ISSN 0097-8078, Water Resources, 2016, Vol. 43, No. 5, pp. 809–817. © Pleiades Publishing, Ltd., 2016.
Original Russian Text © B.V. Adamovich, T.V. Zhukova, T.M. Mikheeva, R.Z. Kovalevskaya, E.V. Luk'yanova, 2016, published in Vodnye Resursy, 2016, Vol. 43, No. 5, pp. 535–543.

WATER QUALITY AND PROTECTION: ENVIRONMENTAL ASPECTS

Long-Term Variations of the Trophic State Index in the Narochanskie Lakes and Its Relation with the Major Hydroecological Parameters

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Received September 25, 2014

Abstract—Variations of the trophic status of lakes Batorino, Myastro, and Naroch were analyzed over a long period of 1978–2013. The lakes form a system of interconnected water bodies with a wide range of trophic states. In the period under consideration, the trophic conditions in the lakes varied from highly eutrophic (Lake Batorino) to oligotrophic (Lake Naroch), making it possible to analyze the long-term changes in the trophic state of the lakes with the use of different variants of evaluating the Carlson index (trophic state index, TSI), to assess the relationship between the three versions of the index with one another, with phytoplankton biomass, and with hydroecological characteristics, such as the concentrations of total N, seston, and organic matter and biochemical oxygen demand. The possibility to evaluate the index by other characteristics, including phytoplankton biomass, was also considered.

Keywords: lakes, trophic status, Carlson index, hydrochemical characteristics, phytoplankton biomass

DOI: 10.1134/S009780781605002X

INTRODUCTION

The trophic status is a key hydroecological characteristic of water bodies. The problem of changes in the trophic status of water bodies has become especially acute in the second half of the XX century, when the processes of eutrophication (an increase in the production of aquatic ecosystems, mostly under the effect of anthropogenic factors) acquired a global scale. The critical importance of the problems associated with the eutrophication of water bodies and water quality deterioration determined the need to adequately evaluate the trophic status of water bodies. The estimate of the environmental condition and the trophic status of a water body can be objective only when based on a maximally wide description of the biological, chemical, and physical parameters of the water body [18]. There are no distinct boundaries between trophic zones, as a water body can be oligotrophic by one criterion and eutrophic by another [13]. In addition, a description of the trophicity status of a water body limited to the main terms of the trophic status (oligo-, meso-, and eutrophic) can be too scarce for assessing its conditions. This implies the need to numerically express the trophic status, thus making it possible to compare the results obtained by different experts at different objects. Carlson index [15] is among the most widely used characteristics of the trophic state. It is calculated by three hydroecological characteristics: the concentrations of chlorophyll (Chl) *a* and total P in water and the Secchi depth (SD). R. Carlson proposed formulas for evaluating an index by each such characteristic, each being an independent variant providing a numerical measure of the trophic status of the water body. Later, in [23] it was proposed to supplement this index by an estimate of trophicity by the total N content of water. These seems to be justified in the case of water bodies where N rather than P is the main limiting factor, a feature most typical of water bodies in the temperate zone. R. Carlson noted that the main hydroecological characteristic of the trophic status of water bodies is phytoplankton biomass [15], which can be indirectly assessed by the indices he had proposed. Phytoplankton biomass evaluation by indirect characteristics is impelled by the methodological problems and labor intensity of its determination, justifying the use of indirect methods of biomass assessment in the calculation of trophicity index of water bodies.

In this context, of particular interest is the analysis of the correlation of different approaches to calculating the trophicity index with the biomass of phytoplankton community, as well as with other major hydroecological characteristics, including biochemical oxygen demand (BOD), water seston content (*S*), the concentrations of total and mineral forms of biogenic elements, etc. Such data can demonstrate the adequacy of trophic state estimate for a water body by the widely used Carlson index, which, in its classic form, involves as little as three characteristics. Moreover, in [14, 26, 33], this index is evaluated with one or two characteristics. The formulated objectives can be

Table 1. Major characteristics of the lakes under study [1]

Characteristics	Lake Batorino	Lake Myastro	Lake Naroch
Water area, km^2	6.3	13.1	79.6
Water volume, million m^3	18.7	70.1	710.0
Depth, m (mean/maximal)	2.4/5.5	5.4/11.3	8.9/24.8
Water exchange time, year	1.0	2.5	10–11

attained only provided that it is possible to analyze data on different hydroecological characteristics measured at the same time at the same water bodies.

