Gary L. Larson, U.S. Geological Survey, Forest and Rangeland Ecosystem Science Center, 3200 SW Jefferson Way, Corvallis, Oregon 97331

Overview of the Limnology of Crater Lake

Abstract

Crater Lake occupies the collapsed caldera of volcanic Mount Mazama in Crater Lake National Park, Oregon. It is the deepest lake (589 m) in the United States and the 7th deepest lake in the world. The water column mixes to a depth of about 200 m in winter and spring from wind energy and cooling. The deep lake is mixed in winter and early spring each year when relatively cold water near the surface sinks and exchanges positions with water in the deep basins of the lake. The lake becomes thermally stratified in summer and early fall. The metalimnion extends to a depth of about 100 m; thus most of the water column is a cold hypolimnion. Secchi disk clarity measurements typically are in the upper-20-m range to the low-30-m range in summer and early fall. Concentrations of nutrients are low, although conductivity is relatively high owing to the inflow of hydrothermal fluids. Total chlorophyll is low in concentration, but typically maximal at a depth of 120 m during periods of thermal stratification. Primary production also is low, with the maximum levels occurring between the depth of 40 and 80 m. Phytoplankton taxa are spatially segregated from each other within the water column to a depth of 200 m in summer and early fall. The same generalization applies to the zooplankton taxa. Water level, clarity, concentrations of total chlorophyll, primary production, and abundances of zooplankton and introduced kokanee salmon exhibit long-term fluctuations. Based primarily on a recent 10-year study of the lake, the lake is considered to be pristine, except for the consequences of fish introductions.

Introduction

Crater Lake is located in Crater Lake National Park in the southern Cascade Mountains of Oregon, USA. It is the deepest lake in the United States and the 7th deepest lake in the world (Hutchinson 1957). The lake basin (caldera) was formed by catastrophic collapse of the sides of Mount Mazama following a violent eruption about 6,800 years ago (Bacon and Lanphere 1990). The present caldera has steep walls and is between 8 and 10 km in diameter. The lake occupies 78% of its own drainage basin. Crater Lake is the deepest caldera lake in the world, as well as one of the highest in elevation and largest in surface area (Larson 1989; Table 1). No surface outlet exists, but over 40 permanent and ephemeral inlet streams drain into the lake.

The objective of this paper is to summarize the general limnological characteristics of the pelagic zone of Crater Lake, based on unpublished studies conducted between 1983 and 1992 (Larson et al. 1993) or as otherwise cited. Copies of unpublished reports may be obtained from the author. Measurements occurred primarily in the deepest basin of the lake at a site designated as Station 13 (Fig. 1).

TABLE 1. Morphometric characteristics of Crater Lake.

Morphological Attribute	Characteristic	Reference
Bench mark surface elevation	1882 m	Byrne 1965
Surface area	53.2 km^2	Phillips 1968
Maximum depth	589 m	Byrne 1965
Mean depth	325 m	Byrne 1965
Shoreline length	31 km	Byrne 1965

Lake Characteristics

Lake Level

Lake level has exhibited considerable long-term variation since the late 1890's. From 1910 to 1942 the lake dropped about 4 m in elevation, but returned to the 1910 level by the late 1950's. The lake fluctuated by 1 m above and below the bench mark level of 1882 m from 1958 to 1985. Between 1986 and 1994, the level dropped to about 3.5 m below the long-term bench mark elevation.

Water Temperature

The surface of Crater Lake seldom freezes over, owing to the heat content of the massive lake volume and wind mixing. The only known occurrences of ice and snow cover occurred in 1948 and 1985. In 1986 the lake was nearly covered by ice at various times in January and March.

In winter and spring the water mass in Crater Lake circulates to a depth of between 200 and 250 m by wind action and cooling. The deep lake is mixed in winter and early spring each year when

