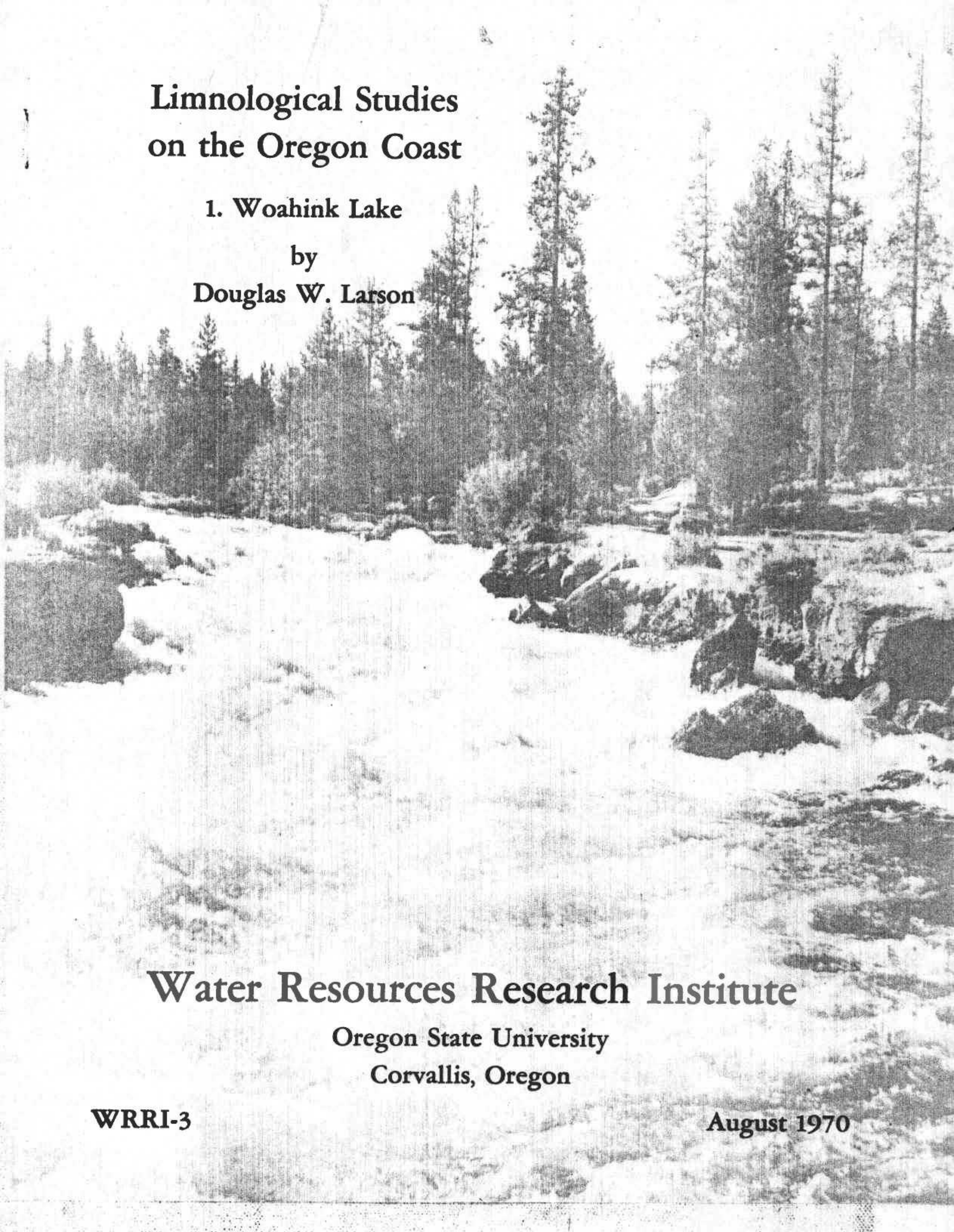

Limnological Studies on the Oregon Coast

1. Woahink Lake

by
Douglas W. Larson

Water Resources Research Institute
Oregon State University
Corvallis, Oregon

WRRI-3

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LIMNOLOGICAL STUDIES ON THE

OREGON COAST

I. WOAHINK LAKE

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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

Woahink Lake, situated on the central coast of Oregon, receives a wide variety of uses, and it is used throughout the year. Recreation ranks highest among all uses. The number of persons who visit the lake for this purpose has increased noticeably over the last 5 to 10 years. More than 150 summer cabins and permanent residences line the shore, nearly 20% of them having been constructed since 1964. Domestic sewage is handled by septic tanks and drainfields. (C. Mulvey, Woahink Lake resort owner, personal comm.).

Water for drinking and other domestic purposes is pumped from the lake without treatment. The Lane County Health Department periodically examines the water to see that it conforms with accepted bacteriological standards of purity. This has insured that domestic wastes will not be discharged directly into the lake. Samples of water tested for coliform bacteria resulted in MPN values ranging from 2 (June, 1964) to 22 (July, 1969) (R. Burns, Lane County Health Dept., Eugene, Oregon, personal comm.).

During the tourist season (June - August), weather and daylight permitting, a commercial floatplane makes, on the average, four take-offs and landings per hour. The quantity of oil that is put into the water by this operation is indeterminable. In places along the shoreline, an oil scum develops, usually following a period of intensive floatplane use.

Several land-development projects have denuded large watershed areas that adjoin the lake. Most notable among these is an extensive recreational facility situated on the terminus of the north-central peninsula. The work has generated a considerable amount of exposed, unconsolidated material, much of which has been consumed by erosion and discharged into the lake. Consequently, the water in the vicinity of the peninsula has become extremely turbid (D. W. Larson and J. G. Malick, aerial observation, August, 1969).

The purposes of this report are (1) to document the limnology of Woahink Lake, particularly at a time when the lake environment has not yet been greatly deteriorated by domestic and recreational development and (2) to provide physical, chemical, and biological data that will establish a reference point, allowing responsible state agencies to estimate periodically the effects of population impact on the Woahink 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. R. Burns, Lane County Health Department, Eugene, Oregon, Mr. D. W. Brackett, Soil Conservation Service, Florence, Oregon, Mr. J. Hutchison, State of Oregon Game Commission and Mr. C. Mulvey, Florence, Oregon 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 and Mr. G. McCoy was much appreciated.

LAKE DESCRIPTION - PHYSICAL FEATURES

Geography and Geology

Woahink Lake is located approximately 216 km north of the Oregon-California border and 5 km inland from the Pacific Ocean. The lake basin, typical of nearly all the coastal lakes in Oregon, is a former stream valley obstructed at its mouth by alluviation and sand dune encroachment (Baldwin, 1964). The movement of sand is generally in an easterly-northeasterly direction. In places along the west shoreline, the lake is adjoined by dune complexes.

The soil of the Woahink basin consists mostly of sand or sandy loam. The soil west of the lake is described as pure sand (Griffiths and Yeoman, 1938). Further inland, between the east shore of the lake and the Coast Range, the sand grades laterally into a weakly-developed sandy loam (Griffiths and Yeoman, 1938). Permeability is extremely rapid; soil fertility is very low (D. W. Brackett, personal comm.).

Woahink Lake is fed by three tributaries that enter from the north and east (McGie and Breuser, 1962). The longest is about 5 km in length. Together, they drain an area of 14.2 km^2. The lake empties southward into adjacent Siltcoos Lake through the Woahink Creek outlet (McGie and Breuser, 1962; D.W. Brackett, personal comm.).

The surface level of Woahink Lake fluctuates very little throughout the year (D.W. Brackett, personal comm.). McGie and Breuser (1962) reported the seasonal fluctuation to be 1/2 m or less. Nothing can be found in the literature, however, concerning the rate of flushing in the lake. Flushing may be an important factor in limiting production, particularly during the late fall and winter months.

Climate

The climate for Woahink Lake is maritime. In the period 1951-1960, annual mean temperature was 11.2° C; annual precipitation during the same period averaged 217.2 cm (U.S. Weather Bureau, 1965). These data were obtained from the nearest recording station, located about 5 km to the east of Woahink Lake (Canary, Oregon). Additional information concerning wind velocity and direction was provided by the U.S. Coast Guard, Siuslaw River Station, Florence, Oregon (1969). Incident radiation during the summers (June - September) of 1968 and 1969 averaged 221.4 and 200.2 g cal/cm^2/4 hrs (1000 - 1400 hrs), respectively.

