International Journal of Advanced Biochemistry Research 2024; SP-8(3): 41-45

International Journal of Advanced Biochemistry Research

ISSN Print: 2617-4693
ISSN Online: 2617-4707
IJABR 2024; SP-8(3): 41-45
www.biochemjournal.com
Received: 02-01-2023
Accepted: 06-02-2023

Adinath T Markad
Assistant Professor, College of Fishery Science, Udgir, Latur, Maharashtra, India

Ajay S Kulkarni
Assistant Professor, College of Fishery Science, Udgir, Latur, Maharashtra, India

Sandip S Markad
Assistant Professor, Toshniwal Arts Commerce & Science College, Sengaon, Hingoli, Maharashtra, India

Vijay B Sutar
Assistant Professor, College of Fishery Science, Udgir, Latur, Maharashtra, India

Supriya D Meshre
Assistant Professor, College of Fishery Science, Udgir, Latur, Maharashtra, India

Vikrant V Bansode
Assistant Professor, College of Fishery Science, Udgir, Latur, Maharashtra, India

Corresponding Author:
Adinath T Markad
Assistant Professor, College of Fishery Science, Udgir, Latur, Maharashtra, India

Comparison of eutrophication level by applying different trophic state indices to the Tiru reservoir, Udgir, dist. Latur

Adinath T Markad, Ajay S Kulkarni, Sandip S Markad, Vijay B Sutar, Supriya D Meshre and Vikrant V Bansode

DOI: https://doi.org/10.33545/26174693.2024.v8.i3Sa.690

Abstract

Freshwater resources are limited in nature and their demand is increasing daily. The use of excessive chemicals and fertilizers increases water fertility. Eutrophication is a common problem all over the world. To conserve these resources, they should be appropriately monitored to know their trophic condition. Various researchers have proposed different water classification criteria and methods. The present study attempted to apply multiple trophic status indicators to the Tiru reservoir water quality characteristics. Water quality data were gathered from the Tiru reservoir, Udgir Tahsil, Latur (Maharashtra) between February 2018 and January 2019. Markad *et al.* (2019) established the TSI model based on the native biological and geographical conditions, which resulted in optimal performance for measuring the trophic state of the Tiru reservoir.

Keywords: TSI, eutrophication, fertilizers

Introduction

Water is life. Water is highly precious for the human population, animals and plants residing in drought-prone areas. Due to tremendous pressure on freshwater resources for human use, agriculture, industries, animal husbandry, electricity production, etc. results in water scarcity issues (Tundisi & Matsumura, 2011) [24]. The limited water resources against the increasing demand for water have put these resources at alarming levels worldwide (Schmutz & Moog, 2018) [21].

Water resources are mainly overexploited for agricultural use. The increasing demand for food with the growing population has forced us to use chemical fertilizers in agriculture practices to achieve greater yields. The excessive use of fertilizers such as nitrogen, phosphorus, and minerals causes harm to the environment as the residues of these fertilizers that remain after plant intake cause soil, water, and air pollution. The residual fertilizers directly enter the aquatic ecosystem during agricultural runoff and, thus increase water fertility (Hughes *et al.*, 2014) [13]. Various ecosystems have been reported at alarming condition all over the world (González & Roldán, 2019; Le Moal *et al.*, 2019) [9, 16]. Increasing nutrient input in the water bodies causes excessive plankton growth in the water and causes eutrophication (Haberman & Haldna, 2014; Havens, 2014) [11, 12]. Excessive growth of harmful plankton like cyanobacterial blooms suppresses native fauna and disturbs the food chain (Jeppesen *et al.*, 2015; Glibert, 2017) [5, 8]. An aquatic ecosystem is deteriorating due to eutrophication and this will affect fish production. Also this polluted water is not helpful for human and livestock consumption.

India has 19,134 small reservoirs (<1000 ha) with a total water spread area of 14,85,557 ha, 180 medium reservoirs with 5,27,541 ha, and 56 large reservoirs with 11,40,268 ha. Central Water Commission (CWC) is monitoring water quality at 552 key locations (519 water quality sites and 33 water quality sampling stations) covering all the major river basins of India and monitoring the live storage status of 121 critical reservoirs of the country every week. Small reservoirs which cover 47% of the total reservoir area, are often ignored due to huge cost involved and the complexity of data collected during the monitoring.

