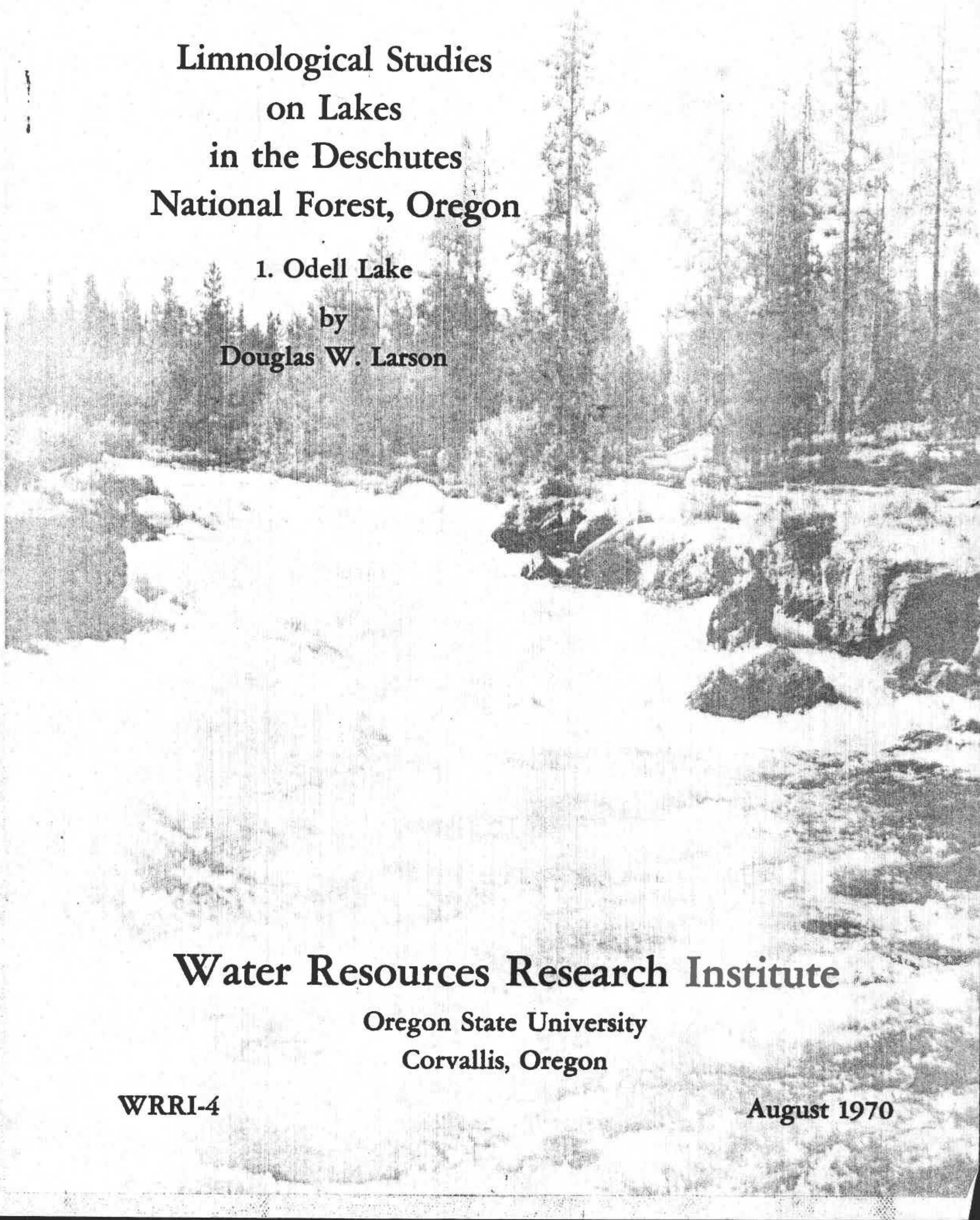

Limnological Studies on Lakes in the Deschutes National Forest, Oregon

1. Odell Lake

by
Douglas W. Larson

Water Resources Research Institute

Oregon State University
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LIMNOLOGICAL STUDIES ON LAKES IN THE DESCHUTES NATIONAL FOREST, OREGON

I. ODELL LAKE

by

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WATER RESOURCES RESEARCH INSTITUTE

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Distribution limited. Copies of this report may be obtained from the Water Resources Research Institute. Single copies are free.

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INTRODUCTION

Odell Lake, situated at the summit of the Cascade Range in the Deschutes National Forest, Oregon, serves various interest groups, including those that fish, camp, boat and waterski. The lake is easily reached by Oregon State Highway 58 which parallels, closely, the shoreline to the north and east.

The U.S. Forest Service maintains five campgrounds and three boating facilities in the Odell basin. The use of these has increased at a rate of about 9% per year (J.H. Nunan, U.S. Forest Service, Crescent, Oregon, personal comm.). All Forest Service toilet facilities are of the vault-type with one exception, this being at the Pebble Bay campground. The vaults are pumped two or three times during the summer and fall and the contents are removed from the basin (J.H. Nunan, personal comm.).

Included in the total development of the lake are two privately-owned resorts, a marina, and 67 summer homes, most of which are situated at the west end of the lake. The homes are occupied usually from May until September. Sewage wastes are removed by drainage-field or pit-type systems. These are located, as a rule, at least 60 m back from the shoreline and 30 m from any water course (J.H. Nunan, personal comm.).

Since 1965, angler use of Odell Lake has nearly doubled. Creel census data, collected by the State of Oregon Game Commission, show that the number of boat hours spent on Odell Lake increased from 46,000 in 1965 (Averett, 1966) to over 69,000 in 1968 (S. Lewis, State of Oregon Game Commission, personal comm.).

The purposes of this report are (1) to document the limnology of Odell Lake, particularly at a time when the lake has not yet been greatly deteriorated by recreational development, (2) to record phytoplankton standing stock and primary production measurements, most of which are thought to be unusually high for an "oligotrophic" lake, and (3) to provide physical, chemical, and biological data that will establish a reference point, allowing responsible state and federal agencies to estimate periodically the effects of population impact on the Odell Lake basin.

I am indebted to Mr. J. Wagner, Department of Oceanography, Oregon State University for certain water analyses, Dr. R. Simon, Department of Fisheries and Wildlife, Oregon State University for use of liquid scintillation counting equipment, Drs. H. C. Curl, Jr. and L. F. Small, Department of Oceanography, Oregon State University for making their laboratory facilities available and Dr. C. E. Bond, Department of Fisheries and Wildlife for use of certain limnological gear. Mr. J. H. Nunan, U.S. Forest Service, Crescent, Oregon, Dr. E. Taylor, Department of Geology, Oregon State University and Mr. S. Lewis, State of Oregon Game Commission supplied important information for which I am very grateful. I thank Drs. J. R. Donaldson, C. E.

Bond, L. F. Small and H. K. Phinney for reviewing the manuscript and providing useful suggestions. My special thanks go to Dr. H. K. Phinney who identified the phytoplankton. The conscientious field and laboratory assistance of Mr. J. Malick, Mr. R. Mailloux, Mr. G. McCoy, Mr. R. Lindland and Dr. R. Averett was much appreciated.

LAKE DESCRIPTION - PHYSICAL FEATURES

Geography and Geology

Odell Lake is located approximately 174 km north of the Oregon-California border, and 180 km inland from the Pacific Ocean. The basin is thought to be a glacial trough closed at the eastern end by a terminal moraine. The age of the basin is estimated at 10,000 to 12,000 years (E. Taylor, personal comm.).

During the eruptions of Mt. Mazama, volcanic ash was carried northward where it showered onto the loamy soils and andesitic lava in the Odell Lake basin. In time, a mantle of pumiceous ash and lapilli covered the basin to a thickness ranging from 35 to 150 cm. The mantle is coarsely textured and, therefore, is extremely permeable. Of the total volume of pumiceous material, 20% to more than 50% is comprised of pebbles or "granules" (Wentworth, 1922) larger than 2 mm in diameter. The upper few inches is darkened by organic accumulation. In places, particularly on high angle slopes, the mantle has been removed by weathering and mass-wasting to expose pre-existing soils and rock. Because of the texture of the surface layer, sheet-wash runoff is very slow or nonexistent. Subsurface percolation of water through pumiceous and loamy materials is very rapid; thereby facilitating the passage of dissolved nutrients into the lake.