The objective of this study is to analyze the long-term variations of the trophic status of the Narochanskie Lakes with the use of several variants of Carlson index evaluation, to assess the interrelationship between the three estimates of the index and their relationships with phytoplankton biomass and other hydroecological characteristics; to consider the possibility to evaluate the index by other characteristics, including phytoplankton biomass.

MATERIALS AND METHODS

The examined lakes of the Narochanskaya group (Batorino, Myastro, and Naroch) are situated in the northwestern Belarus, belong to the Neman R. basin, have a common drainage area, and are interconnected by channels. The lakes are polymictic; they differ by their morphometric and hydrological characteristics (Table 1). The morphometric features of the lakes, including their relatively large area and small mean depth, contribute to an intense dynamic mixing of water resources.

Water samples were taken 1–3 times per month during vegetation season with the use of a two-liter Ruthner bathometer in the deep-water zone of the lakes at stations and horizons of regular observations. Depending on weather conditions, the sampling began in April or May and ended in October. Water samples were taken at six horizons (0.5, 3, 6, 8, 12, and 16 m) in Lake Naroch, at four horizons (0.5, 4, 7, and 9 m) in Lake Myastro, and at three horizons (0.5, 3, and 5 m) in Lake Batorino. Water from all horizons was mixed to form an integral sample for determining the mean chemistry of the lake water. The volume of water from each horizon in the integral sample was proportional to the share of this horizon in the total lake water volume according to bathymetric data. At the same depths, water temperature t was measured with the use of a deep-water thermometer (TG type) with a scale resolution of 0.1°C.

The value of SD was determined with the use of a white Secchi disc 30 cm in diameter. The concentration of suspended mater (seston, S) was determined by a gravimetric method on membrane filters with pore diameter of 1.5 μm. The same filters were used to determine Chl *a* content of suspension without correction for the presence of pheopigments. The analyses were made by a spectrophotometric method with extraction of pigments in 90% acetone [9, 31]. The biochemical oxygen demand over 5 days (BOD_5) was determined by the decrease in O_2 dissolved in water at lake water incubation in darkness at t = 20°C. The total concentration of organic matter (OM) was determined by bichromate oxidability of water samples, evaporated in a water bath. It was assumed that 1 g of O_2 is equivalent to 0.375 g of C. The concentration of total N (N_{tot}) was determined after mineralization of nonfiltered water by Kjeldahl procedure or oxidation of samples with potassium persulfate in an autoclave; the concentration of total P (P_{tot}) was determined after mineralization of nonfiltered water with potassium persulfate in an acid medium on a water bath. The mineral forms of N (N_m) were determined in filtered water by colorimetric methods: ammonium N with Nessler's reagent; nitrate N, with sodium salicylate or Griss reagent after reduction on a copper–cadmium column; nitrate N, with Griss reagent; and mineral P (P_m), with mixed molybdenum reagent and ascorbic acid as a reducer [2, 8, 11].

Phytoplankton samples 0.5 L in volume were fixed by Utermel method modified by T.M. Mikheeva [4]. Phytoplankton biomass (B) was determined by sedimentation method in Fuchs–Rozental chamber. The individual mass of alga was determined by volume–weight method with the comparison of phytoplankton cell shapes with geometric figures [3, 20].

The trophic state index was calculated for each parameter, proposed by Carlson (SD, Chl *a*, and P_{tot}) by formulas describing logarithmic curves of variations in the index [15]:

$$TSI_{SD} = -14.388 \ln (SD) + 59.909,$$

where TSI_{SD} is trophicity index, evaluated by the values of SD, m;

$$TSI_{TP} = 14.427 \ln (P_{tot}) + 4.1504,$$

where TSI_{TR} is trophicity index, calculated by P_{tot} concentration, mg/m^3;

$$TSI_{Chl\ a} = 9.7552 \ln (Chl\ a) + 30.913,$$

where $TSI_{Chl\ a}$ is trophicity index, calculated by Chl *a* concentration, mg/m^3.

