



WALDO LAKE, OREGON: AN ULTRA-OLIGOTROPHIC  
ENVIRONMENT AND SOME IMPLICATIONS  
CONCERNING RECREATIONAL  
DEVELOPMENT<sup>1</sup>

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## ABSTRACT

A limnological study of Waldo Lake, Oregon, showed the lake to be an extremely unproductive freshwater environment. Annual phytoplankton primary production, estimated in situ with  $^{14}\text{C}$ , approximated that of a highly oligotrophic arctic lake. The rate of daily production averaged  $29 \text{ mgC/m}^2/\text{day}$  during June, July and August, 1969.

Waldo Lake, located in the Willamette National Forest near the summit of the Cascade Mountain Range, has been relatively inaccessible. Because of recent recreational development in the basin, including a paved highway leading to several lakeside campsites, use of the lake is expected to increase substantially. Consequently, biological productivity and water quality will be affected.

The limnological data presented, especially productivity estimates, are intended to be used as reference points for future assessments of eutrophication in Waldo Lake as well as other high quality lakes in the Cascade Range.

## INTRODUCTION

The extreme oligotrophic nature of Waldo Lake, Oregon was first reported in a document prepared by the State of Oregon Sanitary Authority (presently the State of Oregon Department of Environmental Quality) and the U. S. Forest Service (Carter et al. 1966). Data reported from the study suggested that Waldo Lake may be one of the most oligotrophic lakes in the world. Subsequent research by the authors in 1968 and 1969 verified the 1966 report.

Since 1967, in an effort to determine rates of eutrophication, we have been comparing the productivity of several oligotrophic lakes in Oregon. These include Crater, Odell, and Waldo lakes, located in the Cascade Mountain Range. Many of these excellent lake environments are being exploited for recreational use and, as a result, are becoming more productive biologically.

Before 1969, Waldo Lake was nearly inaccessible to vehicular traffic. Use estimates by the U. S. Forest Service for the period 1966-1968 showed a yearly average of 33,000 visitor days (e. g. , one person visiting the lake for 12 hours equals one visitor-day). In June, 1969, a paved highway was opened, leading to several newly constructed campsites situated along the east shore of the lake. Consequently, visitor-day estimates for 1969 and future years were expected to rise dramatically.

In view of this and because of the near-pristine condition of Waldo Lake, we initiated a study of the lake's productivity in 1969. Our purposes were: (1) to further document the unusual limnological features of Waldo Lake, particularly at this time when the lake is in a very early stage of evolution, (2) to record phytoplankton standing stock and productivity measurements that may be unique for a temperate freshwater lake, (3) to begin a continuous year-to-year surveillance of algal production, which is expected to increase due to recreational development and (4) to establish Waldo Lake as a "eutrophication baseline" in an attempt to predict the effects of expanded use and subsequent enrichment on other high-quality lakes in the Cascade Range.

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## LAKE DESCRIPTION

### Physical Features

Waldo Lake is located in the Willamette National Forest, approximately 89 km southeast of Eugene, Oregon. The lake basin, estimated to be 10,000 to 12,000 years old, is a glaciated depression enclosed by end and lateral moraines (E. Taylor, personal comm.).

The regolith of the basin consists mostly of light colored pumice and rounded rock boulders up to 1 1/2 m in diameter. The materials are well-drained and are highly permeable. The composition of the bedrock is mainly fractured hard basalts. Depth to bedrock is no greater than 2 m. Bedrock is exposed in many places, especially at the north end of the lake. There, pumice material contains 60 to 70 percent by volume of boulders (L. D. Evans, personal comm.).

The lake receives no permanent surface drainage. During the spring, however, snowmelt runoff enters the lake through countless temporary streams. Carter et al. (1966) suggested that spring seepages may exist on the lake bottom. At the north end, the lake discharges into the North Fork of the Willamette River.

Climatic data, compiled by the U. S. Weather Bureau over a 10-year period (1951-1960), were obtained from the nearest recording station, located about 16 km to the south (Odell Lake). Mean annual temperature is 5.0° C. Total annual precipitation, including 8 1/3 meters of snowfall (yearly mean), averages 152.4 cm. Incident radiation, measured periodically at Waldo Lake with a Belfort recording pyrhelimeter, averaged 266.1 g cal/cm<sup>2</sup>/4 hrs (1000-1400 hrs) during the summer of 1969.

