waterloopkundig laboratorium
delft hydraulics laboratory

Amsterdam university
limnological laboratory

light, photosynthesis and carbon / chlorophyll ratios

a literature review

R 1310 – 2

June 1979

Amsterdam university
limnological laboratory

light, photosynthesis and carbon / chlorophyll ratios

a literature review

R 1310 – 2

June 1979

Preface

This report deals with the results of an extensive literature research to the relation between light and photosynthesis of phytoplankton and carbon-chlorophyll ratios in phytoplankton cells.
It is the second report of a literature research which is performed by Mrs. M. Lingeman-Kosmerchock of the Limnological Laboratory of the University of Amsterdam, in cooperation with Mr. F.J. Los of the Delft Hydraulics Laboratory.
The first report deals with the contents of nitrogen phosphorus, silicon and chlorophyll in phytoplankton cells, the mineralization rates of nutrients from phytoplankton cells and the sinking rates of phytoplankton cells.
This research project is part of an extensive assignment by the Environmental Division of the Delta Department to Delft Hydraulics Laboratory in order to develop ecological models, which can serve as tools in providing adequate guidelines for environmental management in the (future) water basins in the Delta area.
This multi disciplinary project,called Water Basin Model (WABASIM), is carried out in close cooperation between the Environmental Division of the Delta Department and the Environmental Hydraulics Branch of the Delft Hydraulics Laboratory.

CONTENTS

TABLES

1 Light and photosynthesis

Light is one of the most important factors regulating photosynthesis. Some of the earliest experiments on the effect of light intensity on photosynthesis were the laboratory experiments of Sargent (1940), who showed that the ratio of chlorophyll to dry matter in Chlorella increased with an increase in intensity during the growth stage. Working with Nitzschia, Barker (1935) studied the effect of intensity. However, he expressed the intensity and photosynthesis values in relative terms and his results are thus of little value for comparison.

Some of the earliest field work was that of Jenken (1937) who simultaneously measured the photosynthesis of the diatom Coscinodiscus excentricus at various light intensities and depths in the English Channel. In 1938 Manning, Juday, and Wolf presented data on the relationship between in situ photosynthetic rate and intensity for several species of freshwater algae at various depths with concurrent intensity measurements.

After this period of field study attention once again turned to the laboratory. Myers (1946) published a thorough investigation of light/photosynthesis curves obtained when algae were grown at different light intensities. Although this was a rather impressive study, later investigators (Steemann-Nielsen, Hansen, and Jorgensen 1962) were unable to reproduce Myers' results. They stated that contact with Myers revealed that his light meter had been inadequate. In 1948 Winokur published a similar investigation using different Chlorella species and these results were found to be reproduceable by Steemann-Nielsen, Hansen, and Jorgensen (1962).

The photosynthetic response to light intensity can be divided into two definate stages. The first stage is that of light reactions which split water and supply reductive and high energy compounds. The second stage is that of dark reactions during which these high energy compounds are used to complete carbon dioxide assimilation. These two stages are semi-independant (Yentish and Lee 1966) and the rates provide some information to help in understanding the response of the plant cell to environmental factors. Rabinowitch (1951) reviewed the literature dealing with photosynthesis and light in terrestrial and aquatic plants and a few algae. When the results where presented graphically the same general trend was found in every case. The curve describing this trend can

be separated into two regions. The first is the region where the photosynthetic rate increases linearly with an increase in intensity and this is called the region of light limitation. The slope of the curve at this stage is indicative of the rate for light reactions of photosynthesis.
The second region, termed saturation, is the area where the photosynthetic rate increases little or not at all with further increases in intensity. This maximum rate of photosynthesis (P_{max}) is limited by dark reactions of photosynthesis.

In 1957 Talling introduced the concept of I_k to represent the on-set of light saturation. This point is determined by the intersection of extensions of the linear and saturation regions. Steemann-Nielsen and Hansen (1959) in their interpretation of light/photosynthesis curves for natural populations of phytoplankton emphasized the I_k value. Their data illustrates the point that the reduction in I_k results from lower rates of light saturated photosynthesis (P_{max}) and not increased ability to photosynthesize at lower light intensities. Yentisch and Lee (1966) also emphasized the fact that reduced I_k values brought about by decreasing values of P_{max} did not mean an enhanced ability to utilize lower light intensities. They suggested that such a change in the I_k and P_{max} could be induced by methods other than growth at low light intensity.

In the following years attention turned to the concept of light adaption by phytoplankton. It was found that physiological adaption from one intensity to another might mean changes in the content of photosynthetically active pigments, changes in photosynthetically active enzymes, or both. Steemann-Nielsen and Jorgensen (1968) working with Chlorella pyrenoidosa emphasized the difference between expressing photosynthetic rates per cell and per chlorophyll. This algae adapted to reduced light intensity mainly through an increase in cell content of chlorophyll. As a result the rate of photosynthesis per cell was greater in cells previously grown at lower intensities. These authors did stress, however, that this phenomenon did not apply to all algae. This fact was confirmed by the work of Jorgensen (1964A, 1964B, 1968) who studied the adaption of several species to different light intensities. A distinction was made between the "chlorella" type and the "cyclotella" type of adaption. The "chlorella" type adaption was characterized by a change in the chlorophyll content per cell with a change in the intensity. More chlorophyll per cell was found at lower intensities. In the "cyclotella" type the

chlorophyll content remains the same at high and low intensities, while the photosynthetic rate is higher in cells that are grown at higher intensities. In this case it is assumed that the increase in the contents of enzymes causes an increase in the photosynthetic rate. All of the diatoms (Skeletonema costatum, Cyclotella meneghiniana, Nitzschia palea, Nitzschia closterium and Scenedesmus quadricauda) studied by Jorgensen were "cyclotella" type, however, the same investigator (1977) found diatoms of the "chlorella" type (names of these species were not listed). He also stated that his cultures were grown in incandescent light but that he found if he cultured one of the diatoms, Skeletonema costatum. in fluorescent light it adapted as a "chlorella" rather than a "cyclotella" type. These results suggest that the wavelength of light source has considerable influence on the mechanism employed by the cell to adapt to changes in light intensity.

It is accepted that the overall reaction in photosynthetic rate at low light intensities is limited by the rate of photochemical processes while at high light intensities it is limited by the rate of enzymatic processes (Steemann-Nielsen 1962). Beardall and Morris (1976), while working with the diatom Phaeodactylum tricornutum, showed that a change in photosynthetic ability was related to a change in activity of the enzymes responsible for the dark reactions of photosynthesis. They found evidence suggesting that growth of algae in reduced light levels enhances its ability to utilize saturation levels. This enhanced photosynthetic ability, however, does not result in an increase in growth rates.

Although beneficial adaptations have been found with a change in light intensity it has been observed by various investigators that a high intensity can be harmful to algae (Gessner & Diehl, 1951, Godward, 1962, and Van Baalen, 1968). Porphyridium cruentum exhibits considerable vacuolization, disruption of chloroplast lamellae and an increased number of starch grains when exposed to high light intensities (Brody & Vatter 1959). The shrinkage of the chloroplast lamellar structure with high light intensity has also been observed in Chlorella pyrenoidosa (Treharne et al., 1964) and Nostoc mucorum (Lazaroff & Vishniac 1960).

It is only in extreme cases of high intensity that the destruction of cell components including the chlorophyll take place. In most other cases only the rate of photosynthesis is depressed. Detailed reviews of the literature on this topic have been made by Stalfelt (1960), Kessler (1960), as well as Steemann-Nielsen (1962).

The first person to relate the destruction of cell components in light photo-oxidation was Noack (1925). Using Chlorella, Myers and Burr (1940) followed the rate of photosynthesis at a series of high and extremly high light intensities for a period of one hour. From their results it could be concluded that the decrease in the photosynthetic rate was due to photo-oxidative destruction of enzymes active in photosynthesis. Later experiments (Steemann-Nielsen,1949 & 1952, and Kok, 1956) showed that both light and dark reactions could be depressed by high intensity. This was shown by transfering algae from high intensities to low intensities where the rate of photosynthesis is determined by the rate of light reactions. The influence of the high intensity on the light reactions of photosynthesis was called chlorophyll inactivation by Steemann- Nielsen (1942 & 1952). He also believed the decrease in the rate of photosynthesis at light saturation was due to destruction of the enzymes.

It was also observed by Steemann-Nielsen (1952) that although loss or inactivation of photosynthetic capacity occurred at high light intensity the cells recovered significantly when they were put in the dark. This treatment caused no change in composition or amount of pigment. He concluded that inactivation at high intensity was a protective mechanism. Other investigations (Kok, 1956, Myers & Burr, 1940) on the effect of light intensity on photosynthesis of Chlorella, however, revealed that this damage is reversible only below a critical level (specific for species) above which there is irreversible damage and destruction of the photosynthetic apparatus.

This same effect of high intensity is exhibited in natural waters by a marked depression in photosynthesis near the surface where the algae are exposed to nearly full incident solar radiation (Marshall & Orr, 1928, Jenken, 1937, Steemann-Nielsen, 1952, Nelson & Edmondson, 1955, Schomer & Juday, 1935,and Manning & Juday, 1941). On bright days it is common to observe a distinct depression of photosynthesis near the surface. The decrease in photosynthetic rates is associated with photo-oxidative destruction of chlorophyll.

It should be noted, however, that it has also been observed that some species do not exibit inhibition at high light intensities. This is especially the case in those species which inhabit the littoral zone (Manning, Juday, & Wolf, 1938, McMillan & Verduin, 1953). The algae which survive well in high

light intensity are often referred to as "sun" or "sun adapted" species. These algae are genetically and or environmentally adapted to growth at intensities near that of full sunlight (compared to "shade" species which tolerate only less than 5% of full sunlight). In addition,"sun" plants have a higher photosynthetic capacity, a higher dark respiration rate, as well as having higher irradience requirements for light saturation photosynthesis and for compensation of dark respiration (Talling, 1961 and Raven & Glidewell, 1975). Although members of an algal species can show some variation in these characteristics it is generally possible to assign them into the "sun" or "shade" catagories. Species which have been reported to be "sun" species include the marine littoral alga, Chaetomorpha linum and Entromorpha intestinalis (Raven & Smith, 1977) which reach light saturation at about 200 joules $M^{-2}.sec^{-1}$ and the freshwater chlorophytes Ankistrodesmus (Ullrich, 1973) Chlorella (Sorokin,1959), Spirogyra (Thomas et al.,1957) Ulna (Haxo & Clendenning, 1953) Scenedesmus and Hormidium (Argua, 1965, Raven & Glidewell, 1975) and some species of Cladophora (McMillan & Verduin, Raven & Glidewell, 1975) all of which achieve light saturation of photosynthesis at around 100 joules $M^{-2}.sec^{-1}$.

The most direct method of measuring production is simply by the measurement of the increase in the standing crop over a certain known time interval. It is this method which in various forms has been used to measure primary production in freshwater.

In photosynthesis carbon dioxide is reduced to organic carbon with the evolution of free oxygen in a reaction that uses the energy of solar radiation. The reaction equation for photosynthesis is: $CO_2 + H_2O \rightarrow CH_2O + O_2$. The volume of oxygen liberated very nearly approximates the volume of carbon dioxide assimilated. The effect of respiration is the reverse of photosynthesis. Ecologists are generally less concerned with "gross" production that they are with the "net" production which is photosynthesis in excess of respiration and therefore represents the real production of organic matter which is added to a system. If production is measured experimentally for short time periods the effects of respiration are eliminated by preforming parallel experiments in the dark in which only respiration is measured. This method is applicable only if there is no appreciable growth during the experiment and when the rate of respiration in light is the same as in the dark. The following is a summary of methods which are used to

measure production. A detailed discription of all the methods can be found in Rhyther (1956), and Vollenweider (1969).

Oxygen production

This method has usually been employed in the laboratory with the use of elaborate manometric techniques which are unsuitable for the field. Therefore, limnological experiments in the field usually employ the method first described by Gaarder & Gran (1927) which consist of measuring the rate of dissolved oxygen titrametrically with the Winkler method in samples in paired "light/dark" bottles.

Carbon dioxide assimilation

The uptake of carbon dioxide is equivalent mole for mole to the production of organic carbon. In natural water of alkaline pH carbon dioxide exists in equilibrium with carbonate molecules. Thus,photosynthesis can be determined quantitatively only by following the levels of the entire buffer system. The only practical field method to do this is by measuring the change in pH. To be effective a relatively large uptake of carbon dioxide is necessary to produce a pH change. The sensitivity of pH meters usually permit this in freshwaters, however, problems arise in highly alkaline lakes and the ocean where a detectable pH change in 24 hours only occurs in the areas of extremely high algal production.

Fixation of carbon-14

The most recent method, described first by Steemann-Nielsen (1952) and later reviewed and modified by Rhyther and Vaccaro (1954), involves measuring the uptake rate of radioactive carbon (C^{14}) by algae. In this method a small sample of $C^{14}O_2$ is added to the sample of water with natural phytoplankton populations. Photosynthesis then proceeds for a certain time period. The plankton is then filtered onto filter paper which retains the organism. The filter is washed, dried, and the activity measured by standard counting techniques. This method is the most sensitive technique and is now most commonly used in measuring photosynthesis in the field conditions as well as in the laboratory.

Uptake of mineral nutrients

The uptake of nitrogen, phosphorus and other minerals in the environment have been used in the past to estimate the primary production. Since the

changes in concentration are small this method does not lend itself to experimental measurements of ordinary chemical means. Short term uptake has been measured experimentally by a radio-tracer (P^{32}) technique but a problem arises in attempting to relate uptake rates to organic production.

Chlorophyll a

Chlorophyll a is sometimes used as a measurement of plankton productivity. The application of this method is discussed in detail in the section of this report on the carbon:chlorophyll relationships.

Difficulty arises when one attempts to compare rates of photosynthesis in various algae. This is due to the various methods used to measure photosynthesis and the different ways of expressing the results. Photosynthetic production determined by oxygen production and carbon dioxide fixation can not be compared with a great deal of certainty. Strickland (1960, See also Appendix) has given some equations for the conversion of oxygen and carbon dioxide values into a standard carbon unit. In many cases in the literature the photosynthetic quotient which is needed for some of the conversions is omitted from the explanation of the experimental methods. In view of this difficulty separate tables have been made for production in terms of carbon (Tables 2 & 4) and oxygen (Tables 3 & 5).

It is more difficult and nearly impossible to compare the various parameters used by different authors to express the unit of algae cells. This has been done as photosynthesis per unit volume of culture, per number of cells, per dry weight of cells, per unit chlorophyll,and also per packed cell volume. Quite frequently investigators provide very few details of the parameters of their experiment and thus it is once again impossible to convert and standardize the results of the various studies. This is another reason why no attempt was made to standardize the production values in Table 1 through 5.

The photosynthetic ability in relation to light intensity has been studied both in the field and laboratory. Each approach has some limitations. Laboratory determinations can give well defined data on the photosynthesis whereas with observations in natural waters this is not always the case. The field situation, with exposure in the natural water itself, appears to give more applicable results although it is possible the information might be only valid for the specific environmental conditions encountered in the

experimental situation. Perhaps the best solution is a study which combines field and laboratory work. The major difficulty here is comparison of light intensities measured in the two situations, especially in view of spectral modifications of submarine light with depth (Talling, 1960).

Solar radiation covers a spectral wavelength of 3,000 - 30,000 Å. Rabinowitch (1951) fully discusses the wavelength limits of photosynthetic active light. The photosynthetic active part of the spectrum ranges from 3000 - 7200 Å. As light falls on the surface of the water the intensity per unit area diminishes with depth. The two main causes of this are absorption and scattering. The spectral composition of the light changes as it penetrates the water (Clark 1939). Infrared and ultraviolet light are very rapidly absorbed by lake water and only the visable light penetrates to a significant degree.

Solar radiation striking on the surface of a water body does not penetrate totally. A significant portion is reflected from the surface. A reasonable average amount reflected on a clear summer day is 5-6% (Wetzel 1975). This value increases to a mean value of about 10% in the winter. Scattering of light from the water also results in loss of a large amount of light from the lake. The scattering of light is the result of deflection of light energy by molecular components of the water and its solutes as well as particulate materials suspended in the water. The amount of scattered light varies greatly with depth, season, and location. The energy that does penetrate the water undergoes a diminuation of energy with depth both by scattering and absorption. This must be taken into account when in situ measurements of photosynthesis versus light intensity are done.

Total radiation, which is the sum of direct solar and diffuse sky radiation, is measured with a pyranometer. This instrument is either thermo-electric or mechanical. The instrument used to measure total solar radiation is called a pyrheliometer. Light is measured with a photometer which is most commonly a self sufficient barrier-layer instrument.

