Predicting Sportfish Along the Lake Trophic Gradient

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Abstract. The Trophic State Index (TSI) has been widely used to rank and classify lakes and has proven useful in limnological investigations, but it has not been widely used in fisheries investigations. Trophic State Index was developed from chlorophyll *a* (Chl *a*), total phosphorus (TP), total nitrogen (TN), and Secchi disk (SD) transparency measurements for 69 Florida lakes. A combination of TSI parameters was used to develop multiple regression models to predict lake capacity for supporting sportfish biomass (kg/ha). The developed, predictive model could be used by other states with modifications to investigate fish biomass from trophic state information. Also, fish estimates predicted from the model would provide fishery managers feedback for future resource planning.

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Managing lakes on a regional or statewide basis is facilitated in many states by lake classification systems. These classifications range from simple to sophisticated indexing systems designed to incorporate many parameters into a single expression of trophic state (Carlson 1977, Kratzer and Brezonik 1981, Huber et al. 1982, Canfield and Hoyer 1992). Trophic state is the integral expression of nutritional status in waters. Limnologists use many physical, chemical, and biological parameters to describe trophic condition and assign a lake to a certain trophic state: oligotrophic, mesotrophic, eutrophic, or hypereutrophic.

Several studies determined not only the trophic state parameters that regulate fish abundance in lakes, but also developed models that tried to predict fish yields from lakes (Rounsefell 1946, Carlander 1955, Ryder 1965, Ryder et al. 1974). Chlorophyll *a* concentration as an indicator of lake trophic condition is a theoretical basis for predicting fish yield or standing crop (Carlson 1977, Forsberg and Ryding 1980). Chlorophyll *a* concentrations are correlated with nutrient concentrations (Jones and Bachmann 1976), photosynthetic production (Smith 1979, Beaver and Crisman 1991), and zooplankton abundance (Patalas

1972, McCauley and Kalff 1981, Canfield and Watkins 1984). However, the relationships between trophic state and fish biomass are not clear.

One approach to understanding the relationship of trophic state and fish biomass is to study the fish community of 1 or several lakes undergoing trophic change over a long period. A study for this purpose has never been undertaken in Florida. Our objective is to produce a regression model for predicting sportfish biomass (kg/ha) from trophic state parameters data collected during previous years. A reliable estimate of the capacity of a given lake to produce fish would provide fishery managers with a quantitative basis for resource planning. Such an estimate will help establish management objectives, evaluate past management efforts, and allocate resources.

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Methods

Water samples were collected from 69 lakes by Florida Game and Fresh Water Fish Commission (FGFWFC) personnel and analyzed according to the methods specified by the American Public Health Association (APHA, 1975). Chlorophyll *a,* total phosphorus (TP), total nitrogen (TN), and Secchi disc (SD) transparency data were used to classify the trophic status of each lake by the following equations derived from Huber et al. (1982) for the development of trophic state index (TSI):

$$\mathrm{TSI}_{\mathrm{Ch\ l}a} = 10(1.68 + 1.44 \text{ In Chl } a) \tag{1}$$

$$\mathrm{TSI}_{\mathrm{TP}} = 10[2.36 \text{ In}(\mathrm{TP} \times 1000) - 2.38] \tag{2}$$

$$\mathrm{TSI}_{\mathrm{TN}} = 10(5.96 + 2.15 \text{ In TN}) \tag{3}$$

$$\mathrm{TSI}_{\mathrm{SD}} = 10(6.0 - 3.0 \text{ In SD}) \tag{4}$$

The overall trophic state index was determined by combining the appropriate subindexes to obtain an average ($\mathrm{TSI}_{\mathrm{AVG}}$) as described by Brezonik (1984):

$$\mathrm{TSI}_{\mathrm{AVG}} \text{ (for P-limited lakes TN:TP} > 30)$$

$$= 1/3(\mathrm{TSI}_{\mathrm{Chl}\,a} + \mathrm{TSI}_{\mathrm{TP}} + \mathrm{TSI}_{\mathrm{SD}}) \tag{5}$$

$$\text{(for N-limited lakes TN:TP} < 10)$$

$$= 1/3(\mathrm{TSI}_{\mathrm{Chl}\,a} + \mathrm{TSI}_{\mathrm{TN}} + \mathrm{TSI}_{\mathrm{SD}}) \tag{6}$$

