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Title: THE HORIZONTAL DISTRIBUTION AND VERTICAL MIGRATIONS OF THE LIMNETIC ZOOPLANKTON IN CRATER LAKE, OREGON

Abstract approved: John R. Donaldson

Daring the summers of 1967 and 1968 the horizontal distribution and diel vertical migrations of zooplankton were studied within the unique environment of Crater Lake. Sampling of the horizontal distribution was done by towing plankton nets vertically in different locations. The vertical distribution was sampled by towing at different depths with a standard tow net and Miller samplers. During both summers, the greatest numbers of zooplankton were sampled in late August. Bosmina longispina was the most numerous zooplankter, while Daphnia pulex, insignificant in 1967, increased in abundance during 1968. The horizontal distribution of B. longispina was clumped, being consistently more abundant in some locations than others. D. pulex had a random, or near-uniform, distribution. Vertical migrations were not consistent and seem to occur only during certain times of the year. The depth of the maximum concentration of

B. longispina was found to vary between distances of 12.5 and 25 m, and was located at depths of 75 to 50 m daring the day and between 50 to 37.5 m at night. A few B. longispina, however, did migrate to the surface at night. On August 28 and 29, 1968, the entire adult population of D. pulex migrated from 62.5 m during the day to the surface at night. This migration appears to have reproductive advantages. Prior to this time, only a nocturnal scattering of a small portion of the total population of D. pulex occurred. Various ideas are given as to why these different migrations occurred, but based on the information that is presently available, any direct relationships between the variations of vertical migrations and environmental factors are difficult to make.

The Horizontal Distribution and Vertical Migrations of the Limnetic Zooplankton in Crater Lake, Oregon

by

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The Horizontal Distribution and Vertical Migrations of the Limnetic Zooplankton in Crater Lake, Oregon

INTRODUCTION

There is extensive literature on the horizontal distribution and vertical migrations of zooplankton in fresh water lakes. An adequate review is given by Hutchinson (1967). Studies in a wide variety of lakes indicate that water currents are the main environmental factor involved with the horizontal distribution of zooplankton, but vertical migrations may also mediate the horizontal distribution by utilizing different water currents at different depths.

In general, vertical migrations are best observed in lakes that are deep, transparent and unproductive. Worthington (1931) in the Lake of Lucerne found vertical migrations with amplitudes in excess of 50 meters. Past observations and experiments reviewed by Hutchinson suggest light to be the initiating, controlling, and orienting factor affecting diel migrations, but chemical and thermal gradients may also determine the position of zooplankton.

Although the exact causes of vertical migration are not fully understood, predator avoidance (Manteufel, 1959), navigation (Mackintosh, 1937), increased gene flow (Carson, 1957), and a decreased "social stress" (Wynne-Edwards, 1962) have all been proposed as possible adaptive advantages. These are discussed by McLaren (1963) "who offers the most recent and complete treatment of the adaptive significance of vertical migrations. McLaren, however, stresses that reproductive and growth advantages are gained through vertical migrations. He suggests that all necessary feeding is done at the surface while a greater size and fecundity are attained in the lower temperature of deeper waters.

Because of its formation, location, and extreme depth, Crater Lake has unusual optical and thermal properties, and offers an unique environment for zooplankton investigations. It was the intent of this study to record the horizontal distribution of zooplankton by determining variations in density with time and location in the lake. Observations of the diel vertical distribution of zooplankton were made in an attempt to record the timing and extent of vertical migrations under the unusual conditions of light penetration in Crater Lake.

With the exception of some preliminary studies, summarized by Nelson (1961), little is known about the horizontal and vertical distribution of limnetic zooplankton in Crater Lake. Brode (1938) reported Daphnia pulex maxima at 38 and 53 m, and Bosmina longispina maxima at 100 and 150 m. It was his opinion that D. pulex might undergo daily or seasonal vertical migrations. Kemmerer et al. (1923) observed D. pulex maxima at 60 to 80 m in August and at 50 to 60 m in September. He also found B. longispina at 100 to 150 m. Hasler (1938) reported only on D. pulex whose maxima he found between 50 to 100 m during the summer of 1937. During the summer of 1940, Hasler and Farner (1942) found no IX pulex in tow-net samples from 100 m to the surface,

The Environment

Crater Lake is located within the collapse caldera of Mt, Mazama on the crest of the Cascade Mountains in southern Oregon. The near circular lake is the deepest in the United States and is fed entirely by natural precipitation. Its extreme depth, high surface elevation, and isolation with no perraanent inflowing streams account for water that is quite low- in minerals and unusually transparent (Table 1).

Throughout most of the year, the lake is isothermal, stratifying only during the warm summer months. This generally occurs from late June through late September, During thermal stratification the epilimnion is very shallow, the metalirnnion existing between 10 to 20 *m*. Because of strong wind action, which gives rise to a high summer heat increment, Crater Lake seldom completely freezes over. The only major freeze was during February through April of 1949.

Table 1, Selected morphometric, physical and chemical characteristics of Crater Lake, Oregon.

Area	55 km^2	Byrne (1965)
Maximum depth	589 m	Byrne (1965)
Shoreline developraent	1. 33	Byrne (1965)
Surface elevation	1, 88 2 m above mean sea level	Byrne (1965)
Dissolved solids	80/mg/l	Van Winkle and Finkbinder (1913)
Extinction coefficient	0* 033 in the blue (Schott BG 12)	Utterback et al. (1912)
	0. 060 in the green (Wratten 6l)	
Secchi disk dept.	40 m	Hasler (1938)
Summer heat increment	30, 010 cal/cm^2	Kibby etal. (1968)

METHODS

All field data were collected during the summers of 1967 and 1968. Sampling before mid-June or after early September was virtually impossible because of the extreme weather conditions during the long winter season that impair access to the lake. Most of the data obtained in 1967 were the results of exploratory efforts. For convenience in sampling, the lake was divided into one mile square sections. These were numbered consecutively and referred to as stations (Figure 1).

Horizontal Distribution

During the investigations of the horizontal distribution of zooplankton, six stations in 1967 and nine in 1968 were arbitrarily selected to represent a variety of conditions throughout the lake and give an even distribution to the sampling effort. Stations 5, 10, 13, 18, 22, and 25 were sampled in 1967. Stations 3, 5, 10, 13, 18, 21, 23, 25, and 30 were sampled in 1968. During each summer the sampling was repeated five times at intervals of two to three weeks.

Samples were obtained with a standard plankton tow net l/2-m in diameter, with a No. 20 nylon mesh (0. 076 mm aperture). The net was towed vertically from 100 m to the surface at each station sampled. Two samples at each station were taken on

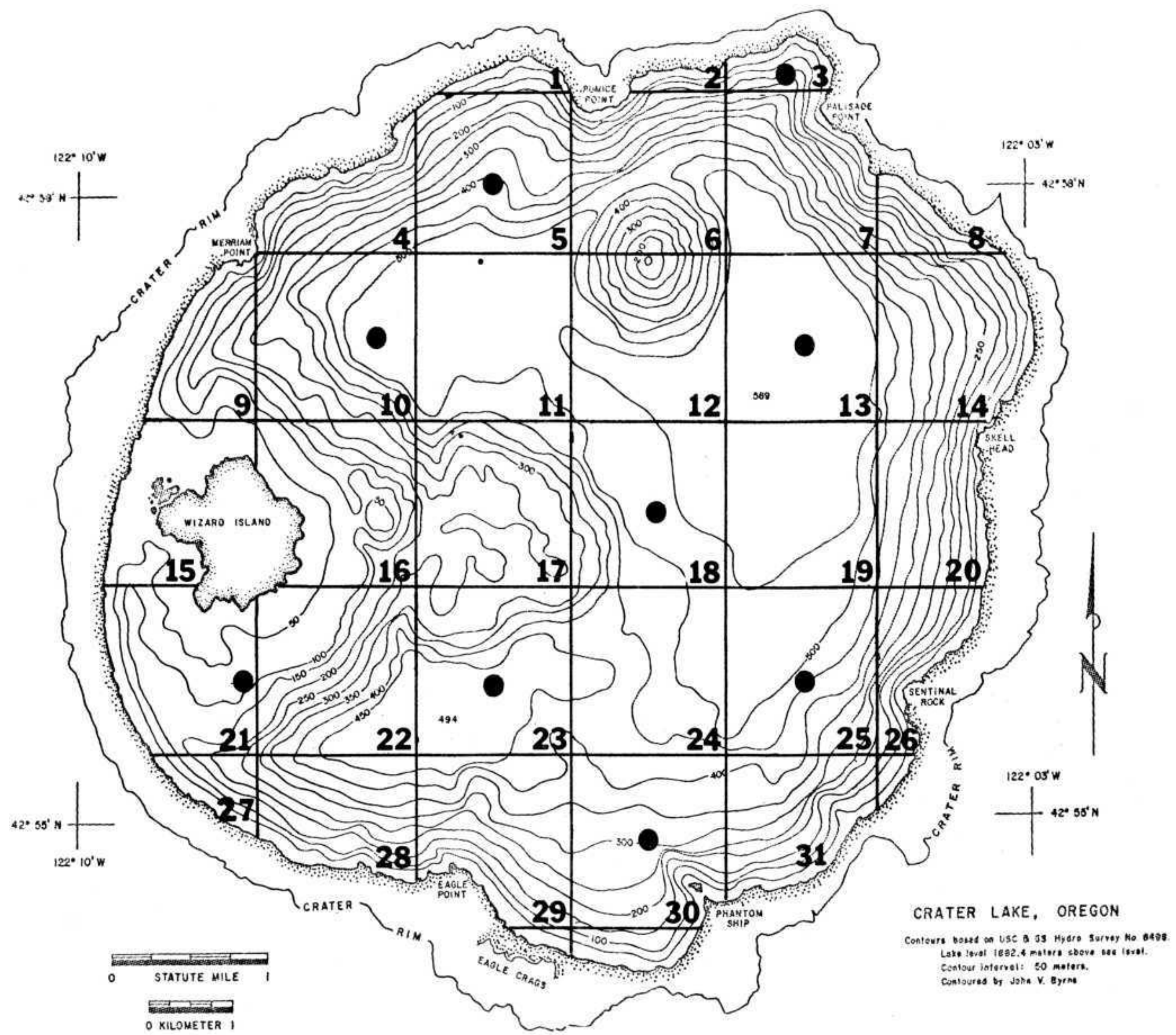

Figure 1. Sampling grid of Crater Lake showing the zooplankton sampling stations marked with a black dot.

August 26, 1967 and August 27 and 28, 1968, to obtain some estimate of sampling error. Only one sample per station was collected on all other dates.

Vertical Distribution

When sampling the vertical distribution it was necessary to tow the net horizontally in order to catch sufficient quantities of zooplankton. At first, vertical tows were made with a l/2-m diameter closing net (No. 20 mesh nylon). But, too few organisms were caught to give meaningful results, and the use of the closing net was discontinued. Exploratory horizontal tows were taken on July 24, 1967. A standard l/2-m diameter tow net with a No. 6 nylon mesh (0. 239 mrn aperture) equipped with a T. S. flow-meter (Tsurumi-Seiki Kosakusho Co. , Ltd.) was used to sample different depths at several locations in the lake (Figure 2a).

The sampling process involved lowering the net vertically to the desired depth. Then, more cable was slowly released to maintain the net at depth as the forward motion of the boat brought the angle of the towing cable to 60 degrees. The cable length at 60 degrees is twice the vertical depth.

The first meaningful series of horizontal tows was made on July 28, 1967. All sampling was restricted to station 13 (Figure 1). Two series of seven tows were made at a range of depths from

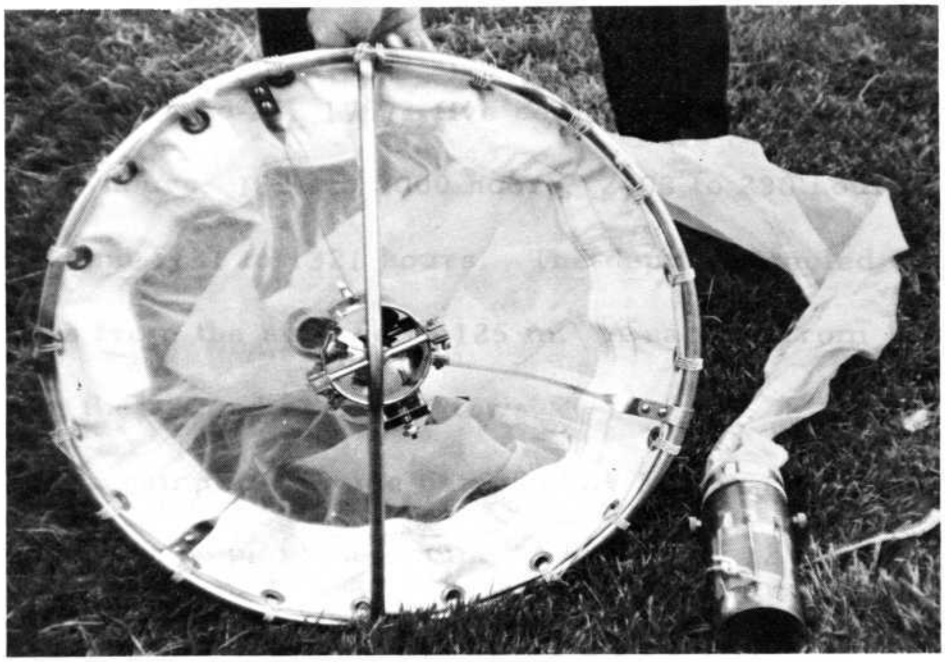

Figure 2a. A standard 1/2-m diameter tow net, with a No. 6 nylon mesh (0. 239 mm aperature), equippmed with a T. S. Flow-meter.

