Forschungszentrum Jülich
in der Helmholtz-Gemeinschaft

Institut für Chemie und Dynamik der Geosphäre
ICG-V: Sedimentäre Systeme

The isotopic composition of valves and organic tissue of diatoms grown in steady state cultures under varying conditions of temperature, light and nutrients - Implications for the interpretation of oxygen isotopes from sedimentary biogenic opal as proxies of environmental variations

Krystyna Kowalczyk

Jül-4217

The isotopic composition of valves and organic tissue of diatoms grown in steady state cultures under varying conditions of temperature, light and nutrients - Implications for the interpretation of oxygen isotopes from sedimentary biogenic opal as proxies of environmental variations

Krystyna Kowalczyk

Berichte des Forschungszentrums Jülich ; 4217
ISSN 0944-2952
Institut für Chemie und Dynamik der Geosphäre
ICG-V: Sedimentäre Systeme Jül-4217
D 38 (Diss., Köln, Univ., 2006)

Zu beziehen durch: Forschungszentrum Jülich GmbH · Zentralbibliothek, Verlag
D-52425 Jülich · Bundesrepublik Deutschland
☎ 02461 61-5220 · Telefax: 02461 61-6103 · e-mail: zb-publikation@fz-juelich.de

Isotopenzusammensetzung von Schalen und Zellgewebe von Kieselalgen aus stationären Kulturen unter verschiedenen Temperatur-, Beleuchtungs- und Nährstoffbedingungen

-Schlussfolgerungen für die Interpretation von Sauerstoffisotopen biogener Silikate aus Sedimenten als Proxies von Umweltvariationen

Zusammenfassung

Der biogene Opal aus Kieselalgenschalen wurde in letzter Zeit vermehrt als Paläotemperatur-indikator vor allem dann benutzt, wenn Karbonate als Träger klimatischer Information nicht zur Verfügung standen. Im Hinblick auf terrestrische Gewässer stellt sich aktuell die Frage, ob und inwieweit diese Paläotemperaturskala auch im limnischen Bereich angewendet werden kann. Weil die jahreszeitlichen Variationen in Seen wesentlich höher als in Ozeanen sind, treten bei der Interpretation der ermittelten Signale andere Probleme auf. Die Frage nach Entstehung und der Zusammensetzung von Isotopensignalen ist daher eine große Herausforderung um zu einer korrekten Interpretation zu kommen. Im natürlichen Milieu ist die gezielte Untersuchung einzelner Umweltparameter auf Grund der sich ständig verändernden Bedingungen nahezu unmöglich. Deshalb wurde der Entschluss gefasst, Laboruntersuchungen durchzuführen, bei denen gezielt unter bestimmten vorgegebenen Parametern experimentiert werden konnte.

Im vorliegenden Fall wurde entschieden, mit dem Einsatz stationärer Algenkulturen einen möglichen Zusammenhang zwischen Sauerstoffisotopenvariationen und verschiedenen Umweltgrößen zu erarbeiten. An Hand der Arbeit sollte überprüft werden, ob verschiedene Diatomeenarten unter gleichen Bedingungen gleiche Sauerstoffisotopenverhältnisse aufweisen (Artabhängigkeit), ob Variationen der Wassertemperatur zu Veränderungen des Isotopenverhältnisses führen (Temperaturabhängigkeit), ob Variationen der Lichtintensität und Nitratkonzentration (Nährstoffe) zu Veränderungen des Isotopenverhältnisses führen, und ob gewisse biologische Prozesse (z.B. Wachstumsrate) zu Abweichungen vom rein physikalischen Isotopenaustausch führen können.

Die Versuchsreihen mit den Diatomeen wurden in zwei Fermentern durchgeführt. Um die Versuche durchzuführen, mußte eine Beleuchtungseinheit mit natürlichem Lichtspektrum konstruiert werden. Für die Untersuchungen wurden zwei Diatomeenstämme ausgewählt, die sich morphologisch unterscheiden. Dies waren: *Fragilaria crotonensis* aus der Ordnung Pennales und C*yclotella meneghiniana* aus der Ordnung Centrales. Die Experimente wurden bei den Temperaturen: 9, 12, 15, 18, 21 und 24°C durchgeführt. Zunächst wurde der Einfluss verschiedener Nitratkonzentrationen im Medium (10.5, 21, 52.5 und 105 mg/l) auf das Verhalten der Diatomeen überprüft. Außerdem wurden Versuche bei verschiedenen Lichtintensitäten (200, 500, 1100 und 1700 µmol Photonen $m^{-2}s^{-1}$) durchgeführt.

Auf Grund der Ergebnisse wurde für beide Arten ein Zusammenhang zwischen dem Isotopenwert des Opalsauerstoffs und der Wassertemperatur gefunden. Dabei hat sich gezeigt, dass die Temperaturkoeffizienten nicht artabhängig sind. Für *Fragilaria crotonensis* wurde im Temperaturbereich von 15-24°C ein Temperaturkoeffizient von ≈ -0.28 ‰/°C ermittelt. Für *Cyclotella meneghiniana,* ergab sich mit einer Wachstumsrate von 0.34 d^{-1} im Temperaturbereich 15-21°C, ein Temperaturkoeffizient von ≈ -0.27 ‰/°C. Dieselbe Art, lieferte bei einer Wachstumsrate von 0.2 d^{-1} im Temperaturbereich 9-18°C, ebenfalls einen Temperaturkoeffizienten von ≈ -0.27 ‰/°C.

Die Untersuchung des Einflusses der verschiedenen Nitratkonzentrationen zeigte keine Änderung der Sauerstoffisotopenfraktionierung im biogenen Opal. Der Befund ist von großer Bedeutung für Rekonstruktionen der Wassertemperatur mittels der Sauerstoffisotopenverhältnisse von Diatomeenschalen die aus verschiedenen Seen gewonnen werden. Denn verschiedene Seen werden sich normalerweise in ihrer chemischen Zusammensetzung unterscheiden.

Zusätzlich konnte gezeigt werden, dass verschiedene Lichtintensitäten die Sauerstoffisotopen-fraktionierung während des Schalenaufbaus signifikant beeinflussen, allerdings ist der Effekt nicht sehr groß. Der Lichtkoeffizient (φ) beträgt ≈ 0.05 ‰/100µmol Photonen $m^{-2}s^{-1}$. Der Effekt der Lichtintensität ist gegenläufig zum Temperatureffekt, und führt offensichtlich zu einer Dämpfung des Isotopensignals. Änderungen der Lichtintensität sollten also bei der Interpretation der Sauerstoffisotopenverhältnisse vom Kieselalgenopal berücksichtigt werden.

Die in dieser Studie entdeckten speziesspezifischen Effekte beziehen sich auf die Absolutwerte der Fraktionierung, haben jedoch keinen Einfluss auf die Temperaturkoeffizienten, welche speziesunabhängig sind. Die untersuchten Diatomeenarten waren also durch verschiedene Fraktionierungswerte charakterisiert. Offensichtlich spielt die Wachstumsrate bei der Fraktionierung eine entscheidende Rolle.

CONTENTS

List of figures

List of Tables

List of abbreviations

a) isotopic abbreviations

α – fractionation factor; shows magnitude of an isotope shift

δ [‰] – the relative difference in the isotope ratio between a sample and the standard in parts per thousand or per mil

$\Delta^{13}C$ [‰] – the difference between the $\delta^{13}C$ of organic matter and the $\delta^{13}C$-value of the corresponding source value, i.e. CO_2.

$\Delta^{15}N$ [‰] - the difference between the $\delta^{13}C$ of organic matter and the $\delta^{13}C$-value of the corresponding source value

ε – fractionation; represents changes in isotope composition

φ [‰/100 µmol photons $m^{-2}s^{-1}$]– light coefficient; shows the permil change of the oxygen isotope ratio per 100 µmol photons $m^{-2}s^{-1}$ of light intensity change

τ [‰/°C] – temperature coefficient; shows the permil change of the oxygen isotope ratio per 1°C of temperature change

b) abbreviations in steady state cultures

D [d^{-1}] – dilution rate of the fermenter

F [l d^{-1}] – flow rate of the fermenter

G [d] – doubling time; time after which the biomass has doubled

K' – equilibrium reaction constant

µ [d^{-1}] – growth rate of an organism

μ_m [d^{-1}] – maximal growth rate of an organism

P [mg $l^{-1}d^{-1}$] – productivity of an organism; an increment of the biomass per time unit, in other words, it is the growth rate multiplied with biomass

S – substrate

V [l] – fermenter volume

X [mg] – biomass

Y – yield coefficient; indicates the degree of the substrate utilisation during formation of the cells

1. Introduction and goals of the study

Palaeoclimatology as a discipline has developed exponentially in the last 25 years. Knowledge in the field of palaeoclimatology is valuable in its own right. It is essential to progress our understanding of the role of the physical environment as a force driving evolutionary and ecological changes (e.g. Stenseth et al., 2002). In addition, developments in other fields have allowed palaeoclimates to be studied at levels of resolution that were not possible before. Understanding palaeoclimate is the key to comprehend the long-term processes in the climate system of our planet (e.g. Zachos et al. 2001, Rahmstorf 2002). Moreover, it is of great significance for distinguishing between natural climate changes and the climate changes caused by humans. The geologic record of climate change continues to be the best source of information on the Earth's climate system. It provides a record of trends in climate and its variability in the recent past that can extend beyond the paltry human time scales on which climate has been measured directly. If we can understand climatic conditions that have not existed during the history of recorded climate, we gain a more fundamental understanding of the climate system than is attainable through studies based solely on modern conditions. Understanding climate change over the full variety of temporal and spatial scales recorded from geologic archives contributes to knowledge of the fundamentals of climate dynamics. This knowledge is essential if we are to model future climate with confidence. Analyses of proxy data (from ice cores, corals, ocean and lake sediments, tree rings etc.) and model studies are complementing one another. Within the set of proxy data stable isotopes constitute an important tool in climatic investigations. Examples are the $\delta^{18}O$ records from ice cores (e.g. Dansgaard et al. 1993, Stuiver et al. 1995), the $\delta^{18}O$-values from carbonate shells of foraminifers (e.g. Shackleton 1987, Mulitza et al. 2003), the $\delta^{13}C$ records from tree rings (Zimmermann et al. 1997, Treydte et al. 2001), the $\delta^{18}O$ data from carbonates of lacustrine sediments (e.g. Dutkiewicz et al. 2000) and the $\delta^{18}O$-values from biogenic silica (e.g. Shemesh et al. 1992). Stable isotope geochemistry has been used increasingly in the palaeoclimate community since the work of McCrea (1950) and Urey et al. (1951) highlighted the potential for oxygen isotope composition to be used for palaeotemperature reconstruction. But not only the oxygen isotopes are subject of environmental investigations. For plant biologists, ecologists and environmental chemists the carbon and nitrogen isotopes are likewise

of great importance. The developed theoretical framework and the empirical database for the use of isotopes to study plants and animals can help to find patterns and mechanisms at the level of single organisms. This knowledge will help to trace e.g. food webs and to follow whole ecosystem cycling in terrestrial as well as marine ecosystems. Terrestrial isotope records have the potential to provide a much higher time resolution for palaeoclimate studies than most other records, but the isotopic systematics of these structures must be understood in much greater detail. E.g., up to now monitoring and calibration studies are not conducted in many lakes. In Central Europe an almost ideal research object constitutes Lake Holzmaar, which is a small soft water lake. The varved sediments, deposited in this lake, offer a well-dated high-resolution record (Negendank et al. 1990). Unfortunately, the sediments of the soft water Lake Holzmaar do not contain carbonates, which normally serve as a surrogate for climatic information. However, diatom valves, accumulated in the varved material, can be used as alternative proxy material. Some time ago an empirical correlation between the marine temperature and the $\delta^{18}O$ values of biogenic silica was suggested as a palaeotemperature scale (Labeyrie 1974, Juillet-Leclerc & Labeyrie 1987). The question which has always been discussed was to what extent this palaeotemperature scale can be applied to limnic systems.

This experimental work constitutes a contribution to our field studies conducted in Lake Holzmaar. On the basis of continuous cultures using diatom species occurring in Lake Holzmaar the following questions were raised:

- Is the water temperature reflected in the oxygen isotope ratio of biogenic silica?
- Is the fractionation between diatom silica and water species-specific?
- Is the fractionation influenced by other environmental factors e.g. nutrients, light intensity?
- Are there vital effects like growth rate involved in the oxygen isotope fractionation process?

Answers to these questions should help in understanding the processes which influence the oxygen isotope ratio of diatomaceous silica in natural environments. As such answers to these questions can be decisive for climate reconstruction if oxygen isotopes from valves are to be used as a palaeothermometer.

2. Theoretical background

2.1 Stable oxygen isotopes, nomenclature and fractionation processes

Oxygen has three stable isotopes, namely ^{16}O, ^{17}O and ^{18}O having the following abundances: ^{16}O=99.763 %, ^{17}O=0.0375 % and ^{18}O=0.195 %.

Because the abundance of ^{17}O is very low its detection requires a considerable technical effort and, therefore, it is commonly not used in oxygen isotope investigations. For studies in which the oxygen isotopes are used the $^{18}O/^{16}O$ ratio will usually be determined and related to the international standard V-SMOW (Vienna Standard Mean Ocean Water).

In this respect the so-called δ-value plays a decisive role. Initially the isotopic composition of oxygen was given in terms of differences of $^{18}O/^{16}O$ ratios relative to the SMOW standard (Standard Mean Ocean Water). This standard is, however, nowadays superseded by the internationally used, almost identical V-SMOW standard (Vienna-SMOW) which will be quoted throughout this study.

The isotopic composition of a sample is expressed in per mil relative to V-SMOW and denoted as δ. The relevant expression is given by:

$$\delta^{18}O\ (‰) = \frac{R_S - R_{St}}{R_{St}} * 1000$$

in which R_S is the $^{18}O/^{16}O$ ratio of the sample and R_{St} is the corresponding $^{18}O/^{16}O$ ratio of the standard. Thus, a δ-value is the relative difference in the isotope ratio between a sample and the standard in parts per thousand or per mil (‰). The sign of a δ-value depends upon the isotope ratio of the sample relative to the standard (being positive when $R_S > R_{St}$ and negative when $R_S < R_{St}$).

Isotope fractionations appear in nature in many ways, e.g. across phase boundaries during kinetic processes etc. Basically they show up during different kinds of chemical reactions and physical processes. Generally, molecules with different isotopic masses have different reaction rates whereby the molecules containing the lighter isotope show a higher mobility and a higher reaction rate. There are principally three categories to be considered:

1. Isotope exchange reactions leading to a redistribution of isotopes from an element amidst different molecules which contain the corresponding element.

2. Reactions operating in one direction (unidirectional) in which rates depend on the isotopic composition of reactants and products.
3. Physical processes such as e.g. evaporation and condensation, adsorption and desorption, melting and crystallisation or diffusion of molecules due to concentration or temperature differences.

The magnitude of an isotope shift is generally expressed by means of the fractionation factor α:

$$\alpha_{A\text{-}B} = \frac{R_A}{R_B}$$

in which R_A is the $^{18}O/^{16}O$ ratio (or generally the ratio of the heavy versus the light isotope) of substance A and R_B is the $^{18}O/^{16}O$ ratio of substance B.
The R-values of the fractionation factor α need, however, to be transformed into δ-values because the ratio of isotopes from an element can not be determined directly. δ-values can be determined mass spectrometrically. From the definition of δ it follows:

$$\delta = \frac{R_S - R_{St}}{R_{St}} * 10^3$$ rearranging results in:

$$R_{St}\,\delta * 10^{-3} = R_S - R_{St} \quad | + R_{St}$$

$$R_{St}\,(1 + \delta * 10^{-3}) = R_S$$

If the ratio of substance A is denoted by $R_{S,A}$ and the ratio of substance B by $R_{S,B}$ the two equations are then given by:

$$R_{St}\,(1 + \delta_A * 10^{-3}) = R_{S,A}$$
$$R_{St}\,(1 + \delta_B * 10^{-3}) = R_{S,B}$$

Note, that the corresponding δ-values are given by δ_A and δ_B, respectively and that the standard which is used, is identical in both cases. From these equations the fractionation factor α follows by dividing the two expressions:

$$\alpha_{A\text{-}B}=\frac{R_{St}\ (1+\delta_{A^*}\ 10^{-3})}{R_{St}\ (1+\delta_{B^*}\ 10^{-3})}$$

This leads to:

$$\alpha_{A\text{-}B}=\frac{1000+\delta_A}{1000+\delta_B} \qquad (1)$$

Under natural conditions changes of the isotope composition are rather small and therefore, α is normally close to 1. This has led to the introduction of the fractionation ε, defined as:

$$\alpha_{A\text{-}B} = 1 + \varepsilon_{A\text{-}B} \qquad \text{with } |\varepsilon| << 1$$

Taking into account equation 1 the following equation evolves for the fractionation between the two phases A and B:

$$1 + \varepsilon_{A\text{-}B}=\frac{1000+\delta_A}{1000+\delta_B}$$

$$\varepsilon_{A\text{-}B}=\frac{1000+\delta_A -1000 - \delta_B}{1000+\delta_B}$$

$$\varepsilon_{A\text{-}B}=\frac{\delta_A - \delta_B}{1000+\delta_B}$$

As mentioned, ε is very small. It has, therefore, been agreed that the value should be given in per mil as in the case for the δ-value. Multiplying by 1000 results in:

$$\varepsilon_{A\text{-}B}\ (‰)=\frac{\delta_A - \delta_B}{1000+\delta_B} * 10^3$$

$$\varepsilon_{A\text{-}B}\ (‰)=\frac{\delta_A - \delta_B}{1 +10^{-3} * \delta_B} \qquad (2)$$

In many cases $10^{-3} * \delta_B$ (δ_B given in per mil) is very small, i.e. $|10^{-3} * \delta_B| << 1$ and, thus, ε can to a good approximation be written as:

$$\varepsilon_{A\text{-}B} \approx \delta_A - \delta_B \text{, the difference } \delta_A - \delta_B \text{ will normally be given as } \Delta. \quad (3)$$

In general changes of the isotope composition will be given either in terms of the fractionation factor α or as the fractionation ε. Both equations are in use internationally. Frequently lnα is used instead of α, the reason being a direct relation of lnα with temperature. For the relation of α and ε this leads to:

$\ln\alpha_{A\text{-}B} = \ln(1 + \varepsilon_{A\text{-}B})$, with $|\varepsilon| << 1$, resulting in:

$$\ln\alpha_{A\text{-}B} \approx \varepsilon_{A\text{-}B}$$

and in terms of per mil it follows:

$1000 \ln\alpha_{A\text{-}B} \approx \varepsilon_{A\text{-}B}$ in this case ε is given in per mil.

Finally this results in:

$$1000 \ln\alpha_{A\text{-}B} \approx \varepsilon_{A\text{-}B} = \frac{\delta_A - \delta_B}{1 + 10^{-3} * \delta_B} \approx \delta_A - \delta_B = \Delta_{A,B} \quad (4)$$

For simplicity reasons this study will primarily concentrate on ε, however, a conversion to α can easily be performed. Most important, the fractionation factor α is temperature dependent, as is the fractionation ε:

$$\alpha_{A\text{-}B} = \alpha(T) \text{ and } \varepsilon_{A\text{-}B} = \varepsilon(T)$$

Thus, from the magnitude of the isotope fractionation it should in principle be possible to determine the temperature conditions, which prevailed at the formation time of the substance in question, provided the initial isotope value is known (the corresponding source value). The higher the temperature is, at which a reaction proceeds, the smaller is the fractionation factor α as well as the fractionation ε.

Relating to the temperature, the subject of interest is the so-called temperature coefficient τ, which can be defined as:

$$\tau = \frac{\Delta\varepsilon}{\Delta T}\ [‰/°C] \qquad \text{or in the exact form:} \qquad \tau = \frac{1000 \ln \alpha_2/\alpha_1}{\Delta T}$$

With α_2 being the fractionation at temperature T_2 and α_1 the fractionation at temperature T_1. This coefficient shows the permil change of the oxygen isotope ratio per 1°C of temperature change (τ [‰/°C]).

2.2 Stable oxygen isotopes of biogenic silica

Ratios of stable isotopes are one of the most useful “detective” tools for understanding physical, chemical, and biological processes in nature, especially for events that occurred in the distant past. The potential of the stable oxygen isotopes of biogenic silica as proxy was hitherto rarely exploited. In many cases the temperature reconstruction on the basis of opaline oxygen isotope values provides a very promising tool in palaeoclimatological research. But its application has been restricted due to difficult and not totally reliable analytical techniques (Juillet 1980; Labeyrie & Juillet 1980; Labeyrie & Juillet 1982). However, biogenic silica can serve as a climate archive where biominerals such as carbonates are not available. Many aquatic plants e.g. diatoms, chrysophytes, silicoflagellates and radiolarians build up amorphous siliceous structures (i.e. valves, cysts, skeletons) which are frequently found in marine sediments as well as lake sediments. Juillet-Leclerc & Labeyrie (1987) developed a palaeotemperature scale, based on $\delta^{18}O_{SiO2}$ values of marine biogenic silica extracted form the upper part of sediment cores. Juillet-Leclerc & Labeyrie (1980, 1982) highlighted two main problems concerning diatom valves. Firstly, separation from the sediment and secondly analytical difficulties associated with the separation of water molecules and OH groups from the silica surface. Achievement of a clean sample is indispensable to produce a reliable relationship between water temperature and the oxygen isotope composition of biogenic silica. Although the existence of a correlation was experimentally confirmed, different authors determined different isotope fractionations depending on the pre-treatment of samples and the extraction technique used for the oxygen isotopes (Juillet-Leclerc & Labeyrie 1987; Matheney & Knauth 1989; Schmidt et al. 1997; Brandriss et al. 1998;

Schmidt et al. 2001; Moschen et al. 2005). The investigations resulted in temperature coefficients which according to different authors varied from -0.19 to -0.50 ‰/°C (Juillet-Leclerc & Labeyrie 1987; Matheney & Knauth 1989; Clayton 1992; Shemesh et al. 1992; Shemesh et al. 1995; Brandriss et al. 1998; Moschen et al. 2005). The reasons of these discrepancies remain up to now unclear.

According to the isotope theory the temperature signal stored in diatom valves should remain unchanged. Schmidt et al. (1997), however, found a distinct difference between the $\delta^{18}O$ of diatoms from sediments and the $\delta^{18}O$ of fresh diatoms. Possibly the isotope exchange processes with ambient H_2O during diatom sedimentation may control the oxygen isotope composition of diatoms deposited in sediments (Rimstidt & Barnes, 1980; Gallinari et al., 2002; Rickert et al, 2002). It is also possible, that metabolic processes associated with the cell cycle of living diatoms may have an influence on the oxygen isotope ratio and, thus, species-specific effects can not be excluded. Storing of a $\delta^{18}O$ signal by diatoms occurs in the course of the valve formation. Prior to the development of a daughter cell the diatom cell transports silicic acid into the silicon deposition vesicle (SDV) and it is possible that during this cycle an additional metabolic effect (biological effect, β) appears apart from the physical equilibrium reaction. Besides temperature environmental factors, such as light or e.g. nutrients, can influence the cell metabolism and thus, the oxygen isotope ratio of silica. Detailed information about these processes derived from laboratory experiments is still missing. Knowledge about the possible processes involved could help in the interpretation and calibration of the isotope thermometer.

According to present day knowledge the oxygen isotope composition of biogenic silica deposited by aquatic organisms depends primarily on the temperature and the isotopic composition of the water. The $\delta^{18}O$ value of the water constitutes the starting point for oxygen isotope fractionation during biogenic silica formation (source value). This dependence can simply be written as:

$$\delta^{18}O_{H4SiO4} = f\,(T, \delta^{18}O_{H2O}) \;\rightarrow\; \delta^{18}O_{SiO2} = f\,(T, \delta^{18}O_{H4SiO4}, \beta)$$

where T is the temperature, $\delta^{18}O$ is the isotope value according to the corresponding index and β is a biological parameter. Hydration between water and dissolved silicic

acid proceeds in isotopic equilibrium. This isotopic distribution at equilibrium is a function of the free energy of the reaction as well as temperature:

$$\tfrac{1}{2}Si^{16}O_2 + H_2{}^{18}O \xleftrightarrow{K'} \tfrac{1}{2}Si^{18}O_2 + H_2{}^{16}O$$

The isotope fractionation between biogenic silica and water is supposed to be an equilibrium reaction with an equilibrium reaction constant K' being related to the fractionation factor α as follows:

$$K' = \frac{[Si^{18}O_2]^{1/2} * [H_2{}^{16}O]}{[Si^{16}O_2]^{1/2} * [H_2{}^{18}O]} = \frac{[Si^{18}O_2]^{1/2} / [Si^{16}O_2]^{1/2}}{[H_2{}^{18}O]/[H_2{}^{16}O]} = \frac{[{}^{18}O/{}^{16}O]_{SiO_2}}{[{}^{18}O/{}^{16}O]_{H_2O}} = \alpha_{SiO_2/H_2O}$$

where $\alpha_{SiO_2/H_2O} = \text{const.}$, for $T = \text{const.}$

2.3 Stable carbon isotopes and fractionation processes

In nature two stable carbon isotopes exist, namely ^{12}C and ^{13}C with the following abundances: ^{12}C= 98.89% and ^{13}C= 1.11%. As in the case of the oxygen isotopes, carbon isotope shifts are described by δ-values and given in the form of differences of $^{13}C/^{12}C$ related to a standard. For carbon isotopes the internationally adopted reference is CO_2 obtained from a fossil belemnite from the Pee Dee formation of South Carolina, USA. It is denoted as PDB (Craig, 1957) and has the following isotope composition: $^{13}C/^{12}C_{PDB}$ = 0.01124. All $\delta^{13}C$ values in this investigation will be related to this standard.

The carbon isotope fractionation both in terrestrial and aquatic plants takes place during photosynthesis as plants take up CO_2 into their cells. Generally two steps are relevant in biological carbon fixation. The first step is the diffusion of CO_2 into the intercellular air spaces and/or diffusion of carbon dioxide into particular intracellular compartments. The second step is the biosynthesis of cellular components:

$$CO_{2\,(external)} \xleftrightarrow{1} CO_{2\,(internal)} \xrightarrow{2} \text{organic compounds}$$

The diffusion process (1) is reversible, whereas the enzymatic carbon fixation (2) is irreversible.

In aquatic environments fractionation of carbon occurs not only during diffusion and assimilation. There is also a fractionation occurring during the dissolution of carbon dioxide in the water and during the dehydration of CO_2 to bicarbonate (Mook et al. 1974, Zhang et al. 1995). The concentration of dissolved CO_2 in water is relatively low compared to the atmosphere, and strongly temperature dependent, so most species of aquatic plants are adapted to the uptake of CO_2 via passive diffusion and bicarbonate ion production (active transport across the diffusion layer)

Environmental conditions such as water movement, light intensity and temperature control the development of aquatic plants and show the dominant influence on their isotopic carbon composition.

1. *Water movement*. The low diffusion rate of CO_2 in water creates severe limitations for the carbon uptake. In addition the carbon influx is restricted by the boundary layer (BL) surrounding the plant cells. The thickness of the BL plays a decisive role for the transport of carbon dioxide and may create a barrier blocking the uptake. Greater water velocity, i.e. movement reduces the BL thickness.
2. *Light*. Many studies have shown that light intensity affects the metabolic rate of aquatic plants and simultaneously the carbon isotope composition of them (e.g. Thompson & Calvert 1994). High light levels increase the carbon demand, which might reduce discrimination against $\delta^{13}C$.
3. *Temperature*. The temperature of the water has an influence on solubility of gases and the solubility increases with decreasing temperatures. The amount of CO_2 dissolved in freshwater at normal pressure (1013 hPa) is about 3350 mg/l at 10°C and 1690 mg/l at 20°C (Schwoerbel 1993). This highlights the strong dependency of dissolved CO_2 on the temperature. In this temperature range of 10°C the solubility decreases almost by a factor of 2. Because the concentration of dissolved CO_2 increases as the temperature decreases, discrimination might well increase due to greater availability of carbon. The $\delta^{13}C$ values of aquatic plants correlate with temperature and are inversely proportional to the temperature (Degens et al. 1968). Temperature also affects the equilibrium fractionation between $CO_{2\,(aq)}$ and HCO_3^- by approximately 3‰ (Mook et al. 1974; Hinga et al. 1994) and produces different amounts of CO_2 and HCO_3^- available for uptake.

2.4 Isotope signatures of nitrogen in algae

Nitrogen has two stable isotopes namely ^{14}N and ^{15}N with the following abundances: ^{14}N= 99,64% and ^{15}N= 0,36%. In isotopic investigations the nitrogen isotopes of atmospheric nitrogen (N_2) are commonly used as reference.

Nitrogen is an essential component of nutrition for all organisms and together with other nutrients like phosphorus and silicon can limit the algal productivity in many lakes. Changes in nitrogen cycling influence the production of organic matter and, thus, affect the composition and accumulation of sedimentary organic matter.

Normally nitrogen of lacustrine sediments is characterized by total nitrogen (TN) or by the C/N ratio. N-isotopes were up to now rarely applied in limnological investigations. However, the isotope ratio and its changes due to kinetic isotope fractionation can provide important information about nitrogen sources and utilisation characteristics of an ecosystem. Nitrogen isotopes can even be useful in interpreting environmental changes of the past (e.g. Haug et al. 1998).

While the mechanisms of carbon isotope discrimination during photosynthetic carbon fixation are well understood, the biochemistry of nitrogen isotope fractionation in microalgae is presently not well known. In addition most of the presently available investigations are based on marine ecosystems.

It is known that the nitrogen isotope fractionation by phytoplankton follows the Rayleigh model (Mariotti et al. 1981). There are several possibilities of fractionation during the uptake of inorganic nitrogen. These are:

1. flux of NO_3^- by diffusion across the boundary layer
2. active transport (uptake step) of NO_3^- across the plasma membrane
3. intracellular reduction of NO_3^- to NO_2^- by nitrate reductase (NR)
4. the reduction of NO_2^- to NH_4^+ and formation of amino acids

Recent studies suggest that the isotope fractionation by phytoplankton occurs during the reduction of nitrate by nitrate reductase and that the efflux of isotopically heavier nitrate is ultimately responsible for the measured isotope effect (Shearer et al. 1991, Needoba and Harrison 2004).

2.5 Diatoms

Diatoms or *Bacillariophyceae* are unicellular, frequently colonial algae found in aquatic habitats. These free-living photosynthetic autotrophs occur as plankton or periphyton. They normally exist as single cells with diameters between 5 µm and 5 mm, depending on the species (Van den Hoek 1997). The cell walls of diatoms are silicified and transparent, forming a structure called frustule containing hydrated amorphous silica with the general formula $[SiO_2 * nH_2O]$. Amorphous silica constitutes an essential component of the diatom cell wall. Thus, Si availability is the key factor regulating diatom growth in nature. The complicated siliceous structures in the diatom cell wall are replicated with precision for each generation creating inimitable morphotypes used generally as taxonomic keys. The number of recognized species amounts to over 100.000 (Round et al. 1990). The chloroplasts of diatoms contain chlorophyll a, c_1 and c_2 with the major carotenoid being fucoxanthin giving the cells its characteristic golden-brown colour.

The *Bacillariophyceae* comprise two major groups namely the centric diatoms (Order Centrales) and the pennate diatoms (Order Pennales). Both orders are systematized according to differences in cell wall structure. The frustule of a pennate diatom is elongated, with a lanceolate or elliptical shape. The shell consists of two halves: hypotheca and epitheca (see Figure 1). The hypotheca consists of a hypovalve and hypocingulum (lower girdle). Analogously, the epitheca comprises an epivalve and epicingulum (upper girdle). In many pennate diatoms the valve possesses a rift lying along the apical plane which is named the raphe. Generally the raphe is involved in locomotion and diatoms without raphes cannot move actively. The skeletons of centric diatoms are round and radially symmetrical. They do not have the raphe.

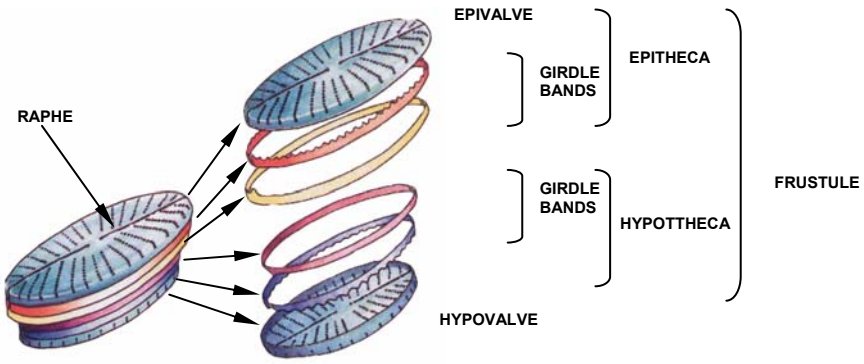


Figure 1: Schematic overview of the diatom structure with its cell walls.

2.5.1 Cell division

Cell division in diatoms is an asexual reproduction process whereby two daughter cells develop. The cell division of both pennate and centric diatoms is very similar (Van den Hoek et al. 1997)

Prior to the cell division both valves elongate (see Figure 2). Mitosis then takes place and division of the protoplast occurs. After that a formation of the silica deposition vesicle (SDV) follows, which is responsible for the development of new valves. The SDV elongates and extents. The new valve is starting to form with the help of the SDV by direct uptake of silica, polysaccharides and proteins. In the course of the silica polymerisation the SDV becomes acidic (Vrieling et al. 1999). Once valve biogenesis is complete the exocytosis occurs, i.e. fusion of the SDV membrane (silicalemma) with the plasma membrane. As a result the inner surface of the silicalemma becomes the new plasma membrane.