(for nutrient balanced lakes $10 < TN{:}TP < 30$)

$$= 1/3(TSI_{Chl\,a} + TSI_{SD} + 0.5(TSI_{TP} + TSI_{TN})) \qquad (7)$$

Equations 5–7 are based on the nutrient index calculated based on TP and TN concentrations and the limiting nutrient concept. The limiting nutrient concept identifies a lake as phosphorus limited (P-limited) if the TN to TP concentration ratio is greater than 30, as nitrogen limited (N-limited) if the ratio is less than 10, and balanced (depending on both TN and TP) if the ratio is between 10 and 30. Thus, the nutrient TSI is based solely on TP if the ratio is >30, solely on TN if <10, or based on both TN and TP if the ratio is between 10 and 30. The overall TSI is calculated based on the average of the chlorophyll *a* TSI, the secchi depth TSI, and the nutrient TSI. For this index to be calculated, both TN and TP measurements are required for the sample. Brezonik and Shannon (1971) and the U.S. Environmental Protection Agency (EPA, 1977) referred to several of the lakes in Florida based on TSI on oligotrophic, mesotrophic, eutrophic, or hypereutrophic.

Fish population data for the study lakes were collected by the FGFWFC using standard 0.08-ha block nets and rotenone. Sampling was conducted to determine fish standing crop and community structure. Fish were identified to species, counted, and weighed.

The relationships between fish biomass and parameters of TSI (Chl *a*, TP, TN, and SD) were used to develop the following multiple regression model:

Sportfish (kg/ha) (for P-limited lakes, $TN{:}TP > 30$)

$$= \beta 0 + \beta 1(TP) + \beta 3(SD) + \beta 4(Chl\ a) \qquad (8a)$$

(for N-limited lakes $10 < TN{:}TP$)

$$= \beta 0 + \beta 2(TN) + \beta 3(SD) + \beta 4(Chl\ a) \qquad (8b)$$

(for nutrient balanced lakes $10 < TN{:}TP < 30$)

$$= \beta 0 + \beta 1(TP) + \beta 2(TN) + \beta 3(SD) + \beta 4(Chl\ a) \qquad (8c)$$

where $\beta 0$, $\beta 1$, $\beta 2$, $\beta 3$, and $\beta 4$ are regression coefficients. The values of regression coefficients are as: $\beta 0 = 117.851$, $\beta 1 = -10.896$, $\beta 2 = -5.219$, $\beta 3 = -13.53$, and $\beta 4 = 1.914$.

To obtain the multiple regression model, equation 8, we recorded the sportfish biomass observed data of all trophic status parameters and produced affect response. The trophic state parameters then were incorporated explicitly into the regression analysis. Correlations and regression analysis were conducted using PC-SAS^R computer software (SAS Inst. Inc. 1988). Regression analysis followed techniques described by Rawlings (1988).

The sportfish biomass (kg/ha) predicted from the model was then compared with observed catch data from blocknetting.

Results

Analysis of water quality data (Table 1) indicate the majority of study lakes, based on TSI classification, were eutrophic. Fifty-four percent of study lakes were P-limited, 36% nutrient-balanced, and 10% N-limited. All of the oligotrophic lakes were P-limited, and majority of the hypereutrophic lakes were nutrient-balanced. Trophic State Index (TSI) values increased with increasing TP ($r^2 = 0.824$), Chl *a* ($r^2 = 0.886$), and TN ($r^2 = 0.841$) concentrations but decreased with increasing SD transparencies ($r^2 = 0.865$). A linear correlation between TP and Chl *a* ($r^2 = 0.666$; $P < 0.05$), SD ($r^2 = 0.5999$; $P < 0.05$), and sportfish biomass ($r^2 = 0.188$; $P < 0.05$) was observed (Fig. 1).

The TSI parameters (Chl *a*, TP, TN, and SD) yielded the following multiple regression model that was used to predict sportfish biomass (kg/ha):

Sportfish (kg/ha) (for P-limited lakes TN:TP >30)

$$= 117.851 - 10.896(\mathrm{TP}) - 13.53(\mathrm{SD}) + 1.914(\mathrm{Chl}\ a) \tag{8a}$$

(for N-limited lakes 10< TN:TP)

$$= 117.851 - 5.219(\mathrm{TN}) - 13.53(\mathrm{SD}) + 1.914(\mathrm{Chl}\ a) \tag{8b}$$

(for nutrient balanced lakes 10< TN:TP <30)

$$= 117.851 - 10.896(\mathrm{TP}) - 5.219(\mathrm{TN}) - 13.53(\mathrm{SD}) + 1.914(\mathrm{Chl}\ a) \tag{8c}$$