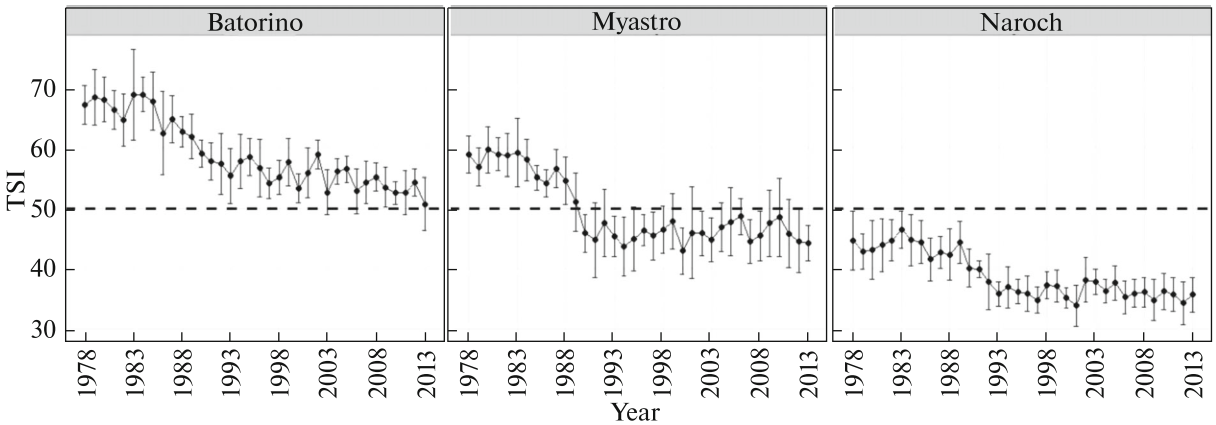

Fig. 1. Long-term TSI dynamics and standard deviations for its values in the Narochanskie Lakes (here and in Fig. 2, the dashed line is the conventional boundary between the eutrophic and mesotrophic zones).

The integrated value was taken to be the mean of the three calculated trophicity indices calculated as

$$TSI = \frac{TSI_{TP} + TSI_{Chl\ a} + TSI_{SD}}{3}.$$

The interrelation between the indices was evaluated by Spearman's rank correlation coefficient.

The trophicity of water bodies decreases from Batorino, the first lake in the chain, to Naroch, the last one. According to the results of observations in the recent 60 years, the Narochanskie Lakes show several distinct stages in the evolution of the structural and functional organization of their ecosystem [7]. In the period of active eutrophication of the lakes (up to 1985), the mean P_{tot} concentrations in Lake Batorino were 80–107 μg P/L, reaching 188 μg P/L in some months. By 2013, the mean P_{tot} concentration in this lake dropped to 22.3 μg P/L. In the least-trophicity Lake Naroch, the mean seasonal concentration of P_{tot} varied within 11–44 μg P/L with an appreciable decrease in the recent years compared with the eutrophication period. The minimum of P_{tot} concentration (6 μg P/L) was recorded in July 2013. In Lake Myastro, showing an intermediate value of trophicity, the range of variations of season-averaged P_{tot} values in the period under consideration was 23–71 μg P/L. The concentration of N_{tot} in water in the period under consideration varied from 0.14 in Lake Naroch to 3.00 mg N/L in Lake Batorino with the season-averaged values in the observation period varying from 0.32 in Lake Naroch in 1994 to 2.32 mg N/L in Lake Batorino in 1979. OM concentration varied from 3.70 in Lake Naroch to 19.87 mg C/L in Lake Batorino, the season-averaged characteristics varying within 4.48–17.01 mg C/L. The maximal concentrations of *S*, Chl *a*, mineral N forms, as well as BOD_5, recorded in individual observations, and their season-averaged values were also observed in Lake Batorino, while their minimal values were observed in Lake Naroch. P_m concentration was everywhere at the determination threshold (<5 μg P/L). The range of Secchi depth (SD) in the study period varied from 0.40 m in Lake Batorino in August 1979 to 10.35 m in July 1999 in Lake Naroch. At the same time, the season-averaged SD in the lakes varied within 0.61–8.17 m. The concentration of Chl *a* also varied within a wide range from 0.26 in Lake Naroch to 164.1 μg/L in Lake Batorino at season-averaged values of 0.94–79.2 μg/L. The values of *B* varied from 0.03 in Lake Naroch to 65.2 mg/L in Lake Batorino, with season-averaged values varying from 0.21 in Lake Naroch in 1999 to 23.72 mg/L in Lake Batorino in 1979. The littoral and pelagic zones showed no significant difference in terms of phytoplankton composition and abundance [5, 6].

Overall, the examined lakes can be regarded as model objects, which show a considerable trophicity range, making it possible to compare different methods of determining the trophic status of lakes based on various criteria, to assess their complementarity and interchangeability, and to identify the most reliable characteristics for evaluating the trophic status of water bodies.

RESULTS OF STUDIES

The values of TSI, averaged over the vegetation season, have been steadily decreasing in all three lakes since 1978 (Fig. 1). In the time interval under consideration, the trophic conditions in the lakes in different periods varied from highly eutrophic in Lake Batorino to oligotrophic in Lake Naroch.