The measurement of submarine light is complicated by the existence of two factors, first the vertical gradient change (quantitative) and second, the radiation spectrum change (qualitative). The quantitative change can be measured directly by means of a pyranometer enclosed in a waterproof box. The qualitative changes are estimated from relative changes, for which a

barrier layer instrument is most suitable. For a complete discussion of methods, calibrations, and their advantages and disadvantages Vollenweider (1969) and Strickland (1958) should be consulted.

Confusion is encountered when one attempts, for comparison, to standardize the intensity units used by the various investigators. The total quantity of radiation energy received on a total unit area of surface over a particular time is called "total irradiance" and if referred to in unit time it is called "intensity" or "irradiance". Photosynthesis is a photochemical process and thus the proper unit to use is quanta per second per surface area. If illumination is to be presented in terms of energy, as it most commonly is, then the wavelength of light must be known to convert the quanta units to energy units. Unfortunatly this is not often done as is the case with the data in Table 1. Here the values given in quanta and einsteins could not be converted since wavelength information was not given in the description of the experimental methods. When photosynthesis is given in terms of energy the units that have been used in the literature include; watts.cm^{-2}, watts.M^{-2}, langlys.min^{-1}, and in some cases the calorie is still used as a unit. The standard unit which according to the Bureau International des Poids et Mesures should now be used for energy is joules (joules.cm^{-2}.sec^{-1}). The conversion units used to get the various energy units in terms of joules are given in the Appendix. To comply with the needs of the WASBASIM model these units are converted to joules.M^{-2}.hr^{-1}. The original energy unit presented in the various papers and the converted values are given in Table 2, for production in terms of carbon, and Table 3, for production in terms of oxygen.

The comparison of the intensity data is made even more complicated by the fact that many biologist have persisted in using the units lux and foot-candles. These units have been used in laboratory work with a definate light source of the same spectral characteristics as a standard candle. In some cases these values have also been used for measurements of daylight at water surface in the field. To be valid the light source must have some resemblance to the standard candle on which the use of lux is based. Thus, for colored light, the use of lux in meaningless as is also the case with submarine light. The use of the lux unit is now to be discouraged in experimental procedure as it provides very little comparible data since it is generally impossible to convert these values into real energy units. With recent developments in instrumentation much more accurate measurements can now be made without relying on the standard light source comparison. If a definate light source

has been used and is given in a paper using lux units the conversion can be fairly accurate. These conversion values are listed in the Appendix and have been used in Tables 4 and 5 to represent the intensity values in terms of joules. However, caution should be taken in the application of these values since they are estimates and not definate values.

2 Carbon: chlorophyl a ratios and assimilation numbers

The measurement of algal chlorophyll a as an index of productivity has a direct application since chlorophyll a is the central component of the photosynthesis mechanism. In many field studies phytoplankton productivity and algal concentrations are estimated by determining the content of chlorophyll a. What is actually desired is the concentration of algal carbon but in field situations direct measurement of standing stock as carbon is sometimes limited and imprecise due to the difficulty in separating zooplankton and detrital carbon from the algal carbon.

Steele & Baird (1961 & 1962) attempted to overcome the problem by carrying out chemical analysis of chlorophyll a and carbon content of a great many samples and then determining the carbon to chlorophyll a ratio from a regression of chlorophyll a on total carbon. The slope of the line equals the average carbon: chlorophyll a and the intercept with the Y axis (carbon) is interpreted as the average amount of carbon which is contained in detritus and zooplankton.

The chief problem in using chlorophyll a as a measure of phytoplankton standing stock is that the ratio is variable and depends on the past history of the cells with light intensity, temperature and nutrient availability being the primary environmental factors affecting the ratio (Eppley 1972).

A rather constant relationship between chlorophyll a and photosynthesis at any given light intensity has been described by several authors who worked in the field (Manning & Juday 1941, Gessner, 1949, and Edmondson, 1955) and in the laboratory (Fleischer, 1935, Emerson et al., 1940, Blaauw-Jansen et al., 1950, and Rhyther, 1956). In these studies the relationships appear to hold constant for different species (Edmondson, Rhyther) and within a wide range of chlorophyll content of the organisms resulting from their state of nutrition (Fleischer) or the duration of the light intensity to which they have previously been exposed (Blaauw-Jansen et al., & Rhyther). While working with laboratory cultures of Chlorella Milner (1953) found the carbon: Chlorophyll a ratio to range between 8-1,600:1 with varying light intensity. Rhyther and Yentisch (1957) deduced a formula which estimated the gross production from a knowledge of incident light, extinction coefficient and chlorophyll a. The main disadvantage to their method is that it did not take into account adaptation of the algae to varying light intensity. Steele (1962), in a later mathematical formulation of these relationships, theorized

that the adaptation of plants to a decrease in intensity would require a continual decrease in the carbon: chlorophyll a ratio but there would be some lower limit of this ratio which defines the lower light limit range to which plants can adapt.

The carbon: chlorophyll a ratio has been studied in laboratory cultures to observe the effect of changing nutrient concentration on the ratio. Is has been observed that at nutrient depletion a corresponding decrease in the photosynthetic rate exists. It was first suggested (Steele 1962) that nutrient limitation operates by varying the carbon: chlorophyll a ratio. Steele felt that the ratio increased as an unspecified function of declining external nutrient concentrations. Experimental data revealed the ratio is about 30:1 for phytoplankton with adequate nutrient concentrations and higher for phytoplankton subject to nutrient depleted water (Strickland, 1960 and Steele & Baird, 1962b).

It was observed by Harrison et al. (1977) that under ammonia starvation and limitation the carbon: chlorophyll ratio was higher than in non-limited cells but this was due to a decrease in chlorophyll per cell. This had een earlier observed by Hobson & Pariser (1971) who found the ratio increased from four to ten times when the diatoms Thalassiosira pseudonana was nitrogen starved. For the first 160 hours of starvation this was due to a decrease in the chlorophyll per cell after which time starvation was due to a decrease in the carbon per cell. Holm-Hansen et al. (1968), working with Skeletonema costatum, found the ratio increased from 70-200 under nitrogen deficient conditions, Eppley and Renger (1974) found the ratio increased from 28.7 - 91.4 as the degree of nitrogen limitation was increased in a chemostat.

Carbon: chlorophyll a ratios under silicate starvation have also been studied by Harrison et al. (1977). The ratio in silicon limited cells was higher than the non-limited cells as a result of an increase in carbon per cell.

Eppley (1972) theorized that as a result of temperature shifts the ratio in algae tends to minimize changes in growth rates. However, it was found in Lake Kinneret, Israel (Berman & Pollingher 1974) that changes in the species composition rather than shifts in chemical make-up within the species determined the physiological processes such as photosynthetic potential and growth rate.

There have been many estimates of the carbon: chlorophyll *a* ratio which cover a large range of values from 13-500:1. Strickland (1971) stated for both marine and freshwater natural populations of algae the ratio usually varies from 30-90 in progression from eutropic to oligothropic situations. Lorenzen (1968) observed a mean value of 40 for healthy natural populations of phytoplankton. It is this value which is frequently used for comparison and calculations (Harrison et al. 1977). The various values of for the ratio which have been found in the literature are summarized in Table 6.

Some investigators have chosen to compare the relationships between chlorophyll *a* and carbon in another manner which is referred to as the assimilation number. This is generally given in terms of the mg carbon fixed .mg chl $a^{-1}.hr^{-1}$ (Platt & Subbo Rao, 1975). In natural populations the variations in assimilation number are related primarily to species composition and environmental factors which influence light saturated growth such as temperature, nutrient supply and toxic imput (Malone 1977).

In a series of laboratory experiments Rhyther (1956) illustrated that although the amount of chlorophyll per cell and the rate of photosynthesis per cell are extremely variable, the rate of photosynthesis per unit chlorophyll remains relatively constant at any given light intensity regardless of the intensity at which the cell was grown.

Is has been shown that high assimilation numbers are characteristic of healthy log phase populations while low numbers are characteristic of senescent populations (Yentsch & Lee, 1966 and Subba Rao, 1969). Phytoplankton in nutrient poor waters have a low assimilation number compared to those of nutrient rich waters (Curl and Small, 1965 & Thomas, 1970, Malone, 1971, Thomas and Dodson, 1972).

Measured assimilation numbers found in the literature are listed in Table 7. The range of values is a low of 0.02 to a high of 68.9 mg C.mg chl.$a^{-1}.hr^{-1}$ with mean values ranging from 0.22 to 25.2 mg C.mg chl.$a^{-1}.hr^{-1}$.

Table 1: Species specific variation in phytoplankton productivity with varied light intensities as $\mu E.m^{-2}.sec^{-1}$ and Quanta.$cm^{-2}.sec^{-1}$

species or dominant species	type of species[1]	environment[2]	type of light used[3]	method of productivity measurement[4]	intensity	productivity	source of data	Remarks	References
CHLOROPHYTA (green algae)									
Chlorella sp.	F	L	N.G.	ΔO_2	$\mu E.m^{-2}.sec^{-1}$		Figure 4	"Shade" adapted culture I_k=125 $\mu E.m^{-2}.sec^{-1}$	Griffiths et al., 1978
					100	0.4 $mm^3\ O_2.10^6.cells^{-1}.hr^{-1}$			
					180	1.2			
					250	1.4			
					600	1.5			
					1600	1.6			
					60	0.5	Figure 3	"Sun" adapted culture	Griffiths et al., 1978
					150	1.4			
					220	2.7			
					610	3.1			
					780	3.15			
Dunaliella tertiolecta	M	L	"Cool white" Fluorescent	ΔO_2	60	10 μg at $O_2.cell^{-1}.min^{-1}x10^{-8}$	Figure 3		Falkowski & Owens, 1978
					250	19			
					600	29			
					1000	39			
					1100	41			
					1200	50			
					1300	55			
BACILLARIOPHYTA (diatoms)									
Cyclotella nana	M	L	"Cool white" Fluorescent	ΔO_2	200	5 μg at $O_2.cell^{-1}.min^{-1}x10^{-8}$	Figure 3		Falkowski & Owens, 1978
					500	10			
					1000	15			
					1200	26			
Ditylum brightwelli	M	L	"Cool white" Fluorescent	ΔO_2	200	5	Figure 3		Falkowski & Owens, 1978
					600	5			
					1080	25			
					1300	30			
Lauderia borealis	M	L	G.E. 500 W Tungsten spot G500-PAE/NSP	ΔO_2	$\mu E.m^{-2}.day^{-1}$		Table 1		Marra, 1978
					9.13	0.057 mmol $O_2.cell^{-1}.day^{-1}$			
					8.27	0.058			
					10.93	0.080			
					10.51	0.080			
					5.36	0.056			
					6.57	0.070			

Table 1: (continued)

species or dominant species	type of species[1]	environment[2]	type of light used[3]	method of productivity measurement[4]	intensity	productivity	source of data	remarks	references
Skeletonema costatum	M	L	"Cool white" Fluorescent	ΔO_2	$\mu E.m^{-2}.sec^{-1}$		Figure 3		Falkowski & Owens, 1978
					7	4 μg at $O_2.cell^{-1}.min^{-1} \times 10^{-8}$			
					50	13			
					200	16			
					700	24			
					1000	33			
CHRYSOPHYTA (Chrysophytes)									
Isochrysis galbana	M	L	"Cool white" Fluorescent	ΔO_2	50	1	Figure 3		Falkowski & Owens, 1978
					200	5			
					550	8			
					1000	10			
					1100	15			
					1300	16			
MIXED POPULATION									
Hawaii-Pacific Ocean	M	N	Natural sunlight 12:00-13:00 hrs	^{14}C	$Quanta.cm^{-2}.sec^{-1}$		Table 1	meters depth	Bienfang & Gunderson, 1977
					165.0	0.174 mg $C/m^3.hr$		10	
					26.0	0.218		50	
					17.4	0.236		70	
					9.2	0.184		90	
					4.4	0.020		110	
					2.4	0.034		150	
					271.0	0.067		10	
					14.5	0.033		90	
					7.0	0.012		110	
					1.6	0.012		150	

1. F refers to a fresh water species
   M refers to a marine species
2. L refers to a laboratory culture experiment
   N refers to an in situ experiment
3. N.G. source not given
4. ΔO_2 by change in oxygen concentration
   ^{14}C by the radiocarbon method
5. Figure - the data was read off this specific figure in the reference given
   Table - the data was taken directly from this table in the reference given

1. M refers to a marine species

   F refers to a fresh water species

2. L - laboratory culture experiment

   N - in situ experiment

3. N.G. - type of light source was not given in reference

4. ^{14}C - radiocarbon method

5. These values are in units as given in the reference. These values were converted into joules.m^{-2}.hr^{-1} as follows;

   w.cm^{-2}

   1 w.cm^{-2} = 1 joule.cm^{-2}.sec^{-1}

   joules.m^{-2}.hr^{-1} = (w.cm^{-2})(3600 sec/hr)(10^4 cm^2/m^2)

   ergs.cm^{-2} sec^{-1}

   1 erg.cm^{-2}.sec^{-1} = 10^{-7} w.cm^{-2} = 10^{-7} joules.cm^{-2}.sec^{-1}

   joules.m^{-2}.hr^{-1} = (ergs.cm^{-2}.sec^{-1})(10^{-7})(3600 sec.hr)(10^4 cm^2/m^2)

   ly.min^{-1}

   1 ly.min^{-1} = 0.0698 w.cm^{-2} = 0.0698 joules.cm^{-2}.sec^{-1}

   joules.m^{-2}.hr^{-1} = (ly.min^{-1})(0.0698)(3600 sec.hr^{-1})(10^4 cm^2/m^2)

   cal.cm^{-2}.min^{-1}

   1 cal.cm^{-2}.min^{-1} = 6.98 x 10^{-2} w.cm^{-2} = 6.98 x 10^{-2} joules.cm^{-2}.sec^{-1}

   joules.m.sec^{-1} = (cal.cm^{-2}.min^{-1})(6.98 x 10^{-2})(3600 sec/hr)(10^4 cm^2/m^2)

   kcal.m^{-2}.hr^{-1}

   1 kcal.m^{-2}.hr^{-1} = 1.16 x 10^4 w.cm^{-2} = 1.16 x 10^{-4} joules.cm^{-2}.sec^{-1}

   joules.m^{-2}.hr^{-1} = (kcal.m^{-2}.hr^{-1})(1.16 x 10^{-4})(3600 sec/hr)(10^4 cm^2/m^2)

6. Units varied from one paper to an other and could not be converted into one uniform value

7. Figure - data read off this figure in the reference given

   Table - data taken directly from this table in the reference given

Table 2: Species specific variation in phytoplankton productivity expressed in terms of carbon with varied light intensities expressed in terms as joules.$m^{-2}.hr^{-1}$

species or dominant species	type of species[1]	environment[2]	light source[3]	method of productivity measurement[4]	light intensity[5] original units		light intensity[5] joules.$m^{-2}.hr^{-1}$ x 10^4	productivity[6]		data source[7]	remarks	references
CHLOROPHYTA (green algae)												
Chlorella pyrenoidosa	M	L	Fluorescent Philips TL20W/33	^{14}C	1	mW.cm^{-2}	3.6	0.8	mg C.10^9 $cells^{-1}.hr^{-1}$	Figure 4		Steemann-Nielsen & Willemoes, 1971
					2		7.2	1.2				
					4		14.4	2.2				
					6.5		23.4	4.1				
					13.5		48.6	4.8				
					24.0		86.4	4.8				
CYANOPHYTA (blue green)												
Coelosphaerium sp.	F	L	Fluorescent Philips TL20W/33	^{14}C	1.0	mW.cm^{-2}	3.6	0.02	mg C.10^9 $cells^{-1}.hr^{-1}$	Figure 5		Steemann-Nielsen & Willemoes, 1971
					1.5		5.4	0.05				
					3.5		12.6	0.1				
					7.0		25.2	0.165				
					14.0		50.4	0.260				
					25.0		90.0	0.255				
BACILLARIOPHYTA (diatoms)												
Melosira sp. (dominant)	M	N	Natural daylight	^{14}C	126	ly.$4hr^{-1}$	131.9	2.96	mg C.$m^{-3}.hr^{-1}$	Table 2	Study in April between 10:00-14:00 hrs	Wallen & Geen, 1971
Navicula pelliculosa	F	L	N.G.	^{14}C	0.1	ergs.$cm^{-2}.sec^{-1}$x10^4	0.36	0.2	mg C.10^6 $cells^{-1}.hr^{-1}$	Figure 1		Wallen & Cartier, 1975
					0.5		1.8	0.95				
					1.0		3.6	1.5				
					1.5		5.4	3.5				
					2.0		7.2	3.6				
					2.8		10.1	3.6				
					4.0		14.4	3.6				
Nitzschia palea	M	L	Fluorescent Philips TL20W/33	^{14}C	0.5	mW.cm^{-2}	1.8	0.45	mg C.10^9 $cells^{-1}.hr^{-1}$	Figure 3		Steemann-Nielsen, Willemoes, 1971
					1.0		3.6	1.0				
					2.0		7.2	1.9				
					3.0		10.8	3.0				
					7.0		25.2	3.9				
					14.0		50.4	4.1				

