Factors related to fish growth in northwestern Wisconsin lakes. Report 162 [1994]

Snow, Howard E.; Staggs, Michael D.
Madison, Wisconsin: Wisconsin Dept. of Natural Resources, [1994]

WISCONSIN DEPARTMENT OF NATURAL RESOURCES
RESEARCH REPORT 162
May 1994

Factors Related to Fish Growth in Northwestern Wisconsin Lakes

by **Howard E. Snow**
Bureau of Research, Spooner
and Michael D. Staggs
Bureau of Research, Monona

Abstract

Average fish growth was compared with physical, limnological, and fish abundance data from 115 northwestern Wisconsin lakes. The target species was bluegill (*Lepomis macrochirus*), but data were also collected on northern pike (*Esox lucius*), rock bass (*Ambloplites rupestris*), pumpkinseed (*Lepomis gibbosus*), largemouth bass (*Micropterus salmoides*), black crappie (*Pomoxis nigromaculatus*), yellow perch (*Perca flavescens*), and walleye (*Stizostedion vitreum*). Statistical models accounting for 35.6-60.6% of the variability in growth of each species were developed and used to identify candidate relationships for further experimentation. Some observed relationships were consistent with ecological theory, but some were difficult to explain and may have been chance associations. The most promising relationships identified for further study were between bluegill growth and walleye abundance, northern pike growth and abundance of likely forage species, largemouth bass and aquatic vegetation levels, black crappie growth and abundance of likely forage and predator species, yellow perch growth and walleye abundance, and walleye growth and abundance of bluegill young. Secchi disk transparency was correlated with growth of most species, and possible density-dependent growth was indicated for bluegill, pumpkinseed, and black crappie. Analyses of proportional stock density were uninformative.

Contents

Introduction

Populations of slow-growing fish have been identified as targets for management in northern Wisconsin lakes for many years (Snow et al. 1970, WDNR 1986). However, understanding the causes of slow growth against a background of environmental variability and community changes has proven difficult. Growth differs among species—different species having evolved different life history strategies (Gross 1982)—however these factors cannot typically be managed.

Variability in fish growth within a species is generally thought to be controlled by 3 main factors: food availability, water temperature and population density (Latta 1975, Weatherly and Gill 1987). Some bioenergetics models further suggest growth is basically a function of food consumption rate and water temperature history (Kitchell 1983, Hewett and Johnson 1992). In these models, population density effects are expressed only through changes in food consumption rates. In these general models, slow fish growth is attributed to limited food availability and/or suboptimal water temperatures.

Food availability is affected by many often interrelated factors. General lake fertility ultimately drives the biomass of prey that can be produced (Ryder et al. 1974, Flickinger and Bulow 1993). The size and species composition of the prey can be further influenced by the morphology and limnology of the lake, and abundance and type of predators (Colby et al. 1987, Hayes et al. 1993). Growth in a species is strongly affected by the size and species composition of the available prey (Weatherly and Gill 1987). Larger predator species, for example, may grow better when larger food items are available (Diana 1987), and nonpiscivorous species may grow better when foraging on zooplankton rather than benthic invertebrates (Mittelbach 1988). Prey preferences can also vary by age and size within a species (Osenberg et al. 1988).

Interspecific and intraspecific competition can strongly affect food availability. Slow growth is often attributed to high population densities (e.g., Hayes et al. 1993) but this is an indirect effect of reducing available food. Sympatric species often avoid competition by using different prey items, but growth can be affected if several species feed on the same prey (Osenberg et al. 1988).

Although intrinsic species growth patterns are largely the result of long periods of evolution, there is increasing evidence that growth can be altered by short-term factors. Size-selective harvest over several generations may alter actual growth rates in some species (Handford et al. 1977, Healey 1980, Nuhfer and Alexander 1991). Growth rates often change following the onset of sexual maturity as energy is used for gonad rather than somatic production (Gross 1982, Jennings and Philipp 1992). Size-specific harvest can influence the age of maturation and affect growth patterns (Regier and Loftus 1972, Spangler et al. 1977). Competition for nesting sites and the presence of other sexually mature fish can also affect the age of maturation for some species (Gross 1982).

Designing appropriate management tools to improve fish growth will require an understanding of the causes of slow growth in the lakes targeted for management. The objective of this work was to identify factors related to fish growth through analysis of a database containing physical, chemical, and fish population growth and abundance data for 115 northwestern Wisconsin lakes. The target species was the bluegill (*Lepomis macrochirus*), but sufficient data was also collected to examine factors related to growth of northern pike (*Esox lucius*), rock bass (*Ambloplites rupestris*), pumpkinseed (*Lepomis gibbosus*), largemouth bass (*Micropterus salmoides*), black crappie (*Pomoxis nigromaculatus*), yellow perch (*Perca flavescens*), and walleye (*Stizostedion vitreum*).

This analysis concentrated on factors likely to affect food consumption. Temperature, harvest and sexual maturity data were not collected. Previous studies have suggested that food consumption was a major limiting factor in growth of these northern Wisconsin species and factors relating to food consumption are typically targeted for management in Wisconsin. We recognize that some of the residual variability observed during this study may be attributable to temperature, harvest, or age of maturation effects.

Caveat

Studies similar to this one are common in the fisheries literature and the results are often presented as definitive (Smith and Pycha 1960, Forney 1966, Walburg 1972, Busch et al. 1975, Kallemeyn 1987, Kingery and Muncy 1988, Theiling 1990). However we emphasize that these correlative studies only highlight variables which showed associations during the study period. They do not prove cause-effect and should not be arbitrarily applied to situations outside the database (other lakes, later years, etc.). The primary use for these analyses should be to suggest hypotheses for testing by future experimentation or observation. When techniques such as stepwise multiple regression are used, the significance levels associated with the final models are incorrect because the procedures implicitly examine many different models before choosing a "best" model. There is a high probability that some or all of the variables in the model are significant by chance association alone. Intuitive interpretations or agreement with other authors adds credibility to these models, but only testing on independent data sets can fully validate the observed relationships. In this work, the observed relationships are the results of substantial screening of the database and must be viewed as hypothetical in nature.

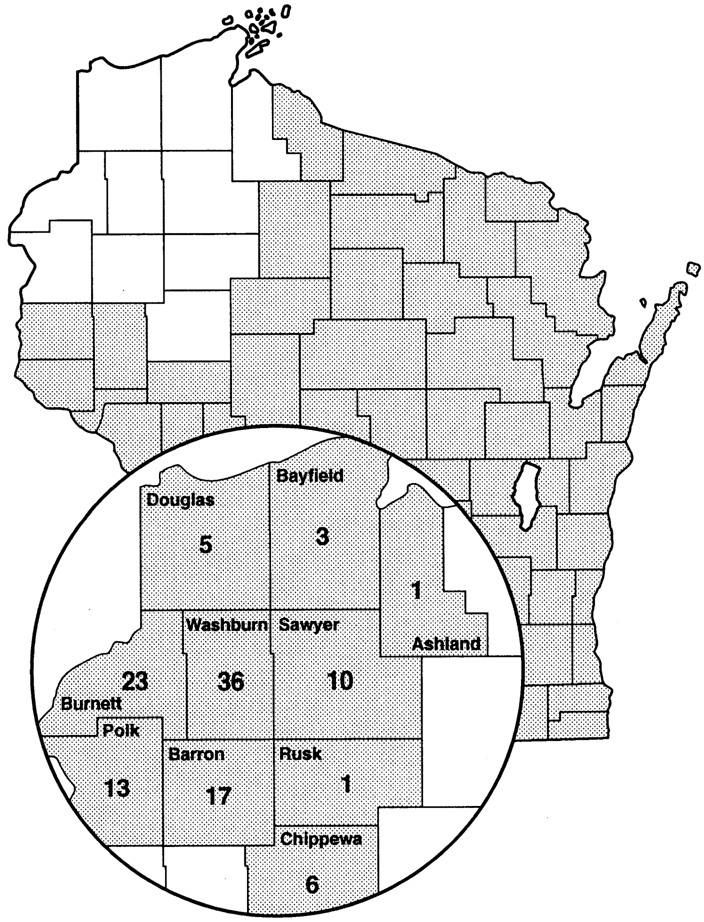


Figure 1. *Location of study counties and number of lakes sampled in each county.*

Study Area

All lakes included in this study are located in a 10-county area in northwestern Wisconsin (Fig. 1). A total of 115 lakes were sampled during 1974-82 (Append. A). Lakes ranged in size from 9 to 1,092 acres but most were under 200 acres (Table 1). The lakes were nonrandomly selected to include a wide range of bluegill growth, alkalinity, predator species composition (primarily largemouth bass, northern pike, and walleye), and macrophyte cover. Information from Department of Natural Resources files, discussions with fish managers and local residents, and on-site observations were used to make the final selection of study lakes. No lakes with known severe winter kill more than once every 5 years were included. However, several lakes with frequent low winter oxygen levels but infrequent or no known winterkill were included.

Table 1. *Total number of lakes 10 acres and larger, and number of lakes sampled during this study in the northwestern Wisconsin study area of Ashland, Barron, Bayfield, Burnett, Chippewa, Douglas, Polk, Rusk, Sawyer, and Washburn Counties. A detailed listing of all study lakes is given in Appendix A.*

	Total Number		Number Samples	
Area (acres)	Number	%	Number	%
10-49	1,145	64.0	31[a]	27.0
50-99	283	15.8	28	24.4
100-199	172	9.6	29	25.2
200-499	120	6.7	22	19.1
500-999	32	1.8	4	3.5
≥1,000	37	2.1	1	0.9
Total	1,789		115	

[a] Includes one 9-acre lake.

Methods

Field Sampling

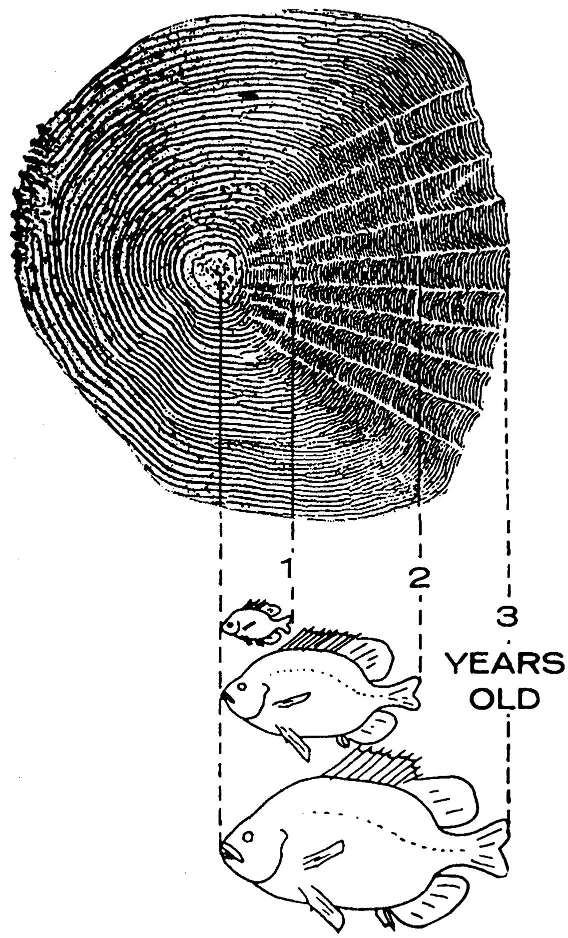
The primary fish sampling gear was the fyke net (1/2-inch square mesh webbing, 4 x 6-foot frames, 8-inch throat diameter, and 35-55 foot leads). Electrofishing (230 V, AC, 3 phase) was used to supplement the catch of predator fish and smaller panfish (the latter for age analyses only) in most lakes. Fish samples were taken throughout the open water season. Electrofishing was usually conducted within 14 days of the netting sample. In each lake all fish captured, or a minimum of 500 of each species, were measured to the nearest 0.10 inch. Scale samples were collected from a subsample of approximately 10 fish from each 1/2-inch length category for panfish and 10 from each 1-inch length category for predator species. Age was determined from plastic impressions of scale samples usually examined under a binocular microscope, but occasionally with a microfiche reader or a microprojector. Length-at-age data were recorded as the length and age at the time of capture; no back-calculations were made. Catch-per-effort (CPE) estimates were determined for each species, however those from the 2 gear types were not comparable.