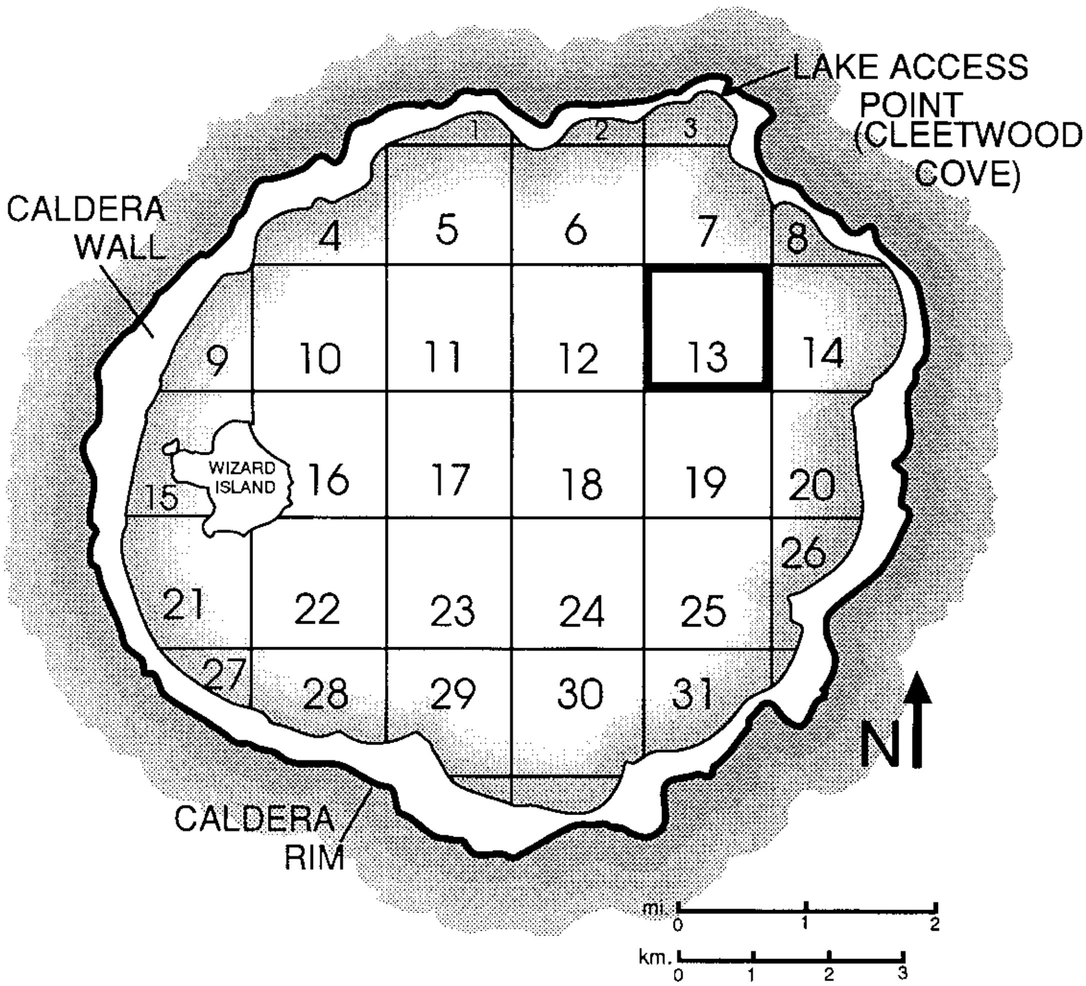

Figure 1. Grid system of Crater Lake stations established by Hoffman (1969). The main monitoring station (13) is 589 m deep.

relatively cold water near the surface sinks and exchanges positions with water in the deep basins of the lake (McManus et al. 1993). In late spring or early summer the temperature of the lake near the surface increases and a thermocline forms between July and September. The depth of the epilimnion is between 5 m and 20 m and is usually deepest in fall because of cooler air temperatures and an increase in mixing generated by storms. Maximum near-surface temperatures ranged from 14.6 to 19.2°C from June or early July to mid-September from 1982 through 1990 (Larson, et al., in press). The metalimnion extends to a depth of about 100 m; thus, most of the water volume is a cold hypolimnion. Annually water temperatures do not vary by more than 1°C below a depth of 100 m. The temperature at the bottom of the water column is about 3.5°C (Larson et al., in press).

