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A CARLSON-TYPE TROPHIC STATE INDEX FOR NITROGEN IN FLORIDA LAKES[1]

Charles R. Kratzer and Patrick L. Brezonik[2]

ABSTRACT: A data base consisting of predominantly nitrogen limited Florida lakes from the National Eutrophication Survey (NES) was used to develop a trophic state index based on total nitrogen concentration. This index was compared with Carlson's (1977) index based on total phosphorus concentration, and the lesser of the two values for each lake was averaged with indices based on Secchi disk transparency and chlorophyll *a* concentration to assess the trophic state of the 40 Florida NES lakes.
(KEY TERMS: eutrophication; water quality; lakes; trophic state index; nitrogen; Florida.)

Carlson (1977) based his trophic state index (TSI) on a simple transformation of the Secchi disk transparency (SD), such that a transparency of 64 m has a TSI value of 0, and a transparency of 6.2 cm has a TSI value of 100. The index was developed so that a doubling, or halving, of the transparency results in a 10-unit change in the TSI value. Carlson used regression analysis to relate transparency to total phosphate and chlorophyll *a* concentrations. The Carlson (1977) index has several advantages including its simplicity, small data requirements, objectivity, and reliance on the three most common and best understood trophic indicators. However, linear regressions of Carlson's (1977) TSI(TP) against both TSI(SD) and TSI(CHA) showed that TSI(TP) was significantly different (at the 95 percent confidence level) from the other two TSI's for the Florida NES lakes. This was not surprising considering the extremely high total phosphorus concentrations in the hypereutrophic lakes, and the high proportion of nitrogen limited lakes (Figure 1). Consequently, it seemed appropriate to develop a TSI(TN) similar to Carlson's (1977) existing TSI's.

The development of TSI(TN) is based on a critical chlorophyll *a* concentration of 10 μg/L as delineating the onset of eutrophic conditions in lakes (e. g., NES, 1975; Rast and Lee, 1978), and on the regression equation between total nitrogen (TN) and Chl-*a* for the Florida NES (1978) data:

$$\text{Chl-}a = 11.51\,(\text{TN})^{1.60} \quad (r = 0.89, n = 39) \tag{1}$$

For a Chl-*a* value of 10 μg/L, the TN value is 0.92 mg N/L. This value should produce an approximate TSI(TN) of 53, based on Carlson's TSI(CHA) (Table 1). Using a mathematical approach similar to that of Carlson, a TSI(TN) equation was developed centered around a TSI value of 60, with each increase of 10 in the TSI signifying a doubling of TN concentration. The simplest equation for TSI(TN) fitting the criteria was found to be:

$$\text{TSI(TN)} = 10\,(6 - \ln(1.47/\text{TN})/\ln 2) \tag{2}$$

or

$$\text{TSI(TN)} = 54.45 + 14.43 \ln(\text{TN}) \tag{3}$$

The resulting index values and trophic states associated with various values for (TN) and Carlson's (1977) values for TP, Chl-*a*, and SD are shown in Table 1.

For equal values of TSI(TN) and TSI(TP) the corresponding values of TN and TP are found to have a ratio of 31, considerably higher than the inorganic N/P requirements of algae. However, it was found that a much higher percentage of the total phosphorus was in the inorganic form (soluble reactive phosphate, SRP) than was the total nitrogen in the Florida NES lakes. The average SRP/TP ratio was 0.48 (range from 0.09 to 0.90), while the average inorg-N/TN ratio was only 0.13 (range from 0.07 to 0.40), indicating that a greater proportion of the nitrogen in the lake is tied up in biomass (organic form) than is the phosphorus. This trend supports the findings that nitrogen is the limiting nutrient for most of the Florida NES lakes. Thus, while TSI(TP) was developed from a primarily phosphorus limited data base, TSI(TN) was developed from a primarily nitrogen limited data base. Ideally, the smaller of these two TSI's should represent the limiting nutrient for any given lake. This hypothesis was generally well supported by the Florida NES data. The five lakes (Yale, Kissimmee, Marion, Reedy, Apopka) with TSI(TP) values considerably less than TSI(TN) were all phosphorus limited according to the algal nutrient bioassays and N/P ratios reported by the EPA-NES (Figure 1 and Table 2).