Some of the habitat variables were measured at times other than when the fish community was sampled. Despite the chronological differences in some of the data collections, we assumed that any strong associations between growth indices and physical, chemical, and biological factors would be evident due to the large number of lakes analyzed. These relationships could then be verified by future studies.

Growth Index

Selection of a growth index was complicated because samples were taken at different times during the year and lengths at age were not comparable. Also some ages in some samples were not present due to natural and sampling variability. A common procedure is to fit an appropriate growth curve to the lengths at age and use one of the parameter estimates as a growth index (Ricker 1975). The only species with sufficient samples to estimate a length-age relationship for a large number of lakes was the bluegill, which had 5 or more lengths at age in all 115 samples. However, the pattern of the plots of mean length versus age for bluegills across all lakes ranged from linear to sigmoidal, making it difficult to fit a standard growth curve (such as the von Bertalanffy curve) and calculate one of the standard growth coefficients (such as the Ford or Brody coefficient). As a compromise, a log-base-ten transformation was applied to both the length and the age axes. This transformation produced a nearly linear plot for all lakes, so the growth indices for bluegills were the slope and intercept of the least-squares line fit to the log-transformed data.

To compensate for the varying sampling dates, the bluegill age axis was transformed into a "completed summers of growth" axis. Samples taken before 1 June were assumed to have had no growth that year, and samples taken after 1 September were assumed to have completed growth for that summer. Samples taken on interim dates were assigned a linear fractional age based on



An enlarged illustration of the scale from a 6-inch bluegill. Lines are drawn from the annuli. Annuli are similar to tree growth rings.

the proportion of days elapsed between 1 June and 1 September. Growth during the summer is probably nonlinear with respect to date. However, some preliminary computer simulation work indicated that the error introduced by the linear fractional age adjustment was small compared to the error introduced when all ages were not represented in each sample.

The growth index for species other than bluegills was the difference between the observed length at age and the mean length at age for all lakes with same age samples. Within each age group the differences (residuals) were then averaged for each lake. For comparative purposes this index was also computed for bluegills.

Selection of Independent Factors

Data on the following physical and chemical factors were available for nearly all lakes: mean depth (ft), maximum depth (ft), surface area (acre), percent of surface area under 5 feet in depth, percent of surface area under 10 feet in depth, shoreline length (mile), shoreline development factor (dimensionless ratio of shoreline length to the circumference of a circle having same area as lake), alkalinity (methyl purple, ppm), conductivity (µmhos, 77 F), water source (seepage or drainage), and a Secchi disk reading (ft). Sather and Busch (1976) provide a more detailed explanation of these parameters and the methods used to measure them. An index of lake productivity is the morphoedaphic index or MEI (Ryder et al. 1974). The MEI is defined as the ratio of total dissolved solids to mean depth. In this study total dissolved solids was estimated by multiplying conductivity by 0.65—a linear correction based on measurements of conductivity and total dissolved solids in a subset of study lakes. All physical and chemical factors were included in the analyses. Information on the percent of area covered by different types of macrophyte vegetation was available for only a limited subset of the lakes and these data were analyzed separately.

We also related growth to abundance levels of the same and other species, as indexed by CPE. It was necessary to summarize or limit the CPE indices considered because of the excessive number of possible variables. One statistic used was proportional stock density (PSD), calculated from the length frequencies (Anderson 1976). The PSD, however, does not preserve information on relative abundance. The CPE data were initially divided into CPE of both young and adults based on the "PSD" stock size (Table 2). For the 3 predator species (largemouth bass, northern pike, and walleye), there were sometimes 2 different gear types. To reduce the number of independent variables considered, CPE data were subjected to principal components analyses (SAS 1982). Two general results were noted: the total CPE did not provide as much information as the separate adult and young CPE, and the netting and shocking indices for predator species were so poorly correlated that they required a separate analysis.

The CPE variables that were included were the adult and young CPE for each species. The CPE of the same species was expected to provide a test of density-dependent growth responses, and the CPE of the 3 major predator species was expected to reveal any predation-influenced growth responses. The CPE of the forage (nonpredator) species was expected to provide information about the effects of forage abundance on predator species growth. Estimates of PSD were not used in the primary analysis because the separate young and adult abundance indices should provide more information than a single length-frequency summary statistic. Because of the recent interest in PSD, it was included in a separate analysis. The bluegill analyses were repeated with 50 lakes using predator electroshocking, and 91 lakes using predator fyke netting. Both analyses produced similar results so only the fyke netting analysis is reported. Predator fyke netting was used for the other species because of sample size considerations.

Table 2. *Total length used to divide catch of different species into young and adults.*

Species	Total Length (inches)
Largemouth bass	8
Walleye	10
Northern pike	14
Bluegill	3
Pumpkinseed	3
Rock bass	4
Black crappie	5
Yellow perch	5
Black bullhead	6
Yellow bullhead	6
Brown bullhead	6

Statistical Analysis

Comparison of the bluegill growth indices with the independent factors could have been done using the slope and intercept as dependent variables in a multiple regression model. However, several authors (Gauch and Whittaker 1972, Green and Vascotto 1978, Green 1979) have suggested that population characteristics often vary nonlinearly with environmental factors, showing optima and modes along their distributions. As a result, traditional linear regression techniques would not provide useful results. An alternate methodology (Tonn et al. 1983) divides the observations into similar groups using cluster analysis or ordination techniques and examines factors relating to group separation using discriminant analysis. Discriminant analysis requires restrictive multivariate normality assumptions and can be seriously biased if these assumptions are not met. However, for hypotheses generation and exploratory analysis, the method should be suitable (Williams 1983).

The variables used for clustering were the calculated bluegill lengths at ages 2-6 based on the log age-log length regression. Using the calculated lengths-at-age still resulted in a covariance matrix of rank 2 because the 5 calculated lengths were based on 2 parameters, the slope and intercept of the regression; however, the resulting clustering was easier to interpret. The clustering method used was a hierarchical procedure known as Ward's method (SAS 1982). The appropriate number of clusters to use was largely subjective but for the purposes of this study was determined by examining plots of the mean lengths-at-age versus age for each cluster. The objective was to get the most clusters possible but still maintain maximum separation between cluster means.

The comparison between bluegill growth, as classified into groups with different growth characteristics, and the independent factors was made using a stepwise discriminant analysis procedure (SAS 1982). The exact nature of any relationship was studied by arranging the clusters in an order approximately corresponding to an increasing growth scale and then plotting the mean values of the independent variables for each cluster.

The growth index for other species, average deviation, was compared to the independent factors using stepwise multiple regression (SAS 1982). The fractional age adjustment (as described for bluegills) was always included as the first variable in the stepwise selection. The sign and nominal significance (significance level if only a single model had been evaluated, see Caveat) of the regression coefficient were used to assess the importance of the independent variables.

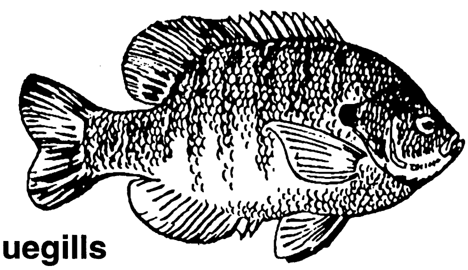
This analysis assumes linear relationships between the growth index and the independent variables, which may be a poor assumption as discussed above. To assess this potential bias, the analysis of average deviations was also repeated for bluegills and the results were compared to the cluster-discriminant analysis. For bluegills, the results of the 2 analyses were similar, which we took as evidence that the analysis of average deviations was producing acceptable results for the other species.

Results and Discussion

Lake Selection Bias

The subjective selection criteria resulted in a relative undersampling of the largest and smallest lakes (Table 1). While 6.4% of all lakes in the 10-county area were sampled, only 2.7% of lakes 10-49 acres and lakes larger than 1,000 acres were sampled. In contrast, 18.3% of the lakes 200-499 acres were sampled. The relative effects of sampling biases were not studied, but should be kept in mind when interpreting these results.

Based on the selection methods discussed, the lakes surveyed could not be considered a random sample. However, because of a rather large sample size and the selection of lakes covering a wide range of physical, chemical, and biological characteristics, we assumed that this was a representative sample.



Bluegills

Cluster analysis divided the 115 lakes into 8 groups with different bluegill growth characteristics (Append. B). Based on the mean length-at-age within each cluster (Table 3), the first 6 clusters had approximately parallel length-age relationships with lengths at ages differing 0.3-0.5 inches between clusters (Fig. 2). The 2 clusters with the highest age 6 lengths had higher growth rates but differed in lengths at age 2. Cluster 8 consistently had the largest lengths at age, while cluster 7 had an average length at age 2 and the second highest length at age 6.

The factors contributing most significantly to separation between the 8 bluegill growth clusters were (in order of selection): abundance of young rock bass, abundance of young yellow perch, Secchi disk transparency reading, abundance of brown bullhead, abundance of young black crappie, abundance of young bluegills, abundance of adult bluegills, MEI, and abundance of young walleyes. All variables were significant at the nominal 8% level. The specific relationship between each factor and the groupings was contained in the derived discriminant functions. However, because of differences in measurement scale and the presence of 8 functions, these were not easy to interpret. A simpler, qualitative interpretation was made by arranging the clusters in order of increasing length at age and plotting the mean value of the independent factor.

