A QUANTITATIVE STUDY OF THE WINTER PLANKTON OF URSCHEL'S QUARRY

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A quantitative study of the plankton populations of Urschel's Quarry was conducted between October, 1958 and February, 1959. This is a relatively shallow limestone quarry, typical of northwestern Ohio, and is located in Bowling Green, Ohio.

In the past there has been much debate over the classification of certain forms which are autotrophic and possess some means of locomotion. For this study, those forms which are autotrophic, the green flagellates, have arbitrarily been classified as phytoplankton while the consumers have been classified as zooplankton.

METHODS

One procedure used to study the distribution of organisms in a body of water requires that the volume of each genus present in a given volume of water be measured. Based upon a review of the literature, two methods from which results may be obtained in volumetric units, the chamber method advocated by Ruttner et al. (1953) and the silk-bolting cloth method of other investigators, were selected as being best suited for use in Urschel's Quarry. The methods were modified slightly, however.

In order to enumerate the plankton by the chamber method, a water sample was shaken vigorously and a subsample of it, 1 cm in depth, was placed in a stender dish. This subsample was then treated with a few drops of either Rohde's fixative or 6–3–1 fixative. However, since the fixatives produced changes in the shape and color of the plankton, it was necessary to examine a sample containing living organisms to see which genera were present.

All the plankton in ten randomly sampled fields of the fixed sample were identified under 450× magnification, counted, and measured with a calibrated Whipple ocular. Next, five fields were examined under low power (100×), and the more common forms were enumerated in a similar manner. After this preliminary count, ten more fields were examined for rarer forms. Since some forms were light and floated, the surface of the sample was also examined for specimens.

The volume of each organism was calculated from the formula for the geometric figure each plankter most nearly resembled and from the measurements which were previously obtained. Appropriate calculations were then made to determine the total volume, in μl/l, of phytoplankton and zooplankton in the water sample.

When the silk-bolting cloth method was used, a 2.5 l sample was filtered through number 25 silk-bolting cloth. The plankton were resuspended in 10 ml of distilled water and were fixed with either of the previously mentioned fixatives. A 1 ml aliquoit was placed in a Sedgwick-Rafter counting chamber and 15 fields, selected at random, were then examined under low power (100×). All the plankton in these fields were identified, counted, and measured. Appropriate calculations were then made to determine the total volume of organisms in a liter of the sample.

The time of day and the depth at which samples were taken were considered important since they might cause variations in the volumes of organisms present in a given quantity of water. Therefore, samples were collected from the surface

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and 3 m in depth at 0830, 1500, and 2100 hours. These samples were collected from the east bank of the quarry with a Kemmerer water sampler. After the ice had formed, samples were taken from the middle of the quarry instead of on the east bank. This enabled the taking of an additional sample from 5 m in depth.

RESULTS

Comparison of methods.—In a comparison of the two methods of sampling, I found that the chamber method yielded the more accurate phytoplankton estimates. In contrast, the silk-bolting cloth method was the superior method for zooplankton analysis.

There was only a very slight loss of phytoplankton in the chamber method. This loss apparently resulted from fragmentation of the plankton. Therefore, this method was used as a control with which the efficiency of the other method was compared.

It was found that, of the phytoplankton under 30 μ in diameter, only 0.47% were retained by the bolting cloth. The retention of some of this small percentage of phytoplankton may be attributed to adhesion of some of the smaller forms to the larger ones which could not pass through the cloth. Of the phytoplankton over 30 μ in diameter, 98% were retained and of the 2% passing through the cloth, none were over 40 μ in diameter.

When the total volumes obtained by both methods were compared, it was found that 9.3% of the phytoplankton were unaccounted for in the bolting cloth method. This apparently resulted from plankton having been trapped and retained by the cloth or fragmented beyond recognition by the pressure used in filtration. The loss was somewhat selective since the smaller organisms were lost in greater amounts. These smaller organisms, principally *Chlorococcum* and diatoms, accounted for 7.6% of the 9.3% lost. The remaining 1.7% was *Pandorina*, which is a considerably larger form.