Parts of the Marathwada region in Maharashtra state of India, especially the Latur and Beed districts, were perpetually in the news for their drought-like conditions, which have continued for years. India's first 'Water Express' train arrived at Latur in 2016 to save people from drought. Conserving and maintaining water quality in such a drought-prone area is the need of the hour. By keeping in mind the importance of small reservoirs for domestic consumption, agriculture, livestock survival and income generation through fish culture as well as capture, this research has been carried out at the Tiru reservoir from drought-prone areas of Marathwada region, Maharashtra, India. With regular monitoring of water quality parameters, it is possible to judge its suitability for fish culture or human consumption. It can adapt or suggest necessary steps for improving water quality as per requirement. An ecosystem's functional properties can be assessed by observing lakes, ponds and reservoirs (Begliutti *et al*., 2007; Solanki *et al*., 2010) [3, 23]. For enhancing the sustainability of the water quality management system, in-depth research on Trophic State Monitoring of water quality and the relevant mitigation approaches is desired.

Various researchers have presented their Trophic State Index Estimation models all over the world. These different models produce varying outputs for the same water body, resulting in confusion while selecting the proper TSI index/model (Pomari *et al*., 2018) [19]. Proper eutrophication assessment would help policymakers take necessary steps to improve water quality. In the present study, an attempt has been made to estimate the trophic state estimation of the Tiru reservoir by using different TSI estimation models and comparing the effectiveness of these models to the Tiru reservoir.

Materials and Methods

Study Area: The present study was conducted at Tiru Reservoir (Fig. 01) in Udgir Tahsil, Latur, Maharashtra. Tiru reservoir has great importance in the locality as the water is mainly used for irrigation, domestic consumption, and animal husbandry. It is an earth fill dam constructed on the Tiru River.

Water sampling was conducted from February 2018 to January 2019 from 5 sampling locations every month. The water samples were brought to the Aquatic Environment Management Department of the College of Fishery Science, Udgir in cool condition with ice packs. Chlorophyll a and Total Phosphorus were estimated by using APHA, 2005 standard protocols in the laboratory by using spectrophotometer and secchi disk transparency was evaluated by using 12 cm secchi disk in the reservoir itself while conducting sampling (Table 2).

Results and Discussion

Trophic State Index estimation

To "rate" bodies of water like lakes, ponds, and reservoirs according to the level of biological production, scientists developed the Trophic State Index (TSI). A water body's TSI is measured on a scale of 0 to 100. Water bodies can be classified based on water quality as oligotrophic (TSI 0-40: good), mesotrophic (TSI 40-60: fair), or eutrophic/hypereutrophic (TSI 60-100: poor).

A) Carlson's (1977) [4] TSI Estimation model

Carlson's (1977) [4] TSI technique to assessing a reservoir's trophic status is the most widely used method and is based on the relationship between SDD, Chl-a, and TP. Carlson's (1977) [4] formulas for estimating trophic status (TSI) using SDD, TP, and Chl-a (Saluja and Garg, 2017) [20] are characterized as:

$$\text{TSI (SDD)} = 10 \times \left(6 - \frac{\ln \text{(SDD)}}{\ln (2)}\right)$$

$$\text{TSI (Chl} - a) = 10 \times \left(6 - \frac{2.04 - 0.68 \times \ln (\text{Chl} - a)}{\ln (2)}\right)$$

$$\text{TSI (TP)} = 10 \times \left(6 - \frac{\ln (48/\text{TP})}{\ln (2)}\right)$$

The trophic state index estimation model developed by Carlson in 1977 [4] is widely regarded as the most straightforward and frequently employed approach to evaluate the productivity of reservoirs (Nalamutt and Karmakar, 2014) [18].

