Journal of Environmental Science and Engineering A 14 (2025) 197-205
doi:10.17265/2162-5298/2025.04.003

Chemical and Physical Parameters at a Shallow-Littoral Site and a Pelagial Site on Lake Ray Roberts, Denton County, Texas (United States)

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Abstract: This research directly supported the author's thesis work in partial fulfilment of Master of Science in biology from the University of North Texas (United States) from August 1996 to September 1997. Two sites at Lake Ray Roberts, Denton County, Texas (United States) were examined and contrasted for productivity. The site located in the pelagic zone exhibited a slight, thermal gradient with no stratification, and a slightly stratified clinograde oxygen profile which is typical for summer-stratified eutrophic lakes. The site located in the shallow, littoral zone exhibited high, increasing turbidity with depth, marked by shallow light attenuation through the water column. Temperature was constant at every depth in the littoral site, with a slight, clinograde oxygen profile, typical for shallow, littoral areas subject to wind-induced mixing. Volume estimations of chlorophyll-*a* shows a strong presence in the euphotic zone, indicating photosynthesis occurs until approximately 2.2 m below the surface. The shallow, littoral site showed the basic signs of higher productivity than the open, pelagic site.

Key words: Littoral, pelagic, eutrophic, light attenuation, euphotic zone, photosynthetically available radiation, vertical extinction coefficients, chemocline, stratification, chlorophyll-*a*, phaeophyton-*a*.

1. Introduction

As the human impact on freshwater lakes becomes increasingly apparent, the effects can be felt by even the smallest living organism. We try to understand the world of the freshwater ecosystem by studying their physical, chemical and biological parameters. The lake is not autonomous but rather it is influenced by outer factors such as input from the lake's drainage basin, the sun, wind and rain, etc. Perhaps the most important way of understanding the ecological status of a lake is to measure its productivity in the quantity of new organic matter created by autotrophs. These include measuring the sun's energy input which is undoubtedly the principle factor in determining the physical, chemical and biological parameters of a lake ecosystem [1, 2]. In the water, photosynthesis is derived from the sun, and the end product is the manufacturing of carbohydrates and oxygen, the latter concentrations in a lake ecosystem coming primarily from aquatic plants and phytoplankton (primary producers), which impacts water quality [2-5]. Primary production in water depends upon the depth of which PAR (Photosynthetically Available Radiation) is transmitted. The maximum depth in which light is used for production by phytoplankton is at 1% of photosynthetically available light, often referred to as the euphotic zone (Z_{eu}) [2, 6, 7]. The depth of the euphotic zone varies between lakes and sites within lakes owing to the different watershed sources of allochthonous and autochthonous inputs [8], both natural and anthropogenetic [6, 9], as well as diurnal and seasonal changes caused by wind-induced mixing and stratification of the water column [3, 6].

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The primary producers in a lake ecosystem are organisms that synthesize energy from the sun [2, 3]. The trophic pathway therefore cycles up to the primary consumers (herbivores and planktivores), which are successively consumed by secondary and tertiary consumers (carnivores) [10]. In this complex food web, nutrients and energy from the lowest to the highest trophic level are utilized with only about 1% reaching the top carnivore [1, 3]. Lakes with high nutrient and high organic production are termed *eutrophic* [2, 3]. There are distinct boundary layers through the water column that are influenced by the sun and wind, all contingent upon the time of day and to greater extent, seasons. In summer-stratified eutrophic lakes, the upper layer (or boundary) is the *epilimnion.* The water is continuously mixed by wind and sun action and is the area of primary productivity. The next lower layer is the *metalimnion,* which is the area separating the upper and lower layers by a thermal boundary. This layer has relatively little mixing and is often determined when the temperature gradient between the upper and lower layers is 1 °C or greater. The bottom layer is termed the *hypolimnion.* This layer is associated with microbial decomposition and sedimentation by dead organic matter, with oxygen concentrations approaching zero.