Table 2: continued

species or dominant species	type of species[1]	environment[2]	light source[3]	method of productivity measurement[4]	light intensity[5] original units	light intensity[5] joules.m^{-2}.hr^{-1} x 10^4	productivity[6]	data source[7]	remarks	references
Chromulina & Rhodomonas dominant	F	L&N	N.G.	^{14}C	0.04 ly.min^{-1}	10.05	0.45 mg C.m^{-2}.hr^{-1}	Figure 1	8° C	Stanley & Daley, 1976
					1.4	351.8	0.90		8° C	
					3.8	954.9	0.81		8° C	
					0.015	3.8	0.1		1.4° C	
					0.04	10.1	0.7		1.4° C	
					1.4	351.8	1.2		1.4° C	
					3.8	954.0	1.3		1.4° C	
					0.015	3.8	0.1		20° C	
					0.04	10.05	0.55		20° C	
					1.4	351.8	1.1		20° C	
					3.8	954.9	1.21		20° C	
N.W. Atlantic	M	N	natural daylight	^{14}C	460 cal.cm^{-2}	80.0	1.18 g C.m^{-2}.day^{-1}	Table 2	Values given in Rhyter&Yentsch, 1957	Riley, 1939
N. Atlantic–Long Is.Sound	M	N	natural daylight	^{14}C	347	60.4	1.06			Riley, 1956
N. Pacific–Friday Harbor	M	N	natural daylight	^{14}C	300	52.2	0.34			Conover, 1956
N. Pacific–Wash. Coast	M	N	natural daylight	^{14}C	700	121.6	5.10			Ryther & Yentsch, 1957
N. Pacific–Gulf of Alaska	M	N	natural daylight	^{14}C	229	39.8	1.50			Ryther & Yentsch, 1957
N. Atlantic–Woods Hole	M	N	natural daylight	^{14}C	547	95.2	1.17			Ryther & Yentsch, 1957
North Sea	M	N	natural daylight	^{14}C	1.65 cal.m^{-2}.day^{-1} x 10^6	28.39	78.4 mg C.m^{-2}.day^{-1}	Table 3	Study conducted February through May	Gieskes & Kraay, 1972
					1.10	18.79	105			
					1.03	17.92	196			
					2.34	40.72	497			
					2.42	42.09	1311			
					3.02	52.74	3503			
					3.95	69.15	1948			
					3.43	59.68	1398			
					6.71	116.76	2945			

Table 2: continued

species or dominant species	type of species[1]	environment[2]	light source[3]	method of productivity measurement[4]	light intensity[5] original units	light intensity[5] joules.m^{-2}.hr^{-1} x 10^4	productivity[6]	data source[7]	remarks	references
Skeletonema, Chaetoceros, Navicula, Thalassiosira & Gymnodinium	M	N	natural daylight	^{14}C	5.5 ly.min^{-1} x 10^{-3}	1.38	0.31 mg C.mg Chl.a^{-1}.hr^{-1}	Table 3		Anita et al., 1963
					9.2	2.31	0.69			
					7.1	1.78	0.35			
					5.1	1.28	0.35			
					4.4	1.11	0.26			
					1.7	0.43	0.18			
					1.9	0.48	0.16			
					1.3	0.34	0.16			
					0.3	0.08	0.056			
					0.5	0.13	0.082			
					0.9	0.23	0.12			
					0.8	0.20	0.085			
MIXED POPULATIONS										
Flagellates dominant	M	N	natural daylight	^{14}C	198 ly.$4hr^{-1}$	207.3	16.31 mg C.m^{-3}.hr^{-1}	Table 2	Study in June	Wallen & Geen, 1971
					205	214.6	8.69		Study in June	
					203	212.5	5.54		Study in July	
Synura, Chlamydomonas, Mallomonas, Akrokomos, Chrysococcus & Rhodomonas	F	N	natural daylight	^{14}C	150 ly.min^{-1} x 10^{-3}	37.69	0.15 mg.C.m^{-3}.hr^{-1}	Table 2	Study conducted in a pond under ice cover	Wright, 1964
					25	6.28	9.09			
					150	37.69	1.56			
					18.7	4.70	8.73			
					1.76	0.44	1.99			
					18.7	4.70	6.35			
					0.235	0.06	0.16			
					0.78	0.20	0.04			
					0.45	0.11	0.04			
					0.16	0.04	0.016			
					0.59	0.15	0.15			
					0.13	0.03	0.016			
Chromulina & Rhodomonas dominant	F	L&N	N.G.	^{14}C	0.015 ly.min^{-1}	3.76	0.1 mg C.m^{-2}.hr^{-1}	Figure 1	2^{o} C	Stanley & Daley, 1976
					0.04	10.05	0.35		2^{o} C	
					1.4	351.7	0.45		2^{o} C	
					3.8	954.8	0.05		2^{o} C	
					0.015	3.8	0.1		8^{o} C	

Table 2: continued

species or dominant species	type of species[1]	environment[2]	light source[3]	method of productivity measurement[4]	light intensity[5] original units	light intensity[5] joules.m^{-2}.hr^{-1} x 10^4	productivity[6]	data source[7]	remarks	references
Skeletonema costatum	M	L	500 W G.E. T 3Q tungsten vapor lamp	ΔO_2	0.01 ly.min^{-1}	2.5	50 mg C.m^{-3}.hr^{-1}	Figure 5		McAllister et al., 1964
					0.05	12.56	300			
					0.08	20.1	400			
					0.1	25.13	485			
					0.155	38.95	450			
					0.295	74.88	475			
					0.360	90.46	475			
Skeletonema costatum	M	L	N.G.	^{14}C	0.08 cal.cm^{-2}.min^{-1}	20.1	1.8 μg C. g Chl.a^{-1}.hr^{-1}	Figure 2	Indoor "shade adapted" culture	Kiefer, 1973
					0.2	50.3	3.5			
					0.3	75.4	5.0			
					0.6	150.8	4.8			
					0.88	221.1	3.1			
					1.25	314.1	0.2			
					0.2	50.25	1.7	Figure 2	Outdoor "sun adapted" culture	
					0.32	80.4	2.0			
					0.60	150.8	2.9			
					0.95	238.7	3.2			
					1.39	349.3	2.0			
Thalassiosira sp. (dominant)	M	N	natural daylight	^{14}C	1.73 ly.4hr^{-1}	1.81	9.47 mg C.m^{-3}.hr^{-1}	Table 2	May study	Wallen & Geen, 1971
					1.86	1.95	4.59	Table 2	June study	
Skeletonema costatum, Thalassiosira sp. (dominant)	M	N	natural daylight	^{14}C	1.43 ly.4hr^{-1}	1.50	0.55 mg C.m^{-3}.hr^{-1}	Table 2	April study	Wallen & Geen, 1971
Melosira sp., Skeletonema costatum (dominant)	M	N	natural daylight	^{14}C	86 ly.4hr^{-1}	90.0	6.29 mg C.m^{-3}.hr^{-1}	Table 2	March study	Wallen & Geen, 1971
Synedra, Thalassiosira	M	N	natural daylight	^{14}C	184 ly.4hr^{-1}	192.6	10.03 mg C.m^{-3}.hr^{-1}	Table 2	June study	Wallen & Geen, 1971

1. M refers to marine species

   F refers to fresh water species

2. L - Laboratory culture experiment

   N - in situ experiment

3. N.G. - light source not given in reference

4. O_2 - by measurement of change in oxygen concentration

5. Original units used in reference were converted to joules.m^{-2}.hr^{-1} as follows:

   W.cm^{-2}

   1 W.cm^{-2} = 1 joule.cm^{-2}.sec^{-1}

   joule.m^{-2}.hr^{-1} = (W.cm^{-2})(3600 sec.hr^{-1})(10^4 cm^2/m^2)

   ergs.cm^{-2}.sec^{-1}

   1 erg.cm^{-2}.sec^{-1} = 10^{-7} W.cm^{-2} = 10^{-7} joules.cm^{-2}.sec^{-2}

   joules.m^{-2}.hr^{-1} = (ergs.cm^{-2}.sec^{-1})(10^7)(3600 sec/hr)(10^4 cm^2/m^2)

   ly.min^{-1}

   1 ly.min^{-1} = 0.0698 W.cm^{-2} = 0.0698 joules.cm^{-2}.sec^{-1}

   joules.m^{-2}.hr^{-1} = (ly.min^{-1})(0.0698)(3600 sec/hr)(10^4 cm^2/m^2)

   Cal.cm^{-2}.min^{-1}

   1 cal.cm^{-2}.min^{-1} = 6.98 x 10^{-2} W.cm^{-2}

   joules.m^{-2}.hr^{-1} = (cal.cm^{-2}.hr^{-1})(6.98 x 10^{-2})(3600 sec/hr)(10^4 cm^2/m^2)

   Cal.cm^{-2}.hr^{-1}

   1 cal.cm^{-2}.hr^{-1} = 1.16 x 10^{-3} W.cm^{-2} = 1.16 x 10^{-3} joules.cm^{-2}.sec^{-1}

   joules.m^{-2}.hr^{-1} = (1.16 x 10^3)(3600 sec/hr)(10^4 cm^2/m^2)

6. Units varied from paper to paper & units convented to one standard

7. Figure - values taken from this figure in the reference given

   Table - values taken from this table in the reference given

Table 3: Species specific variation in phytoplankton productivity expressed in terms of oxygen with varied light intensities expressed as joules.m^{-2}.hr^{-1}

species or dominant species	type of species[1]	environment[2]	light source used[3]	method of productivity measurement[4]	light intensity[5] original units		light intensity[5] joules.m^{-2}.hr^{-1} x 10^4	productivity[6]		Source of data[7]	remarks	references
CHLOROPHYTA												
Cladophora glomerata	F	N&L	500 W projection lamp	ΔO_2	21	W.m^{-}	7.56	41	μmol O_2.mg Chl.a^{-1}.hr^{-1}	Table 2	Cultures isolated from various locations in Lake Erie	Mantai, 1974
					92		33.1	72				
					332		119.5	106				
					72		25.9	94				
					72		25.9	67				
					18		6.5	56				
					98		35.3	145				
					22		7.9	68				
					57		20.5	39				
Chlorella pyrenoidosa	M	L	tungsten light	ΔO_2	1	mW.cm^{-2}	3.6	70	μmol O_2.μmol Chl.a^{-1}.hr^{-1}	Figure 1		Myers, 1970
					2		7.2	125				
					3		10.8	155				
					4.8		17.3	175				
					5.5		19.8	175				
					7.0		25.2	175				
Scenedesmus sp.	F	N&L	500 W projection lamp	ΔO_2	84	W.m^{-2}	30.2	182	μmol O_2.mg Chl.a^{-1}.hr^{-1}	Table 2		Mantai, 1974
Sorastrum sp.	F	L	N.G.	ΔO_2	5	ly.min^{-1}	1256	0.39	mol O_2.$cell^{-1}$.$\frac{1}{2}hr^{-1}$ x 10^{-12}	Figure 3	12 HR L:D cycle	Harris & Lott, 1973
					4		1005	0.41				
					3		753.8	0.43				
					2		502	0.495				
					1		251.6	0.52				
Ulothrix sp.	F	N&L	500 W projection lamp	ΔO_2	111	W.m^{-2}	39.96	108	μmol O_2.mg Chl.a^{-1}.hr^{-1}	Table 2		Mantai, 1974
BACILLARIOPHYTA (diatoms)												
Asterionella formosa	F	N	natural daylight	ΔO_2	2	Kerg.cm^{-2}.sec^{-1}	0.72	1	mg O_2.10^9 $cells^{-1}$.hr^{-1}	Figure 7	experiment at 11°C in situ	Talling, 1957A
					4		1.44	2				
					9		3.24	3				
					17.5		6.3	4				

Table 3: continued

species or dominant species	type of species[1]	environment[2]	light source used[3]	method of productivity measurement[4]	light intensity[5] original units		light intensity[5] joules.m^{-2}.hr^{-1} x 10^4	productivity[6]		source of data[7]	remarks	references
Asterionella formosa	F	N	natural daylight	ΔO_2	5	Kerg.cm^{-2}.sec^{-1}	1.8	1.5	mg O_2.10^9 cells^{-1}.hr^{-1}	Figure 7	experiment at 11°C in situ	Talling, 1957A
					13		4.68	3.5				
					40		14.4	4.5				
Asterionella formosa	F	L	N.G.	ΔO_2	2	Kerg.cm^{-2}.sec^{-1}	0.72	0.5	mg O_2.10^9 cells^{-1}.hr^{-1}	Figure 7	experiment at 6°C	Talling, 1957A
					4		1.4	1.5				
					7		2.5	3.4				
					17		6.1	4.5				
Asterionella formosa	F	L	N.G.		5	Kerg.cm^{-2}.sec^{-1}	1.8	2.5	mg O_2.10^9 cells^{-1}.hr^{-1}	Figure 7	experiment at 11°C	Talling, 1957A
					13		4.7	6.0				
					40		14.4	9.5				
Asterionella formosa	F	N	natural daylight	ΔO_2	150	Kerg.cm^{-2}.sec^{-1}	54.0	137	mg O_2.m^{-2}.hr^{-1}	Table 1	hourly value between 12:00-15:00 hrs	Talling, 1957B
					1.3	Kerg.cm^{-2}.day^{-1} x 10^6	4.1	875	mg O_2.m^{-2}.day^{-1}		daily values for a dull day	Talling, 1957B
					7.1	Kerg.cm^{-2}.day^{-1} x 10^6	29.58	1640	mg O_2.m^{-2}.day^{-1}		daily values , for a sunny day	Talling, 1957B
Asterionella formosa	F	L	80 W Fluorescent	ΔO_2	165	Kerg.cm^{-2}.sec^{-1}	59.4	4.5	mg O_2.10^9 cells^{-1}.hr^{-1}	Table 2		Talling, 1957B
					150		54.0	5.0				
					270		97.2	9.0-11.0				
					280		100.8	11.0				
					115		41.4	10.5				
					205		73.8	12.0				
					225		81.0	10.5				
Asterionella formosa .	F	N&L	Fluorescent	ΔO_2	6.15	Kerg.cm^{-2}.sec^{-1}	2.21	3.5	mg O_2.10^9 cells^{-1}.hr^{-1}	Figure 8	Incubated at 10.6°C, I_k=4.13x10^4 joules.m^{-2}.hr^{-1}	Talling, 1966
					10.25		3.69	5.0				
					20.5		7.38	5.9				
					45.1		16.2	6.0				
					6.15		2.21	3.0				
					10.25		3.69	3.5			Incubated at 4.8°C	Talling, 1966
					20.5		7.38	4.0				
					48.1		17.3	3.5				

Table 3: continued

species or dominant species	type of species[1]	environment[2]	light source used[3]	method of productivity measurement[4]	light intensity[5] original units	light intensity[5] joules.m^{-2}.hr^{-1} x 10^4	productivity[6]	source of data[7]	remarks	references
Chaetoceros affinis	M	L	Fluorescent	ΔO_2	6.15 Kerg.cm^{-2}.sec^{-1}	2.21	0.01 mg O_2.mm^3 cell vol.hr^{-1}	Figure 3	I_k=1.79x10^4 joules.m^{-2}.hr^{-2}	Talling, 1960
					18.45	6.69	0.03			
					45.1	16.2	0.058			
					86.1	30.99	0.06			
					6.15	2.2	0.01	Figure 3	I_k=7.92x10^4 joules.m^{-2}.hr^{-2}	Talling, 1960
					18.45	6.6	0.038			
					45.1	16.2	0.079			
					86.1	30.99	0.08			
Melosira italica	F	N	N.G.		33 Kerg.cm^{-2}.sec^{-1}	11.88	2.7 mg O_2.mm^3 cell vol.hr^{-1}	Table 2		Talling, 1957A
Melosira sp. & Asterionella sp.	F	N&L	N.G.	ΔO_2	0.5 ly.min^{-1}	125.6	0.45 mol O_2.$cell^{-1}$.$\frac{1}{2}hr^{-1}$x10^{-12}	Figure 3	12 hour light: dark cycle	Harris & Lott, 1973
					1.0	251.3	0.30			
Phaeodactylum tricornutum	M	L	tungsten lamp "White light"	ΔO_2	0.5 W.cm^{-2} x 10^3	1.8	8.0 L O_2.mm^{-3}.hr^{-1}	Figure 2		Mann & Myers, 1968
					0.6	2.2	13.5			
					1.1	3.96	21.0			
					1.8	6.5	31.0			
					2.7	9.7	32.0			
					4.1	14.8	34.0			
					6.5	23.4	34.0			
Stephanodiscus astraea (dominant)	F	N	"daylight" Fluorescent	ΔO_2	120 W.m^{-2}	43.2	820 mg O_2.m^3.hr^{-1}	Figure 10	22°C I_k=13.68x10^4 joules.m^{-2}.hr^{-1}	Bindloss, 1976
					60	21.6	800			
					25	9.0	400			
					120	43.2	580		14.5°C I_k=9.36x10^4 joules.m^{-2}.hr^{-1}	
					60	21.6	580			
					22	7.9	390			
					15	5.4	220			