B) Markad *et al.* (2019) [17] TSI Estimation model

Markad *et al.* (2019) [17] has developed this model for Tiru reservoir by considering the native environmental and geographical condition. This model estimates TSI values based on the Chl-a, TP and SDD levels in the reservoir. Estimation of Trophic State Index by this model is given as:

$$\text{TSI (SDD)} = 10 \times \left(5.3354 - \frac{\ln \text{ (SDD)}}{\ln (1.3119)}\right)$$

$$\text{TSI (Chl} - a) = 10 \times \left(5.3354 - \frac{-0.341 - 0.143 \text{ X} \ln (\text{Chl} - a)}{\ln (1.3119)}\right)$$

$$\text{TSI (TP)} = 10 \times \left(5.3354 - \frac{-0.025 - 0.162 \text{ X} \ln \text{ (TP)}}{\ln (1.3119)}\right)$$

Where,
SDD: Secchi disk depth in meters (m)
Chl-*a*: Chlorophyll-*a* content in microgram per liter (µg/l)
TP: Total Phosphorus in microgram per liter (µg/l)
TSI (SDD): Trophic state index based on Secchi disk depth
TSI (Chl-*a*): Trophic state index based on chlorophyll-*a*
TSI (TP): Trophic state index based on Total Phosphorus

Total TSI value can be obtained by adding average TSI values of Chl-*a*, SDD, and TP.

In general, the TSI classification is done by considering three classes *viz.* oligotrophic, mesotrophic and eutrophic. Cheng & Lei (2001) [5] modified this and added some more for complex nutrient loadings, like slightly and fully eutrophic, very eutrophic, hypereutrophic, dystrophic and dystrophic. The basic TSI assessment could be done by physical observation of the appearance of a waterbody.

Markad *et al.* (2019) [17] have revised the trophic state classification for this newly developed model.

Table 1: Trophic State Classes suggested in different models

Sr. No.	TSI	Trophic Classes by Markad *et al.* (2019) [17]	Trophic Classes by Carlson (1977) [4]
1	Oligotrophic	> 30 - 40	> 30 - 40
2	Mesotrophic	40 - 50	40 - 50
3	Meso-eutrophic	50 - 65	--
4	Eutrophic	65 - 70	50-70
5	Poly-eutrophic	70 - 75	--
6	Hyper-eutrophic	> 75	70-100

C) Cheng and Lei (2001) [5] TSI Estimation Model

Cheng and Lei (2001) [5] developed a multiparameter model for Te-chi reservoir. The models are given below:

$$\mathrm{TSI\ (SDD)} = 10 \times \left(8.605 - \frac{\ln\ (\mathrm{SDD})}{\ln\ (1.544)}\right)$$

$$\mathrm{TSI\ (Chl} - a) = 10 \times \left(8.605 - \frac{1.8751 - 0.3264\ \mathrm{X}\ln\ (\mathrm{Chl} - a)}{\ln\ (1.544)}\right)$$

$$\mathrm{TSI\ (TP)} = 10 \times \left(8.605 - \frac{2.1775 - 0.4230\ \mathrm{X}\ln\ (\mathrm{TP})}{\ln\ (1.544)}\right)$$

Trophic status of Tiru reservoir by using different TSI models

Trophic State Index models developed by various researchers were applied to the Tiru reservoir’s water parameters to evaluate the trophic status of the Tiru reservoir based on Chl-*a*, TP, and SDD (Table 3). Seasonwise average TSI values [TSI (Total) = [TSI (Chl-*a*) + TSI (TP) + TSI (SDD)] / 3] in 2018 indicated Eutrophic condition in summer season (57.84) by Carlson (1977) [4] model (Fig. 02) and monsoon season (54.10), however, Mesotrophic during winter season (49.71). Markad *et al.* (2019) [17] model (Fig. 03) reported Polyeutrophic conditions during summer (71.66) and monsoon (70.74), whereas eutrophic status in the winter season (66.62). Cheng & Lei's (2001) [5] model (Fig. 04) reported hypereutrophic condition in the summer (93.20), monsoon (90.86) as well as in the winter season (86.90).

Spatio-temporal variation in TSI readings of the Tiru reservoir: The greatest TSI (SDD) measurements were recorded during the monsoon season due to heavy silt loadings from surface runoff during the rainy season, which inhibits light penetration. TSI(SDD) measurements gradually decreased throughout the summer season, while the lowest levels were observed during the winter season. According to Carlson (1977) [4], calculating the TSI index with a high level of turbidity will provide incorrect findings for estimating trophic status.

The concentration of Chl-a varied both spatially and temporally throughout the year. During the summer, rivers were found to be in a eutrophic condition, while during the monsoon and winter, they were found to be at a meso-eutrophic productivity level. During the monsoon season, the readings gradually decreased owing to the dilution of Chl-a concentration caused by rain. In winter, the lowest Chl-a concentration was likely caused by the effects of low light and cooler temperatures on the formation of algal biomass. The results that Saluja and Garg (2017) [20], Gupta (2014) [10], and James *et al.* (2009) [14] reported were identical.

