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A NOTE ON THE USE OF ALGAL SIZES IN ESTIMATES OF POPULATION STANDING CROPS

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Counts of cell numbers of phytoplankton algae of differing sizes do not accurately reflect the biomass of the population present. For a better estimate it is suggested that cell numbers be multiplied by the average cell volume for each species present. Data on cell volumes for certain species are given and compared with results from other authors. Surface areas and surface area to volume ratios are also given and the importance of these parameters noted.

The quantitative determination of algal populations by direct count methods is well known (Lund & Talling, 1957; Lund, LeCren & Kipling, 1958). A wide range of cell or colony sizes within a population or community, however, may lead to a misleading impression of the biomass present if the results are expressed simply as numbers ml^{-1} or l^{-1}. Some compensation may be attempted by transforming numerical records into volumes (Paasche, 1960; Nauwerk, 1963; Bellinger, 1968a).

For this operation to be a success it is necessary to know the mean cell, colony or other unit volume of each species recorded quantitatively. For those species whose cells are more or less regular in shape, simple geometric formulae may be applied to the measurements of linear dimensions (sphere, $4/3\pi r^3$; cone, $\frac{1}{3}\pi r^2 h$; cylinder, $\pi r^2 h$; truncated cone, $\frac{1}{3}\pi h(r^2_1+r_1r_2+r^2_2)$; etc.). It should be realised that, even for more or less regular cells, a given geometric formula may not exactly fit the shape of an organism, so errors will occur. These errors are, however, small compared with the total volume of the cell in, for example, *Asterionella formosa* Hass. and *Rhodomonas minuta* Skuja. For cells of more complex shape a displacement method with plastic models can be used.

In recent investigations of algal populations in fresh waters (Bellinger, 1968a, 1968b) a wide variety of species was subjected to size analysis. At least 100 cells were measured, and more than 1000 for some species, e.g. *Stephanodiscus astraea* (Ehrenb.) Grun. and *Asterionella formosa*. The calculated results obtained for average cell volume are listed in Table I and are compared with those of Nauwerk (1963), Nalewajko (1966) and Findenegg (1969).

Even though the algae recorded by these authors were from widely different environmental situations, there is very close agreement between the average cell volumes for the majority of comparable species. Of those where agreement is not so close (i.e. less than half or more than twice the volume recorded here), all apart from *Chlamydomonas angulosa* Dill, *Tetraedron minimum* (A. Br.) Hansg., *Stephanodiscus astraea* and *Synedra acus* Kütz. are within the possible range for the maximum and minimum volumes calculated from the linear dimensions recorded in the literature for those species (Pascher, 1915; Hustedt, 1930). The average cell volumes given by Nauwerk (1963) and Nalewajko (1966) (Table I)

TABLE I. The surface area (SA), volume (V) and surface area to volume ratios (SA/V) of some freshwater algae. For comparison, results for cell volumes recorded by Nauwerk (1963), Vollenweider (1969) and Nalewajko (1966) are given in columns 4, 5 & 6, respectively. GF = determined by geometric formula; M = determined by plastic model displacement method.

			1 SA (μm^2)	2 V (μm^3)	3 SA/V	4	5	6
Chlorophyta								
Chlamydomonas angulosa Dill		(GF)	710	1760	0·40			410
C. globosa Snow		(GF)	113	148	0·76			
Pandorina morum (Müll.) Bory (colony)		(GF)	1520	5600	0·27	3000	4000	
Eudorina elegans Ehrenb. (colony)		(GF)	2830	13,500	0·21	3000		10,240
Volvox aureus Ehrenb. (colony)		(GF)		27,000		30,000		
Ulothrix zonata (Web. et Mohr) Kütz.		(GF)	6190*	7000	0·88			
Pediastrum boryanum (Turp.) Menegh. (coenobium)		(GF)	18,200	16,000	1·14			
Coelastrum microporum Näg. (coenobium)		(GF)	1700	6560	0·26	3000		
Chlorella sp.		(GF)	47	30	1·55	20		20
Oocystis solitaria Wittr.		(GF)	380	640	0·59	500	400	
O. crassa Wittr.		(GF)	1020	2960	0·35			
Ankistrodesmus falcatus (Corda) Ralfs		(GF & M)	696	340	2·05	250	250	
A. falcatus var. *spirilliformis* G. S. West		(GF & M)	95	26	3·65			30
A. setigerus (Schrod.) G. S. West [*Schroderia setigera* (Schrod.) Lemm.]		(GF & M)	720	660	1·10	500		
Tetraedron minimum (A. Br.) Hansg.		(GF & M)	238	245	1·03	30	40	
Scenedesmus bijuga (Turp.) Legerh. (coenobium)		(GF)	725	710	1·03			
S. quadricauda (Turp.) Bréb. (coenobium)		(GF)	908	1000	0·91	1000	1000	800
S. quadricauda var. *maxima* W. et G. S. West (coenobium)		(GF)	2470	4450	0·55			
Actinastrum hantzschii Lagerh.		(GF)	310	345	0·90			
Crucigenia tetrapedia (Kirch.) W. et G. S. West (coenobium)		(GF)	442	605	0·73			
Micractinium pusillum Fres.		(GF)	155	180	0·86			
Tetrastrum staurogeniaeforme (Schrod.) Lemm. (coenobium)		(GF & M)	182	147	1·24			
Bacillariophyta								
Melosira varians C. Ag.	(a)	(GF)	503*	2100	0·24	2000		
	(b)			969	0·51			
M. granulata (Ehrenb.) Ralfs.	(a)	(GF)	503*	1590	0·33	1140	860	
	(b)			1087	0·47			
M. granulata var. *angustissima* O.F.M.	(a)	(GF)	440*	440	1·00	500		
	(b)			240	1·83			
Stephanodiscus astraea (Ehrenb.) Grun.	(a)	(GF)	4410	18,870	0·23	2500	2000	310
	(b)			7660	0·58			