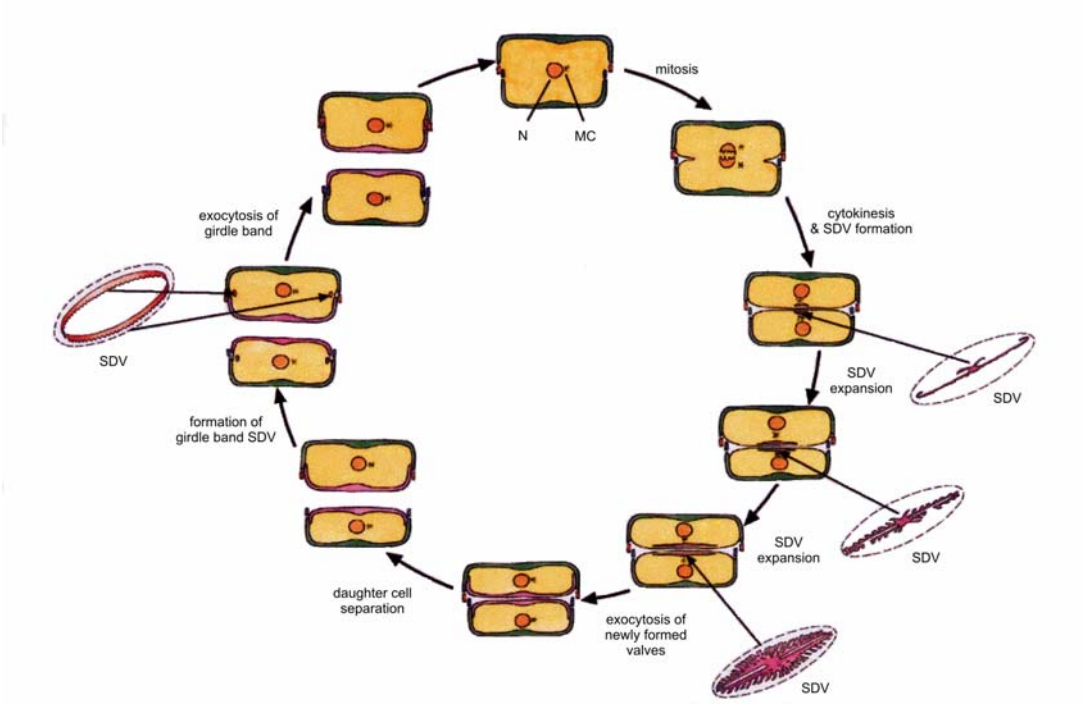


Figure 2: Mitotic division of the diatom cell and formation of new cell walls. N – Nucleus, MC – Microtubule centre, SDV – Silica deposition vesicle (see Zurzolo & Bowler 2001).

Afterwards the daughter cells separate. The new elements of the girdle in daughter cells are formed later, when the valve formation is complete. They are also formed within SDVs.

In each daughter cell the newly synthesized half is always a hypotheca. As an effect of this division, one of the daughter cells retains the same size as the parent cell while the second is smaller. Thus, average cell size in diatom populations decreases successively (see Figure 3). But not all species become smaller during division. Some of them have an elastic girdle and can keep up their size.

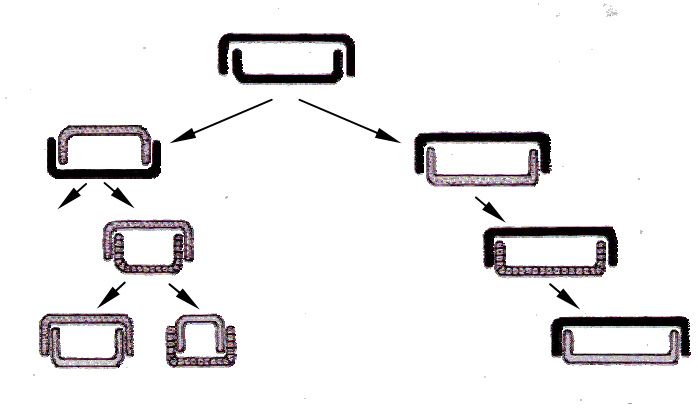


Figure 3: The diatom cell in girdle view showing the reduction in size.

If cells reach a minimal size auxospores will built-up, through which the initial size of the cells will be restored. The auxospores are formed before the cells reach their absolute minimum size, beyond which variability ceases. The smallest cells are unable to form auxospores and divide vegetatively until they die.

2.5.2 Cell cycle and formation of the cell wall

Numerous studies on the process of silification of diatom cell walls have been carried out (e.g. Schmid et al. 1981, Schmid and Volcani 1983). The process of frustule formation is partially understood and is mainly based on microscopical observations. It is known that cell wall silicification and transport of silicic acid are fixed to the cell cycle (e.g. Brzezinski 1992). This coupling of cell cycle and silicic acid uptake has substantial implications. E.g. in *Navicula pelliculosa* (Bréb.) Hilse, the deposition of the entire frustule occurs during one continuous segment beginning just before division and ending just before daughter cell separation. Silicic acid uptake in this species is confined to the same segment of the cell cycle (Sullivan 1977). However, in species constructing the major part of the frustule at other points in the cell cycle the coupling of uptake and division may be weaker (Brzezinski 1994).

In the diatom cell cycle a series of Si dependencies have been identified and generally in diatom mitosis two checkpoints were distinguished (Brzezinski et al. 1990). The first one appears at the G_1/S boundary (see Figure 4) and tests the environment whether sufficient Si exists for completion of the cell division. If not enough Si is available the cell division will be stopped. The second arrest point appears during G_2/M boundary and is associated with the construction of the new valves i.e. the hypotheca (Brzezinski et al. 1990).

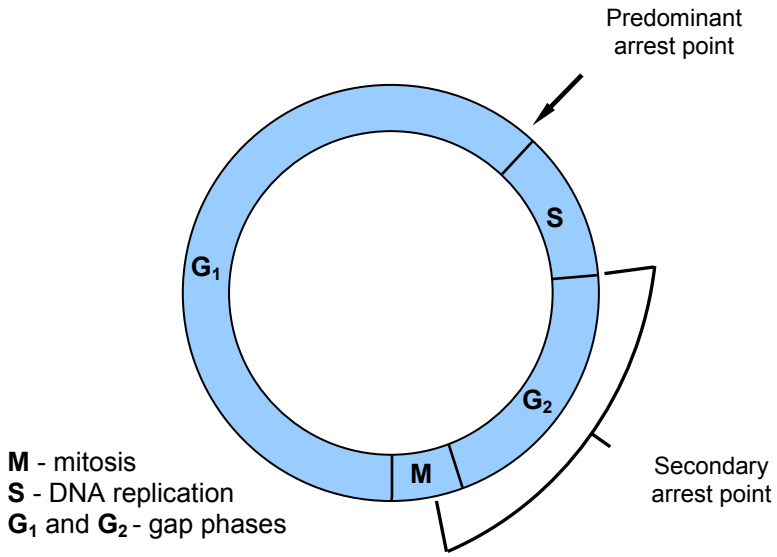


Figure 4: Diatom cell cycle and arrest points due to silicon starvation (Brzezinski et al. 1990).

2.5.3 Silicic acid uptake

Lewin (1954, 1955) first studied silicon uptake by diatoms and Paasche (1973) investigated kinetic measurements of uptake. Subsequent studies by Paasche (1973), Azam et al. (1974), Nelson et al (1976) and Sullivan (1976, 1977) demonstrated that silicic acid assimilation follows Michaelis-Menten or Monod kinetics. Those findings show that silicon transport is carrier-mediated. In marine diatoms it is sodium dependent and in freshwater species it is apparently coupled to sodium and perhaps potassium (Sullivan, 1976).

Diatoms display three different techniques of silicic acid incorporation: surge uptake, internally controlled uptake and externally controlled uptake (Conway et al. 1976, 1977):

- Surge uptake processes occur when intracellular silicon pools are depleted, and the concentration gradient into the cell is maximal. Thus, there is a drag of silicon into the cell. During surge uptake assimilation rates are maximal. This would indicate that the intake of silicon is not purely diffusion controlled but facilitated through energy provided by assimilation.
- Internally controlled uptake occurs when intake is controlled by the rate of silicon utilisation for cell wall deposition (Conway et al. 1976, 1977).
- Externally controlled uptake occurs when the extracellular Si concentration drops to very low levels. In that case the uptake rates are a function of decreasing substrate concentration (Conway et al. 1976, 1977).

These processes might well have an influence on silicon isotope behaviour.

2.6 Culture principles

Physiological, biochemical and isotopic investigations of diatoms are generally conducted by using diatom cultures. The obtained data reflect the activities of diatom cells. The most popular way of culturing algae, i.e. diatoms, is to grow them in so called batch cultures. Patterns of growth and cell metabolism as derived from batch cultures are of interest for understanding the behaviour of phytoplankton in the natural environment.

If a culture is to be investigated with regard to particular conditions over a long time period, whereby just one parameter (e.g. temperature, CO_2-concentration, light intensity etc.) varies, batch cultures are not well suited. In that case a second type of culture method can be used, namely the procedure of continuous culture providing constant growth conditions, i.e. steady state conditions.

2.6.1 Basic principles of batch culture

Theoretical analyses of microbial growth were first made by Monod (1950) and also Novick & Szilard (1950).

Algae grown in batch culture will typically proceed through a number of phases (see Figure 5). The following five phases can be itemised: (I) lag phase without cell density to increase, (II) exponential growth phase with geometric increase of cell density, (III) phase of declining relative growth rate, (IV) stationary phase with constant cell density and (V) death phase. Most interesting are phases (II) and (III). Under ideal conditions with no growth limiting factor growth proceeds exponentially.

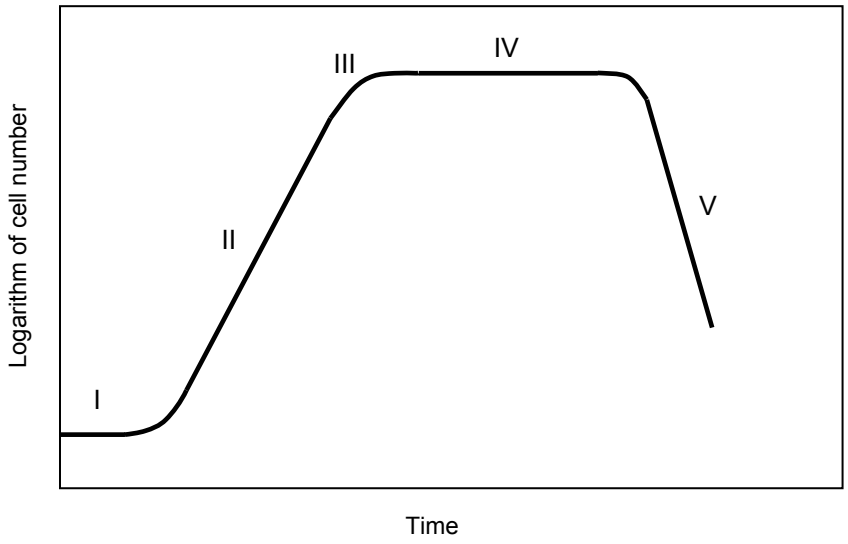


Figure 5: Model of diatom growth in batch culture – phases of growth. (I) lag phase, (II) exponential phase, (III) phase of declining relative growth rate, (IV) stationary phase with constant cell density and (V) death phase.

The actual rate of growth accelerates successively due to continuous cell division and it can be expressed by:

$$X = X_0 * e^{\mu t} \quad (1)$$

and therefrom results:

$$\mu = \frac{\ln X - \ln X_0}{t} = \frac{1}{t} \ln \frac{X}{X_0} \quad (2)$$

where t = time (h) during which algae grew from algal density X_0 to X, X_0 = cell mass (dry weight, biomass or cell count) at time 0, the beginning of growth; X = cell mass at time t, μ = specific growth rate (h^{-1}).

The time after which the initial biomass has doubled taken as X related to X_0 is named the doubling time G, which equals the generation time if the cells divide into two:

$X=2X_0 \rightarrow X/X_0=2$

So when

$$\ln X - \ln X_0 = \ln \frac{X}{X_0} = \ln 2 , \; t = G$$

and thus:

$$G = \frac{\ln 2}{\mu} \quad (3)$$

If the culture reaches growth phase (III) external factors start to limit the growth (i.e. nutrient deficiency) where μ becomes smaller. The specific growth rate is limited by a chemical component of the available substrate S and is for these conditions given by μ. The magnitude of the growth rate μ depends on the concentration of the growth limiting factor. Monod (1942) suggested a formula which is analogous to the enzyme-substrate equation defined by Michaelis & Menten (1913):

$$\mu = \mu_m \frac{S}{K_s + S} \quad (4)$$

μ_m represents the highest specific growth rate attainable for the growth limiting compound used, in this case S. K_s is the saturation constant, also called the Michaelis-Menten constant which represents the substrate concentration at which $\mu = 0.5\ \mu_m$.

2.6.2 Basic principles of continuous culture

When referring to continuous culture systems, the terms lag phase, exponential phase, stationary phase and death phase have no meaning. This is because the system is operating continuously and growth cannot be segregated into phases. In continuous culture the culture conditions remain unchanged and cell density is determined by the rate of supply of growth limiting nutrient.

An important objective of continuous culture operation, though not the only one, is to control cell growth at a level at which productivity is optimal. There are several ways in which this can be achieved. One is to maintain a constant volume of growth medium in a container called fermenter and to use a flow rate that gives an appropriate productivity (see Figure 6). In this mode of operation, the fermenter system is known as a *chemostat* where the flow rate of new medium is regulated by the effluent of culture medium. The chemostat is by far the simplest and most common mode of operation of a continuous culture where a pump controls the volume of the chemostat.

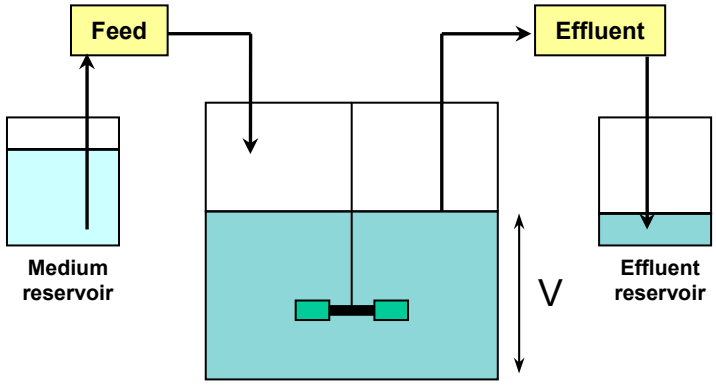


Figure 6: Schematic view of the fermenter. V is the liquid volume in the fermenter maintained by the effluent pump.

Essential parameters for the operation of a chemostat are volume V (l) and flow rate F (l/h). Growth medium flows at a steady rate F from a storage tank into the fermenter. The term that is commonly used is the dilution rate (D) which is defined as the flow rate divided by the volume of the culture and has the dimension h^{-1}:

$$D = \frac{F}{V} \ (h^{-1}) \qquad (5)$$

where F is the flow rate in (l/h) and V is the reactor volume in (l).

The rate at which fresh medium enters the vessel is equal to the rate at which the effluent leaves the reactor. Thus, the reactor volume is kept constant. The dilution rate has a major influence on the productivity of the fermenter. Figure 7 shows how biomass and substrate concentration typically vary with dilution rate.

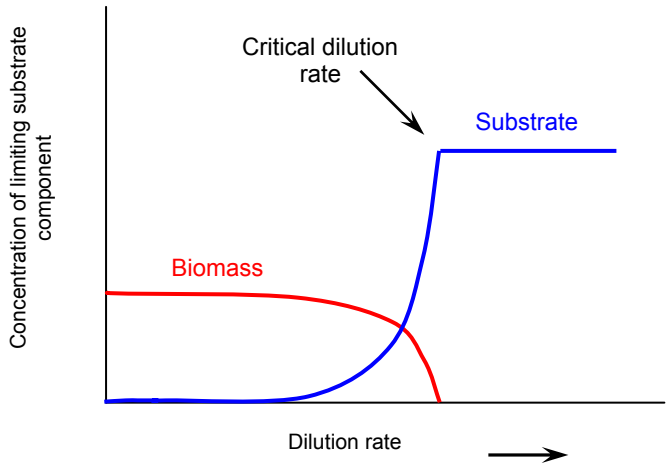


Figure 7: The behaviour of biomass and substrate concentration in a fermenter plotted against the dilution rate

The biomass balance in a chemostat is given by the difference between growth rate (μX) and washout rate (DX). The change in population as algal density X per time unit is given by:

$$\frac{dX}{dt} = \mu X - DX \qquad (6)$$

The biomass in the fermenter will remain constant if the microbial growth becomes equal to the dilution rate. In this case dX/dt = 0 which leads to

$$\mu = D \qquad (7)$$

When μ = D, the culture is in a steady state (Figure 8), a condition that is time-independent. Growth is compensated for by cell removal and all variables remain constant. From equation (7) follows that the steady state specific growth rate μ of an organism is given by the dilution rate D. If μ > D an increase of the cell density X is observed and if μ < D the population density decreases.
Net increase in the population takes place as long as the specific growth rate μ exceeds D. If D exceeds μ (critical dilution rate, see Figure 7) the culture will be washed out. This will always occur if D exceeds μ_{max}, the maximal specific growth rate for the corresponding nutrient conditions including the other cultural parameters such as temperature and so on.

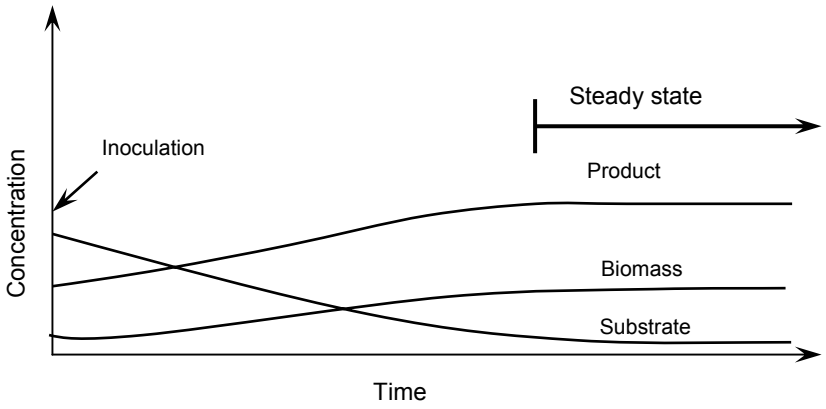


Figure 8: Establishment of the steady state condition in the fermenter.

At steady state biomass (X) and substrate (S) do not vary. Thus, the following equations hold:

$$\frac{dX}{dt} = 0 \qquad \text{and} \qquad \frac{dS}{dt} = 0$$

In practice, a true steady state condition is almost impossible to achieve because cells are much too complex. For this reason, the term "pseudo-steady state" is often used. Under pseudo-steady state conditions, fermenter concentrations vary within a narrow average value.
The change of substrate in a bioreactor can be expressed by:

$$\frac{dS}{dt} = DS_0 - DS - \frac{\mu X}{Y} \qquad (8)$$

where DS_0 is the substrate in the feed, DS is the substrate removal in the effluent and $\frac{\mu X}{Y}$ is the substrate utilisation by the organisms. The yield coefficient Y indicates the degree of the substrate utilisation during formation of the cells e.g. maintenance metabolism and is denoted by:

$$Y = \frac{X}{S_0 - S}$$

In a chemostat $\mu = D$ and assuming that the Monod model holds:

$$D = \frac{\mu_m S}{K_s + S} \qquad (9)$$

Finally we have a relationship between the dilution rate and the concentration of the growth-limiting nutrient, which results by rearranging (9) in:

$$S = \frac{D K_s}{\mu_m - D} \qquad \text{with } \mu_m \neq D$$

As D approaches μ_m the substrate utilised in the fermenter decreases towards zero. For $\mu_m = D$ no substrate is used any more because all the cells are washed out.

3. Methods

3.1 Biological methods

3.1.1 Choice of test diatoms

The plankton community of Lake Holzmaar contains large quantities of diatoms as *Fragilaria crotonensis* Kitton (pennate form) and *Cyclotella meneghiniana* Kützing (centrales form). *Fragilaria crotonensis* is a cosmopolitan and mesotraphentic species, which is very common in plankton communities of standing water bodies and slow flowing waters (Krammer & Lange-Bertalot, 1991). Mass development of this diatom is observed in mesotrophic lakes. This alkaliphilous species occurs mainly at pH>7 (Van Dam et al. 1994) and grows well at low light intensities of 45-95 µmol photons $m^{-2}s^{-1}$ (Hartig & Wallen, 1986). As a eurythermal taxon it can withstand a 20°C annual temperature variation (Hartig & Wallen, 1986). *Cyclotella meneghiniana* is a littoral form rarely found in plankton. It is frequent in eutrophic lakes (Krammer & Lange-Bertalot, 1991) and also typical for waters with a pH>7 (Van Dam et al. 1994). This alga grows well at light intensities of 119-171 µmol photons $m^{-2}s^{-1}$ (Jørgensen 1969).

For the experiments these two species were chosen representing a pennales form and a centrales form. These two species were cultivated in synthetic medium. They grew well under continuous light and aeration conditions.

3.1.2 Growth medium

The chemicals chosen for preparation of the growth medium were of quality “for analysis” and originated from Merck Inc. Only sodium silicate was of “extra pure” quality. The solution ready for use was prepared according to the concentrations given in Tab.1 from stock solutions 1 – 9. For preparation of 1 litre of growth medium a certain amount of each of the corresponding stock solutions was taken and then filled-up to 1 litre (see Table 1).

Table 1: The growth medium used for continuous culture experiments with *Fragilaria crotonensis* and *Cyclotella meneghiniana*.

	Stock solution	Concentration of the stock solution	Utilized amount ml/l medium	Final concentration in medium
1.	$MgSO_4*7H_2O$	1 g/l	25	2.46 mg/l Mg
2.	K_2HPO_4	1 g/l	20	3.55 mg/l P
3.	$Ca(NO_3)_2*4H_2O$			*
4.	Na_2CO_3	1 g/l	20	11.32 mg/l CO_3^{2-}
5.	$Na_2SiO_3*5H_2O$	2.7 g/l	100	35.75 mg/l Si
6.	NaOH	2 g /100 ml	1	20 mg/l
7.	$FeSO_4*7H_2O$ $Na_2EDTA*2H_2O$	0.695 g/100 ml 0.93 g/100 ml	7.3	10.19 mg/l Fe 67.89 mg/l
8.	$MnCl_2*4\ H_2O$ $CuSO_4*5\ H_2O$ $CoSO_4*7\ H_2O$ $ZnSO_4*7\ H_2O$ H_3BO_3 $(NH_4)_6Mo_7O_{24}*4\ H_2O$ NH_4VO_3 $NiSO_4*6\ H_2O$	99 mg/l 0.5 mg/l 2.81 mg/l 6.32 mg/l 30.9 mg/l 1.765 mg/l 1.46 mg/l 26.3 mg/l	1	27.48 µg/l Mn 0.13 µg/l Cu 0.59 µg/l Co 1.44 µg/l Zn 5.4 µg/l B 0.96 µg/l Mo 0.64 µg/l V 5.87 µg/l Ni
9.	Biotin B_{12} Thiamine B_1	33 mg/l 5 mg/l 0.25 µg/l	20	0.66mg/l 0.1mg/l 0.005µg/l

* - A variety of nitrogen concentrations was used, as indicated by the following concentrations of the stock solution number 3 (see Table 2):

Table 2: Different nitrogen concentrations of stock solution 3 from table 1 used in the growth medium for *Fragilaria crotonensis* and *Cyclotella meneghiniana*.

for *Fragilaria crotonensis*	1 g/l	20 ml/l	10.5 mg/l NO_3^-
	2 g/l		21 mg/l NO_3^-
	5 g/l		52.5 mg/l NO_3^-
	10 g/l		105 mg/l NO_3^-
for *Cyclotella meneghiniana*	5 g/l	20 ml/l	52.5 mg/l NO_3^-

3.1.3 Batch culture experiments

In general diatoms are rather sensitive to aeration and fast water movement. Therefore, test measurements were carried out in batch cultures to select diatom species which are best growing in such conditions, i.e. tolerate at least gentle water movements. This was indeed very important for investigations on diatoms in continuous culture.

3.1.3.1 Water tank

For the batch culture experiments two water tanks made of acrylic glass were used, which contained incubation vessels. The tank dimensions were 40cm height, 15cm width, and 1.2m length with a wall thickness of 10mm. The tanks were filled up with deionised water and a thermostat adjusted the preselected water temperature (see Figure 9). Due to a circulating pump the temperature of the tank was kept constant.

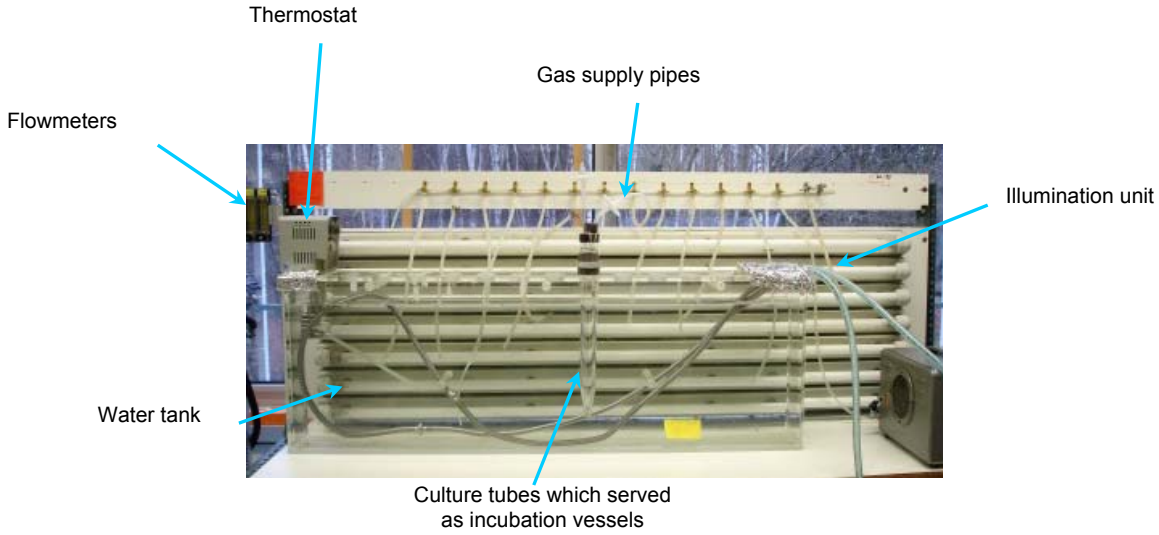


Figure 9: Batch culture set-up with illumination unit.

3.1.3.2 Carbon dioxide supply

In all experiments a mixture of air and carbon dioxide (1% CO_2) was used. The required flow rates were adjusted and controlled using two flowmeters (Reichelt Chemietechnik Ltd Co.). Through supply pipes the desired mixture was introduced into the culture tubes which served as incubation vessels (see Figure 9). The aeration intensity in the culture tube was 3-5 bubbles per second.

3.1.3.3 Illumination unit

The diatoms in batch culture were grown under continuous light conditions. No day-night sequence was used in the experiments. A set of 7 daylight fluorescent tubes (sort OSRAM L65W/21DS) was used which produced a maximum light intensity of 96000 lux (1776 µmol photons $m^{-2}s^{-1}$). The frequency spectrum represents largely normal sunlight.

3.1.3.4 Culture tubes

Batch culture experiments were carried out in tubes made of transparent glass with a total volume of ca. 300 ml (see Figure 9). The caps were provided with two openings to take up two glass pipes. The longer one served as air supply and the shorter one as air exhaust. To prevent contaminations both tubes were equipped with air filters (Midisart 2000 with pore size 0.2 µm; Sartorius Ltd.). Additionally, the tubes were protected from infection by a rubber seal located between the cap and tube thread.

3.1.4 Fermentation

Two fermenter units (Master and Satellite) of LABFORS type (Infors Inc., Bottmingen, CH) were used, equipped with a microprocessor and menu driven control/display system. Both units are constructed in the same way and accommodate vessels with a volume of 7.5 l. The working volume in each fermenter is 5 l. The fermenter consists of three functional sub-divisions: control-master system, base system and vessel (see Figure 10).

Control-master system: It manages the individual control of the two bioreactors (Master and Satellite). Programming of each fermenter (stirrer speed, temperature, pH, pO_2, and mass-flow) is achieved through the use of the IRIS software (Infors Inc., Bottmingen, CH) which guarantees real time run data on the computer.

Base system: It consists of a single column made up of five sections sitting one above another. These sections are (1) the heating module; (2) a service module for air and water supply; (3) a signal conditioning module; (4) a reagent pump and (5) a microprocessor control module (see Figure 10).

Culture vessel: It is a glass cylinder with a double jacket having a total volume of 7.5 l with a stainless steel top-plate. The stirrer-system with axial magnetic drive allows good mixing and stability of the growth conditions in the whole vessel. The top-plate of the vessel is equipped with a temperature sensor Pt-100. The temperature sensor

in conjunction with the PID controller provided a reliable and accurate temperature control. In addition pH and pO_2 electrodes are attached to the vessel, introduced through the stainless steel top-plate.

3.1.4.1 Sterilisation of the vessel

The sterilisation of the culture vessels was achieved in an autoclave HV-110 (BPW Vertriebs Ltd, Süßen) after filling of the reactors with 4 litres of the growth medium. The bioreactors were sterilised at 121°C over 50 minutes. The pH electrodes were calibrated in buffer solutions before the sterilisation process. The pO_2 electrodes were calibrated after sterilisation. The calibration for 0% pO_2 was achieved after saturation of the medium with nitrogen and for 50% pO_2 after saturation with air. The stirrer speed during calibration was 500 rpm.

3.1.4.2 Inoculation of the fermenter

Inoculation of the fermenter was achieved via an orifice in the top-plate. Before sterilisation of the system the opening was equipped with a silicone membrane and closed with a blind plug. For inoculation the blind plug had to be removed. A few drops of alcohol were applied to the opening and the inoculum was aseptically injected through the membrane. After injection the needle was quickly removed. Thus the membrane remained tight. Afterwards the blind plug was put back into its place. Each time inoculum was needed 100 ml of inoculum were taken from a freshly prepared batch culture that was growing in the exponential growth phase with an optical density of 0.45 measured at a wavelength of 560nm. To keep the solution sterile the whole procedure was done under a clean bench.

3.1.4.3 Aeration of the vessel

For the aeration of the culture vessel an integrated rotameter (Type V 100-80.14; 50-500 l/h) was used. The flow rate needed was adjusted according to the flow rate-diagram of the rotameter. The precise dosage of carbon dioxide was achieved using a Brooks Mass Flow Meter (Type 5850 TR, Brooks Instrument, Veendal, NL.).

In all experiments the flow rate of air was 50 l/min and the rate of the CO_2 was 25 ml/min. To prevent any contamination the supplied gas passed through air filters with a pore size of 0.2 µm (Midisart 2000; Sartorius Ltd).

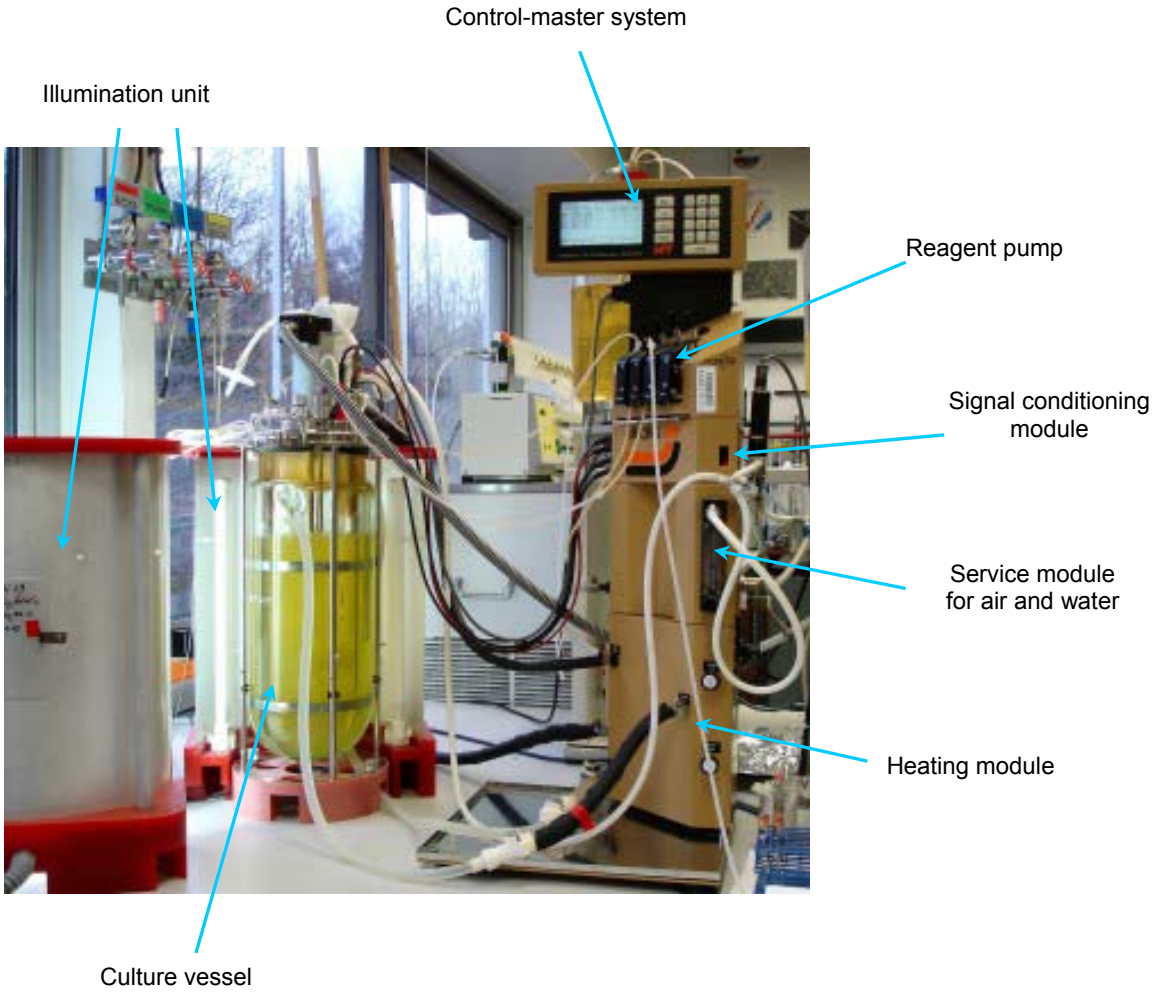


Figure 10: Fermentation set-up with illumination unit.

