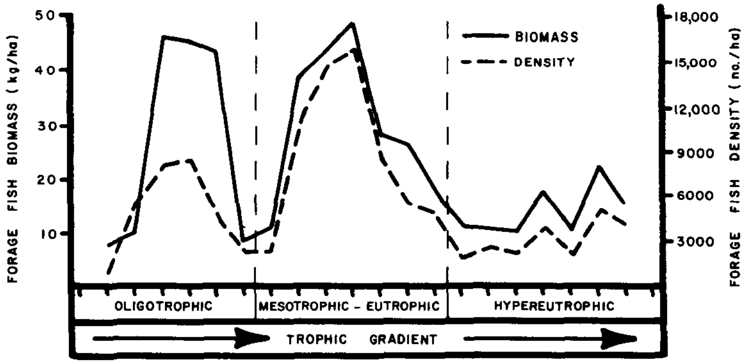

Fig. 6. Responses of biomass and density of forage fishes to increasing levels of eutrophication in Florida lakes.

The trends observed for forage fishes are not supported by the statistical analysis of the lake groups. Mean biomass and density estimates for the populations of forage fishes in the 3 lake groups are as follows: oligotrophic—23.89 kg/ha and 4,775/ha; mesotrophic-eutrophic—30.92 kg/ha and 8,762/ha; and hypereutrophic—13.65 kg/ha and 3,451/ha. No significant differences between the biomass and density estimates of forage fishes in any of the lake groups could be demonstrated.

Biomass and abundance in the fish community as a whole remain fairly constant through the range of oligotrophic lakes and increase rapidly to maximum values in the middle of the mesotrophic-eutrophic group of lakes (Fig. 7). Total fish biomass appears to decline somewhat in response to slightly more eutrophic conditions, but then increases again in hypereutrophic lakes to the same high values observed in mesotrophic-eutrophic

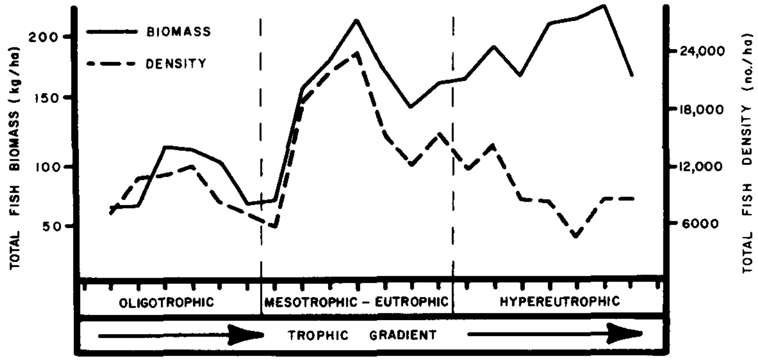

Fig. 7. Responses of total fish biomass and density to increasing levels of eutrophication in Florida lakes.

lakes. Total fish density, on the other hand, shows a steady decreasing trend as eutrophication progresses beyond the middle of the mesotrophic-eutrophic stage. In these stages of eutrophication, the large-bodied, plankton-feeding gizzard shad dominates the fish community. Minimum densities are observed in hypereutrophic lakes.

The trends observed for the total fish community are only partially borne out by the statistical analysis of the 3 lake groups. Mean biomass and density estimates for the total fish communities of the 3 lake groups are as follows: oligotrophic—81.20 kg/ha and 9,865/ha; mesotrophic-eutrophic—156.20 kg/ha and 15,810/ha; and hypereutrophic—204.61 kg/ha and 10,437/ha. The only difference in the biomass estimates of the total fish community exists between oligotrophic and hypereutrophic lakes. No other significant differences in the total biomass or density estimates of the three lake groups could be demonstrated.

Species diversity, as measured by the Shannon-Weaver index, remains fairly constant around a value of 1.8 in oligotrophic lakes but increases to a maximum of approximately 3.0 in the middle of the mesotrophic-eutrophic group of lakes (Fig. 8). Species diversity

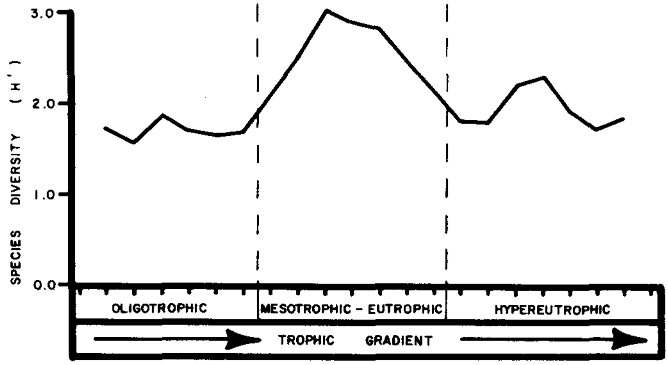

Fig. 8. Responses of the fish community species diversity index to increasing levels of eutrophication in Florida lakes.

declines with advancing eutrophication to fluctuate around 2.0 in hypereutrophic lakes.