In this report, I examine the basic energy production in Lake Ray Roberts, Denton County, Texas. A comparison is made between a "quiescent" pelagic site and "productive" littoral site [3] in an attempt to show differences in productivity measurements. Emphasis is on basic measurements of light energy, oxygen concentration, temperature, and the effects suspended solids have on these parameters.

2. Materials and Methods

Two trips to Lake Ray Roberts (Fig. 1) were made: one to the vicinity of the dam (Site 1, Lat. 33°21′23.6″ N, Long. 097°03′16.2″ W) on September 13, 1996, which is the deeper part of the lake, and the other to the vicinity of Union Creek (Site 2, Lat. 33°24′06.0″ N, Long. 097°07′18.0″ W) on September 27, 1996, chosen because it is a shallow site in the littoral zone. Accesses to these sites were accomplished by two pontoon-boats provided by Ray Roberts Marina.

At Site 1, temperature and dissolved oxygen were taken at 1-meter depths using a Yellow Springs Instruments (YSI) Model 51B temperature-dissolved oxygen meter. Depth was recorded using an electronic fish finder. Incident solar light (downwelling and upwelling) through the water column was measured using a Protomatic submarine photometer. Light levels were recorded at the surface, 0.1 m below and followed by 0.5 m intervals. A Secchi disk was used to roughly determine Z_{eu} [2, 11].

At Site 2, in addition to the above instruments, a Hydrolab was used to take temperature, dissolved oxygen, pH, conductivity and turbidity at 1-meter intervals. Hydrolab conductivity was calibrated at 2,000 mhos standard. Using standard instrumentation, dissolved oxygen and temperature were recorded at 0.1 m followed by 1 m intervals. Light levels were recorded at the surface, 0.1 m and followed by 0.5 m intervals. Alkalinity and hardness were determined by titration from five and three replicate samples of surface water, respectively. Titration followed Standard Methods [12].

Three replicate samples for chlorophyll-*a* and phaeophyton-*a* were taken from the bottom and at 2 m. Phytoplankton pigments for chlorophyll-*a* and phaeophyton-*a* were extracted in accordance with Standard Methods [12]. Pigment absorption for chlorophyll-*a* and phaeophyton-*a* at 664, 665 and 750 nm was taken 2 m below the surface of the water using an Ocean Optics SD-1000 spectroradiometer to measure the optical density (OD), a unitless quantity which represents the ability of chlorophyll-*a* and phaeophyton-*a* to absorb or scatter light in the water column [13, 14]. When OD values become higher, light absorption or scattering increases. OD is defined by [15]:

$$OD = \log_{10} \times (I_0 \div I) \quad (1)$$

where I_0 is the intensity of the incident light entering the water column; I is the intensity of the transmitted light passing through the water column.