3.1.4.4 Illumination unit and light intensity

For the experiments an illumination unit was needed. Since nothing was available on the market at the start of the experiments a special unit was developed (see Figure 10). Fluorescent tubes (OSRAM Dulux L 36W/11-860) with special light units were selected which largely reproduce natural light conditions, i.e. the natural frequency spectrum. The system was capable to produce light intensities of up to 1700 µmol photons $m^{-2}s^{-1}$ (see Figure 11). All experiments dealing with the influence of temperature variations on the oxygen isotope discrimination were carried out at a light intensity of 500 µmol photons $m^{-2}s^{-1}$, i.e. at the upper range of natural systems.

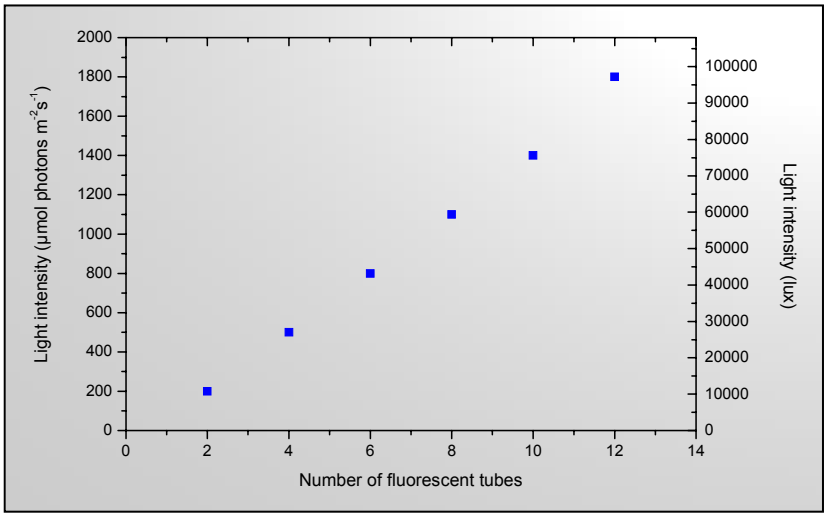


Figure 11: Capacity of the illumination unit used for continuous culture experiments. The light intensities are given in µmol photons $m^{-2}s^{-1}$ and in lux. The system could be run with 2 up to 12 light tubes.

3.1.5 Sampling of diatoms and dry mass determination

Measurements of growth were accomplished by measuring the dry weight of cells. The procedure involved the extraction of samples from the algal suspension, drying the samples to a constant weight, and expressing the dry weight of the cells per unit of volume. Sampling, which is representative for a given culture, is one of the crucial points for reliable estimates of dry weight of the cells. Sample size depended on the population density of the culture.

Samples from the fermenter were taken four times a week always at the same time. In order to inhibit diatom growth of the collected sample it was introduced into a sterile glass bottle which was submerged in ethylene glycol at a temperatue of 2°C. The volume of a sample collected depended on the flow rate D and comprised between 1.01 l and 1.69 l, respectively. The diatom cells of the suspension collected were separated from the culture medium by centrifugation. Samples were centrifuged in a SIGMA centrifuge (Type 6K15, SIGMA Ltd) at 17000 g over 30 minutes and thereafter decanted. The extracted diatoms were then washed four times with distilled water and centrifuged each time. Thus, the rest of salts present in the growth medium were removed. Shortly thereafter the diatom biomass was transferred into glass vials (total volume of 20 ml, Packard Bioscience) and frozen at a temperature of -25°C. The frozen samples were freeze dried and afterwards the mass was determined. Dry mass of samples is given in miligrams per liter (mg/l). All diatom samples were stored in a fridge at a temperature of -25°C.

3.1.6 Determination of the optical density

Optical density measurements (OD) were used for the direct determination of growth stability in the fermenter. The amount of light that is scattered by diatoms in liquid culture is proportional to their numbers, thus the optical density of a suspension of cells is directly related to cell mass, provided the density is not too high.

The OD of the culture was determined using the mobile laboratory photometer LASA 100 (Dr. Lange GmbH & Co. KG). The extinction was measured four times a day at three different wavelengths: 440, 535 and 560 nm. For this purpose about 7 ml of diatom suspension was needed for the cuvette (type LCW 906, Dr. Lange Ltd.). Before each measurement the photometer was calibrated using pure growth medium as blank value.

3.2 Isotope analyses

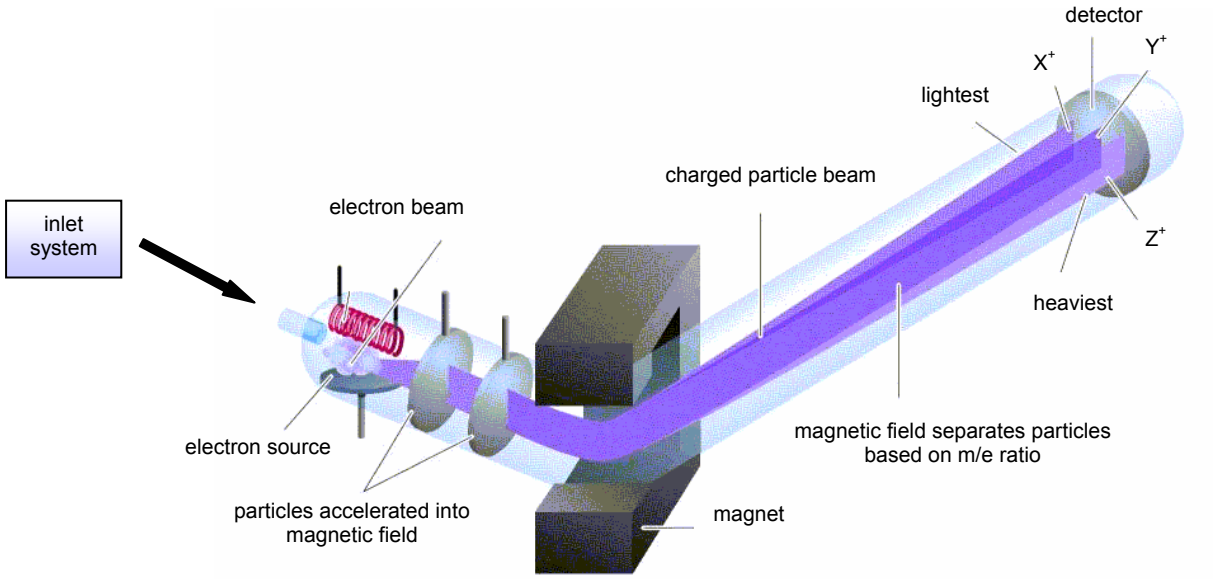
3.2.1 Mass spectrometry

Isotope Ratio Mass Spectrometry (IRMS) was used to determine the isotope ratio of carbon, nitrogen and oxygen isotopes. Mass spectrometers are analytical systems that analyse electronically charged atoms and molecules on the basis of their particle mass. The universal ability to analyse almost all substances that can be ionised has made this technology very popular. A mass spectrometer consists of five essential parts (see Figure 12):

1. **Gas inlet system.** Isotope ratio mass spectrometers require samples in gaseous state. Mass spectrometers equipped with a double inlet system measure the sample gas and the corresponding standard gas alternately. While one gas is flowing into the ion source the other one is pumped off through a waste line. It is important for both gases that flow is viscous and remains identical throughout the time of the measurement (Mean free path length is smaller than the geometrical dimensions of the system). These conditions are a basic prerequisite for attaining precise and reproducible data.
2. **Ion source.** The viscous gas stream from the inlet system is directed into the ion source. There, ions are produced by an electron beam emitted by a heated tantalum filament. The ionized molecules are accelerated and focused into the ion beam. On leaving the source, ions of each isotope possess the same kinetic energy.

3. **Mass analyser.** The ion beam enters a magnetic field where the ions are deflected into circular paths perpendicular to the magnetic field. The radii of the ions are proportional to the m/e ratios of the isotopes, i.e. heavier ions are deflected less than light ones. In this way ions are separated and disposed into ordered collectors
4. **Detector.** Each detector monitors the ion current, amplifies it and the signal is then transmitted to the data system
5. **Control and data system.** The m/e values of the ions are plotted against their intensities, i.e. the molecular weight of each component. The isotopic ratio is calculated by conversion of the electric signals, which are proportional to the number of ions collected in the individual collectors.

The ion source, the mass analyser and the detector are operating under high vacuum conditions.



.

Figure 12: Schematic view of the mass spectrometer.

3.2.2 Oxygen isotope composition of biogenic silica

The oxygen isotopes from biogenic silica of cultured diatoms were determined applying a new technique which is based on the reduction of SiO_2 using an inductively heated high temperature reduction device (iHTR) (Lücke et al. 2005).

Pre-treatment

Dry mass of diatoms was treated with hydrogen peroxide over a period of at least 2 hours at a temperature of 100°C. During this period the organic matter was almost completely destroyed. Thereafter, samples were washed four times with distilled water and each time centrifuged (SIGMA centrifuge, type 6K15) to remove H_2O_2 completely. Thereafter the suspension was poured into a glass vial (20 ml volume, Packard Bioscience), frozen at a temperature of –25°C and freeze dried. Finally the samples were homogenized using a mortar.

Extraction of oxygen isotopes from biogenic silica

The oxygen isotopes from biogenic silica were quantitatively liberated and converted to carbon monoxide (CO) using an inductive high temperature carbon reduction method (iHTR). The iHTR device consists of a double walled glass vessel made of quartz (Corning, USA, Vycor Quartzglass). The double wall enables cooling of the system by a temperature of 8°C. A cylinder containing an inlying rod can be inserted into the vessel. The rod has a small borehole at the top where the samples are to be introduced and is covered with a cap. The device is composed of glassy carbon. Under vacuum $<10^{-3}$ mbar the device is inductively heated stepwise to about 1550°C and thus the liberation of oxygen from biogenic silica is accomplished. Any contaminants like OH-groups or oxygen attached to the silica are released at lower temperatures and pumped away before the silica material is decomposed.

For the mass spectrometric measurement of the oxygen isotope composition the biogenic silica of diatom samples is converted to carbon monoxide. For this purpose a mixture of ca. 1.2 mg graphite and 1.5 mg biogenic silica is normally weighed and introduced into the reaction chamber of the rod. The rod is usually covered with a cap and inserted into the cylinder. Afterwards the vessel is vacuum sealed and the system set to a vacuum of $<10^{-3}$ mbar. By the computer-controlled stepwise heating of the reaction chamber the process of dehydration and subsequent decomposition

of the sample is initiated. In the first phase of heating, i.e. up to 850°C, thermal desorption of OH groups and water molecules are achieved. Also rests of organic matter will be pyrolysed and continuously removed till stabilisation is reached at a pressure of $<10^{-3}$ mbar. Thereafter, the vacuum system is disconnected from the device, the temperature is raised to 1550°C, and disintegration of the biogenic silica takes place. The released oxygen from the silica reacts with graphite and forms carbon monoxide, while silicon is being deposited as silicon carbide. The produced carbon monoxide is trapped in a glass tube which contains a molecular sieve (5Å) kept at liquid nitrogen temperature. With ca. 1.5 mg of biogenic silica a gas pressure of ca 10 mbar is attained in the system. There from more than 99.5% can be condensed into the molecular sieve**.**

Isotope ratio determinations are performed in a dual inlet IRMS and listed against the international standard V-SMOW (Vienna Standard Mean Ocean Water).

3.2.3 Determination of the oxygen isotope composition of the growth medium

The oxygen isotope composition of the water from the fermenter plays an important role, since it represents the source value for the oxygen isotope fractionation to produce the $^{18}O/^{16}O$ ratios of biogenic silica. Incorporation of the oxygen isotopes into the diatom valves occurs in water at the set temperature. The process is assumed to proceed at isotopic equilibrium. Thus, the oxygen isotope composition of the water is the starting point for the oxygen isotope discrimination during the formation of the diatom valves. For the isotope analyses three kinds of samples were taken, namely de-ionised water (used for preparing the growth medium), growth medium (taken after autoclaving) and diatom suspension (taken directly from the fermenter). De-ionised water samples were taken for every bottle of medium that was prepared. Samples of the growth medium were taken twice. Firstly, before the bottle was connected to the fermenter and secondly almost before the bottle was empty. Samples from the suspension of the fermenter were taken five times a week. All samples were stored in plastic vials (total volume of 10 ml) and kept at a temperature of -25°C. From each sample 1 ml was placed in an exetainer vial (Labco Limited Ltd.) with a total volume of 5 ml. After that the samples together with the septum plugs were put into a Glove-Bag (Merk KgaA), airtight closed and then the headspace air was removed using a membrane pump. Afterwards, the headspace was filled with a gas mixture of known isotopic composition. This mixture was composed of 5% of

pure carbon dioxide (CO_2 4.8) and 95% of pure helium (He 5.6). After approximately 5 minutes the vials were plugged.

Water samples prepared in this way were kept at room temperature of 22°C over a period of at least 24 hours. During this time complete equilibration was reached between the oxygen isotopes of water and those of carbon dioxide from atmospheric CO_2.

Determination of the oxygen isotope composition of the water samples was automatically performed. The equilibrated CO_2 gas was automatically introduced into the mass spectrometer.

3.2.4 Determination of the oxygen isotope composition of organic matter

From each freeze dried and homogenized sample of the fermenter about 0.5 – 0.55 mg were packed into a cartridge of silver. In order to remove the more loosely bound water molecules attached to the samples, the samples were put into a vacuum oven (Type VT 6060, Kendro Ltd.) for a period of at least 48 hours. Thereafter, the samples were pyrolysed in an automatic combustion device (Carlo-Erba, NA 1500 Nitrogen Analyser) in continuous-flow mode. The released CO_2 was then measured directly in an isotope ratio mass spectrometer.

All measured $\delta^{18}O$ values were converted to SMOW. For calibration purposes two laboratory standards such as MECe cellulose (Merck Ltd.) and RSta (starch from rice, Fluka Ltd.) were used.

3.2.5 Carbon isotope composition of organic matter

Diatom samples were also investigated for their total carbon isotope composition. About 0.33 - 0.35 mg of each freeze-dried and homogenized sample was packed into a stannous cartridge. Thereafter, the samples were pyrolysed in an automatic combustion device (Carlo-Erba, NA 1500 Nitrogen Analyser) in continuous-flow mode. The released CO_2 was directly measured in the IRMS. All measured $\delta^{13}C$ values were converted to the PDB scale. For calibration purposes two laboratory standards were used, namely graphite G4 and cellulose from spruce (Fluka Ltd.) and measured alternately with diatom samples.

3.2.6 Nitrogen isotope composition of organic matter

Diatom samples were investigated for nitrogen isotope composition. Each freeze-dried and homogenized sample contained about 80 - 130 µg of nitrogen. All samples, packed into stannic cartridges, were pyrolysed in an automatic combustion device (HEKAtech, HT Sauerstoff Analysator) in continuous-flow mode. The released N_2 was directly measured in the IRMS (Micromass IsoPrime).

All measured $\delta^{15}N$ values were calibrated versus Air. For calibration purposes three laboratory standards were used, namely urea, alanine and a Lake Holzmaar sediment sample measured alternately with diatom samples.

3.3 Chemical analyses

3.3.1 Element analysis of diatoms

Diatom samples were analysed for such elements as: C, H, N, S, O, Si. All analyses were done in the Central Division of Analytical Chemistry (ZCH, Research Centre Jülich).

The determination of the silica content from diatom dry mass was done by inductively coupled plasma optical emission spectroscopy (ICP-OES). For this purpose 50 mg of a sample was put into a platinum crucible and placed into a cold muffle furnace. Within 3 hours the sample was heated to a temperature of 1000°C and kept at these conditions for over 30 minutes. Later the samples were solubilised with 0.5 g of lithium borate in the muffle furnace for 20 minutes at a temperature of 1050°C. Then the liquefied material was dissolved in 50 ml of HCl (3%) and filled up to a volume of 100 ml. Then, the samples were analysed. The results were given in weight percent and the relative error was ± 3 to 5 %.

Determination of C, H, N, S, O was achieved using Infrared Absorption Spectroscopy (IR). For C, H, N, S analyses 2 mg of each sample were burned at a temperature of 1000°C using oxygen as carrier gas. Afterwards the combustion gases such as: CO_2, H_2O, NO_x and SO_2 passed through a reduction tube with helium as carrier gas for converting the NO_x nitrogen oxides to N_2 and fixation of free oxygen. Selective IR detectors then measured the gases. After absorption of these gases, the content of the remaining nitrogen was determined by thermal conductivity detection.

Oxygen had to be measured separately. Each sample was decomposed in a pyrolysis furnace at a temperature of 1300°C. The released oxygen reacted with

activated charcoal and formed carbon monoxide. This gas was conducted through an oxidation tube and oxidized to carbon dioxide. An IR detector measured the amount of CO_2. The results are given in weight percent and the relative error is ± 3 to 5%.

3.3.2 Element analysis of medium and diatom suspension

All analyses necessary were carried out in the Central Division of Analytical Chemistry (ZCH, Research Centre Jülich). The concentration of cations such as: Ca, Fe, K, Mg, Na, Si was determined by inductively coupled plasma optical emission spectroscopy (ICP-OES). Simultaneously the concentration of anions such as: chloride, nitrate, phosphate and sulphate were measured. Anions were determined by using the ion chromatography method (IC). The relative error for both cations and anions was ± 3 to 5 %.

4. Results

The physiological state of the diatom cell is a function of its environment, thus the biochemical composition of the cell varies at least partly as the environment changes. For algae, the most important environmental parameters are nutrient availability, light, and temperature. Physiological effects induced by variations of environmental parameters are probably documented by variations of stable oxygen, nitrogen, or carbon isotopes and can, thus, be an option for reconstruction of the environment. Therefore, the behaviour of the stable oxygen, carbon and nitrogen isotopes in diatoms of *Fragilaria crotonensis* and *Cyclotella meneghiniana* was investigated with regard to variations of different environmental conditions such as temperature, light intensity, and nutrient concentration. Results of these studies are presented below.

4.1 Nitrate availability and growth of Fragilaria crotonensis

Dissolved nitrate, nitrite, and ammonium are the most important nitrogen sources for autotrophic organisms. Nitrate is the most thermodynamically stable form in most aquatic environments and is the predominant form of fixed nitrogen. When the rate of supply of inorganic nitrogen is lower than required for full biosynthetic capacity of a cell, the element becomes limiting for growth and leads to a reduction in growth. Nitrate reductase (NR) catalyses the reduction of NO_3^- to NO_2^-, which is the first step and key regulatory site for the conversion of NO_3^- into amino acids, thus for NO_3^- assimilation (Campbell 1988, Solomonson & Barber 1990). The properties of NR therefore play a critical role in the growth of phytoplankton and, consequently, in primary production in aquatic environments.

The growth of *Fragilaria crotonensis* was investigated with respect to varying nitrate concentrations of the inflowing medium, that is, under nitrate-saturated and nitrate-limited conditions. In this investigation, the following concentrations of nitrate in the medium were considered: 10.5, 21, 52.5, and 105 mg/l. During experiments diatoms were grown at a light intensity of 500 µmol photons $m^{-2}s^{-1}$. Growth temperature was 24°C and the growth rate was 0.34 d^{-1}. The results of the steady state culture experiment are listed in Table. 3

Table 3: Results of steady state culture experiment Nr 5, using *Fragilaria crotonensis.* The culture was run for various nitrate concentrations of the medium at a temperature of 24°C and under continuous light conditions.
a) - mean value; b) - standard deviation; c) - (minimum/maximum); d) – number of determinations
a, b, c, d – are related to all table values; susp. = suspension from the fermenter

Temp. (°C)	**Growth rate** μ (d^{-1})	**Nitrate concentration of the medium** (mg l^{-1})	**Extinction of the suspension at** 560nm	**Dry mass** (mg l^{-1})	**Productivity** (mg $l^{-1}d^{-1}$)	ε_{13C} (‰)	ε_{15N} (‰)	**Ca^{2+} susp.** (mg l^{-1})	**Fe^{2+} susp.** (mg l^{-1})	**K^{+} susp.** (mg l^{-1})	**Mg^{2+} susp.** (mg l^{-1})	**Si^{2+} susp.** (mg l^{-1})	**NO_3^{2-} susp.** (mg l^{-1})	**PO_4^{3-} susp.** (mg l^{-1})	**SO_4^{2-} susp.** (mg l^{-1})
24	0.34	10.5	**0.409** [a]	**176.00**	**59.84**	**-25.45**	**-0.22**	**4.20**	**10.40**	**9.30**	**2.20**	**2.10**	**1.60**	**5.10**	**21.70**
			0.01 [b]	**7.12**	**2.42**	**0.13**	**0.05**								
			(0.393 / 0.427) [c]	(169.8 / 186)	(57.73 / 63.24)	(-25.3 / -25.6)	(-0.3 / -0.2)	(4 / 4.4)	(10 / 10.7)	(9 / 9.5)	(2.2)	(1.9 / 2.3)	(1.5 / 1.76)	(4.51 / 5.69)	(21.1 / 22.2)
			n=4 [d]	n=4	n=4	n=4	n=4	n=2	n=2	n=2	n=2	n=2	n=2	n=2	n=2
24	0.34	21	**0.583**	**232.90**	**79.19**	**-25.79**	**-0.07**	non-existent	non-existent	non-existent	non-existent	non-existent	non-existent	non-existent	non-existent
			0.01	**18.20**	**6.19**	**0.20**	**0.09**								
			(0.566 / 0.599)	(206.3 / 246.1)	(70.14 / 83.67)	(-25.58 / -26.06)	(-0.2 / 0)								
			n=4	n=4	n=4	n=4	n=4								
24	0.34	52.5	**0.788**	**293.20**	**99.69**	**-26.23**	**-0.17**	**14.50**	**8.60**	**8.30**	**1.90**	**1.80**	**0.10**	**1.60**	**11.50**
			0.01	**13.00**	**4.42**	**0.23**	**0.08**								
			(0.768 / 0.798)	(277.2 / 316.1)	(94.25 / 107.47)	(-25.98 / -26.67)	(-0.3 / 0)	(13.8 / 15.2)	(8.5 / 8.6)	(8.3)	(1.9)	(1.7 / 1.8)	(0.11 / 0.16)	(1.21 / 1.97)	(10.8 / 12.1)
			n=7	n=7	n=7	n=7	n=6	n=2	n=2	n=2	n=2	n=2	n=2	n=2	n=2
24	0.34	105	**0.862**	**305.40**	**103.84**	**-25.77**	**-0.33**	**30.00**	**5.10**	**9.40**	**2.30**	**0.80**	**11.50**	**2.50**	**13.90**
			0.02	**6.60**	**2.24**	**0.04**	**0.05**								
			(0.827 / 0.877)	(288.8 / 320.8)	(98.19 / 109.07)	(-25.71 / -25.8)	(-0.4 / 0)	(29.0 / 31.0)	(3.6 / 6.5)	(9.2 / 9.5)	(2.2 / 2.3)	(0.56 / 1)	(9.23 / 13.8)	(1.82 / 3.23)	(13.7 / 14.1)
			n=4	n=4	n=4	n=4	n=4	n=2	n=2	n=2	n=2	n=2	n=2	n=2	n=2

4.1.1 Nitrate availability and productivity of Fragilaria crotonensis

Productivity of the algal population is defined as increment of the biomass per time unit, in other words, it is the growth rate multiplied by biomass. The productivity enables a comparison of population growth for various growth rates (see Chapter 4.3). It is well known that the productivity of diatoms is highly affected by the ambient temperature, by different light regimes and also by the available nutrients. In other words, the rate of algal production is amongst other things determined by the rate of nutrient availability. Limitation of algal growth is best described by Liebig's Law of the Minimum, which says that algal productivity will be limited by the element present in least supply relative to algal requirements (Goldman & Horne, 1983). The growth of many algae depending on the availability of exterior nitrogen supply follows saturation kinetics, which is confirmed by this study (see Figure 13). Generally, increase of the nitrate concentration of the inflowing medium resulted in an increase of the productivity which could be controlled by the extinction of the medium.

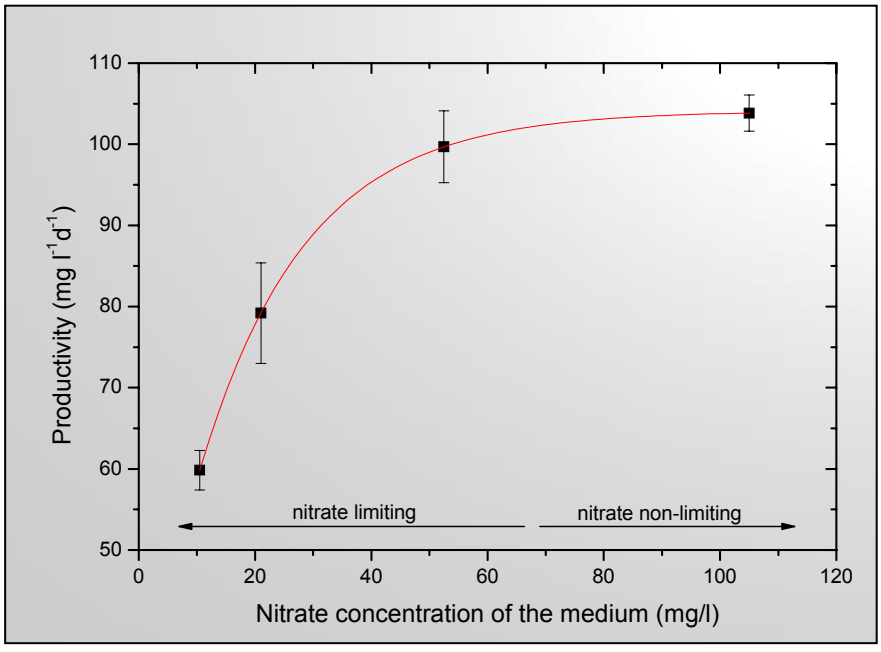


Figure 13: Productivity of *Fragilaria crotonensis* depending on various nitrate concentrations in the inflowing medium. The growth temperature was 24°C; the growth rate was 0.34 d^{-1}. Culture was grown under continuous light conditions at a light intensity of 500 µmol photons $m^{-2}s^{-1}$.

As tests indicated, the rise in the extinction was directly proportional to the increment of the productivity. Therefore, the discussion will only focus on changes in productivity. The productivity of *Fragilaria crotonensis* reached its maximum at about 100 mg $l^{-1}d^{-1}$ when the nitrate content in the medium amounted to about 52.5 mg/l.

Doubling of the NO_3^- concentration from 52.5 to 105 mg/l resulted only in a 4% increase of the productivity (see Figure13). At concentrations higher than 52.5 mg/l, nitrate gradually ceased to be the growth limiting factor and for 105 mg/l an amount of 11.5 mg/l nitrate (see Table 3) remained unconsumed.

4.1.2 Element composition of Fragilaria crotonensis dry mass and C:N:Si ratios

Algae require for their growth a certain supply of inorganic nutrients and their element composition reflects the environmental conditions during growth. If the environmental conditions (e.g. temperature, nutrient concentration) are known it is possible to get more information about the physiological state and behaviour of algal cells. For this purpose, primary elements such as Si, C, H, N, O, and S of dry mass were examined in selected samples of *Fragilaria* accumulated during steady state culture experiment Nr 5. Complete results of this investigation are presented in the appendix. Because availability of C, N, and Si is a main factor controlling diatom growth in aquatic environments, only their influence will be discussed. The concentrations of C, N, and Si depending on the nitrate concentration of the medium are listed below in Table 4. Of course, hydrogen and oxygen are also essential for algal growth, but will not be considered because water is always abundant.

Table 4: The C, N, Si content and C:N:Si ratios of dry mass selected from samples of *Fragilaria crotonensis* accumulated during steady state conditions of experiment 5. Diatoms were grown for different nitrate concentrations, at 24°C. Dilution rate was 0.34 d^{-1}. Si/P, C/P and N/P are accordingly the amounts of Si, C and N (mg/ld) divided by the productivity (P) (mg/ld).

Temp. (°C)	Growth rate μ (d^{-1})	Nitrate concentration of the medium (mg l^{-1})	Sample	Dry mass (mg l^{-1})	Productivity P (mg $l^{-1}d^{-1}$)	Si (wt-%)	Si (mg $l^{-1}d^{-1}$)	Si/P	C (wt-%)	C (mg $l^{-1}d^{-1}$)	C/P	N (wt-%)	N (mg $l^{-1}d^{-1}$)	N/P	C/N	Si/C	Si/N
24	0.34	10.5	V5 D12	172.3	58.58	20.1	11.76	0.2	20.7	12.14	0.21	1.2	0.71	0.012	17.5	0.95	16.7
24	0.34	21	V5 D4	236.0	80.24	16.5	13.23	0.16	29.3	23.49	0.29	1.6	1.29	0.016	18.1	0.55	10.0
			V5 D5	246.1	83.67	15	12.55	0.15	28.3	23.66	0.28	1.5	1.26	0.015	18.7	0.54	10.0
24	0.34	52.5	V5 D19	282.4	96.02	13.3	12.78	0.13	36.9	35.43	0.37	2.8	2.69	0.028	13.2	0.35	4.6
			V5 D22	296.8	100.91	11.7	11.8	0.12	35.7	36.04	0.36	2.7	2.72	0.027	13.3	0.33	4.4
24	0.34	105	V5 D29	320.8	109.72	10.3	11.22	0.1	37.1	40.46	0.37	3.6	3.91	0.036	10.3	0.27	2.8
			V5 D30	305.4	103.84	10.8	11.22	0.11	37.4	38.83	0.37	3.7	3.84	0.037	10.0	0.30	3.0

Variations in the amount of available nitrate resulted in different element compositions of investigated diatoms (see Figure 14). Nitrogen, carbon, and silicon exhibited distinct changes in their concentration of the biomass, indicating that their metabolism was affected by alterations of the nitrate concentration. The N content related to productivity increased nearly linear from 0.012 to 0.037 for nitrate concentrations between 10.5 – 105 mg/l. The more nitrogen was available for growth the more was accumulated in the diatom biomass. The carbon content rose

asymptotically, as rose the biomass production of *Fragilaria.* The largest changes of carbon content were observed at nitrate concentrations lying between 10.5 and 52.5 mg/l (see Figure 14). A further increase of the nitrate concentration from 52.5 to 105 mg/l brought no rise of the carbon content.

The Si content relative to the productivity diminished asymptotically with increasing nitrate concentrations, which indicated that the silicon concentration was not sufficient and became limiting for growth. The data concerning the Si availability in the suspension of the fermenter confirm this situation (see Table 3) showing a successive decrease from 2.1 mg/l Si for nitrate concentration of 10.5 mg/l to only 0.8 mg/l Si for the nitrate concentration of 105 mg/l. Increasing Si limitation leads consequently to a decreased silification of the diatom frustules (Paasche 1973, Brzezinski et al. 1990).

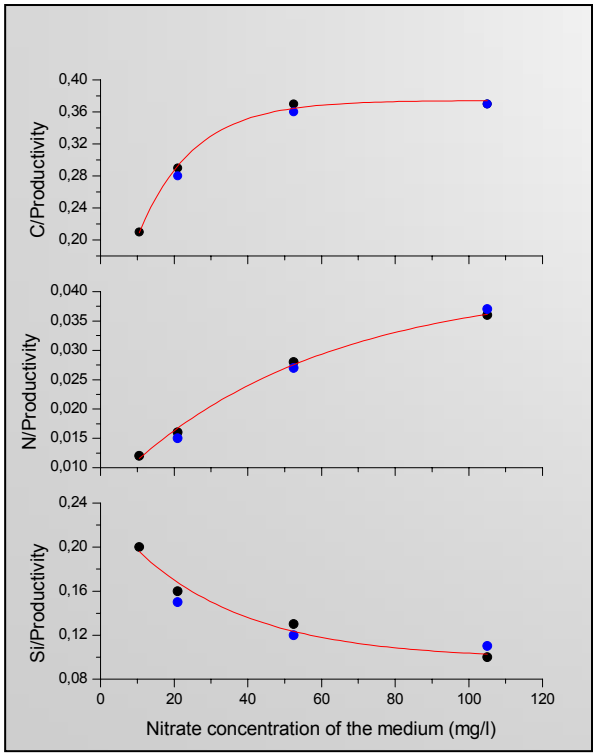


Figure 14: The C, N, Si content of *Fragilaria crotonensis* dry mass relative to the productivity for various nitrate concentrations of the inflowing medium. The growth temperature was 24°C; the growth rate was 0.34 d^{-1}. Culture was grown under continuous light conditions at a light intensity of 500 µmol photons $m^{-2}s^{-1}$.