Tiru reservoir was in a eutrophic condition throughout the winter and was poly-eutrophic during the summer and monsoon. In the summer, nutrient concentrations increase when water levels in the reservoir are low, leading to the greatest TSI (TP) concentrations. Because rainwater dilution during the monsoon months dilutes nutrients, the concentration has been falling over the last several months. Concurrently, the overall phosphorus content is balanced due to the huge quantities of nutrients transported by the water that enters the reservoir by surface runoff from agricultural areas. Grazers' ability to recover phosphorus is another possible reason for maintaining TP balance. Consequently, TSI (TP) measurements showed reduced variation. Saluja and Garg (2017) [20] and James *et al.* (2009) [14] noted similar findings.

Overall patterns depict that TSI (TP) values in comparison with TSI (SDD) and TSI (TP) in the Tiru reservoir were higher during the summer and winter months. TSI (SDD) recorded high values during the monsoon months as compared to TSI (Chl-*a*) and TSI (TP). Several researchers have found similar patterns with higher TP values. (Elmaci *et al.*, 2009; Sheela *et al.*, 2011; Amardeep *et al.*, 2018; Ghashghaie *et al.*, 2018) [6, 22, 1, 7].

Table 2: Spatio-temporal fluctuation in SDD (m), Chl-*a* (µg/l) and TP (µg/l)

Season		Sochi Disc Depth (m)						Chlorophyll-*a* (µg/l)						Total Phosphorus (µg/l)					
	Location Month	01	02	03	04	05	Mean	01	02	03	04	05	Mean	01	02	03	04	05	Mean
Summer 2018	Feb.-18	0.68	0.63	0.66	0.59	0.61	0.64	3.32	3.48	3.34	3.67	3.52	3.47	26.36	25.64	27.26	24.74	27.26	26.25
	Mar.-18	0.64	0.60	0.63	0.56	0.53	0.59	7.31	7.65	7.45	7.94	8.11	7.69	34.52	34.94	33.68	34.94	32.84	34.18
	Apr.-18	0.62	0.58	0.62	0.54	0.51	0.58	8.35	8.39	8.18	8.63	8.83	8.48	41.70	43.24	39.06	40.82	42.36	41.44
	May.-18	0.61	0.53	0.62	0.46	0.48	0.54	8.81	8.83	8.74	9.24	8.93	8.91	44.05	43.13	47.04	43.82	43.59	44.33
	Average						0.59						7.14						36.55
Monsoon 2018	Jun.-18	0.52	0.46	0.49	0.47	0.47	0.48	5.01	5.21	5.18	5.32	5.78	5.30	35.6	36.72	36.08	37.04	36.72	36.43
	Jul.-18	0.53	0.50	0.54	0.51	0.47	0.51	3.83	4.06	3.98	4.04	4.43	4.07	26.12	27.10	25.98	27.52	27.38	26.82
	Aug.-18	0.57	0.53	0.59	0.56	0.52	0.55	2.27	3.35	2.28	3.31	3.36	2.91	16.76	18.20	16.28	17.12	16.28	16.93
	Sep.-18	0.66	0.63	0.59	0.57	0.56	0.60	1.78	1.82	1.88	1.92	1.98	1.88	17.36	19.88	19.16	19.40	18.92	18.94
	Average						0.54						3.54						24.78
Winter 2018	Oct.-18	0.72	0.74	0.76	0.75	0.64	0.72	1.67	1.51	1.23	1.44	1.72	1.51	9.65	8.60	10.25	10.85	7.70	9.41
	Nov.-18	0.65	0.67	0.65	0.67	0.58	0.65	2.52	2.38	2.41	2.22	2.58	2.42	10.16	11.48	10.52	12.20	9.44	10.76
	Dec.-18	0.63	0.71	0.62	0.64	0.58	0.64	2.68	2.57	2.71	2.64	2.74	2.67	19.12	20.38	19.68	20.24	19.54	19.79
	Jan.-19	0.59	0.65	0.63	0.61	0.59	0.62	3.46	3.13	3.21	3.42	3.51	3.35	21.64	21.92	21.08	22.9	20.94	21.70
	Average						0.66						2.49						15.42