Water Chemistry

The average pH of the entire water column of Crater lake is 7.5. Average near-surface pH ranges from about 7.6 to 7.7, whereas the pH decreases with increased lake depth and is about 7.3 at a depth of 550 m. The average total alkalinity and specific conductance are 27 mg/l and 115 µmhos/cm, respectively. Both variables increase slightly with increasing lake depth. The average concentration of dissolved oxygen is relatively uniform in the water column in spring, but decreases to about 90% saturation at 550 m during the period of thermal stratification. Nitrate-nitrogen, ammonia-nitrogen, Kjeldahl-nitrogen, total phosphorus and orthophosphate-phosphorus occur in low concentrations (Table 2). Nitrate-nitrogen is virtually undetectable in the upper 200 m of the water column; however, the concentration increases to maximum with increased depth. Kjeldahl-nitrogen and ammonia-nitrogen decrease in concentration with increased lake depth, whereas orthophosphate-phosphorus increases. Total phosphorus is nearly uniform in concentration throughout the water column (Larson et al., in press).

TABLE 2. Mean concentrations of selected chemical variables for all samples obtained from the indicated depth intervals in Crater Lake. 1982-1990.

Variable	Depth Interval (meters) 0-200	200-550	0-550
Nitrate-N (µg/l)	0.61	10.62	6.98
Ammonia-N (µg/l)	2.55	2.34	2.41
Kjeldahl-N (µg/l)	18.52	11.55	14.08
Orthophosphate-P (µg/l)	12.21	13.88	13.27
Total phosphorus (µg/l)	28.22	29.59	29.09

Secchi Disk Clarity and Depth of 1 Per Cent Incident Light

During the period from 1982 to 1992, water clarity measurements obtained with a Secchi disk generally fluctuated between readings in the upper-20-m range to the low-30-m range from June to September. The deepest reading recorded since 1969 was 40.8 m in August 1994; the shallowest August reading of 22.9 occurred in 1991 (Larson et al., in press). Secchi disk clarity was shallow in late winter and early spring, apparently in relation to input of particles from avalanches and snow-melt. Clarity typically increased in June and early July, and then declined in August when the lake was thermally stratified and then increased in fall; in some years reduced clarity in fall has been associated with storms (Larson et al., in press).

The depth of 1 per cent of the incident sunlight penetrating the surface of the lake, measured by a photometer with a white filter, illustrates the great clarity of the lake. In July the 1 per cent depth ranged between 90.3 and 99.5 m between 1986 and 1989, whereas in August, the 1 per cent depth ranged between 86.1 and 103.4 m (Larson et al., in press).

Phytoplankton

During the period from 1983 to 1990, a total of 157 phytoplankton taxa were identified, including 55 diatoms, 53 chrysophytes, 1 xanthophyte, 21 chlorophytes, 12 dinoflagellates, 6 cryptomonads, 7 cyanobacteria, and 2 unknown taxa. In winter the flora was uniformly distributed to the depth of mixing. *Stephanodiscus hantzschii*, *Ankistrodesmus spiralis*, and a small unidentified chrysophyte were the dominate taxa during this period of the year. During the period of thermal stratification, phytoplankton are spatially segregated within the water column to a depth of 200 m. *Nitzschia gracilis* was the dominant taxa in the upper 40 m of the water column. *Ankistrodesmus spiralis*, *Dinobryon sertularia*, *Tribonema* sp., *Rhodamonas lacustris* and *Gymnodinium inversum* were the dominant taxa from 60 to 100 m. From 120 to 200 m the dominant taxa were the same as during winter (McIntire et al., in press).

Concentrations of total chlorophyll were maximum usually at 120 m during periods of thermal stratification from 1984 to 1990. Peak concentrations of total chlorophyll were always less than 2 µg/l however. Total chlorophyll integrated to a depth of 200 m exhibited cyclic changes between 1979 to 1990. For example, peak concentrations in August occurred in 1980 (120 mg/m^2) and 1986 and 1987 (100 mg/m^2). Primary production was low between 1986 and 1990, using the carbon-14 assimilation method. Maximum primary production occurred between 40 and 80 m during periods of thermal stratification from 1986 to 1990, although relatively high production values occasionally were observed in near-surface samples (McIntire et al., in press). Primary production in August exhibited a similar cyclic pattern as did total chlorophyll. Between 1980 and 1990, peak assimilations in August integrated to a depth of 180 m occurred in 1980 (30 mg C/m^2/hr) and 1987 (58 mg C/m^2/hr).