From the late 1970s to 2013, the averages over the vegetation season of TSI for Batorino Lake, the upper lake in the lake system, dropped from the boundary for the highly eutrophic zone (70) to a conventional boundary of the values of eutrophic and mesotrophic zones (50) (Fig. 1). In Lake Myastro, the season-aver-

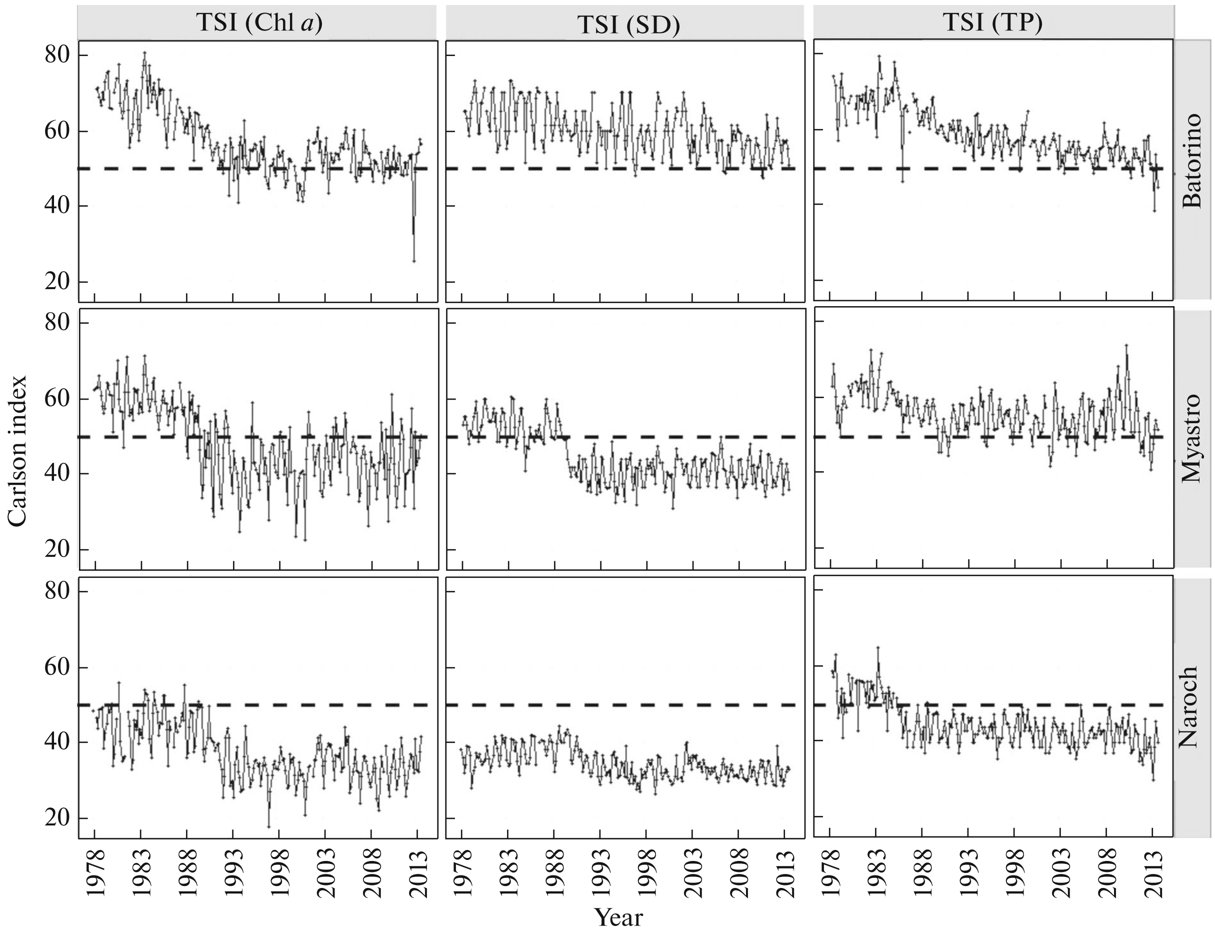

Fig. 2. Long-term dynamics of Carlson trophic state index, calculated by individual characteristics, in the Narochanskie Lakes.

aged TSI dropped below the boundary between the eutrophic and mesotrophic zones in the late 1980s. In Lake Naroch, TSI in the period under consideration varied within the domain of mesotrophic values with drops below 30 (into the oligotrophic domain) in some months. The standard deviation, which characterizes the variation range of the index, was small, varying from as little as 4.78 in Lake Naroch to 6.79 in Lake Myastro. The minimal value of TSI (29.6) was recorded in Lake Naroch in July 2012; and its maximal value (76.7), in August 1983 in Lake Batorino.