Sportfish biomass estimates predicted from the model gave better estimates to the field data ($r^2 = 0.639$) than the observed sportfish biomass data ($r^2 = 0.207$) from blocknets (Fig. 2). Sportfish biomass observed along the trophic gradient

Table 1. Trophic State Index (TSI) (± standard deviation) and correlation coefficients calculated from averaged water quality data for 69 lakes in Florida (Oligo- = Oligotrophic, O-M = Oligo-Mesotrophic, Meso- = Mesotrophic, and M-E = Meso-Eutrophic). Number of P-limited (PL), N-limited (NL), and nutrient-balanced (NB) lakes are mentioned along the trophic gradient.

TSI	Oligo- PL = 9	O-M PL = 5 NB = 2	Meso- PL = 13 NB = 5	M-E PL = 8 NB = 3	Eutrophic PL = 11 NL = 3, NB = 11	Hypereutrophic PL = 4 NL = 4, NB = 9	r^2
$\mathrm{TSI_{TP}}$	53.93 ±13.63	74.13 ±10.46	78.11 ±10.14	80.65 ±9.07	98.88 (117.84) ±10.88 (±14.35)	123.70 (171.72) ±14.51 (±15.38)	0.824
$\mathrm{TSI_{TN}}$	71.26 ±9.94	83.35 ±14.59	86.16 ±21.21	87.95 ±24.34	96.51 (70.82) ±13.33 (±1.67)	116.17 (126.06) ±11.85 (±6.10)	0.841
$\mathrm{TSI_{SD}}$	19.39 ±7.98	28.12 ±12.76	37.56 ±12.63	43.56 ±8.03	51.22 (27.75) ±12.72 (±6.64)	75.86 (81.10) ±12.25 (±4.31)	0.865
$\mathrm{TSI_{Chl\ a}}$	21.31 ±6.55	27.62 ±5.71	33.98 ±8.48	38.03 ±7.40	54.82 (71.37) ±9.08 (2.29)	71.19 (86.07) ±13.78 (±5.78)	0.886
$\mathrm{TSI_{AVG}}$	31.55 ±6.21	44.97 ±3.23	50.34 ±4.91	53.76 ±1.66	70.43 (71.64) ±6.10 (±3.00)	94.42 (97.74) ±11.87 (±5.05)	

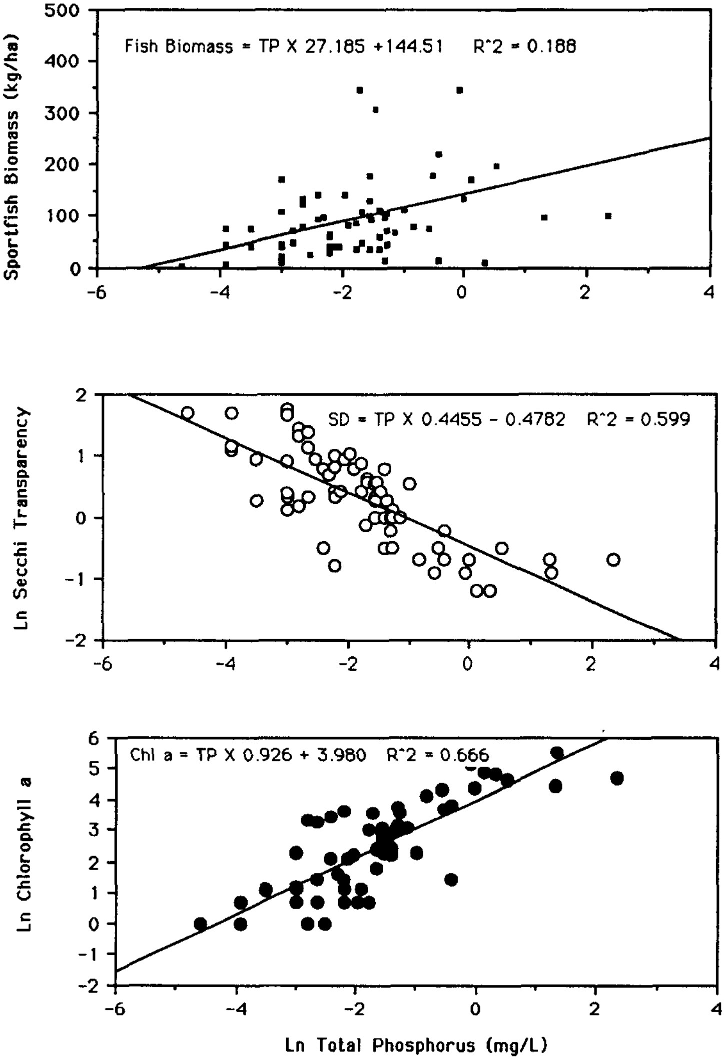

Figure 1. Total phosphorus (mg/liter) related water quality and sportfish biomass relationships for 69 Florida lakes.

increased with the increase in the trophic state and the same trend was observed in predicted sportfish biomass from the model.