Morphometric data are given in Table 1. All values were derived from contour map no. 1014, State of Oregon Game Commission, Portland, Oregon (Fig. 1).

TABLE 1. Approximate Morphometric Values for Waldo Lake, Oregon.

Elevation, surface	1650 m (mean sea level)
Area	25.12 km <sup>2</sup>
Volume	0.95 km <sup>3</sup>
Depth, maximum	128.0 m
Depth, mean	38.0 m
Shoreline length	40.0 km
Shoreline development	2.25
Relative depth	2.26
Mean depth: max depth	0.30
Max depth: surface	0.026

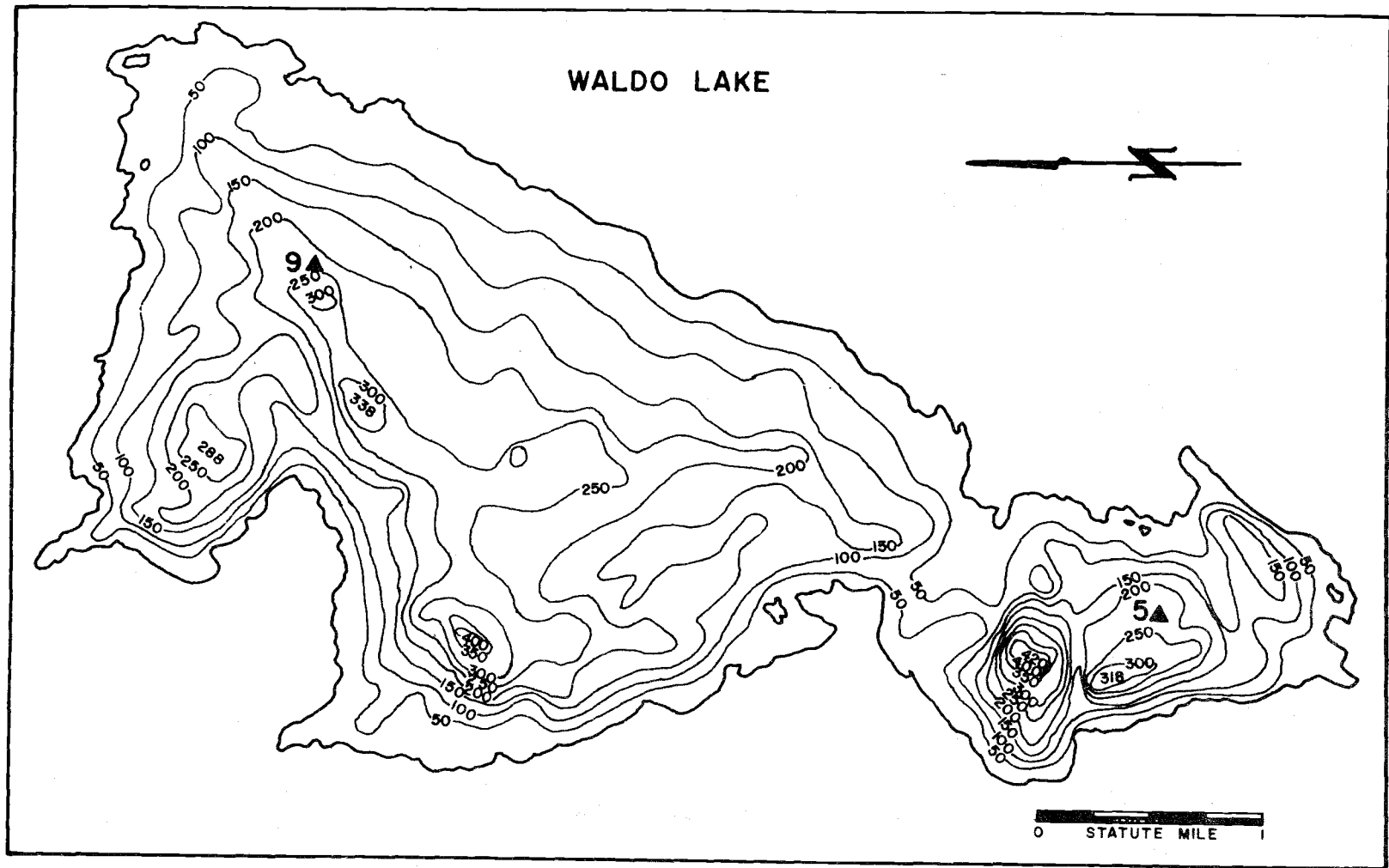


Fig. 1. Bathymetric chart of Waldo Lake, Oregon showing sample station locations. Contours based on 1958 survey by the State of Oregon Game Commission, Portland, Oregon (map number 1014); contour interval, 50 ft.