Morphometry

The morphometry of Woahink Lake (Table 1; Figure 1) was reported by McGie and Breuser (1962). Woahink Lake is a steep-walled basin that extends below sea level. Almost 50% (9 m) of the maximum depth occupies a cryptodepression. The lake has a shoal area (i.e., that area of the lake which is less than 15 m in depth) of about 0.8 km^2. Most of this occurs in the three major arms that project to the north and east. The dendritic shape of the basin, which characterizes the coastal lakes of Oregon, yields a shoreline development index of 3.5.

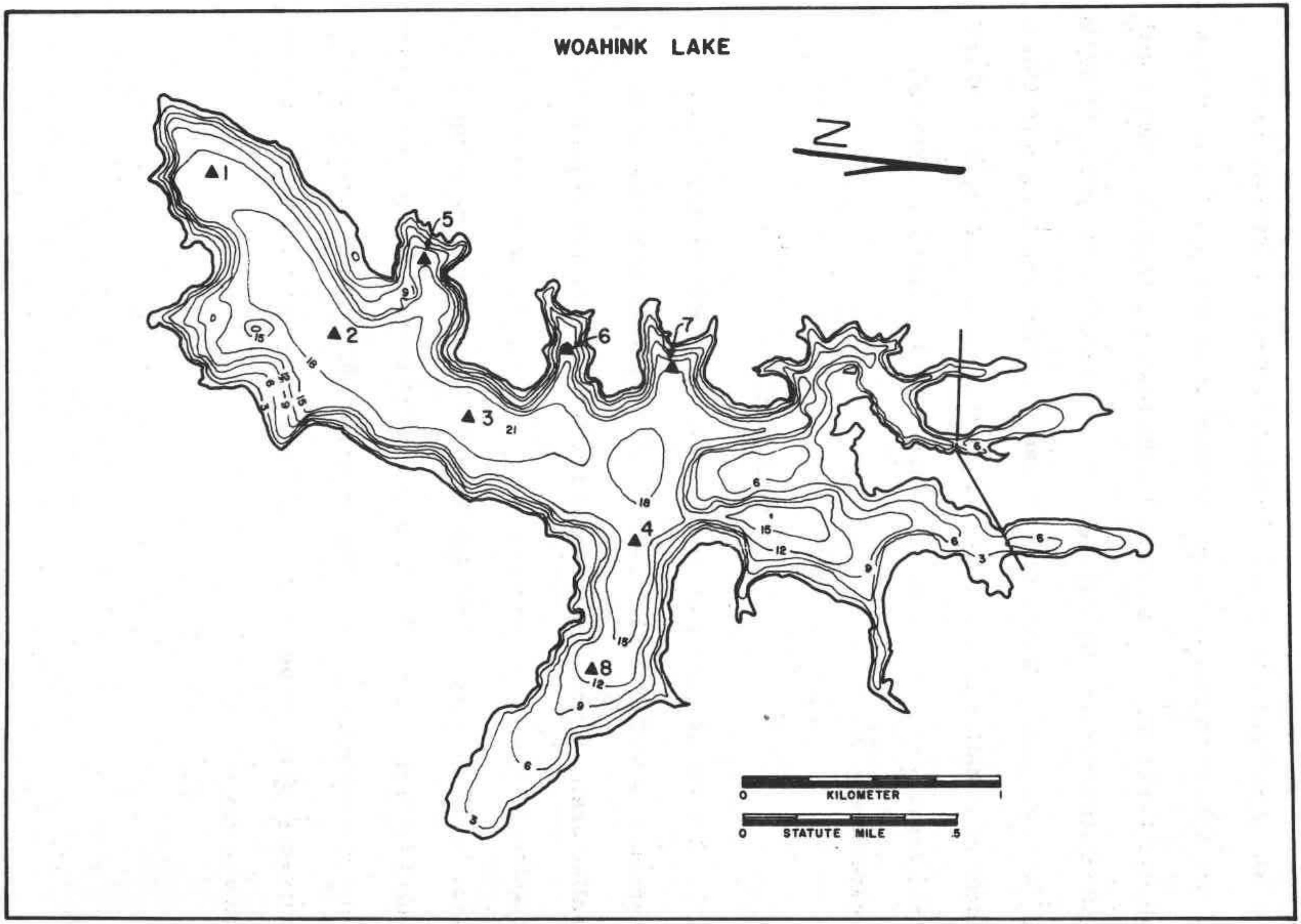


Figure 1. Bathymetric chart of Woahink Lake, Oregon, showing sample station locations Contours based on 1959 survey by the State of Oregon Game Commission, Portland, Oregon (map no. CL-61-6); contour interval, 3 meters.

Table 1. Lake morphology of Woahink Lake, Oregon*

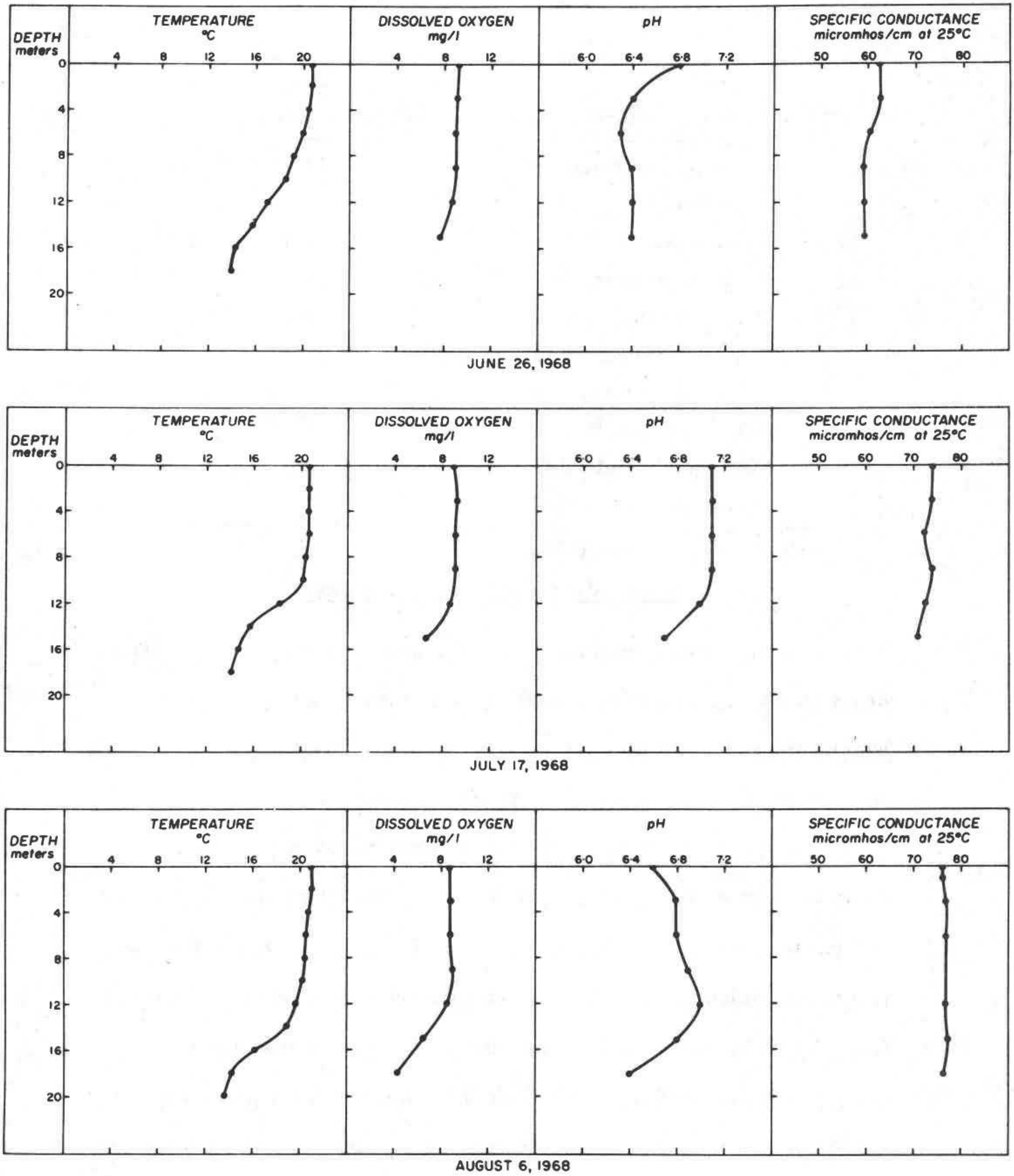
Elevation, surface (m)	12
Area (km^2)	3.2
Volume (km^3)	0.04
Depth, maximum (m)	21
Depth, mean (m)	10.5
Shoreline length (km)	22.3
Shoreline development	3.50
Relative depth (%)	1.18
Mean depth: max depth	0.50
Max depth: surface	0.012

*McGie and Breuser (1962)

Temperature and Dissolved Oxygen

Woahink Lake is classified as a warm monomictic type by virtue of its single yearly mixing period (occurring in the winter), during which time water temperatures at any depth are never less than 4° C. In addition, the lake is stratified in the summer.