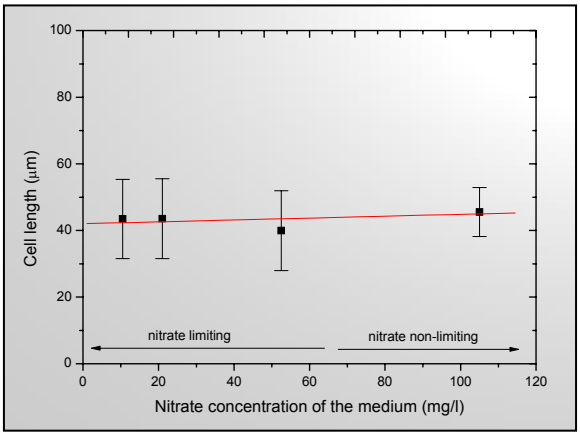


Figure 15: The cell length of *Fragilaria crotonensis* at various nitrate concentrations of the inflowing medium. The growth temperature was 24°C; the growth rate was 0.34 d^{-1}. Culture was grown under continuous light conditions at a light intensity of 500 µmol photons $m^{-2}s^{-}$.

Flynn & Martin-Jézéquel (2000) pointed out, that diatoms limited by Si will release increased amounts of dissolved organic carbon, because cell growth is halted more rapidly than the photosynthetic apparatus can be degraded. This statement can

probably explain the constancy of the carbon content in the diatom biomass of this study for nitrate concentrations lying between 52.5 and 105 mg/l.

Many algae reduce their cell size in response to nitrogen limitation, however, the studies on diatoms of *Asterionella formosa* and *Fragilaria crotonensis* showed no diminution of the cells (Gotham & Rhee, 1981). The silicified cell walls are, as all silicified structures, not elastic, and thus they cannot show plastic extension during growth. Consequently, this study showed that different degrees of N-limitation had no influence on the cell size of *Fragilaria crotonensis* (see Figure 15); therefore, the C/N ratio of the biomass is an adequate indicator for the N-limitation.
Limitation of algal growth due to reduced amounts of N availability results in an increase in the C/N ratio, a decrease in chlorophyll, N, and protein content per cell (e.g. Kiefer 1983, Osborne & Geider 1986). The proteins represent the major source of nitrogen comprising 70-90% of cellular nitrogen.

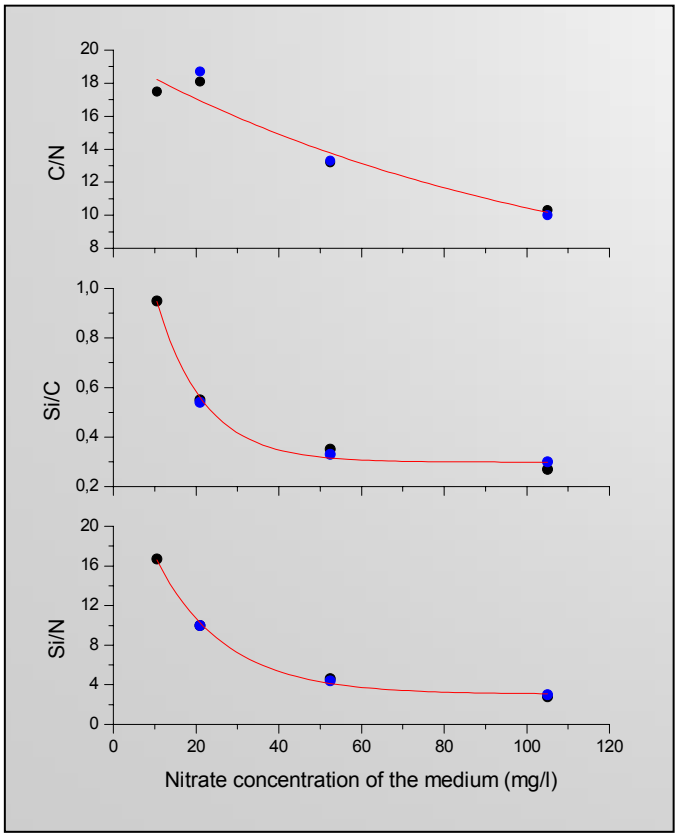


Figure 16: The C/N, Si/N and Si/C ratios of *Fragilaria crotonensis* versus nitrate concentration of the medium. The growth temperature was 24°C and the dilution rate was 0.34 d^{-1}. Culture was grown under continuous light conditions at a light intensity of 500 µmol photons $m^{-2}s^{-1}$.

All changes observed in total cellular nitrogen derive from alterations in the protein pool. If nitrogen is available in excess, algae start to accumulate it as storage nitrogen. Diatoms store nitrogen in form of pigment proteins (Perry et al., 1981). Figure 16 shows C:N:Si ratios of the dry mass of *Fragilaria crotonensis* depending on nitrate concentrations of the inflowing medium. As expected, the C/N ratio increased when the N limitation increased (see Figure 16), and these variations ranged from 10 to 18.7. In all cases, the C/N ratio was higher than the Redfield ratio of 6.6. The trends of the Si/N and Si/C ratios are similar i.e. both decrease with rising nitrate concentration of the medium. The decline of the Si/N ratio was from 16.7 to 2.8, whereas for the Si/C ratio from 0.95 to 0.27. The Si/N ratio indicates that under increasing N stress relatively more silicon is incorporated into the cell.

4.1.3 Changes of nitrate concentration and stable carbon isotope fractionation by Fragilaria crotonensis

The carbon isotope composition ($\delta^{13}C$) of phytoplankton differs from that of dissolved inorganic carbon (DIC) from which it is formed. The difference is due to the discrimination against ^{13}C during photosynthetic carbon fixation. This discrimination reflects the environmental conditions under which the organic matter is synthesized. One of the main factors responsible for the variability of $\delta^{13}C$ in phytoplankton is the concentration of dissolved CO_2. In this experiment, however, the influence of various nitrate concentrations of the inflowing medium was tested on the carbon isotope fractionation. Due to high aeration rates, it was guaranteed that CO_2 was in no case growth limiting. Results of this investigation are presented in Figure 17. With increasing nitrate concentration of the medium, but still under nitrate limiting conditions (10.5 - 52.5 mg/l NO_3^-), a rise of the discrimination against ^{13}C was measured ranging from -25.78 ‰ to -26.37 ‰, i.e. ~0.6 ‰. As nitrate became a non-limiting factor for growth an opposite trend was observed and discrimination diminished to -26.01 ‰. The opposite trend in carbon isotope fractionation found in this study may be due to the fact, that diatoms under Si limitation release increased amounts of dissolved inorganic carbon. If this is the case, diatoms would possibly release the lighter carbon (^{12}C) first, what of course, would result in more positive $\delta^{13}C$ values of the organic matter. The variations of the $\delta^{13}C$ values in this study were higher than the error margins, the corresponding correlation coefficient of the polynomial regression was R^2=0.997. Although the effect is significant, an application

of this finding without further studies will not be possible, because it is unclear at the time, which other possible factors may be responsible for changes in the carbon isotope discrimination.

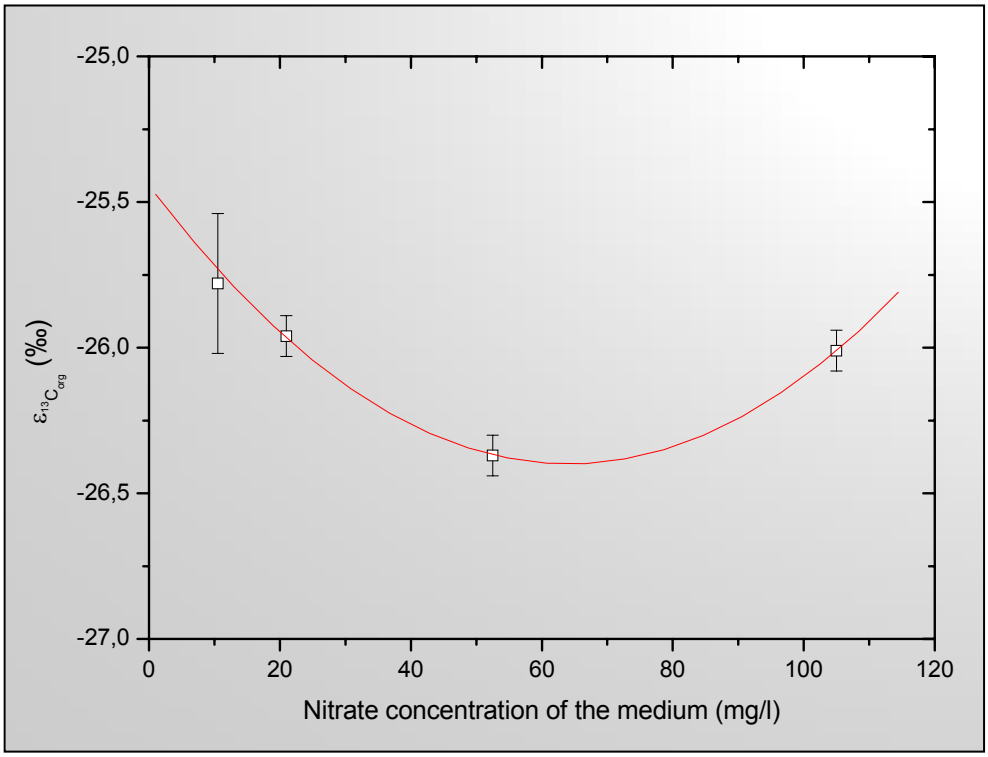


Figure 17: The dependence of the carbon isotope fractionation on various nitrate concentrations of the inflowing medium. The growth temperature was 24°C; the growth rate was 0.34 d^{-1}. Culture was grown under continuous light conditions at a light intensity of 500 µmol photons $m^{-2}s^{-1}$.

4.1.4 Nitrate concentration and nitrogen isotope discrimination by Fragilaria crotonensis

Diatoms preferentially utilise nitrate as a nitrogen source and the isotope composition of nitrate constitutes an initial point for the nitrogen isotope fractionation. Thus the algal $\delta^{15}N$ composition will be lower relative to the $\delta^{15}N$ of nitrate. It is interesting to know, whether or not limiting nitrate concentrations influence the algal nitrogen isotope ratios. If it is the case, they can potentially give evidence about nitrate availability in the water. In this experiment, the influence of four nitrate concentrations of the medium was tested on nitrogen isotope discrimination. Results of this investigation are presented in Figure 18. Although, the amount of the isotope fractionation is not considerable, the discrimination increases with increasing nitrate concentration (see Figure 18). The changes were from -0.1 ‰ at a nitrate

concentration of 21 mg/l to -0.33 ‰ at a concentration of 105 mg/l. It is unclear, why at the lowest nitrate concentration the discrimination was -0.2 ‰.

Wada & Hattori (1976) have documented that variations in the ^{15}N content of organic matter in the sea depend upon the availability and form of inorganic nitrogenous compounds as a source of nitrogen. Additionally, if cells are grown at constant light intensity and rising nitrate concentration of the medium as in this study, the nitrogen isotope fractionation increases (Wada & Hattori 1978). However, the effect seems to be very small. In this study, the discrimination was small and the variability of the measurements high, thus the possible effect is not useful for environmental studies.

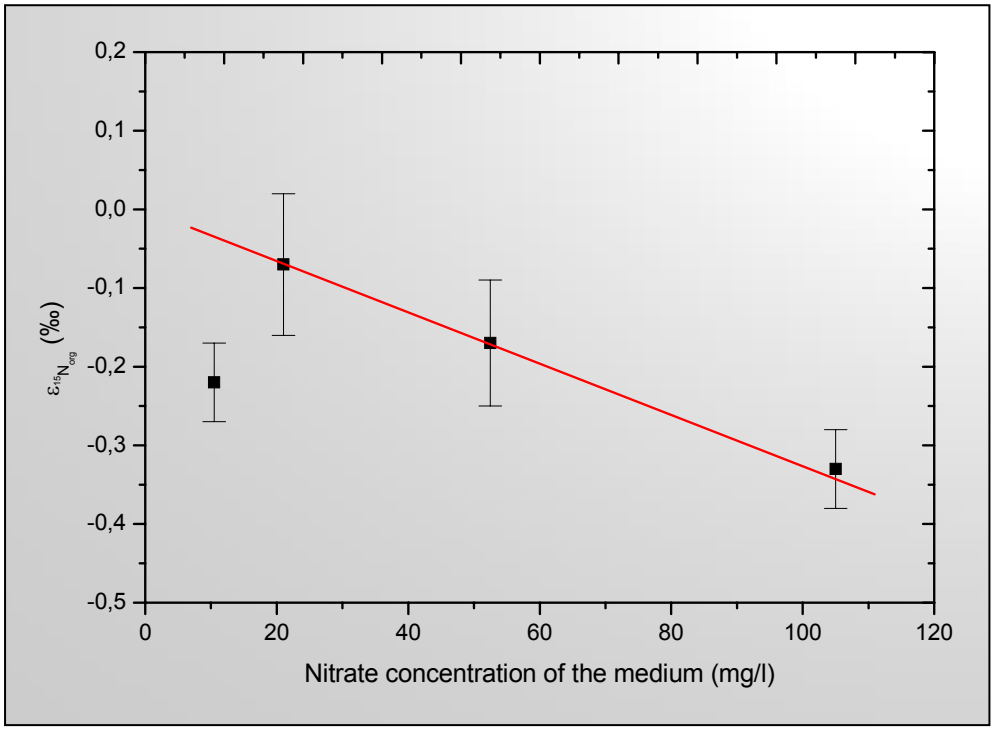


Figure 18: The nitrogen isotope fractionation versus various nitrate concentrations of the inflowing medium. The growth temperature was 24°C; the growth rate was 0.34 d^{-1}. Culture was grown under continuous light conditions at a light intensity of 500 µmol photons $m^{-2}s^{-1}$.

4.2 Temperature variations and growth of Fragilaria crotonensis under nitrate-saturated conditions

The cosmopolitan occurrence of *Fragilaria crotonensis* is attributed to its large temperature tolerance. The temperature optimum for *Fragilaria crotonensis* is in nature between 15-19°C, however the species from Bodensee-Obersee (Germany) grows within a temperature range between 15-30°C with an optimum at 26°C (Hartig & Wallen 1986). From observations of species distribution in nature, it has been hypothesized that temperature can act as a major variable influencing the diversity of phytoplankton in space (with altitude and latitude), and in time (seasonal periodicity). It is well known, that temperature affects growth of the aquatic organisms by changing the rate of metabolic reactions and equilibrium of biochemical reactions. The optimum temperature for enzymatic reactions (nutrient uptake) at 15°C is different from that for growth between 20-25°C (Rhee & Gotham 1981). Chemostat cultures are very useful in studying the effects of temperature, because the same growth rate can be maintained at various temperatures.

In this study, the behaviour of *Fragilaria* was tested for temperatures of 12, 15, 18, 21, 24°C. Diatoms were grown at a fixed growth rate of 0.34 d^{-1} with a nitrate concentration of the medium of 105 mg/l. Results of this investigation are presented in Table 5.

Table 5: Results of steady state culture experiment Nr 5 and Nr 7, using *Fragilaria crotonensis.* The culture was run for different temperatures using a nitrate concentration of the medium of 105 mg/l. The temperature tests at temperatures 12, 18 and 24°C were performed in experiment Nr 5, whereas the temperature tests at 15 and 21°C were done in experiment Nr 7.
a) - mean value; b) - standard deviation; c) - (minimum/maximum); d) – number of determinations
a, b, c, d – are related to all table values; susp. = suspension from the fermenter

Temp. (°C)	**Growth rate** μ (d^{-1})	**Nitrate concentration of the medium** (mg l^{-1})	**Extinction of the suspension at** 560nm	**Dry mass** (mg l^{-1})	**Productivity** (mg $l^{-1}d^{-1}$)	ε_{13C} (‰)	ε_{15N} (‰)	Ca^{2+} **susp.** (mg l^{-1})	Fe^{2+} **susp.** (mg l^{-1})	K^{+} **susp.** (mg l^{-1})	Mg^{2+} **susp.** (mg l^{-1})	Si^{2+} **susp.** (mg l^{-1})	NO_3^{2-} **susp.** (mg l^{-1})	PO_4^{3-} **susp.** (mg l^{-1})	SO_4^{2-} **susp.** (mg l^{-1})
			0.657 [a]	**250.30**	**85.10**	**-26.66**	**-1.35**	**31.40**	**4.10**	**8.50**	**2.00**	**1.20**	**42.70**	**>0.05**	**17.40**
12	0.34	105	**0.01** [b]	**17.30**	**5.88**	**0.01**	**0.06**								
			(0.639 / 0.665) [c]	(223.2 / 297.9)	(75.89 / 101.29)	(-26.65 / -26.67)	(-1.4 / -1.3)								
			n=4 [d]	n=4	n=4	n=2	n=4	n=1	n=1	n=1	n=1	n=1	n=1	n=1	n=1
			0.735	**297.70**	**101.2**	**-26.28**	**-0.89**	**32.60**	**3.40**	**7.70**	**2.10**	**0.40**	**30.60**	**0.30**	**17.30**
15	0.34	105	**0.02**	**15.70**	**5.33**	**0.17**	**0.16**	**0.38**	**0.62**	**0.30**	**0.08**	**0.07**	**1.03**	**0.19**	**1.15**
			(0.697 / 0.766)	(268.8 / 323.9)	(91.39 / 110.13)	(-25.94 / -26.55)	(-1.17/-0.66)	(32.1 / 33)	(2.6 / 4.3)	(7.2 / 7.9)	(2 / 2.2)	(0.34 / 0.52)	(29.7 / 32.3)	(0.05 / 0.49)	(16.1 / 17.7)
			n=18	n=15	n=15	n=14	n=15	n=5	n=5	n=5	n=5	n=5	n=5	n=5	n=5
			0.781	**282.90**	**96.19**	**-26.56**	**-0.82**	**30.90**	**3.30**	**8.90**	**2.10**	**0.80**	**29.60**	**0.80**	**13.50**
18	0.34	105	**0.01**	**4.23**	**1.44**	**0.10**	**0.11**								
			(0.772 / 0.799)	(277.3 / 287.7)	(94.28 / 97.82)	(-26.42 / -26.66)	(-1 / -0.7)	(30.2 / 31.6)	(2.8 / 3.8)	(8.8 / 8.9)	(2 / 2.1)	(0.75 / 0.85)	(29.6)	(0.21 / 1.33)	(12.5 / 14.4)
			n=5	n=5	n=5	n=5	n=5	n=2	n=2	n=2	n=2	n=2	n=1	n=2	n=2
			0.738	**302.30**	**102.8**	**-25.86**	**-0.87**	**32.90**	**4.60**	**8.30**	**2.20**	**0.80**	**18.50**	**1.00**	**15.40**
21	0.34	105	**0.04**	**20.90**	**7.11**	**0.09**	**0.09**	**1.11**	**1.03**	**0.51**	**0.10**	**0.28**		**0.96**	**4.73**
			(0.761 / 0.782)	(261.3 / 321.4)	(88.84 / 109.27)	(-25.77 / -26.02)	(-1.01/-0.77)	(31.8 / 34.2)	(3.5 / 6)	(7.7 / 8.9)	(2.1 / 2.3)	(0.52 / 1.2)	(15.2 / 21.8)	(0.05 / 1.29)	(11.4 / 22.2)
			n=8	n=6	n=6	n=6	n=5	n=4	n=4	n=4	n=4	n=4	n=2	n=4	n=4
			0.862	**305.40**	**103.84**	**-25.77**	**-0.33**	**30.00**	**5.10**	**9.40**	**2.30**	**0.80**	**11.50**	**2.50**	**13.90**
24	0.34	105	**0.02**	**6.60**	**2.24**	**0.04**	**0.05**								
			(0.827 / 0.877)	(288.8 / 320.8)	(98.19 / 109.07)	(-25.71 / -25.8)	(-0.4 / 0)	(29.0 / 31.0)	(3.6 / 6.5)	(9.2 / 9.5)	(2.2 / 2.3)	(0.56 / 1)	(9.23 / 13.8)	(1.82 / 3.23)	(13.7 / 14.1)
			n=4	n=4	n=4	n=4	n=4	n=2	n=2	n=2	n=2	n=2	n=2	n=2	n=2

4.2.1 Changes of the temperature and productivity of Fragilaria crotonensis

Results illustrated in Figure 19 show, that productivity of *Fragilaria* was affected by the temperature. The productivity was positively correlated with the temperature, and the changes were from 85 mg $l^{-1}d^{-1}$ at 12°C to 103 mg $l^{-1}d^{-1}$ at 24°C. During this experiment the diatom growth was not limited by nitrate and the amount of unconsumed nitrate in the suspension of the fermenter increased with the decrease of temperature (see Table 5).

The data obtained in this study suggest, that the optimum of growth for *Fragilaria* grown under nitrate saturating conditions lies at about 24°C.

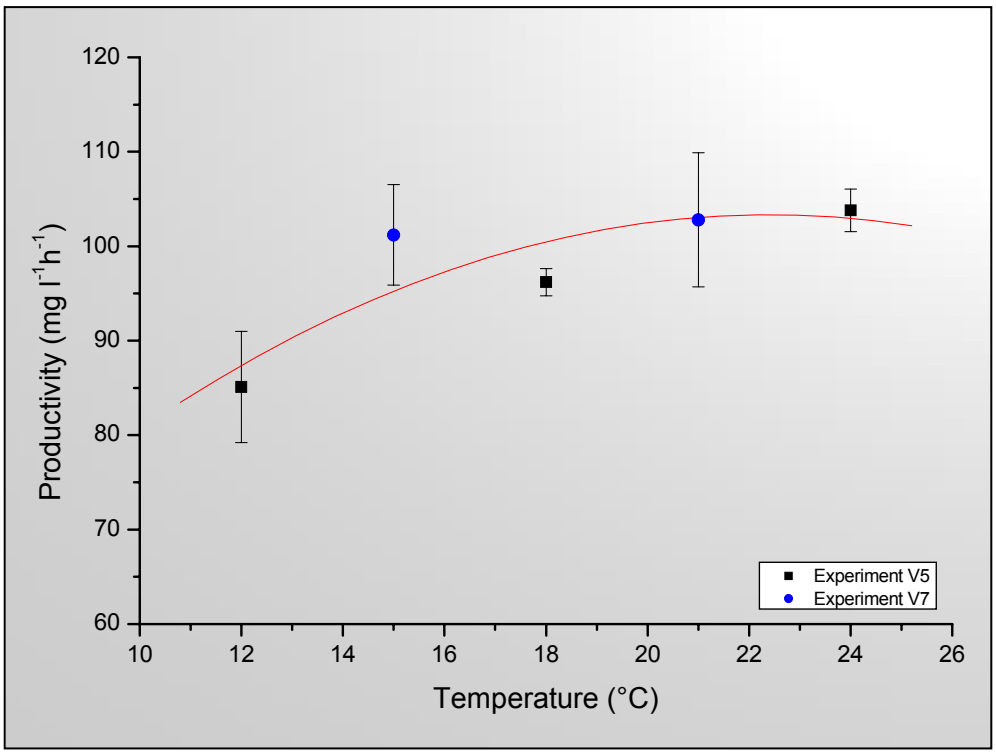


Figure 19: Productivity of *Fragilaria crotonensis* versus temperature. The growth rate was 0.34 d^{-1}. The nitrate concentration of the medium was 105 mg/l. Culture was grown under continuous light conditions at a light intensity of 500 µmol photons $m^{-2}s^{-1}$.

4.2.2 Changes of the temperature, element composition of Fragilaria dry mass and C:N:Si ratios

Nutrient stoichiometry is important in the regulation of both the species composition and the growth rates of phytoplankton communities. A combination of physiological assays and sestonic ratios is useful in proximate assessment of the nutrient status of phytoplankton (Healey and Hendzel 1980, Kilham 1990). Cellular elemental

stoichiometry is affected by the availability of nutrients and therefore can be correlated with the nutrient limitations (Wetzel 2001).

Element composition of selected samples of *Fragilaria* dry mass for different temperatures is listed below in Table 6. The samples were collected during steady state conditions of experiments Nr 5 and 7.

Table 6: Element composition of selected samples of *Fragilaria crotonensis* dry mass collected during steady state conditions of experiment 5 and 7. Diatoms were grown at different temperatures. Dilution rate was 0.34 d^{-1}. Si/P, C/P and N/P are accordingly the amounts of Si, C and N (mg/ld) divided by the productivity (P) (mg/ld).

Temp, (°C)	Growth rate μ (d^{-1})	Nitrate concentration of the medium (mg l^{-1})	Sample	Dry mass (mg l^{-1})	Productivity P (mg $l^{-1}d^{-1}$)	Si (wt-%)	Si (mg $l^{-1}d^{-1}$)	Si/P	C (wt-%)	C (mg $l^{-1}d^{-1}$)	C/P	N (wt-%)	N (mg $l^{-1}d^{-1}$)	N/P	C/N	Si/C	Si/N
12	0.34	105	V5 D46	267.9	91.1	12.6	11.49	0.13	34.2	31.14	0.34	4.2	3.84	0.042	8.1	0.38	3.1
			V5 D47	259.4	88.2	12.4	10.95	0.12	34.6	30.53	0.35	4.2	3.71	0.042	8.3	0.34	2.9
15	0.34	105	V7 D29	302.2	102.7	11.9	12.22	0.12	36.8	37.79	0.37	4.1	4.21	0.04	9.0	0.3	2.9
			V7 D35	294.1	100.0	11.5	11.50	0.12	38.3	38.30	0.38	4.4	4.40	0.04	8.7	0.3	2.6
			V5 D36	287.6	97.8	11.1	10.85	0.11	38.5	37.64	0.38	4.0	3.91	0.04	9.5	0.29	2.8
18	0.34	105	V5 D38	283.4	96.4	12.0	11.56	0.12	38.3	36.89	0.38	4.0	3.84	0.04	9.5	0.32	3.0
			V5 D41	285.9	97.2	11.5	11.19	0.12	38.3	37.23	0.38	3.8	3.71	0.04	9.5	0.32	3.0
21	0.34	105	V7 D9	321.4	109.3	11.5	12.57	0.12	37.7	41.21	0.38	4.6	5.03	0.046	8.2	0.3	2.5
			V7 D11	306.7	104.3	11.3	11.79	0.11	38.4	40.10	0.38	4.0	4.20	0.04	9.6	0.3	2.8
24	0.34	105	V5 D29	320.8	109.7	10.3	11.22	0.1	37.1	40.46	0.37	3.6	3.91	0.036	10.3	0.27	2.8
			V5 D30	305.4	103.8	10.8	11.22	0.11	37.4	38.83	0.37	3.7	3.84	0.037	10.0	0.30	3.0

The results for *Fragilaria crotonensis* grown at various temperatures show diverse element compositions. The element composition for each temperature is almost identical indicating rather stable environmental conditions during diatom growth. The carbon content relative to productivity increased asymptotically with increasing temperature (see Figure 20). These changes ranged from 0.34 at 12°C to 0.37 at 24°C showing a rise of carbon content of about 10%. In the case of nitrogen content relative to productivity, there is a distinct linear decrease of the concentration from 0.042 at 12°C to 0.036 at 24°C. The decline was about 20%.

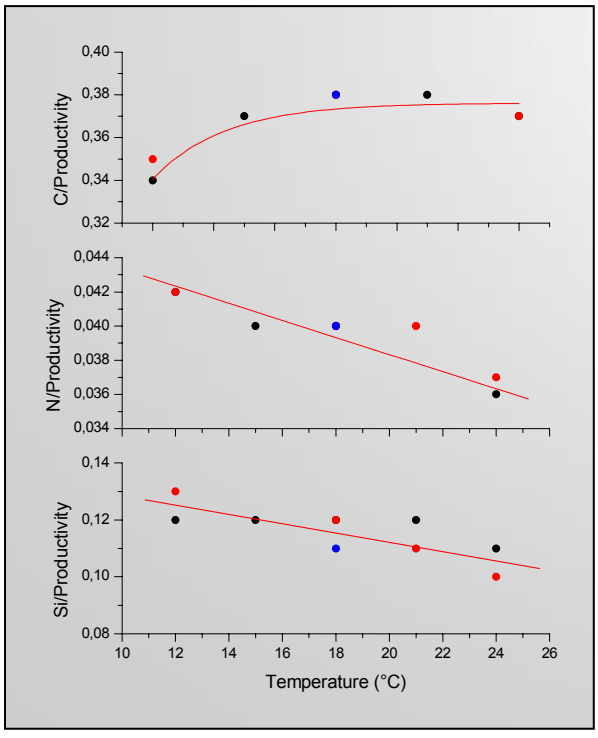


Figure 20: The C, N, Si content of *Fragilaria crotonensis* dry mass relative to the productivity for various temperatures. The growth rate was 0.34 d^{-1}. The nitrate concentration of the medium was 105 mg/l. Culture was grown under continuous light conditions at a light intensity of 500 μmol photons $m^{-2}s^{-1}$.

The data suggest that the nitrogen assimilation was higher at 12°C than at 24°C. The temperature of 12°C was probably not optimal for growth. The silicon content relative to productivity showed a slight decrease with an increase of temperature and the changes were from 0.13 at 12°C to 0.1 at 24°C, what means circa 25% decrease. The C/N, Si/C and Si/N ratios of the dry mass derived from this experiment are presented below in Figure 21.

The C/N ratio was most affected by the temperature, and increased almost linearly with increasing temperature from 8.1 at 12°C to 10.3 at 24°C indicating a change of about 30%. The C/N ratio shows that the photosynthetic carbon fixation was higher at higher temperature. The Si/C ratio of the dry mass changed by about 30% within the temperature range tested. The observed drop of the ratio with increasing temperature ranged from 0.38 at 12°C to 0.27 at 24°C. The review of Brzezinski (1985) gave a mean Si/C ratio for diatoms of 0.3.

The Si/N ratio was constant for the whole temperature range at about 3.0.

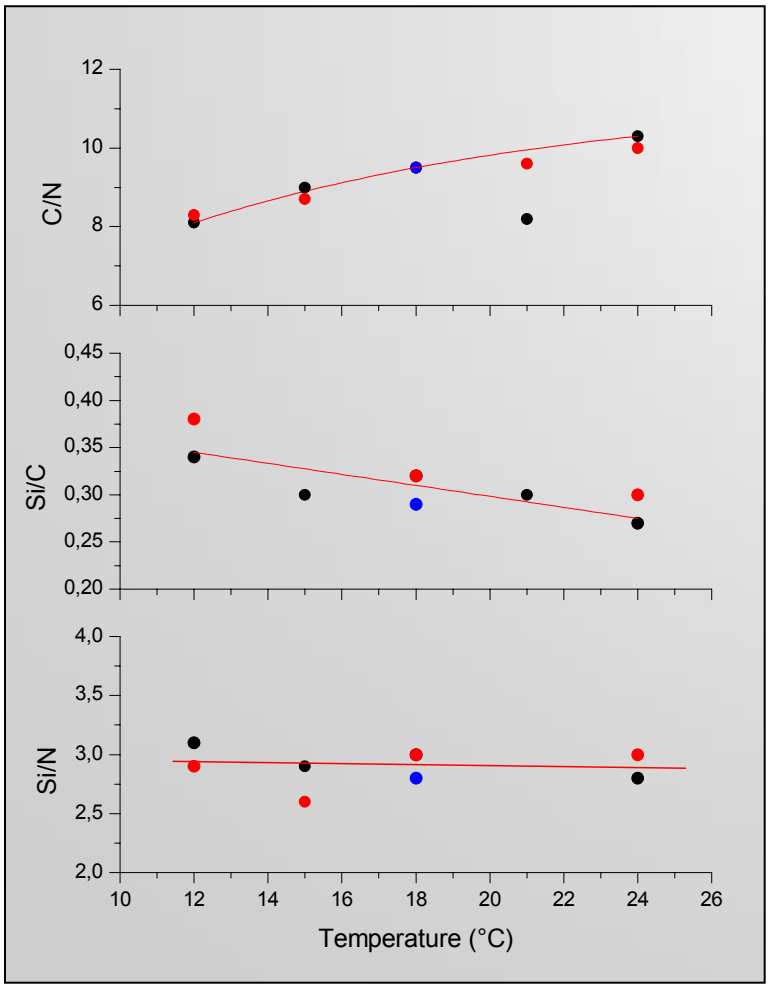


Figure 21: The C/N, Si/N and Si/C ratios of *Fragilaria crotonensis* dry mass versus temperature. The growth rate was 0.34 h^{-1}; the nitrate concentration of the medium was 105 mg/l. Culture was grown under continuous light conditions at a light intensity of 500 µmol photons $m^{-2}s^{-1}$.

4.2.3 Changes of temperature and stable carbon isotope fractionation by Fragilaria crotonensis

The solubility of CO_2 is influenced by the temperature and decreases with increasing temperature. The amount of dissolved CO_2 in water is about 1.1 mg/l at 0°C, 0.6 mg/l at 15°C, and 0.4 mg/l at 30°C. In addition, the pH of the water plays an important role influencing the abundance of inorganic carbon species in water (see Figure 22). During all experiments inorganic carbon (CO_2) was supplied continuously.

The pH of the culture varied between 7.2 and 7.3 for the whole temperature range, thus, enough CO_2 should have been available for diatom cells (see Figure 22). The graph shows that the carbon source is partly present as CO_2 but mainly as HCO_3^-. The results of the investigation presented in Figure 23 show the temperature dependence of the carbon isotope fractionation in *Fragilaria crotonensis*.