S. astraea var. *intermedia* Fricke	(a)	(GF)	1510	3620	0·41	5000		
	(b)			2372	0·64			
S. hantzschii Grun.	(a)	(GF)	537	800	0·67	2500		
	(b)			437	0·23			
Tabellaria fenestrata (Lyngb.) Kütz.	(a)	(GF)	1934	3000	0·65	3000	4000	
	(b)			1600	1·21			
T. flocculosa (Roth.) Kg.	(a)	(GF & M)	996	1440	0·69	2000		620
	(b)			832	1·20			
Diatoma vulgare C. Ag.	(a)	(GF & M)	1050	1361	0·77			
	(b)			835	1·25			
Fragilaria crotonensis Kitton	(a)	(GF)	1006	666	1·51	300	400	
	(b)			592	1·70			
F. capucina Desmaz	(a)	(GF)	666	486	1·37	200		
	(b)		434	1·54				
Asterionella formosa Hass.	(a)	(GF)	867	750	1·15	800	700	650
	(b)			616	1·41			
Synedra acus Kütz.	(a)	(GF)	555	942	0·59	200	1000	1310
	(b)			852	0·65			
Synedra ulna (Nitzsch.) Ehrenb.	(a)	(GF)	2890	4900	0·59	5000		1950
	(b)			2400	1·20			
Nitzschia acicularis W. Sm.	(a)*	(GF)	402	251	1·60			280
N. palea (Kütz.) W. Sm.	(a)*	(GF)	360	270	1·33			
N. sigmoidea (Ehrenb.) W. Sm.	(a)	(GF & M)	3297	5232	0·63			
	(b)			3424	0·96			
Surirella ovata Kütz.**		(GF & M)		4069				
Cryptophyta								
Cryptomonas ovata Ehrenb.		(GF & M)	942	1658	0·57	2500	2500	
Rhodomonas minuta Skuja		(GF)	314	392	0·80	200		
R. minuta var. *nannoplanktica* Skuja		(GF)	154	134	1·15	100		
Cyanophyta								
Microcystis aeruginosa Kütz.		(GF)	50	30	1·50	1×10^5 per 200 μm colony	1×10^5 per colony	
Oscillatoria limosa C. Ag. (cm^{-1})		(GF)	$4·96 \times 10^5$	2×10^6	0·25			
O. tenuis C. Ag. (cm^{-1})		(GF)	$1·63 \times 10^5$	2×10^5	0·82	$1·5 \times 10^5$		880 per cell

* SA measurement excluding area of ends of cells which are joined to form a filament. For the diatoms, (a) gives the total cell volume measurement in column 2, whereas (b) gives the cell volume minus the volume of the cell vacuole with the SA/V ratio adjusted accordingly. Those species marked * were considered to have too small a vacuole to make much difference to the total volume calculations.
** Owing to the shape of this diatom, SA calculations could not be made.

for these four algae are below the minimum recorded size. The results of the present author represent average cell volumes calculated from measurements on numbers of cells. Even within a single population there was, on occasions, considerable size variation between different cells. For example, the volumes of cells of *Stephanodiscus astraea* ranged from 855–29 700 μm³ and of *Scenedesmus quadricauda* (Turp.) Bréb. (for a four-celled coenobium) from 865–3080 μm³. The range of cell sizes in individual populations should therefore be checked and average cell volumes determined for the major species on each occasion.

Although the use of total cell volumes may give a better indication of standing crop, undue stress may be placed on the larger algae in relation to their importance as primary producers. In particular, Lohman (1908) indicated that only a small proportion of a large diatom cell is occupied by chloroplasts and cytoplasm, the rest being vacuole. This should be taken into account when comparing the productive capacity and cell volumes since the cytoplasm may form only a layer of about 2 μm thickness around the periphery of the cell. It may possibly be of greater value to calculate total cell surface area rather than cell volume in these and other algae, especially if the result is used in conjunction with cell chlorophyll content (Paasche, 1960). Table I includes the calculated volumes of some diatom cells, excluding the volume of the cell vacuole, and also the surface areas for all species. Larger surfaces provide greater areas for both light and nutrient absorption and this, together with a small total cell volume, should be indicative of the potential rate of growth of that species. These two parameters are combined to give the surface area to volume ratio in Table I. The higher the surface area to volume ratio (SA/V) the greater should be the photosynthetic and absorption rates of the cell. Cells with such a high ratio might be expected to exhibit rapid population increases. Such increases have been observed for *Chlorella* sp., *Ankistrodesmus falcatus* var. *spirilliformis* G. S. West, *Nitzschia acicularis* W. Sm. and *Rhodomonas minuta*, while slower rates of division and population increase were observed for algae with a low SA/V such as *Melosira varians* C. Ag. (Bellinger, 1968b).

Surface area calculations used in conjunction with cell volumes could thus provide a useful measure of standing crop and give an indication as to the growth potential of the species.

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