The average values of TSI throughout the observation period were 38.9 for Lake Naroch, 49 for Lake Myastro, and 58.8 for Lake Batorino. Note that a decrease in the trophic status of the lakes was accompanied by an increase in the difference between the indices calculated by individual characteristics. Thus, the difference was <4 units for Lake Batorino (TSI_{SD} = 60.13, TSI_{TP} = 59.14, $TSI_{Chl\ a}$ = 56.90), >10 units for Lake Myastro (TSI_{SD} = 44.50, TSI_{TP} = 55.94, $TSI_{Chl\ a}$ = 48.09), and also >10 units for Lake Naroch (TSI_{SD} = 34.51, TSI_{TP} = 44.80, $TSI_{Chl\ a}$ = 37.39). The highest trophicity in two out of the three lakes was shown by the index calculated by P_{tot} concentration. In this case, the indices, evaluated by different characteristics, show similar variation dynamics (Fig. 2).

The coefficients of correlation between the three calculated values of the index also showed a close relationship (Table 2). Thus, the coefficients of correlation for data on all lakes varied within 0.72–0.96, a value, which, at the number of observations of 480, suggests a very high significance level. The variation range for the coefficients of correlation for individual lakes is somewhat wider: 0.48–0.83. The least coefficients were recorded for the correlation between P_{tot} and Chl *a*. However, the significance of the coefficients is still very high. In the authors' opinion, it is not reasonable to consider the significance level at the observation number as large as this. The correlation coefficient alone provides a more adequate estimate. Table 2 shows TSI to be not correlated with P_m concentration and weakly correlated with the concentrations of N_m and N_{tot}. The coefficients of correlation were found to be high between TSI and the concentrations of *S* and OM in water, as well as with BOD_5,

Table 2. Spearman correlation coefficients between variants of Carlson index and hydroecological characteristics of the Narochanskie Lakes

	TSI_{TP}	$TSI_{Chl\ a}$	TSI_{SD}	*S*	BOD_5	OM	N_{tot}
TSI	0.86***	0.94***	0.96***	0.94***	0.73***	0.80***	0.37***
TSI_{TP}	1.00	0.72***	0.75***	0.73***	0.59***	0.65***	0.24***
$TSI_{Chl\ a}$	–	1.00	0.86***	0.89***	0.65***	0.66***	0.38***
TSI_{SD}	–	–	1.00	0.95***	0.75***	0.84***	0.38***
	N_m	P_m	*B*	Chl *a*/*B*	Chl *a*/*S*	*B*/*S*	*t*
TSI	0.46***	–0.07	0.83***	–0.08	0.16**	0.22***	0.08
TSI_{TP}	0.40***	0.18***	0.62***	–0.02	0.13*	0.13*	0.08
$TSI_{Chl\ a}$	0.38***	–0.09	0.80***	0.05	0.38***	0.22***	0.01
TSI_{SD}	0.48***	–0.15*	0.84***	–0.19***	0.00	0.22***	0.12*

* $p \le 0.01$.
** $p \le 0.001$.
*** $p \le 0.0001$.

these coefficients being largest for Lake Batorino, which shows the highest trophic status. No correlation was found to exist between all calculated trophic status indices and the values of water *t*.

B shows a strong correlation with both TSI (Table 2) and individual estimates of the trophic index. The weakest correlation with *B* among the indices was shown by TSI_{TP}. No correlation was found to exist between the abundance of phytoplankton cells and TSI. As noted by R. Carlson [15], the main characteristic of trophic status is *B*. The characteristics chosen by R. Carlson to evaluate the index are closely related with *B*. However, with a considerable data body available on *B*, it is quite reasonable to compare the TSI values obtained by the classical method of Carlson index calculation with *B* and to construct a model direct calculation of TSI by *B*. The most reasonable is the regression logarithmic model proposed by R. Carlson for classical variants of index calculation (Fig. 3). The regression model of TSI variation as a function of *B* in the examined lakes has the form:

$$TSI_B = 5.805 \ln(B) + 42.294,$$

where *B* is wet phytoplankton biomass, g/m^3.

In accordance with the proposed model, an increase in the index by 10 units causes an increase in *B* by a factor of 5.6. In the lakes under consideration, the coefficient of correlation between *B* and the Chl *a* content of water, a characteristic used in the classical Carlson index, was 0.80. At the same time, the mean concentrations (%) of chlorophyll in *B* in lakes Naroch and Myastro were 0.30 ± 0.32 and 0.30 ± 0.25, respectively, and that in Lake Batorino was 0.17 ± 0.15.