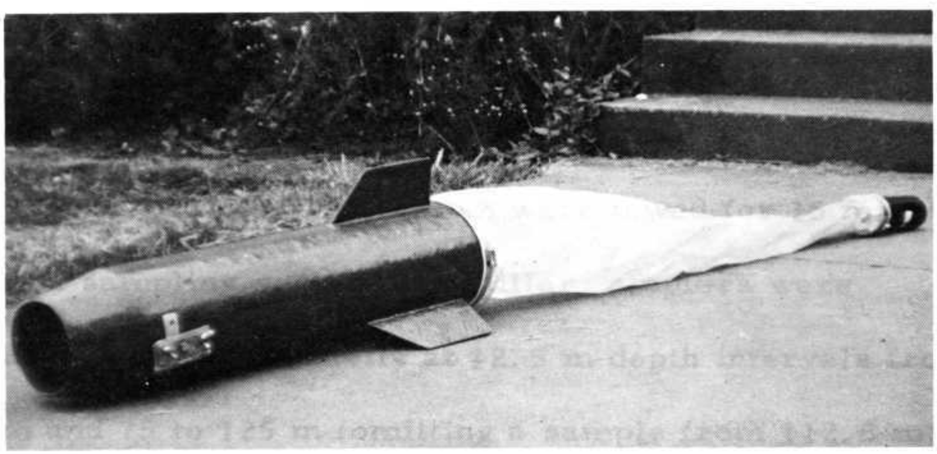

Figure 2b. A Miller Sampler with a No. 12 mesh net (0. 199 mm aperature).

200 to 25 m at 1020 to 1255 hours, and at 2200 to 2435 hours.

On August 24 and 25, 1967, five series of six tows were taken at 1341 to 1555 hours, 1824 to 2000 hours, 2408 to 230 hours, 0655 to 085.5 hours.., and 1131 to 1321 hours. The depths sampled were in 25 m intervals from the surface to 125 m. A sample from 125 m was lost from the second series of tows.

In 1968, a sampling device designed by Miller (1961), a modified small Hardy plankton sampler with a No, 12 mesh net (0. 199 mm aperture), was used in place of the standard tow net (Figure 2b), Its small size, light weight, and increased efficiency made it very effective for sampling the depth strata simultaneously at high towing speeds.

Unlike the standard tow nets, the Miller samplers did not have flow meters. All horizontal tows taken with the Miller sampler were towed exactly 10 minutes in order to standardize the volume of water sampled. The only exception was the first series of tows on July 24, 1968, which were towed for 15 minutes.

During a sampling series four Miller amplers were simultaneously towed horizontally at 12. 5 m depth intervals from 25 to 62. 5 m and 75 to 125 m (omitting a sample from 112. 5 m). Two samplers were simultaneously towed at 1 and 12. 5 m. A cable angle of 70 degrees was maintained after a sufficient cable length was attained to reach the desired depth. The length of cable needed to reach the desired depth was calculated from the following relationship;

$$\text{cable length} = \frac{\text{vertical depth}}{\cos 70^\circ}$$

Six series of horizontal tows were made during July 24 and 25, 1968, at 1340 to 1415 hours, 1700 to 1728 hours, and 2013 to 2100 hours, 2408 to 2457 hours, 0536 to 0639 hours, and 0928 to 1013 hours. No samples were taken from 1 and 12.5 m during the first two series because previous results showed that few if any organisms were to be found at those depths during periods of high illumination. One sample each was lost on the fifth series at 125 m and on the sixth from 12.5 m.

On August 28 and 29, 1968, six additional series of horizontal tows were made at 1200 to 1245 hours, 1617 to 1659 hours, 2115 to 2158 hours, 0205 to 0245 hours, 0739 to 0817 hours, and 1118 to 1159 hours. No samples were lost during this series.

Contamination

Since none of the sampling equipraent eraployed in 1967 or 1968 had a closing apparatus, attempts were made to estimate the extent of contamination of the samples by zooplankton encountered while towing back through depths above 125 m. Immediately after sampling the vertical distribution on August 25, 1967, two vertical tows using the No. 6 mesh standard tow net were made from 125 m to the surface to estimate the contamination from depths above 125 m.

After sampling the vertical distribution on August 29, 1968, a Miller sampler was lowered to 125 m to duplicate the upward path of samples taken at this depth, the cable length was increased and cable angle brought to 70 degrees before the Miller sampler was hauled to the surface.

Sample Analysis

All samples collected from Crater Lake were immediately preserved in 3 percent formalin solution. In the laboratory an aliquot was taken from a thoroughly mixed sample and the organisms counted under a dissecting scope. A graduated bulb pipette was used in extracting the aliquot from the sample.

The relationship between aliquot volume to be counted and sainple volume was determined by weight. By dividing the weight of the aliquot into the weight of the sample and multiplying the quotient times the number of organisms counted, an estimate of the number of organisms in the entire sample could be obtained. This relationship is represented as follows:

$$\frac{\text{weight of sample}}{\text{weight of aliquot}} = \frac{\text{organisms/ sample}}{\text{organisms/aliquot}}$$

The organisms were enumerated by species and two age classes (adults and juveniles) to observe any differences in their horizontal and vertical distributions. Identification of juveniles was deter rained by size. All forms having no eggs and being no larger than one fourth the size of the adults were classified as juveniles.

Two aliquots per sample were counted for the vertical tows in 1967 and the horizontal tows in 1968. Three aliquots per sample were counted for the horizontal tows in August 1967, and the vertical tows in 1968.

Since the T. S. flow-meter is capable of measuring the volume of water sampled, samples taken with nets equipped with a flow meter were computed in organisms per cubic meter of water sampled. Horizontal calibration of the flow meter was done in the Men's Pool at Oregon State University. Calibration of the vertically towed flow meter was done at Crater Lake in 1968. Vertical tows at 100 m were made with both standard and closing nets (No. 20 mesh) with and without a flow meter. Averages of flow meter revolutions per 100 m vertical tow were used for tows made without a flow meter. The standard tow net with a No. 6 mesh was always equipped with a flow meter.

All calculations were programmed for computerization. Calculations were made of sample means and the number of organisms/cubic meter of water sampled (these data are included in the Appendix). The horizontal distribution data were analyzed in a multiple analysis of variance by comparing samples taken in the same stations during both 1967 and 1968. Station 21, sampled in 1968, was compared with station 22, sampled in 1967, because of their relatively similar positions on the lake (Figure 1).

Since sampling error from within station variance might bias the results of the previous analysis, the effect of sampling error was determined by analyzing common stations sampled during August 26, 1967, and August 28, 1968, when two samples per station were taken.

RESULTS

Horizontal Distribution

During each year, the zooplankton density in Crater Lake gradually increased as the summer progressed. The greatest numbers were sampled in late August, but the zooplankton population probably did not reach a maximum density until some time after the last sample in each summer was taken (Figures 3 and 4).

Bosmina longispina was numerically the most abundant organism sampled. In 1967 it was the dominant zooplankter as the larger cladoceran *Daphnia pulex* was hardly present in sufficient numbers to merit graphic representation. In 1968 the density of *D. pulex* had increased greatly over the density observed during 1967, and in a few stations actually outnumbered *B. longispina*. Because of its larger size, the abundance of *D. pulex* during 1968 may have been sufficient to dominate the zooplankton biomass despite a greater overall number of *B. longispina*.

B. longispina varied consistently between the stations sampled during both years, indicating a static clumped horizontal distribution. The stations that were comparatively high and low in *B. longispina* density throughout the summer of 1967 showed similar results in 1968. Stations 10, 13, and 25 had high densities

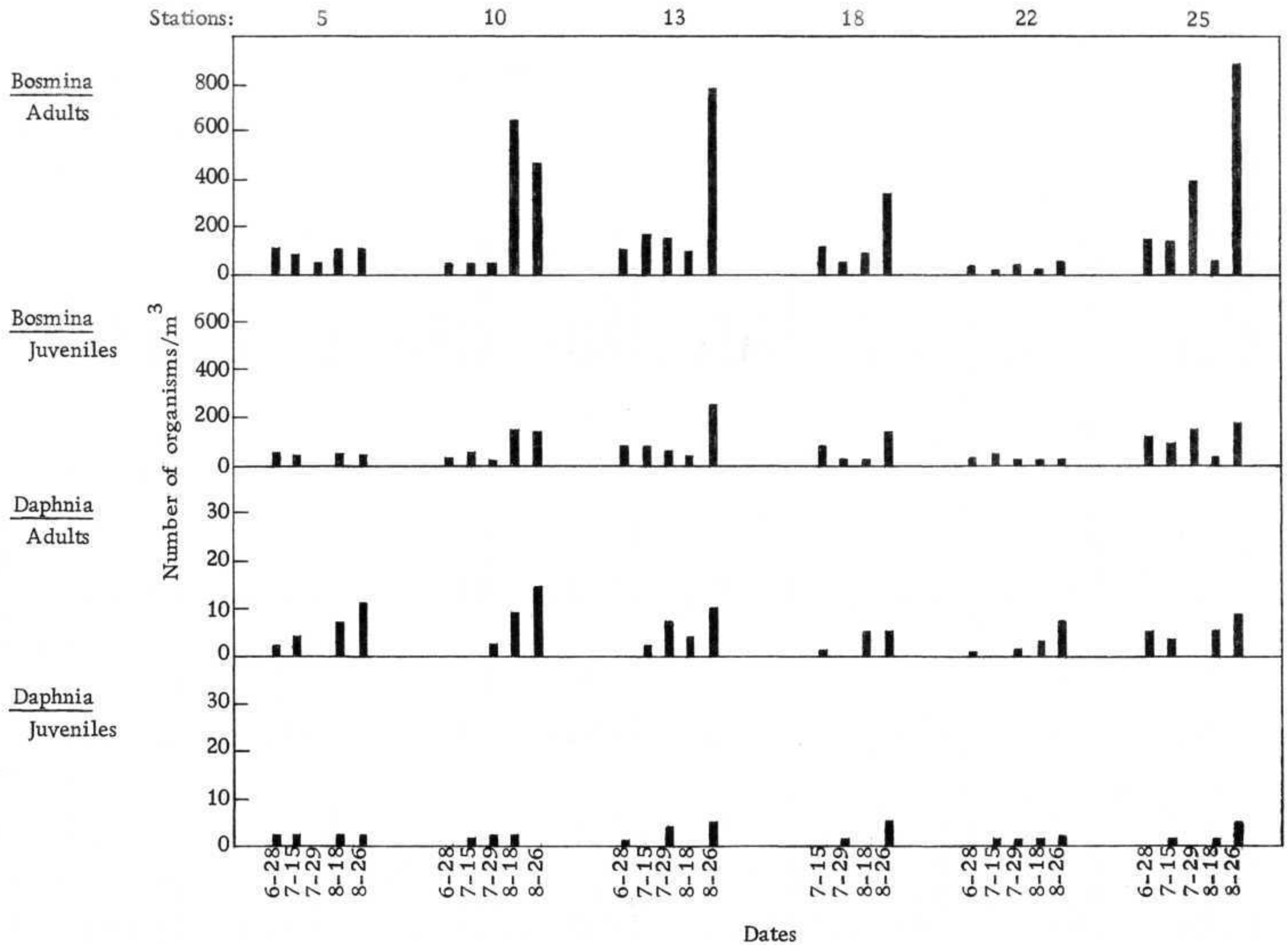

Figure 3, Changes in density of cladocerans in Crater Lake, Oregon at six locations and five dates during the summer of 1967.