Odell Lake is fed by two large, permanent tributaries (i.e., Trapper and Crystal creeks)(Averett and Espinosa, 1968). Both supply the lake with meltwater drained from higher elevations. On a map of Odell Lake, Newcomb (1941) indicated an additional 30 to 35 smaller tributaries. Most of these are shown to enter the lake from the north. The major outlet tributary is Odell Creek which flows eastward for 13 miles until it discharges into Davis Lake (Averett and Espinosa, 1968). Groundwater springs are known to exist along the south shoreline (Averett and Espinosa, 1968).

Climate

Climatic data for the Odell Lake region was obtained from the U.S. Weather Bureau (1965), and Phillips and Van Denburgh (1968). For the period 1951 - 1960 (U.S. Weather Bureau, 1965), annual mean temperature was 5.0° C. Total annual precipitation, including 8 1/3 meters of snowfall (yearly mean), averaged 152.4 cm (U.S. Weather Bureau, 1965). Phillips and Van Denburgh (1968) reported an annual mean precipitation of 156.1 cm in the period 1950 - 1964. During 1968 (June - September), incident radiation averaged 241.1 g cal/cm^2/4 hrs (1000 - 1400 hrs). For the same period in 1969, the value was slightly less (i.e., 236.6 g cal/cm^2/4 hrs).

Morphometry

Morphometric data for Odell Lake are presented in Table 1. All values were computed from contour map no. 1274, State of Oregon Game Commission, Portland, Oregon (Figure 1). As shown, the basin is moderately elongated with a U-shaped cross profile (features that identify the basin as a glacial trough). Maximum depth occurs at the eastern end of the lake where the slope of the basin wall is abrupt. The lake has a relatively low shoreline development of 1.59.

Table 1. Lake morphology for Odell Lake, Oregon.

Elevation, surface (m)	1459
Area (km^2)	14.4
Volume (km^3)	0.59
Depth, maximum (m)	86
Depth, mean (m)	41
Shoreline length (km)	21.5
Shoreline development	1.59
Relative depth (%)	2.01
Mean depth: max depth	0.48
Max depth: surface	0.023

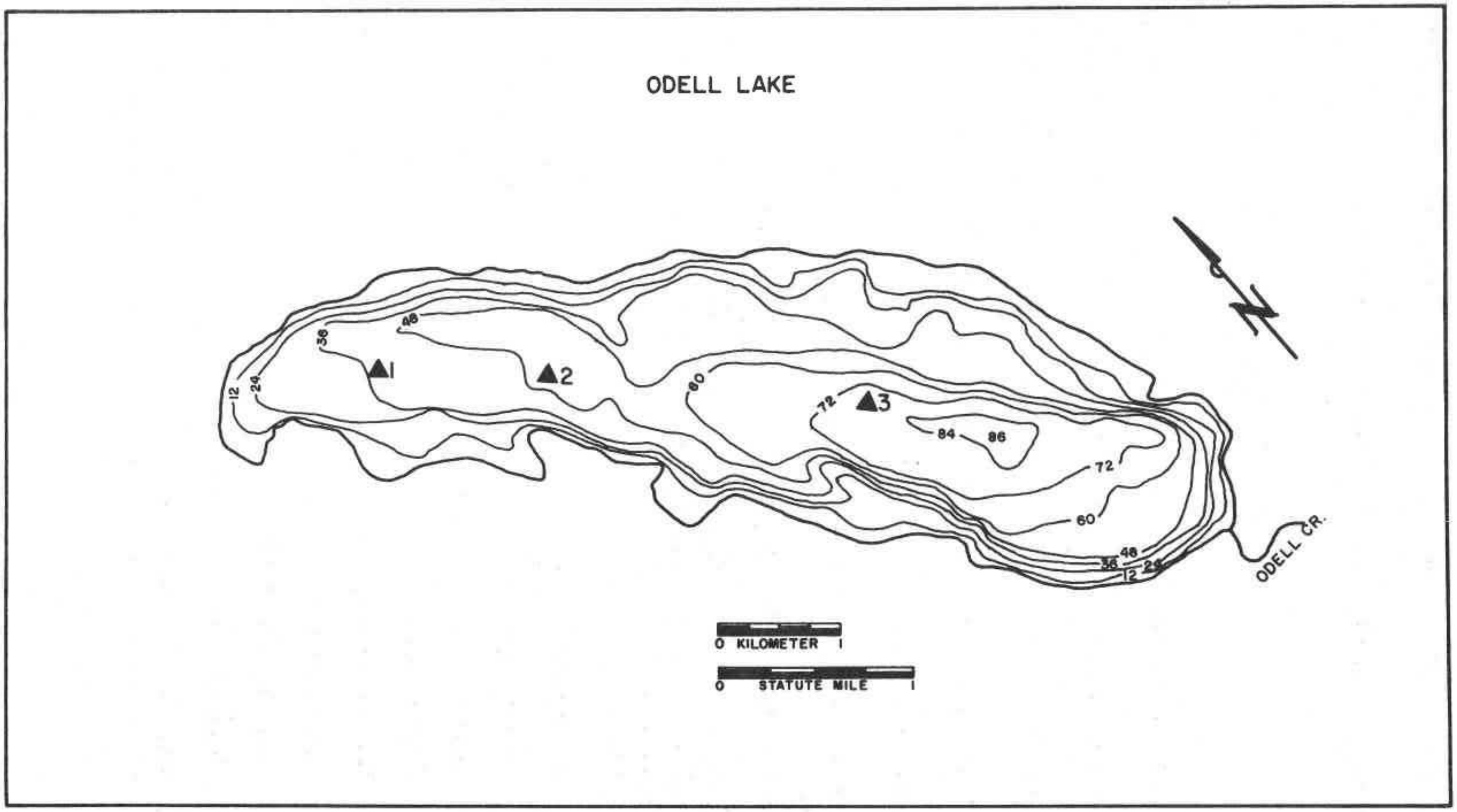


Figure 1. Bathymetric chart of Odell Lake, Oregon, showing sample station locations. Contours based on 1964 survey by the State of Oregon Game Commission, Portland, Oregon (map no. 1274); contour interval, 12 meters.

Temperature and Dissolved Oxygen

Thermal stratification in Odell Lake was well-established by the end of June. Usually, the lake remained stratified until November when fall overturn occurred. In 1968, thermal stratification was evident as late as October 19. On November 26, the lake was homothermal at $6.77 \pm 0.15^{\circ}$ C. During the following winter (1968-69), the lake froze over completely. From June through September, strong westerly winds pushed warm surface water toward the east half of the lake. There it piled up, displacing the thermocline (e.g., the thermocline at Station 3 was always three to five meters deeper than at Station 1). As a result, surface and perhaps internal seiches may have been generated regularly. Current systems such as these could be an important factor in the distribution of nutrients and heat energy throughout the lake. Summer heat incomes of 25,924 g cal/cm^2 and 26,659 g cal/cm^2 were computed for 1968 and 1969, respectively. In earlier studies of Odell Lake, temperatures were recorded vertically near Station 1 (Averett, 1966) and Station 2 (Newcomb, 1941) (Figure 1).

The oxygen profiles at stations 1 and 3 approximated one another. During the summers of 1968 and 1969, the concentration of dissolved oxygen throughout the water column was essentially uniform (Figures 2, 3). Newcomb (1941) measured dissolved oxygen at depths of 0, 15, 38, and 55 meters. He reported a slight difference in measurements (i.e., 8.0 to 7.6 ppm of dissolved oxygen from the surface to maximal