Temperature and dissolved oxygen profiles for August 28, 1969 (Fig. 2), are typical for an oligotrophic lake. Temperature data from Fig. 2 were used to calculate a summer heat income of 21,496 g cal/cm<sup>2</sup>.

Light penetration in Waldo Lake was measured with a standardized (20 cm diameter) Secchi disc and a larger version (1.0 m diameter). Maximum readings of 28.0 m (20 cm disc) and 35.4 m (1.0 m disc) were attained on July 23, 1969. Additional light data were obtained with a Kahl submarine photometer (Model no. 268 WA 310; spectral range in sunlight is 400-640 mμ). Extinction coefficients presented in Table 2 are for non-filtered and filtered light. Percentages of incident radiation transmitted through the water column represent non-filtered light (Table 2). Highly scattered cloud conditions did not interfere with the light readings. Wind velocity was negligible during the time the photometer was being used.

### Chemical

The water quality of Waldo Lake is unusually high (Table 3). The values from the 1969 study (column II, Table 3) represent surface water. However, samples were collected and analyzed from depths of 6, 12, 24, 30 and 40 meters. Surface and deeper samples exhibited near-identical chemical characteristics. Carter *et al.* (1966), in comparing samples collected at 4 and 60 meters, found little or no

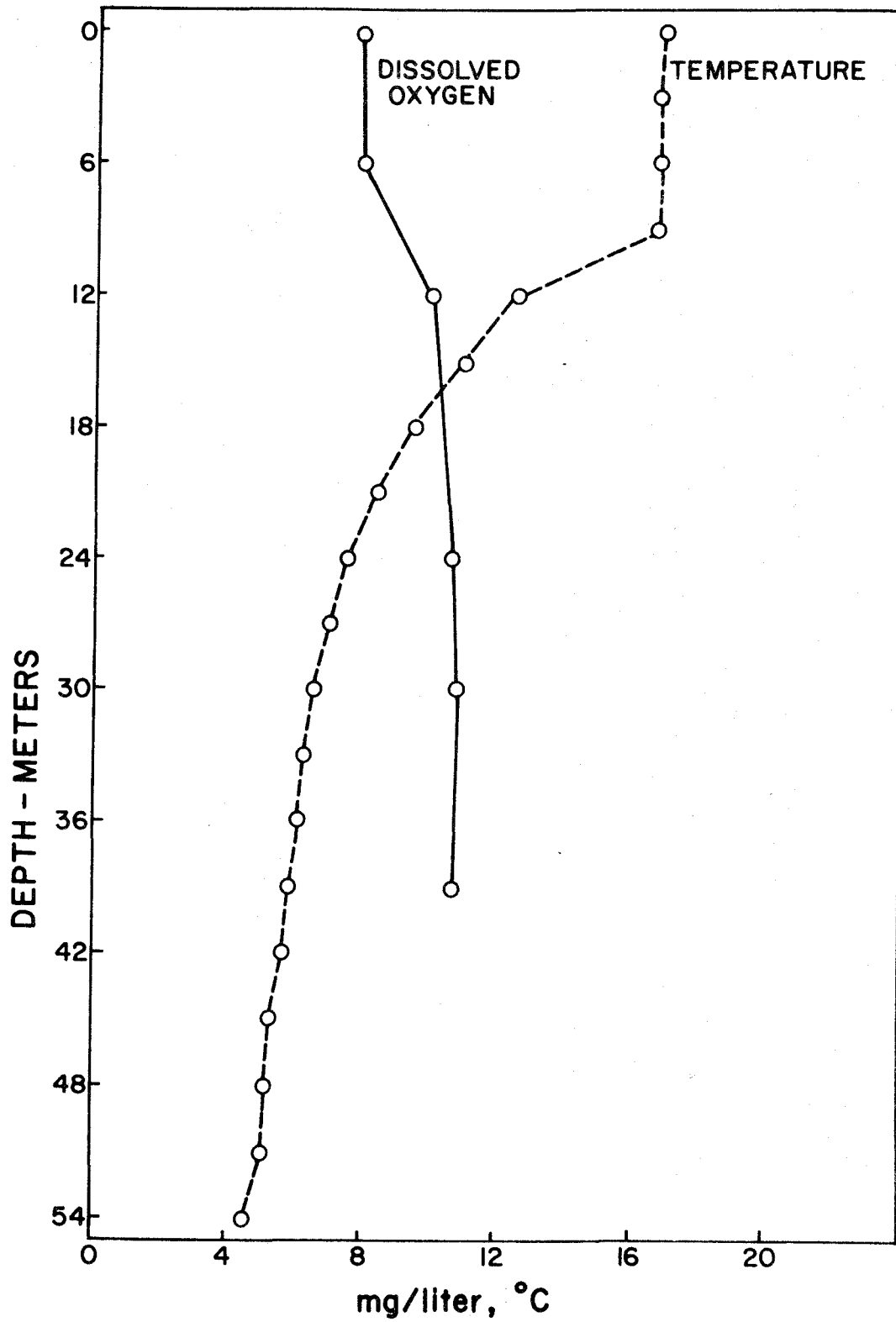


Fig. 2. Dissolved oxygen and temperature profiles recorded on August 28, 1969.

TABLE 2. Light attenuation data for Waldo Lake, Oregon. Measurements taken on July 23, 1969, between 1140-1230 hrs.

Depth (m)	Percent Transmittance	No Filter	Extinction Coefficients*		
			Blue	Green	Red
0	100				
5	60	.104	.087	.125	.355
10	44	.083	.069	.084	.336
15	32	.076	.054	.078	.309
20	25	.070	.049	.094	.280
25	19	.066	.045	.087	.236
30	15	.064	.044	.082	.204
35	13	.058	.044	.081	.184
40	10	.058	.044	.083	.165
45	5	.066	.050	.080	.150
50	4	.065	.049	.078	.141
55	3	.064	.047	.077	.133
60	2	.062	.048	.077	.125
			<u>Blue</u>	<u>Green</u>	<u>Red</u>
*Approximate spectral ranges (m $\mu$ ):			300-550	460-660	500-720
Percent maximum transmittance:			87	65	85