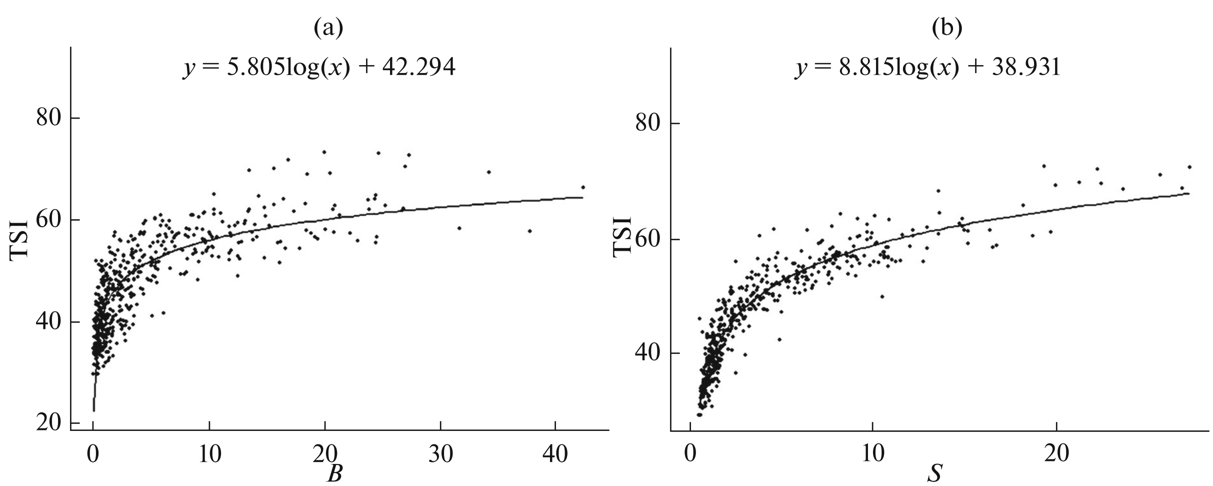

Fig. 3. Relationship of TSI with phytoplankton biomass (B), g/m^3, and the concentration of suspended matter (*S*), g/m^3 in the Narochanskie Lakes. The correlation coefficients are given in Table 2.

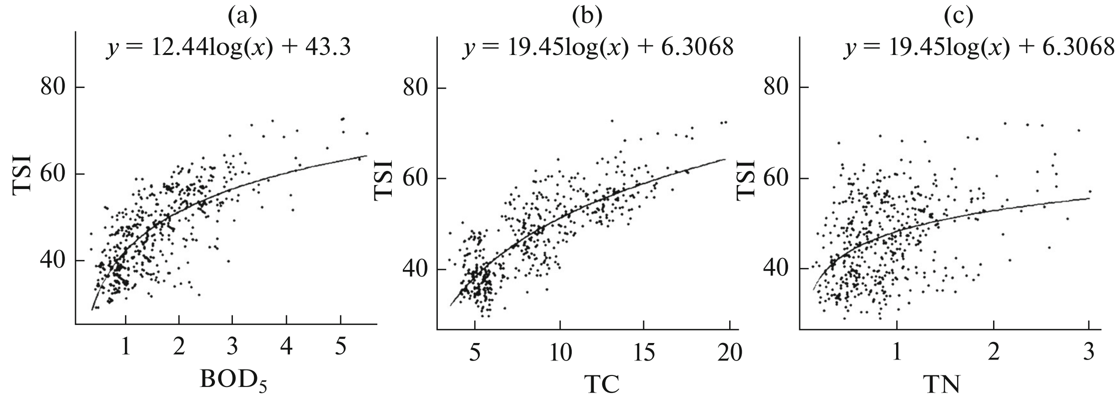

Fig. 4. Relationship between TSI and organic matter content (TC), g/m^3, the total nitrogen (TN), g/m^3, and BOD_5, gO_2/m^3, in the Narochanskie Lakes. The correlation coefficients are given in Table 2.

The construction of models correlating variations of TSI with the dynamics of other examined hydroecological characteristics showed the model with S to be as meaningful as that with B (Fig. 3). Each increase in TSI by 10 units is accompanied by an increase in S concentration by a factor of 3.1. The regression equation is as follows:

$$TSI_S = 8.815\ln(S) + 38.931,$$

where S is seston dry mass, g/m^3.

The average concentration of B in S (%) was similar in all examined lakes and amounted to 20.35 ± 14.69 in Lake Naroch, 21.78 ± 15.53 in Lake Myastro, and 25.62 ± 15.66 in Lake Batorino.