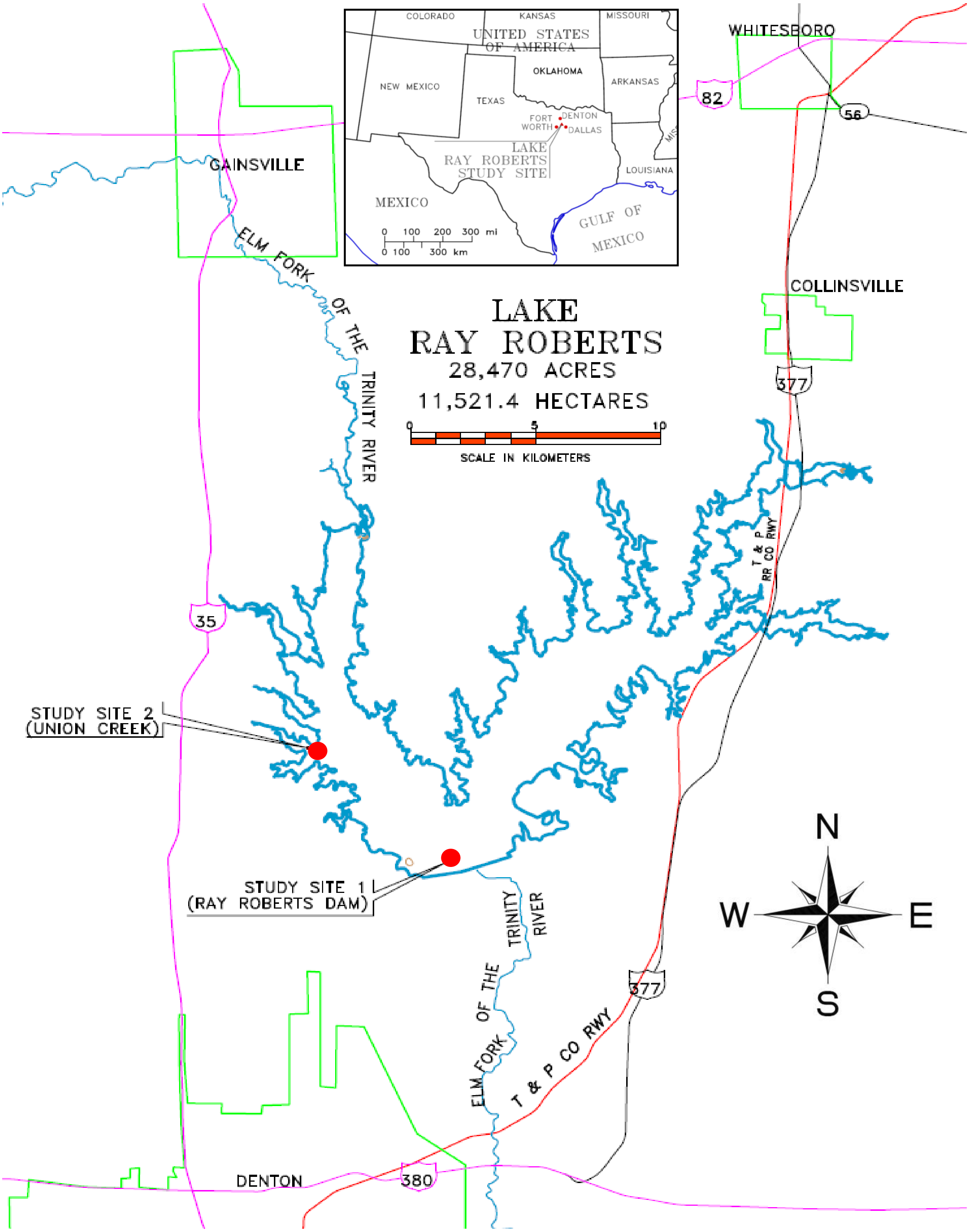

Fig. 1 Location of study Sites 1 and 2 on Lake Ray Roberts, September 13 and 27, 1996.

Volumes for Chlorophyll-*a* and Phaeophyton-*a* were calculated from the turbidity corrected 664 $_{\text{before acidification}}$ and 665 $_{\text{after acidification}}$ by the following equations [16]:

Chlorophyll-*a*:

$$26.7 \times (664 - 665) \times V_1 \div V_2 \times L \quad (2)$$

Phaeophyton-*a*:

$$26.7 \times (1.7 \times [665 - 664]) \times V_1 \div V_2 \times L \quad (3)$$

where: 26.7 is the constant; V_1 = volume of extract (L); V_2 = volume of sample (m^3); L = width of cuvette (cm).