Secchi disk transparency readings had a negative relationship with increasing bluegill length-at-age (Fig. 3). Cluster 7 had a higher Secchi disk reading than expected based on the overall trend and was also unusual in that it had fast growth but poor growth at early ages. Increased abundance of walleye young was associated with increased bluegill growth (Fig. 4). Abundance of walleye adults was also related to bluegill growth and the pattern was very similar to that shown by walleye young. The MEI appeared to be positively associated with increasing length-at-age for the first 6 clusters, but was much lower in the 2 high-growth-rate clusters (Fig. 5). Abundance of adult bluegills had a consistent negative association with bluegill growth, with the 2 fast-growing groups having relatively low adult bluegill CPE (Fig. 6). The abundance of young bluegills appeared to be a negative influence in the first 6 clusters, but was relatively high in the 2 faster growing clusters (Fig. 7). Abundance of young yellow perch was only moderately related to bluegill growth for

Table 3. *Mean bluegill lengths for each cluster number. A detailed listing of the lakes in each cluster and the mean length in each lake is given in Appendix B.*

	Mean Length (inches) by Cluster Number							
	1	2	3	4	5	6	7	8
Age 2	2.18	2.59	2.94	3.32	3.91	4.42	3.27	4.42
Age 3	2.95	3.44	3.87	4.38	4.98	5.58	4.80	6.13
Age 4	3.67	4.22	4.70	5.34	5.93	6.58	6.31	7.76
Age 5	4.34	4.94	5.47	6.23	6.80	7.49	7.80	9.27
Age 6	4.97	5.63	6.20	7.07	7.60	8.32	9.28	10.75

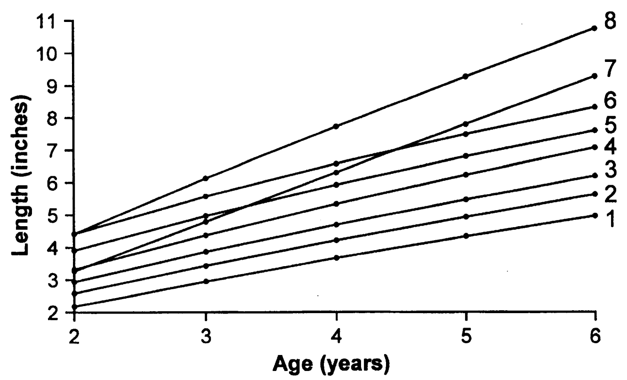


Figure 2. *Bluegill length-at-age averaged for all lakes in each bluegill growth cluster. Clustering was based on bluegill growth and performed using methods described in the text. Eight clusters provided an optimal separation of different bluegill growth patterns.*

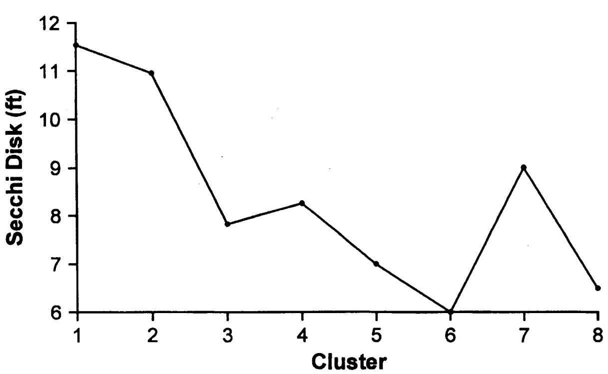


Figure 3. *Mean secchi disc depth for lakes in each of the 8 bluegill growth clusters. Cluster number is from Table 3 and Figure 2, and is arranged in order of increasing length-at-age for ages 5 and 6.*

the first 6 clusters, but was very high in clusters 7 and 8, the fastest growing bluegill groups (Fig. 7).

The relationships between bluegill growth and the remaining variables, young rock bass (Fig. 8), brown bullheads (Fig. 8) and black crappie (Fig. 9), were not linear. The abundance of rock bass was low except in clusters 5 and 7; the abundance of brown bullheads was low except in clusters 1, 6, and 8; and the abundance of black crappies was low except in cluster 6. While these variables contributed significantly to the separation of clusters, relating their abundances to bluegill growth is difficult. Probably the observed relationships were chance associations or nonlinearly dependent on some underlying variable.

When the bluegill lengths-at-age average deviations were subjected to the stepwise regression analysis, a 7-variable model explaining 46.4% of the variance was found. The criteria for selecting the model from the sequence of candidate models were subjective, but the general rule was that the model chosen had the largest R^2 value with all variables (except the included fractional age adjustment) significant at the nominal 5% level. Most of the variables in the multiple regression model for bluegills were included in the stepwise discriminant model discussed above. All variables showed similar relationships to bluegill growth. Secchi disk readings and abundance of bluegill adults were negatively related to bluegill growth, while MEI, abundance of walleye young and abundance of yellow perch young were positively related to bluegill growth.

Abundance of adult walleyes was also positively related to bluegill growth but this variable was not selected by the stepwise discriminant procedure. Conversely, abundances of bluegill, rock bass, black crappie, and brown bullhead young were not selected by the stepwise regression model although included in the stepwise discriminant analysis. This was because the abundance of the latter 4 species was nonlinearly related to bluegill growth and would not be detected by the linear multiple regression techniques.

Lakes with the fastest growing bluegills had relatively low water clarity, high MEI, high walleye populations (particularly walleyes under 10 inches), large numbers of yellow perch under 5 inches, great variation in bluegill reproduction (as indicated by the absence of bluegills under 3 inches in many lakes), and low numbers of bluegills over 3 inches. Conversely, lakes with the slowest growing bluegills had no walleye or low numbers of adult walleyes, and fairly consistent bluegill reproduction

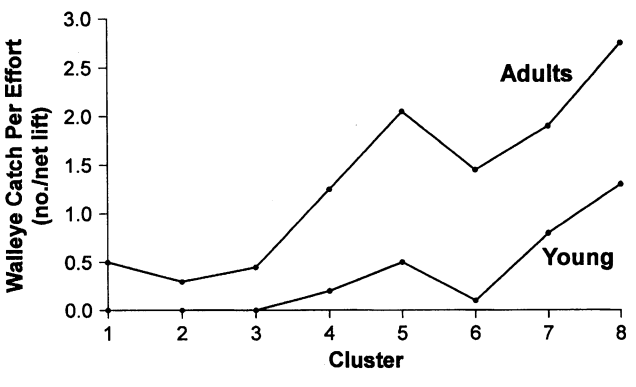


Figure 4. *Mean walleye adult and young catch per effort for lakes in each of the 8 bluegill growth clusters. Cluster number is from Table 3 and Figure 2, and is arranged in order of increasing length-at-age for ages 5 and 6.*

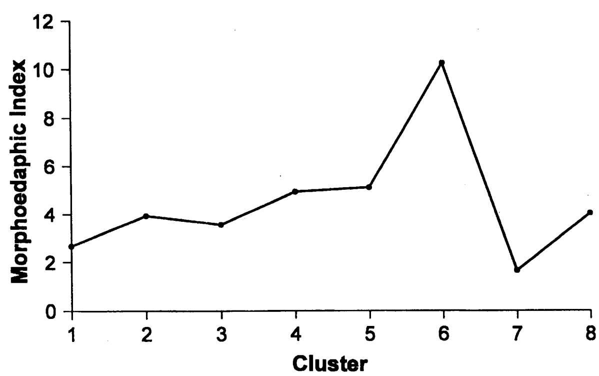


Figure 5. *Mean morphoedaphic index (0.65 x conductivity divided by mean depth) for lakes in each of the 8 bluegill growth clusters. Cluster number is from Table 3 and Figure 2, and is arranged in order of increasing length-at-age for ages 5 and 6.*

as indicated by the high numbers of all sizes of bluegills. Slow-growing bluegill populations also occurred in clear, unproductive lakes with low MEI, low alkalinity, and low conductivity. High adult growth rates but modest young growth rates, as typified by cluster 7, occurred in lakes with higher clarity when the MEI was low and the number of walleye young was very high. Factors such as abundance of rock bass, brown bullhead, and black crappie young may have been related to bluegill growth in certain growth ranges, but no consistent pattern was found.

The majority of lakes with walleye in this study had fast-growing bluegills and did not historically contain walleye. Therefore, it is possible that walleye stocking improved bluegill growth. Of the 115 lakes with bluegills sampled in this study, 61 had walleye; of these only 12 had native walleye populations. The remaining 49 lakes were stocked with walleye. In those lakes where walleye reproduction occurred or where repeated stocking maintained a walleye population of several age groups (clusters 5, 6, 7, and 8), bluegill growth was faster than in lakes where walleye reproduction or stocking did not occur for 8 to 10 years (clusters 1, 2, 3, and 4).

Lakes with low winter dissolved oxygen (DO) levels were also associated with faster growing bluegills. We unsuccessfully and indirectly tried to incorporate low DO levels in our analysis through depth variables. However, a review of the history of each lake reveals that low winter DO is an important variable related to bluegill growth. Eight lakes (44%) of the 18 sampled in the 3 fastest growing clusters (6, 7, and 8), had a history of low winter DO. In contrast, 6 lakes (6%) of the 97 sampled in the remaining 5 clusters had a history of low winter DO. As stated in Methods, no lakes were included in this report that had known winterkill more than once every 5 years. Although winterkill may be rare, low DO can occur frequently or annually. For example, Bucks Lake in cluster 6 had DO levels of 1.0 mg/L or less at the outlet during 8 of 10 consecutive years, but no observed winterkill (Snow and Beard 1972). Low DO and/or high density walleye populations were found in every lake in clusters 6, 7, and 8.

Other authors have found that bluegill populations were food-limited. Osenberg et al. (1988) found that young bluegill growth was significantly density-dependent, and growth of large bluegills—which fed primarily on zooplankton—was food

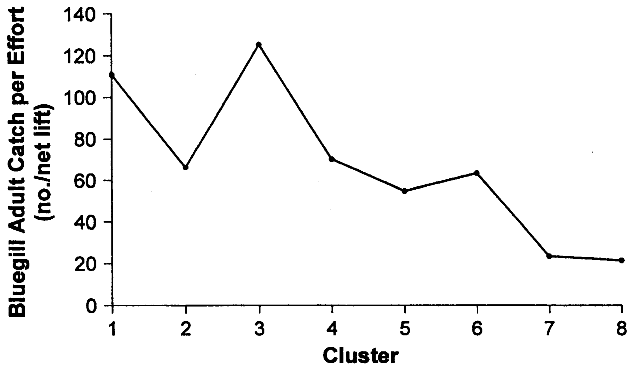


Figure 6. *Mean bluegill adult catch per effort for lakes in each of the 8 bluegill growth clusters. Cluster number is from Table 3 and Figure 2, and is arranged in order of increasing length-at-age for ages 5 and 6.*

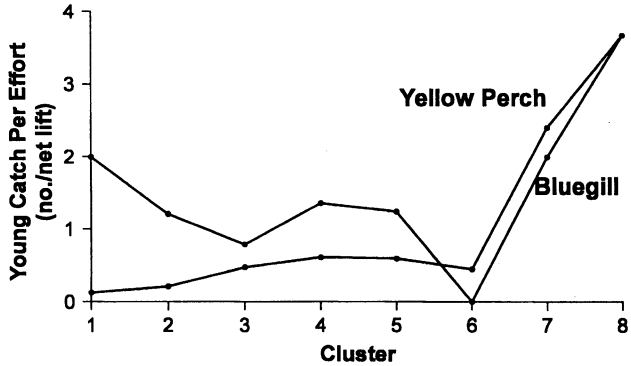
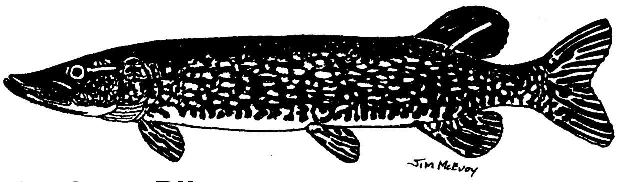


Figure 7. *Mean bluegill and yellow perch young catch per effort for lakes in each of the 8 bluegill growth clusters. Cluster number is from Table 3 and Figure 2, and is arranged in order of increasing length-at-age for ages 5 and 6.*

limited. Studies where bluegill growth is density dependent are common (Gerking 1962, Werner and Hall 1977, Beard 1982, Weiner and Hanneman 1982, Coble 1988, Clark and Lockwood 1990).

Bluegill growth has also been shown to be affected by lake characteristics. Engel (1985) suggested bluegill growth was related to macrophyte composition and density. Theiling (1990) performed an analysis of 30 Michigan lakes and found bluegill growth most closely related to macrophyte density, zooplankton size and profundal benthos, with lake morphology affecting macrophyte distribution.



Northern Pike

Northern pike growth was compared to physical and biological factors using stepwise regression on length-at-age average deviation. The mean length at age was based on 58 lakes. An 8-variable model accounting for 59.0% of the variation includes the following:

Variable	Sign of Relationship
Sample date	+
Yellow perch adults	+
Rock bass young	+
Shoreline length	-
Secchi disk	-
Pumpkinseed adults	-
Largemouth bass adults	-
Bluegill young	-

Disparate units of measurements make the actual values of the coefficients difficult to interpret and the significance levels are inaccurate as discussed above, hence only the sign of the relationship is given. All variables are significant at the nominal 5% level.