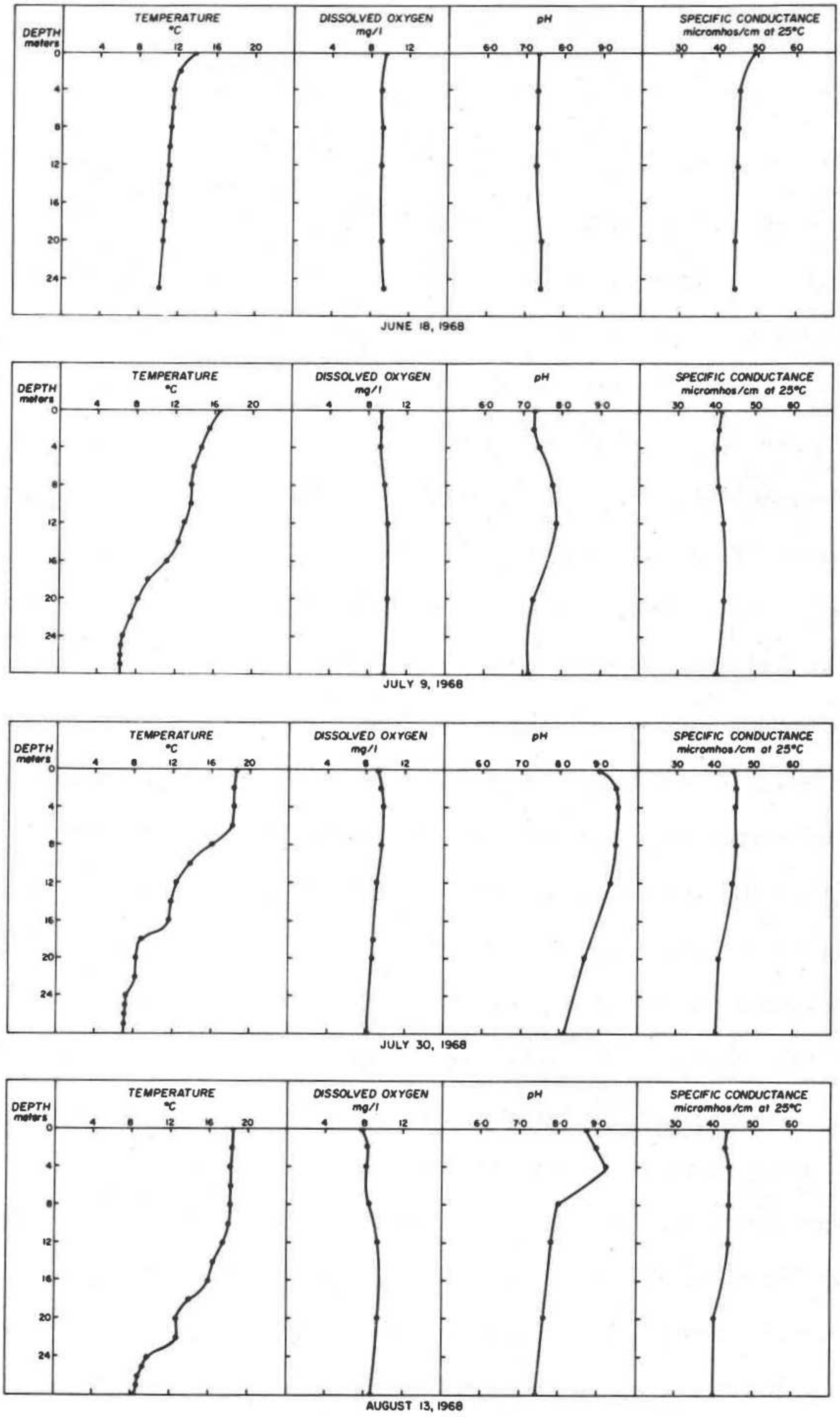


Figure 2.

TEMPERATURE, OXYGEN, pH AND CONDUCTIVITY PROFILES IN ODELL LAKE, OREGON
JUNE-AUGUST, 1968

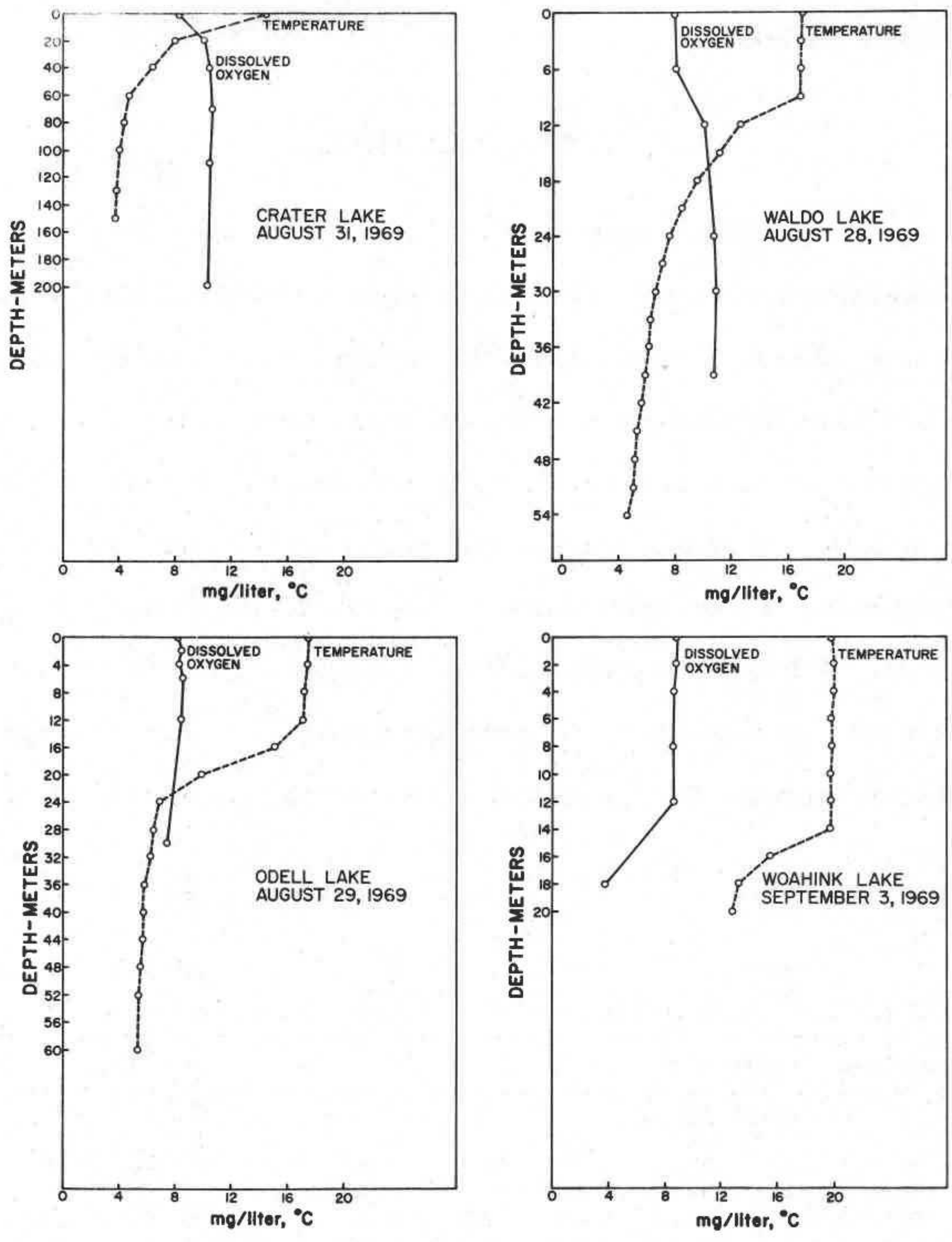


Figure 3. Temperature and dissolved oxygen profiles compared among four oligotrophic lakes in Oregon. Thermal-D. O. profiles for Odell Lake are shown in the lower left-hand panel. Thermal profiles were determined with a Whitney portable thermometer (model TC-5A) which has a meter scale calibrated in 0.1°C units.

sampling depth).

Subsurface Illumination

Some optical properties of Odell Lake are shown in Figure 4 (lower left-hand panel). These are compared with three other oligotrophic lakes in Oregon. To the left of each row of k values (extinction coefficients) is the depth at which the values were obtained. Percent transmittance of incident radiation is read directly from the curve for any depth. Secchi disc transparency depths are included. Additional information is provided in Table 2. The data presented (i. e., except for Secchi depths) were computed from photometric readings taken between 1200 and 1300 hours on the dates indicated. Light readings were taken under clear skies with wind velocities ranging from 8 to 10 knots.

Table 2. Spectral data for Odell Lake, Oregon. Measurements taken July 25, 1969.

Depth (m)	No Filter		Blue		Green		Red	
	k*	T**	k	T	k	T	k	T
1	0.247	78.1	0.205	81.4	0.044	95.7	0.551	57.6
5	0.210	34.9	0.250	28.7	0.167	43.4	0.398	13.7
10	0.185	15.7	0.251	8.2	0.208	12.5	0.421	1.5
14	0.214	5.0	0.243	3.3	0.189	7.0	0.396	0.4
20	0.217	1.3	0.244	0.8	0.196	2.0	0.347	0.2
25	0.248	0.2	0.296	0.1	0.231	0.3	0.349	0.1
30	0.261	0	0.312	0	0.244	0.1		
35	0.263	0			0.251	0		

* Extinction coefficient.