This trend is well supported statistically by lake group. Mean species diversity indices of the 3 lake groups are: oligotrophic—1.71; mesotrophic-eutrophic—2.63; and hypereutrophic—1.96. The mean species diversity index for fishes in mesotrophic-eutrophic lakes is significantly greater than those in oligotrophic and hypereutrophic lakes; however, no significant difference could be demonstrated between the mean species diversity indices for fishes in the latter two lake groups.

## DISCUSSION

Oligotrophic lakes in Florida generally have well-developed communities of littoral vegetation that provide habitat suitable for the production of forage and sport fishes. In some lakes water clarity is so great that submerged aquatic plants grow at depths of 3-4 m providing additional habitat for sport fishes. The lack of nutrients in the limnetic portions of oligotrophic lakes limits plankton production, and plankton-feeding fishes (e.g., gizzard and threadfin shad) are scarce or absent. Where submerged aquatic plants are absent, a thin layer of detritus usually covers a sand bottom. Benthic invertebrate production is therefore limited, and, in turn, the number of bottom-feeding fishes (e.g., catfishes, lake chubsucker) in the system is limited. The end result is that oligotrophic lakes are characterized by a relatively low total biomass of fish, averaging 81 kg/ha, and a low species diversity. The fish community is dominated by sport and forage fishes which comprise 64 percent and 29 percent, respectively, of the total biomass of fish in the system. Rough and commercial fishes are poorly represented comprising only 5 percent and 1 percent, respectively, of the fish biomass.

Mesotrophic and eutrophic lakes in Florida generally have extensive and well-developed communities of littoral vegetation, and the standing crop of sport and forage fishes is high. In the limnetic portions of such lakes, nutrient supplies are sufficient to support a well-developed plankton community, and both the biomass and diversity of fishes using this portion of the lake are increased. Lake bottoms are characterized by fine-grained particle sizes and an aerobic detrital layer that supports increased populations of benthic invertebrates. This, in turn, supports an increase in the biomass of bottom-feeding fishes. Increased productivity and habitat diversity result in a high diversity of fish species. Total fish biomass in mesotrophic-eutrophic lakes averages 156 kg/ha, and sport fishes dominate the fish community comprising 57 percent of the total fish biomass. Over the entire range of lakes, the biomass of forage fishes is greatest in mesotrophic-eutrophic lakes, but the relative importance of forage fishes to the fish community as a whole is diminished with forage species comprising only 20 percent of the total biomass. In response to increased production in the limnetic zones of mesotrophic-eutrophic lakes, rough fishes increase in importance comprising 21 percent of the total fish biomass. Commercial fishes, though increasing in biomass in relation to oligotrophic lakes, show little importance in mesotrophic-eutrophic lakes and account for only 2 percent of the total fish biomass. Optimum production of sport fishes occurs in the middle of the range of the mesotrophic-eutrophic group of lakes or in lakes that would best be described as *meso-eutrophic* (i.e., lakes that would be classified as either late mesotrophic or early eutrophic). Mesotrophic lakes are apparently characterized by stable populations of sport fishes that are increasing whereas eutrophic lakes begin to show populations of sport fishes that are declining and in a state of disequilibrium.

Hypereutrophic lakes in Florida are generally characterized by limited communities of littoral vegetation, the vegetation having been eliminated as a result of shading by high densities of plankton (Jonasson 1969), invasion by noxious aquatic plants (e.g., *Eichhornia crassipes)* and organic sedimentation. Populations of sport and forage fishes are thus drastically reduced. Largemouth bass reproduction is inhibited in such environments (Chew 1972, Smith and Crumpton 1977), and the populations of sport fishes (especially

*Lepomis* sp.) fluctuate wildly. Nutrient levels are so high in hypereutrophic lakes that phytoplankton populations reach densities that result in a reduction in the depth of the photic zone through self-shading; and blooms of blue-green algae, some species of which are toxic to fish (Mitchell 1974), are common. Filter-feeding rough fishes (e.g., gizzard shad) proliferate in such environments; however, even they are susceptible to population fluctuations, dying off when oxygen supplies are reduced following algal blooms and cloudy weather. Plankton production is so great that detritus accumulates on the bottom in quantities that preclude aerobic decomposition, and benthic invertebrate production is severely limited (Jonasson 1969). Bottom feeders such as the catfishes are probably more common in shallow water areas where sufficient oxygen is available in the water column to permit the aerobic decomposition of sediments and the production of benthic invertebrates. Hypereutrophic lakes support a high total biomass of fish that averages 205 kg/ha, but rough fishes dominate the community comprising 51 percent of the biomass. Sport fishes account for only 32 percent of the total biomass, and reproduction is limited. Forage fishes are reduced to only 7 percent of the total biomass, probably contributing to the instability of sport fish populations. Commercial fishes reach their highest levels accounting for 10 percent of the total fish biomass.