Better northern pike growth apparently occurs in smaller, more turbid lakes with good populations of yellow perch and rock bass. Turbidity may be an indicator of higher productivity. Diana (1983) suggests that northern pike growth may be related to primary productivity. Studies in Minnesota indicate northern pike can prey heavily on yellow perch (Anderson and Schupp 1986, Wesloh and Olson 1962). Declines in prey populations, primarily yellow perch and rock bass,

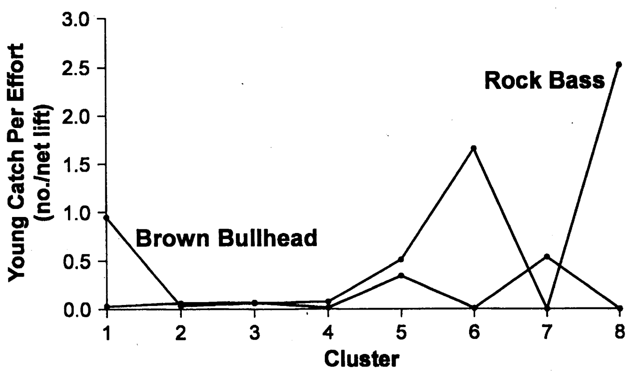


Figure 8. *Mean rock bass and brown bullhead young catch per effort for lakes in each of the 8 bluegill growth clusters. Cluster number is from Table 3 and Figure 2, and is arranged in order of increasing length-at-age for ages 5 and 6.*

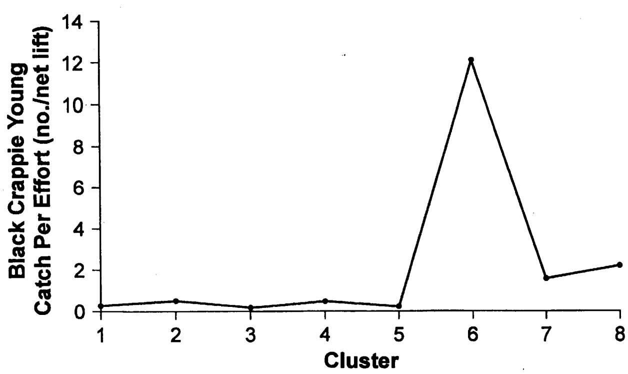
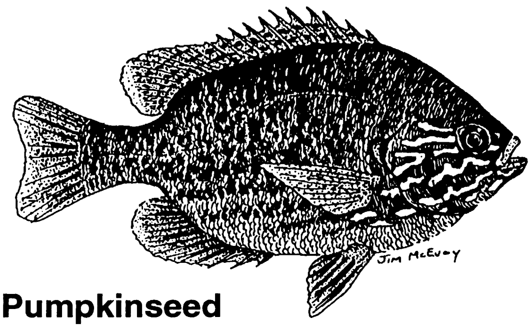


Figure 9. *Mean black crappie young catch per effort for lakes in each of the 8 bluegill growth clusters. Cluster number is from Table 3 and Figure 2, and is arranged in order of increasing length-at-age for ages 5 and 6.*

were linked to increased northern pike populations in Escanaba Lake, Wisconsin (Kempinger and Carline 1977, 1978).

Poorer growth occurred in larger, clearer lakes and/or lakes with good populations of pumpkinseed, bluegill young and largemouth bass. There was no indication of any density-dependent growth effects, although the late spring and summer fyke netting may not have adequately sampled northern pike populations. Diana (1987) suggested that northern pike stunting can result from food competition, lack of larger prey items, and warmer water temperatures. Latta (1971), Mauck and Coble (1971), and Snow (1974) all suggested that northern pike are not an effective predator on bluegill. Johnson (1969) found that bluegill were a common diet item for northern pike in Murphy Flowage, Wisconsin, but still showed slow growth.

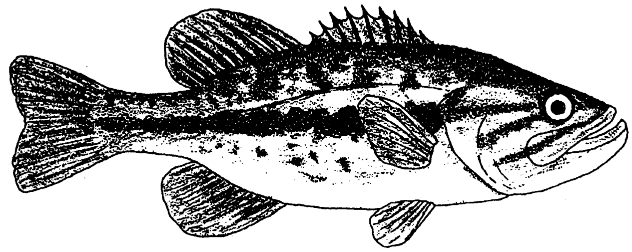


Pumpkinseed

The stepwise regression analysis of pumpkinseed length-at-age average deviations included 64 lakes and produced a 5-variable model accounting for 40.5% of the variation in the growth index:

Variable	Sign of Relationship
Sample date	+
Pumpkinseed young	+
Largemouth bass young	+
Secchi disk	-
Pumpkinseed adults	-

All variables are significant at the nominal 6% level. Larger pumpkinseed seemed to occur in lakes with low water clarity and lakes with high numbers of pumpkinseed and largemouth bass young. A density-dependent effect was indicated by the negative relationship between the growth index and the density of pumpkinseed adults, although this was confounded by an observed positive relationship between growth and pumpkinseed young abundance. Osenberg et al. (1988) found that growth of small pumpkinseeds was density dependent, and that growth of large pumpkinseeds was food limited.



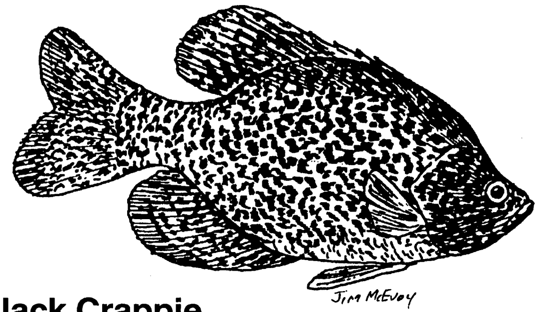
Largemouth Bass

The stepwise regression analysis of the largemouth bass growth index included 67 lakes and yielded a 6-variable model accounting for 35.6% of the variance:

Variable	Sign of Relationship
Sample date	+
Water source	Higher in larger drainage lakes
Shoreline length	+
Brown bullhead adults	+
Walleye adults	+
Secchi disk	-

All variables are significant at the nominal 7% level. Again, growth was negatively related to water clarity. Low water clarity may have been characteristic of more productive lakes, and drainage lakes are typically more productive. Better growth also occurred in larger drainage lakes, and seemed associated with higher populations of walleyes and brown bullheads.

These factors did not provide intuitive interpretation, as many potential forage species and abundance of largemouth bass themselves were not associated with the growth index. Again, fyke netting CPE may not have been a sensitive index of predator density. Colby et al. (1987) discussed a possible negative interaction between largemouth bass and brown bullhead abundance. Hodgson and Kitchell (1987) suggested that largemouth bass diets can include a variety of organisms and can be affected by the level of inter- and intraspecific competition present. Latta (1975) indicated that food availability, temperature, and abundance of other bass are important in controlling largemouth growth.



Black Crappie

Stepwise regression analysis on the black crappie growth index was possible for 58 lakes. A 7-variable model accounted for 49.2 % of the variation in the growth index:

Variable	Sign of Relationship
Sample date	+
Shoreline length	+
Rock bass adults	+
Bluegill adults	+
Walleye adults	+
Brown bullhead young	+
Black crappie adults	-

All variables are significant at the nominal 9% level. There was evidence of a possible density-dependent relationship, and possible positive relationships with abundance of several species. Faster growing crappies also tended to occur in large waters. Water clarity was not a significant predictor of crappie growth. Several authors have reported negative relationships between walleye and black crappie abundance (Kempinger 1972, Schiavone 1981, Colby et al. 1987).

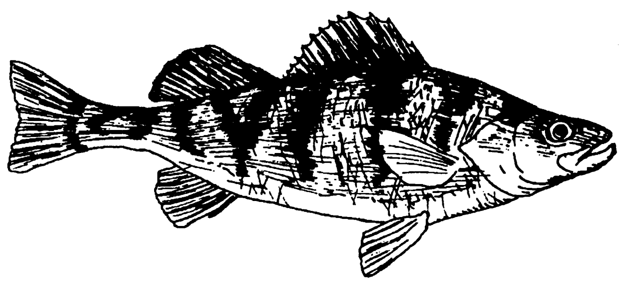
Yellow Perch

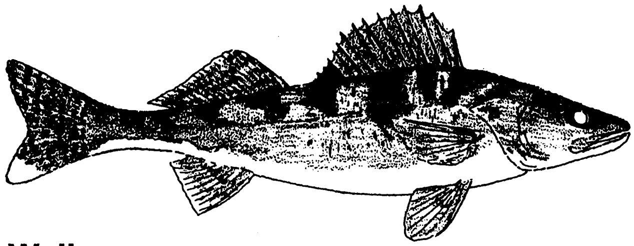
Stepwise regression analysis of yellow perch growth was possible for 52 lakes. A 6-variable regression accounted for 43.2% of the variation in the yellow perch growth index:

Variable	Sign of Relationship
Sample date	+
Conductivity	+
Shoreline development factor	+
Largemouth bass adults	+
Walleye adults	+
Northern pike adults	-

All variables are significant at the nominal 5% level. Although no density-dependent effects were noted, predator-prey relationships with potential predator species were suggested. Again a function of shoreline was related to growth, and yellow perch seem to grow better in waters with high conductivities. Higher conductivity lakes tend to be more productive.

A density-dependent growth relationship for perch in this study may be absent because perch comprised a small proportion of the total fish community in the lakes sampled. Boisclair and Leggett (1989), in a study in 12 Quebec lakes, found that the density of the whole fish community was more important to perch growth rates than attributes of any single species. Several authors have documented the importance of yellow perch as a forage species for walleyes (e.g., Forney 1980, Colby et al. 1987), largemouth bass (Anderson and Schupp 1986) and northern pike (Anderson and Schupp 1986). In Oneida Lake, New York, yellow perch growth was primarily related to abundance of perch young of the year and invertebrates (Tarby 1974).





Walleye

The stepwise regression analysis of the walleye growth index included 46 lakes. An 8-variable model accounted for 60.6% of the variance in the walleye growth index:

Variable	Sign of Relationship
Sample date	+
Secchi disk	+
Yellow bullhead adults	+
Bluegill young	+
Rock bass adults	-
Yellow bullhead young	-
Pumpkinseed young	-
Largemouth bass young	-

All variables are significant at the nominal 3% level. Better walleye growth was associated with higher Secchi disk readings and abundance of yellow bullhead adults and bluegill young. Higher Secchi disk measurements may be characteristic of lower-productivity water but may favor a sight-feeding predator. Negative relationships with rock bass adults and the young of the other species are difficult to explain. There appeared to be no density-dependent effects, although the late spring and summer fyke netting may not have adequately sampled walleye populations.

Walleye growth has been extensively studied in other waters, but do not support the results seen here. Walleye typically grow best when there are abundant fish prey, primarily yellow perch and warmer water temperatures (Smith and Pycha 1960, Forney 1965, Priegel 1969, Serns 1984, Colby et al. 1987). Walleye are also known to grow better when potential prey species exhibit slower growth and remain vulnerable longer (Forney 1980). There is little evidence from the literature that walleye typically prey on bluegill (Snow 1988, Goeman et al. 1990).

Vegetation Parameters

The following vegetation parameters were entered as independent variables in the analyses of growth: percent of lake area covered by submerged, emergent, and floating vegetation and total vegetation cover. The number of lakes that could be included in the analysis ranged from only 22 for walleyes to 39 for bluegills. No relationships between any of the vegetation parameters and growth were found for northern pike, bluegills, or walleyes. Largemouth bass growth was positively associated with percent of lake area covered by emergent vegetation. Pumpkinseed growth was negatively associated with percent submerged vegetation. Both black crappie and yellow perch growth were positively associated with percent floating vegetation. All of these associations are significant at least at the nominal 6% level.