The mean total phosphorus concentrations along the trophic gradients in study lakes are as follows: oligotrophic, 0.03 mg/liter; oligo-mesotrophic, 0.07 mg/liter; mesotrophic, 0.08 mg/liter; meso-eutrophic, 0.09 mg/liter; eutrophic, 0.20 mg/liter; and hypereutrophic, 0.62 mg/liter (Table 2). The mean total phosphorus concentration of the hypereutrophic lakes is significantly greater ($P < 0.05$) than that of other lake groups.

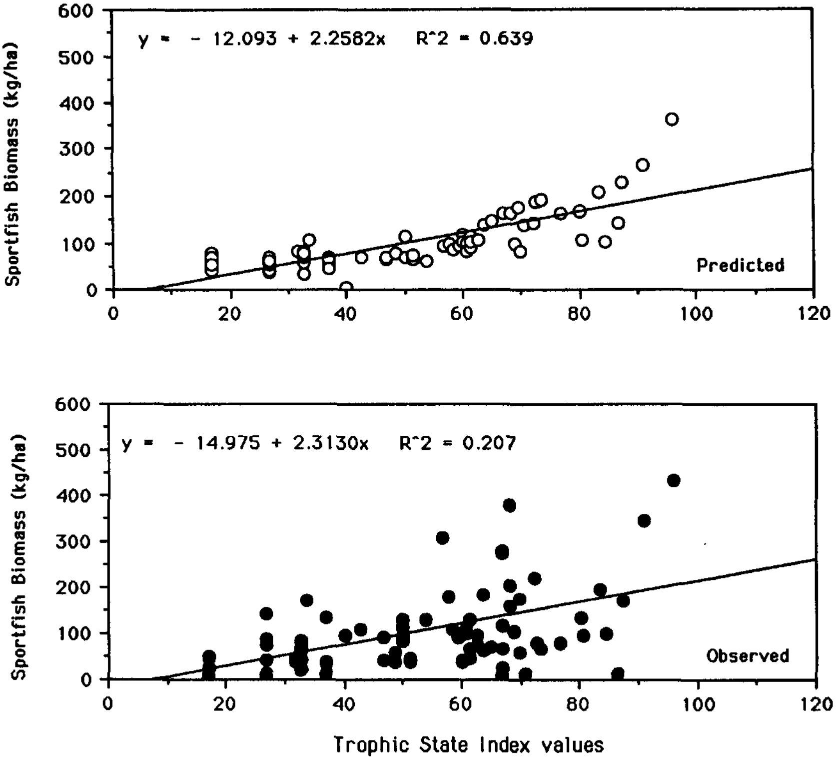

Figure 2. Comparison of sportfish biomass (kg/ha) from blocknetting (lower panel) and predicted from the model (upper panel) for 69 Florida lakes.

The mean total nitrogen concentrations along the trophic gradients are as follows: oligotrophic, 1.91 mg/liter; oligo-mesotrophic, 3.65 mg/liter; mesotrophic, 5.09 mg/liter; meso-eutrophic, 6.01 mg/liter; eutrophic, 6.53 mg/liter; and hypereutrophic, 16.25 mg/liter. Significant differences exist between the mean total nitrogen of trophic state levels (Table 2).

Chlorophyll *a* follows a smoothly increasing trend along the trophic gradient similar to that of total phosphorus. The mean chlorophyll *a* concentrations along the trophic gradients are as: oligotrophic 1.53 μg/liter; oligo-mesotrophic, 2.29 μg/liter; mesotrophic 3.96 μg/liter; meso-eutrophic, 5.02 μg/liter; eutrophic 16.65 μg/liter; and hypereutrophic 63.00 μg/liter. The mean chlorophyll *a* concentrations of hypereutrophic lakes are significantly greater ($P < 0.05$) than that of other lake trophic groups, except eutrophic (Table 2).