Another point which might account for differences in the results obtained was the use of magnifications 4.5 times greater in the chamber method than those used in the silk-bolting cloth method. This discrepency in sampling technique had to exist since it is impossible to use higher magnifications with a Sedgwick-Rafter cell. Therefore, smaller species were more easily seen in the stender dishes. Furthermore, since 22 genera were observed in the stender dishes compared to only 16 in the Sedgwick-Rafter cell, it appears that smaller plankton may not have been noticed in the Sedgwick-Rafter cell. In contrast, some of the larger, rarer forms appeared only in concentrated samples. This is of interest in a qualitative study, but for a quantitative study it has little value since the observation of one organism in many fields of a concentrated sample can produce very little change in the total volume of organisms.

In contrast to the phytoplankton, it was found that 99.89% of the zooplankton were retained by the bolting cloth. Only one species, *Halteria grandinella* (Kahl), was found in the filtrate. This organism has a diameter of approximately 25 μ, which allowed it to pass through the cloth. However, not all of these protozoons passed through the cloth. Some adhered to the larger plankton and floating detritus which was retained by the cloth and in others, the equatorial cirri, radiated out from the organism in a manner which probably prevented passage through the holes in the mesh of the cloth.

Thus, net or silk-bolting cloth catches may be used for comparison with other methods in a volumetric study of zooplankton since the volume of organisms passing through the cloth is practically negligible. However, it must not be assumed that all the zooplankton are recovered from the cloth. Some, particularly the smaller ones, become entangled in the mesh and cannot be resuspended. Even though this fault existed when silk-bolting cloth was used, it was found, from 68 samplings, that the volume retained by the cloth exceeded that collected by the chamber method by 2.7 times. Furthermore, variability was greater in the chamber method. Over the five month period, values ranging from 0 to 188 μl/l were recorded for the stender dishes while the range in the Sedgwick-Rafter cells was from 0 to 93 μl/l.

Several observations have been made concerning the chamber method which might explain the 2.7-fold difference between sampling techniques. First, vigorous shaking of the water sample failed to yield an even distribution of the zooplankton since the larger, stronger swimming forms, such as *Daphnia* and *Cyclops*, swam downward while the subsample was being poured and were not caught in the subsample. Secondly, organisms such as *Bosmina* tended to float on the surface of the water after they had been captured. This effect may have been produced by changes in temperature or pressure which resulted in an impairment of the mechanism controlling the equilibrium of the organism. Finally, as the fixative was added, the organisms swam to the edge of the dish and died. This prevented their being detected since the immersed objective could not be focused on the edge of the dish.

TABLE 1

Classification of the phytoplankton communities of Urschel's Quarry according to the volumertically dominant species

Time interval	Dominant species	Range of plant volume (μl/l)*
Oct. 7–Nov. 16	*Chlorococcum infusionum* Diatom (unidentified)	8–48
Nov. 17–Dec. 17	*Chlorococcum infusionum* Diatom *Pandorina morum*	5–19
Jan. 5–Jan. 12	*Pandorina morum* *Chlamydomonas* sp *Cryptomonas erosa*	2–88
Jan. 19–Feb. 24	*Pandorina morum* *Chlamydomonas* sp. *Cryptomonas erosa* *Asterionella formosa*	1–66

*A μl = 10^9 cubic microns.

Phytoplankton.—Since only a few species accounted for the majority of the phytoplankton volume, at any given time, it was possible to classify the communities according to their volumetrically dominant species. These communities are listed in table 1 together with the dates on which they were observed to be dominant. The ranges in volume of the samples taken within these periods are also presented.

With the formation of surface ice, on December 8, the free-floating plankton, *Chlorococcum* and the diatoms, disappeared. These were replaced by a flagellate community composed of *Pandorina morum* (Muell), *Cryptomonas erosa* Ehrenberg, and *Chlamydomonas* sp. The population of greatest density, 88 μl/l, was recorded at this time.

Table 2 shows that there was a steady decline in the *Chlorococcum*-diatom population during the first three months of this survey. This was followed by a threefold increase in the total phytoplankton population as the flagellate community became the major component. Following this initial increase, the population rapidly decreased so that the February population, composed of flagellates and *Asterionella formosa* Hass, was lower than that of any previous month.

Table 2 also shows that during the first three months of the study, slight variations occurred when samples were taken at different hours and when different depths were sampled. This variation probably represented natural variation between samples. Therefore, it appears that no vertical or upward migration occurred during this period.