Zooplankton

During the period from 1985 to 1990, two crustacean taxa and 11 rotifer taxa were collected in Crater Lake (Table 3). In winter, most of the taxa were distributed from the lake surface to the depth of mixing (200-250 m). During periods of thermal stratification the taxa were spatially segregated within the water column. *Polyarthra* was the dominant taxon in the upper 40 m of the lake, but it occurred in low density. Between 40 m and 80 the dominant taxa were *Bosmina, Polyarthra, Kellicottia* and *Asplanchna*. From 80 to 120 m the dominant taxa were *Daphnia, Keratella, Synchaeta, Filinia* and *Polyarthra*. The dominant taxa from 120 to 200 m were *Philodina, Conochilus, Keratella* and *Collotheca* (Larson et al., in press).

Some taxa were not present every year from 1985 to 1990. *Philodina* was present between 1985 and 1988, *Conochilus* was present in 1985, and *Asplanchna* was present in 1990. *Daphnia* was not present in quantitative subsamples in 1985, and was in low density in 1986. The population reached its maximum abundance in 1988, declined to low density by 1990, and was absent in 1993 (Robert Truitt, personal communication).

TABLE 3. Zooplankton species found in samples from Crater Lake, 1985-1990.

Phylum or Order	Taxon
Cladocera	*Daphnia pulicaria (Forbs) (emend. Hrbacek)*
	Bosmina longirostris (sensu latu)
Rotifera	*Keratella cochlearis (Gosse) morph macracantha (Lauterborn)*
	Keratella quadrata var. dispersa (Carlin)
	Kellicottia longispina (Kellicott)
	Polyarthra dolichoptera (Idelson)
	Philodina cf. acuticornis (Murray)
	Filinia terminalis (Plate)
	Synchaeta oblonga (Ehrenberg)
	Synchaeta lakowitziana (Lucks)
	Conochilus unicornis (Rousselet)
	Collotheca pelagica (Rousselet)
	Asplanchna sp.

Fish

Crater Lake was naturally barren of fish. Several salmonid species were introduced into the lake between 1888 and 1941. Kokanee salmon and rainbow trout were the only species of fish collected from the lake between 1986 and 1994. Kokanee salmon were cyclic in abundance. Rainbow trout appeared to be less cyclic in abundance than were kokanee salmon.

Kokanee salmon primarily live in the pelagic zone of the lake from the surface to a depth of about 100 m. They prey on small emerging benthic macroinvertebrate pupae and larvae and terrestrial insects landing on the lake surface. They also prey on *Daphnia*. Rainbow trout live in the nearshore area of the lake. They prey on large bodied terrestrial insects from the lake surface and benthic macroinvertebrates. Rainbow trout also prey on kokanee salmon.

Discussion

Crater Lake is a dynamic and complex system as illustrated by long-term fluctuations of water level, clarity, chlorophyll, primary production, zooplankton and kokanee salmon, and the spatial segregation of the water column by phytoplankton and zooplankton. Long-term changes in lake level results from shifts in the water budget. Changes in the amount of chlorophyll and primary production appear to be related to deep-water mixing of the water column during winter and spring. This upwelling phenomenon moves nutrient-rich waters in the deep lake to the upper 200 to 250 m of the water column (McManus et al. 1993). *Daphnia* abundances appear linked with periods of increased primary productivity; however, predation by kokanee salmon probably impacts their abundance and may be the reason for its reduced abundance in 1990 and disappearance in quantitative samples by 1993.

Chemical and physical properties of Crater Lake that are most consistent with typical oligotrophic characteristics of lakes include high transparency, an orthograde nitrate-N depth profile, and low concentrations of nitrate-N in the epilimnion. Specific conductance in Crater Lake often exceeds those of eutrophic, mesotrophic and oligotrophic lakes in the Cascade Mountains of Oregon (Table 4). The relatively high conductivities of Crater Lake and the other two caldera lakes included in Table 3 (East Lake and Paulina Lake) are associated with inputs from hydrothermal fluids. In comparison to the range of conductivities of caldera lakes worldwide, however, the conductivities of caldera lakes in Oregon are low (Larson 1989). Furthermore, the relatively high concentrations

TABLE 4. Concentrations of selected chemical variables in water samples from near surface waters of eutrophic (E), mesotrophic (M), and oligotrophic (O) lakes in the Cascade Mountains of Oregon. Data for the State of Oregon were obtained from Johnson et al. (1985).