The relationship between TSI, on the one hand, and BOD_5 and OM, on the other hand is less distinct (Fig. 4). The coefficients of correlation between TSI and these characteristics increase with trophicity. Evaluated for individual lakes, the coefficients of correlation between TSI and OM were 0.19 and 0.14 for lakes Naroch and Myastro, respectively, and 0.54 for Lake Batorino. The correlation with TSI is weakest for N_{tot} (Fig. 4). The regression curves are constructed by logarithmic values of characteristics, as they were used in the classical representation of Carlson index.

DISCUSSION OF RESULTS

The wide use of Carlson index for characterizing the trophic state of water bodies is due to the simplicity and ease of use and the numerous examples of its application [13, 22, 24, 25, 32]. There are no definite criteria for the choice of a characteristic for calculating this index. Researchers most often chose a characteristic based on their own expert opinion or on the possibility to obtain required data. In assessing the state and differences of the trophic status of 26 channel lakes, it was shown that the best estimate can be derived from the mean value of the index evaluated by the values of several characteristics [13]. This, clearly, requires the availability of data on all characteristics involved in the study, i.e., P_{tot}, SD, and Chl *a*. In this case, the characteristics are to be measured simultaneously and under identical conditions, since different conditions, time, and sampling procedures can have a significant effect on the estimated values of the index, especially when a single sample is taken [24].

The authors' data on the Narochanskie Lakes suggest the most objective characteristic of the trophic state to be the mean of the three available estimates of the index (TSI_{SD}, TSI_{TP}, and $TSI_{Chl\ a}$). At the same time, the high coefficients of correlation between the trophicity indices calculated by different characteristics show the comparability of estimates they give and the adequacy of the assessment of the trophic status of Narochanskie Lakes by any variant proposed for their calculation.

The absence of a pronounced correlation between the trophicity indices and water t values shows that the seasonal factor, which is of importance for water bodies of the moderate zone, has not an effect on trophicity strong enough to cause appreciable errors in the estimates of the trophic status of a water body by TSI.

The dynamics of B is in agreement with variations of TSI, calculated by the proposed characteristics and allows a good approximation by a logarithmic curve. This is not surprising, as the Chl *a* content of B unit is relatively steady. This, accordingly, suggests the reliability of estimating B by water Chl *a* content, which is not ubiquitous in surface waters of water bodies [10]. The situation is similar with water S content in the Narochanskie Lakes. The concentration of phytoplankton in S being relatively steady, allows the assessment of trophicity by this characteristic as well. Had the values of Chl *a* in B, as well as B in S varied considerably, then, naturally, Chl *a* and S would have provided wrong information about the actual phytoplankton concentration in lake water. This would have had an adverse effect on the information content of trophicity estimate by Carlson index. In this case, the concentration of Chl *a* per unit *B* (Chl *a*/*B*) does not correlate with trophic state indices. The coefficients of correlation between TSI values and characteristics, such as individual weight of a cell (biomass/the number of cells), the concentration of *B* in *S* (*B*/*S*), the concentration of Chl *a* in *S* (Chl *a*/*S*), were also found to be not large, their absolute values never exceeding 0.38, thus also counting in favor of the use of *B* obtained by a direct method to calculate trophic state index, which is in good agreement with the classic variants of evaluating the trophic state index of water bodies.

Some authors note that the Carlson indices evaluated by different methods may show somewhat different variation dynamics. Thus, in the estimates of the trophic status of Lake Uluabat, Turkey, the maximal values were obtained for the index evaluated by P concentrations. Similar results were obtained in a study of eight lakes in Pomerania [22]. In a study of 26 lakes in the Norfolk Broads, three lake groups were identified based on combinations of various factors [13]. In the first group, at the given biogenic load, the concentration of P is not a critical factor in the development of primary products (the index evaluated by P for this lake group is higher than that evaluated by other characteristics). In the second group, the P load onto the water body is the main factor of alga development (this leads to the variability of all three trophic indices of water bodies with respect to one another). In the third group, the P load onto the water bodies is small (the values of all calculated trophic indices of water bodies are very similar).