Table 3: Comparison of monthly TSI values of Tiru reservoir by different models models

Models Month		Carlson (1977) [4]: Minnesota's Lake			Markad *et al.* (2019) [17]: Tiru reservoir			Cheng & Lei (2001) [5]: Te-Chi reservoir		
		SDD (m)	Chl-*a* (µg/l)	TP (µg/l)	SDD (m)	Chl-*a* (µg/l)	TP (µg/l)	SDD (m)	Chl-*a* (µg/l)	TP (µg/l)
Summer 2018	Feb. 18	66.43	42.81	51.27	69.79	63.32	73.10	96.32	76.65	96.10
	Mar. 18	67.60	50.61	55.08	72.79	67.51	74.68	98.20	82.63	98.67
	Apr. 18	67.84	51.57	57.85	73.42	68.02	75.83	98.59	83.36	100.54
	May. 18	68.87	52.06	58.83	76.05	68.28	76.23	100.24	83.73	101.20
Summer Average TSI		67.60	49.88	56.04	72.79	67.12	75.08	98.20	82.07	99.32
Summer TSI (Tiru Reservoir) = [TSI(SDD) + TSI(TP) + TSI(Chl-a)] / 3		57.84			71.66			93.20		
Monsoon 2018	June. 18	70.57	46.96	56.00	80.39	65.55	75.06	102.95	79.83	99.29
	July. 18	69.70	44.37	51.58	78.16	64.16	73.23	101.55	77.85	96.31
	Aug. 18	68.61	41.08	44.95	75.38	62.39	70.49	99.81	75.33	91.82
	Sep. 18	67.36	36.79	46.56	72.17	60.09	71.16	97.81	72.04	92.92
Monsoon Average TSI		68.87	43.00	50.44	76.05	63.42	72.76	100.24	76.80	95.53
Monsoon TSI (Tiru Reservoir) = [TSI(SDD) + TSI(TP) + TSI(Chl-a)] / 3		54.10			70.74			90.86		
Winter 2018	Oct. 18	64.73	34.64	36.48	65.45	58.93	66.98	93.61	70.40	86.11
	Nov. 18	66.20	39.27	38.41	69.22	61.42	67.78	95.97	73.94	87.41
	Dec. 18	66.43	40.23	47.20	69.79	61.94	71.42	96.32	74.68	93.34
	Jan. 19	66.88	42.46	48.52	70.96	63.13	71.97	97.06	76.38	94.24
Winter Average TSI		65.98	39.55	43.60	68.66	61.57	69.93	95.62	74.15	90.92
Winter TSI (Tiru Reservoir) = [TSI(SDD) + TSI(TP) + TSI(Chl-a)] / 3		49.71			66.72			86.90		

Comparison of the Markad *et al*. (2019) [17] TSI model with different models

Comparison of the Markad *et al*. (2019) [17] TSI model with different models to calculate the TSI values of the Tiru reservoir (Table 3). Carlson's (1977) [4] and Cheng's (2001) TSI model showed a significant abnormality in TSI indices. For all months and seasons during the study period, Carlson's TSI model underpredicted the TSI values of SDD, Chl-*a*, and TP, and the deviations were also very high among them. Cheng's (2001) model for the Te-Chi reservoir overpredicted the TSI measurements in case of Tiru reservoir. The SDD readings evaluated by Cheng's (2001) model were very high and not at all suitable for evaluation of trophic status of Tiru reservoir.

TSI model of Markad *et al*. (2019) [17] has shown optimum performance while evaluating Tiru reservoirs Trophic status because the model has been developed based on the native ecological and geographical condition and the other models are based on the different agroclimatic conditions.

Conclusion

While estimating trophic status of any water body, Trophic State Indices developed by various researchers can be used for reference purpose. The actual trophic condition of the water body must be confirmed by physical observation and the best suited Indices can further be referred for taking necessary measures to control eutrophication.