** Percent transmittance.

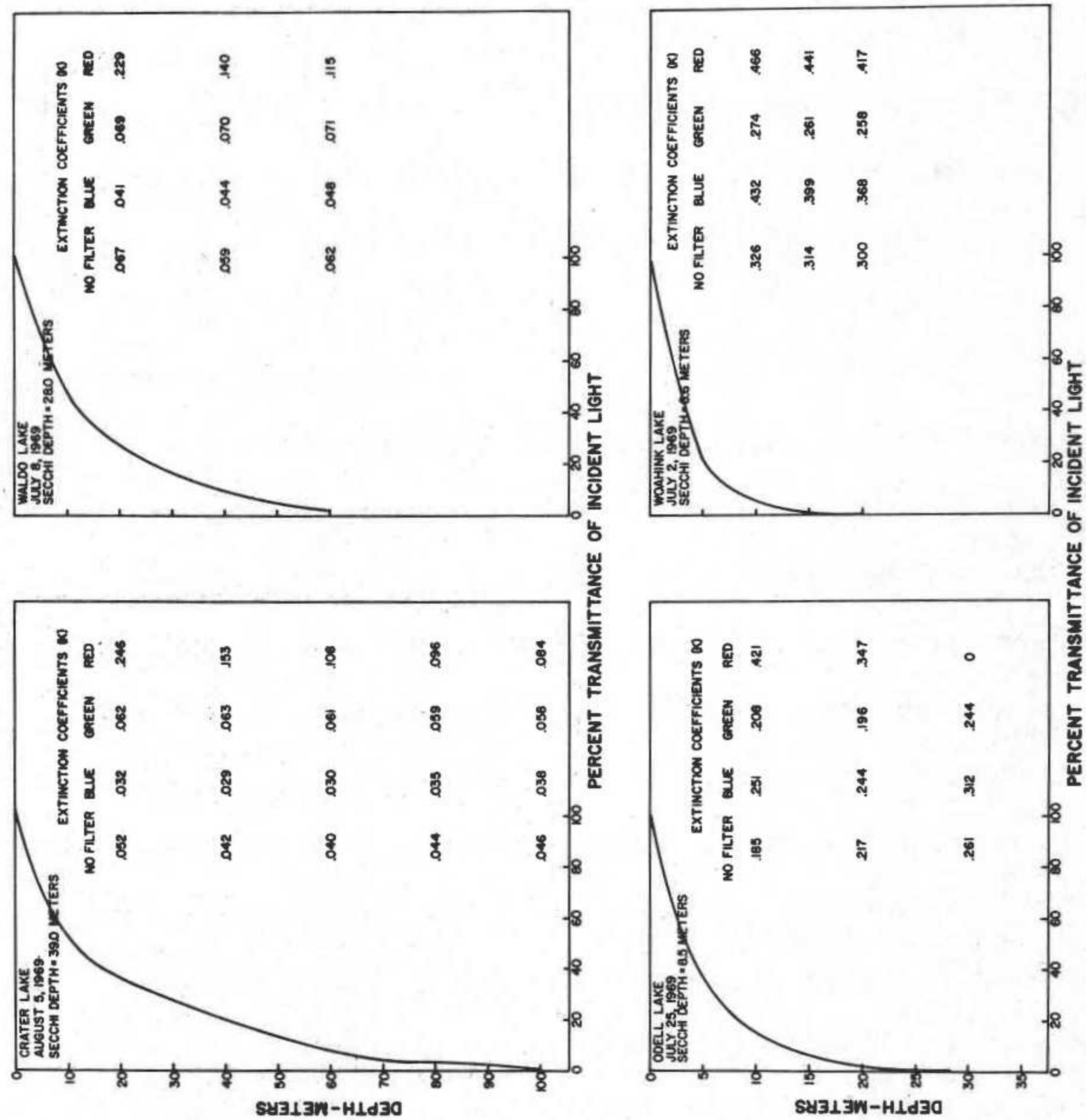


Figure 4. Optical data compared among four oligotrophic lakes in Oregon. Data for Odell Lake are shown in the lower left-hand panel. Light attenuation data were obtained with a Kahl submarine photometer (model 264 WA 310) which has a spectral range (in sunlight) of 400 - 640 mμ.

From the surface to a depth of 10 meters, the red end of the spectrum was absorbed quickly. Less than 5% of the red light (i.e., the bandwidth of 500 to 720 mμ) was transmitted below 10 m. Little difference was observed among k values for white light, perhaps because the red component was absorbed more evenly throughout the water column. Approximately 20% of the incident light was available at Secchi depth (Figure 4).

In Odell Lake, green light was transmitted the farthest. This was observed during every spectral measurement in 1968 and 1969. The rate of absorption of blue light was greatly increased over what it had been found for Crater Lake (Figure 4). Red light was present to some extent throughout the depth of the photic zone (Table 2). Total illumination was quenched very rapidly. Almost 70% of the incident radiation was absorbed in the first five meters (Figure 4). Light was transmitted at a rate one could expect for very turbid inshore waters.

Secchi disc transparency averaged 5.6 m in 1968 (from seven readings taken during the period June through October), with the lowest value recorded during an algal bloom on July 30 (i.e., 3.0 m). The mean of six readings taken in 1969 (June through September) was 7.1 m. Newcomb (1941) reported a Secchi transparency of 12 m at a point near Station 2 on September 27, 1940.

LAKE DESCRIPTION - CHEMICAL FEATURES

The chemical features of four oligotrophic lakes in Oregon, including Odell Lake, are compared in Figure 5. The data presented here are for 1969. pH and conductivity data, collected in 1968, are shown in vertical profile (Figure 2). Chemical determinations for both years are combined in Table 3.

Table 3. Chemical features for Odell Lake, Oregon*

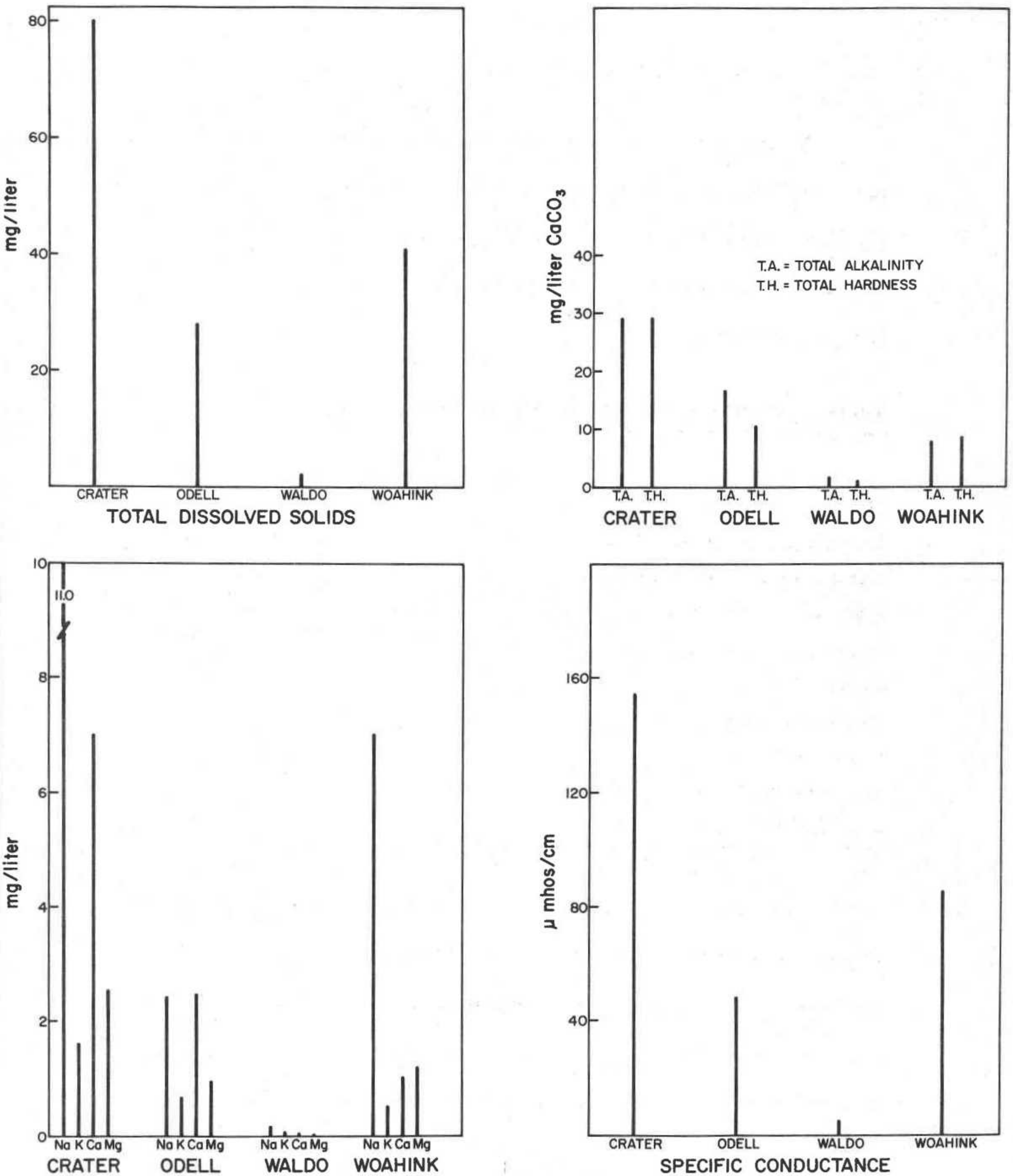
	1968	1969
pH	8.5	7.9
Specific cond. (μmhos/cm)	46	48
Total dissolved solids (mg/l)	25	28
Total alkalinity (mg/l $CaCO_3$)	16.8	16.5
Total hardness (mg/l $CaCO_3$)	11.1	10.6
Sodium (mg/l)		2.39
Potassium (mg/l)		0.62
Calcium (mg/l)		2.46
Magnesium (mg/l)		0.85
Zinc (ppb)		3.93