TABLE 3. Waldo Lake Water Quality Data - Station 9.

	I*	II**
pH	6.1	6.6
Specific conductance ( $\mu$ mhos/cm)	7.1	5.2
Total dissolved solids (mg/liter)	4.8	1.7
Total alkalinity (mg/liter $\text{CaCO}_3$ )	0.2	1.5
Total hardness (mg/liter $\text{CaCO}_3$ )	3.0	1.2
Sulfate (mg/liter)	1.6	
Sodium (mg/liter)		0.16
Potassium (mg/liter)		< 0.10
Calcium (mg/liter)		0.086
Magnesium (mg/liter)		0.043
Chloride (mg/liter)	.4	
Ammonia-N (mg/liter)	< 0.01	
Nitrate-N (mg/liter)	0.11	
Phosphate-P (mg/liter)	< 0.01	
Turbidity (Jackson units)	1.2	
Color	2.0	

\* Data courtesy of the State of Oregon Department of Environmental Quality and the U. S. Forest Service. Water samples collected on July 27, 1966 from a depth of 4 m.

\*\* Data obtained by the authors. Water samples collected on August 28, 1969 from a depth of 1.0 m.

difference in water chemistry.

During the 1966 survey reported by Carter et al., water samples were analyzed at the State of Oregon Department of Environmental Quality laboratory. Analyses were handled in accordance with the Standard Methods handbook (APHA, 1965). Our determinations (excluding those for Na, K, Ca and Mg) were conducted in a mobile laboratory within 12 hours after the water samples were collected. pH values were obtained with a Model 7 Corning pH meter. Specific conductance was measured with a Beckman conductivity bridge (model RC-16B2). Total alkalinity was determined colorimetrically, using bromcresol green-methyl red indicator solution. Total hardness was determined by EDTA titration. Our method for determining total dissolved solids (total residues) was derived from the Standard Methods handbook (APHA, 1965). An atomic absorption spectrophotometer (Perkin-Elmer model 303) analyzed samples for Na, K, Ca and Mg. The Winkler method (azide modification) was used to measure dissolved oxygen (Fig. 2).

#### Biological Features

The plankton in Waldo Lake is indeed sparse. During the 1966 survey, plankton nets were towed horizontally through the surface waters for several minutes (Carter, et al.). Towing was conducted during the day and at night. Only a "few" diatoms were collected.