Lake	Class	Elevation (m)	Area (ha)	Depth (m)	Alkalinity (mg/l)	Cond (μmhos/cm)	pH	T-Phos (μg/l)
Diamond	E	1579.8	1300.7	15.8	15	29	9.5	61
Suttle	E	1047.9	102.4	22.9	15	50	8.4	24
East	M	1941.6	422.5	54.9	103	310	7.9	16
Gold	M	1467.0	38.9	13.1	16	33	7.3	47
Marion	M	1258.8	105.6	56.4	18	37	8.8	33
Odell	M	1459.1	1449.6	86.0	13	32	9.3	28
Paulina	M	1929.7	619.6	76.2	340	560	8.3	45
Big	O	1415.5	76.9	23.5	<1	4	7.2	2
Blue	O	1052.5	21.9	95.7	16	50	6.9	29
Breitenbush	O	1676.4	26.3	7.6	<1	6	7.6	—
Charlton	O	1734.9	63.1	29.0	2	6	6.8	4
Crescent	O	1474.9	1840.2	80.8	11	26	7.6	62
Deer	O	1492.3	21.0	7.9	3	12	6.5	17
Devils	O	1658.1	9.3	3.0	10	25	—	72
Doris	O	1618.5	27.9	29.0	<1	4	—	3
Hariette	O	2057.4	16.2	24.1	<1	3	—	9
Lost	O	958.0	93.5	53.3	2	12	6.6	6
Olallie	O	1504.5	76.1	13.1	<1	3	—	8
Summit	O	1692.6	195.1	19.2	<1	6	6.7	9
Waldo	O	1650.2	2848.8	128.0	<1	3	6.3	9
Crater	O	1882.4	5317.4	589.0	40	108	7.2	17
Crater[1]	O	1882.4	5317.4	589.0	26-30	80-121	7.1-7.9	13-43

[1]Data from 0 to 550 m, 1983-1990 (Larson et al. In press).

of total phosphorus in Crater lake is in the range usually associated with mesotrophic lakes (Wetzel 1983). Therefore, some of the chemical properties of Crater lake do not conform to the entire range of criteria usually associated with oligotrophic status.

Limnological studies of Crater Lake conducted by the National Park Service between 1982 and 1992 were in response to an apparent decline in lake clarity. Congress passed Public Law 97-250 in the fall of 1982, which authorized and directed the Secretary of the Interior to conduct a 10-year limnological study of the lake. At the end of the study, researchers concluded that Crater Lake was pristine except for the consequences of introduced fish. Although fish affected the food web of the lake, no other changes caused by human activities specifically could be identified or separated from those caused by natural phenomena.

Results of the limnological study of Crater Lake between 1982 and 1992 revealed many of the components and processes important to lake clarity and to the dynamics of the lake ecosystem as a whole (Table 5). Although the relative importance of these components and processes was well documented in many instances, the level of knowledge of them was generally low to moderate because they could not be addressed in sufficient detail within the scope of the program. This shortfall posed a problem because several human-related activities and conditions were identified which may have negative impacts on the lake (Table 6). Although our level of knowledge of the magnitude of the impacts on the lake was low in most cases, suspected contamination of an intra-caldera spring, commonly referred to as Spring 42, from a sewage septic-drainfield on the caldera rim in the vicinity of Station 28 (Fig. 1) received considerable attention during the limnological study because of its potential impact on lake productivity. Results from studies of particle flux in the lake clearly demonstrated that any nitrate contamination in Spring 42 from the sewage system would not have a significant affect on lake clarity and productivity. Nonetheless, as a precautionary measure, park management disconnected the sewage system in 1991 and removed it from the caldera

TABLE 5. A rating of the importance of selected processes or components of the Crater Lake ecosystem in relation to knowledge of lake clarity and the lake system. A rating of the level of knowledge of the processes and components is included (after Larson et al. 1993).

Component or Process	Relative Importance to Understanding Lake Clarity	Relative Importance to Understanding the Lake System	Level of Knowledge
Lake level	Moderate	Moderate-High	Moderate
Water budget	Moderate	High	Moderate
Depth of survace mixing in winter	High	High	Moderate
Thermal stratification	High	High	Moderate
Depth of surface mixing in fall	High	Moderate	Low
Abiotic particles: mudslides, avalanches, runoff & storm events	High	Low-Moderate	Low
Nutrient budget	Moderate	High	Moderate
Hydrothermal inputs	Low	High	Moderate
Organic detritus			
Water column	Moderate	High	Moderate
Benthic	Low	High	Moderate
Nutrient upwelling from the deep lake	High	High	Moderate
Spring 42 nitrate - N	Low	Low	High
Atmospheric deposition			
Nutrients	Moderate	High	Moderate
Particles	?	Low-Moderate	Low
Particle flux	Moderate	High	Moderate
Boat and automobile Emissions/Petroleum wastes	?	?	Low
Phytoplankton production dynamics	Moderate-High	High	Moderate
Zooplankton production dynamics	Low-Moderate	High	Low-Moderate
Benthic flora (production & nutrient dynamics)	Low	High (?)	Low
Benthic fauna (production dynamics)	Low	Moderate	Low
Fish production dynamics	Low-Moderate	High	Low-Moderate