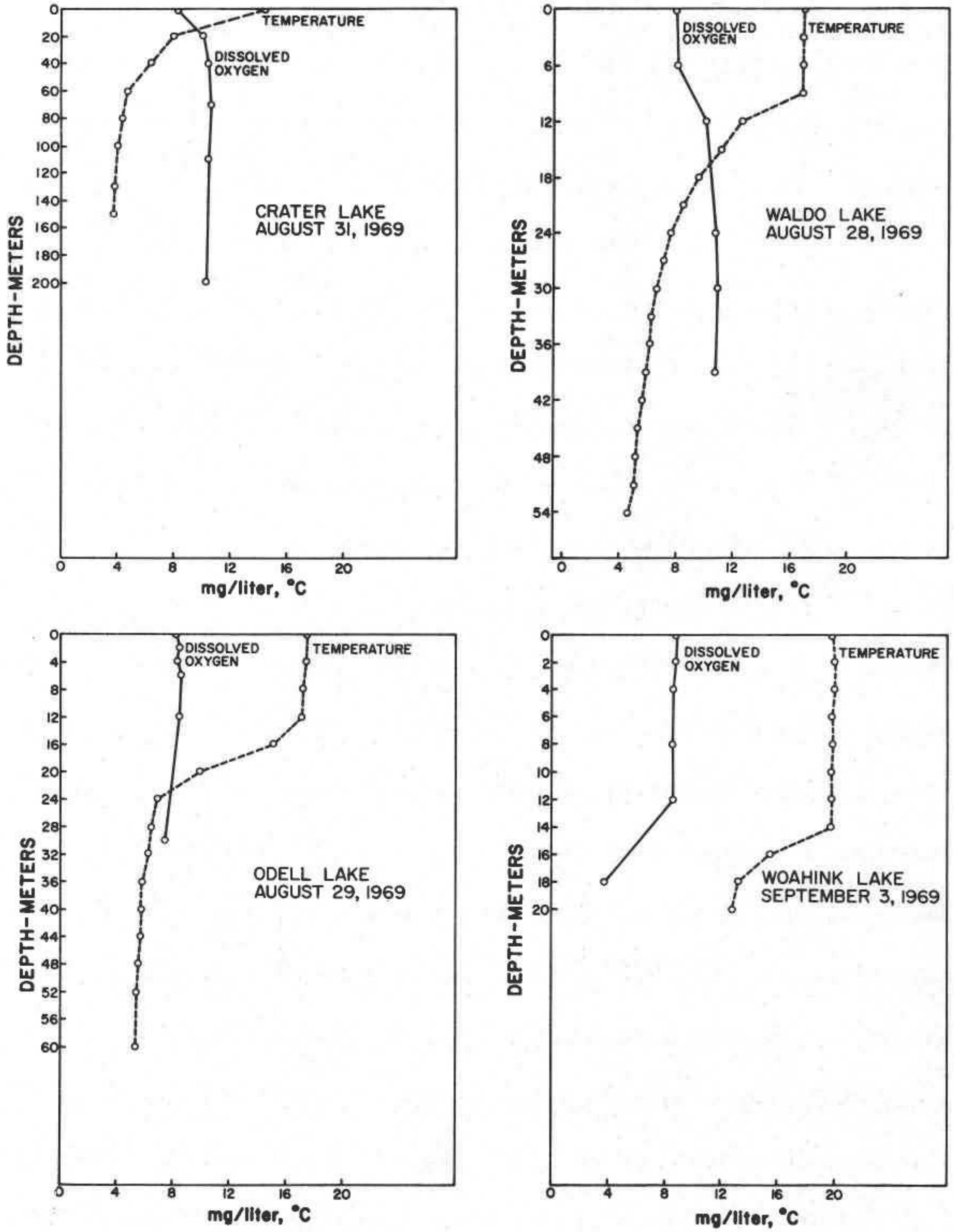
From October to April (1968-69), Woahink Lake was swept continually by strong west-southwesterly winds that commonly reached velocities above 20 to 25 knots. This, in addition to cooler air temperatures, maintained continuous lake circulation during the winter months (i.e., from November to March). By April, with wind action lessening and air temperatures increasing, the lake developed a slight stratification (e.g., on April 14, 1969, temperatures in the water column ranged from 12.3° C at the surface to 9.9° C at 20 m). In June, the thermal



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

Figure 2.

Figure 3. Temperature and dissolved oxygen profiles compared among four oligotrophic lakes in Oregon. Thermal-D.O. profiles for Woahink Lake are shown in the lower right-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.



profile was clearly indicated.

Woahink Lake exhibited thermal and oxygen curves that were generally parallel (Figures 2, 3). This suggests, perhaps, that the lake is, in fact, eutrophic. In 1968, for example, a hypolimnetic oxygen decrement was noted as early as June 26 (Figure 2). On July 1, 1969, the concentration of dissolved oxygen at 18 m was about 25% less than that measured at the surface to a depth of 12 meters. By September 3, there was distinct oxygen deficit at 18 m (Figure 3). Ruttner (1952) described a small oligotrophic lake in which the shape of the oxygen profile was determined by the morphometry of the basin and the reducing power of the mud. Oxygen was consumed by reducing substances (generated at the mud-water interface) at a rate which increases as the bottom or basin floor was approached. In profile, the oxygen gradient showed little change as it passed through the thermocline and entered the hypolimnion. But at an indeterminate depth where the slope of the basin "wall" converged with the basin "floor," the oxygen profile responded by angling rather abruptly along a line that paralleled the bottom profile. Ruttner (1952) differentiated between lakes of this nature and eutrophic lakes in which a thermal density barrier, well-established in late summer between the epi- and hypolimnia, prevented oxygen from being circulated into the hypolimnion. There, the quantity of oxygen was gradually depleted. In the vicinity of the thermocline then, the oxygen gradient showed a tendency to parallel, instead, the thermal profile. Although this occurred in Woahink Lake (Figures 2, 3), it is my opinion that the configuration of the oxygen profile resulted from the reducing power of the bottom mud. At a depth between 12 and 15 meters, the concentration of dissolved oxygen diminished rapidly (Figures 2, 3). McGie and Breuser (1962) found this also. The bathymetric chart of Woahink Lake (Figure 1) shows the basin "walls" converging with the basin "floor" at a point located between 12 and 15 meters. This relationship between the basin profile and the oxygen gradient (in addition to other limnological features) leads me to believe that Woahink Lake is oligotrophic in the broadest sense of the term.

Subsurface Illumination

Some optical properties of four oligotrophic lakes in Oregon, including Woahink Lake, are compared in Figure 4. 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. During the light readings, wind velocity was negligible but the sky was completely overcast.