3. Results and Discussion

3.1 Light

Percent light transmission through the water column at pelagial Site 1, and littoral Site 2 are presented in Tables 1 and 2, respectively. Vertical extinction coefficients (η) and % absorption through the water column at both sites were compared (Tables 3 and 4). The two sites differed greatly in light attenuation at depth. Ninety-nine percent (99%) light attenuation occurred at 7 m and 2.5 m for Sites 1 and 2, respectively. Inversely, % transmission through both water columns shows that light attenuation becomes exponential (Fig. 2). This corresponds to the 1% light level used to define the lower limit of the euphotic zone [2, 6, 11, 17, 18]. Rapid attenuation (by depth) at Site 2 was brought on by its location in a shallower area of the lake, marked by increased turbidity (Table 5). Other examples of light attenuation decreasing more rapidly in a shallow lake compared to a deeper lake are discussed in Jewston and Taylor [6], and Rolbiecki [3], suggesting more production of chlorophyll-*a* is found in shallower eutrophic zones and regulates the ability of light penetration in the water column near the littoral zones of freshwater lakes [19]. *Zeu* Secchi depths for Sites 1 and 2 were 1.4 m and 0.55 m, respectively.

By multiplying these two Secchi depths by 4 (Dr. K. Dickson, 1996 graduate chair personal communication), we arrive at respective lower limit *Zeu* zones of 5.6 m and 2.2 m, which roughly translates to what was measured using the Protomatic submarine photometer (Fig. 2).

Table 1 Percent light transmission through the water column at pelagial Site 1, Lake Ray Roberts Dam on September 13, 1996.

	% Transmission	
Depth (m)	Downwelling	Upwelling
0	100.0	100.0
0.5	63.2	88.9
1.0	52.9	66.7
1.5	35.3	44.4
2.0	26.5	44.4
2.5	20.6	33.3
3.0	14.7	22.2
3.5	11.8	22.2
4.0	5.6	7.8
4.5	4.1	6.7
5.0	3.2	4.4
5.5	2.4	2.7
6.0	1.9	2.2
6.5	1.4	1.8
7.0	1.0	1.3
7.5	0.8	1.1
8.0	0.6	0.9
8.5	0.4	0.7
9.0	0.3	0.4
9.5	0.2	0.4
10.0	0.2	0.2
10.5	0.1	0.2
11.0	0.1	0.2
11.5	0.1	0.2
12.0	0.1	0.1
12.5	0.0	0.1
13.0	0.0	0.1

Table 2 Percent light transmission through the water column at littoral Site 2, Union Creek, Lake Ray Roberts on September 27, 1996.

	% Transmission	
Depth (m)	Downwelling	Upwelling
0.00	100.0	100.0
0.01	77.3	100.0
0.50	34.6	99.5
1.00	15.9	99.0
1.50	6.4	98.5
2.00	2.4	98.0
2.50	1.0	97.5
3.00	0.3	97.0

Table 3 Vertical extinction coefficients (η) and % absorption through the water column at pelagial Site 1, Lake Ray Roberts Dam on September 13, 1996.

	Downwelling		Upwelling	
Depth (m)	η	Absorption (%)	η	Absorption (%)
0.5	0.9166	36.8	0.2356	11.1
1.0	0.6360	47.1	0.4055	33.3
1.5	0.6943	64.7	0.5406	55.6
2.0	0.6646	73.5	0.4055	55.6
2.5	0.6321	79.4	0.4394	66.7
3.0	0.6390	85.3	0.5014	77.8
3.5	0.6114	88.2	0.4297	77.8
4.0	0.7211	94.4	0.6385	92.2
4.5	0.7089	95.9	0.6018	93.3
5.0	0.6862	96.8	0.6227	95.6
5.5	0.6817	97.6	0.6590	97.3
6.0	0.6647	98.1	0.6344	97.8
6.5	0.6620	98.6	0.6200	98.2
7.0	0.6537	99.0	0.6168	98.7
7.5	0.6448	99.2	0.6000	98.9
8.0	0.6420	99.4	0.5904	99.1
8.5	0.6462	99.6	0.5895	99.3
9.0	0.6371	99.7	0.6018	99.6
9.5	0.6371	99.8	0.5701	99.6
10.0	0.6511	99.8	0.6431	99.8
10.5	0.6212	99.9	0.5818	99.8
11.0	0.6132	99.9	0.5554	99.8
11.5	0.6116	99.9	0.5312	99.8
12.0	0.6199	99.9	0.5669	99.9
12.5	0.6505	≈100.0	0.5620	99.9
13.0	0.6336	≈100.0	0.5404	99.9

Table 4 Vertical extinction coefficients (η) and % absorption through the water column at littoral Site 2, Union Creek on September 27, 1996.