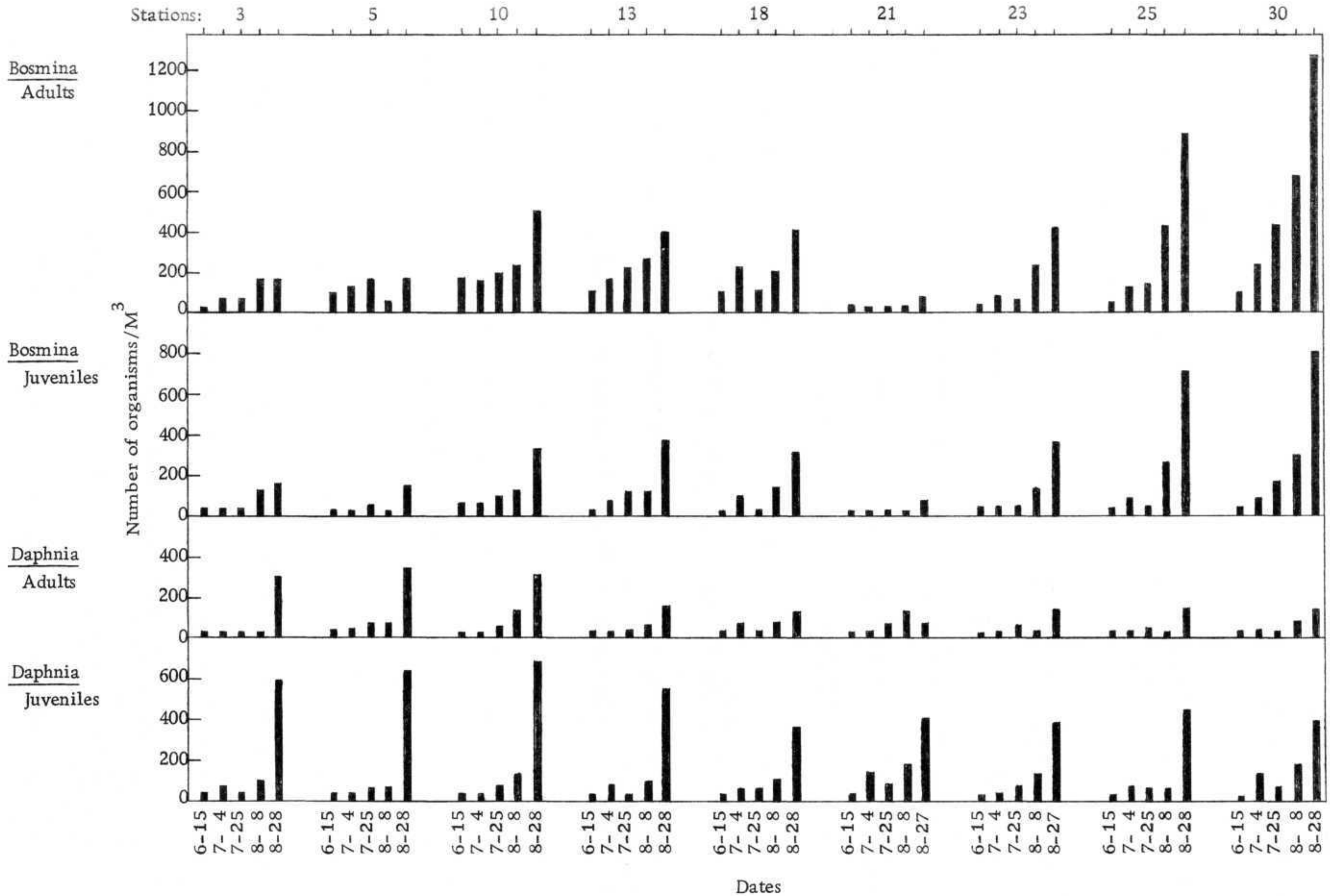

Figure 4. Gianges in density of cladocerans in Crater Lake, Oregon at nine locations and five dates during the summer of 1968.

throughout both summers, while stations 5 and 22 (classified as 21 in 1968) were low. Even when other stations had great increases of B. longispina during late August, station 22 never exceeded 100 organisms/m^3.

The highest densities of B. longispina were recorded throughout the summer of 1968 at station 30. On August 28, 1968, station 30 had in excess of 1200 organisms/m^3. A greater number of B. longispina juveniles occurred in 1968 than 1967, although the abundance and seasonal changes in the adult population were not appreciably different.

Unlike the horizontal distribution of B. longispina, the numerical densities of neither age class of D. pulex illustrated any significant differences between stations sampled. In 1968 there were more juveniles than adults. A ratio of three D. pulex juveniles to one adult was observed on August 27 and 28, 1968, indicating an increase in population. When the population finally reached a maximum size is unknown.

An analysis of variance of the horizontal distribution data (Table 2) listed significant differences between stations and dates for B. longispina adults, with differences in years being significant only for juveniles. Differences between dates and years were listed for both adults and juveniles of D. pulex. There were no significant differences between stations for D. pulex. An analysis of the two

Table 2. Analysis of variance by station, date, and year, of all age classes of cladocerons in stations 5, 10, 13, 18, 22 and 25, sampled with 100 m vertical tows during the summers of 1967 and 1968 in Crater Lake, Oregon.

		Bosmina adults			Bosmina juvenile			Dalphnia adults			Dai)hnia juveililes		
	DF	SS	MS	F	SS	MS	F	SS	MS	F	SS	MS	F
Station	5	591963	118392	7.87**	123501	24700	6.61**	6149	1229	1.07	7448	1489	1.42
Date	4	868707	217176	14.44**	234545	58636	15.69**	61800	15450	13.48**	419644	104911	29.88**
Year	1	23880	23880	1.47	43686	43686	11.69**	64681	64681	56.44**	356202	356202	101.48**
Stat x Date	20	689082	34454	2.29*	105027	5251	1.40	25043	1252	1.09	69389	3469	0.99
Stat x Year	5	25270	5054	0.34	13064	2613	0.70	5654	1130	0.99	7384	1476	0.42
Date x Year	4	5028	1257	0.08	76649	19162	5.12**	50508	12627	11.02**	406823	101705	28.91**
Experimental error	20	300708	15035		74723	3736		22929	1146		70233	3511	
Total	59	2504640			671198			236766			1337126		

** 99% confidence level

* 95% confidence level

samples per station taken in late August of 1967 and 1968 revealed an insignificantly small sampling error (Table 3). This resulted in large differences between stations, dates, age classes, and interactions.

Table 3. Analysis of variance of August 26, 1967 and August 27 and 28, 1968, when two samples were taken from 100 m to the surface in stations 5, 10, 13, 22, and 25.

Source	DF	SS	MS	F
Date	1	1120608	1120608	863.334**
Station	5	974837	194967	105.205**
Age class	3	1268887	422962	325.856**
Date x station	5	112618	22524	17.352**
Date x age class	3	830612	276871	213.305**
Station x age class	15	1324283	88286	68.016**
Date x station x age class	15	235979	15732	12.113**
Sampling error	48	62317	1298	
Total	95	5960141		

##99% confidence level

Vertical Migrations

Before August 28 and 29, 1968, studies indicated that only a fraction of the entire populations of 13. longispina and _D. pulex underwent vertical migration. The maxima at most, moved only

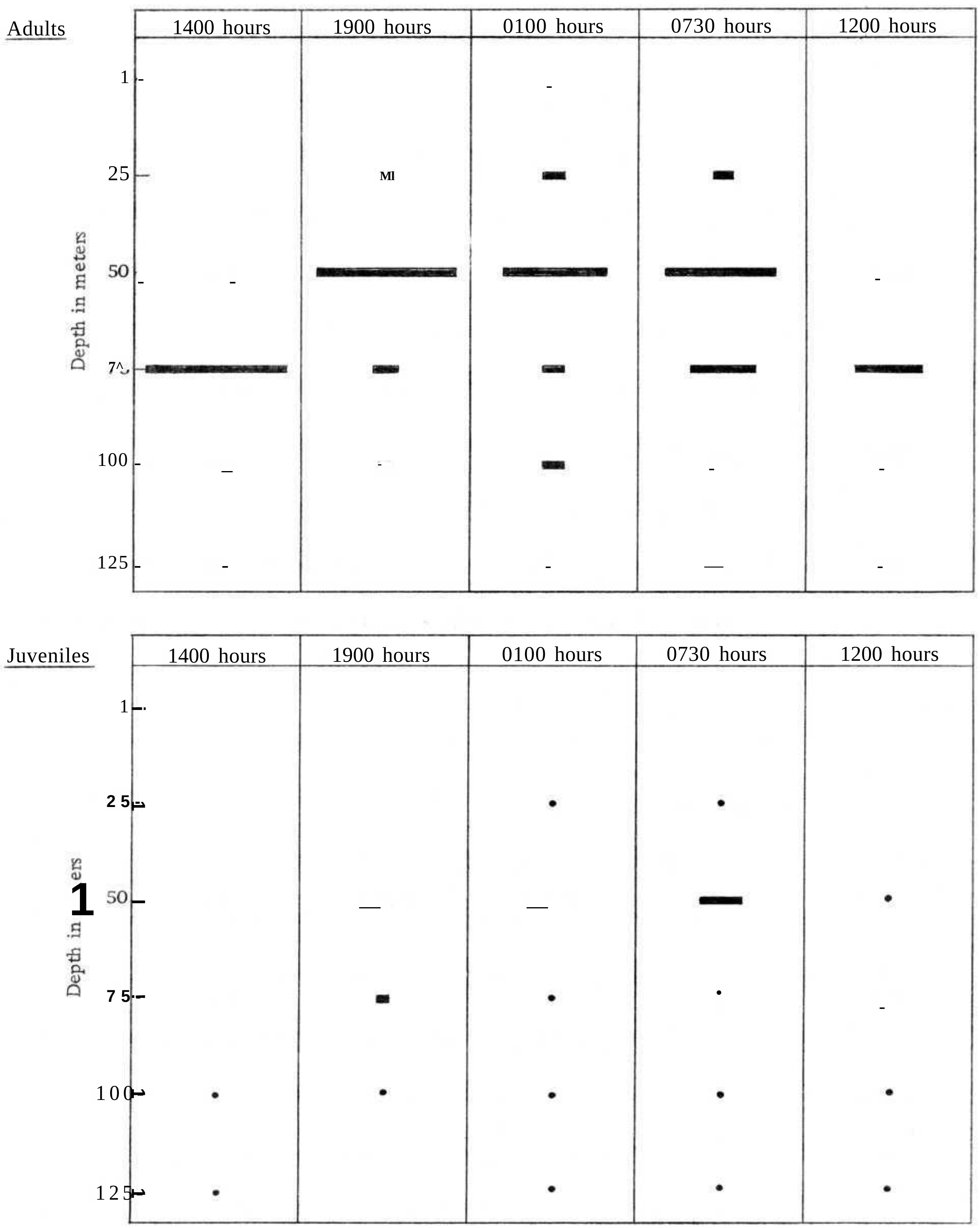

Figure 5. The diel vertical distribution of Bosmina longispina on August 24 and 25, 1967 in Crater Lake, Oregon. (wmm = 100 organisms/m^3)

a distance of 12.5 to 25 m. Preliminary samples taken on July 28 and 29, 1967, showed the maxima of T5_. longispina to move between 75 m daring the day and 50 m at night. A few organisms were found at 25 m during the night, but none were observed at this depth or above during the day.

On August 24 and 25, 1967, the vertical movement of B. longispina was still between 75 m during the day and 5 0 m, with a very few reaching the surface, at night (Figure 5). The initial upward movement of zooplankton began before sunset, and the downward movement happened after sunrise. Again, organisms were extremely rare in the depths sampled above 50 m during periods of intense illumination.

In 1968 the use of the Miller samplers increased the accuracy of sampling the vertical distribution of zooplankton. On July 24 and 25, 1968, the maxima of J^. longispina remained at 50 m, although a movement of individuals from 62. 5 m during the day to 37. 5 m at night was apparent (Figure 6). A few organisms occupied the surface waters at night and early morning, but by midday B. longispina was relatively absent from waters above 37.5 m. There were no major differences between the vertical distributions of adults and juveniles.