* From water samples collected at the surface.

Water samples for chemical analyses were collected at the surface and at several evenly-spaced sampling depths extending to 30 m in Odell Lake. Water analyses, except those for Na, K, Ca, Mg and Zn, were conducted in a mobile laboratory within 12 hours after the samples were collected. pH values were obtained with a Corning pH

Figure 5.

CHEMICAL FEATURES



meter (model 7). 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. The method for determining total dissolved solids (total residue) was derived from the Standard Methods handbook (APHA, 1965). An atomic absorption spectrophotometer (Perkin-Elmer model 303), analyzed samples for Na, K, Ca, Mg and Zn.

Newcomb (1941) reported very little information about the chemistry of Odell Lake. His values for pH ranged from 7.2 at the surface to 6.9 at 55 m. Methyl orange alkalinity (bicarbonate) averaged 27.0 mg/l for the same water column. Phenolphthalein alkalinity (carbonate) did not exist.

In 1968, mid-summer and early fall algal blooms had a marked effect on pH and alkalinity (Figure 2). During a dense bloom in July, 1968, the pH soared to 9.5 in the upper portion of the photic zone due to the removal of free CO_2 and HCO_3^- by phytoplankton. An increase in $CO_3^=$ was indicated by phenolphthalein alkalinity titration. During August and September, pH at a depth of 4 m never fell below 9.0. Phenolpthalein alkalinity was determined as late as October 18, 1968. In 1969, algal blooms were less pronounced; consequently, pH values never exceeded 8.9. Phenolphthalein alkalinity was never more than 1.3 mg/l as $CaCO_3$ (which contrasted with 1968 when values ranged from 4.5 to 3.7 mg/l as $CaCO_3$).

No historical information was available concerning phosphorus and nitrogen in Odell Lake. Apparently, human activities is a major source of these as well as other essential nutrients in the Odell Lake basin.

LIMNETIC PLANKTON AND PRODUCTIVITY

The Composition of the Plankton

The average volume of plankton collected in Odell Lake in September, 1940, was 1.8 mg/m^3 of water (Newcomb, 1941). Thereafter, the production of plankton increased considerably. In 1968 and 1969, the September hauls yielded 15 to 25 mg of plankton/m^3 (very rough estimates by the author).

Newcomb (1941) was perhaps the first investigator to identify the plankton in Odell Lake. The zooplankton included *Epischura sp.*, *Diaptomus sp.*, *Bosmina sp.* and *Holopedium sp.* He identified the phytoplankton as *Asterionella sp.*, *Anabaena sp.*, *Spirogyra sp.*, and *Staurastrum sp.* The results of another study (Malick, unpublished data) are presented in Table 4.

Algae collected in September, 1969, were identified to genera (Table 5). Concentrations of chlorophyll *a* (Table 6) ranged from 52.716 to 150.741 mg/m^2.

Table 4. Numbers of zooplankton collected in vertical tows at Odell Lake, Oregon (Malick, unpublished data).*

Date	Tow Depth (m)	*Daphnia longispina*/m^3	*Cyclops bicuspidatus*/m^3	Total no./m^3
17 June 68	30	286.0	6,264.4	6,550.4
9 July 68	30	2,886.3	1,978.3	4,864.6
30 July 68	30	36,598.3	2,899.1	39,497.4
13 Aug 68	30	56,274.5	6,617.6	62,892.1
6 Sept 68	28	11,960.7	11,352.9	129,313.6
25 Sept 68	28	38,051.4	132,702.2	170,753.6
19 Oct 68	30	7,795.0	81,198.1	88,993.1
10 July 69	30	1,638.6	31,974.7	33,613.3
24 July 69	30	9,130.4	10,409.2	19,539.6
8 Aug 69	30	21,512.0	5,938.9	27,450.9

*Sampling site located at Station I (Figure 1). Both juveniles and adults are represented. Vertical tows taken with a no. 6 mesh net (intake diameter equaled 0.5 m).

Table 5. Some representative phytoplankton genera collected during 1969. Identifications courtesy of Dr. H.K. Phinney, Department of Botany, Oregon State University.

Lake and Date	Genera: Chlorophyta	Genera: Chrysophyta	Genera: Mastigophora (flagellates)
Odell, 24 Sept.	Planktosphaeria	Asterionella	
	Oedogonium	Synedra	Ceratium
	Staurastrum	Fragilaria	Eudorina
		Coscinodiscus	Colacium
		Melosira	
		Cyclotella	
		Stephanodiscus	
		Suriella	
		Cocconeis	

Table 6. Detectable concentrations of chlorophyll *a* in milligrams per meter square for Odell Lake, Oregon (June 19 - September 24, 1969). Samples for chlorophyll analyses were obtained from depths of 0, 2, 4, 6, 12, and 30 meters.

Date	mg chlorophyll *a*/m^2	mg chlorophyll *a*/m^3 (average)
19 June	52.716	1.757
10 July	59.641	1.988
25 July	78.608	2.621
7 August	150.741	5.025
29 August	107.130	3.571
24 September	142.977	4.766

Limnetic Phytoplankton Productivity Estimates

Phytoplankton primary production was measured *in situ* with ^{14}C. The method used was a modification of a 1961 technique prepared by the Fisheries Research Institute, University of Washington, Seattle (F.R.I. field manual, section S6, carbon-14). Water samples were collected at Station 1 (Figure 1) with a 2 1/2 liter plastic water bottle (Van Dorn type). Sampling depths were variable in each lake as will be indicated in later sections. A 125 ml-portion of water from each sampling depth was inoculated with 1 ml of a stock solution of $Na_2{}^{14}CO_3$ (5.0 μ Ci/ml) and returned to the depth from which it was drawn. Dark bottles accompanied light bottles at every other depth to determine nonphotosynthetic uptake of ^{14}C. Occasionally, duplicate light bottles were added to assess experimental error. Following a four-hour incubation period (1000 - 1400 hrs), all samples were retrieved and filtered with a Millipore apparatus (47 mm-diameter AA Millipore filters) in the mobile laboratory. The uptake of ^{14}C was determined by liquid scintillation counting at Oregon State University. Net production rates (mgC/m^3/hr) were plotted against depth for each sampling date. The resulting curves were integrated and net production rates for the sampled water column were estimated for the incubation period (mgC/m^2/hr).

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). The results that are presented in Table 7 are based on the energy fractions computed and modified from Vollenweider (1965) by Platt and Irwin (1968). When bimonthly sampling occurred, a monthly average was derived from the two measurements.

Table 7. Phytoplankton primary productivity for Odell Lake, Oregon. Total production for the periods June 18 to October 19, 1968, and June 19 to September 24, 1969 estimated to be 231.3 gC/m^2 and 118.1 gC/m^2, respectively.