The relationships between Chl *a* and TP for P-limited lakes and Chl *a* and TN for N-limited lakes in this analysis are as follows:

$$\log(\text{Chl } a) = -1.812 + 1.0564 \log(\text{TP});\ r^2 = 0.69 \tag{9}$$

$$\log(\text{Chl } a) = 1.571 + 0.3955 \log(\text{TN});\ r^2 = 0.67 \tag{10}$$

Table 2. Summary of mean observations (± standard deviation) of water quality and sportfish biomass (kg/ha) observed by blocknetting and predicted from the model. (O-M = Oligo-Mesotrophic, and M-E = Meso-Eutrophic). Values in parentheses are for N-limited lakes. Means along a row with a letter (a, b, c) in common are not significantly different and means along a row without a letter (a, b, c) in common are significantly different at $P < 0.05$.

Parameter	Oligotrophic	O-M	Mesotrophic	M-E	Eutrophic	Hypereutrophic
TP (mg/liter)	0.03^a ±0.02	0.07^a ±0.03	0.08^a ±0.03	0.09^a ±0.03	0.20^a (0.48) ±0.08 (±0.24)	0.62^b (4.91) ±0.37 (±3.30)
TN (mg/liter)	1.91^a ±0.88	3.65^{ab} ±1.91	5.09^b ±4.18	6.01^b ±4.90	6.53^b (1.69) ±3.15 (±0.13)	16.25^c (22.89) ±9.57 (±6.43)
SD (m)	4.01^a ±1.07	3.16^a ±1.31	2.32^a ±1.12	1.79^a ±0.48	1.45^a (0.67) ±0.53 (±0.15)	0.64^a (0.50) ±0.25 (±0.07)
Chl *a* (μg/liter)	1.53^b ±0.79	2.29^b ±0.88	3.96^b ±2.61	5.02^b ±2.79	16.65^{bc} (44.77) ±8.81 (±6.71)	63.00^c (134.25) ±49.62 (±62.35)
Sport fish (kg/ha) (Observed)	40.31 ±20.51	72.13 ±47.27	75.32 ±44.58	77.35 ±42.65	92.46 (163.09) ±59.54 (±127.74)	120.53 (206.20) ±90.19 (137.21)
Sport fish (kg/ha) (Predicted)	56.19 ±15.11	59.69 ±14.34	66.52 ±26.13	70.87 ±30.62	93.63 (180.46) ±31.96 (±12.11)	138.20 (195.07) ±56.88 (±105.56)

A gradual increase in sportfish biomass is observed along the trophic gradients as follows: oligotrophic, 40.31 kg/ha; oligo-mesotrophic, 72.13 kg/ha; mesotrophic, 75.32 kg/ha; meso-eutrophic, 77.35 kg/ha; eutrophic, 92.46 kg/ha; and hypereutrophic, 120.53 kg/ha (Table 2). Sportfish biomass predicted from the regression model for 69 lakes along the trophic gradients is as: oligotrophic, 56.19 kg/ha; oligo-mesotrophic, 59.69 kg/ha; mesotrophic, 66.52 kg/ha; meso-eutrophic, 70.87 kg/ha; eutrophic, 93.63 kg/ha, and hypereutrophic 138.20 kg/ha (Table 2). Sportfish biomass predicted from the model follows a smoothly increasing trend along the trophic gradient (Table 3) when applied to subindexes data of Brezonik (1984). There is not any significant difference in sportfish biomass for P-limited, N-limited, and nutrient-balanced lakes. The relationships between TSI and sportfish biomass predicted along the trophic gradient for P-limited, N-limited, and nutrient-balanced lakes are shown in Fig. 3.

Discussion

For a given lake, the lower the nutrient load, the lower the primary production, and the lower the overall fish yield (Fig. 1). A conflict exists in deciding on the degree of trophic state desired for a lake for which one wishes to maintain sport fisheries. Maintenance of an optimal nutrient load will provide an appropriate balance of sport fish production with minimum detrimental eutrophication-related effects. It is possible to assess quantitatively the impact of a given trophic state on sportfish quality. The lack of nutrients in the limnetic region of oligotrophic lakes limits primary production, and planktivorous fish species (e.g., gizzard shad *Dorosoma cepedianum* and threadfin shad *D. petenense*).

Table 3. Application of the model (equation 8) to predict sportfish biomass (kg/ha) along the lake trophic gradient for P-limited, N-limited, and nutrient balanced lakes. Concentrations of Chl *a*, SD, TP, and TN corresponding to TSI values from 0 to 100 were modified from Brezonik (1984).