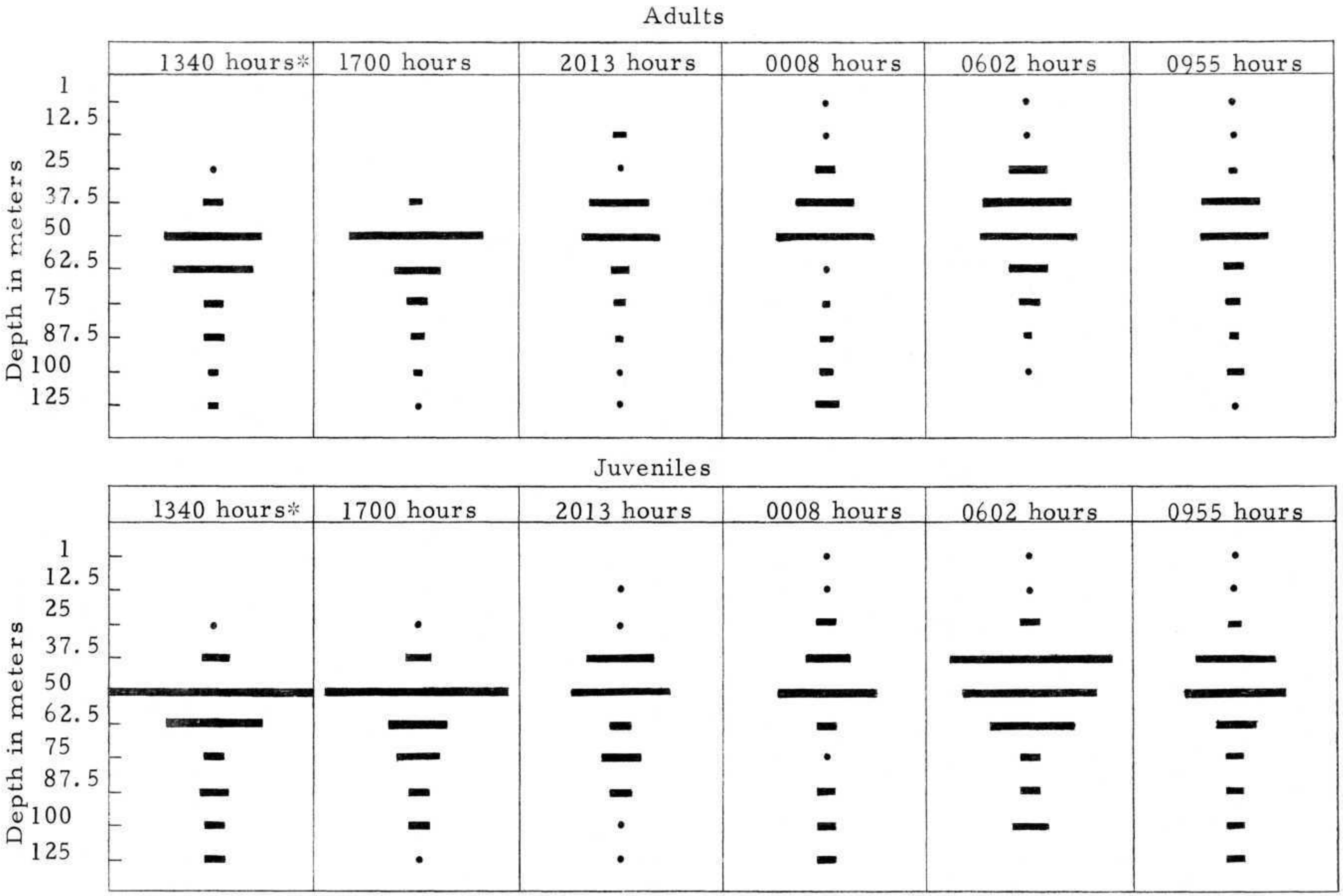

Figure 6. The diel vertical distribution of Bosmina longispina on July 24 and 25, 1968, in Crater Lake, Oregon, (•• = 1000 organisms/10 minute horizontal tow). * = 15 minute horizontal tow.

Vertical migrations of E^. longispina were more pronounced on August 28 and 29, 1968 (Figure 7). The maximum concentration of organisms at 50 m during the day ascended to 37.5 m at night with large numbers present at 12.5 and 25 m. During this period a slight variation occurred between the vertical distribution of adults and juveniles. Not as many juveniles were found in the 12.5 and 25 m depths at night; and while the maximum concentration of adults was at 37.5 at 2140 hours, the maximum concentration of juveniles was not at this depth until 0230 hours.

Even though JD. pulex was present in such low numbers in 1967, samples seemed to indicate that their maxima remained near 75 m. There was no observable migration of this species during this year.

Because of the larger population of JD. pulex in 1968, graphic representation of its vertical distribution was possible. On July 24 and 25, 1968, a day maxima at 62.5 m descended to 87.5 m at night while large numbers of JJ_. pulex also ascended into the shallower depth strata (Figure 8). The largest surface population was recorded at 0602 hours, just before sunrise. Juvenile JD. pulex behaved in a way similar to the adults during this diel sampling period.

During the night of August 28 and 29, tremendous numbers of D_. pulex were found at the surface (Figure 9). These numbers

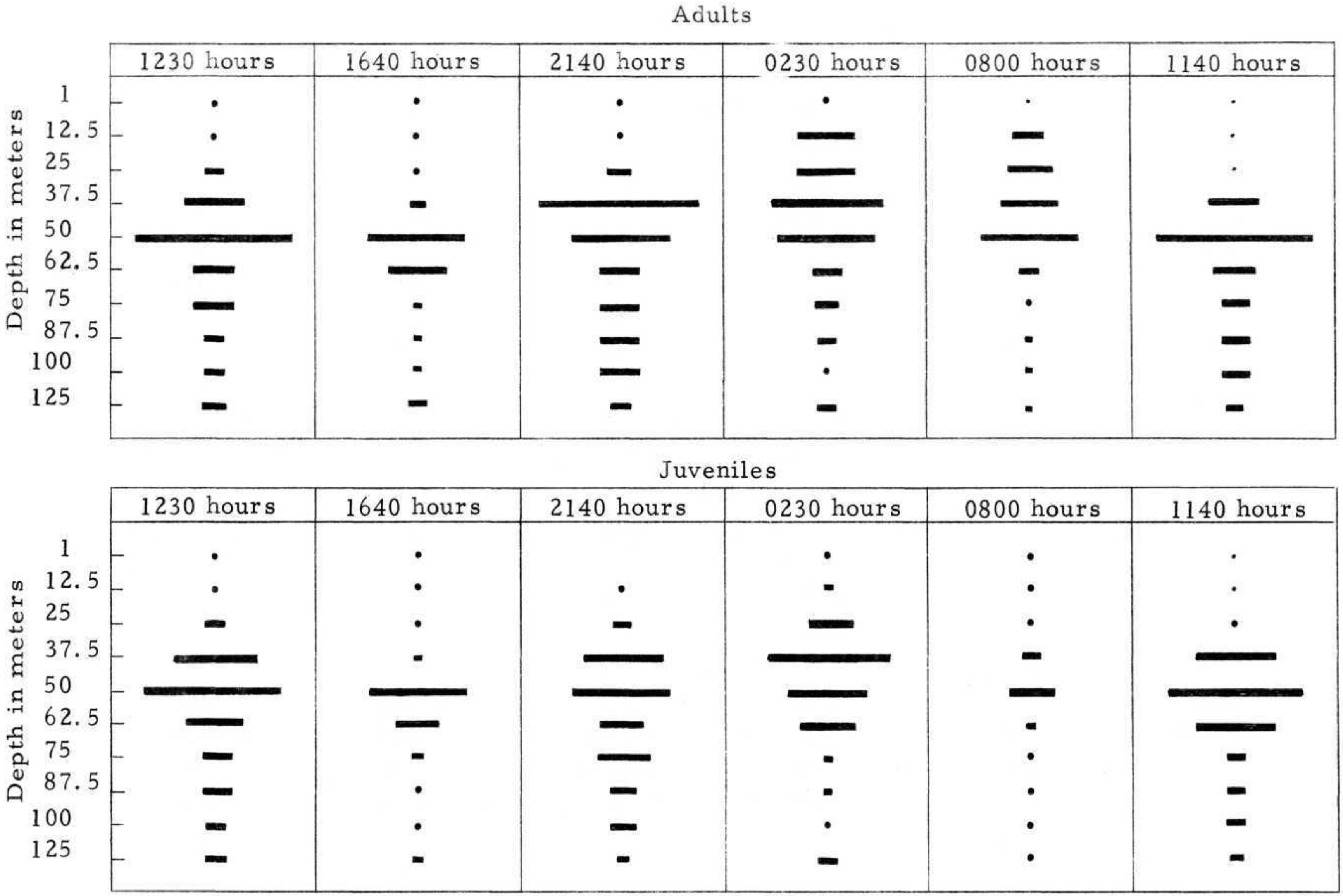

Figure 7. The diel vertical distribution of <u>Bosmina longispina</u> on August 28 and 29, 1968, in Crater Lake, Oregon. (•• = 1000 organisms/10 minute horizontal tow)

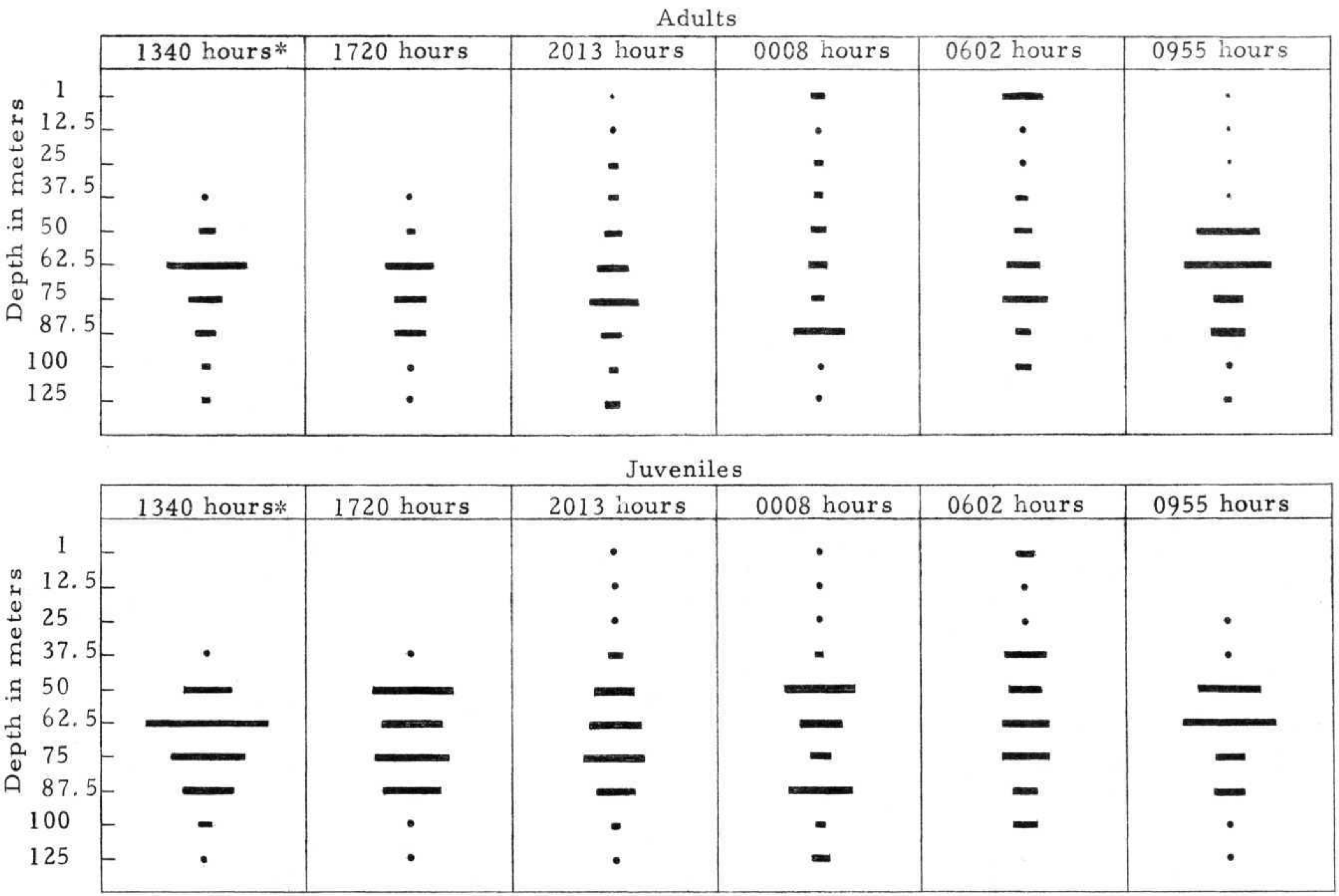

Figure 8. The diel vertical distribution of Daphnia pulex on July 24 and 25, 1968, in Crater Lake, Oregon. (— = 500 organisms/10 minute horizontal tow). * = 15 minute horizontal tow.