In their review of the literature, Larkin and Northcote (1969) cite several instances in which the species composition of the fish community changes in response to eutrophication. In some of the cases, commercially harvested species have been replaced by rough fish as nutrient enrichment progresses similar to the pattern observed in Florida lakes where sport fishes are replaced by rough fish, principally gizzard shad. Larkin and Northcote (1969) also cite one study which showed that the switch from desirable to undesirable species of fish occurs over a relatively narrow range of mesotrophy. The response curves for sport fishes in Florida lakes (Fig. 3) would seem to corroborate this finding. After reaching optimum population characteristics in the middle of the mesotrophic-eutrophic group of lakes, sport fish populations appear to rapidly move into a state of disequilibrium with little additional enrichment.

In his study of 127 reservoirs in the United States, Jenkins (1967) found a significant positive correlation between the total standing crop of fish and both dissolved solids and morphoedaphic index, 2 indirect indicators of trophic state; however, these 2 variables accounted for only 11 percent of the variability in the total standing crop of fish. The application of a second-degree polynomial regression to the total standing crop-morphoedaphic index data proved a much better fit accounting for 40 percent of the variability in standing crop. Assuming that morphoedaphic index truly reflects nutrient conditions, this result indicates that the total standing crop of fish increases, reaches a maximum and then declines progressing through the full range of nutrient conditions observed in U.S. reservoirs.

The curves for sport fish biomass and density (Fig. 3), forage fish density (Fig. 6) and total fish density (Fig. 7) obtained from this study seem to suggest that these groups of fish increase, peak and decline with the progressive nutrient enrichment of Florida lakes in a manner similar to that observed by Jenkins (1967) for the total standing crops of fish in U.S. reservoirs. On the other hand, it appears that biomass and density of commercial (Fig. 4) and rough fishes (Fig. 5), and possibly total fish biomass (Fig. 7), follow a trend of linear increase with progressive nutrient enrichment in Florida lakes. Of these groups of fish, Jenkins (1967) provides data only on rough fish standing crops with which to compare the results of this study. Jenkins (1967) found that the clupeid (i.e., rough fish) standing crops in U.S. reservoirs are positively correlated with dissolved solids but that the percentage of variability accounted for by dissolved solids is low. The suggestion is that rough fish biomass responds linearly with increasing nutrient supply.

One is tempted to compare some of the results of this study to literature on the production and yield of lake fisheries; however, since biomass and production are not linearly correlated and since their ratio is inconstant (R. Kendall, personal communication), such comparisons may not be entirely appropriate. It is nonetheless interesting to note that the biomass and density of sport fishes and total fishes (Figs. 3 and 7) appear to respond logarithmically to nutrient enrichment at least through the middle of the mesotrophic-eutrophic range of Florida lakes. By comparison, Melack (1976) and Oglesby (1977) have shown that the yields of fish from both temperate and tropical lakes similarly respond logarithmically to primary production. Undoubtedly, since the lakes used in their studies were the subject of intensive commercial harvest programs, they were probably in approximately the same state of trophic health as are Florida lakes up to the mesoeutropic stage. This would seem to add some credibility to such a comparison. Unfortunately, the relationships between biomass and production, and production and trophic status, in Florida lakes await further study.

The results of this study also have implications for the management and control of nutrient loadings to Florida lakes. It is clearly evident that the maximum biomass and optimum density of sport fishes occur in the middle of the mesotrophic-eutrophic range of lakes (Figs. 3 and 7). Referring to Figures 1 and 2, it can be seen that the corresponding concentration of total nitrogen at this point is 1.2 mg/l and that of chlorophyll *a* is 11.0 ug/l. This suggests that additional nutrient loadings to Florida lakes from such sources as sewage treatment plants and agricultural runoff may be acceptable only as long as the predicted total nitrogen concentration does not exceed 1.2 mg/l or the predicted chlorophyll *a* concentration does not exceed 11.0 ug/l. In lakes with nitrogen and chlorophyll *a* concentrations greater than these values, sport fisheries are already on the decline. Additional nutrient inputs would only exacerbate a bad situation and should not be permitted.

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