	Downwelling		Upwelling		
Depth (m)	η	Absorption (%)	η	Absorption (%)	Depth (m)
Surface	n/a	n/a	n/a	n/a	Surface
0.01	25.78	22.7	51.08	40.0	0.01
0.5	2.12	65.4	2.54	72.0	0.5
1.0	1.84	84.1	1.97	86.0	1.0
1.5	1.84	93.6	1.68	92.0	1.5
2.0	1.87	97.6	1.91	97.8	2.0
2.5	1.86	99.0	1.84	99.0	2.5
3.0	1.92	99.7	1.94	99.7	3.0
3.5	2.05	99.9	2.04	99.9	3.5

Light attenuation through the water column at both sites was prevalent at lower depths (Fig. 2). This can be associated with the amount of suspended sediments in the water. Turbidity was measured only at Site 2 (Table 5), showing an exponential increase with depth. This corresponds to the rapid light attenuation from 0-4 m depths at Site 1 and 0-2 m depths at Site 2 (Fig. 2). Due to Hydrolab calibration issues at Site 1, turbidity readings were not taken and a comparison with Site 2 was impossible; however, greater turbidity was shown in shallow water than in deeper water at Lake Texoma (personal observation, pre-thesis research and fieldwork). Shallow euphotic zones with a large surface to depth ratio have been reported as being more productive than deeper euphotic zones [2, 3, 6]. Nutrient availability is more measured in shallow, littoral zones, due to the direct allochthonous inputs from the surrounding watershed.

Table 5 Dissolved oxygen, temperature, pH, conductivity alkalinity, and hardness measured at littoral Site 2, Union Creek.

Depth (m)	DO (mg/L)	Temperature (°C)	pH	Conductivity*	Turbidity (NTU)	Alkalinity (mg/L $CaCO_3$)	Hardness (mg/L $CaCO_3$)
0.01	7.4	22.0	Not taken	Not taken	Not taken	100	101
1	7.0	22.0	8.09	329	23.2 +/- 1.18 n = 19	Not taken	Not taken
2	7.0	22.0	8.10	329	27.11 +/-0.76 n = 37	Not taken	Not taken
3	7.0	22.0	8.10	329	28.93 +/- 1.01 n = 28	Not taken	Not taken
4	6.6	22.0	8.07	329	41.66 +/- 1.95 n = 23	Not taken	Not taken
5	2.6	21.5	8.07	329	Not taken	Not taken	Not taken

* Calibrated at 2,000 mhos standard.