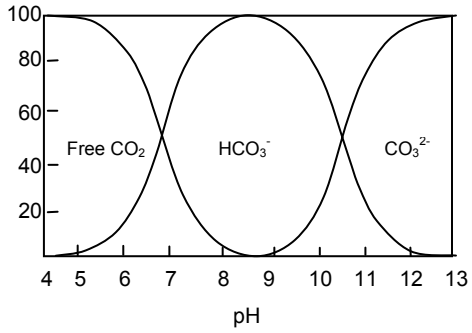


Figure 22: The ordinate gives the percentage of the different molecular and ionic carbon species respectively (Wetzel 2001).

This dependence is linear and positively correlated with temperature. The fractionation varied between -26.66‰ at 12°C, and -25.77‰ at 24°C leading to a difference in the fractionation of circa 0.9‰ for a temperature change of 12°C.

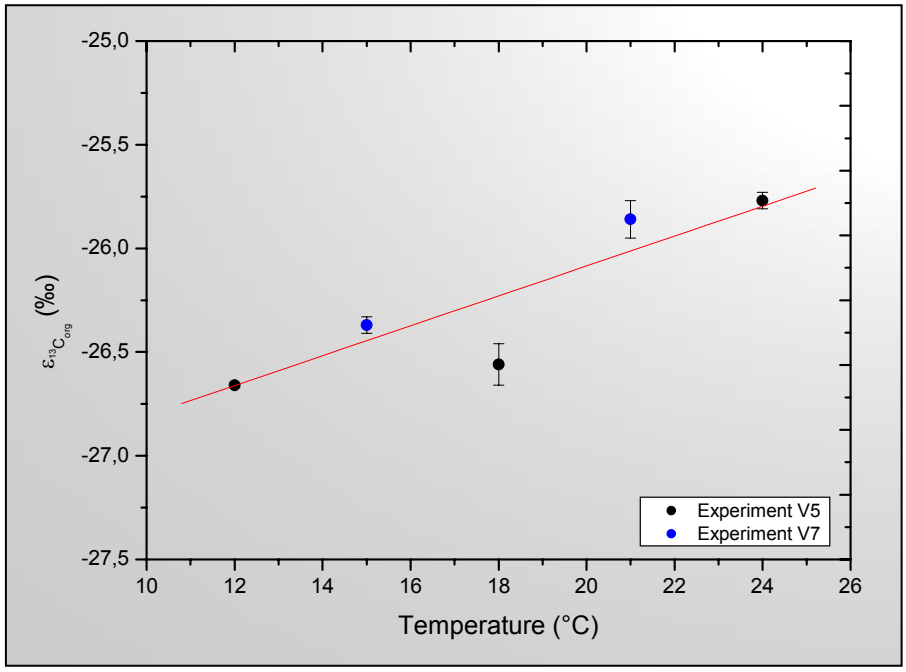


Figure 23: The dependence of the carbon isotope fractionation on various temperatures. The nitrate concentration of the medium was 105 mg/l; the growth rate was 0.34 d^{-1}. Culture was grown under continuous light conditions at a light intensity of 500 µmol photons $m^{-2}s^{-1}$.

The temperature coefficient calculated from the slope is 0.075 ‰/°C. It is positive and not high but probably significant. The decreasing fractionation of carbon in Figure 23 suggests that the availability of dissolved CO_2 decreased with increasing temperature, in spite of high aeration rates, probably caused by lower solubility at higher temperatures. The rise of the temperature caused a higher biomass production (see Chapter 4.2.1), therefore more of CO_2 was needed to maintain a high productivity. In this case almost all of the CO_2 available was consumed by diatoms.

4.2.4 Changes of the temperature and stable nitrogen isotope fractionation by Fragilaria crotonensis

It is well known that temperature affects the productivity of diatoms and thus the nitrogen assimilation, which should be reflected in the nitrogen isotope fractionation. To test the effect of temperature on the nitrogen isotope fractionation the growth of *Fragilaria crotonensis* was examined for various temperatures. During the whole experiment the nitrate concentration of the medium was constant and amounted to 105 mg/l. The nitrogen isotope fractionation for various temperatures is presented in Figure 24. The results show an inverse linear correlation of the nitrogen isotope fractionation with temperature (R^2=0.99). The $\delta^{15}N$ values varied between -1.36‰ at 12°C and -0.33‰ at 24°C. As presented in Chapter 4.2.1, a decrease of the temperature caused a lower productivity of the algae and more nitrate in the suspension remained unconsumed (see Table 5). Simultaneously, as Figure 24 shows, with decreasing temperature more of the nitrate was preserved in the suspension (see Table 5), which is probably responsible for higher fractionation at lower temperatures. The higher the nitrogen concentration of the medium is the more freely the different isotope species can be selected.

In natural environments the expression of fractionation effects are rarely observed since nitrogenous nutrients are usually depleted in limnic and oceanic surface waters. Thus, the $\delta^{15}N$ values derived from this experiment suggest an effect of increasing nitrate availability in the suspension with decreasing temperature rather than a pure effect of the temperature. At lower temperatures, where the nitrate concentration was higher, the isotope equilibration process could probably fully develop.

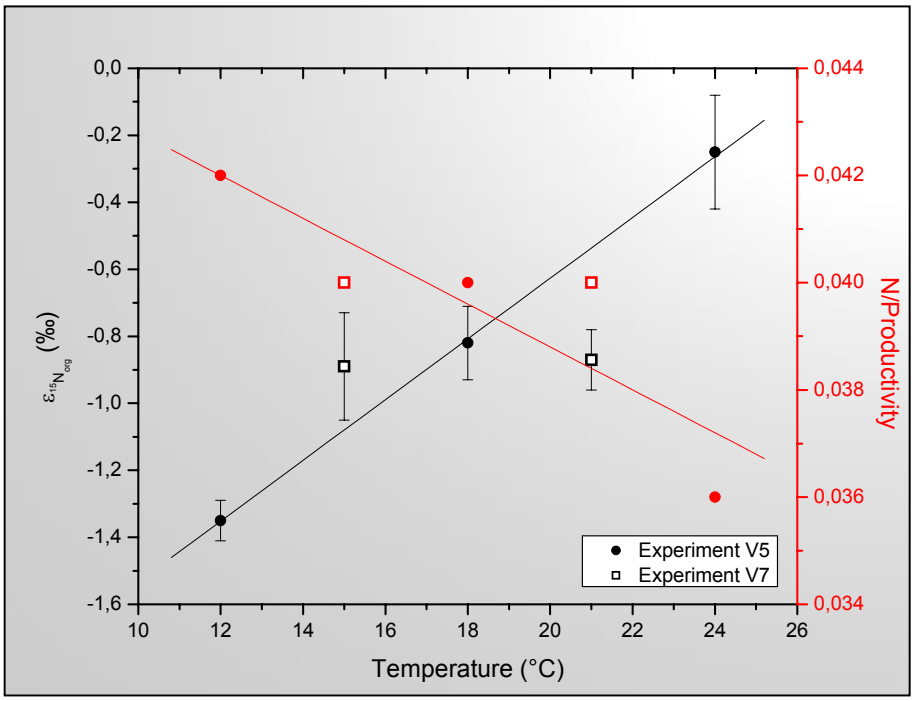


Figure 24: Nitrogen isotope fractionation in *Fragilaria crotonensis* versus temperature. The nitrate concentration of the medium was 105 mg/l. The growth rate was 0.34 d^{-1}; Culture was grown under continuous light conditions at a light intensity of 500 µmol photons $m^{-2}s^{-1}$.

4.3 Growth of Cyclotella meneghiniana

Growth rate reflects interactions between environmental variables which affect phytoplankton growth. In natural environment the light regime, nutrient availability and temperature determine algal growth and different types of limitation result in various physiological responses of phytoplankton cells. In many cases temperature that controls the metabolic rate and nutrient uptake kinetics causes the largest effects. In nature it is almost impossible to observe the influence of a single parameter and there is little information regarding temperature-nutrient interactions (Rhee & Gotham, 1981). In this study the growth of *Cyclotella meneghiniana* was studied for various temperatures using two fixed growth rates, namely µ=0.2 d^{-1} and µ=0.34 d^{-1} respectively. At the higher growth rate diatoms were grown at 15, 18, 21, 24°C. For the lower growth rate temperatures of 12, 15, 18, 21°C were used. The test run for 18°C at the lower growth rate was conducted within experiment Nr 15. The lower growth rate was chosen for the experiments because at lower temperatures the culture would otherwise be washed out of the fermenter, since the maximum growth rate at the lower temperatures would be smaller than the corresponding dilution rate. It means, the flow rate of the fermenter corresponds to a growth rate, which at lower temperatures can not be achieved by the organisms. To control reproducibility of the data obtained from the main experiment Nr 8 some temperature tests were repeated.

Table 7: Results of steady state culture experiment Nr 8, using *Cyclotella meneghiniana*. The culture was run for different temperatures and growth rates.
a) - mean value; b) - standard deviation; c) - (minimum/maximum); d) – number of determinations
a, b, c, d – are related to all table values; susp. = suspension

Temp. (°C)	**Growth rate** μ (d^{-1})	**Extinction of the suspension at** 560nm	**Dry mass** (mg l^{-1})	**Productivity** (mg $l^{-1}d^{-1}$)	ε_{13C} (‰)	ε_{15N} (‰)	**Ca^{2+} susp.** (mg l^{-1})	**Fe^{2+} susp.** (mg l^{-1})	**K^{+} susp.** (mg l^{-1})	**Mg^{2+} susp.** (mg l^{-1})	**Si^{2+} susp.** (mg l^{-1})	**NO_3^{2-} susp.** (mg l^{-1})	**PO_4^{3-} susp.** (mg l^{-1})	**SO_4^{2-} susp.** (mg l^{-1})
		0.568 [a]	**234.00**	**79.56**	**-24.53**	**-0.26**								
15	0.34	**0.05** [b]	**12.50**	**4.25**	**0.14**	**0.03**								
		(0.475 / 0.62) [c]	(211.8 / 246.9)	(72.01 / 83.95)	(-24.39 / -24.66)	**(-0.22 / -0.30)**	**17.20**	**4.70**	**6.60**	**2.30**	**0.80**	**1.90**	**>0.05**	**22.7**
		n=8 [d]	n=6	n=6	n=6	n=6	n=1	n=1	n=1	n=1	n=1	n=1	n=1	n=1
		0.713	**303.60**	**103.22**	**-23.19**	**-0.47**								
18	0.34	**0.01**	**1.49**	**0.51**	**0.11**	**0.09**								
		(0.695 / 0.728)	(301.2 / 305.1)	(102.41 / 103.73)	(-23 / -23.28)	**(-0.39 / -0.59)**	**17.80**	**7.20**	**6.30**	**2.30**	**4.10**	**4.50**	**>0.05**	**24.0**
		n=7	n=5	n=5	n=5	n=4	n=1	n=1	n=1	n=1	n=1	n=1	n=1	n=1
		0.725	**314.20**	**106.83**	**-22.92**	**-0.48**								
21	0.34	**0.02**	**9.70**	**3.30**	**0.23**	**0.11**								
		(0.699 / 0.746)	(299.3 / 330.5)	(101.76 / 112.37)	(-22.69 / -23.41)	**(-0.3 / -0.62)**	**20.00**	**5.60**	**6.40**	**2.80**	**0.60**	**1.70**	**0.30**	**25.40**
		n=11	n=9	n=9	n=9	n=8	n=1	n=1	n=1	n=1	n=1	n=1	n=1	n=1
		0.794	**347.20**	**118.05**	**-23.36**	**-0.66**	**16.90**	**7.00**	**6.80**	**2.20**	**1.80**	**0.10**	**0.30**	**21.80**
24	0.34	**0.02**	**22.10**	**7.51**	**0.31**	**0.09**								
		(0.761 / 0.815)	(310.4 / 373.8)	(105.54 / 127.09)	(-22.94 / -23.57)	(-0.56 / -0.75)	(16.7 / 17.1)	(5.1 / 8.8)	(6.3 / 7.3)	(2.2)	(1.1 / 2.5)	(0.05)	(0.05 / 0.62)	(20 / 23.66)
		n=8	n=6	n=6	n=7	n=7	n=2	n=2	n=2	n=2	n=2	n=2	n=2	n=2
		0.578	**246.50**	**49.30**	**-25.4**	**-0.44**								
12	0.20	**0.01**	**10.20**	**2.04**	**0.23**	**0.07**								
		(0.563 / 0.596)	(233.4 / 255)	(46.68 / 51.00)	(-25.2 / -25.67)	**(-0.35 / -0.52)**	**19.40**	**7.10**	**7.10**	**2.30**	**2.80**	**1.80**	**>0.05**	**22.50**
		n=6	n=5	n=5	n=5	n=4	n=1	n=1	n=1	n=1	n=1	n=1	n=1	n=1
		0.667	**284.40**	**59.46**	**-24.02**	**-0.40**								
15	0.20	**0.01**	**7.20**	**1.44**	**0.10**	**0.08**								
		(0.655 / 0.676)	(280.3 / 295.1)	(56.06 / 59.02)	(-23.89 / -24.11)	**(-0.30 / -0.48)**	**19.60**	**5.20**	**6.90**	**2.20**	**2.30**	**2.20**	**>0.05**	**21.60**
		n=5	n=4	n=4	n=4	n=4	n=1	n=1	n=1	n=1	n=1	n=1	n=1	n=1
		0.681	**297.30**	**56.88**	**-23.22**	**-0.48**								
21	0.20	**0.02**	**8.50**	**1.70**	**0.15**	**0.11**								
		(0.655 / 0.702)	(282.3 / 302.6)	(56.46 / 60.52)	(-23.07 / -23.42)	**(-0.36 / -0.6)**	**18.50**	**4.40**	**6.80**	**2.00**	**0.80**	**0.20**	**0.10**	**18.00**
		n=6	n=5	n=5	n=5	n=5	n=1	n=1	n=1	n=1	n=1	n=1	n=1	n=1

Table 8: Results of steady state repetition experiments using *Cyclotella meneghiniana.*
a) - mean value; b) - standard deviation; c) - (minimum/maximum); d) – number of determinations
a, b, c, d – are related to all table values; susp. = suspension

Temp. (°C)	**Growth rate** μ (d^{-1})	**Extinction of the suspension at** 560nm	**Dry mass** (mg l^{-1})	**Productivity** (mg $l^{-1}d^{-1}$)	ε_{13C} (‰)	ε_{15N} (‰)	**Ca^{2+} susp.** (mg l^{-1})	**Fe^{2+} susp.** (mg l^{-1})	**K^{+} susp.** (mg l^{-1})	**Mg^{2+} susp.** (mg l^{-1})	**Si^{2+} susp.** (mg l^{-1})	**NO_3^{2-} susp.** (mg l^{-1})	**PO_4^{3-} susp.** (mg l^{-1})	**SO_4^{2-} susp.** (mg l^{-1})
		0.721 [a]	**302.20**	**102.75**	**-22.78**	**-0.33**	**18.80**	**8.15**	**6.63**	**2.25**	**2.10**	**0.39**	**0.13**	**20.88**
18	0.34	**0.01** [b]	**13.20**	**4.49**	**0.16**		**2.48**	**2.19**	**0.81**	**0.13**	**0.89**	**0.18**	**0.09**	**0.94**
		(0.706 / 0.737) [c]	(282 / 317.8)	(95.88 / 108.05)	(-22.99 / -22.58)	(-0.23 / -0.42)	(17.3 / 22.5)	(5.1 / 10.0)	(6.0 / 7.8)	(2.1 / 2.4)	(1.2 / 3.2)	(0.21 / 0.59)	(0.05 / 0.24)	(20.0 / 22.2)
		n=9 [d]	n=7	n=7	n=7	n=2	n=4	n=4	n=4	n=4	n=4	n=4	n=4	n=4
		0.603	**283.90**	**56.78**	**-25.11**		**18.60**	**6.90**	**5.50**	**2.50**	**1.80**	**1.10**	**0.20**	**24.20**
12	0.20	**0.01**	**8.93**	**1.79**	**0.11**		**0.86**	**0.19**	**0.12**	**0.19**	**0.10**	**0.57**	**0.34**	**1.00**
		(0.577 / 0.618)	(258.6 / 292.1)	(51.72 / 58.42)	(-24.96 / -25.31)		(17.2 / 19.6)	(6.7 / 7.2)	(5.3 / 5.6)	(2.2 / 2.7)	(1.7 / 2)	(0.3 / 1.75)	(0.05 / 0.93)	(22.9 / 25.3)
		n=13	n=11	n=11	n=11		n=6	n=6	n=6	n=6	n=6	n=6	n=6	n=6
		0.732	**327.20**	**65.44**	**-24.27**		**18.8**	**6.00**	**5.30**	**2.20**	**1.20**	**0.20**	**>0.05**	**22.30**
15	0.20	**0.03**	**24.70**	**4.94**	**0.30**		**0.91**	**0.50**	**0.11**	**0.10**	**0.20**	**0.14**	**0.00**	**0.69**
		(0.687 / 0.789)	(270.3 / 351.8)	(54.06 / 70.36)	(-23.77 / -24.95)		(17.8 / 19.8)	(4.9 / 6.4)	(5.1 / 5.4)	(2.1 / 2.4)	(0.8 / 1.4)	(0.06 / 0.45)	(0.05)	(21.4 / 23.3)
		n=19	n=16	n=16	n=16		n=7	n=7	n=7	n=7	n=7	n=7	n=7	n=7
		0.743	**356.30**	**71.26**	**-23.67**	**-0.79**	**17.30**	**5.00**	**5.00**	**2.10**	**0.90**	**0.20**	**>0.05**	**20.60**
18	0.20	**0.01**	**25.50**	**5.10**	**0.36**	**0.11**	**0.84**	**0.60**	**0.24**	**0.14**	**0.14**	**0.20**	**0.00**	**0.80**
		(0.719 / 0.765)	(303.3 / 392.7)	(60.66 / 78.54)	8-23.31 / -24.26)	(-0.69 / -0.98)	(16.2 / 18.9)	(4.3 / 6.3)	(4.6 / 5.3)	(2 / 2.4)	(0.7 / 1.1)	(0.05 / 0.67)	(0.05)	(19.7 / 21.7)
		n=16	n=10	n=10	n=10	n=9	n=8	n=8	n=8	n=8	n=8	n=8	n=8	n=8

For the higher growth rate the temperature of 18°C (experiment Nr 6) was chosen, and for the lower growth rate 12 and 15°C (experiment Nr 14) were chosen. Results of all investigations are presented in Tables 7 and 8.

The data obtained from the culture experiments suggest that culture conditions for the same diatom strain using fermenter system could be restored. Differences appearing among separate tests are within the error margins, so that information included in the data can be compared.

4.3.1 Productivity of Cyclotella meneghiniana

Productivity of *Cyclotella meneghiniana* is presented in Figure 25. Generally, productivity was higher at μ=0.34 d^{-1} than at μ= 0.2 d^{-1}. At the higher growth rate there was a significant rise in productivity with increasing temperatures. For μ =0.34 d^{-1} a distinct increase was observed between 15 and 18°C from 79.56 ± 4.25 to 103.22 ± 0.51 mg $l^{-1}d^{-1}$. Further temperature increases brought smaller changes in productivity. At 21°C the productivity was 106.83 ± 3.30 mg $l^{-1}d^{-1}$ and at 24°C the corresponding value was 118.05 ± 7.51 mg $l^{-1}d^{-1}$ respectively. Optimal growth conditions for *Cyclotella* are presumably in the range of 24°C or even somewhat higher. The productivity from repetition tests for the higher growth rate at 18°C was in accordance with results of the main experiment (see Figure 25 and Tables 7, 8.).

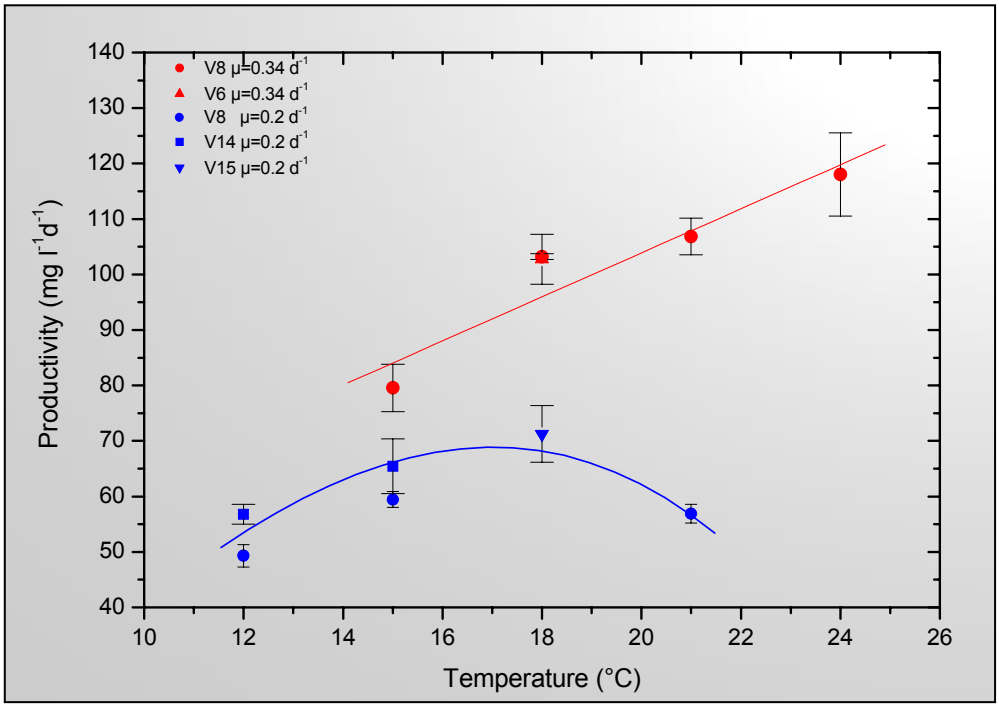


Figure 25: Productivity of the steady state main culture experiment V8 and repetition tests with *Cyclotella meneghiniana.* The results are presented for different growth rates. Culture was grown under continuous light conditions at a light intensity of 500 μmol photons $m^{-2}s^{-1}$.

During tests conducted at the lower growth rate (μ=0.2 d^{-1}) the changes in productivity were less pronounced. For temperatures of 12, 15 and 21°C the following values were obtained: 49.3 ± 2.04, 59.46 ± 1.44 and 56.88 ± 1.7 mg $l^{-1}d^{-1}$. In contrast to the results of the main experiment (μ=0.2 d^{-1}), the results of repetition tests show linear increase of the productivity with temperature, with an optimum at 18°C. Additionally, the productivity of repetition tests was about 13% higher.

4.3.2 Element composition and C:N:Si ratios

The steady state cultures were established for investigating changes of one parameter by keeping the others constant. At the beginning of the experiments it was not clear how well this could be established. Element composition of the *Cyclotella* dry mass from the main experiment and repetition tests are presented in the appendix. In this discussion only concentrations of N, C and Si were taken into consideration (see Table 9 below).

Table 9: The concentrations of C, N and Si in selected samples from *Cyclotella maneghiniana* dry mass accumulated during steady state conditions of main experiment V8 and repetition experiments – V6, V14 and V15. Diatoms were grown at different temperatures and growth rates.

Temp, (°C)	Growth rate μ (d^{-1})	Sample	Dry mass (mg l^{-1})	Productivity P (mg $l^{-1}d^{-1}$)	Si (wt-%)	Si (mg $l^{-1}d^{-1}$)	Si/P	C (wt-%)	C (mg $l^{-1}d^{-1}$)	C/P	N (wt-%)	N (mg $l^{-1}d^{-1}$)	N/P	C/N	Si/C	Si/N
15	0,34	V8 D32	242,5	82,45	12,2	10,06	0,12	32,4	26,72	0,32	3,9	3,23	0,039	8,3	0,4	3,1
		V8 D34	239,8	81,53	12,7	10,37	0,13	32,3	26,35	0,32	3,9	3,20	0,039	8,2	0,4	3,2
		V8 D18	306	104,04	10,6	11,02	0,11	34,4	35,80	0,34	3,2	3,33	0,032	10,7	0,3	3,3
18	0,34	V8 D20	303,7	103,26	10,7	11,05	0,11	34,2	35,33	0,34	3,2	3,30	0,032	10,7	0,3	3,4
		V8 D24	275,9	93,81	10,8	10,13	0,11	34,2	32,10	0,34	3,1	2,92	0,031	11,0	0,3	3,5
		V8 D53	327,1	111,21	10,6	11,80	0,11	33,4	37,16	0,33	3,3	3,67	0,033	10,1	0,3	3,2
21	0,34	V8 D57	317,8	108,05	10,7	11,56	0,11	33,6	36,31	0,34	3,3	3,57	0,033	10,2	0,3	3,2
		V8 D62	299,7	101,9	10,8	11,02	0,11	33,4	34,03	0,33	3,6	3,67	0,036	9,3	0,3	3,0
24	0,34	V8 D9	345,7	117,54	9,4	11,05	0,09	36,2	42,53	0,36	2,7	3,16	0,027	13,5	0,3	3,5
		V8 D12	348,5	118,49	9,5	11,25	0,09	36,2	42,91	0,36	2,6	3,09	0,026	13,9	0,3	3,6
12	0,2	V8 D91	237,6	47,52	12,6	5,98	0,13	33,3	15,82	0,33	4,2	2,00	0,042	7,9	0,4	3,0
15	0,2	V8 D80	281,1	56,22	11,6	6,52	0,12	32,9	18,50	0,33	3,6	2,02	0,036	9,2	0,4	3,2
		V8 D82	280,3	56,06	11,6	6,50	0,12	33	18,50	0,33	3,5	1,96	0,035	9,4	0,4	3,3
21	0,2	V8 D70	282,3	56,46	11,7	6,60	0,12	32	18,06	0,32	3,5	1,98	0,035	9,1	0,4	3,3
18	0,34	V6 D12	312,1	106,11	10,3	10,91	0,10	34,3	36,41	0,34	3,3	3,50	0,033	10,4	0,3	3,1
		V6 D14	317,8	108,05	11	11,90	0,11	34	36,75	0,34	3,3	3,57	0,033	10,3	0,3	3,3
		V14 D50	292,1	58,42	12,8	7,48	0,13	33,2	19,40	0,33	3,8	2,22	0,038	8,7	0,4	3,4
12	0,2	V14 D52	288,7	57,74	12,4	7,16	0,12	33,6	19,40	0,34	3,9	2,26	0,039	8,6	0,4	3,2
		V14 D54	285,7	57,14	12,5	7,14	0,12	33,7	19,26	0,34	3,9	2,22	0,039	8,7	0,4	3,2
		V14 D56	284,4	56,88	12,7	7,22	0,13	33,5	19,06	0,34	4	2,28	0,040	8,4	0,4	3,2
		V14 D28	345,5	69,1	11	7,60	0,11	37,5	25,92	0,38	3,1	2,14	0,031	12,1	0,3	3,6
15	0,2	V14 D30	351,3	70,26	10,7	7,52	0,11	37,3	26,20	0,37	3,1	2,18	0,031	12,0	0,3	3,4
		V14 D34	316,3	63,26	11,3	7,14	0,11	36,2	22,90	0,36	3,2	2,02	0,032	11,3	0,3	3,5
		V14 D38	270,3	54,06	12,8	6,92	0,13	37,2	20,12	0,37	3,3	1,78	0,033	11,3	0,3	3,9
18	0,2	V15 D15	362	72,4	10,4	7,52	0,10	38,1	27,58	0,38	2,6	1,88	0,026	14,7	0,3	4,0
		V15 D17	334,1	66,82	11,7	7,82	0,12	37,4	25,00	0,37	2,7	1,80	0,027	13,9	0,3	4,3

The diatoms grown at two different growth rates exhibited distinctly different element contents. The carbon content was influenced by temperature as well at higher as at lower growth rates. At μ=0.34 d^{-1} the C content relative to productivity rose linearly with temperature from 0.032 at 15°C to 0.036 at 24°C. The C content from the repetition experiment at 18°C amounted 0.034, which is well in agreement with the results form the main experiment. At the lower growth rate the carbon content relative to productivity remained unchanged (see Table 9). Repetition experiments, however, show an increase of the carbon content relative to productivity from 0.33 at 12°C to 0.38 at 18°C (see Table 9). The reason for differences in carbon content relative to productivity within the temperature range of 15-24°C is unclear.

The nitrogen content of *Cyclotella* dry mass relative to productivity showed distinct variations with temperature, both at higher and lower growth rate (see Figure 26). For μ= 0.34 d^{-1} the nitrogen content varied between 0.026-0.039 and for μ=0.2 d^{-1} the N content relative to productivity diminished between 12-15°C from 0.042 to 0.035, and between 15-21°C persisted constant (0.035). The replication test at 18°C (μ=0.34 d^{-1}) provided the N concentration relative to productivity at the same level as in the main experiment.

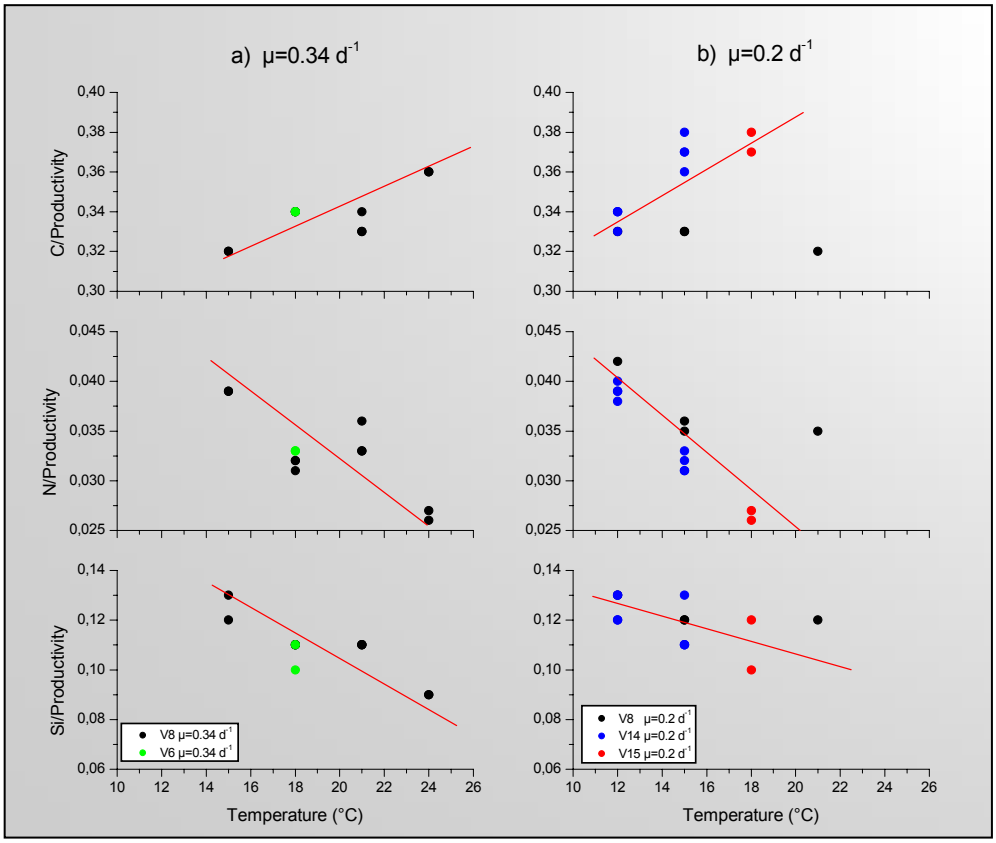


Figure 26: The concentrations of C, N and Si from *Cyclotella meneghiniana* dry mass depending on growth rate. Culture was grown under continuous light conditions at a light intensity of 500 μmol photons $m^{-2}s^{-1}$.

The results obtained from replication tests at the lower growth rate were consistent with the results of the main experiment between 12-15°C, however, the values were somewhat lower. The results for the higher growth rate show a decrease of the nitrogen content relative to productivity for the whole temperature range. At the lower growth rate, the nitrogen content relative to productivity decreased from 0.040 to 0.026 between 12-18°C. The results for the temperature range 18-21°C suggest a rise of the nitrogen content. Such behaviour seems to be uncertain, but it is reliable. Considering a metering precision ±5%, the nitrogen contents for all tests are within error margins.

The silicon content relative to productivity at the higher growth rate from the main experiment decreased linearly from 0.13 at 15°C to 0.09 at 24°C. The Si content relative to productivity from the repetition test at 18°C was in accordance with Si content from the main experiment. At the lower growth rate the Si content relative to productivity, despite broad data scatter, shows almost no trend for an increase of temperature (see Figure 26).

The Si:C:N ratios of the *Cyclotella* dry mass versus temperature and growth rate are illustrated in Figure 27.

At higher growth rates the C/N ratio was a linear function of the temperature and rose with increase of the temperature from 8.2 at 15°C to 13.9 at 24°C. The C/N ratios of the repetition test at 18°C are in accordance with the main experiment. The results of the main experiment obtained at the lower growth rate show an increase of the C/N ratio between 12 and 15°C, whereas, there was no difference in the C/N ratio between 15 and 21°C. The C/N ratios from repetition tests show distinct increase with temperature. Additionally the C/N ratios are higher than those derived from the main experiment. The Si/C ratios both at higher and lower growth rates were almost constant in the range 0.3 and 0.4 for the whole temperature interval (see Table 9 and Figure 27).