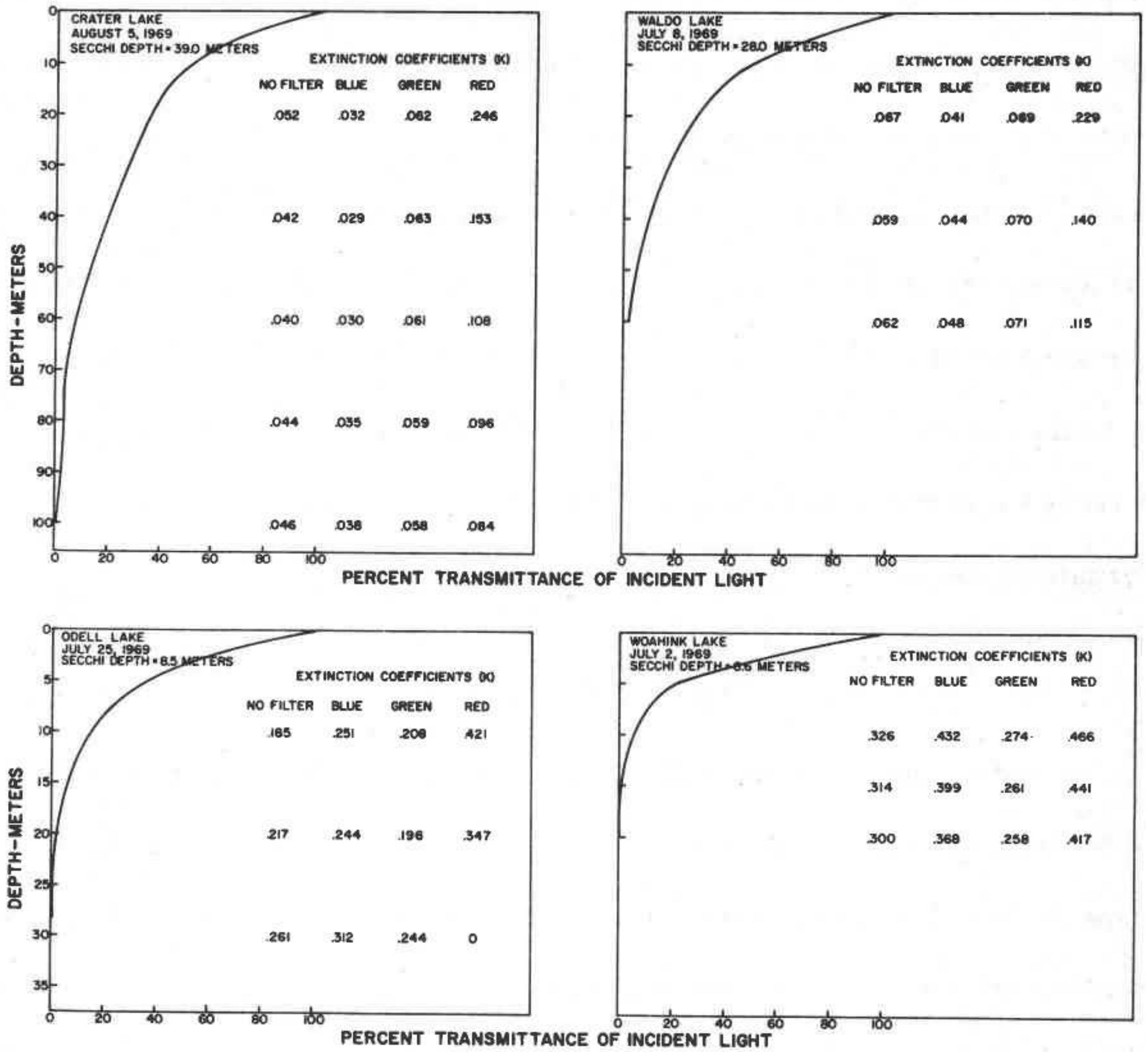


Figure 4. Optical data compared among four oligotrophic lakes in Oregon. Data for Woahink Lake are shown in the lower right-hand panel. Light attenuation data were obtained with a Kahl submarine photometer (model 268 WA 310) which has a spectral range (in sunlight) of 400-640 mμ.

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

Depth (m)	No Filter		Blue		Green		Red	
	k*	T**	k	T	k	T	k	T
1	0.326	72.2	.464	62.9	.263	76.9	.310	73.4
3	0.387	31.3	.552	19.1	.329	37.2	.664	13.6
5	0.319	20.3	.470	9.5	.279	24.8	.535	6.9
7	0.302	12.1	.439	4.6	.260	16.2	.500	3.0
10	0.326	3.8	.432	1.3	.274	6.5	.466	1.0
14	0.319	1.1	.407	0.3	.264	2.5	.447	0.2
20	0.300	0.2	.368	0.1	.258	0.6	.417	0.1

* Extinction coefficient.
** Percent transmittance

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).

The waters of Woahink Lake were moderately stained, caused perhaps by humic materials that were brought in from the watershed. Consequently, blue light was absorbed about as rapidly as red. From 10 to 20 meters, the intensities of blue and red light were essentially equal (Table 2). Green light was least absorbed throughout the water column. Actual maximum transmission was probably in the yellow (i.e., 550 mμ), although, at the time, there was no way of determining this. Welch (1952) referred to lakes of this nature as moderately transparent types. Average extinction coefficients for white and blue light were considerably higher than they had been in the other oligotrophic lakes.(Figure 4).

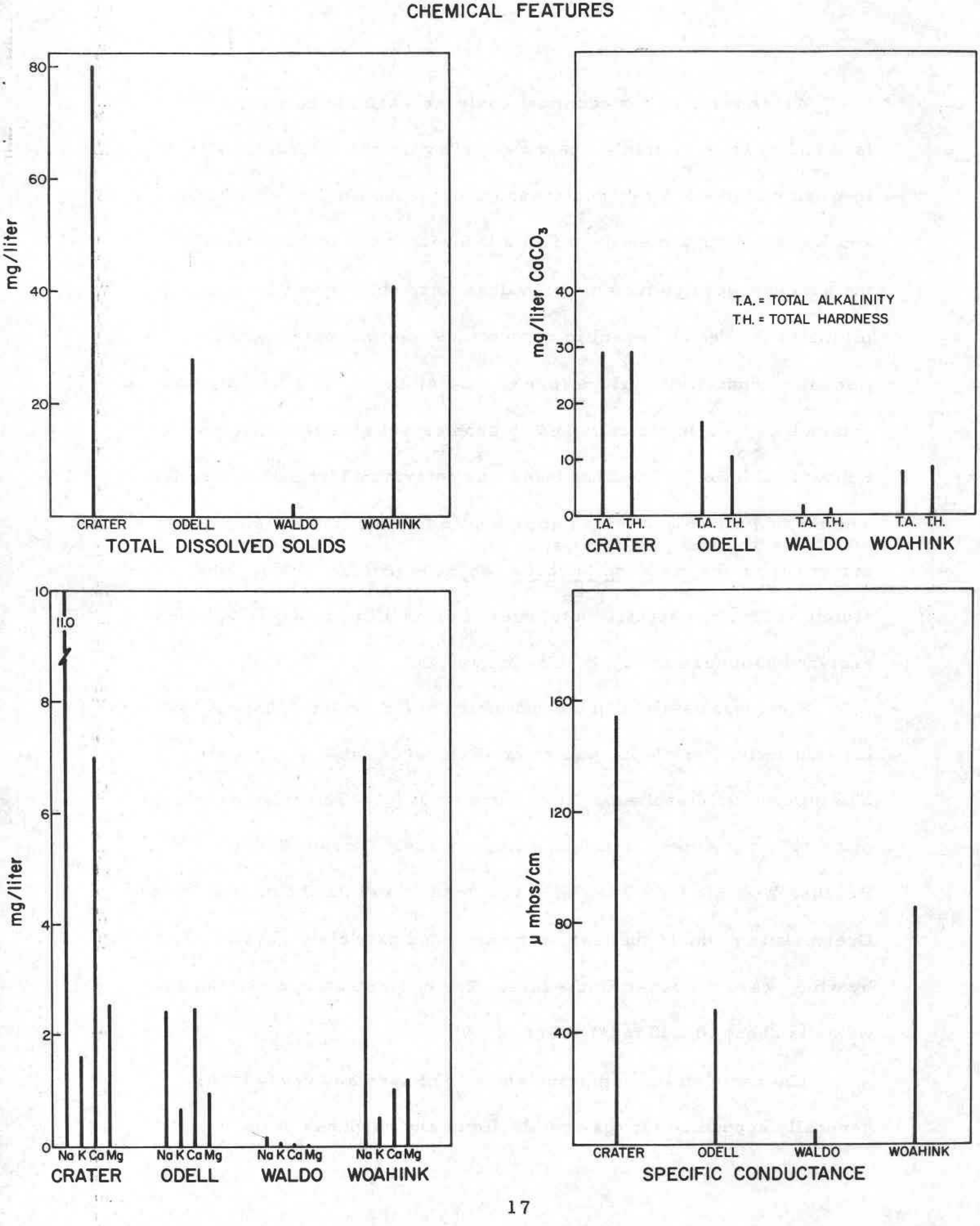
Transmitted radiation was reduced by 50% in the first three meters. By 5 m, an additional 30% was lost (Figure 4). This rather rapid reduction of surface illumination was another distinguishing feature of Woahink Lake (Figure 4).

Secchi readings, taken almost every month throughout the 15-month sampling period, were found to be quite similar. The lowest reading (4. 0 m) was recorded on October 14, 1968. The highest reading (7. 3 m) followed in November. The reason for this is not known. The average Secchi disc transparency for the period June, 1968, to September, 1969, was 6. 1 m. McGie and Breuser (1962) reported a Secchi depth of 3. 6 m taken on August 16, 1960 near Station 3 (Figure 1).

LAKE DESCRIPTION - CHEMICAL FEATURES

The chemical features of four oligotrophic lakes in Oregon, including Woahink 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.

Figure 5.