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[2] Respectively, Environmental Science and Engineering Program, UCLA, Los Angeles, California 90024; and Department of Environmental Engineering Sciences, University of Florida, Gainesville, Florida 32611.

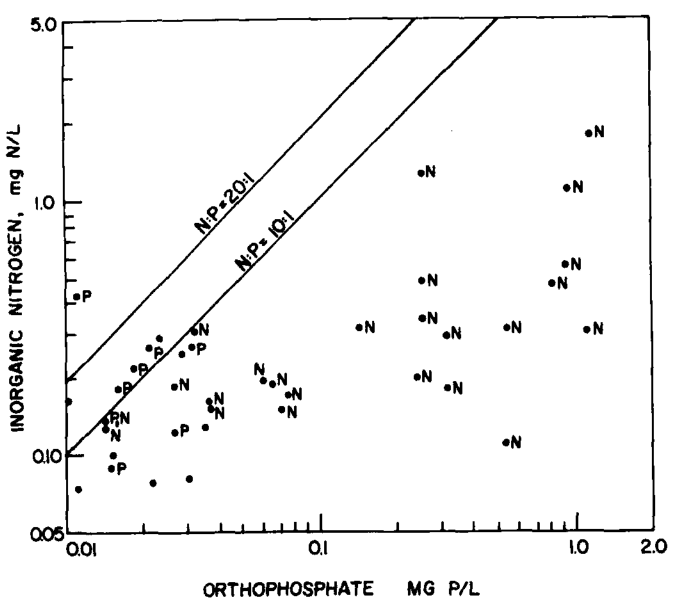

Figure 1. Total Inorganic Nitrogen vs. Orthophosphate Concentrations (mean values) in the Florida NES Lakes. N and P next to data points indicate nutrient found limiting in lake by Algal Assay Procedure.

TSI(TN) is a valuable classification tool when combined with Carlson's (1977) TSI values. It makes it possible to correctly consider both phosphorus and nitrogen limited lakes. For this study the lesser of TSI(TP) and TSI(TN) for each lake was averaged with the corresponding TSI(SD) and TSI(CHA) values to compute a TSI(AVG). This allows one to combine the physical response (SD), the biological response (CHA), and the limiting nutrient (either TP or TN). The TSI values for the Florida NES lakes are shown in Table 2 along with the TSI(AVG) values and trophic state classifications from the EPA-NES trophic state assessments. TSI(AVG) has two major advantages over the use of each individual TSI value: (1) the simplicity of one number for comparative and management purposes; and (2) the combination of the physical, biological, and chemical components of trophic state into one index.

Trophic state is a multidimensional phenomenon, and it is generally agreed that no single trophic indicator adequately measures the underlying concept. Combining the major physical, chemical, and biological expressions of trophic state into a single index smooths out the variability associated with individual indicators and provides a reasonable composite measure of trophic conditions in a lake.

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TABLE 1. Trophic States Associated With Carlson's TSI and TSI (TN).

TSI*	Trophic State**	Water Transparency (Secchi Disk, m)	Chlorophyll *a* (μg/L)	Total Phosphorus (μg P/L)	Total Nitrogen (mg N/L)
0	Ultraoligotrophic	64	0.04	0.75	0.02
10	Ultraoligotrophic	32	0.12	1.5	0.05
20	Ultraoligotrophic	16	0.34	3	0.09
30	Oligotrophic	8	0.94	6	0.18
40	Oligotrophic	4	2.6	12	0.37
45	Mesotrophic	2.8	5	17	0.52
50	Mesotrophic	2	7.3	24	0.74
53	Eutrophic	1.6	10	30	0.92
60	Eutrophic	1	20	48	1.47
70	Hypereutrophic	0.5	56	96	2.94
80	Hypereutrophic	0.25	154	192	5.89
90	Hypereutrophic	0.12	427	384	11.7
100	Hypereutrophic	0.06	1183	768	23.6