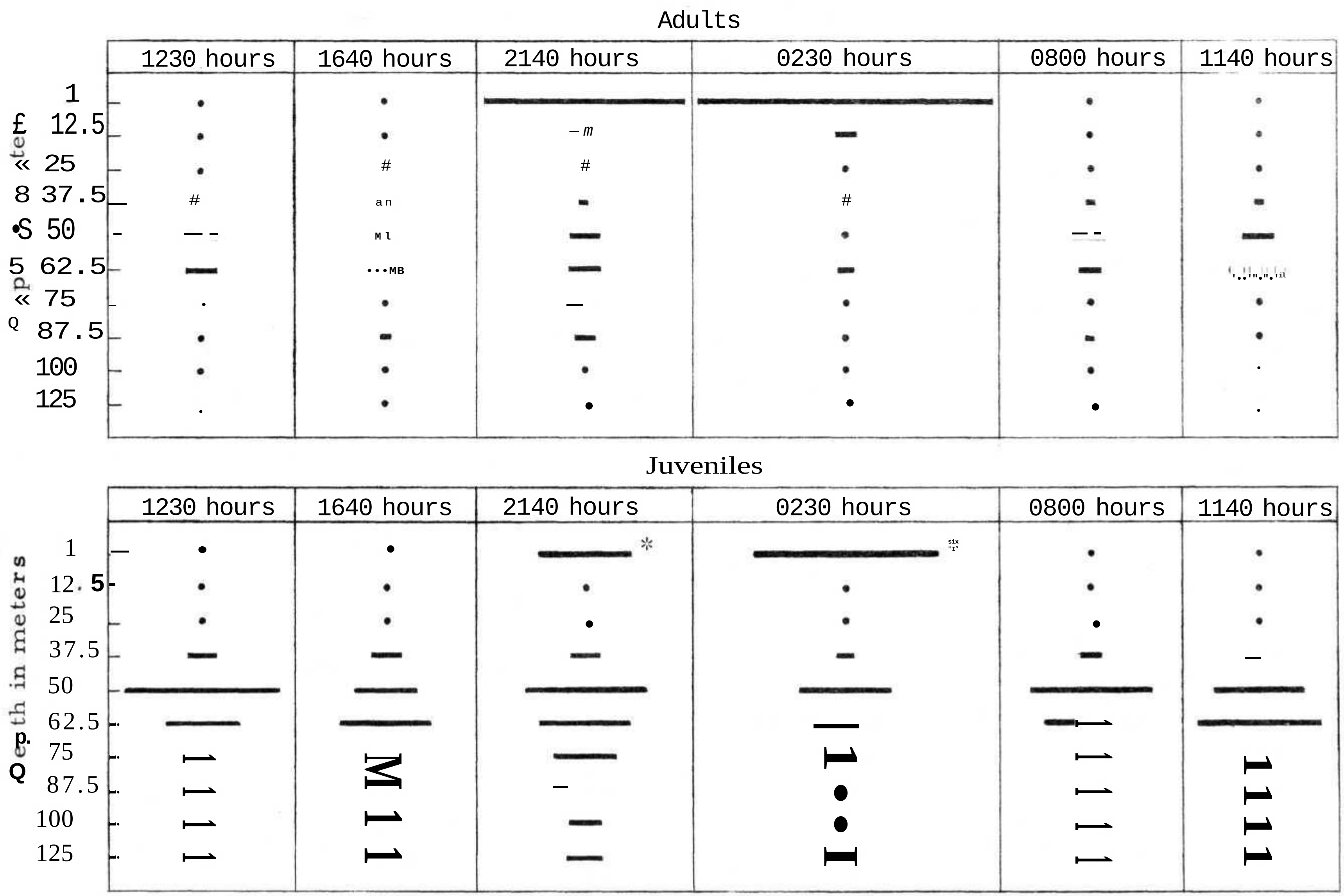

Figure 9- The diel vertical distribution of Daphnia pulex on August 28 and 29, 1968, in Crater Lake, Oregon, (-•• = 1000 organisms/10 minute horizontal tow). * = Juveniles at this depth are those in the earliest molt just released from brood pouches of the adults.

consisted primarily of large adult females whose brood pouches contained eggs or juveniles in the earliest molt. Those juveniles recorded at the surface -were probably those just released from the brood pouches of the largest D. pulex females. Juveniles in the more advanced molt stages were not observed at the surface, and no changes were observed in their diel vertical distribution.

The maximum concentration of adult D. pulex during the day was between 5 0 and 62. 5 m while almost the entire adult population migrated to the surface at night. If the presence of small numbers of adult D. pulex in samples taken from the lower depths can be attributed to contaraination while towing up through the surface, then we may assume that almost no D. pulex adults were below the surface layers at 0230 hours.

Contamination

Estimates of contamination from depths above 1 25 m showed that most if not all of the organisms sampled at 125 in were contaminants (Table 4). This may also be true of the 100 m samples.

Environmental Studies

Most of the research on the Crater Lake environment during the period of this study was conducted by Larson (unpublished). Thermal and water transparency (Secchi disc) information was made

Table 4. Comparison of sample averages of zooplankton per horizontal tow at 125 m and sample averages from tows made to estimate contamination by zooplankton above 125 m.

August 24 and 25, 1967, horizontal tows	*Bosmina longispina*		*Daphnia pulex*		M3
Time	Adults	Juveniles	Adults	Juveniles	water
1555	10570	2442	135	158	114
0008	8405	1883	194	163	93
0655	12489	2725	249	117	80
1131	15738	4306	475	0	106
Contamination	9625	2316	109	26	22
August 28 and 29, 1968, horizontal tows					
Time					
1200	1666	1747	867	2225	
1617	1252	950	926	3013	
2115	1228	1103	995	2583	
0205	1293	1430	1044	2301	
0739	601	561	422	2181	
1118	1625	1171	614	1707	
Contamination	1178	1053	527	1538	

available. *In situ* ^{14}C incubation was used to estimate the rates of primary productivity at various depths down to 140 m.

The summer of 1967 was exceptionally warm and calm, creating conditions favorable to thermal stratification. On August 22, 1967, the thermal gradient was unusually pronounced for Crater Lake (Figure 10). The onset of thermal stratification was apparent on July 22, 1968, (Figure 11), but further

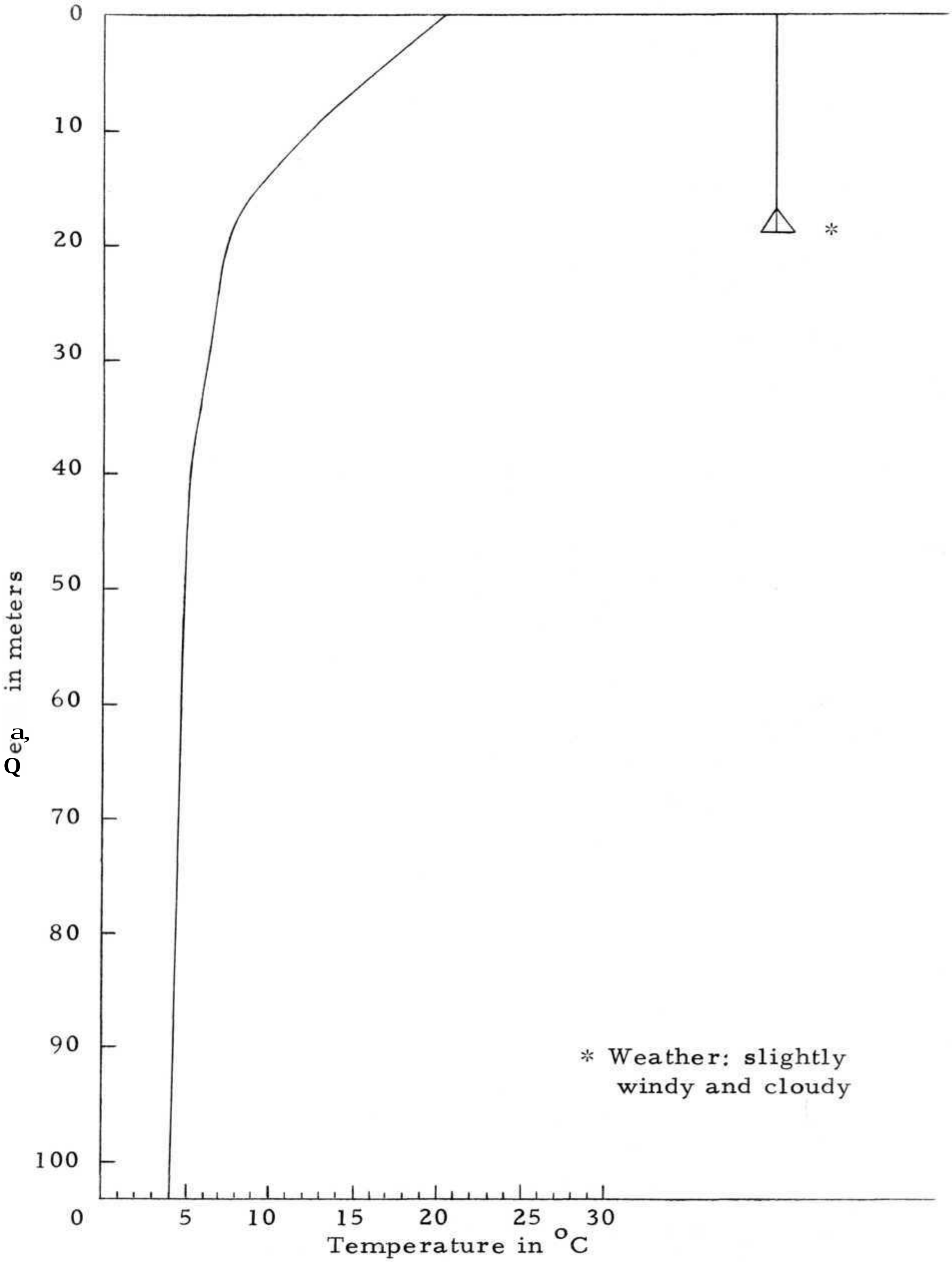

Figure 10. Thermal profile and Secchi disc depth on August 22, 1967 in Crater Lake, Oregon.

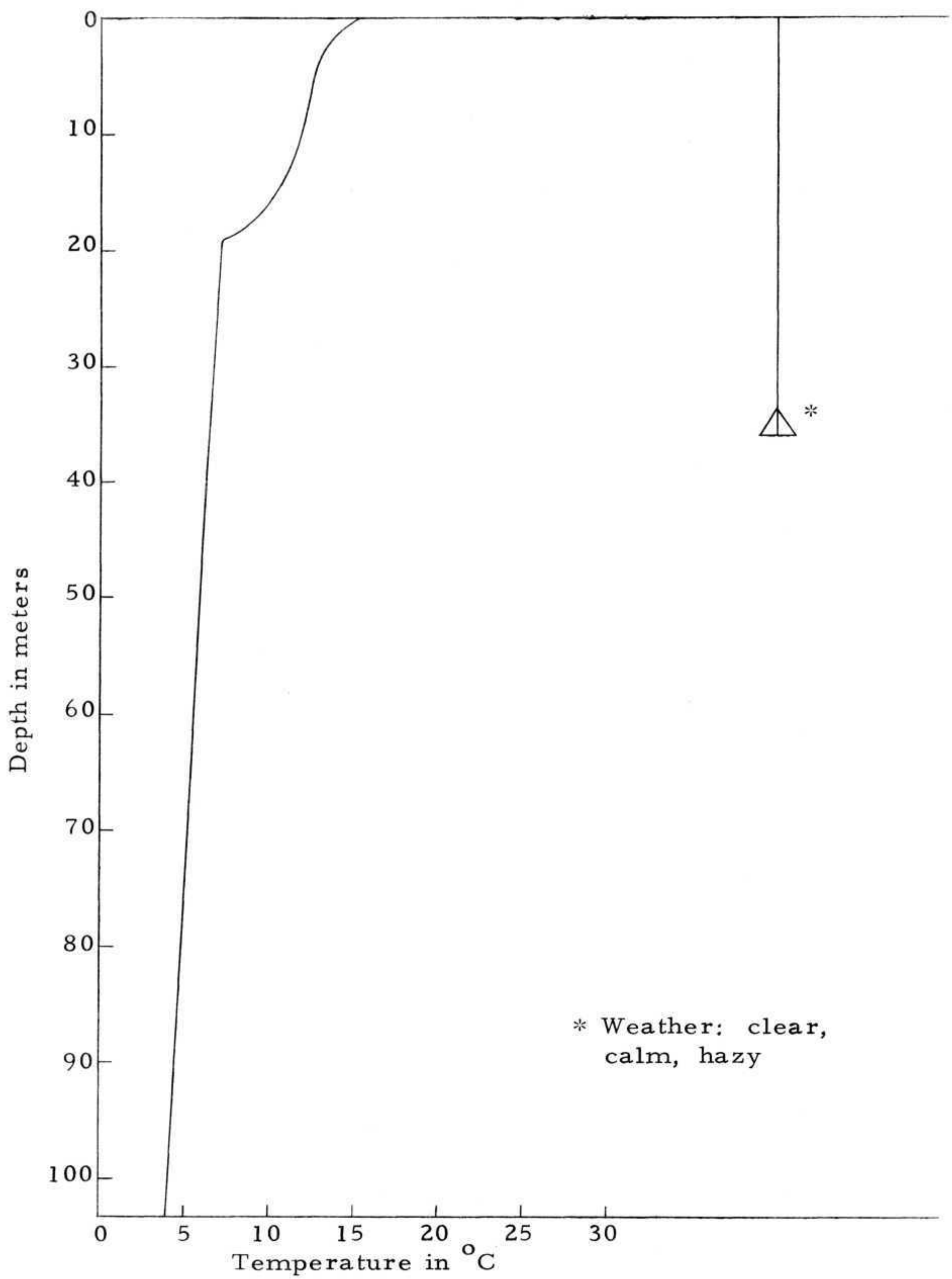

Figure 11. Thermal profile and Secchi disk depth on July 22, 1968, in Crater Lake, Oregon

stratification was destroyed by a month-long period of extremely cold and windy weather. The thermal gradient had lessened by the last sampling period in late August (Figure 1 2).