CHEMICAL FEATURES
mg/liter
80
60
40
20
CRATER
ODELL
WALDO
WOAHINK
TOTAL DISSOLVED SOLIDS
mg/liter $CaCO_3$
40
30
20
10
0
T.A. = TOTAL ALKALINITY
T.H. = TOTAL HARDNESS
T.A. T.H.
T.A. T.H.
T.A. T.H.
T.A. T.H.
CRATER
ODELL
WALDO
WOAHINK
mg/liter
10
11.0
8
6
4
2
0
Na K Ca Mg
Na K Ca Mg
Na K Ca Mg
Na K Ca Mg
CRATER
ODELL
WALDO
WOAHINK
µ mhos/cm
160
120
80
40
CRATER
ODELL
WALDO
WOAHINK
SPECIFIC CONDUCTANCE

Water samples for chemical analyses were collected at the surface and at several evenly-spaced sampling depths extending to 18 m in Woahink 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 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.

A comparatively high concentration of Na, which enhanced values for conductivity and TDS, was noted (Figure 5, Table 3). Nearly 20% of the total dissolved solids consisted of Na. The mean percentage of Na in North American inland waters is 7.46 (Clarke, 1942b). Because Woahink Lake is located less than 5 km inland from the Pacific Ocean, it is possible that sea spray and sand particles, carried aloft by wind, were deposited in the lake. The concentration of Na in sea-water is about 10,000 mg/l (Hem, 1959).

The basin soils, composed entirely of sand and sandy loam, generally accounted for the low alkalinity and hardness of the water

(Griffith and Yeoman, 1938; McGie and Breuser, 1962). This may have been an important factor in limiting production in the lake.

Table 3. Chemical features of Woahink Lake, Oregon*

	1968	1969
pH	7.1	7.2
Specific cond. (µ mhos/cm)	80	85
Total dissolved solids (mg/l)	44	41
Total alkalinity (mg/l $CaCO_3$)	8.2	7.7
Total hardness (mg/l $CaCO_3$)	8.9	8.5
Sodium (mg/l)		7.04
Potassium (mg/l)		0.51
Calcium (mg/l)		0.97
Magnesium (mg/l)		1.18
Zinc (ppb)		5.33

*Water samples collected at the surface.

During the period of thermal stratification in 1968 and 1969, the pH was observed to decrease gradually below the thermocline (Figure 2). Under reducing conditions at the mud-water interface (during summer stratification), the concentrations of dissolved oxygen and carbon dioxide are inversely related. The consumption of oxygen near the bottom is associated with an increase in CO_2 which lowers the pH effectively (Mortimer, 1942).

LIMNETIC PLANKTON AND PRODUCTIVITY

The Composition of the Plankton

The zooplankton in Woahink Lake was studied intensively in 1968 and 1969 (Table 4, Malick, unpublished data).

Cladocerans were the most important source of food for Kokanee salmon, Oncorhynchus nerka kennerlyi in Woahink Lake (McGie and Breuser, 1962). Opossum shrimps (Mysidacea), mayflies (Ephemeroptera) and crane flies (Tipulidae) were included in the diet.

The benthos of Woahink Lake was relatively unproductive. Ekman dredge samples taken throughout the basin yielded very few organisms (McGie and Breuser, 1962).

In Table 5, some of the algae that occurred in Woahink Lake are identified. Cyanophyta appeared to be more common than in the other oligotrophic lakes. Concentrations of chlorophyll a (Table 6) were reasonably uniform from July to September, 1969.

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 3 (Figure 1) with a 2 1/2 liter plastic water

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

	Tow Depth (m)	*Daphnia longispina*/m^3	*Cyclops bicuspidatus*/m^3	*Diaphanosoma brachyurum*/m^3	*Diaptomus franciscanus*/m^3	*Epischura nevadensis*/m^3	Total no. /m^3
17 July 68	16		105.7	280.8	943.4	84.2	1,414.1
6 Aug 68	17		39.2	2,150.9	1,541.1	21.5	3,752.7
3 Sept 68	17.5	72.5	569.6	27.9	5,020.4	117.2	5,807.6
19 Sept 68	15	860.2	1,014.7	114.7	1,305.8	30.8	3,326.2
14 Oct 68	17	3,492.6	765.9	2,015.9	747.5	18.3	7,042.2
13 Nov 68	16	255.2	253.2	205.2	165.4	68.4	947.4
9 Dec 68	16	113.3	36.5	50.1	41.2	424.0	665.1
23 Feb 69	16	16.6		0.8	731.5	73.9	822.8
13 Apr 69	16	46.0		9.8	3,007.0	15.9	3,743.8
25 May 69	16	93.0	42.5	152.7	1,630.4	13.2	1,931.8
13 June 69	16	287.7	37.0	758.3	2,721.6	145.8	3,950.4
1 July 69	16	443.3	3.3	5,058.2	1,411.6	44.9	6,961.3
1 Aug 69	16	602.5	516.5	95.4	613.9	42.4	1,870.8

* Sampling site located at Station 3 (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.

	Genera			
Lake and Date	Chlorophyta	Cyanophyta	Chrysophyta	Mastigophora (flagellates)
Woahink, 5 Aug	Planktosphaeria	Gomphosphaeria	Synedra	Volvox
	Staurastrum	Anacystis	Fragilaria	
		Merismopedia		

Table 6. Detectable concentrations of chlorophyll *a* in milligrams per meter square for Woahink Lake, Oregon (June 13 - September 28, 1969). Samples for chlorophyll analyses were obtained from depths of 0, 2, 4, 8, 12, and 18 meters.

Date	mg chlorophyll *a*/m^2	mg chlorophyll *a*/m^3 (average)
13 June	11.870	0.659
2 July	24.476	1.360
2 August	24.839	1.380
3 September	29.783	1.655
28 September	25.062	1.392

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 (mg $C/m^3/hr$) 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 (mg $C/m^2/hr$).

Measurements of carbon fixed per incubation period were converted to approximate daily values. This was done by dividing the 4-hr <u>in situ</u> 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 Woahink Lake, Oregon. Total production for the periods June 27 to December 9, 1968, and February 2 to September 28, 1969 estimated to be 28.3 gC/m^2 and 35.4 gC/m^2, respectively.

Date	$mgC/m^2/hr$	Energy Fraction (F)*	$mgC/m^2/day$ (approximated)
27 June 68	37.051	0.37	400.55
18 July 68	23.136	0.38	243.54
7 Aug 68	27.031	0.40	270.31
4 Sept 68	22.326	0.50	198.61
19 Sept 68	26.434	0.50	211.47
15 Oct 68	8.218	0.54	60.87
12 Nov 68	13.134	0.60	87.56
9 Dec 68	1.984	0.72	11.02
24 Feb 69	3.949	0.64	24.68
14 Apr 69	5.889	0.46	51.21
10 May 69	16.579	0.42	157.89
26 May 69	12.525	0.42	119.29
13 June 69	2.501	0.37	27.04
2 July 69	22.443	0.38	236.24
2 Aug 69	36.708	0.40	367.08
3 Sept 69	42.550	0.50	340.40
28 Sept 69	45.959	0.50	367.67

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

Net phytoplankton productivities (in $mgC/m^2/hr$) among four oligotrophic lakes in Oregon (including Woahink 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 are summarized in Table 8. The