Theiling (1990) found a correlation between bluegill growth and macrophyte density. Other authors have identified macrophyte density and species composition as likely determinants of fish growth in bluegills and largemouth bass (Diggins et al. 1979, Crowder and Cooper 1982, Fairchild 1982, Savino and Stein 1982, Keast 1984, Engel 1985, Mittelbach 1988, Savino and Stein 1989, Gotceitas 1990). It is likely that if the vegetation parameters had been available for more study lakes and had been included with the other physical and biological independent factors, more information on the relationships between growth and vegetation would have been revealed.

Analyses of PSD

The relationships between PSD and the growth indices of various species were analyzed because there has been much emphasis on the use of PSD as an index of the condition of the fish community structure (e.g., Anderson 1976, Anderson and Weithman 1978). The use of PSD instead of the CPE independent factor produced models that accounted for less variation and were more difficult to interpret. The most consistent relationships were for northern pike, bluegill, black crappie, yellow perch, and walleye, where the growth index was positively associated with the PSD estimate. This result suggests that PSD may be influenced by growth rates as was found by Carline et al. (1984). However, Serns (1985) found that PSD for walleyes in Escanaba Lake were unrelated to growth.

Other associations were: (1) northern pike exhibited better growth in lakes with higher brown and black bullhead PSD, (2) pumpkinseeds and black crappie grew larger in lakes with a high yellow perch PSD, (3) walleye grew better in lakes with high black and yellow bullhead PSD and worse in lakes with a high northern pike PSD, (4) bluegills grew better in lakes with high PSD of walleye and brown bullhead, and (5) largemouth bass grew better in lakes with high bluegill PSD. Some of these relationships, such as the largemouth bass-bluegill association, may have predator-prey relationship interpretation; but others, such as the positive association with bullhead PSD, may be no more than an association of species with similar patterns of abundance and growth.

Summary

As stated previously in the Caveat section, these results should be viewed as hypothetical. Some of the findings were consistent with commonly accepted notions about predator-prey interactions and population growth dependencies as indicated by similar results from other studies, but many were difficult to rationalize or contradicted results from other studies. Our failure to identify some expected relationships may be due to lake selection, gear type, and sampling date biases. Also, other studies clearly show that there is considerable variation in factors which correlate with growth of these 8 species.

In this study, most species showed better growth in waters with lower clarity and larger shorelines. If water clarity can be taken as an index of general productivity, then future work may identify more specific predictive models based on Secchi disk readings. Walleyes showed better growth in clearer lakes. Density-dependent growth effects were noted in bluegills, pumpkinseed and black crappies. However, for the pumpkinseed, better growth was associated with high abundances of smaller fish of the same species, possibly underscoring the importance of good reproduction.

Forage abundance was not clearly associated with growth of largemouth bass, walleyes, or northern pike. Walleye growth may have been associated with bluegill young abundance, and northern pike growth may have been associated with rock bass young and yellow perch adults, but predator growth was often negatively related to potential forage fishes. The selection of the size groups for classifying potential forage species as young versus adults may have contributed to the insensitivity of the analysis. An index that included other forage species (minnows, suckers, crayfish, etc.) and abundance of young-of-the-year panfish may have shown a positive relationship with predator growth, but the necessary data were not available. Also the forage abundance was indexed by a single sample in only one year while predator growth was probably influenced by forage abundance over more than that single year.

In contrast, abundance of predators seemed to be consistently related to growth of panfishes. High populations of walleyes were associated with good growth of bluegills, black crappies, and yellow perch. Low winter DO was also associated with good bluegill growth. Largemouth bass young were found in high numbers in lakes with good pumpkinseed growth. Predators, especially walleye and largemouth bass, generally live longer than most prey species so a single abundance sample has a better likelihood of portraying the predator population during the preceding growth periods. The success of detecting predation effects versus the failure to detect the effect of the prey on the predators may be linked to the difference in longevity.

Growth of many species apparently influenced estimates of one species PSD. Bluegills exhibited better growth in lakes with high walleye PSD and largemouth bass showed better growth in lakes with high bluegill PSD. The PSD of the 3 bullhead species was often positively associated with growth of bluegills, northern pike, black crappie, and walleye.

Little information could be obtained from the vegetation analyses because of the lower number of lakes sampled. From the data available, however, largemouth bass grew better in lakes with more emergent vegetation, while black crappies and yellow perch grew better in lakes with more floating vegetation. Pumpkinseeds exhibited slower growth in lakes with more submerged vegetation.

As a final note, these lakes were selected in a nonrandom fashion. We believe the lakes are a "representative sample" of the lakes in northwestern Wisconsin. Thus the associations suggested by these analyses should be generally representative of other northwestern Wisconsin lakes and probably of lakes in other areas as well.

Management Implications

Results from this study can not be used to directly justify management actions. Biases in lake selection, sampling gear, and sampling dates and the lack of clearly testable study hypotheses make the results primarily useful for hypothesis generation. We have, however, identified some correlations which, if borne out through further observation or experimentation, will have practical management applications.

Bluegill growth appeared to be at least partially density dependent. Further experimentation with management actions that reduce bluegill density or reproduction such as predator stocking or removals may yield workable management options.

A positive relationship between bluegill growth and walleye density reinforced this finding. There was also evidence for density dependence in pumpkinseed and black crappie, although management of these species is often a lower priority.

Largemouth bass growth was positively correlated with aquatic vegetation cover. Further work on the use of aquatic plants by largemouth bass and their prey may suggest effective management activities for aquatic plants in northwestern Wisconsin waters. Northern pike growth was positively correlated with the abundance of yellow perch and rock bass, both potential prey species. If northern pike are found to prey heavily on these species, growth could be improved in some waters by managing prey species more intensively.

Secchi disk transparency may be a useful predictor of growth in many species. Lower water transparency probably associated with higher lake productivity was correlated with higher growth rates in bluegills, northern pike, pumpkinseed, and largemouth bass. The reverse was found for walleye. Further study of this relationship may allow managers to classify waters or predict fish growth using this inexpensive index.

The statistical grouping of bluegill growth into clusters provides a practical classification system for bluegill lakes. Comparing observed lengths at age with Figure 2 and Table 3 will quickly identify lakes with similar growth patterns. A better understanding of the mechanisms that control growth will suggest appropriate management actions for lakes in slower growth groups.

Finally, the development of the fractional age adjustment and average deviation growth index provide new analysis options for managers or researchers faced with nonstandardized data sets. The successful application of the cluster and discriminant analyses again verifies the usefulness of these analytical techniques for nonlinear ecological relationships.

Appendix A. *List of all lakes sampled for the study with physical and limnological characteristics.**

Lake Name and County	Sample Date	Surface Area			Depth		Water Source	Shoreline Length	SDF	Secchi Disc	Alkalinity	Conductivity	MEI
		Total	% < 5 ft	% < 10 ft	Mean	Max							
Anderson, Barron	04/27/76	14	21	47	10	17	2	0.7	1.5	5	12	29	1.9
Antler, Polk	08/13/77	101	16	52	9	22	2	2.8	2.0	8	15	41	3.0
Bashaw, Burnett	09/21/77	171	41	77	7	16	1	3.2	1.8	3	102	195	18.1
Bass T31R8S19, Chippewa	08/05/76	9	–[a]	–	–	23	2	0.5	1.1	13	9	22	–
Bass T31R8S24, Chippewa	09/17/74	12	–	–	–	41	2	0.9	1.8	13	5	15	–
Bass T39R14S24, Burnett	07/20/76	31	–	–	–	27	2	1.0	–	12	24	39	–
Bass T39R16S23, Burnett	07/25/78	226	24	49	11	24	2	2.4	1.1	8	15	38	2.2
Bass T40R10S17, Washburn	09/28/77	188	14	24	20	35	2	2.9	1.5	9	20	42	1.4
Bass T40R13S29, Washburn	10/05/77	144	15	29	18	31	2	2.7	1.6	15	40	86	3.1
Bean, Washburn	10/11/78	100	20	32	16	35	1	2.1	1.5	11	67	139	5.6
Bear Track, Washburn	05/02/78	65	24	54	14	36	2	2.3	1.7	11	15	36	1.7
Big Butternut, Polk	10/11/80	378	16	25	13	19	1	3.4	1.2	8	83	187	9.3
Big Moon, Barron	06/28/78	191	24	29	24	48	1	3.2	1.7	5	91	238	6.4
Big Ripley, Washburn	08/22/78	190	14	61	10	27	2	2.5	1.3	13	12	31	2.0
Big, Polk	09/16/80	259	15	22	17	24	1	3.0	1.3	4	85	192	7.3
Bladder, Bayfield	10/18/78	81	18	37	16	35	2	2.2	1.7	13	16	30	1.2
Boner, Burnett	07/20/77	89	14	53	9	15	2	1.8	1.4	4	4	21	1.5
Bucks, Rusk	09/06/79	83	93	98	3	18	1	4.0	3.1	13	50	117	25.3
Burlingame, Burnett	07/21/77	57	30	51	10	19	1	1.4	1.3	12	43	87	5.7
Cable, Washburn	09/09/78	185	31	85	7	24	2	2.8	1.5	8	25	57	5.3
Callahan, Sawyer	08/08/79	586	40	79	7	18	1	6.4	2.8	9	40	88	8.2
Chicog, Washburn	07/28/77	125	14	27	15	25	1	2.7	1.7	5	65	142	6.2
Clear, Sawyer	09/12/75	77	17	41	14	32	2	2.2	1.8	18	32	63	2.9
Crooked T38R16S8, Burnett	07/27/78	180	42	98	6	10	2	4.3	2.3	9	4	36	3.9
Currier, Sawyer	05/21/75	19	16	26	18	39	2	0.9	1.5	13	3	7	0.3
Deep T38R11S18, Washburn	04/25/78	43	16	33	13	29	2	1.8	1.9	8	5	12	0.6
Diamond, Bayfield	06/21/78	341	11	21	33	83	1	5.0	1.9	12	33	68	1.3
Dowling, Douglas	10/13/78	154	18	89	7	13	1	2.0	1.1	4	22	56	5.2
Dugan, Washburn	08/25/76	53	14	29	14	35	2	1.3	1.8	5	8	21	1.0
Dunham, Burnett	06/27/78	243	12	18	35	63	1	3.0	1.4	11	80	148	2.7
Dunn, Washburn	08/03/78	193	17	25	18	39	1	3.6	1.8	8	40	92	3.3
Elbow, Washburn	06/27/75	36	–	–	–	25	2	1.9	2.2	15	4	18	–
Ellsworth, Washburn	07/20/78	174	89	99	4	6	2	3.1	1.7	6	37	64	10.4
Falk, Burnett	09/26/79	82	42	56	11	31	1	2.7	2.1	11	50	92	5.4

(Continued on next page).