Date	$mgC/m^2/hr$	Energy Fraction (F)*	$mgC/m^2/day$ (approximated)
18 June 68	31.928	0.37	345.17
9 July 68	170.771	0.38	1797.59
31 July 68	396.772	0.38	4176.55
13 Aug 68	206.103	0.40	2061.03
6 Sept 68	196.496	0.50	1571.97
25 Sept 68	195.151	0.50	1561.21
19 Oct 68	165.444	0.54	1225.51
19 June 69	10.354	0.37	111.74
10 July 69	56.779	0.38	597.67
25 July 69	149.889	0.38	1577.78
7 Aug 69	223.027	0.40	2230.27
29 Aug 69	172.709	0.40	1727.09
24 Sept 69	112.696	0.50	901.57

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

Net phytoplankton productivities (in $mgC/m^2/hr$) among four oligotrophic lakes in Oregon (including Odell Lake) for 1968 and 1969 are compared in Figure 6. The values for 1969 are related to concentrations of chlorophyll a per square meter (Figure 6). Assimilation numbers for Odell Lake are summarized in Table 8. The values represent the amount of carbon that is synthesized by phytoplankton per hour per mg of chlorophyll a. The number may be related to nutrient availability (Curl and Small, 1965; Fogg, 1966). That is, the low availability of nutrients would be reflected by low assimilation numbers. At sea, in a region of nutrient enrichment caused by upwelling, the average assimilation number was found to be 13. Conversely, in an area where upwelling did not occur (i.e., a region where nutrients were perhaps less available), the mean was reduced to about 6 (Small, et al. in press). An average assimilation number of 3 has been determined for natural lake populations (Gessner, 1949). Other values obtained for lake populations were 2 (Manning and Juday, 1941) and 4 to 6 (Gessner, 1943). Assimilation numbers in eutrophic environments may exceed those under oligotrophic conditions by a factor of 4 or more (Ichimura, 1958).

At all times, primary productivity in Odell Lake was unusually high for a lake that has been classified as oligotrophic. Vertical profiles of productivity for 1968 and 1969 are compared in Figures 7 and 8 (note that the scales along the x-axis in Figure 7 differ from those in Figure 8).

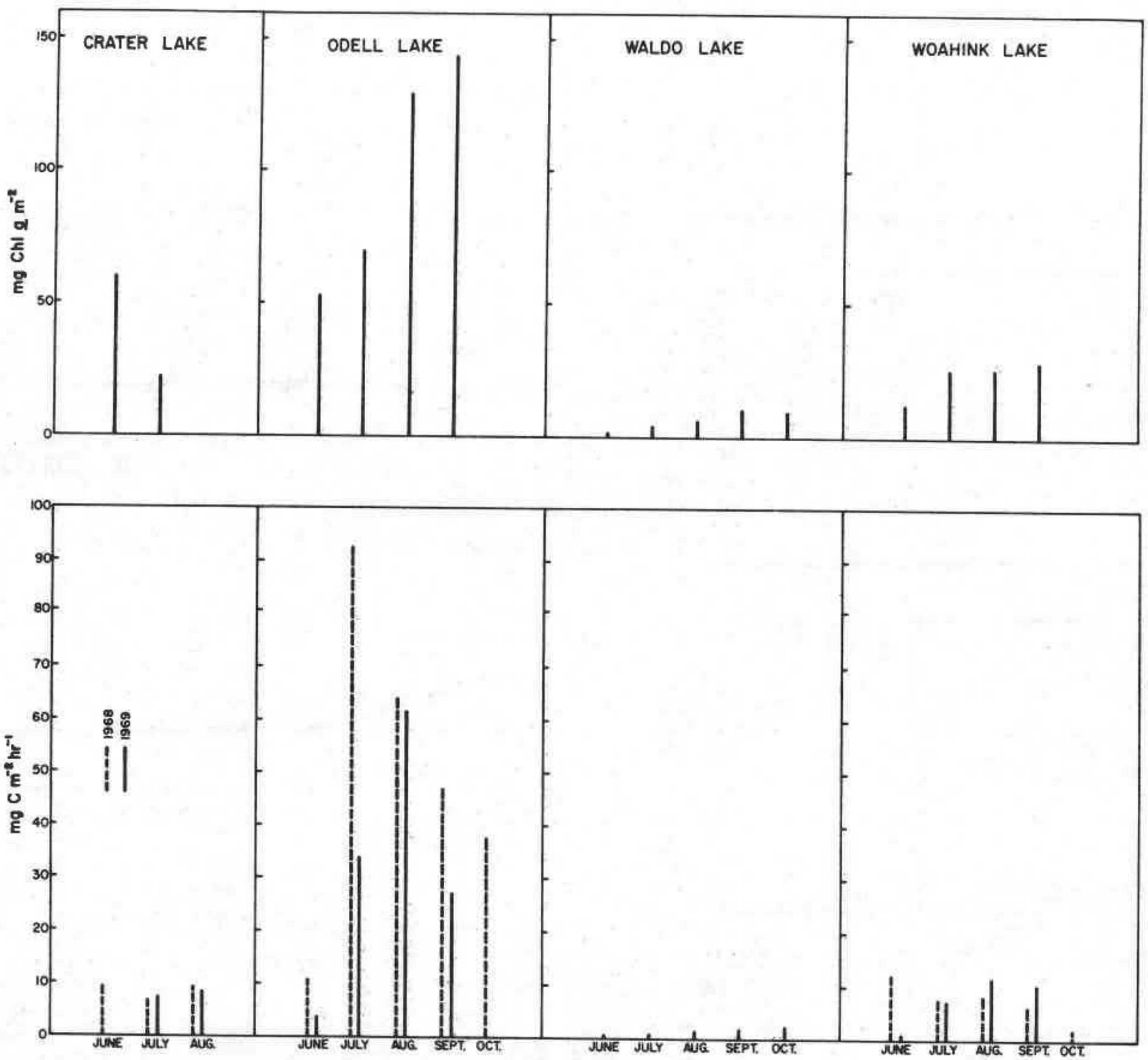


Figure 6. The monthly average rates of production (lower panel) and concentrations of chlorophyll a per meter squared for four oligotrophic lakes in Oregon.

Figure 7.