Variations between Secchi disk readings were affected more by weather conditions than optical properties of the lake. Estimates of primary production showed a maximum ^{14}C uptake at 80 m on June 14, 1968 (Figure 13), with very little uptake of ^{14}C above 30 m. On July 25, and August 27, 1968, this difference in primary production with depth had disappeared. An increasing uptake of ^{14}C in the shallower depth strata and a decreasing uptake between 60 to 100 m created an apparent orthograde condition.

It is likely that conditions do exist -when food is absent from the surface waters. The ^{14}C data recorded on July 24, 1967, appeared similar to the data of June 14, 1968, Utterback _et al_. (1942) in their study of the distribution of phytoplankton in Crater Lake found very few cells above 30 m. Their reported maximum concentration was at 75 m with large numbers occurring down to 200 m.

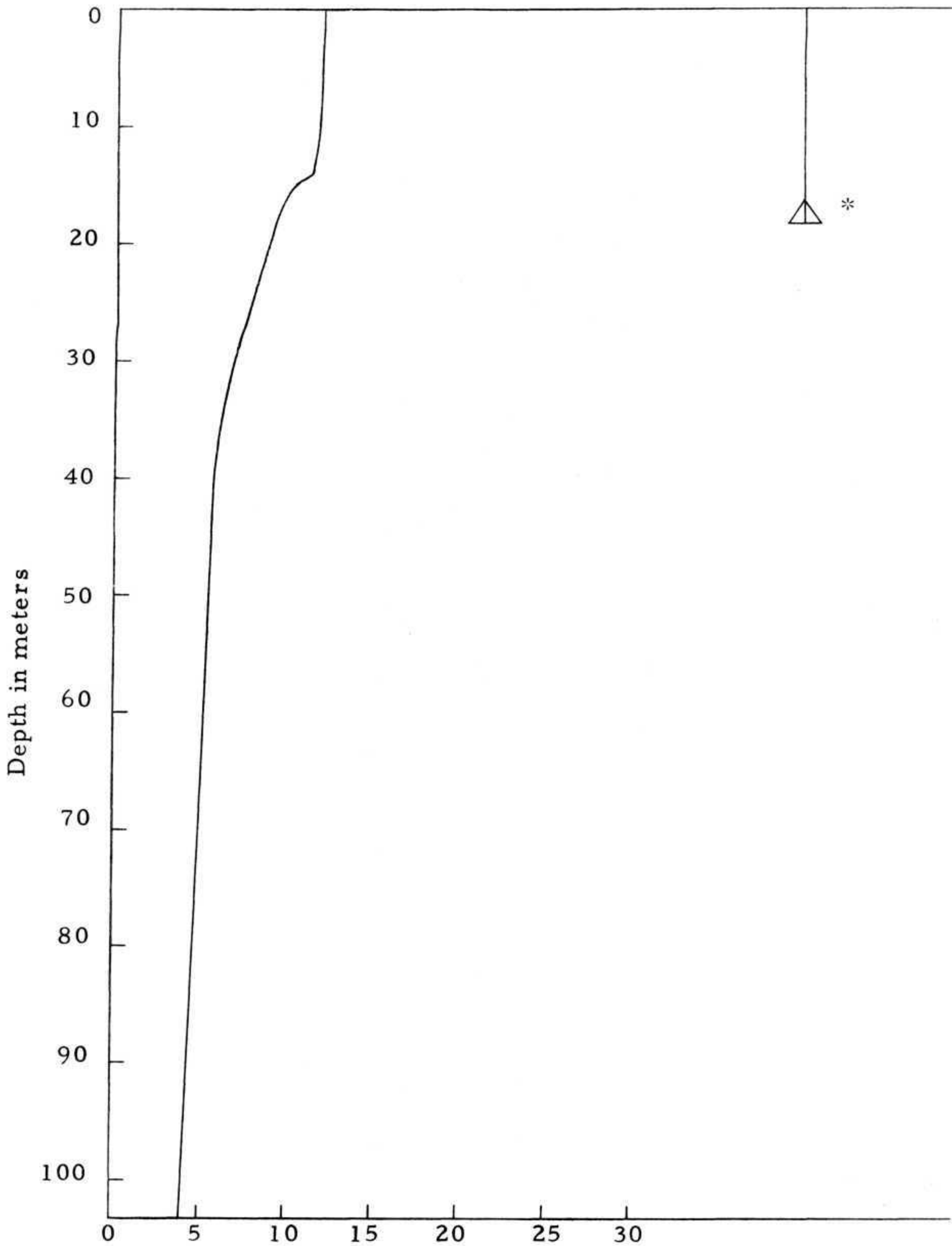

Figure 12. Thermal profile and Secchi disc depth on August 27, 1968, in Crater Lake, Oregon. *Read during extremely rough weather: cold, windy, rain.

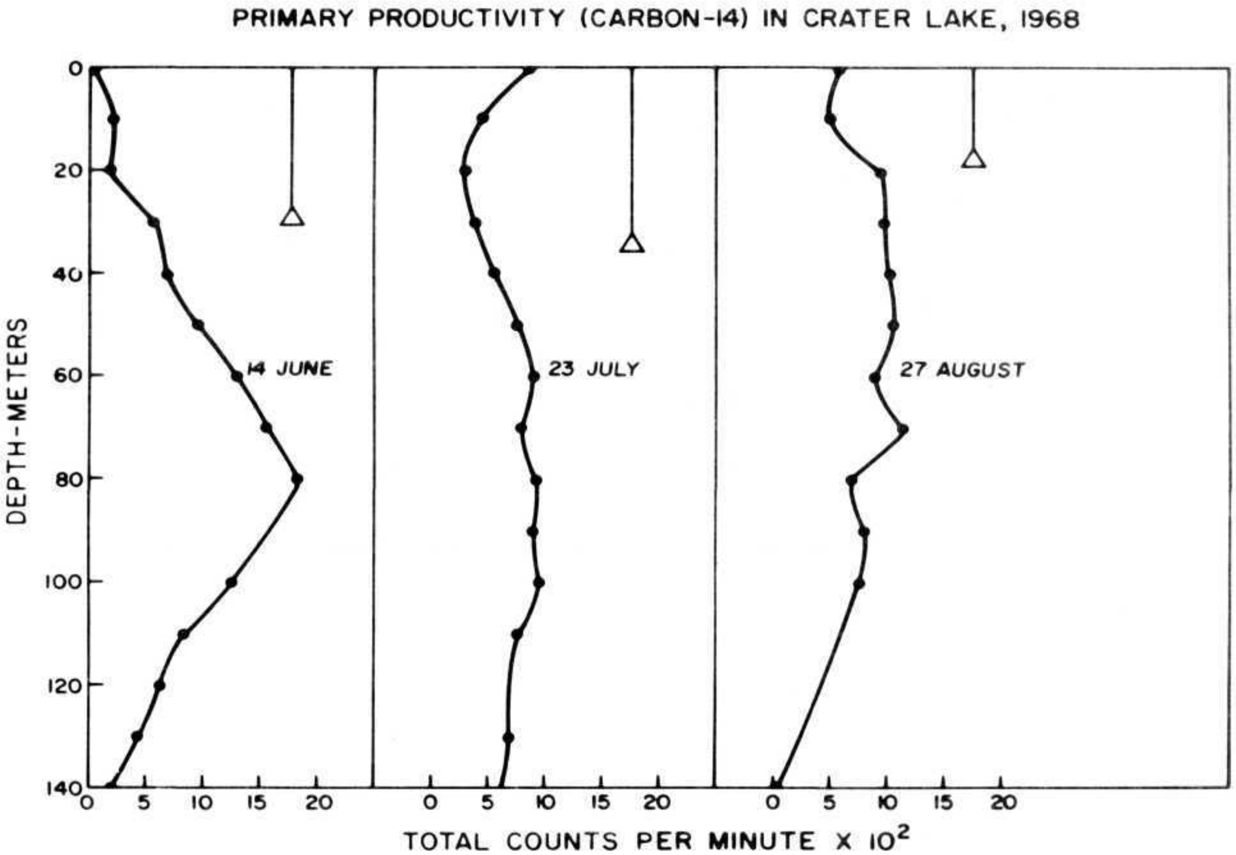

Figure 13, Primary productivity (carbon-14) in Crater Lake, 1968, represented in total counts per minute. (Courtesy of D. W. Larson.)

DISCUSSION

The rapid increase in the numbers of zooplankton during late August of both summers appears to indicate a monocyclic seasonal variation that usually occurs during spring in most temperate lakes (Hutchinson, 1967). There seems to be some correlation between the warming of the surface water and the increase of zooplankton populations, but only the adult D. pulex and their contained juveniles show any movement into these warmer waters. It is not certain when the maximum population size of either species is reached, but it apparently peaks some time in the summer or fall after the last samples were taken.

Despite the dominance of D. pulex that has consistently been reported by past investigators, only during the latter part of the summer of 1968 were its numbers comparable to the numbers of B. longispina. The depths at which the maximum numbers of these two species occurred were also shallower than those reported in earlier studies. Seasonal succession through competition could be responsible for the variation in species composition, however, no decrease in the population of B# longispina was observed -with the concurrent increase of D. pulex in 1968.

In general, B. longispina has a static clumped dispersal. High and low densities occurred in the same respective stations during both 1967 and 1968. The highest densities occurred in the central and eastern stations, and the lowest densities occurred in the more northerly and south-westerly stations that are less than one-half mile (800 m) from shore. *D. pulex*, however, does not have any definite dispersal pattern. A random or near uniform dispersal seems likely. Where *B. longispina* definitely seems to avoid an area like station 22 near Wizard Island there is no corresponding absence of *D. pulex*.

It is possible that the differences in the vertical migrations of the two species could account for their differences in horizontal distribution. A greater vertical movement of *D. pulex* would expose it to a greater diversity of water currents both on the surface and below, dispersing the population in different directions. In contrast, *B. longispina*, which has only a slight vertical movement, maintains an almost uniform depth. If upwelling occurs *B. longispina* could become locally concentrated, according to Ragotzkie and Bryson (1953). Strong upwelling was suspected by Kibby *et al.* (1968) during their study of the surface temperatures and currents in Crater Lake.

Even though Crater Lake is exceptionally deep, clear, and unproductive, the observed vertical migrations were not as marked as those reviewed by Hutchinson (1967) in similar lake environments. Except for the migration of the entire adult population of D. pulex in late August 1968, diel vertical migrations are limited to a partial upward scattering of both IX pulex and B^. longispina during the night. Evidently true diel vertical migrations are not consistent and occur only during certain times of the year in Crater Lake. Seasonal and annual variations in the vertical distribution are apparent. Differences within the reported depths of the day maxima of zooplankton in previous studies by Kemmerer ej^ aL (1923), Hasler (1938), and Brode (1938), indicate that these variations may be even more pronounced than those observed in this study. Of course, these observations may be biased by differences in sampling methods and equipment.