Table 3: continued

species or dominant species	type of species[1]	environment[2]	light source used[3]	method of productivity measurement[4]	light intensity[5] original units	light intensity[5] joules.m^{-2}.hr^{-1} x 10^4	productivity[6]	source of data[7]	remarks	references
PYRROPHYTA (dinoflagellates)										
Gonyaulax polyedra	M	L	Fluorescent G.E. F48P617-CW 110 W "cool-white"	ΔO_2	4.00 W.cm^{-2}	1.44	179 mol O_2 .mol Chl.a^{-1}	Table 1	All photosynthesis values are P_{max} at the respective intensity	Prezelin & Sweeney, 1978
					8.00	2.88	179			
					12.50	4.5	198			
					17.00	6.12	244			
					25.00	9.0	306			
					40.00	14.4	201			
MIXED POPULATION										
Closterium, Netrium, Navicula, Oedogonium & Spiryogyra (dom. species)	F	N	natural daylight	ΔO_2	32.6 cal.cm^{-2}.hr^{-1}	135.69	19.9 ml O_2.m^{-2}.hr^{-1}	Table 1	0.5 m depth	Gruendling, 1971
					23.0	96.32	22.7		1.0 m depth	
					14.4	60.30	19.4		2.0 m depth	
					10.06	42.13	14.5		3.0 m depth	
					5.5	23.03	2.4		4.0 m depth	
Mixed population Scottish Lake	F	N	natural daylight	ΔO_2	0.12 cal.cm^{-2}.min^{-1}	30.15	450 mg O_2.m^{-3}.hr^{-1}	Figure 2		Jewson, 1975
					0.9	226.15	700			
					0.5	125.6	800			
					0.8	201.0	650			
					0.06	15.08	200			

Tabel 4: Species specific variation in phytoplankton productivity expressed in terms of carbon with varied light intensities expressed as Klux, as well as estimated values in joules.m^{-2}.hr^{-1}.

species or dominant species	type of species[1]	environment[2]	light source[3]	method of productivity measurement[4]	intensity: Klux	intensity: joules.m^{-2}.hr^{-1} x 10^4	productivity	source of data[6]	remarks	reference
CHLOROPHYTA (green algae)										
Actinastrum hantzschii	F	L	NG	^{14}C	9.1		3.9 μg C.mg dry wt^{-1}.hr^{-1}	Table 4	dry wt is 37.1 μg/10^6 cells	Nalewajko, 1966
Ankistrodesmus falcatus	F	L	NG	^{14}C	9.1		12.9 μg C.mg dry wt^{-1}.hr^{-1}	Table 4	dry wt is 4.87 μg/10^6 cells	Nalewajko, 1966
Ankistrodesmus falcatus	F	L	incandescent	^{14}C	3.0	5.8*	1.0 μg C.10^6 $cells^{-1}$.hr^{-1}	Tables 1&2	pre-adapted to 3 klux I_k = 7 klux	Jørgensen, 1969
Ankistrodesmus falcatus	F	L	incandescent	^{14}C	30.0	58.2*	1.95 μg C.10^6 $cells^{-1}$.hr^{-1}	Tables 1&2	pre-adapted to 30 klux I_k = 17	Jørgensen, 1969
Asterococcus superbus	F	L	NG	^{14}C	9.1		3.7 μg C.mg dry wt^{-1}.hr^{-1}	Table 4	dry wt is 1.180 μg/10^6 cells	Nalewajko, 1966
Bracteococcus minor	F	L	daylight fluorescent lamp	CA	0.54 3.77 8.61 18.8	0.544** 3.80 8.68 18.95	0.3 μmole O_2/(Cell)(min)x10^8 1.23 1.4 1.43	Table 3	culture incubated 48 hr in dark before the photosynthesis experiment	Sheath & Hellebust, 1974
Chlamydomonas angulosa	F	L	NG	^{14}C	9.1		2.8 μg C.mg dry wt^{-1}.hr^{-1}	Table 4	dry wt is 130.9 μg/10^6 cells	Nalewajko, 1966
Chlamydomonas moewusii	F	L	incandescent	^{14}C	1 5 6 9 19 29	1.94 9.7 11.64 17.46 36.86 56.26	1.1 μg C.10^6 $cells^{-1}$.hr^{-1} 3.1 4.9 5.2 5.5 6.9	Figure 1	cells grown at and adapted to 3 klux, I_k = 9 klux	Jørgensen, 1969
					1 5 6 9 19 20	1.94 9.7 11.64 17.46 36.86 38.8	0.2 0.8 1.0 1.2 2.1 2.5	Figure 1	cells grown at and adapted to 30 klux, I_k = 14 klux	Jørgensen, 1969
Chlorella sp.	F	L	NG	^{14}C	3.2 5.5 10.75 43.0 75.3		1.5 μg C.mg dry wt^{-1}.hr^{-1} 2.0 2.1 2.15 2.0	Figure 3	dry wt is 130.9 μg/10^6 cells	Nalewajko, 1966
Chlorella pyrenoidosa	M	L	NG	^{14}C	1.5 2.0 4.5 8.0		0.3 mg C.10^9 $cells^{-1}$.hr^{-1} 1.0 1.9 3.5	Figure 3	experiment designed to study effects of mercury	Kamp-Nielsen, 1971
Chlorella pyrenoidosa	M	L	incandescent	^{14}C	3	5.82*	1.1 μg C.10^6 $cells^{-1}$.hr^{-1}	Table 2	grown at and adapted to 3 klux I_k = 6 klux	Jørgensen, 1969
					21	40.74*	2.0	Table 2	grown at and adapted to 21 klux I_k = 25 klux	Jørgensen, 1969
Chlorella pyrenoidosa	M	L	incandescent	^{14}C	9.1	17.65*	4.8 μg C.mg dry wt^{-1}.hr^{-1}	Table 4		Nalewajko, 1966
Chlorella pyrenoidosa	M	L	Philips TL20 W/33	^{14}C	1.5 2.5 5.0 10.0 19.0	1.52** 2.52 5.04 10.08 19.15	0.2 mg C.10^9 $cells^{-1}$.hr^{-1} 0.9 1.8 3.0 4.0	Figure 1	Cells grown at and adapted to 6 klux, Light:Dark cycle 16L:8D	Steemann-Nielsen et al., 1969

Table 4 (continued)

species or dominant species	type of species[1]	environment[2]	light source[3]	method of productivity measurement[4]	intensity: klux	intensity: joules.m^{-2}.hr^{-1} x 10^4	productivity	source of data[6]	remarks	references
Chlorella vulgaris	F	L	incandescent	^{14}C	1	1.94*	0.15 mg C.10^9 cells^{-1}.hr^{-1}	Figure 2	grown at and adapted to 30 klux	Steemann-Nielsen et al., 1962
					2	3.88	0.4			
					5	9.7	0.6			
					9	17.46	1.0			
					18	34.92	1.4			
					28	54.32	1.6			
					1	1.94*	0.42		grown at and adapted to 3 klux I_k = 4.2 klux	
					2	3.88	1.2			
					5	9.7	1.4			
					9	17.46	1.4			
Chlorella vulgaris	F	L	incandescent	^{14}C	3	5.82*	1.0 μg C.10^6 cells^{-1}.hr^{-1}	Table 2	adapted to 3 klux, I_k = 10	Jørgensen, 1969
					30	58.2*	1.6		adapted to 30 klux, I_k = 13	
Chodatella sp.	F	L	NG	^{14}C	3.2		3.2 μg C.mg dry wt^{-1}.hr^{-1}	Figure 3	dry wt is 126 μg/10^6 cells	Nalewajko, 1966
					5.5		4.95			
					43.0		7.0			
					75.3		6.8			
					9.1		9.6			
Dictyosphaerium ehrenbergianum	F	L	NG	^{14}C	9.1		4.3 μg C.mg dry wt^{-1}.hr^{-1}	Table 4	dry wt is 80.4 μg/10^6 cells	Nalewajko, 1966
Dunaliella euchlora	M	L	NG	^{14}C	75.30		0.34 mg C.10^6 cells^{-1}.4hr^{-1}	Table 5	cells were grown at 3.77 klux and are designated "shade adapted"	Rhyther, 1956B
					50.57		0.49			
					25.82		1.30			
					10.22		1.50			
					3.01		0.73			
					1.29		0.36			
					75.3		0.06	Table 5	cells were grown at 16.1 klux and are designated "sun adapted"	
					50.57		0.17			
					25.82		0.28			
					10.22		0.24			
					3.01		0.17			
					1.24		0.07			
Eudorina elegans	F	L	NG	^{14}C	9.10		4.1 μg C.mg dry wt^{-1}.hr^{-1}	Table 4	dry wt is 250 μg/10^6 cells	Nalewajko, 1966
Micractinium pusillum	F	L	NG	^{14}C	9.1		6.0 μg C.mg dry wt^{-1}.hr^{-1}	Table 4	dry wt is 37.4 μg/10^6 cells	Nalewajko, 1966
Monodus subterraneus	F	L	incandescent	^{14}C	0.5	0.97	0.1 μg C.10^6 cells^{-1}.hr^{-1}	Figure 3	cells grown at and adapted to 3 klux, I_k = 6 klux	Jørgensen, 1969
					1.0	1.94	0.25			
					1.5	2.91	0.3			
					7.0	13.58	0.8			
					10.0	19.4	0.9			
					19.0	36.86	0.9			
					30.0	58.2	0.9			
					0.5	0.97	0.1	Figure 3	cells grown at and adapted to 30 klux, I_k = 6 klux	
					4.5	8.73	0.35			
					7.0	13.58	0.4			
					10.0	19.4	0.45			
					19.0	36.86	0.45			
					30.0	58.2	0.45			
Pediastrum duplex	F	L	NG	^{14}C	9.1		3.6 μg C.mg dry wt^{-1}.hr^{-1}	Table 4	dry wt is 197.5 μg/10^6 cells	Nalewajko, 1966
Scenedesmus dimorphus	F	L	NG	^{14}C	9.1		5.3 μg C.mg dry wt^{-1}.hr^{-1}	Table 4	dry wt is 503.9 μg/10^6 cells	Nalewajko, 1966

Table 4 (continued)

species or dominant species	type of species[1]	environment[2]	light source[3]	method of productivity measurement[4]	intensity: klux	intensity: joules.m^{-2}.hr^{-1} x 10^4	productivity	source of data[6]	remarks	reference
Scenedesmus obliquus	F	L	incandescent	^{14}C	3,0	5.82*	0.22 µg C.10^6 cells^{-1}.hr^{-1}	Table 2	grown at and adapted to 3 klux I_k = 10 klux	Jørgensen, 1969
Scenedesmus obliquus	F	L	incandescent	^{14}C	30	58.2*	0.65 µg C.10^6 cells^{-1}.hr^{-1}	Table 2	grown at and adapted to 30 klux I_k = 15 klux	Jørgensen, 1969
Scenedesmus quadricauda	F	L	incandescent	^{14}C	3	5.82*	0.95 µg C.10^6 cells^{-1}.hr^{-1}	Table 2	grown at and adapted to 3 klux I_k = 9 klux	Jørgensen, 1969
					30	58.2*	4.55	Table 2	grown at and adapted to 30 klux I_k = 16 klux	Jørgensen, 1969
Scenedesmus quadricauda	F	L	NG	^{14}C	9.1		6.3 µg C.mg dry wt^{-1}.hr^{-1}	Table 4	dry wt is 92.9 µg/10^6 cells	Nalewajko, 1966
Staurastrum sp.	F	L	NG	^{14}C	9.1		4.0 µg C.mg dry wt^{-1}.hr^{-1}	Table 4	dry wt is 4.551 µg/10^6 cells	Nalewajko, 1966
					3.2		0.5	Figure 3		
					5.5		1.7			
					10.8		1.25			
					43.0		1.15			
					75.0		1.15			
Stichococcus bacillaris	F	L	NG	^{14}C	9.1		4.8 µg C.mg dry wt^{-1}.hr^{-1}	Table 4	dry wt is 15.3 µg/10^6 cells	Nalewajko, 1966
Ulothrix sp.	F	L	NG	^{14}C	9.1		2.1 µg C.mg dry wt^{-1}.hr^{-1}	Table 4	dry wt is 141,5 µg/10^6 cells	Nalewajko, 1966
Ulothrix sp.	F	L	NG	^{14}C	3.2		0.15 µg C.mg dry wt^{-1}.hr^{-1}	Figure 3	dry wt is 141.5 µg/10^6 cells	Nalewajko, 1966
					5.5		0.8			
					10.75		0.9			
					43.0		0.7			
					75.3		0.4			
CYANOPHYTA (blue-green algae)										
Oscillatoria sp.	F	L	NG	^{14}C	9.1		4.5 µg C.mg dry wt^{-1}.hr^{-1}	Table 4		Nalewajko, 1966
Oscillatoria sp.	F	L	NG	^{14}C	3.2		0.6 µg C.mg dry wt^{-1}.hr^{-1}	Figure 3		Nalewajko, 1966
					5.5		0.7			
					10.75		0.95			
					43.0		0.9			
					75.0		0.9			
Synechococcus elongatus	F	L	incandescent	^{14}C	1	1.94*	2 µg C.10^6 cells^{-1}.hr^{-1}	Figure 2	cells grown at and adapted to 3 klux, I_k = 5 klux	Jørgensen, 1969
					2	3.88	7.5			
					7	13.58	22.0			
					10	19.4	24.0			
					19	36.86	21.0			
					30	58.2	15.5			
					1.0	1.94	2.5 µg C.10^6 cells^{-1}.hr^{-1}	Figure 2	cells grown at and adapted to 30 klux, I_k = 10 klux	Jørgensen, 1969
					2.0	3.88	10.0			
					4.5	8.73	11.0			
					7.0	13.58	15.0			
					10.0	19.4	21.0			
					19.0	36.86	25.0			
					30.3	58.78	25.5			
BACILLARIOPHYTA (diatoms)										
Asterionella formosa	F	L	NG	^{14}C	9.1		5.2 µg C.mg dry wt^{-1}.hr^{-1}	Table 4		Nalewajko, 1966

species or dominant species	type of species[1]	environment[2]	ligth source[3]	method of productivity measurement[4]	intensity klux	intensity joules.m^{-2}.hr^{-1} x 10^4	productivity	source of data[6]	remarks	reference
Cyclotella meneghiaiana	F	L	incandescent	^{14}C	1	1.94	0.5 µg C.10^6 cells^{-1}.hr^{-1}	Figure 3	cells grown at and adapted to 3 klux	Jørgensen, 1964
					5	9.7				
					6	11.64				
					9.5	18.43				
					19.0	36.86				
					30.0	58.2				
Cyclotella meneghiaiana	F	L	incandescent	^{14}C	1	1.94*	0.5 µg C.10^6 cells^{-1}.hr^{-1}	Figure 3	cells grown at and adapted to 30 klux, I_k = 12.2 klux	Jørgensen, 1964
					4	7.76	1.9			
					6	11.64	2.2			
					9	17.46	3.5			
					19	36.86	4.2			
					30	58.2	5.0			
Fragilaria capucina	F	L	NG	^{14}C	9.1		5.0 µg C.mg dry wt^{-1}.hr^{-1}	Table 4	dry wt is 103.7 µg/10^6 cells	Nalewajko, 1966
Melosira sp.	F	L	NG	^{14}C	9.1		3.7 µg C.mg dry wt^{-1}.hr^{-1}	Table 4	dry wt is 147.7 µg/10^6 cells	Nalewajko, 1966
Melosira sp.	F	L	NG	^{14}C	3.2		0.8 µg C.mg dry wt^{-1}.hr^{-1}	Figure 3	dry wt is 147.7 µg/10^6 cells	Nalewajko, 1966
					5.5		1.0			
					10.75		1.1			
					43.0		1.1			
					75.3		0.8			
Navicula pelliculosa	F	L	NG	^{14}C	9.1	5.82*	3.1 µg C.mg dry wt^{-1}.hr^{-1}	Table 4	dry wt is 22.4 µg/10^6 cells	Nalewajko, 1966
Nitzschia closterium	M	L	incandescent	^{14}C	3	58.2*	0.55 µg C.10^6 cells^{-1}.hr^{-1}	Table 2	grown at 3 klux, I_k = 9 klux	Jørgensen, 1969
					30		2.18		grown at 30 klux, I_k = 14 klux	
Nitzschia kutzingiana	F	L	NG	^{14}C	9.1		4.8 µg C.mg dry wt^{-1}.hr^{-1}	Table 4	dry wt is 18.7 µg/10^6 cells	Nalewajko, 1966
Nitzschia palea	F	L	incandescent	^{14}C	1.0	1.94*	0.1 µg C.10^6 cells^{-1}.hr^{-1}	Figure 4	cells grown at and adapted to 3 klux, I_k = 8 klux	Jørgensen, 1969
					3.5	6.79	0.9			
					6.0	11.64	1.1			
					9.0	17.46	1.5			
					19.0	36.86	1.15			
					30.0	58.2	1.1			
Nitzschia palea	F	L	incandescent	^{14}C	1.0	1.94*	0.15 µg C.10^6 cells^{-1}.hr^{-1}	Figure 4	cells grown at and adapted to 3 klux, I_k = 8 klux	Jørgensen, 1969
					3.5	6.79	0.9			
					6.0	11.64	1.0			
					9.0	17.46	1.7			
					19.0	36.86	2.5			
					30.0	58.2	2.5			
					1.0	1.94	0.15	Figure 4	cells grown at and adapted to 30 klux, I_k = 13 klux	
					3.5	6.79	0.9			
					6.0	11.64	1.0			
					9.0	17.16	1.7			
					19.0	36.86	2.5			
					30.0	58.2	2.5			
Skeletonema costatum	M	L	fluorescent Philips TL W/33	^{14}C	1.0	1.008**	2.0 µg C.10^6 cells^{-1}.hr^{-1}	Figure 5		Jørgensen, 1966
					2.5	2.52	4.0			
					5.0	5.04	7.5			
					10.0	10.08	15.0			
					18.0	18.14	21.0			
					31.0	31.24	23.0			