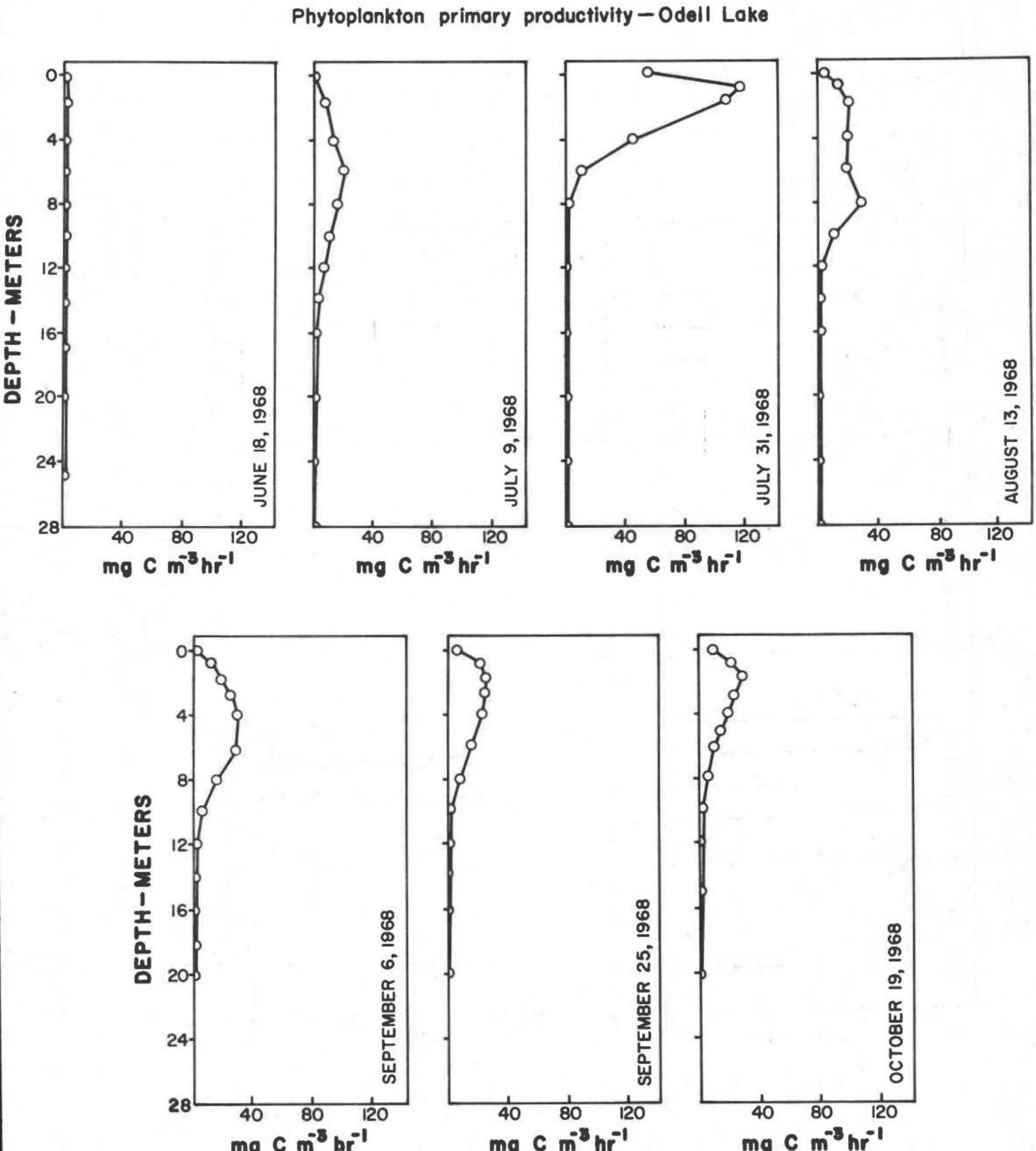

Phytoplankton primary productivity — Odell Lake
DEPTH - METERS
0
4
8
12
16
20
24
28
40
80
120
mg C m^{-3} hr^{-1}
JUNE 18, 1968
JULY 9, 1968
JULY 31, 1968
AUGUST 13, 1968
SEPTEMBER 6, 1968
SEPTEMBER 25, 1968
OCTOBER 19, 1968

Figure 8.

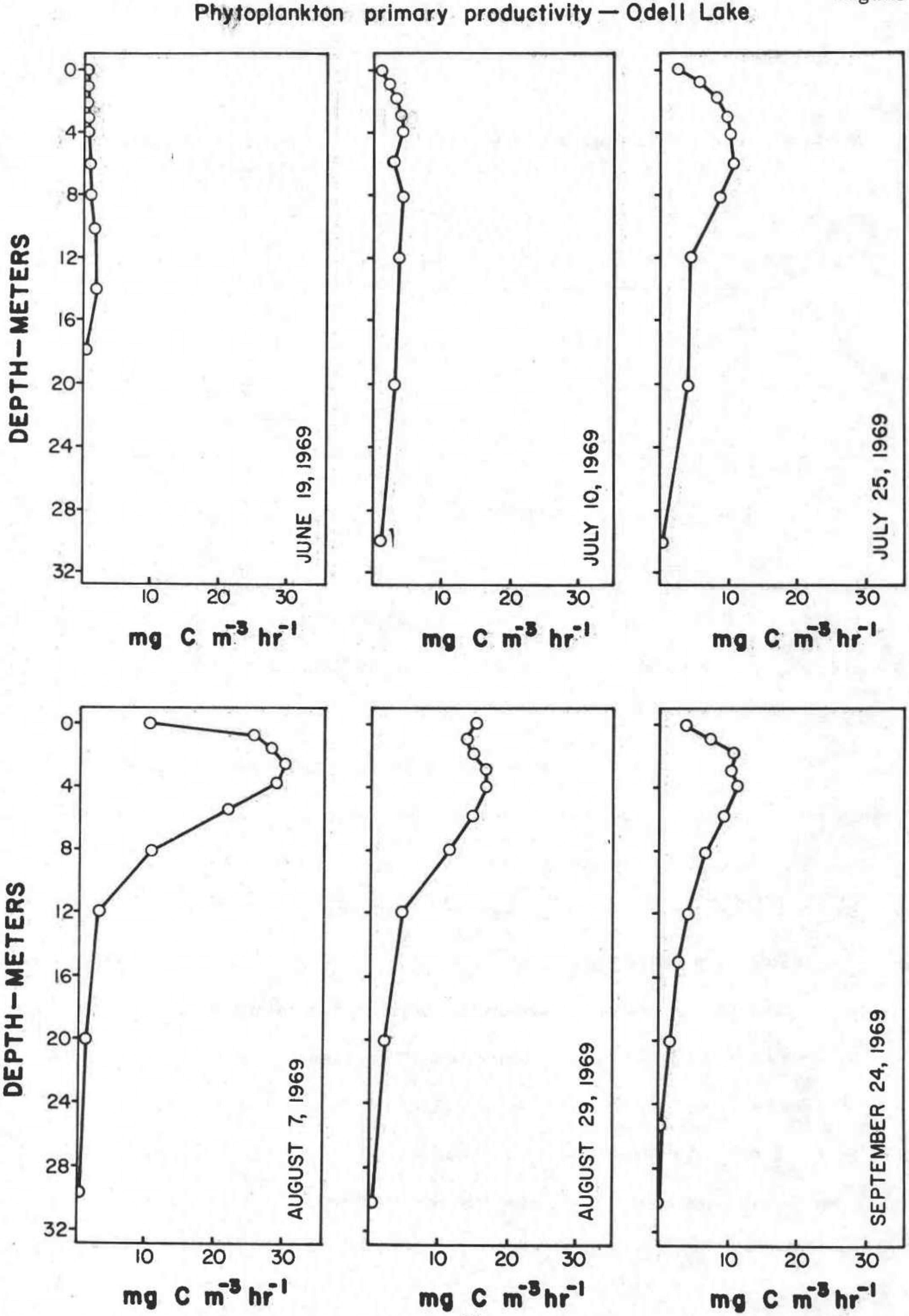

Phytoplankton primary productivity — Odell Lake
DEPTH-METERS
0
4
8
12
16
20
24
28
32
10
20
30
mg C m-3 hr-1
JUNE 19, 1969
JULY 10, 1969
JULY 25, 1969
AUGUST 7, 1969
AUGUST 29, 1969
SEPTEMBER 24, 1969

Table 8. Rate of phytoplankton photosynthesis per unit of chlorophyll a at the depth of maximum productivity (assimilation number).

Lake	Date	Assimilation Number (mg C hr^{-1} per mg chlorophyll a)
ODELL	10 July 69	2.34
	25 July 69	7.60
	7 Aug 69	5.10
	29 Aug 69	3.10
	24 Sept 69	3.20
		$\bar{x}$ = 4.27

Productivity was generally higher in 1968 than in 1969. Total production by phytoplankton for the period June 18 to October 19, 1968 was 231.3 gC/m^2. In 1969, production was measured over a shorter period (i.e., June 19 to September 24) and totalled 118.1 gC/m^2 (Table 7).

In 1968, production was relatively low during June. An algal bloom (unidentified) reached maximum proportions in late July (Figure 7). Throughout the remainder of the summer and fall, production diminished rather slowly (Figures 6 and 7; Table 7). Weather conditions prohibited sampling beyond October.

The cycle of summer production developed similarly in 1969. June was a period of limited production. The seasonal maximum occurred in late July or early August (Figure 8). Earlier, in May, a diatom bloom had been reported. Another bloom (unidentified) was observed in November (S. Lewis, personal comm.). Both pulses were thought to be quite unusual for Odell Lake.