*TSI (SD) = 10(6 – ln (SD)/ln 2), SD in meters (Carlson, 1977).
TSI (CHA) = 10(6 – (2.04 – 0.68 ln (CHA))/ln 2), CHA in μg/L (Carlson, 1977).
TSI (TP) = 10(6 – ln (48/TP)/ln 2), TP in μg/L (Carlson, 1977).
TSI (TN) = 10(6 – ln (1.47/TN)/ln 2), TN in mg/L (this study).
**Approximate trophic states based on trophic indicator values; names assigned by us and not by Carlson.

TABLE 2. Carlson's Trophic State Index Values and TSI(TN) Values for Florida Lakes in the National Eutrophication Survey.

Lake Name	Trophic State Index					
	TSI(SD)	TSI(CHA)	TSI(TP)	TSI(TN)	TSI(AVG)*	EPA-NES Assessment
Lake Minneola	47	42	47	49	45 (O-M)	O-M
East Lake Tohopekaliga	54	47	57	55	52 (M)	M
Lake Minnehaha	53	52	61	51	52 (M)	M
Lake Weohyakapka	59	51	59	52	54 (E)	M
Lake Tarpon	47	50	55	51	49 (M)	M
Lake Istokpoga	62	49	59	57	56 (E)	M-E
Lake Yale	54	62	52	59	56 (E)	E
Lake Kissimmee	62	62	56	62	60 (E)	E
Lake Jessie	57	63	61	54	58 (E)	E
Lake Horseshoe	60	55	60	55	58 (E)	E
Lake Haines	60	63	63	56	60 (E)	E
Lake South	62	61	66	61	61 (E)	E
Lake Okeechobee	65	57	65	64	61 (E)	E
Lake Marion	63	64	60	66	62 (E)	E
Lake Crescent	65	53	66	59	59 (E)	E
Lake Poinsett	63	49	68	63	58 (E)	E
Doctors Lake	62	63	68	61	62 (E)	E
Lake Reedy	63	66	55	64	61 (E)	E
Lake Gibson	63	61	79	59	61 (E)	E
Lake Dora	73	71	71	72	72 (H)	H
Lake Talquin	60	53	70	51	55 (E)	E
Lake Apopka	73	73	68	75	71 (H)	H
Lake Griffin	70	72	62	72	61 (E)	E
Glenada Lake	57	63	64	58	59 (E)	E
Lake Thonotosassa	62	66	99	60	63 (E)	H
Lake Seminole	65	76	83	68	70 (E-H)	E
Lake George	65	65	76	62	64 (E)	E
Lake Tohopekaliga	65	64	88	64	64 (E)	E
Lake Monroe	67	57	81	64	63 (E)	E
Lake Hancock	73	76	99	77	75 (H)	E
Lake Eloise	62	72	93	67	67 (E)	E
Lake Howell	62	70	107	62	65 (E)	E
Lake Banana	70	83	97	76	76 (H)	H
Lake Jessup	77	73	94	69	73 (H)	H
Alligator Lake	65	74	100	69	69 (E)	H
Trout Lake	65	73	105	69	69 (E)	H
Lake Lawne	93	74	118	79	82 (H)	E
Lake Munson	73	79	113	79	77 (H)	H
Lake Effie	77	85	109	78	80 (H)	H
Lake Lulu	73	86	110	79	79 (H)	E

*If TSI(TP) $>$ TSI(TN), TSI(AVG) = [TSI(SD) + TSI(CHA) + TSI(TN)]/3.
If TSI(TP) $\leqq$ TSI(TN), TSI(AVG) = [TSI(SD) + TSI(CHA) + TSI(TP)]/3.