rim in 1992. Sewage from the rim now is piped by gravity to settling ponds on the flanks of Mount Mazama about 300 m in elevation below the caldera rim.

Crater Lake is a unique lake from an international perspective, and it is highly valued both nationally and locally. Responsibility for management of such a system is a priority for the National Park Service. Furthermore, the long-term data set that now exists for the lake has great scientific value for understanding processes that are common to all aquatic systems. Few pristine lake have received such extensive and intensive studies. The National Park Service recognizes that maintaining the pristine conditions of the lake will require regulation of human activities within the context of existing information and regulations, while simultaneously supporting the collection of additional information. Long-term monitoring of selected features of the lake system coupled with special short-term studies are needed for additional information for management and scientific purposes. In 1994, the National Park Service provided funding to continue long-term limnological studies of the lake.

TABLE 6. Activities or conditions that may impact Crater Lake and a rating of the level of understanding of the potential impacts (after Larson et al. 1993).

Issues of Concern	Processes or Components Impacted	Level of Understanding of the Impact
Atmospheric deposition	Nutrients	Moderate
	Particles	Low
Automobile and boat emissions	Carbon particles	Low
	Chemicals	Low
Contamination of Spring 42	Nitrate-N concentration	High
Road and parking lot runoff	Release of petroleum products	Low
Global climate change	Depth of surface mixing	Low
	Amount of deep lake circulation	Low
	Amount of preciptation	Low
	Primary and secondary production	Low
Introduced species:		
Crayfish	Benthic food web	Low
Rainbow trout	Predation on:	
	Benthic macroinvertebrates	Low
	Terrestrial insects	Low
	Amphibians	Low
	Benthic and pelagic food webs	Moderate
Kokanee salmon	Predation on:	
	Benthic macroinvertebrates	Low
	Terrestrial insects	Low
	Daphnia pulicaria	High
	Pelagic food web	Moderate

The long-term limnological monitoring program at Crater Lake will focus on the collection of meaningful information about the status and trends of the lake. The program will provide a minimum set of standards by which the status of the system can be evaluated as well as baseline data needed to support specific investigations into lake processes that we do not fully understand. Understanding those processes that affect lake clarity will be the highest priority of the monitoring program. An array of variables will be monitored (Table 7) following methods developed during the initial study and described in various chapters of the final report from the study (Larson, et al. 1993). The lake will be sampled at monthly intervals between June and September, when the lake is accessible by foot and when boats can be moored on the lake. Although weather conditions in the park are not predictable from year to year, sampling also will be attempted each year in January and April to match the "off-season" sampling conducted during the initial study. January and April samples provide estimates of the amount of deep-water circulation, concentrations of nutrients, primary productivity, and characteristics of the phytoplankton and zooplankton communities. Sampling from June through September provides information on limnological conditions of the lake during the period of thermal stratification. With few exceptions, samples will be taken at Station 13 to be consistent with the major sampling site used in the initial study.

Acknowledgements

I thank the staffs of Crater Lake National Park and the Pacific Northwest Regional Office for their support of the project. I sincerely appreciated the support and efforts of Jim Larson, Shirley Clark, Ray Herrmann, Robert Benton, David Morris, Jon Jarvis, Mark Buktenica, and Stanford Loeb. Many thanks also are extended to the faculty and staff of Oregon State University for their support and assistance. I also thank Jack Stanford and an anonymous peer reviewer for their constructive comments on the manuscript. Ruth Jacobs assisted with editing; Becca Berkey typed the manuscript.

TABLE 7. Monitoring variables at Crater Lake and at intra-caldera springs of the lake.