Exact numbers of organisms per tow were not recorded. Throughout the summer of 1969, vertical plankton tows with no. 6 mesh nets (intake diameter equaled 0.5 m), yielded no more than 13 zooplankters per haul (Table 4). Chlorophyll a concentrations were similarly minute, ranging from 0.263 to 9.436 mg/m<sup>2</sup> (Table 5).

The benthic community in Waldo Lake was described by Carter et al. (1966). It consists primarily of aquatic mosses including Sphagnum sp. in the littoral zone (seldom occurring at depths greater than 2 m) and Drepanocladus sp. in deeper water. We collected the latter form at depths of 70 to 75 meters. Associated with the deep-water mosses were at least two species of diatoms (Cymbella ventricosa Kuetz and Tabellaria flocculosa Kuetz) and several desmids (Staurostrum sp., Cosmarium sp., Netrium sp., Micrasterias sp.). Diatoms and a blue-green algae (Anabaena sp.) commonly occurred in the Sphagnum clumps.

Carter et al. concluded in their 1966 report that the benthos, particularly the mosses, was contributing most to the primary productivity of Waldo Lake. They surmised that the few algal cells (mostly diatoms) collected in the limnetic zone had not originated as plankton but as benthic forms washed into the open water.

TABLE 4. Numbers of zooplankton collected periodically at Station 9, Waldo Lake, Oregon.

Date	Tow Depth (m)	No. /Tow				Total	Total No. /m <sup>3</sup>
		<u>Daphnia sp.</u>	<u>Cyclops sp.</u>	<u>Polyphemus sp.</u>	<u>Diaptomus sp.</u>		
7/ 8/69	60	3	2			5	0.55
7/ 8/69	60		2			2	0.24
7/24/69	70		2			2	0.26
7/24/69	80		1			1	0.13
7/24/69	78		1		1	2	0.19
7/24/69	70	2			1	3	0.27
8/ 6/69	60	9	3	1		13	1.40
8/ 6/69	60	6			2	8	0.97

TABLE 5. Detectable concentrations of chlorophyll a in milligrams per meter square for Waldo Lake, Oregon (June 20-October 3, 1969). Samples for chlorophyll analyses were obtained from depths of 0, 6, 12, 24, 30, and 40 meters, usually between 1100 and 1130 hours.

Date	AVERAGE	
	mg chlorophyll <u>a</u> /m <sup>2</sup>	mg chlorophyll <u>a</u> /m <sup>3</sup>
20 June	0.263	.0066
7 July	2.870	.0718
23 July	4.439	.1109
6 August	2.932	.0733
28 August	8.477	.2119
30 September*	9.436	.2359
3 October*	8.518	.2129

\*Samples collected at Station 5. All others are from Station 9.

#### LIMNETIC PRIMARY PRODUCTIVITY ESTIMATES

Phytoplankton primary production was measured in situ with <sup>14</sup>C. The method used was a modification of a 1961 technique prepared by the Fisheries Research Institute, University of Washington, Seattle (Fisheries Research Institute field manual, section S6, carbon-14). Water samples were obtained at the surface and from depths of 2, 6, 8, 12, 18, 24, 28, 30 and 40 meters. Each water sample was inoculated with a stock solution of 1 ml of Na<sub>2</sub><sup>14</sup>CO<sub>3</sub> (5.0 μCi/ml) and returned to the depth from which it came. Dark bottles accompanied light bottles at every other depth to determine non-photosynthetic



uptake of  $^{14}\text{C}$ . Following a 4-hr incubation period (1000-1400 hrs), all samples were retrieved and filtered with a Millipore apparatus in the mobile laboratory. The uptake of  $^{14}\text{C}$  was determined by liquid scintillation counting at Oregon State University. Net production rates ( $\text{mgC}/\text{m}^3/\text{hr}$ ) were plotted against depth for each sampling date (Fig. 3). The resulting curves were integrated and net production rates through the sampled water column were determined ( $\text{mgC}/\text{m}^2/\text{hr}$ ).

Normally, Station 9 was the sampling site. Rough surface conditions created by strong northwesterly winds made it necessary, however, to use Station 5 for sampling on October 3 (Fig. 1).