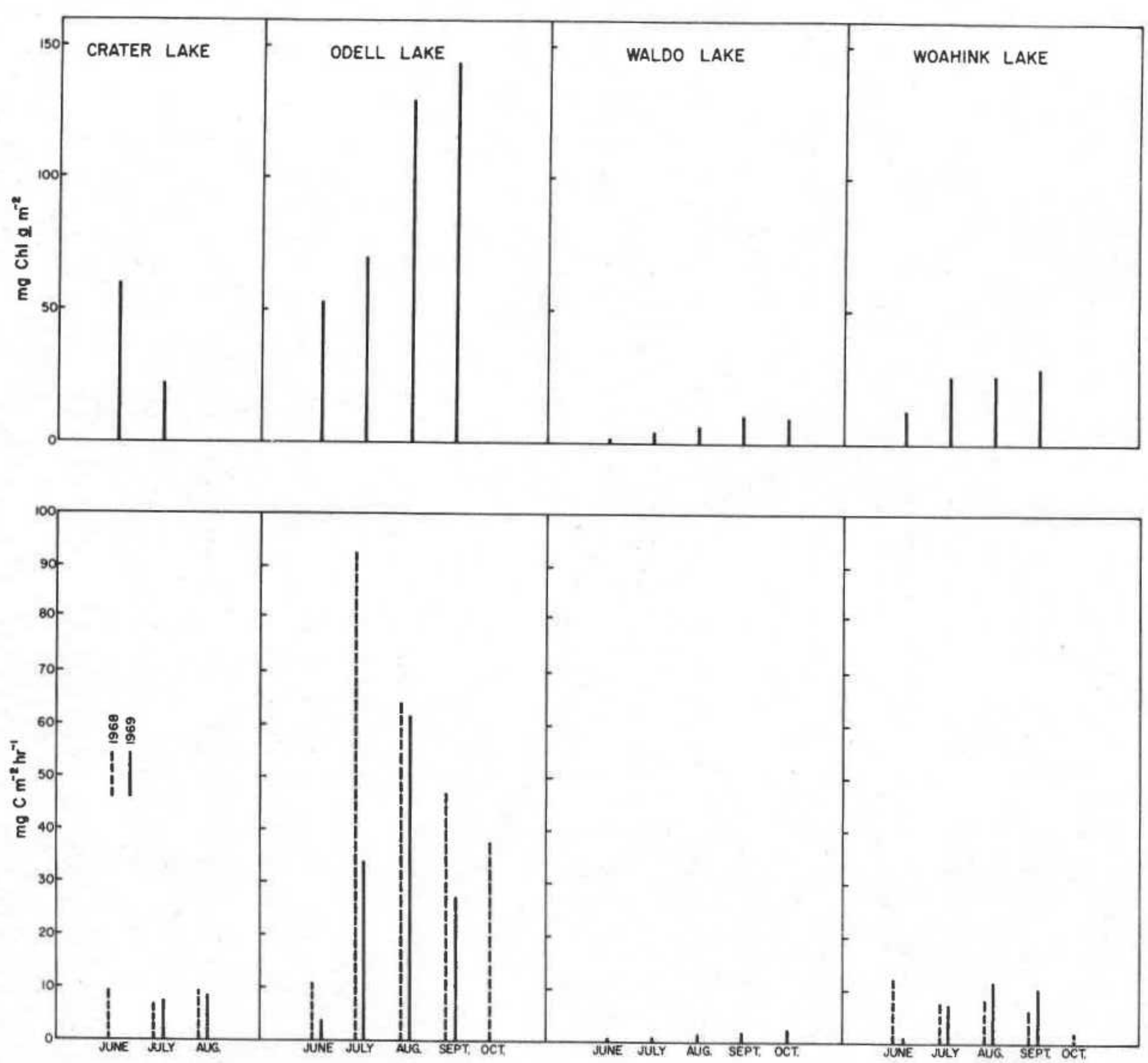


Figure 6. The monthly average rates of production (lower panel) and concentrations of chlorophyll a per meter squared for four oligotrophic lakes in Oregon.

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).

Net productivity for Woahink Lake averaged 7.9 g C/m^2/month (July-August, 1968) and 9.4 g C/m^2/month (July-August, 1969). Total annual productivity (June 27, 1968 to June 13, 1969) was calculated to be 37.2 g C/m^2/year.

In Woahink Lake, the zone of maximum production during the summer and fall months was generally between depths of 2 and 6 m (Figures 7 and 9). In reference to Figure 4, about 20% of the incident light penetrated to 6 m in Woahink Lake. At 16 m, incident radiation had been reduced to zero.

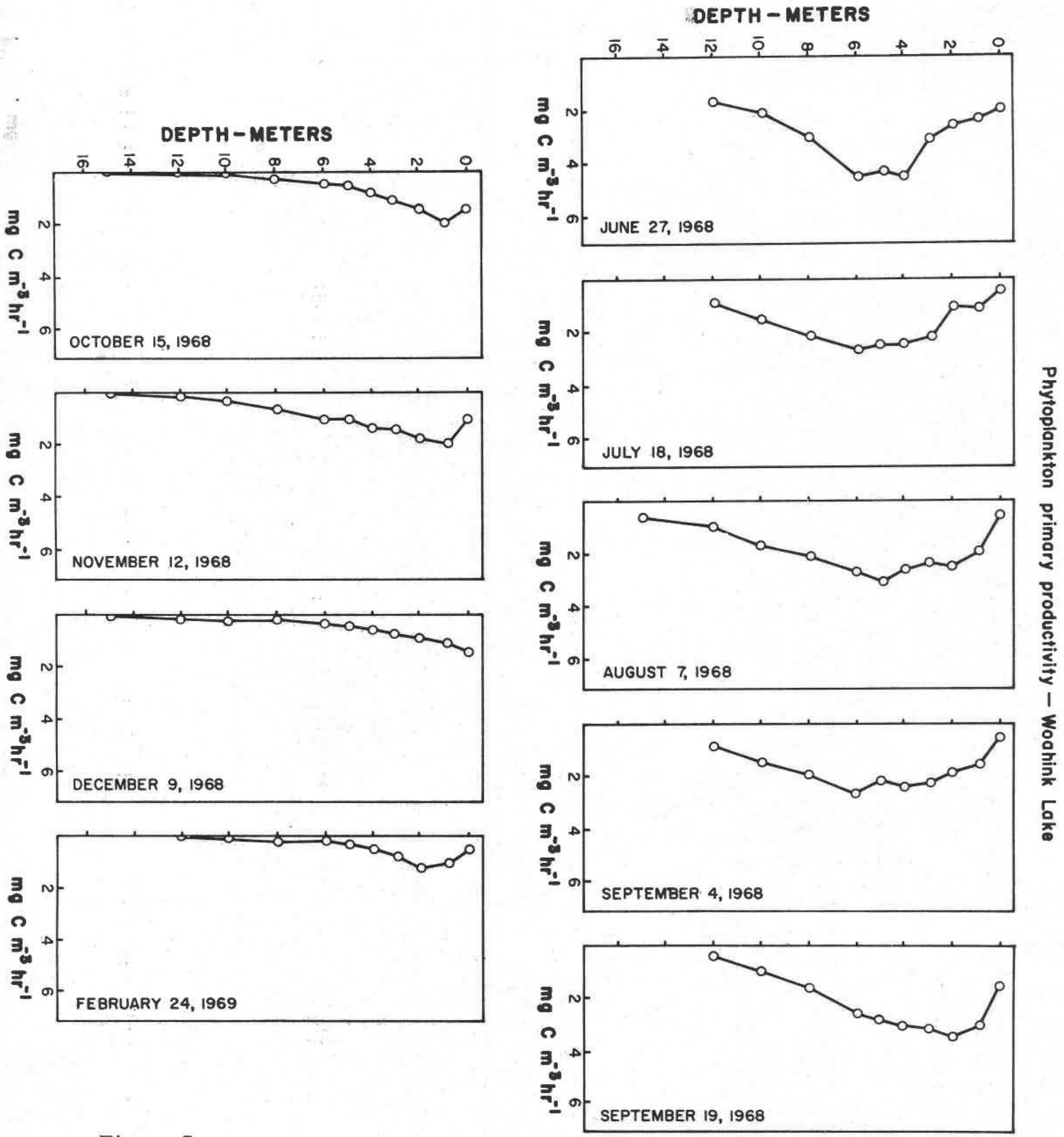
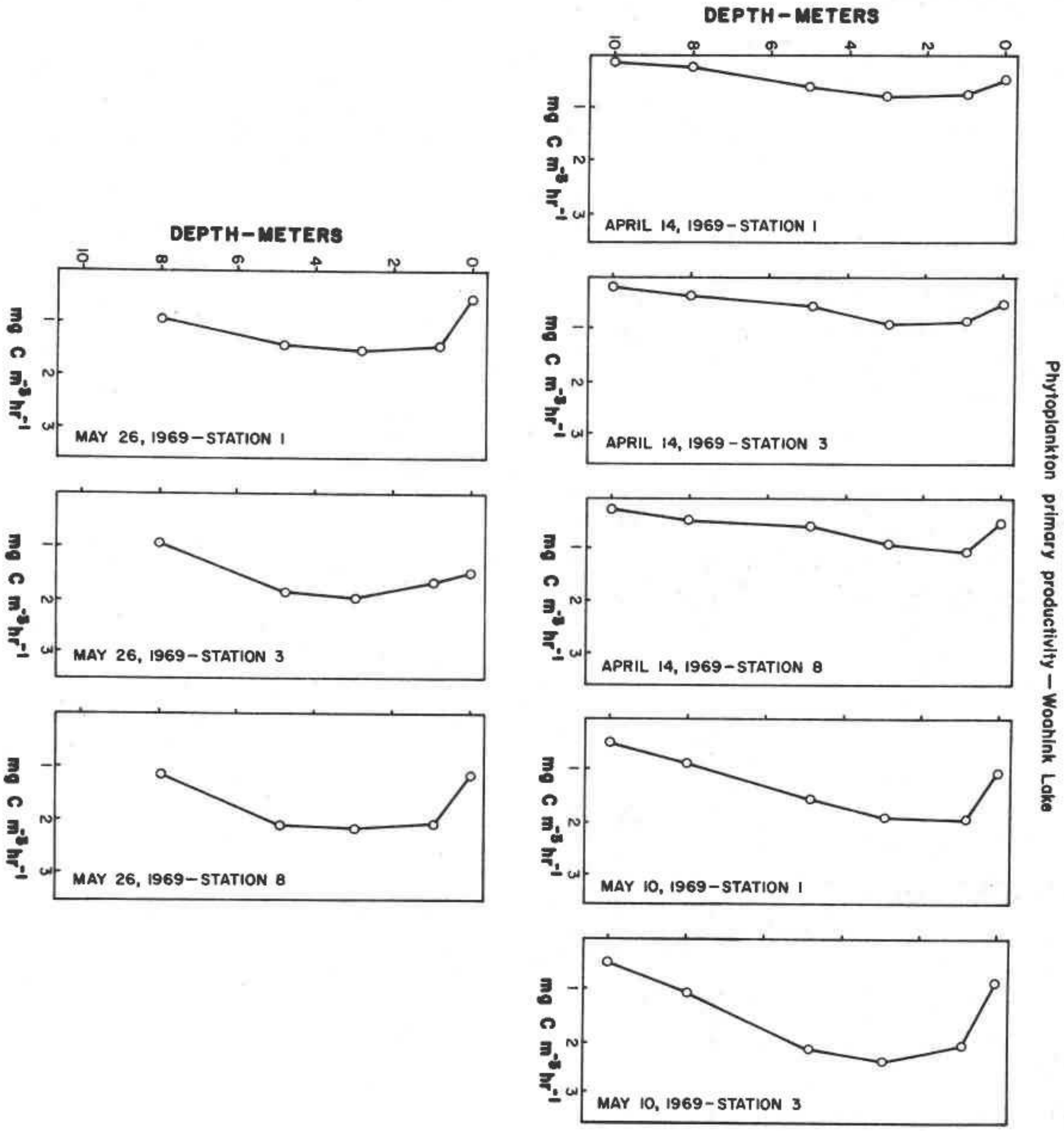