Tabel 4 (continued)

species or dominant species	type of species[1]	environment[2]	light source[3]	method of productivity measurement[4]	intensity: klux	intensity: joules.m^{-2}.hr^{-1} x 10^4	productivity	source of data[6]	remarks	reference
Skeletonema costatum	M	L	incandescent	^{14}C	3	5.82*	0.7 µg C.10^6 cells^{-1}.hr^{-1}	Table 2	adapted to 3 klux, I_k = 9 klux	Jørgensen, 1969
					30	58.2	3.5	Table 2	adapted to 30 klux, I_k=16 klux	
Synedra sp.	F	L	NG	^{14}C	9.1		2.83 µg C.mg dry wt^{-1}.hr^{-1}	Table 4	dry wt is 1,024 µg/10^6 cells	Nalewajko, 1966
Tabellaria sp.	F	L	NG	^{14}C	3.2		0.15 µg C.mg dry wt^{-1}.hr^{-1}	Figure 3	dry wt is 207,7 µg/10^6 cells	Nalewajko, 1966
					5.5		0.8			
					10.75		0.9			
					43.0		0.7			
					75.3		0.4			
Tabellaria floculosa	F	L	NG	^{14}C	9.1		3.7 µg C.mg dry wt^{-1}.hr^{-1}	Table 4	dry wt is 207.7 µg/10^6 cells	Nalewajko, 1966
MIXED POPULATION										
North Atlantic	M	N	incandescent and natural daylight	^{14}C	5.0	9.7*	1.9 mg C.mg Chla^{-1}.hr^{-1}	Figure 2	35 meter depth	Steemann-Nielsen & Hansen, 1959
					10.0	19.4	3.0			
					15.0	29.1	1.9			
					5.0	9.7	1.9	Figure 2	surface to 16 meters	Steemann-Nielsen & Hansen, 1959
					10.0	19.4	3.5			
					15.0	29.1	3.5			

1. M refers to marine species
   F refers to fresh water species
2. L refers to laboratory culture experiment
   N refers to in situ experiment
3. NG - type of light used is not given in reference
   14C - radiocarbon method
   CA - carbon analyzer
5. Units vary and are given as cited in reference as it is not possible to standardize these values
6. Figure - data is read off this figure in the reference given
   Table - data is taken directly from this table in the given reference

* indicates values in joules.m^{-2}.hr^{-1} estimated according to Hill & Whittingham, 1955 - see Appendix

** indicates values in joules.m^{-2}.hr^{-1} estimated according to Westlake, 1965 - see Appendix

1. M refers to a salt water species
   F refers to a fresh water species
2. L – cultured and studied under laboratory conditions
   N – studied <u>in situ</u>
3. NG – light source is not given in reference
4. ΔO_2 – photosynthesis measured by changes in oxygen concentration
5. Productivity – units variedfrom paper to paper and it was not possible to standardize the values
6. Refers to how data was obtained from the reference
   Figure – values read as close as possible from a graph or graph in paper. The number refers to which figure in the reference was used
   Table – values read directly as tabulated in the reference. The number refers to which table in that particular reference

* – indicates values in joules.m^{-2}.hr^{-1} estimated according to Hill & Whittingham, 1955 – see Appendix

** – indicates values in joules.m^{-2}.hr^{-1} estimated according to Westlake, 1965 – see Appendix

*** – illumination given in m-candles, joules.m^{-2}.hr^{-1} estimated according to Strickland, 1958 assuming that the standard candle was used as the light source.

Table 5: Species specific variation in phytoplankton productivity expressed in terms of oxygen with varied light intensities expressed as Klux, as well as estimated values in joules.$m^{-2}.hr^{-1}$

species or dominant species	type of species[1]	environment[2]	source of light[3]	method of productivity measurement[4]	intensity		productivity[5]	source of data[6]	remarks	reference
					klux	joules.m^{-2}.hr^{-1} x 10^4				
CHLOROPHYTA (green algae)										
Chlorella ellipsoidea	F	L	NG	ΔO_2	0.7	1.031***	48.0 mm^3 O_2.10^9 $cells^{-1}.hr^{-1}$	Table 2	Grown at 6 klux	Winokur, 1948
					1.7	2.51	100.3			
					3.6	5.31	176.7			
					6.8	10.04	207.7			
					11.6	17.12	228.3			
					18.8	27.16	248.3			
					26.7	39.4	245.7			
					0.7	1.03	33.7	Table 2	Grown at 2 klux	
					2.0	2.95	80.7			
					4.0	5.90	115.0			
					6.0	8.86	128.3			
					11.6	17.12	136.3			
					18.4	27.16	138.7			
					0.7	1.03	22.7	Table 2	Grown at 0.7 klux	
					2.0	2.95	48.7			
					4.0	5.90	63.3			
					6.0	8.86	64.3			
					11.6	17.12	59.3			
					18.4	27.16	52.3			
Chlorella luteoviridis	F	L	NG	ΔO_2	0.7	1.03***	38.0 mm^3 O_2.10^9 $cells^{-1}.hr^{-1}$	Table 2	Grown at 6 klux	Winokur, 1948
					1.7	2.51	76.3			
					3.6	5.31	112.0			
					6.8	10.04	144.3			
					11.6	17.12	155.7			
					18.8	27.16	159.3			
					26.7	39.4	168.3			
					0.7	1.03	25.7	Table 2	Grown at 2 klux	
					2.0	2.95	58.3			
					4.0	5.90	78.7			
					6.0	8.86	84.3			
					11.6	17.12	95.0			
					18.4	27.16	95.3			
					0.7	1.03	13.7	Table 2	Grown at 0.7 klux	
					2.0	2.95	29.7			
					4.0	5.90	35.7			
					6.0	8.86	40.3			
					11.6	17.12	39.7			
					18.4	27.16	37.7			

Tabel 5 (continued)

species or dominant species	type of species[1]	environment[2]	source of light[3]	method of productivity measurement[4]	intensity		productivity[5]	source of data[6]	remarks	references
					klux	joules.m^{-2}.hr^{-1} x 10^4				
Chlorella luteoviridis var. aureoviridis	F	L	NG	ΔO_2	0.7	1.03	42.3 mm^3 O_2.10^9 $cells^{-1}$.hr^{-1}	Table 2	Grown at 6 klux	Winokur, 1948
					1.7	2.51	94.7			
					3.6	5.31	141.7			
					6.8	10.04	172.3			
					11.6	17.12	185.3			
					18.8	27.75	191.3			
					0.7	1.03	27.3	Table 2	Grown at 2 klux	
					2.0	2.95	67.7			
					4.0	5.90	88.7			
					6.0	8.86	102.3			
					11.6	17.12	106.7			
					18.4	27.16	107.3			
					0.7	1.03	17.3	Table 2	Grown at 0.7 klux	
					2.0	2.95	35.7			
					4.0	5.90	44.7			
					6.0	8.86	46.7			
					11.6	17.12	41.7			
					18.4	27.16	39.0			
Chlorella luteoviridis var. lutescens	F	L	NG	ΔO_2	0.7	1.03	32,7 mm^3 O_2.10^9 $cells^{-1}$.hr^{-1}	Table 2	Grown at 6 klux	Winokur, 1948
					1.7	2.51	78.7			
					3.6	5.31	122.7			
					6.8	10.04	153.0			
					11.6	17.12	166.7			
					18.8	27.75	179.0			
					26.7	39.40	176.3			
					0.7	1.03	24.7	Table 2	Grown at 2 klux	
					2.0	2.95	58.0			
					4.0	5.90	79.7			
					6.0	8.86	87.7			
					11.6	17.12	98.3			
					18.4	27.15	100.3			
					0.7	1.03	14.7	Table 2	Grown at 0.7 klux	
					2.0	2.95	32.7			
					4.0	5.90	40.3			
					6.0	8.86	44.3			
					11.6	17.12	39.7			
					18.4	26.57	37.0			

Table 5 (continued)

species of dominant species	type of species[1]	environment[2]	source of light[3]	method of productivity measurement[4]	intensity: klux	intensity: joules.m^{-2}.hr^{-1} x 10^4	productivity[5]	source of data	remarks	reference
Chlorella pyrenoidosa	M	L	NG	ΔO_2	0.7	1.03****	42.3 mm^3 O_2.10^9 $cells^{-1}$.hr^{-1}	Table 2	grown at 6 klux	Winokur, 1948
					1.7	2.51	95.3			
					3.6	5.31	145.7			
					6.8	10.04	185.0			
					11.2	16.53	200.3			
					18.8	27.75	213.7			
					26.7	39.41	216.3			
					0.7	1.03	28.3	Table 2	grown at 2 klux	
					2.0	2.95	67.7			
					4.0	5.90	98.3			
					6.0	8.86	104.7			
					11.6	17.12	114.3			
					18.4	27.16	121.3			
					0.7	1.03	20.3	Table 2	grown at 0.7 klux	
					2.0	2.95	42.3			
					4.0	5.90	53.3			
					6.0	8.86	55.7			
					11.6	17.12	54.3			
					18.4	26.86	53.3			
Chlorella saccharophila	F	L	NG	ΔO_2	0.7	1.03****	83.7 mm^3 O_2.10^9 $cells^{-1}$.hr^{-1}	Table 2	grown at 6 klux	Winokur, 1948
					2.0	2.95	143.7			
					3.6	5.31	300.3			
					6.8	10.03	388.0			
					11.2	16.53	426.3			
					18.8	27.75	447.3			
					26.7	39.41	452.3			
					0.7	1.03	62.7	Table 2	grown at 2 klux	
					2.0	2.95	150.3			
					4.0	5.90	200.7			
					6.0	8.86	225.0			
					11.6	17.12	242.3			
					18.4	27.16	246.7			
					0.7	1.03	46.3	Table 2	grown at 0.7 klux	
					2.0	2.95	107.7			
					4.0	5.90	135.3			
					6.0	8.86	149.7			
					11.6	17.12	139.0			
					18.4	27.16	127.3			

Tabel 5 (continued)

species or dominant species	type of species[1]	environment[2]	source of light[3]	method of productivity measurement[4]	intensity: klux	intensity: joules.m^{-2}.hr^{-1} x 10^4	productivity[5]	source of data[6]	remarks	reference
Chlorella vulgaris	F	L	NG	ΔO_2	0.7	1.03***	69.4 mm^3 O_2.10^9.$cells^{-1}$.hr^{-1}	Table 2	grown at 6 klux	Winokur, 1948
					2.0	2.95	186.4			
					3.1	4.58	233.3			
					4.0	5.90	264.8			
					6.0	8.86	300.3			
					8.6	12.69	326.3			
					11.6	17.12	333.3			
					18.4	27.16	348.6			
					26.7	39.41	354.6			
					51.6	76.16	330.7			
					81.8	120.74	287.7			
					0.7	1.03	50.2	Table 2	grown at 2 klux	
					2.0	2.95	124.5			
					4.0	5.90	162.8			
					6.0	8.86	174.6			
					11.6	17.12	185.8			
					18.4	27.16	192.6			
					26.7	39.41	191.0			
					0.7	1.03	30.6	Table 2	grown at 0.7 klux	
					2.0	2.95	64.8			
					4.0	5.9	85.0			
					6.0	8.86	91.4			
					11.6	17.12	85.5			
					18.4	27.16	77.4			
Chlorella vulgaris var. viridis	F	L	NG	ΔO_2	0.7	1.03***	93.3 mm^3 O_2.10^9.$cells^{-1}$.hr^{-1}	Table 2	grown at 6 klux	Winokur, 1948
					2.0	2.95	92.7			
					3.9	5.76	142.7			
					6.8	10.04	170.3			
					10.8	15.94	187.0			
					18.4	27.16	191.0			
					26.7	39.40	194.7			
					51.6	76.16	188.7			
					81.8	120.74	164.3			
					0.7	1.03	27.7	Table 2	grown at 2 klux	
					2.0	2.95	64.0			
					4.0	5.90	84.7			
					6.0	8.86	104.0			
					11.6	17.12	106.3			
					18.4	27.16	112.3			
					26.7	39.40	110.7			
					0.7	1.03	17.7	Table 2	grown at 0.7 klux	
					2.0	2.95	39.3			
					4.0	5.90	51.3			
					6.0	8.86	55.3			
					11.6	17.12	53.7			
					18.4	27.16	52.7			

Table 5 (continued)

species or dominant species	type of species[1]	environment[2]	source of light[3]	method of productivity measurement	intensity: klux	intensity: joules.m^{-2}.hr^{-1} x 10^4	productivity[5]	source of data[6]	remarks	reference
CYANOPHYTA (Blue-green algae)										
Anabaena variabilis	F	L	tungsten lamp	ΔO_2	.107	0.207*	40 $\mu l\ O_2.hr^{-1}.mg\ dry\ wt^{-1}$	Figure 3	dry weight is 0.206 mg/cm cells	Kratz & Myers, 1956
					.484	0.939	85			
					5.272	10.23	110			
					6.725	13.04	145			
					7.962	15.45	150			
					10.706	20.77	152			
					15.602	30.27	152			
Anacystis nidulans	F	L	tungsten lamp	ΔO_2	.215	0.417*	10 $\mu l\ O_2.hr^{-1}.mg\ dry\ wt^{-1}$	Figure 3	dry weight of cells is 0.271 mg/cm cells	Kratz & Myers, 1956
					.538	1.04	75			
					1.076	2.09	90			
					5.270	10.22	115			
					6.730	13.05	150			
					8.610	16.68	155			
					10.760	20.87	160			
					12.110	83.49	170			
					13.450	26.10	170			
					17.220	33.41	170			
Nostoc muscorum	F	L	tungsten lamp	ΔO_2	0.215	0.41*	10 $\mu l\ O_2.hr^{-1}.mg\ dry\ wt^{-1}$	Figure 3	dry weight of cells is 0.194 mg/cm cells	Kratz & Myers, 1956
					0.517	1.02	25			
					2.420	4.69	50			
					5.920	11.45	60			
					10.76	20.87	75			
					16.14	31.31	72			
Synechoeoccus lividus	F	L	NG	ΔO_2	1.60		1.5 $\mu l\ O_2.\mu M\ chl\ a^{-1}.15\ min^{-1}$	Figure 2		Sheridan, 1972
					1.83		2.1			
					3.23		2.8			
					4.30		3.8			
					5.34		4.0			
					7.50		4.15			
					9.68		4.2			
					11.84		4.5			
					16.14		4.8			
					22.60		5.0			