An estimate of net phytoplankton productivity for a 103-day sampling period (June 21 to October 3, 1969) is presented in Table 6. Measurements of carbon fixed per incubation period were converted to approximate daily values. This was done by dividing the 4-hr in situ production measurement by an appropriate energy fraction (function F; Vollenweider, 1965). An energy fraction was that portion of the total daily radiation which was incident during the incubation period (Platt and Irwin, 1968). Our results are based on the energy fractions computed and modified from Vollenweider (1965) by Platt and Irwin (1968).

When bimonthly sampling occurred (July and August), we derived a monthly average from the two measurements. For September, when weather conditions prohibited in situ  $^{14}\text{C}$  experiments, we assumed that production increased linearly between August 28 and October 3.

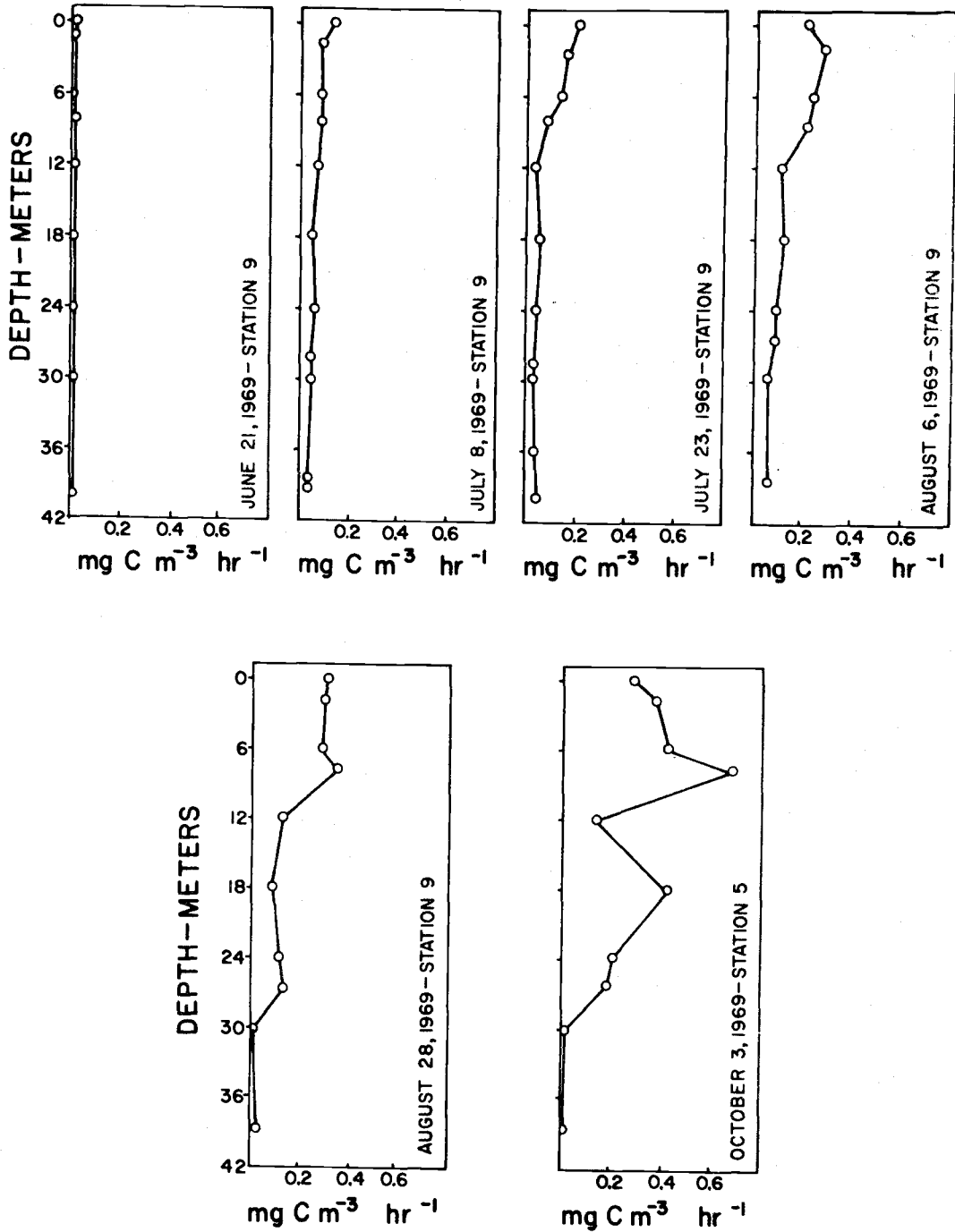


Fig. 3. Vertical profiles of phytoplankton productivity, Waldo Lake, 1969.