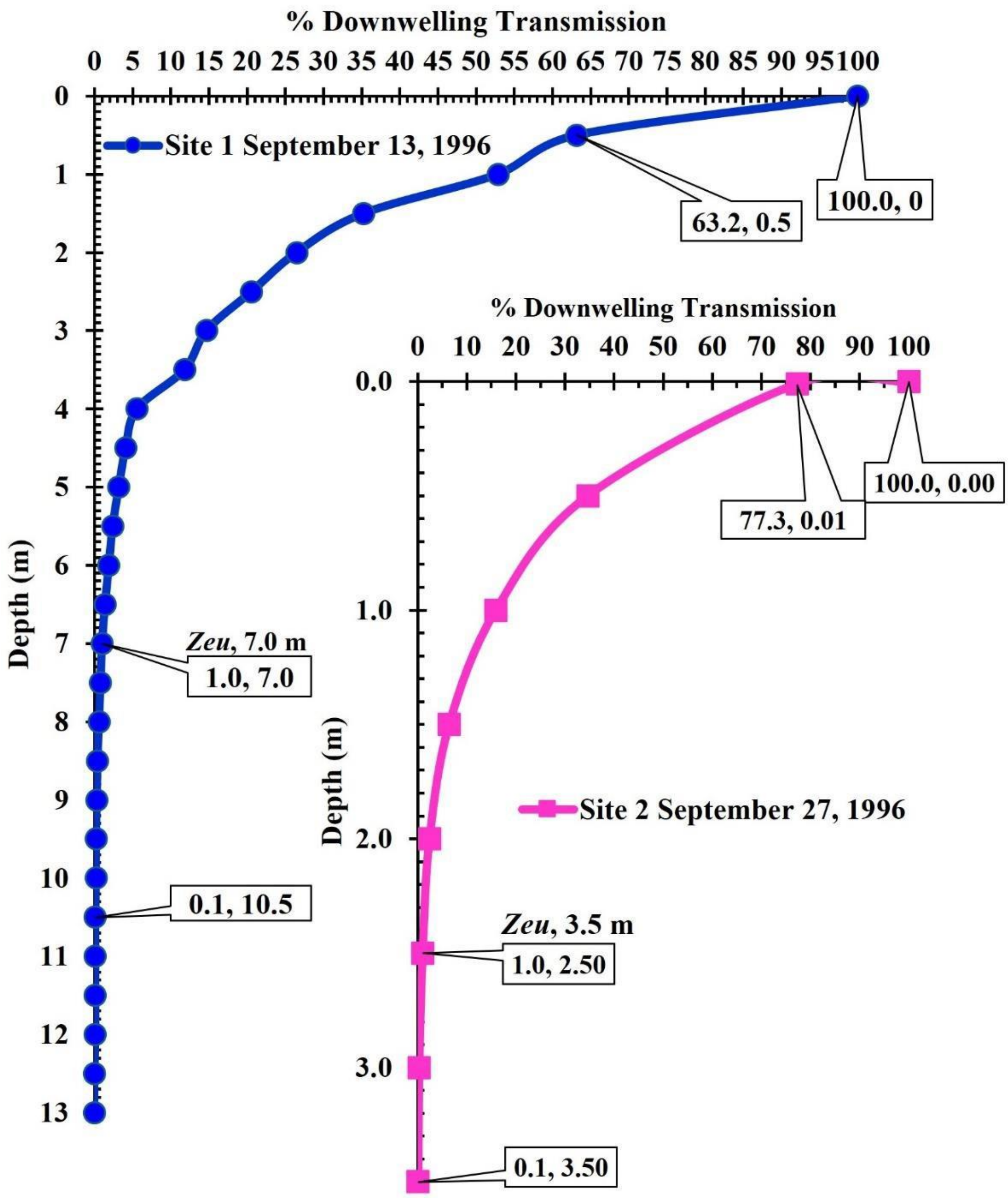

Fig. 2 Light transmission through the water column, Lake Ray Roberts, September 13 and 27, 1996. Site 1 is the pelagial area at Lake Ray Roberts Dam. Site 2 is the littoral area at Union Creek.