The Si/N ratio for the higher growth rate shows a positive correlation with temperature. However, the scatter was very large. The variations were from 3.1 at 15°C to 3.6 at 24°C. The repetition test at 18°C provided Si/N ratios which were slightly lower than those of the main experiment. The Si/N ratios obtained in the main experiment at the lower growth rate exhibit a similar pattern, but repetition tests revealed an increase of the ratio with temperature (3.0-4.3). Additionally the repetition

experiments provided higher Si/N ratios. Although, the culture conditions during particular experiments were kept constant, there are sometimes differences between single tests.

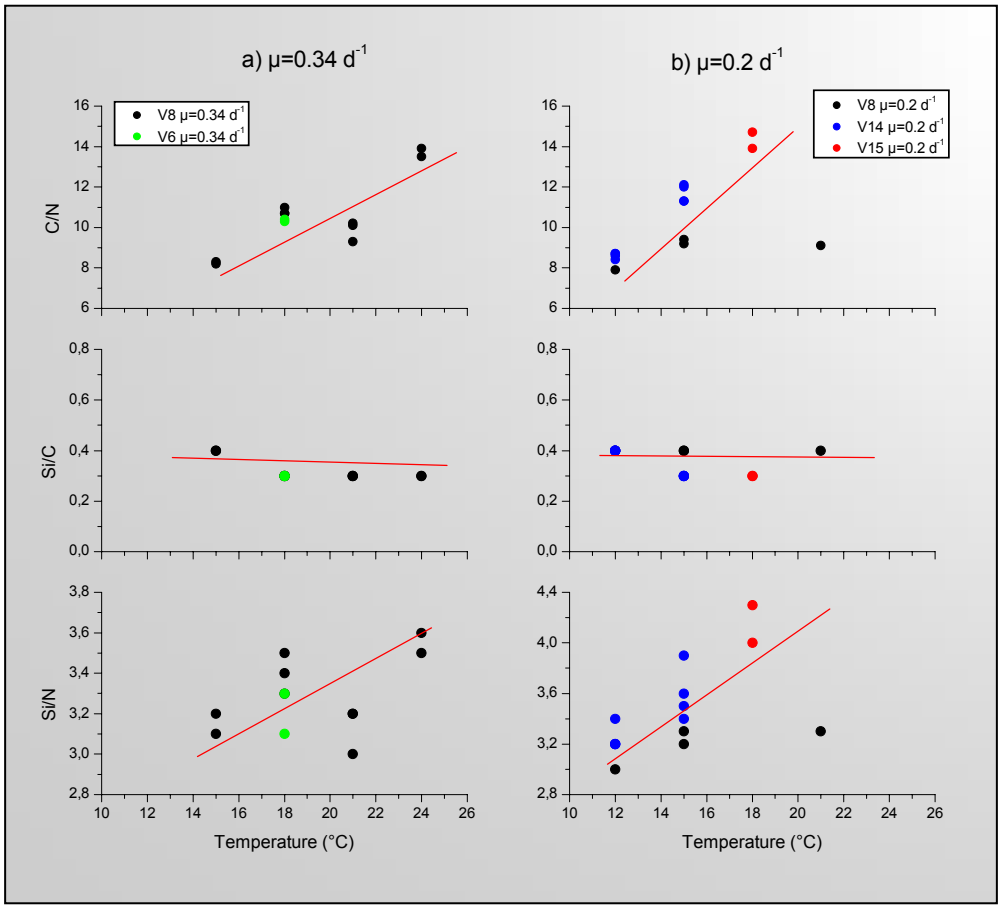


Figure 27: The C/N, Si/C and Si/N ratios of *Cyclotella meneghiniana* versus growth rate and temperature. Culture was grown under continuous light conditions at a light intensity of 500 µmol photons $m^{-2}s^{-1}$.

4.3.3 Carbon isotope fractionation for two different growth rates

Stable carbon isotope ratios of organic matter can potentially provide an insight into the environmental conditions under which carbon fractionation occurs. Several investigations reported that growth rate might influence the carbon isotope ratios of phytoplankton (e.g. Takahashi et al. 1991, Laws et al. 1995, Korb et al. 1996). The theoretical relationship between growth rate and $\delta^{13}C$ was based on cells which obtained their inorganic carbon by diffusive uptake of CO_2. In this study the stable carbon isotope ratio of dry mass of *Cyclotella* was measured for two growth rates and the results are presented in Figure 28.

In general, relative proportions of inorganic carbon in solution change with pH (Golterman, 1969). At pH higher than 8 free CO_2 does not exist and carbon exists mainly in the form of HCO_3^- ions (see Figure 22 in Chapter 4.2.3). During individual culture experiments the pH was relatively constant. In the main experiment the values varied between 7 and 7.2. Repetition of experiments at a lower growth rate resulted in a slightly lower pH value lying between 6.7 – 6.8. In this case the pH of the cultures was presumably irrelevant because the cultures were well stirred and aerated. This should ensure constant re-supply of CO_2 to the system.

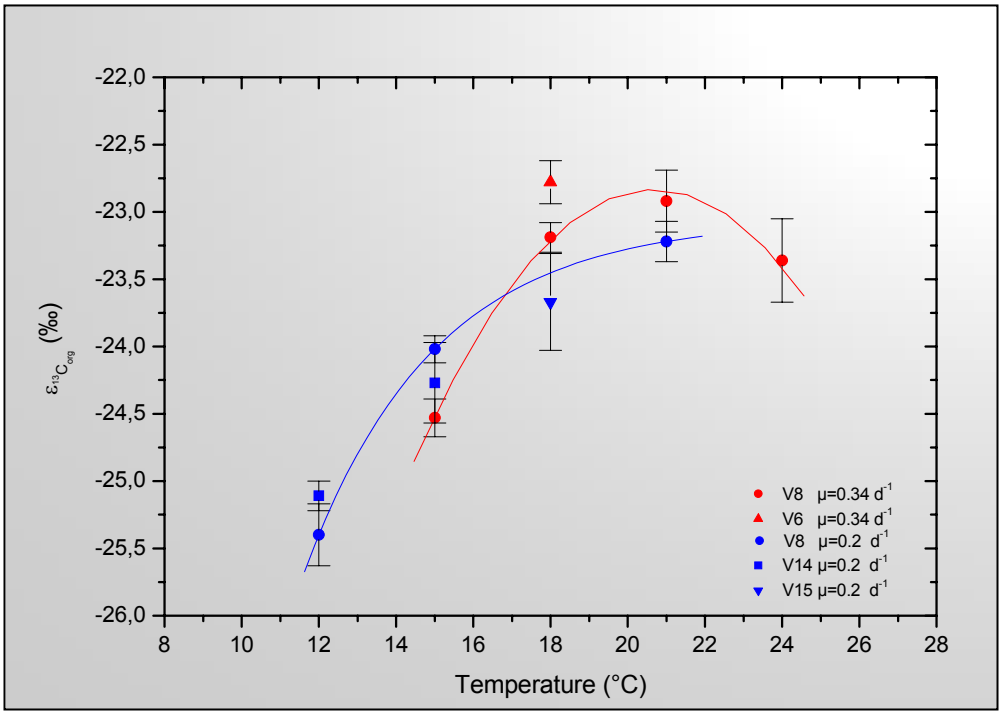


Figure 28: The carbon isotope discrimination of *Cyclotella meneghiniana* grown at various growth rates and temperatures. Algae were grown under continuous light conditions at a light intensity of 500 µmol photons $m^{-2}s^{-1}$.

Figure 28 shows that not only the temperature influenced the carbon isotope ratio, but also the growth rate. If the growth rates are considered separately, there is a significant increase in the discrimination with decreasing temperature. An increase in discrimination against ^{13}C was observed for µ=0.2 d^{-1} from 21°C to 12°C. For µ=0.34 d^{-1} an increase was measured from 21°C to 15°C, and in the range of 19°C to 21°C the increase in discrimination was marginal. A further temperature increase from 21°C to 24°C (at µ=0.34 d^{-1}) resulted in a reversal of the fractionation trend and the $\delta^{13}C$ values became more negative again.

The concentration of dissolved CO_2 is inversely correlated with temperature. Thus, as this study shows, at lower temperatures the carbon isotope fractionation increases due to greater availability of carbon as CO_2 (e.g. Degens et al. 1968). Similar effects, i.e. increase of the fractionation, are also observed in slower growing phytoplankton cells. Korb et al. (1996) in their study on two different diatom species found that mean $\delta^{13}C$ values became slightly more negative with decreasing growth rate. Although in the present study the $\delta^{13}C$ values of the organic matter of two different growth rates originate from one diatom species the results show, that slower growing cells have more negative isotope values than cells growing faster. However, this does not apply for all temperatures tested and, therefore, the results are more complex than implied by Korb et al. (1996).

4.3.4 Changes of temperature, growth rate and nitrogen isotope fractionation in Cyclotella meneghiniana

In nature not only temperature affects phytoplankton growth but also growth rate is influencing the metabolic rate. Therefore, it is also possible that the nitrogen isotope fractionation during nitrate assimilation will be affected by it. In order to examine the effect of growth rate and temperature, the dry mass of *Cyclotella meneg*hiniana was studied for its nitrogen isotope composition. Results of this investigation are presented in Figure 29 and in Tables 7 and 8. The $\delta^{15}N$ values for the higher growth rate show a linear increase of the discrimination with increasing temperature. The values varied between -0.26‰ at 15°C and -0.66‰ at 24°C. On the basis of errors the changes are significant. The nitrogen isotope ratio from a repetition test is about 0.1‰ more positive than the ratio from the main experiment. The temperature coefficient for the temperature range 15-24°C was 0.04‰/°C. In contrast to the results for the higher growth rate, the stable nitrogen isotope ratios obtained at the lower growth rate show no differences with increasing temperature. Only the values from the temperature test at 18°C are about 0.4‰ more negative than those from the main experiment (see blue points in Figure 29). However, the scatter is large and by considering the whole temperature interval an increase in discrimination could also be deduced for μ=0.2 d^{-1}. If the discrimination will be compared with the productivity (see Figure 25 in Chapter 4.3.1) an increase of the discrimination by faster growing diatoms can be identified with an increase of the productivity. Almost constant productivity is seen for slower growing diatoms.

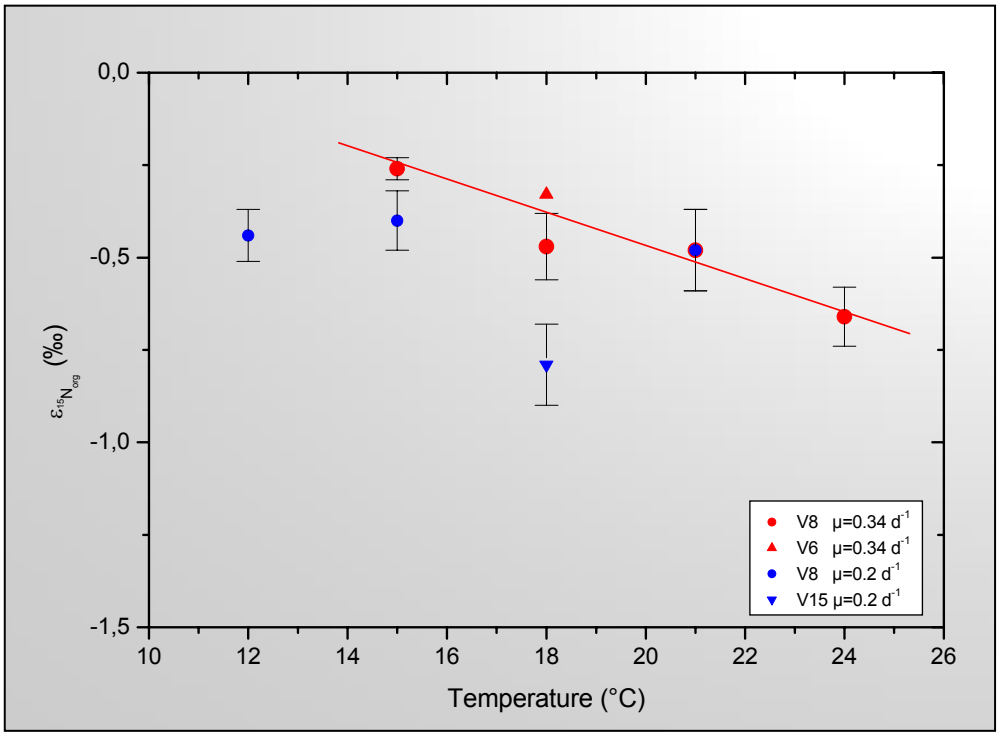


Figure 29: Nitrogen isotope discrimination of *Cyclotella meneghiniana* versus temperature and growth rate. Culture was grown under continuous light conditions at a light intensity of 500 µmol photons $m^{-2}s^{-1}$.

Montoya (1990) reported that none of the species investigated in his study showed significant variations in fractionation as a function of growth rate. Moreover, the fractionation associated with nitrate reduction will not be observable if all of the nitrate transported into the cell is assimilated. No differences in the fractionation by slower growing diatoms in this study could arise as a consequence of the utilization of almost all of the nitrate available for diatoms (see Tables 7 and 8). Another possibility might be that fractionation during nitrate uptake will be lower in well mixed cultures (as in this study), than in unstirred cultures (Wada & Hattori 1978).

4.4 Effect of light intensity on growth of Cyclotella meneghiniana

Planktonic diatoms are the dominant group of phytoplankton which have to cope with large fluctuations of light intensity as well as periodic exposures to extreme light conditions. Light quality and intensity play a very important role in phytoplankton growth, thus, affecting its metabolism. Photosynthetic apparatus converts the light energy into chemical energy that is used during CO_2 fixation. Fluctuations of the light intensity have an influence on photosynthesis and, thus, also for CO_2 assimilation. Generally, the photosynthetic rate rises with increasing light intensity. If the tolerance limit of an organism is exceeded light intensity becomes damaging.

Because the light intensity influences the metabolism of diatom cells, it is also possible that the silicon metabolism will be affected by it, and as a consequence the diatom valve morphogenesis, which is important for interpretation of stable oxygen isotope values of biogenic silica. In previous studies of the oxygen isotope composition of biogenic silica no attention was paid to possible fractionation mechanisms induced by varying light intensities. Only the temperature dependency of this process was taken into consideration. Therefore, diatom growth in continuous light was tested for various light intensities such as: 200, 500, 1100 and 1700 µmol photons $m^{-2}s^{-1}$. This range of light intensities was chosen for the experiments because they are normally experienced in nature (see Table 17 in Chapter 4.6.5) During these experiments the diatoms were grown at a temperature of 18°C and the growth rate was fixed at $\mu=0.2\ d^{-1}$. Results of the experiments are presented in Table 10.

Table 10: Results of steady state culture experiment Nr 15, using *Cyclotella meneghiniana.* The culture was run for different light intensities.
a) - mean value; b) - standard deviation; c) - (minimum/maximum); d) – number of determinations
a, b, c, d – are related to all table values; susp. = suspension

Temp. (°C)	**Growth rate** μ (d^{-1})	**Light intensity** (µmol photons $m^{-2}s^{-1}$)	**Extinction of the suspension at** 560nm	**Dry mass** (mg l^{-1})	**Productivity** (mg $l^{-1}d^{-1}$)	ε_{13C} (‰)	ε_{15N} (‰)	Ca^{2+} **susp.** (mg l^{-1})	Fe^{2+} **susp.** (mg l^{-1})	K^{+} **susp.** (mg l^{-1})	Mg^{2+} **susp.** (mg l^{-1})	Si^{2+} **susp.** (mg l^{-1})	NO_3^{2-} **susp.** (mg l^{-1})	PO_4^{3-} **susp.** (mg l^{-1})	SO_4^{2-} **susp.** (mg l^{-1})
18	0.20	200	**0.824** a) **0.01** b) (0.807 / 0.842) c) n=15 d)	**364.30** **15.60** (327.1 / 392.9) n=13	**72.9** **3.12** (65.42 / 78.58) n=13	**-24.03** **0.17** (-23.7 / -24.29) n=16	**-0.77** **0.15** (-1.04/-0.41) n=13	**18.50** **0.40** (17.9 – 19) n=5	**5.90** **0.50** (5.3 / 6.8) n=5	**6.50** **0.17** (6.4 / 6.8) n=5	**2.2** **0.08** (2.1 / 2.3) n=5	**1.00** **0.24** (0.8 / 1.4) n=5	**0.4** **0.72** (0.03 / 1.68) n=5	**>0.05** **0.00** (0.05) n=5	**17.8** **0.70** (17.2 / 18.9) n=5
18	0.20	500	**0.743** **0.01** (0.719 / 0.765) n=16	**356.30** **25.50** (303.3 / 392.7) n=10	**71.3** **5.10** (60.66 / 78.54) n=10	**-23.72** **0.29** (-23.32 / -24.31) n=8	**-0.61** **0.12** (-0.8/-0.43) n=10	**17.30** **0.84** (16.2 / 18.9) n=8	**5.00** **0.60** (4.3 / 6.3) n=8	**5.00** **0.24** (4.6 / 5.3) n=8	**2.10** **0.14** (2 / 2.4) n=8	**0.90** **0.14** (0.7 / 1.1) n=8	**0.20** **0.20** (0.05 / 0.67) n=8	**>0.05** **0.00** (0.05) n=8	**20.60** **0.80** (19.7 / 21.7) n=8
18	0.20	1100	**0.650** **0.03** (0.575 / 0.686) n=25	**304.90** **11.70** (273.1 / 324.8) n=20	**61.0** **2.62** (54.62 / 64.96) n=20	**-24.15** **0.21** (-23.78 / -24.44) n=20	**-0.79** **0.15** (-1.02/-0.49) n=15	**18.80** **0.81** (17.6 / 20.3) n=11	**7.30** **0.90** (6.4 / 9.4) n=11	**5.00** **0.56** (4.5 / 5.9) n=11	**2.80** **0.22** (2.4 / 3.2) n=11	**3.70** **2.30** (2 / 8.3) n=11	**4.10** **3.12** (1.39 / 10.09) n=11	**1.00** **0.31** (0.48 / 1.74) n=11	**23.90** **1.4** (21.7 / 26.2) n=11
18	0.20	1700	**0.518** **0.01** (0.494 / 0.533) n=13	**226.30** **13.10** (206.7 / 241.3) n=10	**45.3** **2.34** (41.34 / 48.26) n=10	**-24.13** **0.21** (-23.88 / -24.49) n=10	**-0.62** **0.10** (-0.74/-0.39) n=11	**17.60** **1.04** (16.7 / 19.4) n=6	**6.30** **0.30** (5.9 / 6.7) n=6	**6.27** **0.62** (5.8 / 7.5) n=6	**2.45** **0.45** (2.1 / 3.3) n=6	**1.50** **0.06** (1.4 / 1.6) n=6	**0.50** **0.45** (0.04 / 1.25) n=6	**>0.05** **0.00** (0.05) n=6	**25.10** **3.14** (22.2 / 25.5) n=6

4.4.1 Productivity of Cyclotella meneghiniana grown at various light intensities

As outlined earlier the light intensities used in these experiments affected the productivity of *Cyclotella meneghiniana.* In the illumination unit, constructed for this experiment, the lowest light intensity possible to apply was 200 µmol photons $m^{-2}s^{-1}$. The actual intensity in the suspension will be lower since the penetration of light through the vessel walls into the suspension will lead to an absorption which decreases the light intensity. This does not mean that the intensity of 200 µmol photons $m^{-2}s^{-1}$ was an optimal supply for diatoms. Increase of the light intensity resulted in a decline of the productivity with a maximum of 72.9 mg $l^{-1}d^{-1}$ at 200 µmol photons $m^{-2}s^{-1}$ (see Figure 30). Rise of the intensity to 500 µmol photons $m^{-2}s^{-1}$ resulted in a 2% drop of the productivity. Statistically there was no difference in productivity between both light intensities (see error bars on Figure 30). Therefore, it may well be that along these light intensities the productivity is in an optimal range. At light intensities of 1100 and 1700 µmol photons $m^{-2}s^{-1}$ presumably a photoinhibition occurred and the productivity diminished to circa 61 mg $l^{-1}d^{-1}$ and to 45 mg $l^{-1}d^{-1}$ respectively. According to Jørgensen (1969) the diatom *Cyclotella meneghiniana* shows an optimum of growth at 119-171 µmol photons $m^{-2}s^{-1}$ under natural conditions. The results of this experiment are in accordance with data of Jørgensen because this range may be experienced by the algae due to absorptive loss during light penetration into the suspension.

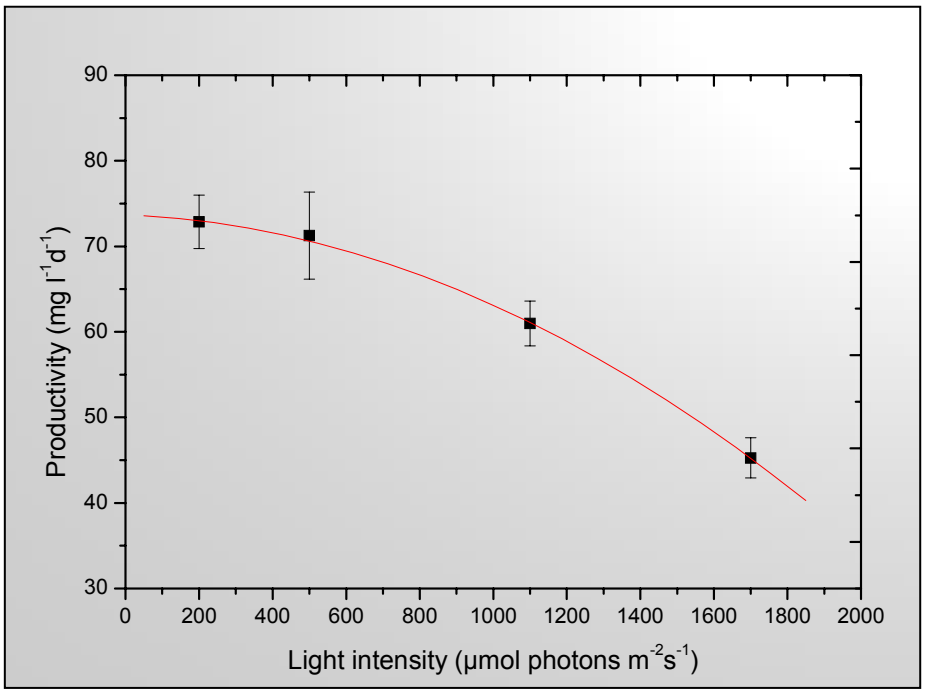


Figure 30: Productivity of *Cyclotella meneghiniana* grown under various light intensities. The growth temperature was 18°C. The growth rate was 0.2 d^{-1}. Culture was grown under continuous light conditions.

4.4.2 Light intensity, element composition and Si:C:N ratios

Light affects diatom growth in natural environments and physiological adaptations allow surviving in a variable light. These adaptations reflected in the metabolism of diatom cells can probably influence the oxygen isotope fractionation of diatom silica, which is of major importance for this study. Thus, in this experiment it was looked at the changes that occur under varying light intensities. Indeed *Cyclotella meneghiniana* exhibited physiological changes in response to varying light intensities. Element composition and Si:C:N ratios of dry mass are presented in Table 11. Dry mass samples of *Cyclotella* selected for particular light intensities have an almost identical element composition (see Table 11).

Table 11: Element composition of selected samples from *Cyclotella meneghiniana* dry mass accumulated during steady state conditions of experiment 15. Diatoms were grown at different light intensities at a temperature of 18°C and a fixed growth rate of 0.2 d^{-1}.
Si/P, C/P, N/P – are Si, N, C concentrations divided by the productivity.

Temp, (°C)	Growth rate μ (d^{-1})	* Light intensity	Sample	Dry mass (mg l^{-1})	Productivity P (mg $l^{-1}d^{-1}$)	Si (wt-%)	Si (mg $l^{-1}d^{-1}$)	Si/P	C (wt-%)	C (mg $l^{-1}d^{-1}$)	C/P	N (wt-%)	N (mg $l^{-1}d^{-1}$)	N/P	C/N	Si/C	Si/N
18	0.2	200	V15 D103	365.0	73.0	9.5	6.94	0.10	39.5	28.84	0.40	3.1	2.26	0.031	12.8	0.2	3.1
			V15 D105	367.4	73.5	9.7	7.12	0.10	39.2	28.80	0.39	3.0	2.20	0.030	13.1	0.2	3.2
			V15 D107	356.6	71.3	9.9	7.06	0.10	39.6	28.24	0.40	3.0	2.14	0.030	13.2	0.3	3.3
18	0.2	500	V15 D15	362.0	72.4	10.4	7.52	0.10	38.1	27.58	0.38	2.6	1.88	0.026	14.7	0.3	4.0
			V15 D17	334.1	66.8	11.7	7.82	0.12	37.4	25.00	0.37	2.7	1.80	0.027	13.9	0.3	4.3
18	0.2	1100	V15 D53	291.4	58.3	11.9	6.94	0.12	34.1	19.88	0.34	3.2	1.86	0.032	10.7	0.3	3.7
			V15 D55	317.9	63.6	12.5	7.94	0.12	33.0	20.98	0.33	3.1	1.98	0.031	10.6	0.4	4.0
			V15 D57	311.3	62.3	12.5	7.78	0.12	32.8	20.42	0.33	3.1	1.94	0.031	10.5	0.4	4.0
18	0.2	1700	V15 D71	231.2	46.2	15.7	7.26	0.16	29.2	13.50	0.29	4.2	1.94	0.042	7.0	0.5	3.7
			V15 D74	234.4	46.9	14.5	6.80	0.15	30.6	14.34	0.31	4.2	1.96	0.042	7.3	0.5	3.5
			V15 D76	206.7	41.3	15.6	6.44	0.16	29.6	12.24	0.30	4.4	1.82	0.044	6.7	0.5	3.5

*- Light intensity in μmol photons $m^{-2}s^{-1}$

Nitrogen content of the *Cyclotella* dry mass relative to productivity amounted 0.030 at a light intensity of 200 μmol photons $m^{-2}s^{-1}$. Increasing the light intensity to 500 μmol photons $m^{-2}s^{-1}$ resulted in a decrease of the nitrogen content relative to productivity to 0.026 (see Figure 31). Between the light intensities of 500 and 1700 μmol photons $m^{-2}s^{-1}$ the nitrogen concentration relative to productivity rose strongly. At an intensity of 1100 μmol photons $m^{-2}s^{-1}$ the nitrogen content was 0.031 and at the intensity of 1700 μmol photons $m^{-2}s^{-1}$ the corresponding value amounted to 0.044.

The light intensity has an influence on the photosynthetic apparatus and its efficiency, and therefore plays an important role in carbon fixation. The carbon content relative to the productivity was a linear function of the light intensity and decreased with increasing light intensity (R^2=-0.998). The highest carbon content relative to productivity was 0.4 and the lowest content was 0.29 (see Table 11 and Figure 31).

The light intensities of 1100 and 1700 µmol photons $m^{-2}s^{-1}$ caused a physiological stress for diatom cells. To survive such an increase in light intensity, phytoplankton develops photoprotective mechanisms (Niyogi, 1999).

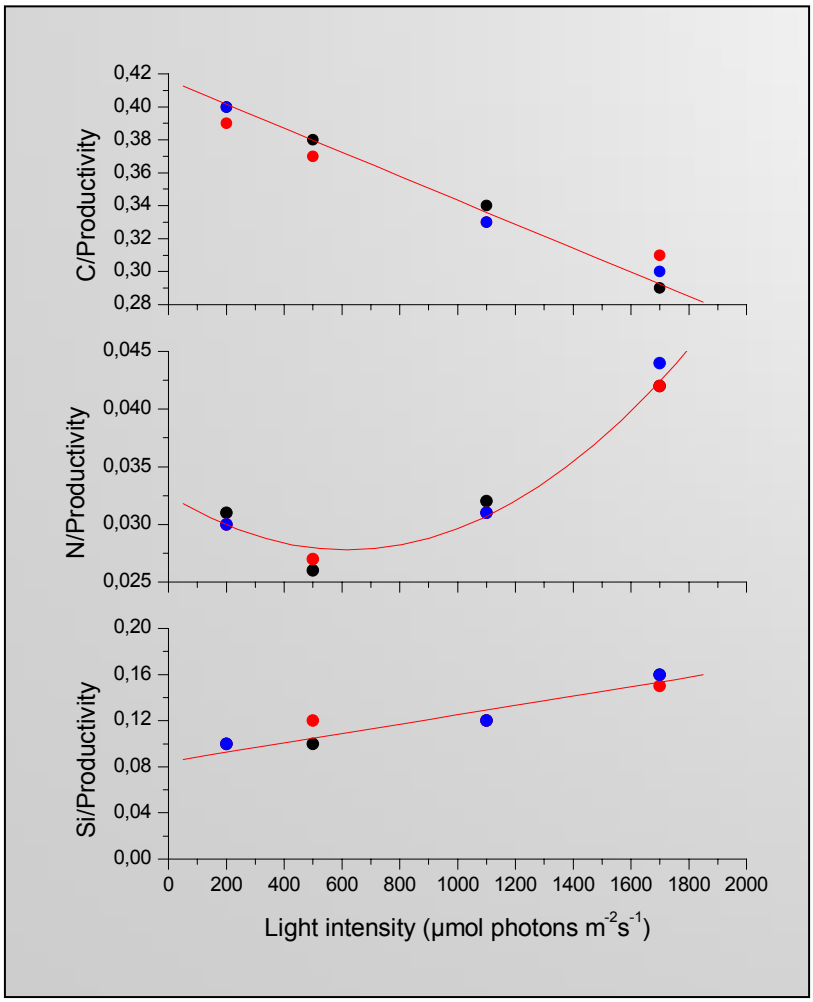


Figure 31: The C,N and Si content of *Cyclotella* dry mass relative to productivity as a function of the light intensity. Culture was grown under continuous light conditions.

Common acclimation response to excess light is an increase of the capacity of photosynthetic electron transport and CO_2 fixation, as well as a decrease in the size of the light-harvesting system. In this study, *Cyclotella* responded to high light intensities by reducing the photosynthetic pigment content and chloroplast volume. In that situation a dissipation of overdose of photons and electrons was necessary to protect the photosynthetic apparatus from light-induced damage (Niyogi 2000; Rosen & Lowe 1984). Such photoadaptive response served to maximize the ability of the algal cells to survive under non optimal light intensity.

Silicon concentration relative to productivity was a linear function of the light intensity (R^2=0.957). The silicon content related to the productivity rose with increasing light intensity from 0.1 to 0.16. It is interesting to note, that Claquin and Martin-Jézéquel (2002) found that the Si content of the cells is uncoupled from the other cellular elements. The physiological patterns observed in their study demonstrate that the mechanisms regulating silicon assimilation are different from those controlling assimilation of nitrogen and carbon.

The Si:C:N ratio of diatoms can be affected by environmental variables (e.g. light, temperature, nutrient concentration) (e.g. Brzezinski, 1985). Additionally, literature data suggest that the net effect of photoperiod on the Si:C:N composition over diurnal periods may be small (Brzezinski 1985). The mean ratios obtained by Brzezinski (1985) under continuous light were not distinguishable from those under the light-dark cycle. Variations of Si:C:N molar ratios due to influences of different light intensities are presented in Figure 32.

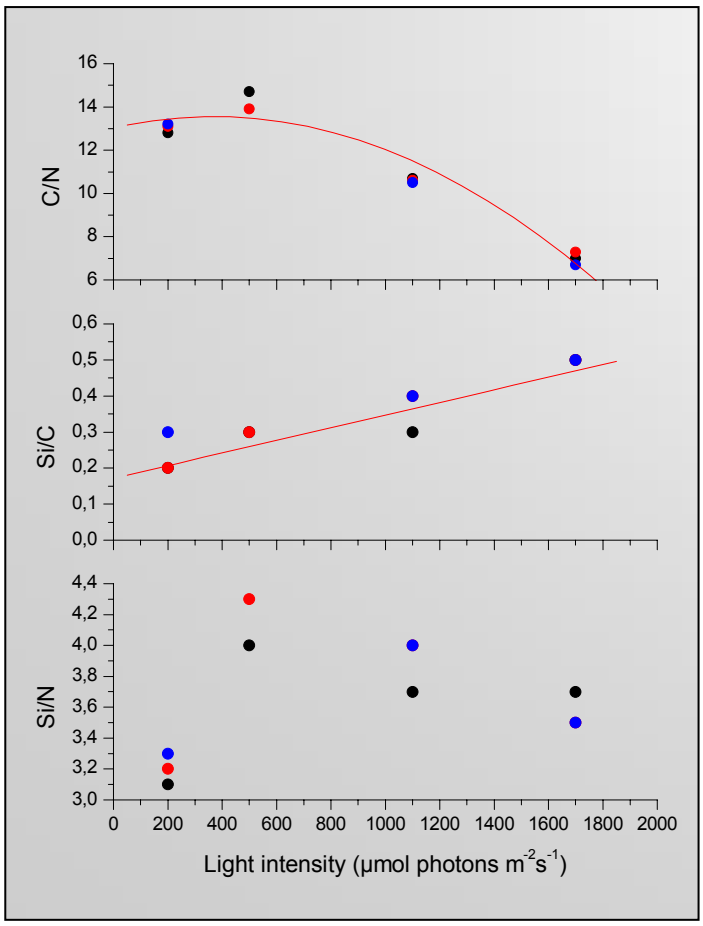


Figure 32: The Si:C:N ratios of *Cyclotella meneghiniana* dry mass versus the light intensity. The growth temperature was 18°C; the growth rate was 0.2 d^{-1}. Culture was grown under continuous light conditions.