Appendix A. *Continued.*

Lake Name and County	Sample Date	Surface Area			Depth		Water Source	Shoreline Length	SDF	Secchi Disc	Alkalinity	Conductivity	MEI
		Total	% < 5 ft	% < 10 ft	Mean	Max							
Fenton, Washburn	09/18/78	139	21	37	15	52	2	4.2	2.5	12	8	24	1.0
Gibson, Polk	09/15/76	43	–	–	–	12	2	1.0	–	2	14	48	–
Godfrey, Burnett	06/29/76	56	68	80	8	41	2	1.6	1.4	10	42	77	6.3
Granite, Barron	09/30/78	154	12	24	18	34	1	3.7	2.0	3	34	74	2.7
Green T38R9S29, Sawyer	08/03/76	12	33	50	12	35	2	0.7	1.5	17	6	17	0.9
Greenquist, Polk	04/28/80	58	14	36	13	30	2	1.5	1.4	3	10	34	1.7
Gull, Burnett	09/07/78	182	76	91	4	19	1	5.0	2.6	9	55	102	16.6
Helbig, Polk	08/27/75	61	–	–	–	44	2	2.3	2.1	–	16	54	–
Herby, Polk	06/13/77	69	16	31	16	36	2	2.4	2.1	3	60	164	6.7
Horseshoe, Barron	06/13/78	115	23	54	10	19	2	2.6	1.7	9	13	31	2.0
Iron, Bayfield	09/15/82	248	–	–	–	13	1	3.3	1.5	8	63	121	–
Kekegama, Washburn	10/24/78	110	25	36	12	24	1	3.2	2.1	8	82	186	10.1
Knickerbocker, Chippewa	08/03/76	14	16	28	–	24	2	0.7	1.2	3	10	27	–
Knuteson, Sawyer	08/29/78	70	18	49	10	17	1	1.5	1.3	3	40	79	5.1
Leach, Washburn	07/13/76	30	30	47	13	32	2	2.0	2.6	9	12	–	–
Lincoln, Washburn	10/12/77	101	28	41	13	27	1	1.9	1.4	8	35	83	4.1
Little Bass T40R13S31, Washburn	9/01/77	26	23	36	17	51	2	0.9	1.2	13	34	67	2.6
Little Sand, Barron	08/16/79	101	24	39	13	36	2	2.1	1.5	2	9	45	2.2
Little Kekegama, Washburn	06/13/78	30	–	–	–	21	2	1.1	1.4	8	5	21	–
Little Mirror, Polk	05/01/79	33	15	33	10	13	2	0.9	1.2	7	99	267	17.4
Little McGraw, Burnett	08/04/76	55	44	95	6	12	2	1.5	1.4	10	12	34	3.7
Little Sand, Washburn	10/04/78	74	14	32	12	21	2	1.3	1.1	11	24	45	2.4
Little Long, Burnett	09/09/79	97	21	58	10	40	2	2.1	1.5	7	5	14	0.9
Long T41R14S28, Burnett	09/22/79	251	20	40	18	41	2	4.7	2.1	20	42	78	2.8
Loon, Barron	09/13/80	94	17	43	11	26	2	2.4	1.8	4	9	31	1.8
Love, Burnett	09/26/79	253	–	–	–	63	1	5.4	2.4	13	62	134	–
Loveless, Polk	05/28/79	141	10	17	15	20	2	2.5	1.6	9	69	192	8.3
Lower Vermillion, Barron	06/21/78	208	15	26	24	55	1	3.0	1.5	4	92	189	5.1
Lower Devils, Barron	06/21/78	162	36	61	9	26	2	5.6	2.5	7	8	32	2.3
Lower Turtle, Barron	10/04/80	276	16	30	14	24	1	3.8	1.6	4	108	192	8.9
Lower McKenzie, Washburn	08/01/78	185	30	54	9	17	1	3.1	1.6	10	62	127	9.2
Magnor, Polk	10/15/78	231	25	64	10	15	1	2.6	1.2	3	21	–	–
McGraw, Burnett	09/13/77	135	18	39	13	25	2	2.7	1.6	4	44	93	4.6
McLain, Washburn	08/30/77	150	15	53	11	30	2	2.0	1.2	19	12	47	2.8

(Continued on next page).

Appendix A. *Continued.*

Lake Name and County	Sample Date	Surface Area Total	Surface Area % < 5 ft	Surface Area % < 10 ft	Depth Mean	Depth Max	Water Source	Shoreline Length	SDF	Secchi Disc	Alkalinity	Conductivity	MEI
Minerva, Burnett	09/19/79	222	–	–	–	22	1	5.9	2.8	7	24	46	–
Minnesuing, Douglas	09/04/80	432	20	27	18	43	1	6.9	2.4	7	48	96	3.5
Murray, Douglas	07/31/75	43	–	–	–	15	2	1.0	1.0	9	20	48	–
No Mans, Washburn	07/25/75	70	40	79	7	23	2	1.8	1.5	7	7	18	1.7
Oak T38R11S7, Washburn	07/02/75	33	–	–	–	50	2	1.1	1.3	13	6	24	–
Pear, Washburn	05/16/79	49	14	16	17	32	2	1.3	1.4	12	34	123	4.7
Plummer, Chippewa	08/18/76	41	–	–	–	28	2	1.4	1.5	6	106	227	–
Pokegama, Burnett	10/10/79	224	12	29	19	56	2	5.1	2.4	9	62	125	4.3
Poskin, Barron	09/12/78	150	15	25	16	30	1	4.1	2.4	4	81	167	6.8
Prinel, Burnett	06/28/77	64	17	99	7	12	2	1.3	1.2	10	10	27	2.5
Red, Douglas	05/24/78	258	27	41	11	37	2	3.5	1.6	10	40	77	4.5
Ripley, Washburn	08/27/76	42	–	–	–	25	2	1.7	1.9	9	8	20	–
Rock, Douglas	07/30/75	42	41	95	6	15	2	2.2	2.4	3	4	20	2.2
Rooney, Burnett	08/01/79	322	25	67	10	30	2	4.3	1.7	12	11	27	1.8
Round T37R18S27, Burnett	09/15/79	204	11	19	15	27	1	3.2	1.6	2	86	190	8.2
Saginaw, Burnett	07/15/75	13	–	–	–	19	2	0.6	1.2	14	3	13	–
Sandhill, Polk	07/11/75	44	–	–	–	12	2	1.3	1.3	6	83	178	–
Scott, Barron	04/27/80	81	36	68	9	26	2	2.1	1.7	7	9	33	2.4
Scovils, Washburn	07/23/75	66	21	62	12	37	2	1.5	1.3	13	14	34	1.8
Silver, Washburn	09/06/78	188	17	68	10	28	2	3.2	1.7	9	14	45	2.9
Sissabagama, Sawyer	05/15/80	719	22	36	16	48	1	8.2	2.2	8	34	76	3.1
Sleepy Eye, Washburn	07/18/75	39	23	98	7	10	2	1.2	1.4	7	16	23	2.1
Smith, Sawyer	09/26/80	323	7	29	15	29	1	4.5	1.8	6	51	100	4.3
Spider, Barron	07/06/75	40	–	–	–	13	2	1.9	2.1	9	3	14	–
Spider #5, Washburn	08/16/78	177	18	38	13	49	2	9.3	5.0	14	5	20	1.0
Spider #4, Washburn	08/11/78	24	29	67	9	30	2	1.5	2.2	14	6	22	1.6
Spider #3, Washburn	08/10/78	20	25	70	8	20	2	1.3	2.1	14	6	24	1.9
Spooner, Washburn	08/24/77	1092	19	95	7	17	1	11.2	2.4	7	55	108	10.0
Spring, Barron	10/02/79	60	22	35	25	67	2	2.3	2.1	8	8	13	0.3
Spring T39R10S36, Washburn	05/06/75	42	24	67	8	13	2	2.0	2.1	4	6	36	2.9
Spring T40R11S25, Washburn	09/30/78	211	30	52	12	24	2	2.5	1.2	11	30	63	3.4
Sunfish, Washburn	09/24/75	68	35	56	11	27	2	1.9	1.6	6	12	28	1.7
Sylvan, Barron	07/24/79	67	10	19	21	37	2	1.9	1.7	5	10	17	0.5
T37R10S15-02, Washburn	06/25/75	12	–	–	–	27	2	0.7	1.5	6	3	12	–
Tarbert, Polk	08/19/75	42	–	–	–	20	2	1.6	1.7	2	99	185	–

(Continued on next page).

Appendix A. *Continued.*

Lake Name and County	Sample Date	Surface Area			Depth		Water Source	Shoreline Length	SDF	Secchi Disc	Alkalinity	Conductivity	MEI
		Total	% < 5 ft	% < 10 ft	Mean	Max							
Taylor, Burnett	09/09/76	80	29	99	6	10	2	1.6	1.3	10	9	18	1.9
Thirty, Barron	07/28/76	74	23	38	13	27	2	2.3	1.7	3	8	35	1.7
Town Line, Chippewa	08/18/77	48	–	–	–	26	2	2.7	2.7	9	5	21	–
Two Island, Chippewa	08/17/77	29	–	–	–	29	2	0.9	1.2	17	5	18	–
Upper Devils, Barron	09/25/78	87	75	99	4	10	2	4.1	3.1	6	10	24	3.9
Upper Turtle, Barron	09/06/80	438	22	31	14	25	1	4.8	1.6	7	110	200	9.3
Upper Clam, Ashland	06/07/78	166	18	42	11	20	1	2.8	1.6	5	44	97	5.7
Viola, Burnett	09/12/79	285	18	52	13	33	2	4.4	1.8	15	10	30	1.5
Ward, Polk	07/30/76	91	24	36	16	43	2	2.3	1.7	17	15	39	1.6
Windfall, Sawyer	05/31/78	102	14	26	12	16	2	1.6	1.1	7	15	30	1.6
Windigo, Sawyer	08/30/80	522	28	46	14	51	2	9.0	2.8	12	6	23	1.1
Winter, Sawyer	08/08/79	676	25	50	9	22	1	10.4	2.9	5	56	126	9.1

* The following units of measurement were used:

1. Surface area—acres.
2. Depth and secchi disk—feet.
3. Shoreline length—miles.
4. Water source—1 = drainage (outlet), 2 = seepage (no outlet).
5. Alkalinity—ppm determined by methyl purple titration.
6. Conductivity—µmhos @ 77 F.
7. Shoreline development factor (SDF)—dimensionless ratio of shoreline length to to the circumference of a circle having same area as lake.
8. Morphoedaphic index (MEI)—ratio of total dissolved solids (estimated as 0.65 x conductivity) and mean depth.

[a] Missing data is indicated by a dash.

Appendix B. *Statistical grouping of study lakes into 8 clusters. Analysis was based on mean lengths at age for ages 2-6 generated from a natural log-base-ten transformed length-age relationship.*

	Mean Length (inches)				
Lake Name and County	**Age 2**	**Age 3**	**Age 4**	**Age 5**	**Age 6**
CLUSTER 1					
Antler, Polk	2.40	3.14	3.81	4.42	4.99
Big Ripley, Washburn	2.03	2.89	3.72	4.53	5.31
Clear, Sawyer	1.92	2.56	3.15	3.70	4.21
Little McGraw, Burnett	2.19	3.07	3.90	4.70	5.47
Pear, Washburn	2.10	2.91	3.67	4.39	5.08
Rooney, Burnett	2.39	3.12	3.76	4.36	4.91
Scovils, Washburn	2.21	2.98	3.69	4.35	4.98
Silver, Washburn	2.28	2.92	3.48	3.99	4.46
Spring T40R11S25, Washburn	2.18	3.07	3.92	4.72	5.51
Sunfish, Washburn	2.08	2.85	3.57	4.25	4.90
Viola, Burnett	2.22	2.97	3.66	4.30	4.90
CLUSTER 2					
Bass T31R8S1-9, Chippewa	2.92	3.54	4.06	4.52	4.93
Bass T39R16S23, Burnett	2.87	3.58	4.18	4.72	5.20
Bass T40R13S29, Washburn	2.60	3.52	4.37	5.17	5.94
Callahan, Sawyer	2.70	3.47	4.14	4.75	5.31
Dunham, Burnett	2.53	3.39	4.16	4.89	5.57
Falk, Burnett	2.44	3.41	4.32	5.19	6.04
Godfrey, Burnett	2.87	3.63	4.29	4.88	5.42
Green T38R9S29, Sawyer	2.58	3.38	4.10	4.75	5.37
Lincoln, Washburn	2.81	3.66	4.41	5.09	5.73
Little Kekegama, Washburn	2.88	3.67	4.36	4.98	5.56
Little Long, Burnett	2.60	3.50	4.33	5.09	5.82
Little Mirror, Polk	2.15	3.15	4.13	5.10	6.05
Long T41R14S28, Burnett	2.42	3.41	4.34	5.24	6.11
Loon, Barron	2.03	3.13	4.26	5.40	6.56
Love, Burnett	2.45	3.44	4.39	5.29	6.17
McGraw, Burnett	2.78	3.58	4.29	4.94	5.54
McLain, Washburn	2.57	3.39	4.13	4.82	5.46
Red, Douglas	2.59	3.45	4.22	4.94	5.61
Ripley, Washburn	2.83	3.52	4.11	4.64	5.12
Sleepy Eye, Washburn	2.65	3.48	4.22	4.90	5.54
Spider #3, Washburn	2.48	3.36	4.16	4.91	5.63
Spider #4, Washburn	2.40	3.27	4.06	4.81	5.52
Spider #5, Washburn	2.47	3.27	4.00	4.68	5.32
CLUSTER 3					
Anderson, Barron	3.17	3.90	4.52	5.07	5.56
Bean, Washburn	2.88	3.78	4.58	5.32	6.02
Chicog, Washburn	3.01	3.87	4.63	5.32	5.96
Dugan, Washburn	3.17	4.11	4.93	5.68	6.37
Elbow, Washburn	2.66	3.80	4.89	5.95	6.99
Greenquist, Polk	2.83	3.90	4.89	5.83	6.73
Helbig, Polk	3.01	4.02	4.95	5.81	6.63

(Continued on next page).