For the first two out of the three lakes studied by the authors, the trophic index calculated by the concentration of P_{tot} was generally somewhat larger than the indices calculated by other characteristics. At the same time, the assessment of the state of Portuguese reservoirs yielded good results based on an index evaluated by the concentration of P_{tot} alone [14]. The choice of this characteristic was substantiated by P being the key factor in the process of surface water eutrophication. Importantly, there were no relationship between P_{tot} and water body area, a fact that suggests the objectivity of P_{tot} in trophic status assessment [14]. It was noted, however, that the most objective characteristic of the trophicity of a water body as estimated by a single index, is Chl *a* concentration, followed by P [14]. The use of P_{tot} concentration in the calculation of Carlson index is based on the assumption that, among all biogenic elements, it is P that limits the development of phytoplankton [25, 29, 34–36]. According to [12], P becomes a limiting factor at $N/P > 7$; according to [16, 17], this takes place at $N/P > 12–17$. However, there are many data [19, 21, 28–30] about the conditions under which the concentration of N in water limits the development of primary producers in a water body. Thus, studies of some reservoirs in China show them to gradually become limited by N; this, in the authors' opinion, requires monitoring the concentrations of both components. Nowadays, data on N limiting lakes become even more frequent [21, 28–30], though the main limiting element for the development of primary producers in fresh water is still considered P [25, 29, 34–36]. Clearly, under N limiting, an index evaluated by P_{tot} can give a less objective estimate. As an addition, in studying lakes where N can be limiting in some periods, a calculation of Carlson index based on data on the concentration of this element in water is proposed in [23].

In the case under study, a very weak correlation was found to exist between TSI and N_{tot} concentration. This implies the absence of phytoplankton development limiting by N in the examined Narochanskie Lakes; therefore, the calculation of Carlson index by it is not informative. On the average for all lakes, the ratio $N_{tot} : P_{tot}$ was 35 : 1. For Lake Naroch, this ratio was 47 : 1; for Lake Myastro, 27 : 1; and for Lake Batorino, 31 : 1. This also show P to be the main factor to govern the development of primary producers in the Narochanskie Lakes.

Studies on Lake Lanier showed that the indices calculated by the concentration of Chl *a* are lower (suggesting less trophic conditions) than those calculated by SD values [26]. It was found that different interpretations of index values are due to the strong dependence of SD on the characteristics not related to algae. SD is among the easiest to access and measure characteristics; it adequately characterizes the trophic status of a water body. However, in lakes with water high in the share of resuspended suspension, SD may not reflect the actual alga concentration in it [26]. However, as noted in a study of Vistula Lagoon, the assessment of its water trophicity by SD values alone can be considered unreliable because of the intense resuspension of sediments, which reduces water transparency irrespective of whether it contains phytoplankton [27].

In the Narochanskie Lakes, the absolute value of the correlation coefficient between Secchi depth (SD) and *B* was even higher than that between *B* and Chl *a* content (–0.84 compared with 0.80), implying that SD, as well as the index derived from it, are good characteristics of the trophic status of water bodies. At the same time, SD measurement requires lesser time and resources. The situation is similar with the index, proposed for the Narochanskie Lakes and based on the concentration of *S* in water, which is also simpler to measure than the concentrations of Chl *a* and *B*. In this case, it should be taken into account that the relative concentration in *S* of both phytoplankton and Chl *a* in the examined lakes kept relatively stable.

CONCLUSIONS

Long-term studies of the Narochanskie Lakes showed Carlson index to adequately reflect the changes in the trophic status of the water bodies. In the study period (1978–2013), the trophic conditions in the lakes varied from highly eutrophic in Lake Batorino to oligotrophic in Lake Naroch. The most objective characteristic of their trophic state is the mean value of three versions of its estimate (TSI_{SD}, TSI_{TP}, and $TSI_{Chl\ a}$). The high coefficients of correlation between the trophic indices, calculated by different characteristics, suggest the comparability of estimates based on them and the adequacy of trophic status estimates of the Narochanskie Lakes by any of the variants proposed for its calculation. The indices, evaluated by different characteristics show similar variation dynamics.

The index calculated by P_{tot} concentration shows the highest trophic status in two out of the three lakes. The correlation was found to be weakest between TSI and N_{tot} content. This suggests that phytoplankton development in the Narochanskie Lakes is not limited by N and, therefore, the evaluation of Carlson index based on it is not reasonable. Also, no relationship was shown to exist between the values of trophicity indices TSI, TSI_{SD}, TSI_{TP}, $TSI_{Chl\ a}$, and water temperature t.

The value of B found by direct method shows a strong correlation with both TSI and TSI_{SD}, TSI_{TP}, $TSI_{Chl\ a}$. In accordance with the regression model relating TSI and B, proposed based on the authors' results, an increase in the index by 10 units is accompanied by an increase in B by a factor of 5.6. A model of relationship between S and TSI shows that any increase in TSI by 10 units is accompanied by an increase in the concentration of S by a factor of 3.1. At the same time, the relative concentrations of phytoplankton and Chl a in S in the water of the examined lake were relatively stable.

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Translated by G. Krichevets