The C/N ratio at a light intensity of 200 µmol photons $m^{-2}s^{-1}$ varied between 12.8 and 13.2. An increase of the light intensity to 500 µmol photons $m^{-2}s^{-1}$ resulted in a rise of the C/N ratio to values between 13.9 and 14.7. Further increase of the light intensity to 1100 and then to 1700 µmol photons $m^{-2}s^{-1}$ resulted in a significant decrease of the C/N ratio. At an intensity of 1100 µmol photons $m^{-2}s^{-1}$ the ratio was 10.5 – 10.7 and at 1700 µmol photons $m^{-2}s^{-1}$ the ratio was 6.7 – 7.3. The C/N ratios obtained in this study are significantly higher than the ratios reported for phytoplankton by Redfield et al. (1963). Hecky et al. (1993), however, showed that freshwater systems have a much greater deviation from the Redfield ratio than marine systems.

The Si/C ratio of *Cyclotella* increased linearly from 0.2 at 200 µmol photons $m^{-2}s^{-1}$ to 0.5 at 1700 µmol photons $m^{-2}s^{-1}$. The rise was positively correlated with the light intensity (R^2=0.926).

The Si/N ratio was lowest at 200 µmol photons $m^{-2}s^{-1}$ and resulted in 3.1 to 3.3. The subsequent, increase of the light intensity to 500 µmol photons $m^{-2}s^{-1}$ resulted in a significant rise of the Si/N ratio leading to 4.0 - 4.3. Higher irradiances, namely 1100 and 1700 µmol photons $m^{-2}s^{-1}$, caused a decrease of the Si/N ratio. The values obtained at 1100 µmol photons $m^{-2}s^{-1}$ varied between 3.7 and 4.0 and for an intensity of 1700 µmol photons $m^{-2}s^{-1}$ the Si/N ratio was 3.5 - 3.7.

4.4.3 Light intensity and the carbon isotope fractionation during growth of Cyclotella meneghiniana

During photosynthesis carbon assimilation takes place, but the CO_2 availability in the water is most important for the carbon isotope fractionation in aquatic environment. Results of the carbon isotope analysis of *Cyclotella* grown under various light regimes are presented in Table 10 and in Figure 33. Figure 33 demonstrates that carbon isotope fractionation was not affected by various light intensities. The discrimination varied between -23.72‰ ± 0.29 and -24.15‰ ± 0.21. The suspension of the fermenter was continuously aerated with CO_2 providing constant supply of the $^{13}C/^{12}C$ ratio into the culture vessel. The growth temperature of 18°C and the pH of 6.7 were irrelevant (i.e. constant). Thus the diatoms had an unlimited carbon pool available for growth. In this study, however, various light intensities may have affected the photosynthetic apparatus and influenced carbon metabolism (see Figure 31), however, the carbon isotope discrimination was almost constant.

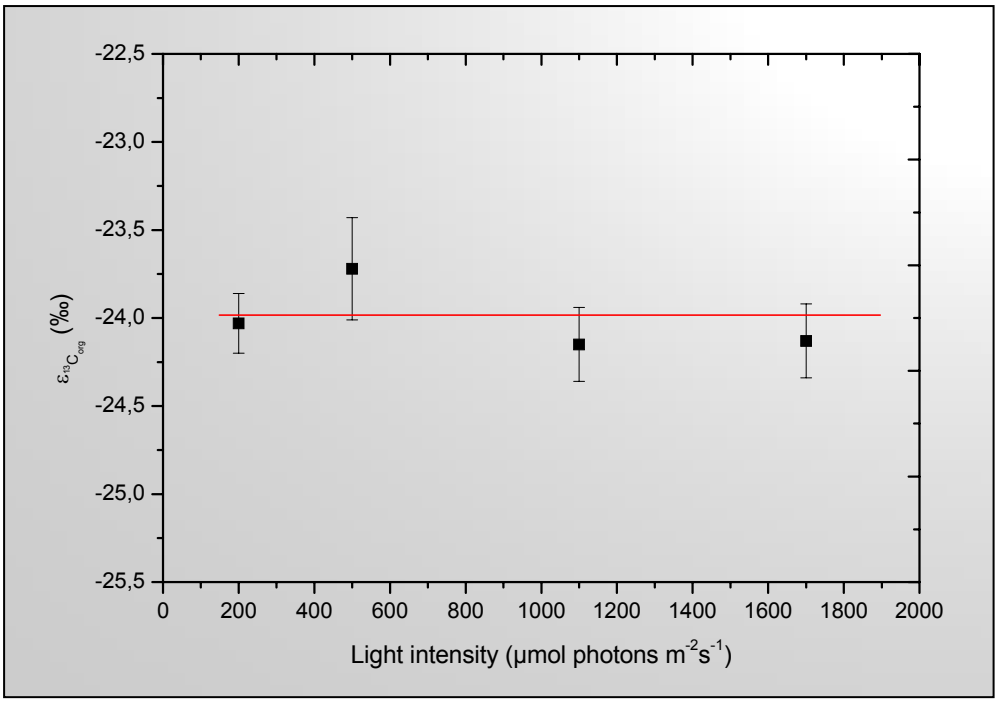


Figure 33: The carbon isotope discrimination of the *Cyclotella* grown under various light intensities. The growth temperature was 18°C; the growth rate was 0.34 d^{-1}. Culture was grown under continuous light conditions.

4.4.4 Light intensity and the nitrogen isotope fractionation during growth of Cyclotella meneghiniana

Nitrate reductase activity, an enzyme responsible for nitrate reduction, in natural populations of phytoplankton is higher at daytime than at night. Hattori (1962) reported that light invariably accelerates algal nitrate reduction. Additionally the nitrate uptake in continuous light is relatively constant (Needoba & Harrison 2004). Higher light intensities cause a larger flux of electrons through the photosynthetic electron transport system, thus elevated levels of electron donor are available for nitrate reduction.

The dry mass of *Cyclotella meneghiniana* grown under various light intensities was measured for its nitrogen isotope composition. Results of this investigation are presented in Figure 34 and Table 10. Nitrate concentration of the medium in this experiment was 52.5 mg/l and almost all of the nitrate was assimilated by the diatoms (see Table 10). This may be a reason for the fact that fractionation does hardly occur. As presented in Figure 34, varying light intensities had no influence on nitrogen isotope fractionation by *Cyclotella*. The fractionation varied between -0.79‰ ± 0.15 and -0.61‰ ± 0.12. Statistically all values are within the error margins. In this

experiment, the nitrate concentration available for diatom growth was responsible for the $\delta^{15}N$ values rather than the light intensity itself.

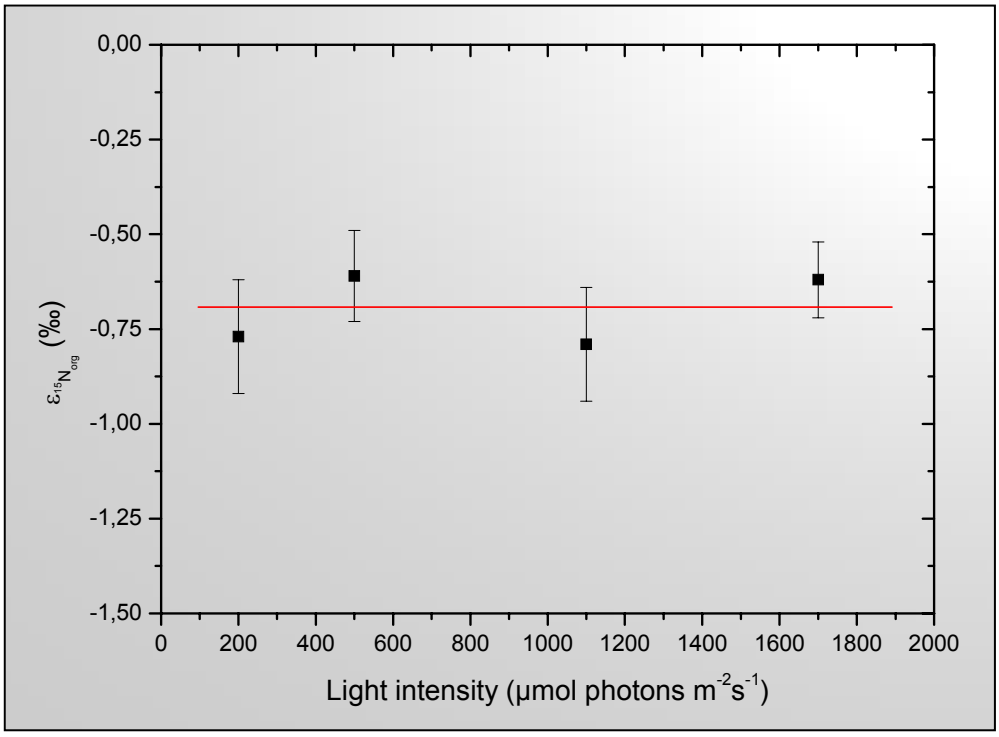


Figure 34: The nitrogen isotope discrimination of *Cyclotella* grown under various light intensities. The growth temperature was 18°C; the growth rate was 0.2 d^{-1}. Culture was grown under continuous light conditions.

4.5 The stable oxygen isotope values of the water from continuous cultures

The $\delta^{18}O$ values of lake water, which constitute the starting point for the oxygen isotope fractionation, are on the one hand controlled by interactions between lake water and external water supplies like rainfall and inflow of river waters. On the other hand, the water temperature is responsible for an evaporation effect and the air temperature for the rainfall effect. Precise information about the hydrological cycle constitutes a basic requirement for the interpretation of the stable oxygen isotope values.

The $\delta^{18}O$ of the lake water is often modified by the isotope ratio of the rain fall, but also by the balance of isotope ratios from all outflows and inflows. The evaporation plays also an important role, especially within small lakes, and is responsible for a seasonal variation in $\delta^{18}O$ of the water.

In experiments conducted during this study all aqueous components flowing into the fermenter system were controlled for their stable oxygen isotope composition. These

components were laboratory water used for preparation of the growth medium, the growth medium itself, and the suspension. Samples of the fermenter medium were taken each day directly from the fermenter. Results of analyses for each culture experiment are presented in Table 12.

Table 12: The $\delta^{18}O$ values of the laboratory water, freshly prepared medium and medium from the fermenter of the individual experiment; a) mean value; b) standard deviation; a, b are related to all table values; n- is the number of determinations

Experiment number	$\delta^{18}O$ VSMOW of the laboratory water (‰)	$\delta^{18}O$ VSMOW of the growth medium (‰)	$\delta^{18}O$ VSMOW of the medium from the fermenter (‰)
5	**-7.55** a) 0.10 b) n=15	**-7.43** 0.07 n=31	**-7.26** a) 0.21 b) n=61
6	**-7.78** 0.07 n=11	**-7.44** 0.05 n=24	**-7.5** 0.10 n=51
7	**-7.70** 0.16 n=29	**-7.50** 0.12 n=51	**-7.13** 0.07 n=78
8	**-7.64** 0.12 n=31	**-7.40** 0.10 n=60	**-7.28** 0.19 n=160
14	**-7.33** 0.06 n=26	**-7.70** 0.1 n=43	**-7.04** 0.28 n=278
15	**-7.59** 0.07 n=24	**-7.36** 0.07 n=46	**-7.14** 0.14 n=202

The standard deviation for each $\delta^{18}O$ value listed in Table 12 is within a metering precision. Most important for this study was stability of the $\delta^{18}O$ values of the suspension which constituted the starting point (the source value) for the stable isotope fractionation between the suspension and diatomaceous silica. In spite of the fact that $\delta^{18}O$ values of the suspension varied slightly between experiments, the $\delta^{18}O$ values of the suspension within particular experiments were kept constant, thus the source was constant. The particular values were used in the evaluation of the oxygen isotope ratios of biogenic silica.

As an example, Figure 35 presents the $\delta^{18}O$ values of the suspension derived from the experiment no. 15 with *Cyclotella meneghiniana*. A systematic change of the water isotope composition with time was not observed indicating that evaporation processes during experiments did not affect the isotope composition. The oxygen isotope composition of the suspension during the whole experiment varied within error margins.

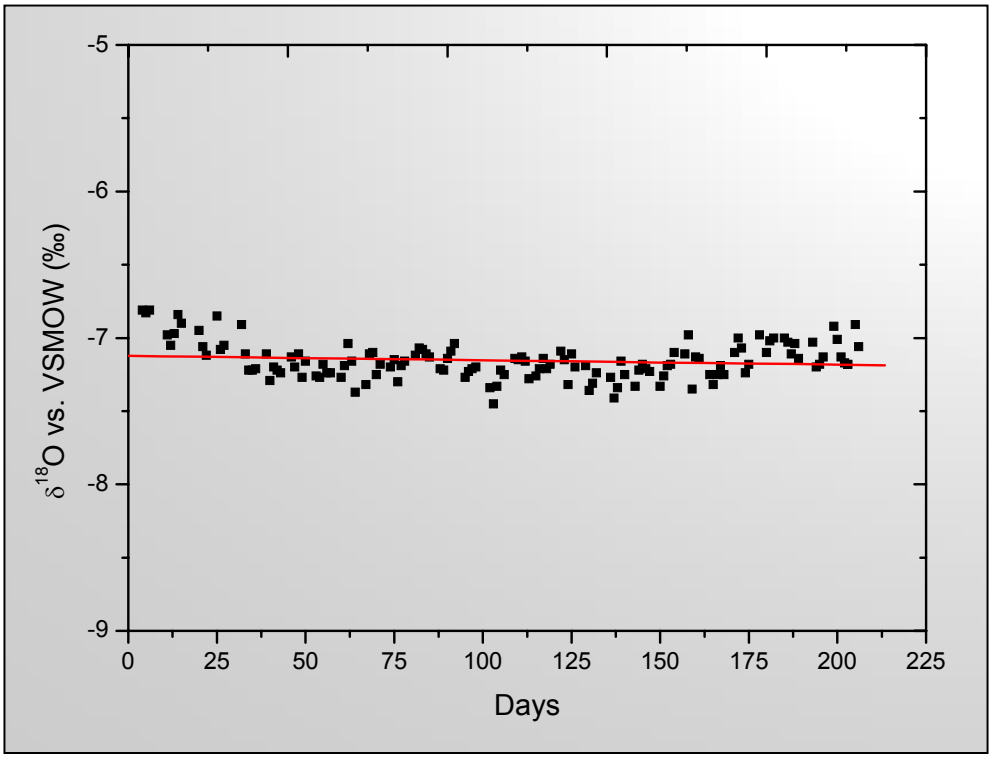


Figure 35: The $\delta^{18}O$ values of the medium from the fermenter derived from experiment Nr 15 with C*yclotella meneghiniana*. Culture was grown under continuous light conditions.

4.6 Stable oxygen isotope composition of biogenic silica from freshwater diatoms

Oxygen isotope ratios of biogenic silica originating from diatoms were used as palaeothermometer since a relationship between water temperature and the oxygen isotope fractionation in diatoms was proven by Labeyrie (1974). Although the potential of oxygen isotopes from biogenic silica is very promising as a proxy in palaeoclimate research, its application is still limited. On the one hand, there exists no clear answer regarding the exact temperature dependence of the oxygen isotope fractionation during formation of biogenic silica. On the other hand, there are still analytical problems concerning the preparation of biogenic silica for liberating the oxygen isotopes.

This study with continuous cultures of freshwater diatoms was initiated for providing a basis for understanding and interpreting oxygen isotope variations in natural diatom assemblages. Because influences of species specific metabolic responses during growth in various environments can not be excluded, the aim of this study was to test the growth of two single diatom species for various temperatures, growth rates, light

intensities and nutrient concentrations. These tests should answer the question of whether or not the oxygen isotope ratio in diatoms is only dependent on water temperature or whether other parameters are also involved in influencing the oxygen isotope signature.

4.6.1 The reproducibility of the stable oxygen isotope ratios of samples taken during steady state conditions from the fermenter

To be able to make use of the stable isotope data derived from continuous culture experiments, the constancy of growth conditions was of major importance. In order to examine the information stored in diatoms in form of the stable oxygen isotope ratios nine samples of *Cyclotella meneghiniana* grown during steady state conditions in the fermenter were chosen for inspection. The results of this test are presented in Table 13. As Table 13 shows the oxygen isotope ratios were reproducible during steady state conditions of the fermenter system and only one of the $\delta^{18}O$ values has to be considered as an outlier. The standard deviation for the nine diatom samples was ±0.27‰. Under such circumstances the culture method chosen in this study was suitable for calibration of the diatom palaeothermometer.

Table 13: The reproducibility of the $\delta^{18}O$ values of biogenic silica from samples of *Cyclotella meneghiniana* taken during steady state conditions from the fermenter system. The culture was grown under continuous light conditions at a light intensity of 500 µmol photons $m^{-}s^{-1}$. The growth rate was 0.34 d^{-1}.

Temperature (°C)	Sample	$\delta^{18}O$ vs. SMOW (‰)	n	Mean value ‰
21	V8/D54	**25.35** (25.46; 25.23)	2	**25,54** ± 0.27
	V8/D55	**25.51** ± 0.17	5	
	V8/D56	**25.36** ± 0.08	3	
	V8/D57	**25.25** ± 0.21	3	
	V8/D58	**25.66** ± 0.08	3	
	V8/D59	**26.15** (26.1; 25.6)	2	
	V8/D60	**25.40** ± 0.13	3	
	V8/D61	**25.45** (25.32; 25.58)	2	
	V8/D62	**25.71** ± 0.19	5	

4.6.2 Nitrate availability and stable oxygen isotope ratios of biogenic silica from Fragilaria crotonensis

In order to examine a possible influence of the nutrient concentration on the stable oxygen isotope fractionation during morphogenesis of diatom valves, the growth of *Fragilaria crotonensis* was analyzed with respect to various nitrate concentrations.

During this experiment the diatoms were grown at a temperature of 24°C under permanent light conditions. Results of the investigations are presented in Table 14. Forsberg & Ryding (1980) developed criteria for classifying lakes into various trophic states. With regard to nitrogen concentration of the lake water they classified the lakes as follows: oligotrophic - < 40 mg/l N; mesotrophic – between 40 and 60 mg/l N; eutrophic – between 60 and 150 mg/l N.

The nitrate concentrations used for diatom growth in this experiment refer to the classification of Forsberg & Ryding (1980). From Table 14 it follows, that various concentrations of nitrate had no influence on the oxygen isotope discrimination during the development of diatom valves. The good repeatability of the $\delta^{18}O$ values for particular diatom samples selected for the analyses confirms the stable growth conditions.

Table 14: Stable oxygen isotope ratios of biogenic silica from experiment Nr 5 with *Fragilaria crotonensis* grown for various nitrate concentrations of the medium. The growth temperature was 24°C. Culture was grown under continuous light conditions at a light intensity of 500 µmol photons $m^{-}s^{-1}$.

Nitrate concentration of the medium (mg/l)	Sample	$\delta^{18}O_{SiO2}$ vs. V-SMOW (‰)	n
10.5 oligotrophic	V5/D3	**25.98** (26.18; 25.78)	2
	V5/D4	**26.09** (26.24; 25.94)	2
	V5/D5	**25.52** (25.67; 25.37)	2
	V5/D6	**26.08** ± 0.1	3
21 oligotrophic	V5/D10	**25.8** ± 0.1	3
	V5/D11	**26.21** ± 0.1	3
	V5/D12	**26.32** (26.32; 26.32)	2
	V5/D13	**25.85** (25.75; 25.45)	2
52.5 mesotrophic	V5/D22	**26.51** (26.56; 26.46)	2
	V5/D23	**26.45** (25.55; 25.35)	2
	V5/D25	**26.15** ± 0.16	4
105 eutrophic	V5/D28	**25.63** ± 0.1	3
	V5/D30	**25.75** ± 0.1	3

For nitrate concentrations between 10.5 – 105 mg/l the $\delta^{18}O_{SiO2}$ values are comparable. The $\delta^{18}O_{SiO2}$ values in Table 14 refer to the classification of lakes by Forsberg & Ryding (1980) and suggest that biogenic silica from diatoms growing in waters with different concentrations of nitrate but at the same temperature should be characterized by the same fractionation.

4.6.3 Temperature and stable oxygen isotope ratios of biogenic silica from Fragilaria crotonensis

In order to determine the influence of temperature on the oxygen isotope fractionation in biogenic opal, the growth of *Fragilaria crotonensis* was investigated for various temperatures. Results of this investigation are presented in Table 15. Table 15 shows that the oxygen isotope fractionation in biogenic silica from *Fragilaria crotonensis* was influenced by the temperature. The lowest $\delta^{18}O$ values were obtained at 24°C; whereas the highest values were noted for 15°C (see Table 15). The $\delta^{18}O$ values calculated for samples from particular temperature tests were well reproducible.

Table 15: Stable oxygen isotope ratios of biogenic silica from *Fragilaria crotonensis* grown for various temperatures. The growth rate was 0.34 d^{-1}; Culture was grown under continuous light conditions at a light intensity of 500 µmol photons $m^{-}s^{-1}$.

Temperature (°C)	Sample	$\delta^{18}O_{SiO2}$ vs. V-SMOW (‰)	n
15	V7/D31	**28.54**)	3
	V7/D34	**28.71** (28.84; 28.57)	2
18	V5/D40	**26.76** (26.83; 26.68)	2
	V5/D41	**26.71** ± 0.15	5
21	V7/D12	**26.42** ± 0.15	3
24	V5/D28	**25.63** ± 0.05	3
	V5/D30	**25.75** ± 0.23	3

4.6.4 Temperature, growth rate effects and stable oxygen isotope ratios of biogenic silica from Cyclotella meneghiniana

In aquatic environments various diatom species grow with different growth rates. Because it is not clear if the growth rate plays a role in the oxygen isotope fractionation of biogenic silica, this study was initiated to test the growth of *Cyclotella meneghiniana* with respect to various temperatures at two fixed growth rates. Results of this investigation are presented in Table16.

Generally the results obtained in this study suggest that diatoms growing in natural environment at different growth rates but at the same temperature have to be characterised by dissimilar $\delta^{18}O$ values. This finding can play a decisive role in the interpretation of the $\delta^{18}O$ values of biogenic opal derived from natural environment. For the lower growth rate the highest $\delta^{18}O$ values were noted at a temperature of 9°C, and the lowest for a temperature of 18°C (see Table 16). Increase of the temperature to 21°C caused, however, again an increase of the $\delta^{18}O$ values. For the

higher growth rate the highest $\delta^{18}O$ values were observed at a temperature of 15°C and the lowest at 21°C (see Table 16). An increase of the temperature to 24°C resulted in higher $\delta^{18}O$ values than at a temperature of 21°C (see Table 16). The $\delta^{18}O$ values for particular samples were well reproducible. Only three samples had a standard deviation higher than ±0.25‰.

Table 16: Stable oxygen isotope ratios of biogenic silica from *Cyclotella meneghiniana* grown for temperatures at two growth rates. Culture was grown under continuous light conditions at a light intensity of 500 µmol photons $m^{-}s^{-1}$.

Growth rate µ (d^{-1})	Temperature (°C)	Sample	$\delta^{18}O_{SiO2}$ vs. V-SMOW (‰)	n
	9	V14/D82	**28.41**± 0.02	3
		V14/D91	**28.66** (28.42; 28.89)	2
		V8/D89	**26.89** ± 0.16	3
		V8/D90	**27.24** (27.46; 27.01)	2
0.2	12	V8/D91	**27.56**	1
		V8/D92	**27.78** ± 0.17	4
.		V14/D55	**27.11** ± 0.35	3
		V8/D80	**26.35** ± 0.13	4
		V8/D81	**26.33** ± 0.11	5
0.2	15	V8/D82	**26.58** ± 0.12	3
		V8/D83	**26.77** ± 0.34	4
		V14/D29	**26.51** ± 0.14	5
		V14/D31	**26.73** ± 0.14	4
		V15/D14	**25.79** (25.79; 25.58)	2
0.2	18	V15/D15	**25.86** ± 0.2	3
		V15/D16	**25.82** ± 0.23	3
		V15/D17	**25.95** ± 0.19	4
		V8/D67	**26.73** ± 0.09	3
0.2	21	V8/D68	**26.83** (26.96; 26.7)	2
		V8/D69	**26.09** (26.25; 25.92)	2
		V8/D71	**26.46** ± 0.39	3
		V8/D35	**26.61** ± 0.08	3
		V8/D36	**26.81** ± 0.07	4
0.34	15	V8/D37	**26.59** ± 0.13	5
		V8/D39	**28.61** ± 0.05	3
		V8/D19	**26.5** ± 0.22	3
		V8/D22	**26.24** ± 0.17	3
0.34	18	V8/D23	**26.33** ± 0.05	5
		V6/D11	**26.2** (26.15; 26.25)	2
		V6/D14	**26.38** ± 0.12	5
		V8/D54	**25.35** (25.46; 25.23)	2
		V8/D55	**25.51** ± 0.17	5
		V8/D56	**25.36** ± 0.08	3
		V8/D57	**25.25** ± 0.21	3
0.34	21	V8/D58	**25.66** ± 0.08	3
		V8/D59	**26.15** (26.1; 25.6)	2
		V8/D60	**25.40** ± 0.13	3
		V8/D61	**25.45** (25.32; 25.58)	2
		V8/D62	**25.71** ± 0.19	5
0.34	24	V8/D7	**26.17** ± 0.12	3
		V8/D13	**26.24** (26.26; 26.21)	2

4.6.5 Light intensity and stable oxygen isotope ratios of biogenic silica from Cyclotella meneghiniana

So far the influence of varying light intensities on the oxygen isotope fractionation was not taken into consideration. Studies on the stable oxygen isotope composition of biogenic silica concentrated on the temperature dependency, the effect of light intensity was not examined. However, in the course of the year not only temperature changes, but also the light regime. There exists a possibility that the light intensity has an impact on the stable oxygen isotope fractionation of biogenic silica. Thus, this study was initiated to examine the diatom growth at various light intensities which commonly appear in lakes, also in Lake Holzmaar (see Table 17). Table 17 shows changes of the light intensity of Lake Holzmaar in 2003 for various depths. From Table 17 arises that light regimes are changing during a day, due to the actual weather conditions, but also throughout the year. Additionally, the quantity and quality of light available for photosynthetic organisms decreases with increasing water depth. During sunny days the photic zone reaches a depth of 7m, whereas during cloudy days sufficient light only extends to a depth of 2-3 m.

Table 17: Light intensity in Lake Holzmaar throughout the year 2003. Light intensity in µmol photons $m^{-2}s^{-1}$.

Depth (m)	11.03.03	09.04.03	24.04.03	06.05.03 *	17.06.03	15.07.03	26.08.03	09.09.03	07.10.03 *	21.10.03 *	03.11.03 *	17.11.03 *	01.12.03 *	16.12.03 *
Air	2016,0	1837,4	2900,0	207,5	2222,0	2327,0	1996,6	2615,0	494,4	616,0	415,0	185,0	468,0	215,2
0	1266,1	1180,9	1200,0	105,4	1550,9	1944,0	1327,1	968,0	250,0	236,0	238,0	90,5	91,1	130,4
0,5	824,6	786,8	900,0	83,4	1213,7	1440,0	806,0	610,0	162,3	172,0	129,0	52,5	58,5	72,4
1	442,3	558,6	820,0	68,2	941,7	848,0	435,6	370,0	136,5	128,0	72,0	41,2	38,9	50,4
1,5	222,2	411,0	400,0	67,1	638,3	676,5	225,9	240,0	78,2	89,0	48,0	24,5	28,4	36,5
2	122,7	299,2	250,0	61,0	552,2	414,1	125,9	140,0	46,8	64,0	32,0	13,4	25,1	25,6
2,5	64,1	207,8	215,0	48,7	424,6	294,4	76,2	92,0	38,3	47,0	19,0	8,4	20,0	17,6
3	40,8	144,5	202,0	51,6	299,6	186,8	41,7	57,0	21,6	34,0	11,0	5,6	15,2	12,0
3,5	24,8	107,5	250,0	42,9	238,3	137,8	25,8	38,0	17,8	25,0	7,0	3,4	13,7	8,3
4	14,1	81,6	225,0	33,1	178,0	93,9	15,2	25,0	12,4	19,0	5,0	2,2	10,2	5,9
4,5	8,7	60,4	190,0	31,5	143,7	64,5	8,5	16,0	8,3	14,0	3,0	1,4	7,2	4,0
5	5,2	45,5	157,0	26,1	115,8	41,5	4,7	9,0	7,1	-	2,0	0,9	5,1	2,8
5,5	3,1	34,2	118,0	15,7	88,6	17,7	2,1	4,5	5,4	-	1,0	0,6	3,7	1,9
6	1,9	25,3	70,0	5,3	53,4	8,2	1,1	2,0	3,8	-	1,0	0,4	2,6	1,4
6,5	1,2	11,2	19,0	1,1	26,3	3,5	0,7	1,1	1,5	-	-	0,2	1,9	1,0
7	0,7	3,9	3,0	0,3	5,5	1,6	-	0,7	0,7	-	-	0,2	1,4	0,7

* cloudy days
- non-existent

To simulate the natural conditions, it was necessary to choose a relatively broad range of light intensities beginning from optimal conditions for the growth of *Cyclotella* to supraoptimal conditions. The diatoms in this experiment grew at a temperature of 18°C under continuous light conditions. Results of these investigations are presented in Table 18. Table 18 shows clearly that the oxygen isotope fractionation during diatom valve formation was affected by the light intensity. The variation of the stable oxygen isotope ratios for the light intensity range of 200-1700 µmol photons $m^{-2}s^{-1}$

amounted to 0.8‰. The lowest $\delta^{18}O_{SiO2}$ value was obtained at an intensity of 200 µmol photons $m^{-2}s^{-1}$ showing 25.68‰, whereas the highest $\delta^{18}O_{SiO2}$ value of 26.44‰ was achieved at an intensity of 1700 µmol photons $m^{-2}s^{-1}$.

Table 18: Stable oxygen isotope ratios of biogenic silica from experiment Nr 15 with *Cyclotella meneghiniana* grown for various light intensities. The growth temperature was 18°C; Culture was grown under continuous light conditions.

Light intensity (µmol photons $m^{-2}s^{-1}$)	Sample	$\delta^{18}O_{SiO2}$ vs. V-SMOW (‰)	n	Mean value
200	V15/D104	**25.57** (25.57;25.56)	2	
	V15/D106	**25.79** ± 0.14	4	
	V15/D108	**25.67** ± 0.13	4	**25.68** ± 0.1
500	V15/D14	**25.79** (25.79; 25.58)	2	
	V15/D15	**25.86** ± 0.2	3	
	V15/D16	**25.82** ± 0.23	3	
	V15/D17	**25.95** ± 0.19	4	**25.86** ± 0.07
1100	V15/D54	**26.1** ± 0.15	5	
	V15/D56	**26.1** ± 0.07	3	
	V15/D58	**26.02** ± 0.18	3	**26.07** ± 0.05
1700	V15/D70	**26.55** ± 0.1	4	
	V15/D73	**26.38** ± 0.15	4	
	V15/D77	**26.39** ± 0.05	5	**26.44** ± 0.09

The $\delta^{18}O_{SiO2}$ values of the diatom samples chosen for the analysis from particular tests with the light intensity are in accordance with each other. This indicates that the growth conditions during separate tests were constant.

5. Discussion

After a short discussion of the problems concerning analytical precision of oxygen isotope measurements in diatomaceous silica and the approach applied in this work, the relationship of abiotic factors such as temperature, nitrate availability and light intensity on the fractionation, the relation between fractionation and growth rate and complexity of continuous cultures are presented.

5.1 Analytical precision

To be able to make use of information recorded in biogenic silica in form of the $\delta^{18}O$ values, a high analytical precision is needed because of its crucial role in calibration studies. Oxygen in diatomaceous silica is not only bound to atoms of silicon. It is also included in water (H_2O and OH-groups) up to 7 - 12% (Knauth 1973), which can be exchangeable and which is of different isotope composition as compared to the silica itself. Many analytical techniques have been used in the study of the oxygen isotope composition of the biogenic silica and all of them were encountered with the problem of preparation and separation of the contaminating compounds containing exchangeable oxygen. Removal of hydroxyl groups and molecular water was achieved in one of the methods (Labeyrie 1974, Wang and Yeh 1984, Brandriss et al. 1998) by dehydration of silica samples under vacuum and temperatures near 1000°C. Another technique (Thorleifson and Knauth 1984, Matheney and Knauth 1989) consisted in a stepwise fluorination, where in a series of steps the loosely bound oxygen was removed. A third technique (Labeyrie & Juillet 1982, Juillet-Leclerc & Labeyrie 1987) was a controlled isotope exchange (CIE) of oxygen to approach the original isotope compositions of loosely bound oxygen. All these time consuming techniques are hardly suitable for routine measurements. Therefore, in this study a newly developed method was used for preparation and determination of oxygen isotopes, namely an inductive high-temperature carbon reduction technique (iHTR) (Lücke et al. 2005), which assures good reproducibility of the oxygen isotope ratios of biogenic opal derived from diatoms independent of their origin. From the determined $\delta^{18}O$ values only four samples had a standard deviation higher than ±0.25‰, what makes the results credible. The oxygen isotope fractionation determined for particular samples ranged between 32 and 36‰ which is about 3-10‰ lower than the values measured for sediment samples by e.g. Juillet-Leclerc

and Labeyrie 1987 or Schmidt et al. 2001. Earlier studies on diatoms sampled from marine and lake water (Schmidt et al. 2001, Moschen et al. 2005) and from diatoms grown in batch cultures (Brandriss et al. 1998, Schmidt et al. 2001) resulted also in fractionations between 31 and 38‰. Brandriss et al. (1998) postulated that fractionation factors of living diatoms may be of low precision due to uncertainties in the amounts of exchangeable oxygen possibly due to deficiencies of the extraction methods. The method of extraction of the oxygen used in this study overcame the laboratory problems discussed in earlier studies confirming the lower fractionation factors in living diatoms. As a conclusion, the high fractionation must be a result of post-mortem changes of the isotopic composition of the diatom silica, e.g. partial dissolution or diagenesis.