TSI	Chl *a* (μ/liter)	SD (m)	P-limited[a] lakes TP (mg/liter)	N-limited[b] lakes TN (mg/liter)	Nutrient-balanced[c] lakes TP (mg/liter)	Nutrient-balanced[c] lakes TN (mg/liter)	Sportfish[a] biomass (kg/ha)	Sportfish[b] biomass (kg/ha)	Sportfish[c] biomass (kg/ha)
0	0.3	7.4	0.003	0.06	0.003	0.06	18.27	17.99	17.96
10	0.6	5.3	0.004	0.10	0.005	0.10	47.25	46.77	46.72
20	1.3	3.8	0.006	0.16	0.008	0.16	68.86	68.09	68.00
30	2.5	2.7	0.010	0.25	0.014	0.27	86.00	84.80	84.55
40	5.0	2.0	0.015	0.40	0.023	0.45	100.20	98.27	97.76
50	10	1.4	0.023	0.64	0.040	0.74	117.80	114.71	113.76
60	20	1.0	0.034	1.02	0.068	1.23	142.23	137.28	135.44
70	40	0.72	0.052	1.62	0.116	2.04	184.10	176.21	172.76
80	80	0.51	0.080	2.58	0.198	3.40	263.20	250.61	244.17
90	160	0.37	0.122	4.11	0.340	5.60	417.76	397.63	386.15
100	320	0.26	0.185	6.54	0.581	9.30	724.80	692.68	671.95

[a] P-limited TN: TP > 30 [b] N-limited TN: TP < 10 [c] Nutrient balanced 10 < TN; TP < 30

Where submerged aquatic plants are absent, a thin layer of detritus usually covers a sand bottom. Benthic invertebrate production is limited, and, in turn, the number of benthic feeding species (for example, catfishes *Ictalurus,* lake chubsucker *Erimyzon* species) in the system are limited. Consequently, oligotrophic lakes are generally characterized by relatively low fish biomass and species diversity that is dominated by sport and forage fishes. Mesotrophic and eutrophic lakes in Florida generally have well developed communities of littoral vegetation and support more sport and forage fish species compared to oligotrophic lakes. In the limnetic regions of mesotrophic and eutrophic lakes, nutrient supplies are sufficient to support a well-developed plankton community and increased biomass and diversity of fish species. Increased productivity and habitat diversity result in a higher diversity of fish species.

Some uncertainty exists in the relationship between Chl *a* and TP in Florida lakes. Huber et al. (1982) assembled a data base on 313 Florida lakes and reported regressions among trophic state variables. Their relationship is similar to Chl *a*-TP relationships for our studied lakes (equation 9). Canfield (1983) reported a Chl *a*-TP relationship based on 223 Florida lakes that had a smaller slope than equation 9 in our study. For N-limited lakes in our study, the regression of Chl *a* versus TN yielded equation 10. This equation agrees with results that Huber et al. (1982) obtained with large data set of Florida lakes. A variety of coefficients have been reported for regression relationships between log (Chl *a*) and log (TP) in P-limited Florida lakes. Reasons for the variations still are not completely resolved.

Fish abundance increased along the lake trophic status in the study lakes (Table 2) and predicted from the model (Table 3). This relationship is consistent with other published findings (Oglesby 1977, Jones and Hoyer 1982, Hanson