TABLE 2

The average monthly populations of phytoplankton in relation to time and depth

Month	Time	Avg surface population µl/1	Avg 3 m population µl/1	Avg 5 m population µl/1
Oct.	0830	27.83	25.06	
	2100	25.09	24.32	
Nov.	0830	15.98	14.73	
	2100	15.94	16.01	
Dec.	0830	10.06	9.31	
	2100	7.76	7.90	
Jan.	0830	33.49	10.88	3.34
	1500	21.62	3.51	4.23
	2100	35.17	3.39	3.80
Feb.	0830	5.82	4.69	3.80
	1500	9.13	3.89	2.87
	2100	15.00	5.08	

TABLE 3

Classification of the zooplankton communities of Urschel's Quarry according to the volumetrically dominant species

Time interval	Dominant species	Range of animal volume (µl/1)
Oct. 19–Dec. 8	*Cyclops vernalis* *Keratella cochlearis*	0–90
Dec. 10–Jan. 22	*Cyclops vernalis*	0–93
Jan. 26–Feb. 10	*Cyclops vernalis* *Bosmina coregoni*	0–57
Feb. 11–Feb. 24	*Cyclops vernalis*	0–71

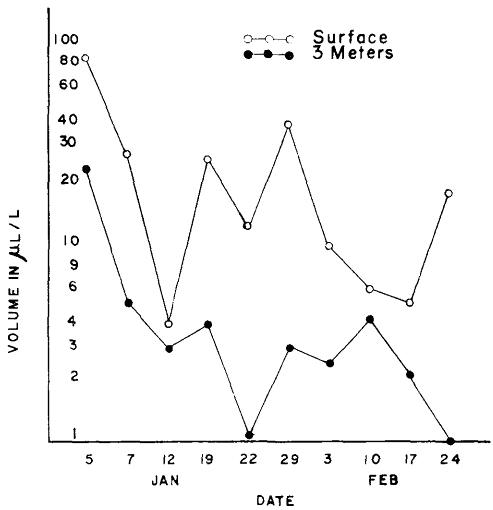
However, in January and February, the majority of the flagellates were found at the surface regardless of the time of sampling. Figure 1 shows approximately a fivefold difference in populations between the surface samples and those taken at 3 m. It should also be noted that, except for the samples of February 10 and February 24, an increase or decrease in the flagellate population at the surface was accompanied by a similar change at the 3-m depth. The variation on these two dates cannot readily be explained. However, on February 24, a tremendous increase in the volume of *Chlamydomonas* occurred at the surface. This was accompanied by a decrease of the other flagellates at all levels. In fact, within one week after this event, *Pandorina* completely disappeared from the samples. These data thus suggest that conditions were better at the surface and that the flagellates usually migrated to this zone.

An unusual distribution of *Asterionella formosa* (fig. 2) was found. This diatom was noted to increase in numbers as the depth increased. Since *Asterionella* has no means of locomotion, it is most likely that a combination of gravity and currents was responsible for its distribution. This haphazard method of distribution appears likely since there was no positive correlation between values obtained at the surface and at 3 m on different sampling dates.

Therefore, it may be stated that, in this study, only those forms which possessed some locomotory powers carried on vertical or upward migration. The rest of the phytoplankton were probably distributed, by physical forces, within the epilimnion.

Zooplankton.—The zooplankton communities may also be characterized by the volumetrically dominant species. Table 3 gives such a classification.

The formation of ice appeared to have a distinct effect on the zooplankton community since the rotifer population, dominated by *Keratella cochlearis* (Gosse), disappeared simultaneously with the freezing of the quarry. This left a copepod community composed of nauplii and adults of *Cyclops vernalis* Fischer. The



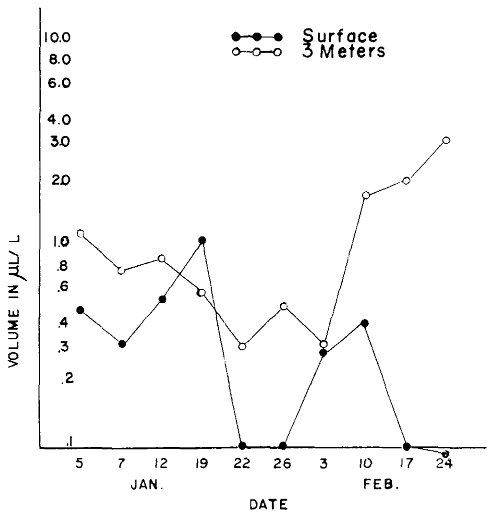


FIGURE 1. (Left) A comparison of the flagellate population at the surface and at a 3-m depth.