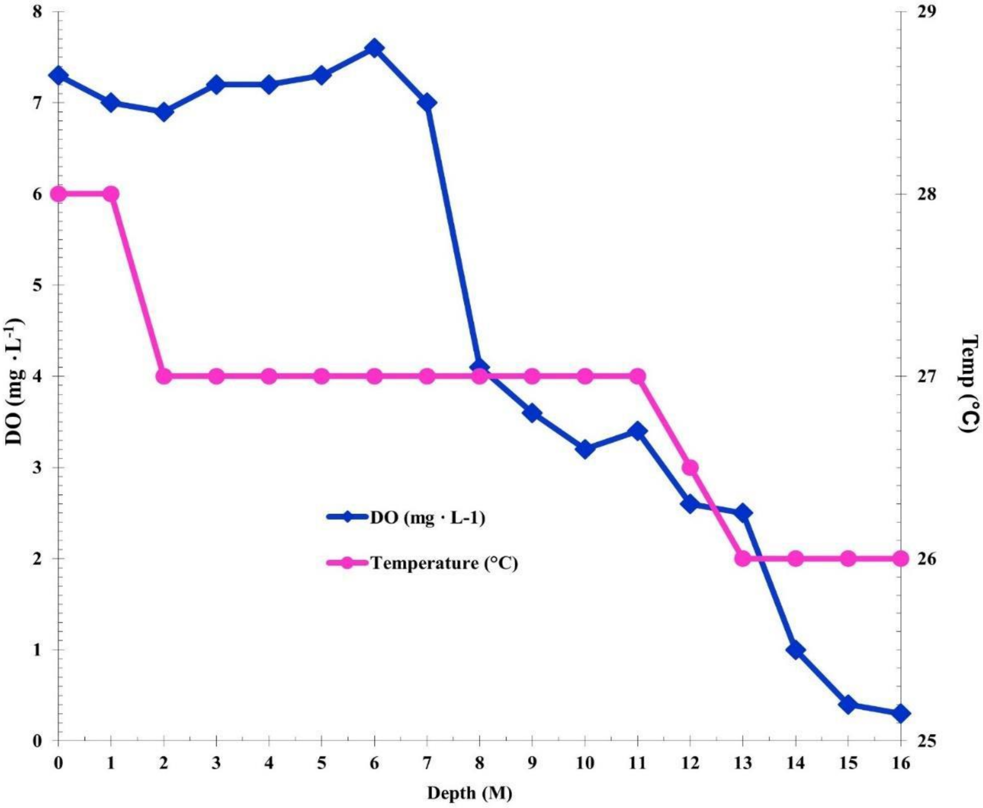

Fig. 3 Pelagial Site 1 temperature and dissolved oxygen profiles at Lake Ray Roberts Dam.

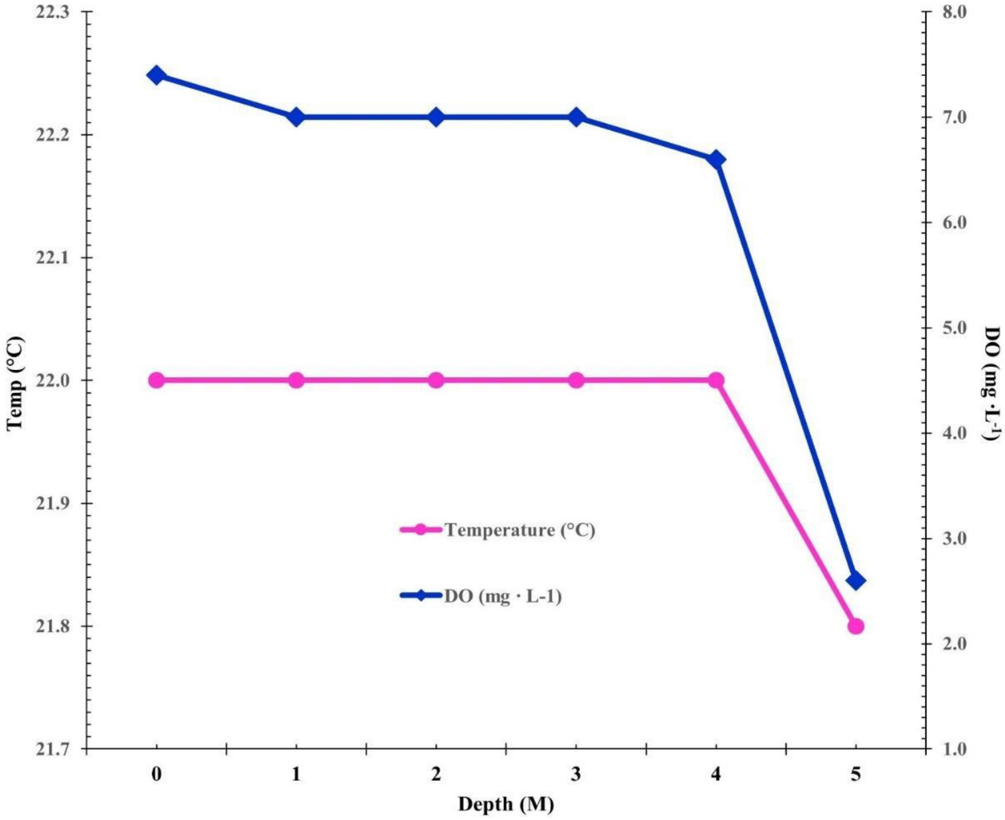

Fig. 4 Littoral Site 2 temperature and dissolved oxygen profiles at Union Creek.