Appendix B. *Continued.*

Lake Name and County	Mean Length (inches)				
	Age 2	Age 3	Age 4	Age 5	Age 6
Little Bass T40R13S31, Washburn	3.09	3.86	4.52	5.10	5.64
Little Sand, Barron	2.88	3.80	4.62	5.38	6.10
Lower McKenzie, Washburn	2.98	3.82	4.55	5.22	5.84
Lower Vermillion, Barron	2.96	3.98	4.91	5.78	6.61
Minerva, Burnett	2.80	3.70	4.51	5.25	5.95
Pokegama, Burnett	2.69	3.68	4.59	5.45	6.27
Saginaw, Burnett	2.69	3.74	4.72	5.67	6.57
Scott, Barron	2.48	3.56	4.60	5.61	6.60
Spider, Barron	3.35	4.16	4.85	5.46	6.01
Sylvan, Barron	3.06	3.94	4.71	5.41	6.06
Town Line, Chippewa	3.30	4.03	4.65	5.19	5.68
CLUSTER 4					
Bass T31R8S2-4, Chippewa	3.76	4.62	5.36	6.01	6.59
Bass T39R14S24, Burnett	2.86	4.18	5.47	6.74	7.99
Big Moon, Barron	3.88	4.81	5.59	6.28	6.91
Big, Polk	3.04	4.15	5.19	6.16	7.09
Bladder, Bayfield	3.15	4.31	5.38	6.39	7.36
Boner, Burnett	3.52	4.44	5.24	5.96	6.62
Burlingame, Burnett	3.25	4.23	5.09	5.88	6.62
Currier, Sawyer	3.78	4.70	5.48	6.17	6.80
Deep T38R11S18, Washburn	3.29	4.44	5.50	6.49	7.43
Dunn, Washburn	3.39	4.31	5.11	5.83	6.50
Fenton, Washburn	3.49	4.49	5.35	6.14	6.87
Gull, Burnett	3.36	4.33	5.19	5.97	6.69
Kekegama, Washburn	3.27	4.28	5.18	6.00	6.77
Knuteson, Sawyer	3.32	4.33	5.22	6.04	6.80
Little Sand, Washburn	2.73	3.95	5.15	6.32	7.47
Loveless, Polk	3.31	4.36	5.36	6.25	7.10
Minnesuing, Douglas	3.06	4.25	5.37	6.43	7.46
Plummer, Chippewa	2.95	4.17	5.33	6.45	7.54
Poskin, Barron	3.57	4.58	5.47	6.27	7.02
Sandhill, Polk	3.60	4.56	5.39	6.13	6.82
Spooner, Washburn	3.28	4.34	5.29	6.17	6.99
Spring, Barron	2.78	4.10	5.41	6.70	7.98
Taylor, Burnett	3.41	4.33	5.14	5.86	6.53
Thirty, Barron	3.75	4.70	5.52	6.26	6.93
Two Island, Chippewa	3.48	4.49	5.39	6.21	6.97
T37R10S15-02, Washburn	2.86	4.18	5.47	6.73	7.99
Winter, Sawyer	3.61	4.64	5.55	6.37	7.13

(Continued on next page).

Appendix B. *Continued.*

Lake Name and County	Mean Length (inches) Age 2	Age 3	Age 4	Age 5	Age 6
CLUSTER 5					
Bashaw, Burnett	3.80	4.99	6.05	7.02	7.93
Bass T40R10S17, Washburn	3.54	4.76	5.88	6.93	7.92
Bear Track, Washburn	3.23	4.49	5.66	6.78	7.86
Cable, Washburn	3.69	4.93	6.05	7.09	8.07
Dowling, Douglas	4.85	5.68	6.34	6.91	7.41
Ellsworth, Washburn	4.22	5.14	5.91	6.59	7.21
Granite, Barron	3.24	4.51	5.70	6.84	7.93
Herby, Polk	3.62	4.76	5.78	6.73	7.61
Knickerbocker, Chippewa	4.47	5.23	5.85	6.38	6.85
Murray, Douglas	4.09	4.93	5.62	6.23	6.77
No Mans, Washburn	3.76	4.95	6.01	6.99	7.91
Oak T38R11S7, Washburn	4.14	5.02	5.75	6.39	6.97
Rock, Douglas	4.38	5.30	6.07	6.74	7.35
Sissabagama, Sawyer	3.51	4.80	5.99	7.11	8.19
Upper Clam, Ashland	3.98	5.10	6.07	6.96	7.78
Upper Turtle, Barron	3.60	4.75	5.77	6.72	7.60
Ward, Polk	4.32	5.29	6.11	6.83	7.48
Windfall, Sawyer	3.85	5.05	6.13	7.13	8.06
CLUSTER 6					
Big Butternut, Polk	4.19	5.42	6.50	7.48	8.40
Bucks, Rusk	4.65	6.00	7.19	8.28	9.28
Crooked T38R16S8, Burnett	4.16	5.27	6.23	7.10	7.91
Gibson, Polk	4.14	5.32	6.36	7.30	8.18
Round T37R18S27, Burnett	4.53	5.58	6.46	7.24	7.95
Smith, Sawyer	4.25	5.38	6.35	7.23	8.04
Tarbert, Polk	5.01	6.09	6.99	7.78	8.50
CLUSTER 7					
Diamond, Bayfield	3.17	4.73	6.29	7.85	9.41
Iron, Bayfield	3.18	4.79	6.42	8.05	9.69
Magnor, Polk	3.28	4.83	6.36	7.87	9.37
Prinel, Burnett	3.41	4.87	6.26	7.62	8.94
Windigo, Sawyer	3.32	4.80	6.23	7.62	8.99
CLUSTER 8					
Horseshoe, Barron	4.56	6.51	8.25	9.93	11.54
Leach, Washburn	4.05	5.75	7.38	8.96	10.49
Lower Devils, Barron	4.57	6.37	8.07	9.70	11.26
Lower Turtle, Barron	3.73	5.39	7.01	8.59	10.14
Spring T39R10S36, Washburn	5.00	6.55	7.952	9.18	10.35
Upper Devils, Barron	4.50	6.19	7.78	9.27	10.71

Literature Cited

Anderson, D. W. and D. H. Schupp
1986. Fish community responses to northern pike stocking in Horseshoe Lake, Minnesota. Minn. Dep. Nat. Resour. Fish. Invest. Rep. No. 387. 38 pp.

Anderson, R. O.
1976. Management of small warm water impoundments. Fisheries 1(6):5-7, 26-28.

Anderson, R. O. and A. S. Weithman
1978. The concept of balance for coolwater fish populations. Am. Fish. Soc. Spec. Publ. 11:371-81.

Beard, T. D.
1982. Population dynamics of young-of-the-year bluegill. Wis. Dep. Nat. Resour. Tech. Bull. No. 127. 32 pp.

Boisclair, D. and W. C. Leggett
1989. Among-population variability of fish growth. III. Influence of fish community. Can. J. Fish. Aquat. Sci. 46:1539-50.

Busch, W. N., R. L. Scholl and W. L. Hartman
1975. Environmental factors affecting the strength of walleye (*Stizostedion vitreum vitreum*) year-classes in western Lake Erie. Can J. Fish. Aquat. Sci. 32:1733-43.

Carline, R. F., B. L. Johnson and T. J. Hall
1984. Estimation and interpretation of proportional stock density for fish populations in Ohio impoundments. North Am. J. Fish. Manage. 4(2):139-54.

Clark, R. D. Jr. and R. N. Lockwood
1990. Population dynamics of bluegills subjected to harvest within the 5.0 to 6.9-inch size range. Mich. Dep. Nat. Resour. Fish. Res. Rep. No. 1961. 32 pp.

Coble, D. W.
1988. Effects of angling on bluegill populations: management implications. North Am. J. Fish. Manage. 8(3):277-83.

Colby, P. J., P. A. Ryan, D. H. Schupp and S. L. Serns
1987. Interactions in north-temperate lake fish communities. Can. J. Fish. Aquat. Sci. 44(Suppl. 2):104-28.

Crowder, L. B. and W. E. Cooper
1982. Habitat structural complexity and the interaction between bluegills and their prey. Ecology 63(6):1802-13.

Diana, J. S.
1983. Growth, maturation and production of northern pike in three Michigan lakes. Trans. Am. Fish. Soc. 112:38-46.
1987. Simulation of mechanisms causing stunting in northern pike populations. Trans. Am. Fish. Soc. 116:612-17.

Diggins, M. R., R. C. Summerfelt and M. A. Mnich
1979. Altered feeding electivity of the bluegill form increased prey accessibility following macrophyte removal. Proc. Okla. Acad. of Sci. 59:4-11.

Engel, S.
1985. Aquatic community interactions of submerged macrophytes. Wis. Dep. Nat. Resour. Tech. Bull. No. 156. 79 pp.

Fairchild, G. W.
1982. Population responses of plant-associated invertebrates to foraging by largemouth bass fry (*Micropterus salmoides*). Hydrobiologia 96:169-176.

Flickinger, S. A. and F. J. Bulow
1993. Small impoundments. pp. 469-91 *in* C. C. Kohler and W. A. Hubert, eds. Inland fisheries management in North America. Am. Fish. Soc., Bethesda, Md.

Forney, J. L.
1965. Factors affecting growth and maturity in a walleye population. N.Y. Fish Game J. 12(2):217-32.
1966. Factors affecting first-year growth of walleyes in Oneida Lake, New York. N.Y. Fish Game J. 13(2):146-67.
1980. Evolution of a management strategy for the walleye in Oneida Lake, New York. N.Y. Fish Game J. 27(2):105-41.

Gauch, H. G. Jr. and R. H. Whittaker
1972. Comparison of ordination techniques. Ecology 53(5):868-75.

Gerking, S. D. 1962. Production and food utilization in a population of bluegill sunfish. Ecol. Monogr. 32:31-78.