Phytoplankton primary productivity — Woahink Lake
DEPTH - METERS
mg C m^{-3} hr^{-1}
JUNE 27, 1968
JULY 18, 1968
AUGUST 7, 1968
SEPTEMBER 4, 1968
SEPTEMBER 19, 1968
OCTOBER 15, 1968
NOVEMBER 12, 1968
DECEMBER 9, 1968
FEBRUARY 24, 1969

Figure 7.

Figure 8. Vertical profiles of phytoplankton photosynthetic rates for Woahink Lake, Oregon, 1969. Data compared among stations on three separate occasions.



Phytoplankton primary productivity — Woahink Lake

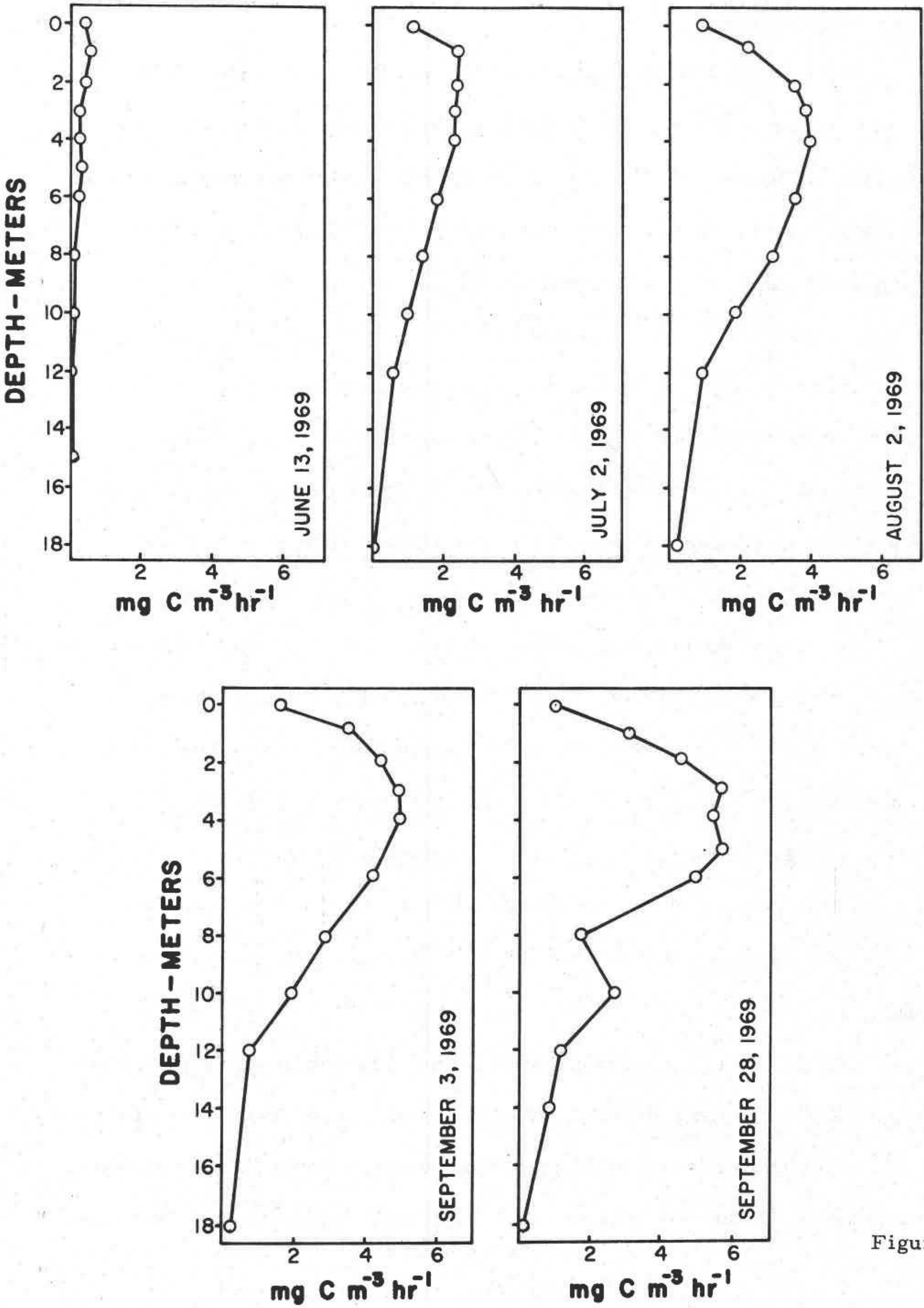


Figure 9.

During the June through September periods in 1968 and 1969, there were relatively slight fluctuations in productivity per unit area (Table 7; Figures 7 and 9). In fact, it was not possible to distinguish a marked seasonal maximum (Figures 7 and 9). Algal blooms never appeared while the lake was being studied.

Coincidental with the fall overturn in October, 1968 (Figure 7) was a steep decline in production. Photosynthetic rates by phytoplankton were minimal during the winter months (Figures 7 and 8). Starting in April, a pulse in production developed (Figure 8). By June, the bloom had ended; the level of production returned to what it had been during the winter (Figure 9; Table 7).

A separate study was initiated in April, 1969, to determine whether brisk wind action (common for the Woahink basin) and an unusually high shoreline development had any effect on phytoplankton production estimates in Woahink Lake. Normally, production was measured from a single index station (Station 3) located at the approximate center of the lake (Figure 1). I was interested in knowing whether the estimate made at that point was a reasonable representation for the entire lake.

In all lakes, the spatial distribution of phytoplankton is influenced considerably by the morphometry of the basin--especially the configuration of the shoreline and local prevailing winds. Welch (1952) discussed, in general, the effects of wind on the horizontal and vertical distribution of plankton. He noted that wind action caused plankton to drift and become concentrated, especially in bays and in smaller indentations along the lake shoreline. Tucker (1948), Verduin (1951) and Pomeroy, Haskin and Ragotzkie (1956) found that during periods of low wind velocity, phytoplankters became concentrated, resulting in patchy distribution. These aggregations were dispersed by high wind velocities creating a more uniform distribution of cells throughout the epilimnion.