It is difficult to explain the vertical migration of zooplankton in Crater Lake based on presently considered theories for such phenomenon. Since the depth of the maximum zooplankton population by day is dependent on transparency (Kikuchi, 1930), high surface illumination must be the main environmental factor that determines the vertical distribution during the day. However, there are no obvious explanations for what determines the nocturnal distribution of zooplankton.

A direct relationship between the nocturnal distribution and environmental variations is not clear. Variations in weather conditions affected Secchi disc depths more than any variation in

-water transparency, so it is impossible to say anything about the relationship of water transparency and the nocturnal distribution based on Secchi disc information,

A relationship between the nocturnal distribution and water temperature is also difficult to make. Different thermal gradients occurred during each sampling of the diel vertical distribution, yet B, longispina underwent a nocturnal upward scattering regardless of these differences. However, a full migration of adult I?- pulex was observed to occur in August 1968 when there was the least change of temperature between the surface waters and the depths of the day maxima.

Primary production was observed to have increased in the surface water, and has a similar curve during both July and August 1968, but the migrations of zooplankton tend to favor the conditions that existed in August, Vertical movements of Bo longispina were more pronounced in August, but only the adult !•?• pulex migrated en masse to the surface, Juvenile IX pulex scattered upward like the adults in June, but no upward vertical movement of juvenile D, pulex was observed in August.

An explanation of the 1968 migration of adult D, pulex from 62, 5 m during the day to the surface at night may be offered by McLaren's (1963) theory on the adaptive value of vertical migration,, McLaren concludes that migrations are favorable to reproduction and growth when a thermal gradient exists between the depths of the day and night zooplankton maxima. Assuming that all feeding is done at or near the warmer surface waters, the energy gained by "resting" in the colder lower depths during the day would result in a more efficient growth, larger size, and greater fecundity.

Since the inigrants are mainly large adult IX pulex carrying juveniles and eggs, there appears to be a definite reproductive advantage in this migration. This migration was observed to take place when there is a thermal gradient and when food appears to be more abundant in the shallower depths. However, a marked thermal gradient and increased primary production at the surface occurred in July of 1968, but only a few adult IX pulex were found at the surface during the night. The only major difference between July and August 1968 is that IX pulex adults and juveniles were more abundant in August.

It could be possible that either the full migration of D, pulex does not occur until a maximum fecundity is reached, or that a new generation of diel vertical migrants are being produced during this July 1968 period, McLaren states that both phenomenon are possible. As the surface temperature begins to warm and as food becomes abundant at the surface, those few organisms migrating to the surface will have a higher reproductive rate producing a greater number of offspring (Hutchinson, 1967 and Pennak, 1953). Eventually the greater proportion of the entire zooplankton population will be made up of descendants from those few July vertical migrants. The great increase in the density of juvenile D. pulex during August 1968 seems to support this idea (Figure 4).

Primary productivity studies (Larson, unpublished) along with phytoplankton studies (Utterback et al., 1942) seem to indicate that at certain times of the year the food source in Crater Lake is concentrated at lower depths coinciding with the depths of the day zooplankton maxima. This could explain the initial inhibition of migration as all upward movement would be away from the food source.

Although an increase in numbers at 12, 5 and 25 m is observed with B. longispina at night in August 1968, the population does not generally experience much of a temperature change during its slight upward movement. However, full migrations of B. longispina may occur later in the season. Marked migrations of Bosmina sp. have been shown by Worthington (1931) who found the amplitudes of migration of B. coregoni to exceed that of Daphnia longispina in the Lake of Lucerne.

These ideas suggest that greater study is needed on the relation of the physical and biotic environment of Crater Lake to the horizontal and vertical distribution of zooplankton. Correlations of nutrient availability and phytoplankton density should be made with the difference in the abundance and diel vertical distribution of zooplankton. Primary productivity studies done in Crater Lake have just been estimates of photosynthesis and are not necessarily a true indicator of food density.

Similarities between current patterns and the horizontal distribution should be done to try to solve the problem of the apparent static clumped distribution of B. longispina. Optical properties should be studied with a light photometer in relation to vertical migrations. Finally, sampling earlier and later in the season should be done, especially when the maximum density of both D. pulex and B. longispina is reached. Unfortunately, the period of conventional access to Crater Lake is extremely limited.

Nowhere are the exact causes of vertical migrations fully understood. But, it is ray opinion that Crater Lake would be an ideal environment in which to attempt to solve this problem. Here, the environmental variables are few, and the numbers of species to observe are limited to B. longispina and D. pulex, I hope that this study will inspire future investigations of Crater Lake zooplankton to atterapt to answer the question of why there are diel vertical migrations.

SUMMARY

1. Studies of the horizontal distribution and diel vertical migrations of zooplankton were initiated because of the unique environment created by the unusual optical and thermal properties of Crater Lake.

2. Plankton nets were towed vertically in different locations and horizontally at different depths in order to sample, respectively, the horizontal distribution and vertical migration of zooplankton during the summers of 1967 and 1968.

3. Bosmina longispina was numerically the most abundant zooplankter sampled during the course of the study. Daphnia pulex, insignificant in 1967, increased in abundance during 1968, and in some locations may have dominated the zooplankton biomass by August.

4. During both summers the greatest numbers of zooplankton were sampled in late August. However, it is not known when the zooplankton populations reach a maximum density.

5. A monocyclic seasonal variation seems to be indicated by the rapid increase of zooplankton numbers during late August of both 1967 and 1968.

6. Studies of the horizontal distribution indicated that *B. longispina* was clumped, and was consistently more abundant in some locations than others. *D. pulex* did not have any definite dispersal pattern, and a random or near uniform dispersal seems likely,

7. Upwelling as well as vertical migrations may have affected the horizontal distribution of both *D. pulex* and *B. longispina*.

8. Seasonal and annual variations in the vertical distribution are apparent. Vertical migrations are not consistent and may only occur during certain times of the year.

9. Vertical migrations of *B. longispina* were only represented by a fraction of the entire population. The depth of their maximum concentration was found to vary only a distance of 12.5 to 25 m. No major differences were observed between the vertical distribution of adults and juveniles.

10. Vertical migrations of D. pulex were represented by the entire adult population in late August 1968. No apparent migration of juveniles was observed at this time. Prior to August 28 and 29, 1968, only a portion of the entire population underwent vertical migrations.

11. The range of the vertical distribution of zooplankton, contrary to previous investigations, was shallower than 125 m. Estimates of contamination of samples by zooplankton encountered in the shallower depths indicated that few zooplankters, if any, were present at 125 m.

12, It was not possible to make direct relationships between the different vertical migrations and the variations of water transparency, water temperature, and primary production.

13. An explanation of what causes the different vertical migrations in Crater Lake is difficult, but there appears to be a definite reproductive significance in the migration the entire adalt population of D. pulex on August 28 and 29, 1968. A greater size and fecundity can be attained by remaining in cooler waters, but as food and temperatures increase in the surface waters, then migrations are advantageous.

14, It might also be possible that the August 1968 migrations of D. pulex are descendants of the few migrants in July whose reproductive rate was increased by the warmer surface waters.

15, The initial inhibition of vertical migrations could be explained by the concentration of primary production at depths coinciding with the depths of the diurnal zooplankton maxima during early summer. When primary production was concentrated at lower depths, any migration towards the surface would be away from the food source.

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APPENDIX

Appendix Table 1

100 m vertical tows taken during five dates at different locations in Crater Lake, Oregon, using a No. 20 mesh l/2-m diameter net daring the summer 1967.

Date	Station	Bosmina longispina Adults n/m3	Bosmina longispina Juveniles n/m3	Daphnia pulex Adults n/iri3	Daphnia pulex Juveniles n/m3	M 3 wafcer sampled
6/28/67	3	80	67	2	0	7
6/28/67	5	104	40	2	2	7
6/28/67	10	38	11	0	0	7
6/28/67	13	107	84	0	2	7
6/28/67	21	4	6	1	0	7
6/28/67	22	28	21	2	0	7
6/28/67	25	114	98	5	0	7
7/15/67	5	79	59	3	1	7
7/15/67	10	17	41	0	1	7
7/15/67	13	184	77	2	1	7
7/15/67	18	104	84	1	0	7
7/15/67	22	35	41	0	1	7
7/15/67	25	123	84	1	0	7
7/29/67	5	36	26	1	2	7
7/29/67	10	12	7	2	2	7
7/29/67	13	164	55	7	4	7
7/29/67	18	37	20	0	1	7
7/29/67	22	25	13	1	1	7
7/29/67	25	392	182	3	1	7
8/18/67	4	95	35	6	1	7
8/18/67	10	628	116	9	3	7
8/18/67	13	92	17	3	0	7
8/18/67	18	3	1	1	0	7
8/18/67	18	74	25	5	0	7
8/18/67	22	7	2	3	1	7
8/18/67	25	32	8	5	1	7
8/25/67*	13	414	104	5	1	22

* This tow was made with a No. 6 nylon mesh to estimate contamination.

Appendix Table 1 (continued)

8/26/67	5	77	1	12	3	7
8/26/67	5	132	34	8	2	7
8/26/67	10	487	121	15	3	7
8/26/67	10	476	124	10	3	7
8/26/67	13	773	303	9	7	7
8/26/67	13	671	187	10	1	7
8/26/67	18	292	118	5	5	7
8/26/67	18	403	127	4	7	7
8/26/67	22	61	23	8	3	7
8/26/67	22	49	21	4	4	7
8/26/67	25	822	174	9	5	7
8/26/67	25	925	174	5	5	7
Total		8197	2732	166	76	

Bosmina	10928
Daphnia	242
All species	11170

Appendix Table 2

100 m vertical tows taken during five dates at different locations in Crater Lake, Oregon, using a No. 20 mesh 1/2-m diameter net daring the summer 1968.

Date	Station	Bosmina longispina Adults n/m3	Bosmina longispina Juveniles n/m3	Daphnia pulex Adults n/m3	Daphnia pulex Juveniles n/m3	M3 water sampled
6/15/68	3	18	15	4	31	7
6/15/68	5	124	32	10	5	7
6/15/68	10	221	62	34	39	7
6/15/68	13	164	45	19	30	7
6/15/68	18	114	30	15	74	7
6/15/68	22	18	14	18	32	7
6/15/68	23	43	14	10	6	7
6/15/68	25	66	22	11	41	7
6/15/68	30	108	63	13	18	7
7/ 4/68	3	91	26	16	54	7
7/ 4/68	5	135	53	7	45	7
7/ 4/68	10	172	63	13	34	7
7/ 4/68	13	204	107	19	62	7
7/ 4/68	18	268	115	40	87	7
7/ 4/68	22	23	18	55	183	7
7/ 4/68	23	86	32	18	51	7
7/ 4/68	25	167	88	21	65	7
7/ 4/68	30	242	108	33	124	7
7/22/68	13	247	134	23	43	7
7/25/68	3	71	37	16	20	17
7/25/68	5	170	60	44	88	16
7/25/68	10	197	91	44	69	16
7/25/68	18	104	40	25	82	15
7/25/68	22	17	5	79	81	16
7/25/68	23	69	43	46	63	16
7/25/68	25	136	61	50	50	16
7/25/68	30	429	157	21	79	16
8/ 8/68	3	149	109	48	103	15
8/ 8/68	5	45	23	56	74	15
8/ 8/68	10	245	127	109	135	15
8/ 8/68	13	237	115	62	91	15

Appendix Table 2 (continued)

8/ 8/68	18	200	144	74	103	15
8/ 8/68	22	13	12	113	190	15
8/ 8/68	23	241	121	69	152	15
8/ 8/68	25	420	256	38	65	15
8/ 8/68	30	670	346	88	192	15
8/27/68	22	78	64	96	314	15
8/27/68	22	107	68	97	443	15
8/27/68	23	483	329	171	395	15
8/27/68	23	539	335	120	386	16
8/28/68	3	189	205	282	638	12
8/28/68	3	95	116	312	537	12
8/28/68	5	144	177	314	676	11
8/28/68	5	155	155	339	638	12
8/28/68	10	501	324	315	667	12
8/28/68	10	475	302	269	673	12
8/28/68	*13*	*471*	*370*	*133*	*501*	*13*
8/28/68	13	462	392	160	534	12
8/28/68	18	499	311	136	348	12
8/28/68	18	332	275	116	375	12
8/28/68	25	904	589	118	401	12
8/28/68	25	792	821	177	486	11
8/28/68	30	1464	868	161	374	13
8/28/68	30	930	736	131	367	11
Total		14543	9227	4809	11414	

Bosmina	23770
Daphnia	16224
All species	39994

Appendix Table 3

The vertical distribution of cladocerans in Crater Lake, Oregon, sampled with a No. 6 mesh 1/2-m diameter standard tow net in July, 1967, using a towing angle of 60 degrees while towing horizontally for 15 minutes.