Goeman, T. J., D. W. Anderson and D. H. Schupp
1990. Fish community responses to manipulation of yellow perch and walleye abundance. Minn. Dep. Nat. Resour. Fish. Invest. Rep. No. 404. 21 pp.

Gotceitas, V.
1990. Variation in plant stem density and its effects on foraging success of juvenile bluegill sunfish. Environ. Biol. Fish. 27:63-70

Green, R. H.
1979. Sampling design and statistical methods for environmental biologists. John Wiley and Sons, New York. 257 pp.

Green, R. H. and G. L. Vascotto
1978. A method for the analysis of environmental factors controlling patterns of species composition in aquatic communities. Water Res. 12:583-90.

Gross, M. R.
1982. Sneakers, satellites and parentals: polymorphic mating strategies in north American sunfishes. Z. Tierpsychol. 60:1-26.

Handford, P., G. Bell and T. Reimchem
1977. A gillnet fishery considered as an experiment in artificial selection. Can. J. Fish. Aquat. Sci. 34:954-61.

Hayes, D. B., W. W. Taylor and E. L. Mills
1993. Natural lakes and large impoundments. pp. 493-13 *in* C. C. Kohler and W. A. Hubert, eds. Inland fisheries management in North America. Am. Fish. Soc., Bethesda, Md.

Healey, M. C.
1980. Growth and recruitment in experimentally exploited lake whitefish (*Coregonus clupeaformis*) populations. Can. J. Fish. Aquat. Sci. 37:255-67.

Hewett, S. W. and B. L. Johnson
1992. Fish bioenergetics model 2. Univ. of Wisc. Sea Grant Inst. Publ. WIS-SG-92-250. Madison, Wis. 79 pp.

Hodgson, J. R. and J. F. Kitchell
1987. Opportunistic foraging by largemouth bass (*Micropterus salmoides*). Am. Midl. Nat. 118(2):323-336.

Jennings, M. J. and D. P. Philipp
1992. Reproductive investment and somatic growth rates in longear sunfish. Envir. Biol. of Fish. 35:257-71.

Johnson, L. D.
1969. Food of angler-caught pike in Murphy Flowage. Wis. Dep. Nat. Resour. Tech. Bull. No. 42. 25 pp.

Kallemeyn, L. W.
1987. Correlations of regulated lake levels and climatic factors with abundance of young-of-the-year walleye and yellow perch in four lakes in Voyageurs National Park. North Am. J. Fish. Manage. 7:513-21.

Keast, A.
1984. The introduced aquatic macrophyte, *Myriophyllum spicatum*, as habitat for fish and their invertebrate prey. Can. J. Zool. 62:1289-1303.

Kempinger, J. J.
1972. Walleye fry maintenance stocking evaluation. Wis. Dep. Nat. Resour. Fed. Aid in Sport Fish Restor. Proj. F-83-R Prog. Rep. 6 pp.

Kempinger, J. J. and R. F. Carline
1977. Dynamics of the walleye (*Stizostedion vitreum vitreum*) population in Escanaba Lake, Wisconsin, 1955-72. Can. J. Fish. Aquat. Sci. 34:1800-11.

1978. Changes in population density, growth, and harvest of northern pike in Escanaba Lake. Wis. Dep. Nat. Resour. Tech. Bull. No. 104. 15 pp.

Kingery, R. W. and R. J. Muncy
1988. Walleye spawning movements and habitat usage in Tombigbee River drainages. Proc. Ann. Conf. Southeast Fish Wild. Agencies 42:249-57.

Kitchell, J. F.
1983. Energetics. pp. 312-28 *in* P. W. Webb and D. Weihs eds. Fish biomechanics. Praeger Publ., New York. 398 pp.

Latta, W. C.
1971. The northern pike in Michigan: a commentary on regulations for fishing. Mich. Dep. Nat. Resour. Res. Dev. Rep. No. 241. 21 pp.

1975. Dynamics of bass in large natural lakes. pp. 175-82 *in* R. H. Stroud and H. Clepper eds. Black bass biology and management. Sport Fish. Inst. Washington D. C. 534 pp.

Mauck, W. and D. Coble
1971. Vulnerability of some fishes to northern pike (*Esox lucius*) predation. Can. J. Fish. Aquat. Sci. 28(7):957-69.

Mittelbach, G. G.
1988. Competition among refuging sunfishes and effects of fish density on littoral zone invertebrates. Ecology 69:614-23.

Nuhfer, A. J. and G. R. Alexander
1991. Growth, survival, and vulnerability to angling of three wild brook trout strains exposed to different levels of angler exploitation over time. Mich. Dep. Nat. Resour. Fish. Res. Rep. No. 1973. 15 pp.

Osenberg, C. W., E. E. Werner, G. G. Mittelbach and D. J. Hall
1988. Growth patterns in bluegill (*Lepomis macrochirus*) and pumpkinseed (*Lepomis gibbosus*) sunfish: environmental variation and the importance of ontogenetic niche shifts. Can. J. Fish. Aquat. Sci. 45:17-26.

Priegel, G. R.
1969. Food and growth of young walleyes in Lake Winnebago, Wisconsin. Trans. Am. Fish. Soc. 98(1):121-24.

Regier, H. A. and K. H. Loftus
1972. Effects of fisheries exploitation on salmonid communities in oligotrophic lakes. Can. J. Fish. Aquat. Sci. 29:959-68.

Ricker, W. E.
1975. Computation and interpretation of biological statistics of fish population. Fish. Res. Board Can. Bull. 191. 382 pp.

Ryder, R. A., S. R. Kerr, K. H. Loftus, and H. A. Regier
1974. The morphoedaphic index, a fish yield estimator—review and evaluation. J. Fish. Res. Board Can. 31:663-88.

SAS Institute, Inc.
1982. Statistical analysis system: user's guide 1982. SAS Inst., Cary, NC.

Sather, L. M. and C. D. Busch
1976. Surface water resources of Washburn County. Wisc. Dept. Nat. Res., Madison, Wis. 275 pp.

Savino, J. F. and R. A. Stein
1982. Predator-prey interaction between largemouth bass and bluegills as influenced by simulated submersed vegetation. Trans. Am. Fish. Soc. 111:255-66.
1989. Behavior of fish predators and their prey: habitat choice between open water and dense vegetation. Environ. Biol. Fish. 24:287-93.

Schiavone, A. Jr.
1981. Decline of the walleye in Black Lake. N.Y. Fish Game J. 28:68-72.

Serns, S. L.
1984. Walleye growth in relation to water temperature, food availability, and population density in Escanaba Lake, 1956-82. Wis. Dep. Nat. Resour. Res. Rep. No. 130. 16 pp.
1985. Proportional stock density index—is it a useful tool for assessing fish populations in northern latitudes? Wis. Dep. Nat. Resour. Res. Rep. No. 132. 11 pp.

Smith, L. L. and R. L. Pycha
1960. First-year growth of the walleye, *Stizostedion vitreum vitreum* (Mitchill) and associated factors in the Red Lakes, Minnesota. Limn. Ocean. 5:281-90.

Snow, H. E.
1974. Effects of stocking northern pike in Murphy flowage. Wis. Dep. Nat. Resour. Tech. Bull. No. 79. 20 pp.
1988. Effects of the introduction of muskellunge and walleye on bluegill and other species in Clear Lake, Sawyer county, Wisconsin, 1959-1984. Wis. Dep. Nat. Resour. Res. Rep No. 147. 17 pp.

Snow, H. E. and T. D. Beard
1972. A ten-year study of native northern pike in Bucks Lake, Wisconsin, including evaluation of an 18.0 inch size limit. Wis. Dep. Nat. Resour. Tech. Bull. No. 56. 20 pp.

Snow, H. E., A. Ensign, and J. Klingbiel
1970. The bluegill: its life history, ecology and management. Wis. Dept. Nat. Resour. Publ. 230-70. 14 pp.

Spangler, G. R., N. R. Payne, J. E. Thorpe, J. M. Byrne, H. A. Regier and W. J. Christie
1977. Responses of percids to exploitation. Can. J. Fish. Aquat. Sci. 34:1983-88.

Tarby, M. J.
1974. Characteristics of yellow perch cannibalism in Oneida Lake and the relation to first year survival. Trans. Am. Fish. Soc. 103:462-71.

Theiling, C. H.
1990. The relationships between several limnological factors and bluegill growth in Michigan lakes. Mich. Dep. Nat. Resour. Fish. Res. Rep. No. 1970. 55 pp.

Tonn, W. M., J. J. Magnuson, and A. M. Forbes
1983. Community analysis in fishery management: an application with northern Wisconsin lakes. Trans. Am. Fish. Soc. 112:368-77.

Walburg, C. H.
1972. Some factors associated with fluctuation in year-class strength of sauger, Lewis and Clark Lake, South Dakota. Trans. Am. Fish. Soc. 101:311-16.

Weatherly, A. H. and H. S. Gill
1987. The biology of fish and growth. Academic Press, London. 443 pp.

Weiner, J. G. and W. R. Hanneman
1982. Growth and condition of bluegills in Wisconsin lakes: effects of population density and pH. Trans. Am. Fish. Soc. 111:761-67.

Werner, E. E. and D. J. Hall
1977. Competition and habitat shift in two sunfishes (Centrarchidae). Ecology 58:869-76.

Wesloh, M. L. and D. E. Olson
1962. The growth and harvest of stocked yearling northern pike, *Esox lucius* Linnaeus, in a Minnesota walleye lake. Minn. Dep. Nat. Resour. Invest. Rep. No. 242. 9 pp.

Williams, B. K.
1983. Some observations on the use of discriminant analysis in ecology. Ecology 64(5):1283-91.

Wisconsin Department of Natural Resources (WDNR)
1986. Wisconsin Department of Natural Resources Fish Management Handbook, Wis. Dep. Nat. Resour., Madison, Wis. [var. pp.]

Acknowledgments

Appreciation is extended to Leon Johnson, Tom Beard, David A. Hanson, and Terry Margenau, biologists in the Warm Water North Group for their counsel, advice, and assistance in data analysis at various times throughout the study. Completion of the extensive field work and preliminary data analysis would have been impossible without the capable assistance of technicians Lyle Groth, Don Stafford, and Ronnie Masterjohn and several seasonal employees and work study students. To these we give a special "thank you" for their faithful dedicated assistance. Don Thompson and Gene Lange advised on initial statistical design and procedures. The manuscript was critically reviewed by Lyle Christenson, John Lyons, Steve Serns, John Klingbiel, Gene Lange, James C. Schneider, Richard O. Anderson, and T. Doug Beard.

This is the final report for DNR Research Study 602, "Characteristics of slow-and fast-growing panfish in Wisconsin." This research was supported in part by funds provided by Federal Aid in Sport Fish Restoration Act grant F-83-R and F-95-P and the Wisconsin Department of Natural Resources.

About the Authors

Howard E. Snow was a fisheries research biologist for the Wisconsin DNR from 1957 until his retirement in March 1992. At the time of his retirement he was the warmwater fish research group leader for northern Wisconsin with the Bureau of Research. He can be contacted through the DNR, Box 309, Spooner, WI 54801.

Michael D. Staggs is currently the Fish Research Section Chief for the DNR Bureau of Research. He has been with the Department since 1982. At the time this work was done, he was a biometrician in the Bureau of Research. He was also the Systems Ecologist for the DNR Bureau of Fisheries Management during 1987-92. He can be reached at the DNR Research Center, 1350 Femrite Drive, Monona, WI 53716.

Production Credits

Wendy M. McCown, Managing Editor
William T. Manci, Fisheries Technology Associates, Inc., Copy Editor
Michelle E. Jesko, Figure Preparation, Layout/Production

Printed on recycled paper.

Wisconsin Department of Natural Resources
PUBL-RS-162 94