Table 6 Concentrations of chlorophyll-*a* and phaeophyton-*a* at 2 m and at the bottom correlated with light attenuation (η) at 664 and 750 nm.

	OD before acidification		OD after acidification		Chlorophyll-*a* (mg/m^3)	Phaeophyton-*a* (mg/m^3)
	664 nm	750 nm	664 nm	750 nm		
η (Bottom)	0.043	0.006	0.032	0.005	9.34	8.32
η (2 m)	0.038	0.004	0.027	0.005	11.21	3.18

3.2 Temperature and Dissolved Oxygen

Site 1 exhibited a slight, thermally stratified water column and a classic, clinograde oxygen profile, with a small spike on DO at 6 m, just above Z_{eu} (Fig. 3). Site 2, however, showed constant temperatures down to the shallow bottom, with a gradual oxygen profile (Fig. 4). By comparing these profiles to the light profiles in Fig. 2, a correlation between light attenuation, lowered temperature and dissolved oxygen can be made. At Site 1, the depth where a marked drop in dissolved oxygen occurred (6.5-7.5 m) corresponds with the depth of Z_{eu} measured at 7 m. Dissolved oxygen dropped off significantly at Site 2 and corresponds to the euphotic zone at 2.5 m. Both sites clearly showed anoxic conditions in the hypolimnion, which is indicative of highly eutrophic lakes [2, 3] and reflects oxygen stratification.

3.3 Water Chemistry

Conductivity, pH, alkalinity and hardness were measured at Site 2 only (Table 3). There was little to no change in the values as depth increased. Alkalinity and hardness were taken just below the surface and show similar concentrations of $CaCO_3$. Alkalinity is the pH to the alkaline side of neutrality. The pH at Site 2 shows slight alkalinity; however, if it was measured at Site 1, it would probably show a classic eutrophic distribution, following the temperature and dissolved oxygen profiles, with an inverse clinograde CO_2 curve [3].

3.4 Chlorophyll-a and Phaeophyton-a

The water bottle samples at Site 2 yielded more concentrations of chlorophyll-*a* at 2 m than at the bottom (Table 6). Conversely, the concentrations of phaeophyton-*a* were greater at the bottom than at 2 m, which correlates with light attenuation (Fig. 2).

Phaeophyton-*a* occurs in the hypolimnion where there is anaerobic respiration of dead, sinking phytoplankton, as shown by the dramatic drop in dissolved oxygen from 4 to 5 m (Fig. 4). Essentially, phaeophyton lacks magnesium, which is essential in chlorophyllous plants for the porphyrin component of chlorophyll-*a* molecules [3].

4. Summary

Two sites at Lake Ray Roberts were examined and contrasted for productivity. Site 1 located in the pelagic zone near Lake Ray Roberts Dam exhibited a slight, thermal gradient with no stratification, and a slightly stratified clinograde oxygen profile which is typical for summer-stratified eutrophic lakes. Site 2 is located in a shallow, littoral zone, and exhibited high, increasing turbidity with depth, marked by shallow light attenuation through the water column. Temperature was constant at every depth at Site 2, with a slight, clinograde oxygen profile, typical for shallow, littoral areas subject to wind-induced mixing. Volume estimations of chlorophyll-*a* shows a strong presence in the euphotic zone, indicating photosynthesis occurs until approximately 2.2 m. The shallow, littoral Site 2 showed the basic signs of higher productivity than the open, pelagic Site 1.

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