		Bosmina longispina		*Daphnia pulex*					
Depth	Time	Adults n/m3	Juveniles n/m3	Adults n/m3	Juveniles n/m3	Station	Cable L	M3 water sampled	Date
50	1330	1	0	0	0	7	100	331	7/23/67
50	1400	9	3	0	0	7	100	216	7/23/67
75	1436	227	75	3	4	13	150	171	7/23/67
75	1617	116	54	0	1	13	150	227	7/23/67
100	1100	25	11	4	3	16	200	235	7/23/67
100	1640	35	15	3	3	13	200	175	7/23/67
125	1740	19	13	1	0	13	250	114	7/23/67
25	1415	0	0	0	0	6	50	234	7/24/67
150	1503	9	2	1	1	23	300	173	7/24/67
200	1150	21	5	1	1	11	400	138	7/24/67
50	1044	129	52	0	0	13	100	186	7/28/67
50	1044	95	45	1	0	13	100	186	7/28/67
75	2355	73	15	4	4	13	150	135	7/28/67
75	1108	183	31	4	1	13	150	133	7/28/67
100	2330	28	3	3	2	13	200	120	7/28/67
100	1130	31	9	2	1	13	200	132	7/28/67
125	2302	56	23	4	1	13	250	81	7/28/67
125	1155	27	6	1	0	13	250	115	7/28/67
150	2233	30	9	2	1	13	300	76	7/28/67

Appendix Table 3 (continued)

150	1223	9	3	0	0	13	300	116	7/28/67
200	1255	24	6	1	1	13	400	164	7/28/67
200	2200	26	8	1	0	13	400	112	7/28/67
25	1412	0	0	0	0	13	50	151	7/29/67
25	1412	0	0	0	0	13	50	151	7/29/67
25	35	10	3	1	0	13	50	130	7/29/67
50	17	182	54	1	0	13	100	165	7/29/67
Total		1264	445	39	25				

Bosmina	1709
Daphnia	64
All species	1773

Appendix Table 4

The vertical distribution of cladocerans in Crater Lake, Oregon, sampled with a No. 6 mesh l/2-m diameter standard tow net in August, 1967, using a towing angle of 60 degrees while towing horizontally for 15 minutes.

		Bosmina longispina		*Daphnia pulex*					
Depth	Time	Adults n/m3	Juveniles n/m3	Adults n/m3	Juveniles n/m3	Station	Cable length	M3 water sampled	Date
1	1403	2	1	0	0	13	2	102	8/24/67
25	1341	1	0	0	0	13	50	80	8/24/67
50	1432	117	44	1	0	13	100	132	8/24/67
75	1459	735	167	6	1	13	150	121	8/24/67
100	1527	133	37	2	1	13	200	122	8/24/67
125	1555	93	21	1	0	13	250	114	8/24/67
1	2000	1	0	3	0	13	2	115	8/24/67
25	1930	10	1	3	1	13	50	157	8/24/67
50	1916	735	211	2	1	13	100	142	8/24/67
75	1840	95	40	4	5	13	150	130	8/24/67
100	1824	68	14	1	1	13	200	128	8/24/67
1	230	18	4	2	1	13	2	132	8/25/67
25	206	89	21	0	0	13	50	143	8/25/67
50	138	498	198	3	1	13	100	131	8/25/67
75	110	125	35	13	5	13	150	129	8/25/67
100	43	123	33	2	3	13	200	121	8/25/67
125	8	90	20	2	2	13	250	93	8/25/67

Appendix Table 4 (continued)

1	855	1	1	0	0	13	2	143	8/25/67
25	835	129	46	0	0	13	50	144	8/25/67
50	813	461	169	1	2	13	100	134	8/25/67
75	748	290	74	5	3	13	150	130	8/25/67
100	722	97	24	2	1	13	200	128	8/25/67
125	655	157	34	3	1	13	250	80	8/25/67
1	1321	0	0	0	0	13	2	82	8/25/67
25	1302	1	0	0	0	13	50	145	8/25/67
50	1242	141	48	0	0	13	100	120	8/25/67
75	1219	296	71	10	3	13	150	107	8/25/67
100	1155	109	36	1	0	13	200	103	8/25/67
125	1131	148	41	4	0	13	250	106	8/25/67
Total		4765	1392	75	32				

Bosmina	6157
Daphnia	107
All species	6265

Appendix Table 5

The vertical distribution of cladocerans in Crater Lake, Oregon, sampled with Miller samplers in July, 1968, using a towing angle of 70 degrees while towing horizontally for a duration of 10 minutes.

		Bosmina longispina		Daphnia pulex			Cable	
Depth	Time	Adults	Juveniles	Adults	Juveniles	Station	length	Date
25	1340*	0	64	0	0	13	73	7/24/68
38	1340*	793	1350	175	45	13	111	7/24/68
50	1340*	5436	11490	532	1805	13	146	7/24/68
63	1340*	4399	4754	2418	4456	13	184	7/24/68
75	1415*	1477	1319	1026	2349	13	219	7/24/68
88	1415*	1043	1704	897	1748	13	257	7/24/68
100	1415*	991	1196	299	392	13	292	7/24/68
125	1415*	778	936	289	150	13	365	7/24/68
25	1700	0	99	0	0	13	73	7/24/68
38	1700	1261	1660	56	148	13	111	7/24/68
50	1700	7110	9560	442	2772	13	146	7/24/68
63	1700	2428	3500	1478	1939	13	184	7/24/68
75	1728	1468	1915	908	2349	13	219	7/24/68
88	1728	889	915	1028	1844	13	257	7/24/68
100	1728	836	1670	97	339	13	292	7/24/68
125	1728	427	493	296	395	13	365	7/24/68

*Horizontal tow of 15 minutes duration.

Appendix Table 5 (continued)

I	2100	0	0	73	38	13	3	7/24/68,
13	2100	313	360	343	175	13	38	7/24/68
25	2013	216	506	117	161	13	73	7/24/68
38	2013	2739	3532	390	604	13	111	7/24/68
50	2013	3765	5073	579	1713	13	146	7/24/68
63	2013	833	1536	967	1881	13	184	7/24/68
75	2038	768	1902	1588	2049	13	219	7/24/68
88	2038	817	1333	767	1241	13	257	7/24/68
100	2038	258	476	193	249	13	292	7/24/68
125	2038	622	562	362	261	13	365	7/24/68
1	57	34	44	429	59	13	3	7/25/68
13	57	72	18	130	18	13	38	7/25/68
25	8	1045	841	193	136	13	73	7/25/68
38	8	3011	2203	180	647	13	111	7/25/68
50	8	4962	5622	530	2250	13	146	7/25/68
63	8	644	910	860	1441	13	184	7/25/68
75	35	613	323	614	775	13	219	7/25/68
88	35	906	1038	1455	2241	13	257	7/25/68
100	35	962	923	216	471	13	292	7/25/68
125	35	1309	1642	481	768	13	365	7/25/68

Appendix Table 5 (continued)

1	536	159	118	1275	530	13	3	7/25/68
13	536	70	29	55	13	13	38	7/25/68
25	536	1562	770	127	16	13	73	7/25/68
38	536	4880	8381	467	1330	13	111	7/25/68
50	602	5356	7212	620	1150	13	146	7/25/68
63	602	2069	4458	1189	1765	13	184	7/25/68
75	602	1422	1684	1637	1457	13	219	7/25/68
88	602	1014	1333	530	685	13	257	7/25/68
100	630	2013	2063	490	830	13	292	7/25/68
1	1013	35	88	9	18	13	3	7/25/68
25	955	483	1133	0	0	13	73	7/25/68
38	955	2775	4320	309	34	13	111	7/25/68
50	954	3523	5186	1305	2001	13	146	7/25/68
63	955	793	1686	1668	2821	13	184	7/25/68
75	928	519	893	877	938	13	219	7/25/68
88	928	492	1041	715	1021	13	257	7/25/68
100	928	1047	1321	502	206	13	292	7/25/68
125	928	935	1575	499	477	13	365	7/25/68
Total		82372	114759	32676	53198			

<u>Bosmina</u>	197132
<u>Daphnia</u>	85874
All species	283006

Appendix Table 6

The vertical distribution of cladocerans in Crater Lake, Oregon, sampled with Miller samplers in August, 1968, using a towing angle of 70 degrees while towing horizontally for a duration of 10 minutes.

		Bosmina longispina		*Daphnia pulex*			Cable	
Depth	Time	Adults	Juveniles	Adults	Juveniles	Station	length	Date
1	1245	132	203	24	49	13	3	8/28/68
13	1245	14	114	0	57	13	38	8/28/68
25	1230	922	1122	104	706	13	73	8/28/68
38	1230	2715	4094	430	2713	13	111	8/28/68
50	1230	9557	7294	2218	10592	13	146	8/28/68
63	1230	1805	3168	2201	6426	13	184	8/28/68
75	1200	1750	1277	1117	3550	13	219	8/28/68
88	1200	1322	1751	749	2085	13	257	8/28/68
100	1200	1045	1813	622	1980	13	292	8/28/68
125	1200	1666	1747	867	2225	13	365	8/28/68
1	1659	13	25	0	26	13	3	8/28/68
13	1659	38	15	8	8	13	38	8/28/68
25	1640	169	206	93	277	13	73	8/28/68
38	1640	860	738	615	1967	13	111	8/28/68
50	1640	5488	5484	1521	4547	13	146	8/28/68
63	1640	3062	2203	2572	6713	13	184	8/28/68
75	1617	577	915	577	2512	13	219	8/28/68
88	1617	683	576	841	2119	13	257	8/28/68
100	1617	543	652	563	1964	13	292	8/28/68
125	1617	1252	950	926	3013	13	365	8/28/68

Appendix Table 6 (continued)

1	2158	181	0	13300	6259	13	3	8/28/68
13	2158	568	133	1327	436	13	38	8/28/68
25	2140	1621	1152	605	357	13	73	8/28/68
38	2140	9446	4154	983	1718	13	111	8/28/68
50	2140	5133	5285	2333	7999	13	146	8/28/68
63	2140	2166	2860	2466	5170	13	184	8/28/68
75	2115	1819	2536	2155	6298	13	219	8/28/68
88	2115	1856	1980	1609	3300	13	257	8/28/68
100	2115	1716	1570	993	2627	13	292	8/28/68
125	2115	1228	1103	995	2583	13	365	8/28/68
1	245	246	250	19081	11933	13	3	8/29/68
13	245	3424	710	1375	451	13	38	8/29/68
25	230	3487	2001	680	764	13	73	8/29/68
38	230	5644	6040	692	1623	13	111	8/29/68
50	230	5406	3967	1384	6524	13	146	8/29/68
63	230	1634	2029	1499	4893	13	184	8/29/68
75	205	969	557	1362	3037	13	219	8/29/68
88	205	1102	1217	812	1526	13	257	8/29/68
100	205	465	493	506	5'66	13	292	8/29/68
125	205	1293	1430	1044	2301	13	365	8/29/68

Appendix Table 6 (continued)

1	817	0	29	0	196	13	3	8/29/68
13	817	1167	473	304	176	13	38	8/29/68
25	800	2179	670	968	813	13	73	8/29/68
38	800	3133	2184	1012	2272	13	111	8/29/68
50	800	4651	3935	2395	7524	13	146	8/29/68
63	800	1096	936	1820	6904	13	184	8/29/68
75	739	442	472	691	2210	13	219	8/29/68
88	739	769	535	937	2134	13	257	8/29/68
100	739	809	719	836	1959	13	292	8/29/68
125	739	601	561	422	2181	13	365	8/29/68
1	1159	73	54	29	26	13	3	8/29/68
13	1159	13	59	38	110	13	38	8/29/68
25	1140	307	498	57	385	13	73	8/29/68
38	1140	2796	4189	866	2459	13	111	8/29/68
50	1140	9536	7806	2358	6966	13	146	8/29/68
63	1140	2398	4046	3746	7992	13	184	8/29/68
75	1118	969	1024	739	1532	13	219	8/29/68
88	1118	1191	1251	696	2226	13	257	8/29/68
100	1118	1767	1337	630	1580	13	292	8/29/68
125	1118	1625	1171	614	1707	13	365	8/29/68
*125	1210	1178	1053	527	1538	13	365	8/29/68
Total		119713	106815	90928	176781			
Bosmina		226528	267710					
Daphnia		494238						

* This tow made to estimate contamination.