FIGURE 2. (Right) A comparison of the *Asterionella formosa* population at the surface and at a 3-m depth.

population of greatest density, 93 µl/l, was recorded during this period. After this period, *Bosmina coregoni* Baird became one of the major components, but this organism disappeared within a short time and once again *Cyclops* was the major component of the fauna.

The volume of zooplankton increased with depth (table 4). Furthermore, no vertical or diurnal migration of the zooplankton was observed.

In a comparison of tables 3 and 4, it may be noted that, except for the month of December, the total zooplankton volume nearly equalled or exceeded the total phytoplankton volume. Measurements of the zooplankton volume from 3 m were not taken during the first three months of this study. If such measurements had been made, the total volume might possibly have been greater and the low December zooplankton volume more than likely would have equalled or exceeded the phytoplankton volume.

From the foregoing information, no conclusion as to the carrying capacity of Urschel's Quarry can be made since only incomplete data concerning the daily utilization of the phytoplankton, detritus and other nutrients by the zooplankton exist. Cladocerans have been observed to have algae and detritus within their digestive tracts and in one instance a cyclops was observed eating a smaller copepod. Therefore, all of these substances must play some part in the maintenance of the zooplankton.

DISCUSSION

Quantitative studies based on the volumes of organisms are not new. Comita and Anderson (1959), Riley (1940), Verduin (1959), and others have advocated this method. However, the majority of limnological investigations have utilized the numbers of plankton per liter as a unit of measurement.

Verduin (1959) states, "The wide variation in volumes of different organisms emphasized the importance of determining volumes instead of reporting populations as numbers of cells per liter." This relationship has been clearly demonstrated in table 5. The smallest phytoplankter, *Chamydomonas* sp. is 1800 times smaller in volume than the largest phytoplankter, *Pandorina morum*. Similarly, the smallest zooplankter, *Halteria grandinella*, is 15,800 times smaller than the largest zooplankter, *Daphnia pulex* de Geer. If these organisms were reported as individuals per liter, they would receive equal weight and thereby obscure the significant difference which they represent as elements in the food chain.

TABLE 4

The average monthly population of zooplankton in relation to time and depth

Month	Time	Avg surface population µl/l	Avg 3 m population µl/l	Avg 5 m population µl/l
Oct.	0830	17.85		
	2100	33.37		
Nov.	0830	25.92		
	2100	15.37		
Dec.	0830	4.25		
	2100	4.81		
Jan.	0830	21.04	29.89	32.35
	1500	3.71	18.88	14.15
	2100	2.18	41.63	33.41
Feb.	0830	1.07	16.37	12.60
	1500	9.57	43.60	45.99
	2100	37.35	13.97	----

Even with this knowledge, some investigators, who have used volumetric determinations of phytoplankton, have persisted in the utilization of numbers per liter for zooplankton analysis. Davis (1954) believes that irregularity of shape and great variability of size among the individuals of many species prevent the determination of volumes of the various zooplankters. However, if each individual organism is measured carefully, the approximation of the total volume is a more significant figure than the number of individuals per liter.

Verduin (1956) lists literature citations which show that there is a rough inverse correlation between the depth of the epilimnion, or the total depth in unstratified lakes, and the standing crop of autotrophic plants. Since Urschel's Quarry has an average depth of 3 m or a relatively small epilimnion, this might partially explain the comparatively high value of 88 μl/1 of phytoplankton found in this study and the value of 130 μl/1 found by Verduin (1959) during the previous year. Both of these high values were obtained from surface samples which were taken through an ice cover. This tends to indicate that the flagellates were capable of maximal utilization of that light which penetrated the ice. This abundance of phytoplankton under the ice has also been confirmed by Smayda (1958) who found an abundant species of *Chlamydomonas* which was capable of phototrophic and chemotrophic assimilation under the ice.