Weather	
	Precipitation, wind speed and direction, tempearture, humidity, and solar radiation
Lake temperature and conductivity	
	Conductivity, temperature, and depth probe (CTD) from surface to a depth of 550 m.
Optical properties of the lake	
	20-cm Secchi disk
	Photometer (to 150 m)
	Transmissometer (to 550 m)
Abiotic properties of the lake	
Chemical properties of the lake	
	Total alkalinity, pH, specific conductance, and concentrations of dissolved oxygen, total phosphorus, orthophosphate-phosphorus, nitrate-nitrogen, total Kjeldahl-nitrogen, ammonia-nitrogen, silica, and trace elements at selected depths from the following depth sequence: 0, 5, 10, 20, 60, 100, 200, 300, 400, 500, and 550 m.
Biological properties of the lake	
	Chlorophyll *a* concentration
	In vitro chlorophyll concentration according to the following depth sequence: 5-m intervals from 0 to 10 m, 20-m intervals from 20 to 200 m, and 25-m intervals from 200 to 300 m, including contribution from picoplankton collected through differential filtering.
	C-14 primary production at the chlorophyll sampling depths to 180 m, including contribution from picoplankton collected through differential filtering
	Phytoplankton
	Species, density, and biovolumes at all chlorophyll sampling depths to a maximum depth of 200 m
	Zooplankton
	Species, density, and biomass in samples obtained by a vertical tow of a .5 m diameter, number 25 closing net
	Fish
	Species, abundance, biomass, spatial distribution, age, sex, growth, and food habits. Samples collected with gill nets, hook and line, and down rigger. Pelagic distributions estimated using an echo-sounder.
Bulk atmospheric deposition to the lake	
Springs 20, 38, 39, 42, 48	
	Temperature, pH, conductivity, alkalinity, nutrients, trace elements, and bacteria (total coliform, fecal coliform, and fecal streptococcus).

Literature Cited

Bacon, C. R. and M. A. Lanphere. 1990. The geologic setting of Crater Lake, Oregon. Pages 19-27 in E. T. Drake, G. L. Larson, J. Dymond, and R. Collier, eds., Crater Lake: An ecosystem study. Pacific Division, American Association for the Advancement of Science, San Francisco, California.

Byrne, J. V. 1965. Morphology of Crater Lake. Limnology and Oceanography 10: 462-465.

Hoffman, F. O. 1969. The horizontal distribution and vertical migration of the limnetic zooplankton in Crater Lake, Oregon. M.S. Thesis, Oregon State University, Corvallis. 60 pp.

Hutchinson, G. E. 1957. A treatise on limnology. Vol. 1. Geography, physics, and chemistry. John Wiley, New York. 1015 pp.

Johnson, D. M., R. R. Peterson, D. R. Lycan, J. W. Swift, and M. E. Neuhaus. 1985. Atlas of Oregon lakes. Oregon State University Press, Corvallis, Oregon. 317 pp.

Larson, G. L. 1989. Geographical distribution, morphology, and water quality of caldera lakes: A review. Hydrobiologia 171: 23-32.

Larson, G. L., C. D. McIntire, M. Hurley, and M. W. Buktenica. In press. Temperature, water chemistry, and optical properties of Crater Lake. Lake and Reservoir Management.

Larson, G. L., C. D. McIntire, and R. W. Jacobs [eds.]. 1993. Crater Lake limnological studies—final report. Technical report NPS/PNROSU/NRTR- 93/03. 722p.

Larson, G. L., C. D. McIntire, R. E. Truitt, M. W. Buktenica, and E. Karnaugh-Thomas. In press. Zooplankton assemblages of Crater Lake, Oregon, USA. Lake and Reservoir Management.

McIntire, C. D., G. L. Larson, R. E. Truitt, M. W. Buktenica, and M. K. Debacon. In press. Taxonomic structure and productivity of phytoplankton assemblages in Crater Lake, Oregon. Lake and Reservoir Management.

McManus, J., R. W. Collier, and J. Dymond. 1993. Mixing processes in Crater Lake, Oregon. J. Geophys. Res. 98(10):18, 295-18, 307.

Phillips, K. N. and A. S. Van Denburg. 1968. Hydrology of Crater, East and Davis Lakes, Oregon. U. S. Geological Survey Water Supply Paper 1859-E.

Wetzel, R. 1983. Limnology. Second Edition, W. B. Saunders College Publishing, Philadelphia, Penn. 767 pp.