TABLE 6. Phytoplankton primary productivity for Waldo Lake, Oregon. Total production for the period June 21 to October 3, 1969 estimated to be 4.225 g C/m<sup>2</sup>.

Date	mg C/m <sup>2</sup> /hr	Energy Fraction (F)*	Approximated mg C/m <sup>2</sup> /day
21 June	0.107	0.37	1.16
8 July	2.185	0.38	23.00
23 July	2.264	0.38	23.83
6 August	4.474	0.40	44.74
28 August	5.050	0.40	50.40
3 October	9.880	0.54	73.19

\*Modified after Vollenweider (1965) by Platt and Irwin (1968).

The comparatively high production for October 3 (Fig. 3, Table 6) is explained perhaps by the use of Station 5 as an alternate sampling site. Station 5, located at the south end of the lake in a relatively sheltered area, is less than 1000 meters from shore (Fig. 1). These features are considerably different from those at Station 9. Strong northwesterly winds, persisting for several days prior to October 3, may have produced a concentration of plankton in the vicinity of Station 5.

The total production estimate given in Table 6 (i. e., 4.225 gC/m<sup>2</sup>) represents perhaps 75-80 percent of the annual phytoplankton production in Waldo Lake. Presumably, during the November to April period, low light and temperature conditions greatly restrict phytoplankton production. In Waldo Lake, this period of restriction may include May and June as well (Fig. 3). However, this is yet to be ascertained through yearlong sampling.

## CONCLUSIONS

Waldo Lake may rank as the most oligotrophic and consequently, the least productive, freshwater temperate lake ever encountered. The biological production of the lake compares favorably with other oligotrophic lakes in the world. Hobbie (1964), after estimating the primary productivity of two Alaskan arctic lakes, concluded that they were the "least productive ever extensively measured." Lake Peters produced  $0.9 \text{ g C/m}^2/\text{year}$  while net productivity estimates for Lake Schrader varied from  $6.6$  to  $7.5 \text{ g C/m}^2/\text{year}$ . Net productivity for Crater Lake, Oregon--often regarded as being extremely low in biological production (Nelson, 1967)--averaged  $6.70 \text{ g C/m}^2/\text{month}$  (June-August, 1968) and  $6.61 \text{ g C/m}^2/\text{month}$  (July-August, 1969). (D.W. Larson, unpublished data).

It is difficult to predict how the recreational development and use of Waldo Lake will affect various components of the lake's ecology. Certainly, some aspects of the environment will likely be altered. The degree of alteration will depend, for the most part, on the implementation of policies currently proposed by the Federal Water Pollution Control Administration and the U.S. Forest Service (1969).

The lake changed little, if at all, during the time before 1969 when the number of users was limited. Now that the lake is easily accessible and construction projects are disturbing the watershed, continuous limnological monitoring is essential. Our research will hope-

fully provide a reference point, allowing responsible agencies to estimate periodically the effects of population impact on the Waldo Lake basin.

## REFERENCES

- American Public Health Association. 1965. Standard methods for the examination of water and wastewater, 12th ed. APHA, New York. 769 p.
- Carter, G., A. Hose, R. McHugh, J. Kettunen, and W. Christiansen. 1966. A limnological survey of Waldo Lake in Oregon. State of Oregon Dept. of Environmental Quality and U. S. Forest Service. 11 p. (mimeographed).
- Federal Water Pollution Control Administration and U. S. Forest Service. 1969. Proposal for a study to provide a management program for Waldo Lake. FWPCA, Pacific Northwest Water Lab, Corvallis, Oreg. 9 p. (mimeographed).
- Hobbie, J. E. 1964. Carbon 14 measurements of primary production in two arctic Alaskan lakes. Verh. Internat. Verein. Limnol. 15: 360-364.
- Nelson, C. H. 1967. Sediments of Crater Lake, Oregon. Geol. Soc. Am. Bull. 78: 833-848.
- Platt, T. and B. Irwin. 1968. Primary productivity measurements in St. Margaret's Bay, 1967. Fish. Res. Bd. Can. Tech. Rpt. No. 77. 123 p.

Vollenweider, R. A. 1965. Calculation models of photosynthesis-depth curves and some implications regarding day rate estimates in primary production measurements, p. 428-457. In C. R. Goldman (ed.), Primary productivity in aquatic environments. Univ. Calif. Press, Berkeley.