Nutrient Bioassay Experiments

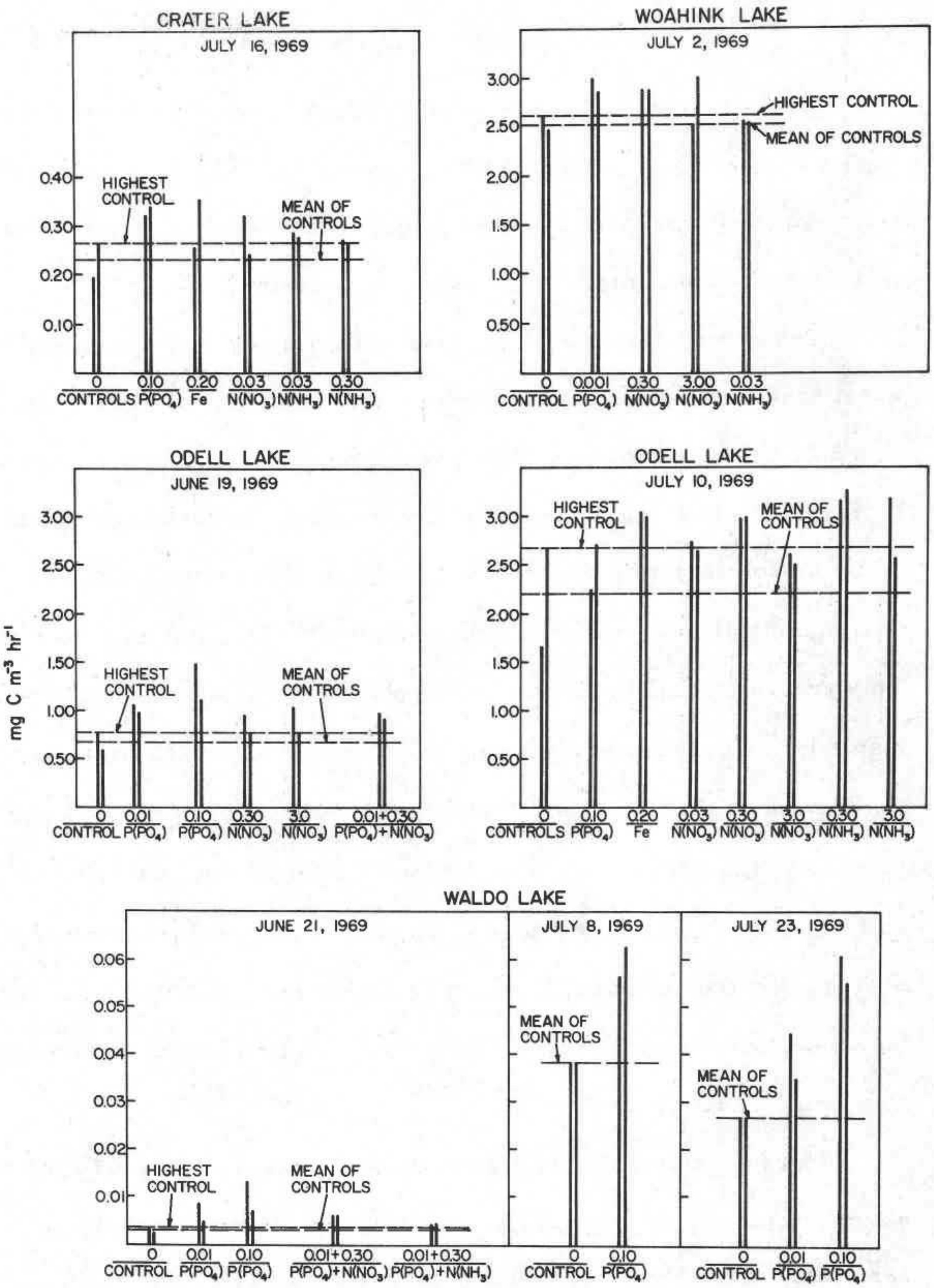
During the summer of 1969, an attempt was made to determine the relative effects of various nutrients (P, Fe, NO_3, NH_3) on rates of photosynthesis by phytoplankton. Four nutrient stock solutions (KH_2PO_4, $NaNO_3$, NH_4Cl and $FeCl_3$) were prepared using analytical grade reagents. Every effort was made to avoid contamination and to insure sterile nutrient media. Glassware was rinsed repeatedly with concentrated HCl. Other precautions recommended by Dr. C.R. Goldman, University of California at Davis (personal comm.) and Dr. J. Shapiro, University of Minnesota (personal comm.) for the preparation and utilization of nutrient media were followed. Each stock solution was diluted to an initial concentration and dispensed into 20 ml glass ampules. The ampules were sealed by flame, autoclaved and placed in refrigerated storage. During bioassay experiments, the nutrient media were transferred from the ampules to 125 ml culture bottles using disposable hypodermic syringes. Three 2 1/2 liter water samples, drawn from a predetermined depth in the photic zone (i.e., 6 m in Odell Lake), were apportioned into 40 125 ml culture bottles. Each subsample (and a duplicate) was treated with a different concentration of one or more nutrient salts and 1 ml of the stock solution of $Na_2{}^{14}CO_3$. For comparative purposes, two additional subsamples (controls) received the $Na_2{}^{14}CO_3$ solution only. All culture bottles (subsamples) were suspended from the same rack and lowered to the depth from which they were drawn. After four hours (usually during 1100 - 1500 hrs), the samples were recovered and filtered using the materials described earlier.

During the June bioassay experiment (Figure 9), the response of phytoplankton to several nutrient additives (Ref. Table 9) was, as a whole, not significant. In July, prior to the summer pulse, productivity was stimulated to some extent following the addition of most nutrient solutions. The significance of these results was not tested. In all probability they do not reflect nutrient deficiencies in the lake. Considering the level of phytoplankton biomass and productivity (including assimilation numbers, Table 8), it is reasonable to assume that Odell Lake is nutrient-enriched.

Table 9. Types and concentrations of algal nutrients employed during bioassay experiments in 1969.

Lake and Date	Nutrient Additives	Concentrations (mg/liter)			
Odell, 19 June	$P(KH_2PO_4)$	0.001		0.01	0.10
	$N(NaNO_3)$	0.03		0.30	3.00
	$N(NH_4Cl)$	0.03		0.30	3.00
	$P + N(NO_3)$	0.01	+	0.30	
	$P + N(NO_3)$	0.10	+	3.00	
	$P + N(NH_3)$	0.01	+	0.30	
Odell, 10 July	$P(KH_2PO_4)$	0.001		0.01	0.10
	$Fe(FeCl_3)$	0.002		0.02	0.20
	$N(NaNO_3)$	0.03		0.30	3.00
	$N(NH_4Cl)$	0.03		0.30	3.00

Figure 9. Response of lake phytoplankton populations to nutrient enrichment bioassays.



CONCLUSIONS

Temperature, light and nutrients appeared to favor productivity in Odell Lake. High production was sustained during the summer and fall. Algal blooms were not uncommon. Large densities of zooplankton were observed on almost every sampling occasion (Malick, 1970).

The concentration of total dissolved solids in Odell Lake was about one-third that for Crater Lake. Yet, production in Odell Lake was 8 to 10 times greater. This is not completely in line with Northcote and Larkin (1956) and Larkin and Northcote (1958) who stated that "total dissolved solid content is by far the most important factor in determining standing crops of organisms in British Columbia lakes." This generalization would probably apply only to remote regions where man's limited presence has had little effect on the trophy of the lakes. In addition, it should be noted that six elements in Crater Lake water (i.e., Na, Ca, Mg, Cl, Si, S) comprise 75% of the total dissolved solids. This would suggest that although the value of TDS is relatively high still certain essential ions could be deficient. In Odell Lake, on the other hand, there is probably a better-balanced supply of ions with none being deficient.

The soils in the Odell basin were described. Perhaps the most salient feature of the soil profile was the large porosity and highly permeable nature of the underlying pumiceous layers. As stated before, the subsurface percolation of water through these materials would be very rapid, thereby facilitating the transport of dissolved nutrients and suspended organic materials into the lake.

The overall use of Odell Lake has grown rapidly, especially within the last 10 years (J. T. Atkinson, Odell Lake marina owner, personal comm.). Lake users have brought a substantial load of nutrients into the basin that otherwise would not have been available. As expected, the algae responded positively. Now, frequent pulses by phytoplankton populations and a relatively high rate of primary production throughout the growing season are features of the lake's biology. Algal blooms were never observed in the years prior to 1960 (J. T. Atkinson, personal comm.).

In 1940, the State of Oregon Game Commission conducted a biological survey of forty lakes, including Odell Lake, in the Upper Deschutes River Watershed (at that time, construction of the Willamette Highway no. 58 had just been completed; Newcomb, 1941). Part of the task was to quantify the benthic and planktonic communities and to classify the lakes accordingly. Each lake was assigned a numerical grade (or index value) that ranged between 1.0 and 2.5. The magnitude of the number depended upon the degree of eutrophy (i.e., the more eutrophic the lake, the larger the number). The number itself was based on a set of limnological conditions that were common to each lake. If a lake received a number between 1.0 and 1.5, it was classified as oligotrophic (implying that the value 1.0 represented ultra-oligotrophy). The ensuing ranges of values from 1.6 to 2.0 and 2.1 to 2.5, designated lakes that were eutrophic and advanced eutrophic, respectively. Interestingly enough, Odell Lake was graded 1.4.

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