High volumes of zooplankton such as those found in this study have also been found by Anderson, Comita and Engstrom-Heg (1955), who frequently observed a low or inverse correlation between the phytoplankton and zooplankton volumes. Pennak (1949) also reported zooplankton volumes exceeding phytoplankton volumes in six of nine lakes which he studied in Colorado. The data from Urschel's Quarry indicate that an equal or higher volume of animals is not unusual when investigators compare volumes of both phytoplankton and zooplankton instead of comparing volumes of phytoplankton to numbers of zooplankton.

TABLE 5

The range of volumes of organisms frequently found in Urschel's Quarry

Organism	Volume (μ^3)
A. Phytoplankton	
Asterionella formosa (cell)	1,250
Chlamydomonas sp	36
Chlorococcum infusionum	520–4,160
Cryptomonas erosa	900–1,728
Mallomonas caudata	8,038
Microcystis incerta	4,160
Pandorina morum (colony)	4,160–65,000
Scenedesmus quadricauda	2,100
B. Zooplankton	
Bosmina coregoni	36×10^6
Cyclops vernalis	3×10^6–32.256×10^6
Cyclops (nauplii)	768×10^3–1.024×10^6
Daphnia pulex	128×10^6
Halteria grandinella	8,100
Keratella cochlearis	81,000

The problem of how the zooplankton can survive on a lesser volume of phytoplankton must be considered. Several theories may be presented in an attempt to clarify this problem.

Anderson, Comita and Engstrom-Heg (1955) have proposed that the phytoplankton population is controlled by the grazing of the zooplankton. High zooplankton populations are maintained by high reproductive rates of the phytoplankton. However, when the algae stop reproducing, the zooplankton population declines.

Rodhe (1955) suggests that the higher zooplankton volumes found under the arctic ice by various investigators were a result of inadequate technique. He found a very large population of microplankton, 1 to 2 μ in diameter, which escaped normal quantitative studies. Thus, the high zooplankton population might be maintained by very small phytoplankton.

Pennak (1949) found no correlation between the magnitude of algal populations and zooplankton populations. Furthermore, he concluded that food materials do not appear to be a limiting factor for zooplankton and that the relative significance of the algae and detritus is unknown, but it is likely that the detritus is an important food source.

Edmondson (1957) also suggests that detritus has value as a nutrient for zooplankton. He believes that in distinguishing between living and dead organisms one should not lose sight of the original material. Therefore, dead plankton should not be thought of as an entity separate from the phytoplankton. However, it appears that Edmondson neglected the detritus formed from decomposition of the higher aquatic and terrestrial plants found around the body of water when he formulated this opinion.

One further food source has been denoted by Pennak (1946). He points out that in addition to eating plankton, detritus, and bacteria, certain zooplankton, especially *Cyclops*, are carnivorous and eat rotifers and other copepods.

A consideration of these publications suggests that a combination of all the above mentioned factors influences the abundance of the zooplankton. Furthermore, no one theory should be considered to be independent of the others.

SUMMARY

1. A quantitative study of the winter plankton was conducted in Urschel's Quarry, Bowling Green, Ohio.

2. Two sampling methods, the chamber method and the silk-bolting cloth method were compared. Little loss of phytoplankton occurred in the chamber method and only 0.47% of the phytoplankton, under 30 μ in diameter, were retained by the bolting cloth. In contrast, 99.89% of the zooplankton were retained by the bolting cloth. Volumes of zooplankton 2.7 times as great as those recorded by the chamber method were obtained by the silk-bolting cloth method.

3. No upward migration was noted among the nonflagellated phytoplankton. When flagellates occurred, surface samples contained 5 times as many organisms as did the samples taken at 3 m.

4. The zooplankton were found to increase in numbers and volume with depth. No diurnal migration was observed.

5. The volume of zooplankton nearly equalled or exceeded the volume of phytoplankton at most times. If other investigators would report zooplankton volumes per liter rather than numbers per liter, their results might show similar trends.

6. Insufficient evidence prevents a complete explanation of the cause of the high zooplankton volumes. However, it is most likely that the zooplankton obtain their nutrition from a combination of phytoplankton, detritus, bacteria, and carnivorous activity since no one nutrient appears sufficient to support the entire zooplankton population.

ACKNOWLEDGMENTS

I wish to acknowledge the assistance of Dr. William Jackson, Dr. Edward Karlin, and Dr. Jacob Verduin. Funds for equipment were supplied by the Atomic Energy Commission, grant number AT–(11–1)–536.

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