Table 5 (continued)

species or dominant species	type of species[1]	environment[2]	source of light[3]	method of productivity measurement[4]	intensity: klux	intensity: joules.m^{-2}.hr^{-1} x 10^4	productivity[5]	source of data[6]	remarks	reference
BACILLARIOPHYTA (diatoms)										
Achnathes exigua	F	L	G.E. "cool white"	ΔO_2	1.08	1.09**	3.0 $\mu l\ O_2.\mu g\ Chla^{-1}.15\ min^{-1}$	Figure 3	I_k = 1.29 klux incubated at 15°C	Fairchild & Sheridan, 1974
					2.15	2.17	3.8			
					4.30	4.33	3.8			
					5.38	5.42	3.8			
					7.53	7.59	3.8			
					11.83	11.92	3.8			
					1.08	1.09	5.2 $\mu l\ O_2.\mu g\ Chla^{-1}.15min^{-1}$	Figure 3	I_k = 1.94 klux incubated at 30°C	
					2.15	2.17	8.3			
					4.30	4.33	9.0			
					5.38	5.42	9.0			
					7.53	7.59	9.0			
					11.84	11.92	9.0			
					1.08	1.09	5.2	Figure 3	I_k = 2.37 klux incubated at 40°C	
					2.15	2.17	7.9			
					4.30	4.33	9.0			
					5.38	5.42	10.2			
					7.53	7.59	11.0			
					11.84	11.92	10.2			
					1.08	1.09	5.2		I_k = 2.69 klux incubated at 42°C	
					2.15	2.17	7.0			
					4.30	4.33	10.5			
					5.38	5.42	11.9			
					7.53	7.59	12.5			
					11.84	11.92	12.5			
Phaeodactylum tricornutum	M	L	NG	ΔO_2	0.55		5.2 $\mu M\ O_2.10^8$ cells^{-1}.hr^{-1}	Figure 8		Beardall & Morris, 1976
					0.85		9.4			
					1.00		14.9			
					12.00		15.0			
EUGLENOPHYTA (euglenoids)										
Euglena sp.	F	L	NG	ΔO_2	1.29		17.8 $\mu l\ O_2.cell^{-1}.hr^{-1}$	Table 1		Cook, 1963
					4.3		43.9			
					12.9		75.8			
					32.28		74.0			
PYRROPHYTA (dinoflagellates)										
Cachonina niei	M	L	"cool white" fluorescent	ΔO_2	32.28	32.45**	15.5 $\mu l\ O_2.\mu g\ Chla^{-1}.hr^{-1}$	Figure 7		Loeblich, 1975
					21.52	21.69	15.5			
					13.45	13.56	13.0			
					8.07	8.13	8.0			
					5.16	5.20	4.2			
MIXED POPULATION										
Stream population	F	L	"warm white" fluorescent	ΔO_2	1.5	1.51**	1.9 g $O_2.m^{-2}.5\ dag^{-1}$	Figure 5		McIntire et al, 1964
					3.0	3.02	3.5			
					4.1	4.13	4.5			
					5.8	5.85	5.0			
					7.3	7.36	5.9			

TABLE 6 : The carbon to chlorofyll ratios of some phytoplankton species

SPECIES or Dominant species	Marine or Fresh-water[1]	Laboratory or Natural population[2]	Method of Carbon Analysis[3]	Method of Chlorofyll Analysis[4]	Carbon : Chl. a ratio			Remarks	References
					min.	max.	mean		
CHLOROPHYTA (green algae)									
Chlamydomonas flagellate	M	L	CA	SP	25	86	46.5	3 months light, 3 months dark	Bunt & Lee, 1972
Dunaliella sp.	M	L					22.3	High N&P low light	McAllister et al., 1964
							38.0	High N&P high light	
							15.5	Low P	
							57.0	N-deficient media	
Nannochloris sp.	M	L	^{14}C	SP		28.0			Steele & Baird, 1962B
CYANOPHYTA (blue-green algae)									
Trichodesmium spp.	M	L	CA	HH			0.29	Value per Colony	Mague et al.,1972
BACILLARIOPHYTA (diatoms)									
Chaetoceros debilis	M	L		SU	53.6	57.4		Nitrogen limitation	Harrison at al., 1977
Chaetoceros debilis	M	L	CA	SU			76.0	Silicon starved	
Chaetoceros debilis							55.0	Silicon limited	
Chaetoceros debilis							32.0	Non-limited	
Chaetoceros debilis							47.0	NH4 limited	
Chaetoceros debilis							43.0	NH4 starved	
Chaetoceros fragile	M	L	CA	SP	15.0	44.0	24.0	3 months light, 3 months dark	Bunt & Lee, 1972
Cyclotella nana	M	L	CA	SU	76.0	500			Harrison et al.,1977
Cyclotella cryptica	M	L		SP			58.0		Sloan & Strickland, 1966
Ditylum brightwelli	M	L	^{14}C	YM			22.8		Eppley, 1968
Ditylum brightwelli	M	N		SP			34.1	NH4 grown	
Ditylum brightwelli							83.0	Nutrient starved	Strickland et al.,1969
Ditylum brightwelli							57.5	Nitrate grown	
Fragilaria sublinearis	M	L	CA	SP	25.0	61.0	40.3	3 months light, 3 months dark	Bunt & Lee, 1972
Skeletonema costatum	M	L	CA	SU	70.0	220.0		Nitrogen limitation	Harrison et al., 1977
Skeletonema costatum	M	L		SP			38.0		Sloan & Strickland, 1966
Skeletonema costatum	M	L	CA	SU			178.0	Silicon starved	Harrison et al., 1977
Skeletonema costatum							65.0	Silicon limited	
Skeletonema costatum							61.0	Non-limited	
Skeletonema costatum							72.0	NH4 limited	
Skeletonema costatum							98.0	NH4 starved	

TABLE 6 : Continued

SPECIES or Dominant species	Marine or Fresh-water[1]	Laboratory or Natural population[2]	Method of Carbon Analysis[3]	Method of Chlorofyll Analysis[4]	Carbon : Chl. a ratio			Remarks	References
					min.	max.	mean		
MIXED POPULATIONS									
Skeletonema, Chaetoceros, Navicula, Thalassiosira & Gyrodinium	M	N	^{14}C	SP	23.5	114.0	54.9	Values daily for 47 days	Anita et al., 1963
Rhodomonas, Cryptomonas, Ceratium & Peridinium	F	N	^{14}C	SP + RT	55.3	186.8	122.4		Berman & Pollingher, 1974
Skeletonema, Thalassiosira, Gymnodinium, Nitzschia & Asterionella	M	N		RT	13.0	56.0	29.0		McAllister et al., 1961
Rhizosolena, Richelia & Trichodesmium	M	N	CA	HH	171	650	372		Mague et al., 1977
Biddulphia, Streptotheca & Phaeocystis	M	N	^{14}C	SP			17.0		Gieskes & Kraay, 1977
Nitzschia, Thalassiosira, Rhizosolena & Asterionella	M	N	CA	SP			46.0	0° C	Malone, 1977
							72.0	5° C	
							72.0	10° C	
							72.0	15° C	
							72.0	20° C	
							72.0	25° C	
Skeletonema, Thalassiosira & Coscinosira	M	N	CA	HH	17.0	69.0	28.3		Tett et al., 1975
Mixed population	M	N	^{14}C	YM	53.1	58.7	54.4		Platt & Conover, 1971
Mixed population	M	N		SP			30.0		Strickland, 1960
Mixed population	M	N	CA	YM	39.0	64.0	40.5		Lorenzen, 1968
Mixed population	M	N			14.0	51.0			McAllister, 1969
Mixed population	M	N	CA	SP			30.0		Bunt, 1968
Mixed population	M	N	^{14}C	SP	47.0	213.0			Steele & Baird, 1961
Mixed population	M	N	^{14}C	SP	30.0	230.0			Steele & Baird, 1962B
Mixed population	M	N	^{14}C	SP	20.0	100.0			Steele & Baird, 1965
Mixed population	M	N	^{14}C	SP	20.0	250.0			Steele & Baird, 1965
Mixed population	M	N	^{14}C	YM	80.0	307.0	189.6		Eppley et al., 1977
Mixed population	M	N	^{14}C	YM			76.0		Eppley, 1968
Mixed population	M	N	^{14}C	YM			100.0		Eppley, 1968
Mixed population	M	N	^{14}C	YM	71.0	120.0	98.0	No nitrate in media	Eppley, 1968
Mixed population	M	N	^{14}C	YM	22.0	48.0	33.0	Nitrate detectable	Eppley, 1968

TABLE 6 : Continued

SPECIES or Dominant species	Marine or Fresh-water[1]	Laboratory or Natural population[2]	Method of Carbon Analysis[3]	Method of Chlorofyll Analysis[4]	Carbon : Chl. a ratio			Remarks	References
					min.	max.	mean		
Skeletonema costatum	M	N	CA	SP	39	98			Mullin & Evans, 1974
Skeletonema costatum	M	L	^{14}C	SP		26			Steele & Baird, 1962B
Skeletonema costatum	M	L					25.0	High N&P (medium)	McAllister et al., 1964
Skeletonema costatum	M	L					28.0	Natural sea water	
Skeletonema costatum	M	L					93.0	Deficient in P (medium)	
Skeletonema costatum	M	L					68.0	Deficient in N (medium)	
Thalassiosira fluviatilis	M	L	CA	SU	18	26		Nitrogen limitation	Harrison et al., 1977
Thalassiosira fluviatilis	M	L				220.3			Canelli & Fuhs, 1976
Thalassiosira gravida	M	L	CA	SU			46.0	Silicon starved	Harrison et al., 1977
Thalassiosira gravida	M	L	CA	SU			34.0	Silicon limited	
Thalassiosira gravida	M	L	CA	SU			26.0	Non-limited	
Thalassiosira gravida	M	L	CA	SU			55.0	NH4 limited	
Thalassiosira gravida	M	L	CA	SU			106.0	NH4 starved	
Thalassiosira pseudonana	M	L	CA	SU	110	200		Nitrate limitation	Harrison et al., 1977
Thalassiosira pseudonana	M	L	CA	SU	28.7	91.4		Nitrogen limitation	Harrison et al., 1977
Thalassiosira pseudonana	M	L					243.9		Canelli & Fuhs, 1976
Thalassiosira rotula	M	L		SP			78.0		Sloan & Strickland, 1966
PYRROPHYTA (Dinoflagellates)									
Amphidinium sp.	M	L					54.0	High N&P (medium)	McAllister et al., 1964
Cachonina niei	M	N		SP			34.1	NH4 grown	Strickland et al., 1969
Cachonina niei	M	N		SP			83.0	Nutrient starved	
Cachonina niei	M	N		SP			75.5	Nitrate grown	
Ceratium tripos	M	N	CA	SP			278.0		Malone, 1977
Gonyaulax polyedra	M	N		SP			294.1		Strickland et al., 1969
CHRYSOPHYTA (Crysophytes)									
Chrysomonad flagellate	M	L	CA	SP	26	44	38.2	3 months light, 3 months dark	Bunt & Lee, 1972
Coccolithus huxleyi	M	L					78.0		Sloan & Strickland, 1966
Monochrysis sp.	M	L		SP			71.0	High N+P (medium)	McAllister et al., 1964

TABLE 6 : Continued

SPECIES or Dominant species	Marine or Fresh-water[1]	Laboratory or Natural population[2]	Method of Carbon Analysis[3]	Method of Chlorofyll Analysis[4]	Carbon : Chl. a ratio			Remarks	References
					min.	max.	mean		
Mixed population (diatoms)	M	N					4		Gillbricht, 1952
Mixed population (dinoflagellates)	M	N					12		Gillbricht, 1952

1 - M is marine species
F is freshwater species

2 - L is laboratory experiment
N is a natural population

3 - ^{14}C is radiocarbon method
CA is carbon analyzer

4 - SP Method of Strickland & Parsons (1965, 1972)
SU SCOR-UNESCO method
YM Method of Yentsch & Menzel (1963)
RT Method of Richards & Thompson (1952)
HH Method of Holm-Hansen et al., (1965)

TABLE 7 : The assimilation ratio (mg carbon to mg Chlorophyll per hour) of some species of phytoplankton.

SPECIES or Dominant Species	Marine or Fresh-water[1]	laboratory or Natural population[2]	Method of Carbon Analysis[3]	Method of Chlorofyll Analysis[4]	Assimilation ratio mgC/mg Chlor. hr^{-1}			Remarks	Reference
					min.	max.	mean		
CHLOROPHYTA (Green Algae)									
Chlorella vulgaris	F	L		TD			0.34	Grown at 3Klux incubated at 1Klux	Jorgensen, 1974B
CYANOPHYTA (Blue-green Algae)									
Anabaena sp. (dominant)	F	N	O_2	S-U	0.71	1.71	1.11	June samples	Megard & Smith, 1974
Aphanizomenon (dominant)	F	N	O_2	S-U	0.79	2.5	1.16	August samples	Megard & Smith, 1974
Aphanizomenon (dominant)	F	N	O_2	S-U	0.05	2.63		Surface to 4 meter interval samples 0600 hrs	
Aphanizomenon (dominant)	F	N	O_2	S-U	0.08	1.5		Surface to 4 meter interval samples 1200 hrs	
Phormidium sp.	M	L	^{14}C		0.19	1.22			Shimura & Fujito, 1975
Trichodesmium thiebautti	M	N	^{14}C		0.05	1.27			Shimura & Fujito, 1975
Trichodesmium sp.	M	L	CA	HH			0.38		Mague et al., 1977
BACILLARIOPHYTA (diatoms)									
Asterionella japonica	M	N	O_2	SU	4.57	6.04	5.41	data from bloom	Subba Rao, 1969
Chaetoceros sp.	M	L	CA	SP	0.5	3.9	2.21	Nitrate uptake experiments	Malone et al., 1972
Cyclotella meneghiniana	F	L		TD	0.29	0.41		Grown at 3Klux incubated at 1Klux	Jorgensen, 1964B
Cyclotella meneghiniana	F	L		TD	2.1	3.4		Grown at 30Klux incubated at I_k	
Cyclotella meneghiniana	F	L		TD	0.28	0.40		Grown at 30Klux incubated at 1Klux	
Cyclotella spp.	F	L		TD			0.28	Grown at 3Klux incubated at 1Klux	Jorgensen, 1964B
Cyclotella spp.	F	L		TD			0.41	Grown at 30Klux incubated at 1Klux	
Skeletonema costatum	M	L	^{14}C	J	0.19	0.57		Effect of Phosphorus on photosynthesis experiments	Jorgensen, 1970
Skeletonema costatum	M	L	^{14}C	J	0.09	0.43		Effect of Nitrogen on photosynthesis experiments	
Skeletonema costatum	M	L	^{14}C	SP	1.17	4.17			Steele & Baird, 1962A
Skeletonema costatum	M	L	O_2	RT	6.1	68.9	25.2	Values over period of 22 days	Cassie, 1971
Skeletonema costatum	M	L	^{14}C	SP	1.87	3.65	2.68		Eppley et al., 1971
Thalassiosira pseudonana	M	L	CA	SP	4.4	6.4	5.52		Eppley & Renger, 1974

TABLE 7 : continued

SPECIES or Dominant Species	Marine or Fresh-water[1]	laboratory or Natural population[2]	Method of Carbon Analysis[3]	Method of Chlorofyll Analysis[4]	Assimilation ratio mgC/mg Chlor. hr^{-1}			Remarks	Reference
					min.	max.	mean		
CHRYSOPHYTA (Chrysophytes)									
Coccolithus huxleyi	M	L	^{14}C	SP	0.38	6.8	3.26		Eppley et al.,1974
MIXED POPULATIONS									
Skeletonema, Navicula, Asterionella & Peridinium	M	N	^{14}C	SU	0.54	7.42	4.43		Moll, 1977
Skeletonema, Thalassiosira Gymnodinium, Nitzschia & Asterionella	M	N	O_2	RT	0.95	1.75	1.4	Daily samples for period of 14 days	Mc Allister et al., 1961
Skeletonema, Thalassiosira & Coscinosira	M	N	CA	HH	0.02	0.99	0.28		Tett et al., 1975
Skeletonema, Chaetoceros, Navicula, Thalassiosira & Gyrodinium	M	N	^{14}C	SP	0.037	0.69	0.22	Values daily over period of 14 days	Anita et al., 1963
Rhodomonas, Cryptomonas, Ceratum & Peridinium	F	N	^{14}C	RT	0.2	2.3	0.84		Berman & Pollingher, 1974
Mixed population	M	N	^{14}C	YM	9.0	25.0	15.0		Eppley et al., 1977
Mixed population	M	N	^{14}C	YM	6.0	7.0			Eppley, 1968
Mixed population	M	N	^{14}C	RT	0.1	4.6	1.65		Glooschenko & Curl, 1971
Mixed population	M	N	O_2	RT			5.7		Ryther & Yentsch, 1957
Mixed population	M	N	O_2	RT			3.8		Ryther & Yentsch, 1957
Mixed population	F	N					2.1		Manning & Juday, 1941
Mixed population	M	N	^{14}C	YM	2.21	2.45	2.28	6 stations, 1 day	Platt & Conover, 1971
Mixed population	M	N	^{14}C	YM			6.8	light saturation, summer	Small et al., 1972
Mixed population	M	N	^{14}C	YM			3.2	light saturation, winter	Small et al., 1972
Mixed population	M	N	^{14}C	YM	0.05	3.48	0.94	Values from depth intervals	Bienfang & Gunderson, 1977
Mixed population	F	N	^{14}C	SP			0.83		Tunzi & Porcella, 1974
Mixed population	M	N	^{14}C	YM	1.15	5.18	3.15	Nitrogen poor water	Thomas, 1970
Mixed population	M				4.04	6.19	4.95	Nitrogen rich water	Thomas, 1970

Table 7 : Continued

1 - F is freshwater Species
M is marine Species

2 - L is a laboratory experiment
N is an experiment in situ

3 - O_2 Winkler method, - Change in concentration of oxygen with time
CA Carbon analyzer
^{14}C Radiocarbon method

4 - RT Method as described by Richards & Thompson, 1952
YM Method as described by Yentsch & Menzel, 1963
SP Method as described by Strickland & Parsons, 1965, 1972
HH Method as described by Holm-Hansen et al., 1975
SU Method as described by SCOR-UNESCO standards
TD Method as described by Talling & Driver, 1963
J Method as described by Jorgensen, 1966

APPENDIX

Conversion factors for light intensity and photosynthetic productivity.