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)
Woahink	2 July 69	2.10
	2 Aug 69	3.10
	3 Sept 69	4.30
	28 Sept 69	4.90
		$\overline{x}$ = 3.80

The combined effect of shoreline development and wind action may complicate the sampling design that is being used to estimate production. Several authors (Verdüin, 1951; Rodhe, 1958; Fogg, 1966) have criticized the view that samples obtained from a single station located at mid-lake are, for all practical purposes, representative of the lake as a whole. They contend that production estimates gained from a single station can be misleading--particularly if wind action is a prominent feature of the basin climate. In order to achieve greater accuracy in the estimation of phytoplankton production, Small (1963) suggested that sampling stations be selected with reference to wind effects on a particular lake.

If primary production is being estimated *in situ*, a multi-station system may be difficult to maintain. In a lake with a deep photic zone, a sizeable amount of time may be required to draw water samples from depth, inoculate them with a ^{14}C-carrier and return them for incubation (in Crater Lake, about 1 hr was needed to obtain, prepare, and return water samples to *in situ* positions, located at various intervals down to 200 m). Furthermore, travel-time between stations might be considerable, depending on inter-station distances and the speed of transport. As a result, a period of 1 to 2 hrs may lapse between the actual deployments (for *in situ* incubation) of water samples at the first and second (and additional) stations. Goldman (1960) conducted near-simultaneous primary production *in situ* experiments at three stations in a large Alaskan lake. He reported a significant statistical difference among stations even when the three starting times differed by only 20 minutes.

In order to obtain some idea of the between-station differences, three stations in Woahink Lake (Station 1, 3 and 8; Figure 1) were sampled on April 14 and May 26, 1969. Only two stations (Stations 1 and 3) could be reached on May 10. Wind data for the three dates are shown in Table 9.

Table 9. Wind data for Woahink Lake, Oregon (approximate values)*.

Date (1969)	Velocity (knots)	Direction
12 April	35	SW
13 April	7	SW
14 April	4	SW
8 May	5	SW
9 May	0	--
10 May	12	WNW
24 May	15	SW
25 May	10	SW
26 May	20	SSW

*Courtesy of the U.S. Coast Guard, Siuslaw River Station, Florence, Oregon.

The vertical profiles (Figure 8) were integrated to obtain $mgC/m^2/hr$. Results of each sampling date were handled separately. A statistical analysis of primary production, using a randomized-block design followed by analysis of variance test, showed no significant differences among stations at the $\alpha = 0.025$ level. Surface concentrations of chlorophyll a were analyzed, also. The results indicated no significant differences among stations at the $\alpha = 0.025$ level.

The above suggests that despite the unusual wind action and shoreline development of the Woahink basin, the phytoplankton in the lake are distributed rather uniformly on a horizontal plane. Therefore, samples obtained from a single station were sufficient to estimate the productivity of Woahink 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., 4 m in Woahink 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.

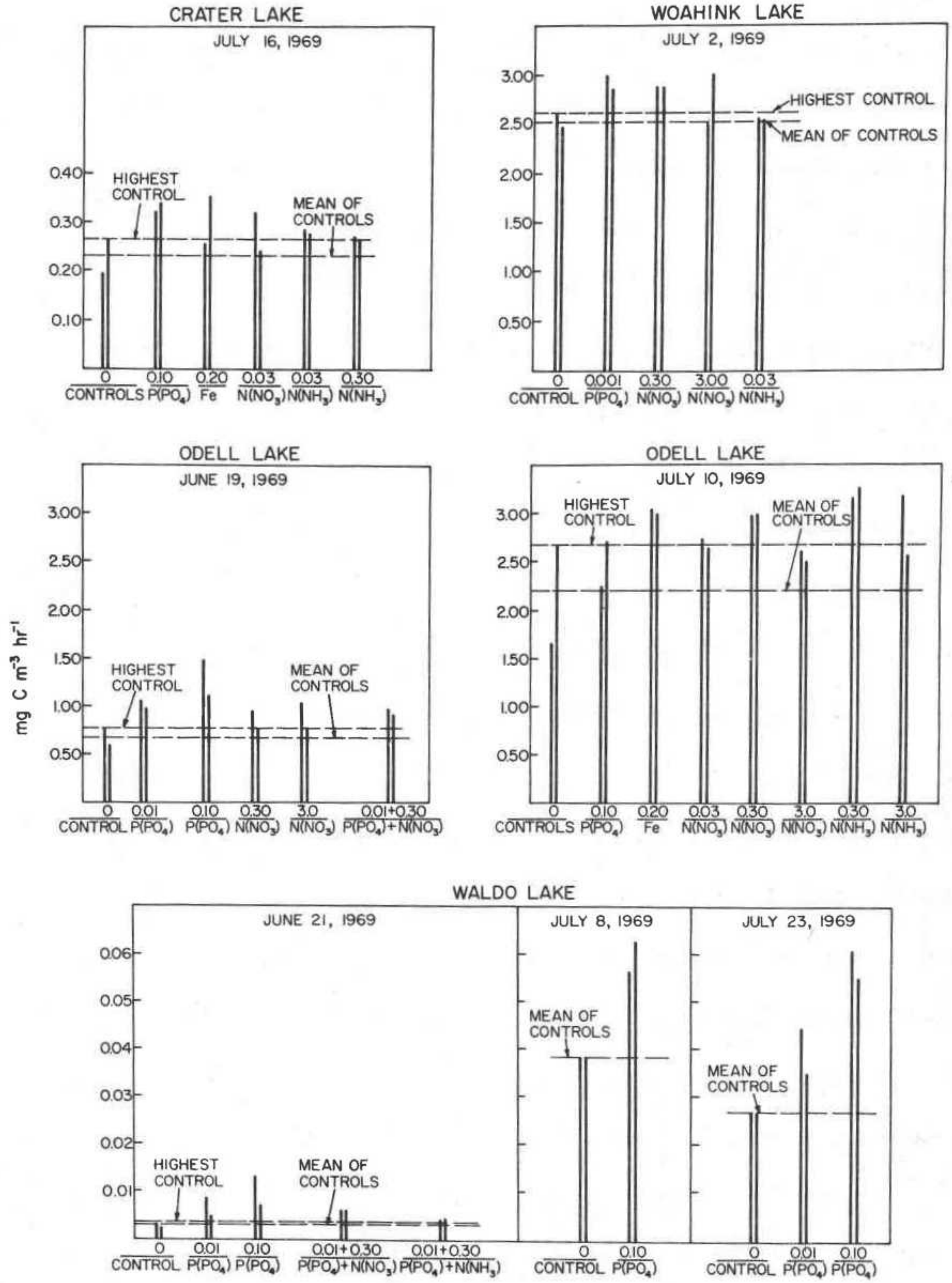
Nutrient bioassay experiments were not conclusive (Figure 10). Generally, the response of phytoplankton to various nutrient solutions (Table 9) was negligible. Mr. W. Miller (FWPCA, Corvallis, Oregon, personal comm.) suggested, in light of their culture bioassays, that carbon may be limiting (Ref. chemical description of Woahink Lake in which low pH, alkalinity and total hardness were noted).

CONCLUSIONS

Climate and morphometry play an important role in determining the rate of production in Woahink Lake. Due to a combined set of conditions, the lake probably undergoes a high rate of flushing and water renewal. Thus, perhaps often during the year, portions of the phytoplankton standing crop are removed from the lake. Presumably, nutrients are lost as well. Furthermore, the "new" water that replenishes the lake volume may diminish productivity for a considerable length of time thereafter (Findenegg, 1965).

Periodic flushing of Woahink Lake is brought about by (1) the small storage capacity of the lake basin as indicated by low seasonal fluctuations in the level of the lake (e.g., variations were less than

Figure 10. Response of lake phytoplankton populations to nutrient enrichment bioassays.



0.5 m), (2) moderately heavy precipitation during the period October through April (approximately 87% of the total annual precipitation of 203 cm occurs then), (3) heavy runoff from the surrounding terrain (the drainage area is 14.2 km^2), and (4) a high volume development of the basin (i.e., 1.50). Robertson (1954) attributed high rates of flushing in a similar lake in British Columbia to (1) small storage capacity, (2) heavy precipitation (about 300 cm per year, 60 to 70% of which occurred in the period September through March), (3) heavy runoff from a small drainage area (9.3 km^2) and (4) a high volume development (i.e., 1.53).

Lakes undergo continuous physical, chemical and biological changes in response to natural or cultural impositions. Unlimited use by man entails increased nutrient enrichment which in turn accelerates lake eutrophication. But in Woahink Lake, eutrophication (particularly that resulting from artificial or man-induced enrichment) is perhaps being repressed naturally by the effects of flushing and water renewal. Certainly, this possibility should and can be explored.

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