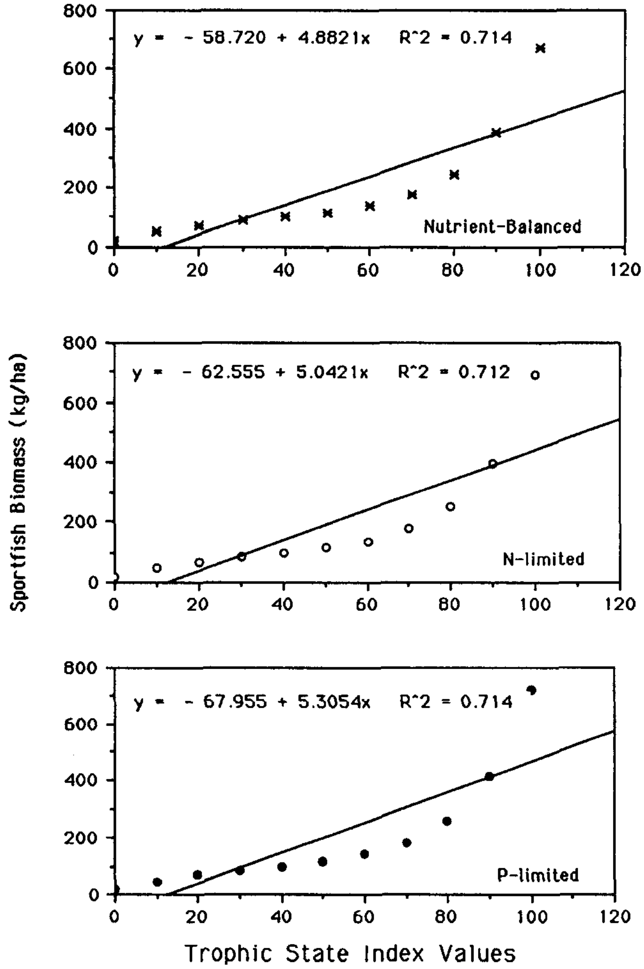

Figure 3. Relationships between TSI and sportfish biomass (kg/ha) predicted from the model for P-limited (lower panel), N-limited (middle panel), and nutrient-balanced (upper panel) lakes.

and Leggett 1982). By comparison, Kautz (1980) has shown that sportfish biomass responds logarithmically to trophic state, at least through the middle of the mesotrophic-eutrophic range in Florida lakes. There seems to be a tremendous variability in fish abundance for any given trophic state (Ryder et al. 1974, Melack 1976, McConnell et al. 1977, Oglesby 1977, Jones and Hoyer 1982, Hanson and Leggett 1982, Canfield and Hoyer 1992). Numerous biotic and abiotic factors combine to create the large variance observed (Chew 1975, Smith and Crumpton 1977, Schramm et al. 1987).

The trophic state concept has proven useful in limnological investigations but has not proven useful in fish harvest investigations in Florida lakes. Fish biomass predicted by the model should be used cautiously (Fig. 3). Harvest of sport fishes from lakes in various geographical regions will vary since they have different limnological potentials based on regional geology (Canfield 1981). Within a given geographical region, lake morphometry, hydrology, and submerged aquatic plants will affect the trophic status of individual lakes (Vollenweider 1976, Canfield and Bachmann 1981). Thus, fishery management goals must be realistic in their expectations. Chlorophyll *a,* TN, TP, and SD values may vary within and among years in any given lake, so multiple samples over time ($>$1 year) may be required for a reliable estimate of trophic state.

Finally, other factors such as submerged aquatic plants need to be addressed when comparing TSI with sportfish biomass. Predicted value can then be treated as an estimate of the average potential for a Florida lake of a given trophic state to produce sportfishes. Although the estimate may be of value for lake comparisons, caution should be employed when using it to develop management practices. Additional studies are needed to verify the relationships between TSI and sportfish biomass along the lake trophic gradient.

Literature Cited

American Public Health Association (APHA). 1975. Standard methods for the examination of water and wastewater. Washington, D.C. 1,193pp.

Beaver, J. R. and T. L. Crisman. 1991. Importance of latitude and organic color on phytoplankton primary productivity in Florida lakes. Can. J. Fish. Aquat. Sci. 48:1145–1150.

Brezonik, P. L. 1984. Trophic state indices: rationale for multivariate approaches. Pages 441–445 *in* Lake and Reservoir Management. Proc. 3rd Annu. Conf. North Am. Lake Manage. Soc. 18–23 Oct. 1983. Knoxville, Tenn. EPA 440/5-84-001. U.S. Environ. Protection Agency (EPA), Washington, D.C.

——— and E. E. Shannon. 1971. Trophic state of lakes in North Central Florida. Fla. Water Resour. Res. Ctr. Univ. Fla., Gainesville. Publ. 13. 102pp.

Canfield, D. E. Jr. 1981. Chemical and trophic state characteristics of Florida lakes in relation to regional geology. Fla. Coop. Fish and Wildl. Unit, Univ. Fla., Gainesville. Final Rep. 444pp.

———. 1983. Predictions of chlorophyll *a* concentrations in Florida lakes: The importance of phosphorus and nitrogen. Water Resour. Bul. 19:255–262.

——— and R. W. Bachmann. 1981. Prediction of total phosphorus concentrations, chlorophyll *a,* and secchi depths in natural and artificial lakes. Can. J. Fish. Aquat. Sci. 40:1713–1718.