1 watt.cm^{-2} = 1 joule.cm^{-2}.sec^{-1}

1 ly.min^{-1} = 0.0698 watt.cm^{-2}.sec^{-1}

1 watt.m^{-2} = 10^{-4} watt.cm^{-2}

1 erg.cm^{-2}.sec^{-1} = 10^{-7} watt.cm^{-2}

1 calorie.cm^{-2}.sec^{-1} = 4.19 watt.cm^{-2}

1 calorie.cm^{-2}.min^{-1} = 6.98 x 10^{-2} watt.cm^{-2} (Wetzel, 1975)

1 calorie = 419 x 10^{5} ergs = 4.19 watt.sec^{-1} = 4.19 joules (Edmondson, 1965)
(Vollenweider, 1969)

1 ft candle = 10.764 lux

1 lux = 1 metre candle (Vollenweider, 1969 & Wetzel, 1975)

1 cal.cm^{-2}.hr^{-1} = 1.2 x 10^{3} lux (Sverdrup, Johnson, & Flemming, 1942)

For natural daylight (noon)

1 lux ≃ 4 ergs.cm^{-2}.sec^{-1} = 4.1 x 10^{-7} watt.cm^{-2}.sec^{-1} (Talling 1957, 1966)

For an incandescent light 65 cm from culture surface

1.6 x 10^{15} Quanta.cm^{-2}.sec^{-1} = 0.60 m watt.cm^{-2}

For Philips W/33 lamp

1.1 x 10^{15} Quanta.cm^{-2}.sec^{-1} = 0.47 m watt.cm^{-2} (Steemann-Nielsen & Willemoes, 1971)

When standard candle is the light source

1 lux = 1.5 x 10^{-7} watt.cm^{-2}

1 ft candle = 1.6 x 10^{-6} watt.cm^{-2}

When noon sun + sky light is source

1 lux = 4.1 x 10^{-7} watt.cm^{-2}

1 Klux = 0.41 - 0.50 watt.cm^{-2} (Strickland, 1958)

When light source comes from a tungsten (incandescent) source it emits a total of 60 ergs.cm^{-2}.sec^{-1} per lux of which 9% is less than 700 mμ. Therefore the photosynthetically active energy is:

1 lux = 5.4 ergs.cm^{-2}.sec^{-1} = 8 x 10^{-6} cal.cm^{-2}.min^{-1} (Hill & Whittingham, 1955)

When light source is a fluorescent lamp it emits a total radiation of about 3.5 ergs.cm^{-2}.sec^{-1} per lux of which the photosynthetically active radiation equivalent is:

1 lux = 2.8 ergs.cm^{-2}.min^{-1} = 4 x 10^{-6} cal.cm^{-2}.min^{-1} (Westlake, 1965)

Mg Carbon assimilated in photosynthesis per unit time =
(mg-at CO_2 assimilated per unit time) x 12
(mg-CO_2 assimilated per unit time) x 0.273
(ml CO_2 assimilated per unit time) x 0.536
(mg O_2 evolved per unit time) x 0.375/PQ
(mg-at.O_2 evolved per unit time) x 12/PQ
(ml O_2 evolved per unit time) x 0.536/PQ (Strickland, 1960)

PQ = Photosynthetic Quotient.

LITERATURE

ANITA, N.J., McALLISTER, C.D., PARSONS, T.R., STEPHEN, K., STRICKLAND, J.D.H. Further measurements of primary production using a large volume plastic sphere.
Limnol. Oceanogr., 1963.
8: 163-183

ARUGA, Y. Ecological studies of photosynthesis and matter production of phytoplankton. II. Photosynthesis of algae in relation to light intensity and temperature.
Bot. Mag., 1965.
78: 360-365.

BANSE, K. Determining the carbon to chlorophyll ratio of natural phytoplankton.
Mar. Biol., 1977.
41: 199-212.

BARKER, H.A. Photosynthesis in diatoms.
Arch. Mikrobiol., 1935.
6: 141-156.

BEARDALL, J., & MORRIS, I. The concept of light intensity adaptation in marine phytoplankton: some experiments with Phaeodactylum tricornutum.
Mar. Biol., 1976.
37: 377-387.

BERMAN, T., & POLLINGHER, U. Annual and seasonal variations of phytoplankton chlorophyll and photosynthesis in Lake Kinneret.
Limnol. Oceanogr., 1974.
19: 31-54.

BIENFANG, P., & GUNDERSON, K. Light effects on nutrient limited oceanic primary production.
Mar. Biol., 1977.
43: 187-199.

BINDLOSS, M.E. The light climate of Loch Leven a shallow Scottish lake in relation to primary production by phytoplankton.
Freshwater Biol., 1976.
6: 501-518.

BLAAUW-JANSEN, G., KOMEN, J.G., & THOMAS, J.B. On the relation between the formation of assimilatory pigments and the rate of photosynthesis in etiolated oat seedlings.
Biochim. Biophys. Acta, 1950.
5: 179-185.

BRODY, M., & VATTER, A.E. Observations on cellular structures of Porphyridium cruentum.
J. Biophys. Biochem. Cytol, 1959.
5: 289-296.

BROWN, T.E., & RICHARDSON, F.L. The effect of growth environment on the physiology of algae: light intensity.
J. Phycol., 1968.
4: 38-54.

BUNT, J.S. Some characteristics of micro-algae isolated from the Antarctic sea ice.
Antarctic Res. Ser., 1968.
11: 1-14.

BUNT, J.S., & LEE, C.C. Data on the composition and dark survival of four sea-ice microalgae.
Limnol. Oceanogr., 1972.
17: 458-461.

CANELLI, E., & FUHS, G.W. Effect on the sinking rate of two diatoms (Thalassiosira spp.) on uptake from low concentrations of phosphate.
J. Phycol., 1976.
12: 93-99.

CASSIE, R.M. Relationship between plant pigments and gross primary production in Skeletonema costatum.
Limnol. Oceanogr., 1963.
8: 433-439.

CLARKE, G.L. The utilization of solar energy by aquatic organisms.
Amer. Assoc. Adv. Sci. Sp. Publ. 1939.
10: 27-38.

CONOVER, S.A.M. Oceanography of Long Island Sound, 1952-1954. IV. Phytoplankton.
Bull. Bingh. Oceanogr. Coll., 1956.
15: 62-112.

COOK, J.R. Adaptations in growth and division in Euglena effected bu energy supply.
J. Protozool., 1963.
19: 436-444.

CURL, H., & SMALL, L.F. Variations in photosynthetic assimilation ratios in natural marine phytoplankton communities.
Limnol. Oceanogr., 1965.
10(Suppl.): R67-R73.

EDMONDSON, W.T. Factors affecting productivity in fertilized salt water.
Deep Sea Res., 1955.
3: 451-464.

EDMONDSON, W.T. The relation of photosynthesis by phytoplankton to light in lakes.
Ecology, 1956.
37: 161-174.

EMERSON, R., GREEN, L., & WEBB, J.L. Relation between quatity of chlorophyll and capacity for photosynthesis.
Plant Physiol., 1940.
15: 311-317.

EPPLEY, R.W. An incubation method for estimating the carbon content of phytoplankton in natural samples.
Limnol. Oceanogr., 1968.
13: 574-582.

EPPLEY, R.W. Temperature and phytoplankton growth in the sea.
Fish. Bull., 1972.
70: 1063-1085.

EPPLEY, R.W., & RENGER, E.H. Nitrogen assimilation of an oceanic diatom in nitrogen-limited continuous cultures.
J. Phycol., 1974.
10: 15-23.

EPPLEY, R.W., RIGERS, J.N., McCARTHY, J.J., & SOURINA, A. Light/dark periodicity in nitrogen assimilation of the marine phytoplankters Skeletonema costatum and Coccolithus huxleyi in N-limited chemostat culture.
J. Phycol., 1971.
7: 150-154.

EPPLEY, R.W., SHARP, J.H., RENGER, E.H., PERRY, M.J., & HARRISON, W.G. Nitrogen assimilation by phytoplankton and other microorganisms in the surface waters of the Central North Pacific Ocean.
Mar. Biol., 1977.
39: 111-120.

FALKOWSKI, P.G., & OWENS, T.G. Effects of light intensity on photosynthesis and dark respiration in six species of marine phytoplankton.
Mar. Biol., 1978.
45: 289-295.

FAIRCHILD, E., & SHERIDAN, R.P. A physiological investigation of the hot spring diatom Achnanthes exigua (GRUN.).
J. Phycol., 1974.
10: 1-4.

FAUST, M.A., & GANTT, E. Effect of light intensity and glycerol on the growth pigment composition, and ultrastructure of Chroomonas sp.
J. Phycol., 1973.
9: 489-495.

FLEISCHER, W.E. The relation between chlorophyll content and rate of photosynthesis.
J. Gen. Physiol., 1935.
18: 573-597.

GAARDER, T., & GRAN, H.H. Investigations of the production of plankton in the Oslo Fjord.
Rapp. et Proc. Verb. Cons. Int. Explor. Mer., 1927.
42: 1-48.

GESSNER, F. Der chlorophyllgehalt im see und seine photosynthetische balenz als geophysikalische problem.
Schweiz. Zeit. Hydrol., 1949.
11: 378-410.

GESSNER, F., & DIEHL, A. Die wirkung naturlicher ultravioelstrahlung auf de chlorophyllzerstorung von plankton algan.
Arch. Mikrobiol., 1951.
15: 439-453.

GIESKES, W.W.C., & KRAAY, G.W. Primary production and consumption of organic matter in the Southern North Sea during the spring bloom of 1975.
Netherlands J. Sea Res., 1977.
11: 146-167.

GILLBRIGHT, M. Untersuchungen zur produktionsbiologie des planktons in der Kieler Bucht.
Kieler Meeresforsch., 1952.
8: 173-191.

GLOOSCHENKO, W.A., & CURL, H. Influence of nutrient enrichment on photosynthesis and assimilation ratios in natural North Pacific phytoplankton communities.
J. Fish. Res. Bd. Can., 1971.
28: 790-793.

GODWARD, M.B.E. Invisible radiations.
R.A. Lewin ed.
Physiology and Biochemistry of algae, 1962.
N.Y. Academic Press., p. 551-566.

GRIFFITHS, D.J., VAN THINH, L., & FLORIAN, Z. A modified chamber for use with an oxygen electrode to allow measurement of incident illumination within the reaction suspension.
Limnol. Oceanogr., 1978.
23: 368-371.

GRUENDLING, G.K. Ecology of the epipelic algal communities in Marion Lake British Columbia.
J. Phycol., 1971.
7: 239-247.

HARRIS, G.P., & LOTT, J.N.A. Light intensity and photosynthetic rates in phytoplankton.
J. Fish. Res. Bd. Can., 1973.
30: 1771-1778.

HARRISON, P.J., CONWAY, H.L., HOLMES, R.W., & DAVIS, C.O. Marine diatoms grown in chemostats under silicate or ammonium limitation. III. Cellular chemical composition and morphology of Chaetoceros debilis, Skeletonema costatum, and Thalassiosira gravida.
Mar. Biol., 1977.
43: 19-31.

HAXO, F.T., & CLENDENNING, K.A. Photosynthesis and phototaxis in Ulva lactuca gametes.
Biol. Bull., 1953.
105: 103-114.

JORGENSEN, E.G. Photosynthetic activity during the live cycle of synchronous Skeletonema cells.
Physiol. Plant., 1966.
19: 789-799.

JORGENSEN, E.G. The adaptation of plankton algae. II. Aspects of the temperature adaptation of Skeletonema costatum.
Physiol. Plant., 1968.
21: 423-427.

JORGENSEN, E.G. The adaptation of plankton algae. IV. Light adaptation in different algae species.
Physiol. Plant., 1969.
22: 1307-1315.

JORGENSEN, E.G. The adaptation of plankton algae. V. Variation in the photosynthetic characteristics of Skeletonema costatum cells grown in low light intensity.
Physiol. Plant., 1970.
23: 11-17.

JORGENSEN, E.G. Photosynthesis.
In: The biology of diatoms.
D. Werner, ed.
Bot. Mon., 177.
13: 150-167.

JUPEN, H. Modifications pigmentaires et ultrastructurales chez la diatomee Detonula sp. cultivee in lumiere rouge.
Arch. Mikrobiol., 1973.
91: 19-27.

KAMP-NIELSEN, L. The effect of deleterious concentrations of mercury on photosynthesis and growth in Chlorella pyrenoidosa.
Physiol. Plant. 1971.
24: 556-561.

HILL, R., & WHITTINHAM, C.D. Photosynthesis.
Mehtuen's Monographs.
John Wiley, New York, 1955.

HOBSON, L.A., & PARISER, R.J. The effect of inorganic nitrogen on macro-molecular synthesis by Thalassiosira fluviatilis Hustedt and Cyclotella nana Hustedt grown in batch culture.
J. Exp. Mar. Biol. Ecol., 1971.
6: 71-78.

HOLM-HANSEN, O., LORENZEN, C.J., HOLMES, R.W., & STRICKLAND, J.D.H. Fluorometric determination of chlorophyll.
J. Cons. Perm. Int. Explor. Mer., 1968.
30: 3-15.

JENKEN D.M. Oxygen production by the diatom Coscinodiscus excentricus in relation to submarine illumination in the English Channel.
J. Mar. Biol. Assoc. U.K., 1937.
22: 301-343.

JEWSON, D.H. The relation of incident radiation to diurnal rates of photosynthesis in Lough Neagh.
Int. Rev. Ges. Hydrobiol., 1975.
60: 759-767.

JORGENSEN, E.G. Adaptation to different light intensities in the diatom Cyclotella meneghiniana.
Physiol. Plant., 1964.
17: 136-145.

JORGENSEN, E.G. Chlorophyll content and rate of photosynthesis in relation to cell size of the diatom Cyclotella meneghiniana.
Physiol. Plant., 1964B.
17: 407-413.

KESSLER, E. Der einfluss von sauerstoff auf die photosynthese.
Handbuch der Pflanzenphys., 1960.
Band V, Teil 1.
935 p.

KIEFER, D.A. Chlorophyll a fluorescence in marine centric diatoms:
responses for chloroplasts to light and nutrient stress.
Mar. Biol. 1973.
23: 39-46.

KOK, B. On the inhibition of photosynthesis by intense light.
Biochim. Biophys. Acta, 1956.
21: 234-244.

KRATZ, W., & MYERS, J. Photosynthesis and respiration of three blue-green algae.
Plant Physiol., 1965.
30: 275-280.

LAZAROFF, N., & VISHNIAC, W. The effect of light on the developmental cycle
of Nostoc muscorum, a filamentous blue green algae.
J. Gen. Microbiol., 1960.
151: 170-185.

LOEBLICH, A.R. A seawater medium for dinoflagellates and the nutrition of
Cachonina niei.
J. Phycol., 1975.
11: 80-86.

LORENZEN, C.J. Carbon/chlorophyll relationships in an upwelling area.
Limnol. Oceanogr., 1968.
13: 202-204.

MAGUE, T.H., MAGUE, F.C., & HOLM-HANSEN, O. Physiology and chemical composition
of nitrogen-fixing phytoplankton in the North Central Pacific Ocean.
Mar. Biol., 1977.
41: 213-227.