References

1. Amardeep K, Abubakr A, Hassan SS. Trophic status assessment of Nigeen Lake, Kashmir (India). J Entomol Zool Stud. 2018;6(4):1004-1009.
2. APHA. Standard methods for the examination of water and waste-water. 21st ed. Washington DC: American Public Health Association; c2005.
3. Begliutti B, Buscarinu P, Marras G, Sechi G, Sulis A. Reservoirs water-quality characterization for optimization modelling under drought conditions. Part 1-reservoirs trophic state characterization. Methods Tools Drought Anal Manag. 2007;62:239-261.
4. Carlson RE. A trophic state index for lakes. Limnol Oceanogr. 1977;22:361-369.
5. Cheng KS, Lei TC. Reservoir Trophic State Evaluation using Landsat TM Images. J Am Water Resour. Assoc. 2001;37:1321-1334.
6. Elmaci A, Ozengin N, Teksoy A, Topac FO, Baskaya HS. Evaluation of trophic state of Lake Uluabat, Turkey. J Environ Biol. 2009;30(5):757-760.
7. Ghashghaie M, Maralan MRS, Ostad-Ali-Askari K, Eslamian S, Singh VP. Determining the Eutrophication State of Ecbatan Reservoir using Carlson Index. Am J Eng Appl Sci. 2018;11(2):491-500.
8. Glibert PM. Eutrophication, harmful algae and biodiversity — Challenging paradigms in a world of complex nutrient changes. Mar Pollut Bull. 2017;124(2):591–606.
9. González JE, Roldán G. Eutrophication and phytoplankton: Some generalities from lakes and reservoirs of the Americas. In: Vítová M, editor. Microalgae – From physiology to application Vol. I. 2019. p. 1–13.
10. Gupta M. A New Trophic State Index for Lagoons. J Ecosystems. 2014;152473.
11. Haberman J, Haldna M. Indices of zooplankton community as valuable tools in assessing the trophic state and water quality of eutrophic lakes: Long term study of Lake Võrtsjärv. J Limnol. 2014;73(2):61–71.
12. Havens KE. Lake Eutrophication and Plankton Food Webs. In: Ansari AA, Gill SS, editors. Eutrophication: Causes, Consequences and Control. Dordrecht, Netherlands: Springer; c2014. p. 73–80.
13. Hughes RM, Dunham S, Maas-Hebner KG, Yeakley JA, Schreck C, Harte M, Schaeffer J. A review of urban water body challenges and approaches: (1) Rehabilitation and remediation. Fisheries. 2014;39(1):18–29.

14. James RT, Havens K, Zhu G, Qin B. Comparative analysis of nutrients, chlorophyll, and transparency in two large shallow lakes. Hydrobiologia. 2009;627:211-231.
15. Jeppesen E, Brucet S, Naselli-Flores L, Papastergiadou E, Stefanidis K, Nõges T, *et al*. Ecological impacts of global warming and water abstraction on lakes and reservoirs due to changes in water level and related changes in salinity. Hydrobiologia. 2015;750(1):201-227.
16. Le Moal M, Gascuel-Odoux C, Ménesguen A, Souchon Y, Étrillard C, Levain A, Pinay G. Eutrophication: A new wine in an old bottle? Sci Total Environ. 2019;651:1-11.
17. Markad AT, Landge AT, Nayak BB, Inamdar AB, Mishra AK. Trophic state modeling for shallow freshwater reservoir: A new approach. Environ Monit Assess. 2019;191:586.
18. Nalamutt TD, Karmakar S. Modeling impreciseness of trophic state levels for eutrophication assessment. J Clean Energy Technol. 2014;2(2):140-144.
19. Pomari J, Kane DD, Nogueira MG. Application of multiple-use indices to assess reservoirs water quality and the use of plankton community data for biomonitoring purposes. Int. J Hydrology. 2018;2(2):168-179.
20. Saluja R, Garg JK. Trophic state assessment of Bhindawas Lake Haryana. Environ Monit Assess. 2017;189:32.
21. Schmutz S, Moog O. Dams: Ecological impacts and management. In: Schmutz S, Sendzimir J, editors. Riverine ecosystem management; c2018. p. 111-127.
22. Sheela AM, Letha J, Joseph S, Ramachandran KK, Sanalkumar SP. Trophic state index of a lake system using IRS (P6-LISS III) satellite imagery. Environ Monit Assess. 2011;177(1-4):575-592.
23. Solanki VR, Hussain MM, Raja SS. Water quality assessment of Lake Pandu Bodhan, Andhra Pradesh State, India. Environ Monit Assess. 2010;163:411.
24. Tundisi G, Matsumura T. Limnology. Boca Rotan, FL: CRC Press; c2011.