——— and C. E. Watkins II. 1984. Relationships between zooplankton abundance and chlorophyll *a* concentrations in Florida lakes. J. Freshwater Ecol. 2:335–344.

——— and M. V. Hoyer. 1992. Aquatic macrophytes and their relation to limnology of Florida lakes. Fla. Dep. Nat. Resour., Tallahassee. Final Rep. 598pp.

Carlander, K. D. 1955. The standing crop of fish in lakes. J. Fish. Res. Board Can. 12:543–570.

Carlson, R. E. 1977. A trophic state index of lakes. Limnol. Oceanogr. 22:361–369.

Chew, R. L. 1975. The Florida largemouth bass. Pages 450–458 *in* H. E. Clepper and

R. H. Stroud, eds. Black bass biology and management. Sport Fish. Inst., Washington, D.C.

Forsberg, C. and S. O. Ryding. 1980. Eutrophication parameters and trophic state indices in 30 Swedish waste-receiving lakes. Arch. fur Hydrobiol. 88:189–207.

Hanson, J. M. and W. C. Leggett. 1982. Empirical prediction of fish biomass and yield. Can. J. Fish. Aquat. Sci. 39:257–263.

Huber, W. C., P. L. Brezonik, J. P. Heaney, R. E. Dickinson, S. D. Preston, D. S. Dwornik, and M. A. DeMaio. 1982. A classification of Florida lakes. Fla. Dep. Environ. Regulation, Tallahassee, Final Rep. ENV-05-82-1. 220pp.

Jones, J. R. and R. W. Bachmann. 1976. Prediction of phosphorus and chlorophyll levels in lakes. J. Water Pollut. Control Fed. 48:176–182.

——— and M. V. Hoyer. 1982. Sportfish harvest predicted by summer chlorophyll a concentrations in midwestern lakes and reservoirs. Trans. Am. Fish. Soc. 111:176–179.

Kautz, R. S. 1980. Effects of eutrophication on the fish communities of Florida lakes. Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 34:67–80.

Kratzer, C. R. and P. L. Brezonik. 1981. A Carlson type trophic state index for nitrogen in Florida lakes. Water Resour. Bul. 17:713–715.

McCauley, E. and J. J. Kalff. 1981. Empirical relationships between phytoplankton and zooplankton biomass in lakes. Can. J. Fish. Aquat. Sci. 38:458–463.

McConnell, W. J., S. Lewis, and J. E. Olson. 1977. Gross photosynthesis as an estimator of potential fish production. Trans. Am. Fish. Soc. 106:417–423.

Melack, J. M. 1976. Primary productivity and fish yield in tropical lakes. Trans. Am. Fish. Soc. 105:575–580.

Oglesby, R. T. 1977. Relationships of fish yield to lake phytoplankton standing crop, production, and morphoedaphic factors. J. Fish. Res. Board Can. 34:2271–2279.

Patalas, K. 1972. Crustacean plankton and the eutrophication of St. Lawrence Great Lakes. J. Fish. Res. Board Can. 29:1451–1462.

Rawlings, J. O. 1988. Applied regression analysis: A research tool. Wadsworth & Brooks/Cole. Pacific Grove, Calif. 553pp.

Rounsefell, G. A. 1946. Fish production in lakes as a guide for estimating production in proposed reservoirs. Copeia 1:29–40.

Ryder, R. A. 1965. A method for estimation the potential fish production of north temperate lakes. Trans. Am. Fish. Soc. 94:214–218.

———, 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. 31:663–688.

SAS Institute Inc. 1988. SAS/STAT User's Guide, Release 6.03 Ed. SAS Inst. Inc., Cary, N. C. 1,028pp.

Schramm, H. L. Jr., K. L. Jirka, and M. V. Hoyer. 1987. Epiphytic macroinvertebrates on dominant macrophytes in two central Florida lakes. J. Fresh. Ecol. 4:151–161.

Smith, V. H. 1979. Nutrient dependence of primary productivity in lakes. Limnol. Oceanogr. 24:1051–1064.

Smith, S. H. and J. E. Crumpton. 1977. Interrelationship of vegetative cover and sunfish population density in suppressing spawning in largemouth bass. Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 31:405–411.

U.S. Environmental Protection Agency (EPA). 1977. National eutrophication survey. Work. Pap. Nos. 224, 225, and 243–280, Corvallis, Ore.

Vollenweider, R. A. 1976. Advances in defining critical loading levels for phosphorus in lake management. Memo. 1st. Ital. Idrobiol. Dott Marco Marchi 33:53–83.