MALONE, T.C. The relative importance of nannoplankton and net plankton as primary producers in tropical oceanic and neritic phytoplankton communities.
Limnol. Oceanogr., 1971.
16: 633-639.

MALONE, T.C. Light saturated photosynthesis by phytoplankton size fractions in the New York Bight, U.S.A.
Mar. Biol., 1977.
42: 281-292.

MALONE, T.C., GARSIDE, C., HAINES, K.C., & ROELS, O.A. Nitrate uptake and growth of Chaetoceros sp. in large outdoor continuous cultures.
Limnol. Oceanogr., 1975.
20: 9-19.

MANN, J.E., & MYERS, J. On pigments, growth and photosynthesis of Phaeodactylum tricornutum.
J. Phycol., 1968.
4: 349-355.

MANNING, W.H., JUDAY, R.E. The chlorophyll content and productivity of some lakes in north-eastern Wisconsin.
Trans. Wis. Acad. Sci., 1941.
31: 337-410.

MANNING, W.M., JUDAY, C., & WOLF, M. Photosynthesis of aquatic plants at different depths in Trout Lake Wisconsin.
Trans.Wis. Acad. Sci., Arts, & Lett., 1938.
31: 337-410.

MANTAI, K.E. Some aspects of photosynthesis in Cladophora glomerata.
J. Phycol., 1974.
10: 288-291.

MARRA, J. Effect of short term variations in light intensity on photosynthesis of a marine phytoplankter: a laboraory simulation study.
Mar. Biol., 1978.
46: 191-202.

MARSHALL, S., & ORR, A.P. The photosynthesis of diatom cultures in the sea.
J. Mar. Biol. Assoc. U. K;, 1928.
15: 321-360.

McALLISTER, C.D. Aspects of estimating zooplankton production from phytoplankton production.
J. Fish. Res. Bd. Can., 1969.
26: 199-220.

McALLISTER, C.D., PARSONS, T.R., STEPHENS, K., & STRICKLAND, J.D.H. Measurements of primary production in coastal sea water using a large volume plastic sphere.
Limnol. Oceanogr., 1961.
6: 237-258.

McALLISTER, C.D., SHAH, N., & STRICKLAND, J.D.H. Marine phytoplankton photosynthesis as a function of light intensity: a comparison of methods.
J. Fish. Res. Bd. Can., 1964.
21: 159-181.

McINTIRE, C.D., GARRISON, R.L., PHINNEY, H.K., & WARREN, C.E. Primary production in laboratory streams.
Limnol. Oceanogr., 1964.
9: 92-102.

MC MILLAN, G.L., & VERDUIN, J. Photosynthesis of natural communities dominated by Cladophora glomerata and Ulothrix Zonata.
Ohio J. Sci., 1953.
53: 373-377.

MEGARD, R.O., & SMITH, P.D. Mechanisms that regulate growth rates of phytoplankton in Shagawa Lake, Minn.
Limnol. Oceanogr., 1974.
19: 279-296.

MILNER, H.W. The chemical composition of algae.
In: Algal culture from laboratory to pilot plant.
J.N. Burlew ed., 1953.
Carnegie Inst. Wash.
Publ. 600:285-302.

MOLL, R.A. Phytoplankton in a temperate zone salt marsh. Net production and exchanges with coastal waters.
Mar. Biol., 1977.
42: 109-118.

MULLIN, M.M., & EVANS, P.M. The use of a deep tank in plankton ecology.
2. Efficiency of a planktonic food chain.
Limnol. Oceanogr., 1974.
19: 902-911.

MYERS, J. Culture conditions an the development of the photosynthetic mechanism. IV. The influence of light intensity on photosynthetic characteristics of Chlorella.
J. Gen. Physiol., 1946.
29: 429-440.

MYERS, J. Genetic and adaptive physiological characteristics observed in Chlorella.
In: Prediction and measurement of photosynthetic productivity.
Pudoc., Wageningen, 1970.
p. 447-454.

MYERS, J., & BURR, G. Studies on photosynthesis. Some effects of light of high intensity on Chlorella.
J. Gen. Phys., 1940.
24: 45-67.

MYERS, J., & GRAHM, J. The photosynthetic unit in Chlorella measured by short flashes.
Plant Physiol., 1971.
48: 282-286.

NALEWAJKO, C. Photosynthesis and excretion in various planktonic algae.
Limnol. Oceanogr., 1966.
11: 1-10.

NELSON, P.R., & EDMONDSON, W.T.
Limnological effects of fertilizing Bare Lake, Alaska.
U.S. Fish. & Wild. Serv.
Fish. Bull. 102, 1955.
56: 413-436.

NOACK, K. Photochemische wirkungen des chlorophylls und ihre bedeutung fur die kohlensaureassimilation.
Z. Bot., 1925.
17: 481-485.

PLATT, T., & CONNOVER, R.J. Variability and its effects on the 24th chlorophyll budget of a small marine basin.
Mar. Biol., 1971.
10: 52-65.

PLATT, T., & SUBBA RAO, D.V. Primary production of marine microphytes.
In: Photosynthesis and productivity in different environments.
J.P. Cooper ed.
Cambridge Press, 1975.
p. 249-280.

PREZELIN, B.B., & SWEENY, B.M. Photoadaptation of photosynthesis in Gonyaulax polyedra.
Mar. Biol., 1978.
48: 27-35.

RABINOWITCH, E. Photosynthesis and related processes.
Vol. II pt. 1.
Interscience, N.Y., 1951.

RAVEN, J.A., & GLIDEWELL, S.M. Photosynthesis, respiration, and growth in the "shade" alga Hydrodictylon africanum.
Photosyn., 1975.
9: 361-371.

RAVEN, J.A., & SMITH, F.A. "Sun" and "Shade" species of green algae: relation to cell size and environment.
Photosyn.,1977.
11: 48-85.

RHYTHER, J.H. The measurements of primary production.
Limnol. Oceanogr., 1956.
1: 72-84.

RHYTHER, J.H., & VACCARO, R.F. The ratio of photosynthesis to respiration in marine plankton algae and its effect upon the measurement of productivity.
Deep Sea Res., 1954.
2: 134-139.

RHYTHER, J.H., & YENTSCH, C.S. The estimation of phytoplankton production in the ocean from chlorophyll and light data.
Limnol. Oceanogr., 1957.
2: 281-286.

RICHARDS, F.A., & THOMPSON, T.G. The estimation and characterization of plankton populations by pigment analysis. II. A spectrophotometric method for the estimation of plankton pigments.
J. Mar. Res., 1952.
11: 156-172.

RILEY, G.A. Plankton studies. II. The Western North Atlantic May-June, 1939.
J. Mar. Res., 1939.
2: 145-162.

RILEY, G.A. Oceanography of Long Island Sound 1952-1954. IX. Production and utilization of organic matter.
Bull. Bingh. Oceanogr. Coll., 1956.
15: 324-334.

SARGENT, M.C. Effect of light intensity on the development of photosynthetic mechanisms.
Plant Physiol., 1940.
15: 275-290.

SCHOMER, H.A., & JUDAY, C. Photosynthesis of algae at different depth in some lakes of north-eastern Wisconsin. I. Observations of 1933.
Trans. Wisc. Acad. Sci., Arts, & Lett., 1935.
29: 173-193.

SHEATH, G., & HELLEBUST, J.A. Glucose transport systems and growth characteristics of Bracteacoccus minor.
J. Phycol., 1974.
10: 34-41.

SHERIDAN, R.P. Kinetics of chlorophyll a and plastaquinone a: changes in response to light intensity.
J. Phycol., 1972.
8: 166-169.

SHIMURA, S., & FUJITA, Y. Phycoerythrin and photosynthesis of the pelagic blue-green algae Trichodesminium threbautii in the waters of Kurbshio, Japan.
Mar. Biol., 1975.
31: 121-128.

SLOAN, P.R., & STRICKLAND, J.D.H. Heterotrophy of four marine phytoplankters at low substrate concentration.
J. Phycol., 1966.
2: 29-32.

SMALL, L.F., CURL, H., & GLOOSCHENKO, W.A. Estimates of primary production off Oregon using an improved chlorophyll-light technique.
J. Fish. Res. Bd. Can., 1972.
29: 1261-1267.

SOROKIN, C. Tabular comparative data for low and high temperature strains of Chlorella.
Nature, 1959.
184: 613-614.

STALFELT, M.G. Vorleben, aktivierung, inaktivierung, "ermudung" Wundreiz.
Handbuch der Pflanzenphys., 1960.
Band, V Teil 2.
186 p.

STANLEY, D.W., & DALEY, R.J. Environmental control of primary productivity in Alaska tundra ponds.
Ecology, 1976.
57: 1025-1033.

STEELE, J.H. Environmental control of photosynthesis in the sea.
Limnol. Oceanogr., 1962.
7: 137-150.

STEEL, J.H., & BAIRD, I.E. Relations between primary production, chlorophyll and particulate carbon.
Limnol. Oceanogr., 1961.
6: 68-78.

STEELE, J.H., & BAIRD, I.E. Further relations between primary production, chlorophyll and particulate carbon.
Limnol. Oceanogr., 1962A.
7: 42-47.

STEELE, J.H., & BAIRD, I.E. Carbon-chlorophyll relations in cultures.
Limnol. Oceanogr., 1962B.
7: 101-102.

STEELE, J.H., & BAIRD, I.E. The chlorophyll-a content of particulate organic matter in the Northern North Sea.
Limnol. Oceanogr., 1965.
10: 261-267.

STEEMANN-NIELSEN, E. A reversible inactivation of chlorophyll in vivo.
Physiol. Plant., 1949.
2: 247-251.

STEEMANN-NIELSEN, E. The use of radioactive carbon (^{14}C) for measuring organic production in the sea.
J. Cons., Cons. Int. Explor. Mer., 1952.
18: 117-140.

STEEMANN-NIELSEN, E. On detrimental effects of high light intensities on the photosynthetic mechanism.
Physiol. Plant., 1952.
5: 334-344.

STEEMANN-NIELSEN, E. In activation of the photochemical mechanism of photosynthesis as a means to protect the cells against too high light intensity.
Physiol. Plant., 1962.
15: 161-171.

STEEMANN-NIELSEN, E. Marine photosynthesis: with special emphasis on the ecological aspects.
Elsevier Oceanogr. Series, No. 13, 1975.
Elsevier Sci. Publ. Co., Amsterdam.
141 p.

STEEMANN-NIELSEN, E., & HANSEN, V.K. Light adaptation in marine phytoplankton populations with its interrelation with temperature.
Physiol. Plant., 1959.
12: 353-370.

STEEMANN-NIELSEN, E., HANSEN, V.K., & JORGENSEN, E.G. The adaptation to different light intensities in Chlorella vulgaris and the time dependance on transfer to new light intensity.
Physiol. Plant., 1962.
15: 505-517.

STEEMANN-NIELSEN, E., & JORGENSEN, E.G. The physiological background for using chlorophyll measurements in hydrobiology and a theory explaining daily variations in chlorophyll concentrations.
Arch. Hydrobiol., 1962.
58: 349-357.

STEEMANN-NIELSEN, E., & JORGENSEN, E.G. The adaptation of algae. I. General part.
Physiol. Plant., 1968.
21: 401-413.

STEEMANN-NIELSEN, E., KAMP-NIELSEN, L., & WIUM-ANDERSON, S. The effect deleterious concentrations of copper on the photosynthesis of Chlorella pyrenoidosa.
Physiol. Plant., 1969.
22: 1121-1133.

STEEMANN-NIELSEN, E., & WILLEMOES, M. How to measure the illumination rate when investigating the rate of photosynthesis of unicellular algae under various light conditions.
Int. Rev. Ges. Hydrobiol., 1971.
56: 541-556.

STRICKLAND, J.D.H. Solar radiation penetrating the ocean. A review of requirements data, and methods of measurement with particular reference to photosynthetic productivity.
J. Fish. Res. Bd. Can., 1958.
15: 453-494.

STRICKLAND, J.D.H. Measuring the production of marine phytoplankton.
Bull. Fish. Res. Bd. Can., 1960.
122: 1-172.

STRICKLAND, J.D.H. Microbiol activity in aquatic environments.
Symp. Soc. Gen. Microbiol., 1971
21: 231-253.

STRICKLAND, J.D.H., & PARSONS, T.R. A manual of seawater analysis.
Bull. Fish. Res. Bd. Can., 1965.
125: 203 p.

STRICKLAND, J.D.H., HOLM-HANSEN, O., EPPLEY, R.W., & LINN, R.J. The use of a deep tank in plankton ecology. I. Studies of the growth and composition of phytoplankton crops at low nutrient levels.
Limnol. Oceanogr., 1969.
14: 23-34.

STRICKLAND, J.D.H., PARSONS, T.R. A practical Handbook of seawater analysis.
Bull. Fish. Res. Bd. Can., 1972.
No. 167: 311 p.

SUBBA RAO, V.D. Asterionella japonica bloom and discoloration of Waltair, Bay of Bengal.
Limnol. Oceanogr., 1969.
14: 632-634.

TALLING, J.F. Photosynthetic characteristics of some freshwater plankton diatoms in relation to underwater radiation.
New Phytol., 1957A.
56: 29-50.

TALLING, J.F. The phytoplankton populations as a compound photosynthetic system.
New Phytol., 1957B.
56: 133-149.

TALLING, J.F. Comparative laboratory and field studies of photosynthesis by a marine planktonic diatom.
Limnol. Oceanogr., 1960.
5: 62-77.

TALLING, J.F. Photosynthesis under natural conditions.
Ann. Rev. Plant Physiol., 1961.
12: 133-154.

TALLING, J.F. Photosynthetic behaviour in stratified and unstratified lake populations of a planktonic diatom.
J. Ecology, 1966.
54: 99-127.

TALLING, J.F., & DRIVER, D. Some problems in the estimation of chlorophyll a in phytoplankton.
Proc. conf. primary production measurements in marine and freshwater.
U.S. Atomic Energy. Comm., 1963.
TID-7633.
142 p.

TETT, P., COTRELL, J.C., TREW, D.O., & WOOD, B.J.B. Phosphorus quota and the chlorophyll:carbon ratio in marine phytoplankton.
Limnol. Oceanogr., 1975.
20: 587-603.

THOMAS, W.T. On nitrogen deficiency in tropical pacific oceanic phytoplankton: Photosynthetic parameters in poor and rich water.
Limnol. Oceanogr., 1970.
15: 380-385.

THOMAS, W.H., & DODSON, A.N. On nitrogen deficiency in tropical Pacific oceanic phytoplankton. 2. Photosynthetic and cellular characteristics of a chemostat grown diatom.
Limnol. Oceanogr., 1972.
17: 515-523.

THOMAS, J.B., HAANS, A.J.M., & VAN DER LEUR, A.A. Photosynthetic activity of isolated chloroplast fragments of Spirogyra.
Biochim. Biophys. Acta, 1957.
25: 453-462.

TREHARNE, R.W., MELTON, C.W., & ROPPEL, R.M. Electron spin resonance signals and cell structure of Chlorella pyrenoidosa grown under different light intensities.
J. Mol. Biol., 1964.
10: 57-62.

TUNZI, M.G., & PORCELLA, D.B. Carbon-14 assimilation, chlorophyll, and particulate organic matter in steady state systems at Lake Tahoe.
Limnol. Oceanogr., 1974.
19: 420-428.

ULLRICH, W.R. Untersuchungen uber die raten der polyphosphatsynthese durch die photophosphorylierung bei Ankistrodesmus braunii.
Arch. Mikrobiol., 1973.
87: 323-339.

VAN BAALEN, C. The effects of ultraviolet irradiation on a coccoid blue-green algae survival, photosynthesis and photoreactivation.
Plant. Physiol., 1968.
43: 1689-1695.

VAN DER VEEN, R., & MEIJER, G. Light and plant growth.
Philips techn. library, 1959.
161 p.

VERDUIN, J. The volume based photosynthetic rates of aquatic plants.
J. Bot., 1952.
39: 157-159.

VOLLENWEIDER, R.A. A manual on methods for measuring primary production in aquatic environments.
IBP Handbook No. 12, 1969.
Blackwell Scientific Publ., Oxford.
213 p.

WALLEN, D.G., & CARTIER, L.D. Molybdenum dependence nitrate uptake and photosynthesis of freshwater algae.
J. Phycol., 1975.
11: 345-349.

WALLEN, D.G., & GEEN, G.H. The nature of the photosynthate in natural phytoplankton populations in relation to light quality.
Mar. Biol., 1971.
10: 157-168.

WESTLAKE, D.F. Some problems in the measurement of radiation under water: a review.
Photochem. & Photobiol., 1965.
4: 849-868.

WETZEL, R. Limnology.
W.B. Saunders Publ., Philadelphia, 1975.
743 p.

p.o. box 177 delft the netherlands