5.2 Temperature dependent oxygen isotope fractionation

The oxygen isotope ratio of diatomaceous silica is temperature dependent because the isotope fractionation proceeds as an equilibrium reaction. Equilibrium isotope fractionation is directly related to the thermodynamics of the mineral precipitation reaction. The increase in vibrational, and other energy associated with increased temperature leads to a decrease in the isotope fractionation between water and the mineral that precipitates from it. Thus, it is possible to obtain a relationship between water temperature and the $\delta^{18}O_{SiO_2}$ value if the $\delta^{18}O_{H_2O}$ value of water is known. From the magnitude of change of the fractionation relative to the change of water temperature [$\Delta\varepsilon/\Delta T$] the so-called temperature coefficient [τ] is determined which is the subject of interest in studies on isotope geothermometry.

This is the first study with freshwater diatoms where the continuous culture method was applied. The results derived from these experiments demonstrated that the temperature signal was recorded for diatoms of *Fragilaria crotonensis* and of *Cyclotella meneghiniana* in form of oxygen isotope ratios (see Figure 36). The temperature coefficient for *Fragilaria crotonensis* calculated for the temperature range 15 – 24°C was -0.28‰/°C. The temperature coefficient for *Cyclotella meneghiniana* obtained at alower growth rate namely for the temperature range 9 - 18°C was -0.27 ‰/°C. At the higher growth rate, the temperature coefficient for the temperature range 15 - 21°C was -0.27‰/°C. The temperature coefficients presented above represent the main results of this study.

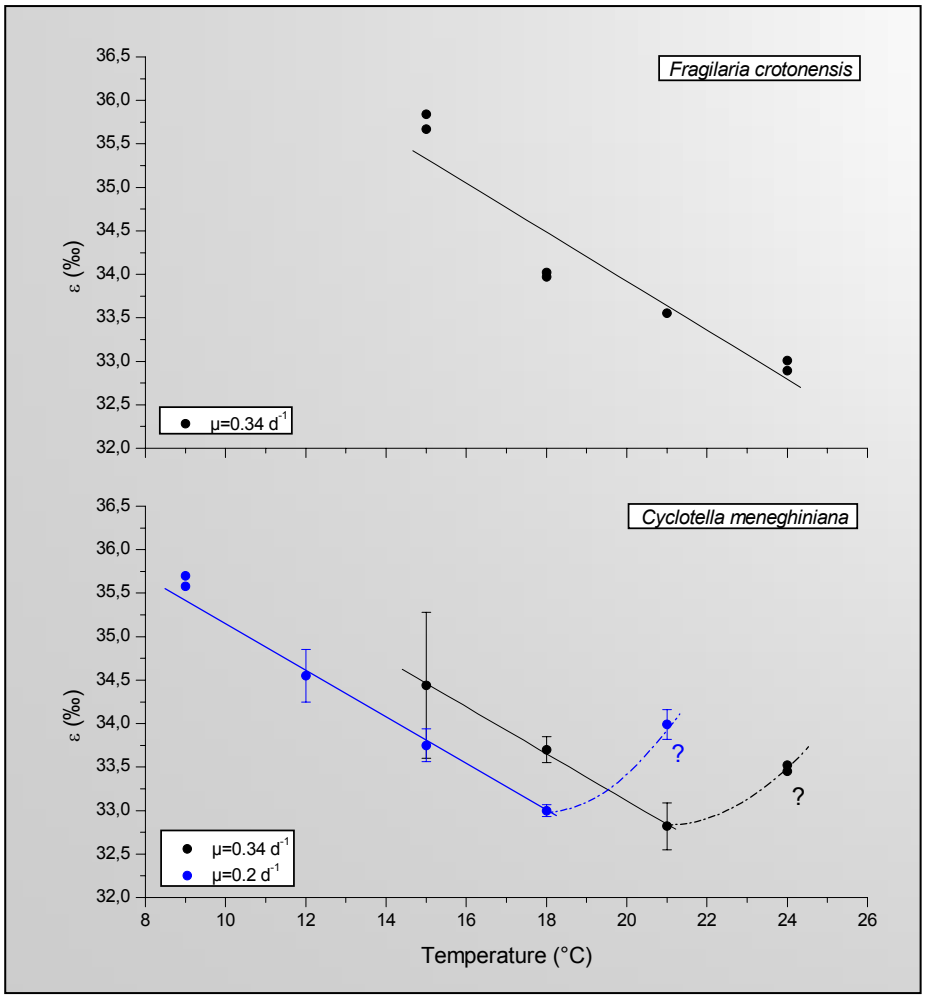


Figure 36: Temperature dependent oxygen isotope fractionation of diatomaceous silica from *Fragilaria crotonensis* and *Cyclotella meneghiniana*. Culture was grown under continuous light conditions at a light intensity of 500 µmol photons $m^{-}s^{-1}$.

Up to now, the temperature dependence of the oxygen isotope fractionation in diatomaceous silica was confirmed by five studies. Investigations of the temperature dependency of the oxygen isotope fractionation in biogenic opal were inaugurated by Labeyrie (1974) who first proposed a temperature coefficient of -0.25‰/°C. For the evaluation of the coefficient, the author used two recent samples of freshwater diatoms derived from the lakes Pavin (France) and Myvatn (Iceland), and one sample of marine diatoms from the Gulf of California.

A new temperature coefficient of -0.29‰/°C was later introduced by Juillet-Leclerc & Labeyrie (1987). This time, the calibration study was performed with sediment core samples taken from the Pacific Ocean, the Gulf of California and the Southern Pacific Ocean which contained diatom assemblages of various species. The water temperature used in their study was the mean of the local six summer months while the oxygen isotope composition of the water ($\delta^{18}O_{H_2O}$) was estimated.

The third calibration carried out by Matheney & Knauth (1989) comprised two diatom samples namely recent diatom ooze collected south of the Aleutian Trench and very clean diatomite from the Lompoc Quarry in the Miocene Formation of southern California. For the first sample, the water temperature was assumed to be that of surface waters of this area of about 7°C and, for the second sample, the surface temperature was assumed to be 15°C. Appropriate $\delta^{18}O$ values of the waters were assumed to be 0.0‰ and -0.9‰ respectively. The temperature coefficient evaluated by these authors was -0.49‰/°C which is considerably lower than those obtained in earlier studies. An error can not be excluded for these evaluations because the real water temperature and water isotope composition were not known.

The first controlled laboratory experiments with freshwater diatoms to be used as a calibration of the diatom palaeothermometer were performed by Brandriss et al. (1998). In their study, the temperature dependence of the oxygen isotope fractionation between diatomaceous silica and water was determined by analyzing diatom valves cultured at temperatures ranging from 3.6 to 20°C. Important was that, for the first time, the $\delta^{18}O$ values of the water could be determined and thus were known. According to the ten $\delta^{18}O$ values of biogenic silica obtained from these measurements, the authors calculated a temperature coefficient of about -0.2‰/°C which was distinctly smaller in terms of absolute values than the coefficients evaluated in earlier studies. In addition the fractionation values determined by Brandriss et al. (1998) were lower by about 3 - 10‰ as compared to fractionations measured for diatoms from sediment samples.

Recent work by Moschen et al. (2005) used planktonic diatoms sampled from the pelagial of a lake for calibration. He determined the temperature effect on the oxygen isotope fractionation between silica and water under ecosystem conditions. The study showed a relation between water temperature and fractionation for the temperature range between 4 to 22°C with respect to three size fractions of diatom valves. The separation of the frustules according to their size should give information about possible ‘species-specific effects’. Based on identical results for three diatom size fractions, the authors proposed a temperature coefficient for oxygen isotope fractionation between diatomaceous silica and water of about -0.2‰/°C which is in accordance with the temperature coefficient for cultured diatoms reported by Brandriss et al (1998).

The temperature coefficients calculated in this study are comparable with coefficients estimated by Labeyrie (1974) of about -0.25‰/°C and Juillet-Leclerc & Labeyrie (1987) of about -0.29‰/°C. However, the temperature and the isotopic composition of the water were not measured directly by these authors. Interestingly the temperature coefficients from this study are higher, in absolute values, than those obtained by Brandriss et al. (1998) on cultured diatoms and Moschen et al. (2005) on diatoms sampled from a lake ecosystem. It is also conspicuous that the amount of fractionation from the present study is in accordance with the values from Brandriss et al. (1998) and Moschen et al. (2005). Thus, the difference of about 3 - 10‰ between the fractionation of sedimentary diatom silica and silica of living diatoms is evident. The reason for the discrepancies is not clear. Earlier studies suggested that the differences in isotopic characteristics of fossil and recent diatom valves are a possible explanation of the divergences. Lewin (1961) and Juillet (1980) inferred the presence of an unstable and soluble surface layer of newly developed diatom valves which is isotopically light, as a possible reason. After removal of this layer from recent diatom valves in hot acids, the $\delta^{18}O$ values of biogenic silica increased by 1.8 and 5.3‰ (Juillet 1980). However, the same treatment had no influence on the $\delta^{18}O$ values of diatoms from a thousand year old marine sediment.

A complete dehydration of recent diatom frustules under vacuum at a temperature of about 1050°C performed by Brandriss et al. (1998) and by Lücke et al. (2005) resulted in a loss of 10 - 15% of the sample weight, whereas the fossil diatom sample lost only 4%. These extraction methods suggest that the recent diatoms contain more water molecules and OH groups.

In the present study, the possible species-specific oxygen isotope fractionation was also tested. For this purpose, two diatom species, namely *Fragilaria crotonensis* and *Cyclotella meneghiniana,* were grown under the same temperature conditions. Stability of the growth conditions was assured by applying the steady state culture method called chemostat (see also Chapter 4.6.1). The diatom species *Fragilaria crotonensis* was grown at a growth rate of μ=0.34 d^{-1} while the diatom species *Cyclotella meneghiniana* was grown at two growth rates, namely μ=0.34 d^{-1} and μ=0.2 d^{-1}. The temperature coefficients deduced for each diatom species are almost identical. The temperature coefficient for *Fragilaria crotonensis* was about -0.28‰/°C which is similar to the temperature coefficients deduced for *Cyclotella meneghiniana* grown with the same growth rate. For *Cyclotella meneghiniana*, the following

temperature coefficients were estimated: -0.27‰/°C for the higher growth rate and -0.27‰/°C for the lower growth rate. In this situation, species-specific temperature coefficients were not found. Moschen et al. (2005), sieved recent diatom samples into three size fractions namely 5 - 10 µm, 10 - 20 µm and 20 - 80 µm. Only the temperature coefficient for the largest diatom valves was slightly lower than the coefficients obtained for the smaller valves. In natural environments, the smaller cells usually grow faster than the larger cells. The diatom *Fragilaria crotonensis* has larger cells than *Cyclotella meneghiniana* but growth rate seems to be responsible only for differences in the amount of the fractionation. This question will be discussed below.
The results of this study suggest, however, that the various extraction techniques are not necessarily responsible for the differences between temperature coefficients evaluated in earlier studies on diatom palaeothermometry.

5.3 Oxygen isotope fractionation and nitrate availability

In studies of the oxygen isotope fractionation between diatomaceous silica and water the effects of varying nutrient concentrations which affect diatom growth in natural environments were not taken into consideration until today. Not only temperature plays an important role in diatom growth, essential are also nutrients that permit the development of diatom blooms. In general lakes differ in their chemical composition of water, thus the phytoplankton composition and succession is also different for particular lakes. The diatom *Fragilaria crotonensis* chosen for this study is normally abundant in lakes and grows very well in mesotrophic lakes (see also Chapter 3.1.1), where total nitrogen (TN) ranges between 40 and 60 mg/l. In this study diatoms were grown at nitrate concentrations between 10.5 and 105 mg/l which is in line with observations from natural environment because optimal growth was noted for nitrate concentrations of the medium of 52.5 mg/l. From this study it was concluded that nitrate concentration influences the metabolism of diatom cells (see Chapter 4.1.2). In natural environments it is often noted that various nutrients can limit a phytoplankton growth and changes of nutrient availability result in various responses of the algal cells. In this study with nitrate limiting growth, the availability of silicic acid was abundant for diatoms and their valves were more silicified. As nitrate became non-limiting diatom growth became limited by the availability of silicic acid. Although the cell size of *Fragilaria crotonensis* remained unchanged (see Chapter 4.1.2) the

cell walls were less silicified. This result was confirmed by element analyses of the dry mass (see Chapter 4.1.2).

If the variations of the element content of the dry mass are compared with the fractionation presented in Table 19 and in Figure 37 a dependency of the stable oxygen isotope fractionation is inexistent, neither on the nitrate concentration, nor on the degree of silicon limitation, nor on the grade of silification of diatom frustules. Small variations of the ε values are within the error margins. In view of studies on the oxygen isotope fractionation by diatoms this is a very important finding.

Table 19: The fractionation between biogenic silica and water from experiment Nr 5 with *Fragilaria crotonensis* grown for various nitrate concentrations of the medium. The growth temperature was 24°C; During the experiments continuous light conditions prevailed and the light intensity was 500 µmol photons $m^{-}s^{-1}$.

Nitrate concentration of the medium (mg/l)	Sample	ε (‰)
10.5	V5/D3	**33.24** ± 0.2
	V5/D4	**33.35** ± 0.15
	V5/D5	**32.78** ± 0.15
	V5/D6	**33.34** ± 0.1
21	V5/D10	**33.06** ± 0.1
	V5/D11	**33.47** ± 0.1
	V5/D12	**33.58** ± 0.0
	V5/D13	**33.11** ± 0.15
52.5	V5/D22	**33.7** ± 0.1
	V5/D23	**33.71**± 0.18
	V5/D25	**33.41** ± 0.16
105	V5/D28	**32.89** ± 0.1
	V5/D30	**33.01** ± 0.1

.

The metabolism of silicic acid as a part of the cell cycle and associated with it the oxygen isotope fractionation during diatom valve morphogenesis does not seem to be influenced by other metabolic processes (e.g. NO_3^-, CO_2 assimilation) which take place throughout the whole lifetime of *Fragilaria crotonensis*. Uncoupling of silicon metabolism compared with metabolism of nitrogen and carbon was reported by Claquin et al. (2002), thus the oxygen isotope ratios stored in frustules should be affected by factors other than nutrient availability. Silicon uptake and deposition is associated with the formation of new siliceous valves before cell division and daughter cell separation (Sullivan & Volcani 1981, Sullivan 1986, Hildebrand 2000) and the deposition proceeds very fast (e.g. Hazelaar et al. 2005). The processes controlling silica deposition are driven by species specific sets of polyamines and a few silica-precipitating proteins (Kröger et al. 1999, 2000) to which silicic acid is added by an energetically cheap process linked to respiratory metabolism (Martin-Jézéquel et al. 2000).

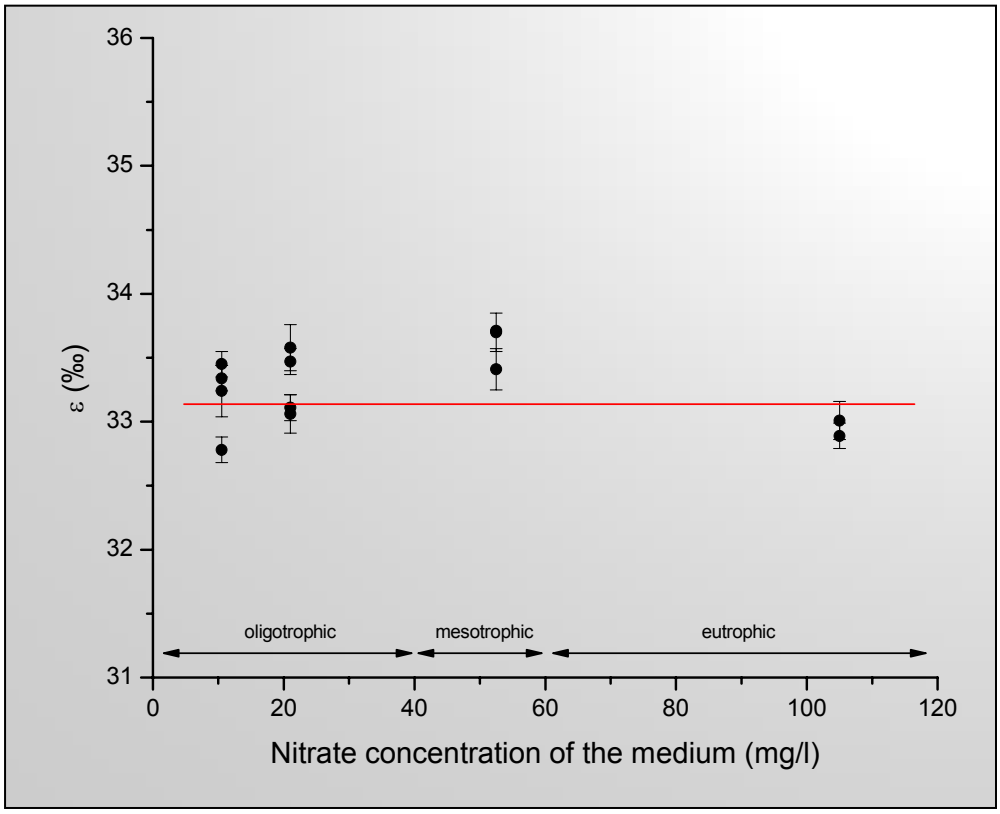


Figure 37: The oxygen isotope fractionation between biogenic silica and water from experiment Nr 5 with *Fragilaria crotonensis* grown for various nitrate concentrations of the medium. The growth temperature was 24°C; during experiments continuous light conditions prevailed and the light intensity was 500 µmol photons $m^{-}s^{-1}$.

As a consequence, the energy demand of the uptake and assimilation process is very low. Thus, as the cell takes up silicic acid the assimilation into the frustule can occur (Claquin et al. 2002) and exactly during this step the oxygen isotope fractionation has to take place.

For further studies, it will be interesting to test the influence of other nutrients which control diatom growth, including more diatom species because species-specific effects can still not be excluded.

5.4 Oxygen isotope fractionation and light intensity

The availability of light as an energy source is very important for photoautotrophs. Although temperature influences the growth rates of diatoms, Lund (1949) has shown that the spring increase in division rate of *Asterionella formosa* was more closely correlated with increased illumination than with increased temperature. In the natural environment light intensity and temperature distinctly change with season. The spring is characterized by high light conditions and low temperatures, summer by high light conditions and high temperatures, during autumn low light conditions and high temperatures prevail and winter is characterized by low light conditions and low

temperatures. Thus, various effects of diverse light-temperature combinations on diatom growth can be expected. If the spring increase in the growth rate is caused by increasing light intensity as suggested by Lund (1949), light plays an important role in the regulation of growth at low temperature conditions. Thus it cannot be excluded that light intensity affects the oxygen isotope fractionation of diatoms during frustule formation. This option was not taken into consideration until today. Earlier studies concerning the oxygen isotope fractionation between biogenic silica and water were only based on the temperature dependence of this process. The latter is clear, since this effect is based on physico-chemical grounds. However, effects which are based on irradiation variations are difficult to relate to physico-chemical behaviour.

In order to examine a possible influence of the light intensity on the oxygen isotope fractionation during the growth of diatoms, *Cyclotella meneghiniana* was cultured under four different light intensities leaving the water temperature constant. The respective fractionations determined for different light conditions are presented in Table 20 and Figure 38. The difference in the fractionation between the lowest and highest light intensity used was 0.76‰. The fractionation (ε) plotted in Figure 38 demonstrated a positive linear correlation of the oxygen isotope fractionation during biogenic silica formation with light intensity. The variance was R^2=0.993. The light coefficient φ derived from the slope indicates that an increase of the light intensity by 100 µmol photons $m^{-2}s^{-1}$ causes a rise of the oxygen isotope fractionation by 0.05‰. It is very remarkable, that the tendency of the oxygen isotope fractionation caused by increasing light intensity is inverse to the respective effect of temperature.

Table 20: Stable oxygen isotope ratios of biogenic silica from experiment Nr 15 with *Cyclotella meneghiniana* grown for various light intensities. The growth temperature was 18°C; culture was grown under continuous light conditions.

Light intensity (µmol photons $m^{-2}s^{-1}$)	Temperature (°C)	Sample	ε (‰)	ε (‰)
200	18	V15/D104	32.73	**32.82 ± 0.10**
		V15/D106	32.93	
		V15/D108	32.81	
500	18	V15/D14	32.93	**33.00 ± 0.07**
		V15/D15	33.0	
		V15/D16	32.96	
		V15/D17	33.09	
1100	18	V15/D54	33.24	**33.21 ± 0.05**
		V15/D56	33.24	
		V15/D58	33.16	
1700	18	V15/D70	33.69	**33.58 ± 0.09**
		V15/D73	33.52	
		V15/D77	33.53	

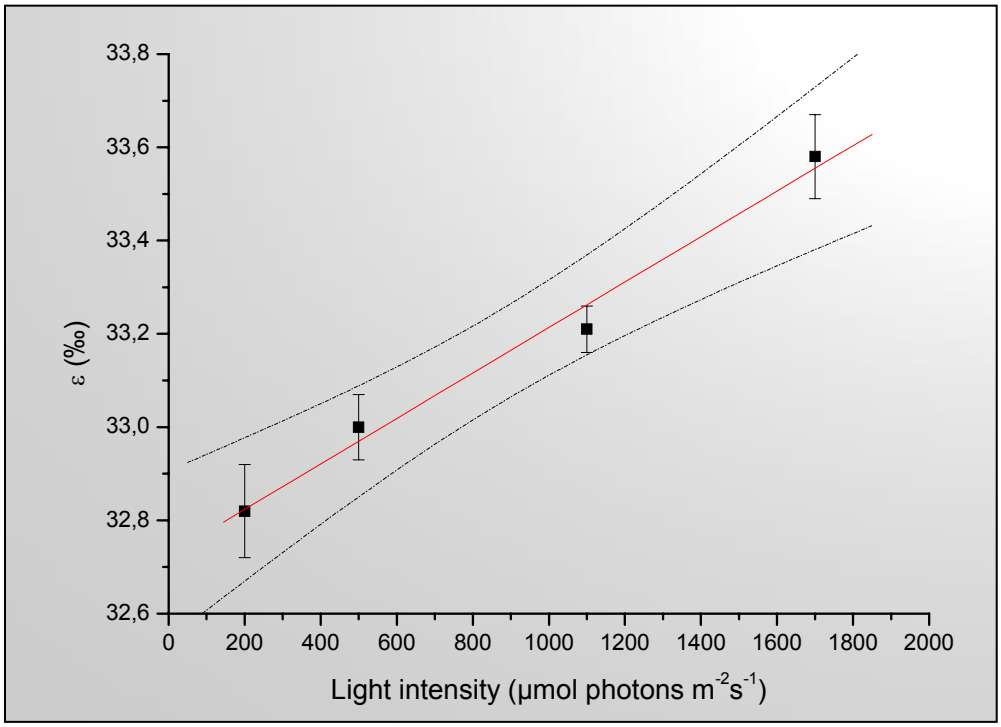


Figure 38: Dependence of the oxygen isotope fractionation in biogenic opal on the light intensity. Centre line is regression line; neighbouring curves present 95% confidence intervals. Culture was grown under continuous light conditions.

Thus, the light-temperature interactions are more important in the oxygen isotope fractionation than the single effect of temperature alone. For example, interactive effects of light and temperature at higher light intensities were found by Harris 1986 and Raven & Geider 1988. In the natural environment growth is normally proportional to irradiance over the range from very low to some optimal irradiance (Falkowski et al. 1985). Thus, increasing light intensity will stimulate the growth of phytoplankton by increase of the growth rate (Thompson 1999), but suboptimal irradiances should cause a limitation of the growth rate. According to the productivity of *Cyclotella meneghiniana* from this study (see Chapter 4.4.1) the optimal light intensities were noted between 200 and 500 µmol photons $m^{-2}s^{-1}$, where the productivity was maximal. Further increase of the light intensity, however, caused stress in the diatom cells and the productivity diminished.

Under natural conditions *Cyclotella meneghiniana* grows well at light intensities of 119-171 µmol photons $m^{-2}s^{-1}$ (Jørgensen 1969), thus very interesting are light intensities between 0 and 200 µmol photons $m^{-2}s^{-1}$. Probably at low light levels the temperature has no effect on growth (Harris 1986). Unfortunately, low light conditions could not be tested in this study because of technical limitations of the illumination unit, which allowed as lowest light intensity about 200 µmol photons $m^{-2}s^{-1}$.

During summer months the light intensities in the surface water of lakes can reach up to 1500 µmol photons $m^{-2}s^{-1}$ (see Table 17 in Chapter 4.6.5) which would obviously lead to strongly increased effects of the light on diatom growth. This study shows that the light intensity influences the oxygen isotope fractionation by compensating some of the fractionation effect induced by temperature. A numerical example of such a possible combined light-temperature fractionation effect calculated for a temperate lake during a summer day is presented in Table 21. The example suggests that the overall oxygen isotope fractionation will be affected by the light intensity between 0 and 2 m water depth, where the highest changes of the light intensity and the water temperature are observed. The calculations are based on the assumption that the specific growth rate is constant at 0.2 d^{-1}.

Table 21: A numerical example for a possible combined light-temperature fractionation effect calculated for temperature variations in Lake Holzmaar during a summer day.
ε_T –fractionation induced by temperature; $\varepsilon_{T,\ Light}$ – fractionation induced by the combination of temperature and light intensity.

Water depth (m)	Temperature (°C)	Light intensity (µmol photons $m^{-2}s^{-1}$)	ε_T (‰)	Combined light-temperature fractionation effect $\varepsilon_{T,\ Light}$ (‰)
0.0	22.9	1550	31.68	32.21
0.5	14.7	1213	33.89	34.25
1.0	7.3	942	35.89	36.11
1.5	5.8	638	36.29	36.36
2.0	5.1	552	36.48	36.51
2.5	5.0	425	36.51	36.47
3.0	4.9	299	36.54	36.44
3.5	4.9	238	36.54	36.41

This finding is important for further calibrations of the oxygen isotope palaeo-thermometer using diatom valves, because under certain conditions the effect of light intensity can not be ignored. As this study suggests varying light intensities can be responsible for changes of the oxygen isotope ratios stored in diatom valves. What has to be kept in mind is that light conditions in the lake water can change faster than the water temperature. Thus, during diatom blooms the light conditions of single days, when valve development and cell division of diatoms take place, might be very important for the isotope signal. Light changes could simulate temperature variations. In addition it is possible that varying light intensities can act on various diatom species in different ways; therefore, further studies with various diatom species are needed to test this possibility.

5.5 Oxygen isotope fractionation, growth rate and species-specific effects

It is well established that growth rate increases with increasing temperature up to a maximum value. If temperature exceeds a certain value growth rate is decreasing again. In many temperate lakes the spring to summer transition corresponds to a shift in temperature within the range of about 8 - 17°C characterized by the enhancement of growth rate of phytoplankton with temperature. There are also known clear interspecific differences in the growth rates of algae at different temperatures which in the case of diatoms can affect the silica – water fractionation, what was pointed out by Brandriss et al. (1998). In order to examine the effect of growth rate on the fractionation the diatom *Cyclotella meneghiniana* was grown at two different growth rates. The oxygen isotope fractionation from this experiment presented in Figure 39 indicates a distinct dependency of the oxygen isotope fractionations on growth rate. If the curves from Figure 39 are considered separately a marked increase of the fractionation with decreasing temperatures can be observed. The slopes of the curves are identical, thus the change of the fractionation with the temperature for each growth rate is also equal. As a result, the temperature coefficients calculated from the slopes are identical (see Chapter 5.2). It should be pointed out that the upper limit of the temperature range up to which the fractionation is a linear function of the temperature varied with growth rate (see Figure 39).

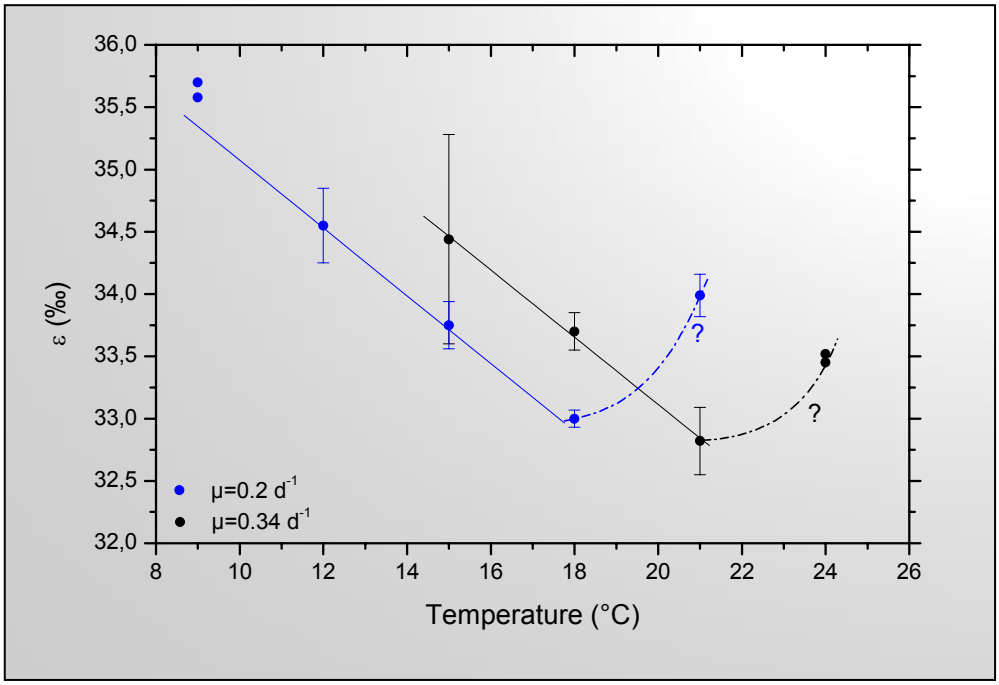


Figure 39: The oxygen isotope fractionation of biogenic silica from *Cyclotella meneghiniana* shown for two different growth rates.

For the lower growth rate the limit was noted at 18°C, whereas at the higher growth rate it was noted for 21°C. At temperatures above these limits the trend of the fractionations turned round and increased. The reason of this nonlinearity is unclear. It seems to be species-specific, because for *Fragilaria crotonensis* this phenomenon was not observed (see Figure 36). It is possible, that the effect with *Fragilaria crotonensis* will appear at temperatures higher than those examined in this study. Probably effects observed by *Cyclotella meneghiniana* can be referred to the temperature optimum for growth, which apparently depends on species. There exists also the possibility that other environmental factors are responsible for effects observed in this study with *Cyclotella meneghiniana*. For example, the relationship between algal growth rate and temperature is subject to significant interaction with light flux density (Gibson & Foy 1989). Not optimal irradiances can influence the growth rate of phytoplankton. Other possibilities for the growth rate limitation of photoautotrophs constitute nutrients (Blackman 1905, Dugdale 1967), but in this study in the experiment with various nitrate concentrations (see Chapter 5.3) the growth rate was constant during the whole experiment. Thus, it is impossible to say more about an influence of nutrients and further studies are needed.

Table 22 summarizes the fractionations both for *Cyclotella meneghiniana* grown at different growth rates and for *Fragilaria crotonensis*.

Table 22: The stable oxygen isotope fractionation (ε) of biogenic silica from *Cyclotella meneghiniana* and *Fragilaria crotonensis* relative to the temperature and growth rate.

Diatom species	Growth rate μ (d^{-1})		ε (‰)					
			9°C	12°C	15°C	18°C	21°C	24°C
Cyclotella meneghiniana	0.2		35.45	34.17	33.63	32.93	34.01	
			35.7	34.52	33.61	33	34.11	
			-	34.84	33.86	32.96	34.08	
			-	35.06	34.05	33.09	33.74	
			-	34.15	33.55	-	-	
			-	-	33.77	-	-	
		mean value	**35.58**	**34.55**	**33.75**	**33.00**	**33.99**	
Cyclotella meneghiniana	0.34				33.89	33.78	32.63	33.45
					34.09	33.52	32.79	33.52
					33.87	33.61	32.64	-
					35.89	33.7	32.53	-
					-	33.88	32.94	-
					-	-	33.43	-
					-	-	32.68	-
					-	-	32.73	-
					-	-	32.99	-
		mean value			**34.44**	**33.7**	**32.82**	**33.48**
Fragilaria crotonensis	0.34				35.67	34.02	33.55	32.89
					35.84	33.97	-	33.01
		mean value			**35.75**	**34.00**	**33.55**	**32.95**

- non-existent

The data clearly indicate that the magnitude of the oxygen isotope fractionation in this study was not only influenced by the growth rate but also by diatom species. Brandriss et al. (1998) and Schmidt et al. (2001) suggested that fast growing diatoms fractionate the oxygen isotopes relatively little whereas slow diatom growth causes relatively large isotope fractionations. The presented experiments show mainly the opposite situation (see Fig. 40). In the case of *Cyclotella meneghiniana* for example the fractionation is lower for the lower growth rate. If the fractionation is compared for temperatures of 15 and 18°C the difference in the fractionation between growth rates is about 0.7‰. (see Table 22 and Figure 39). Only at 21°C the fractionation was higher at the lower growth rate (see Figure 39 and 40). The difference in the fractionation at this temperature was about 1.2‰.

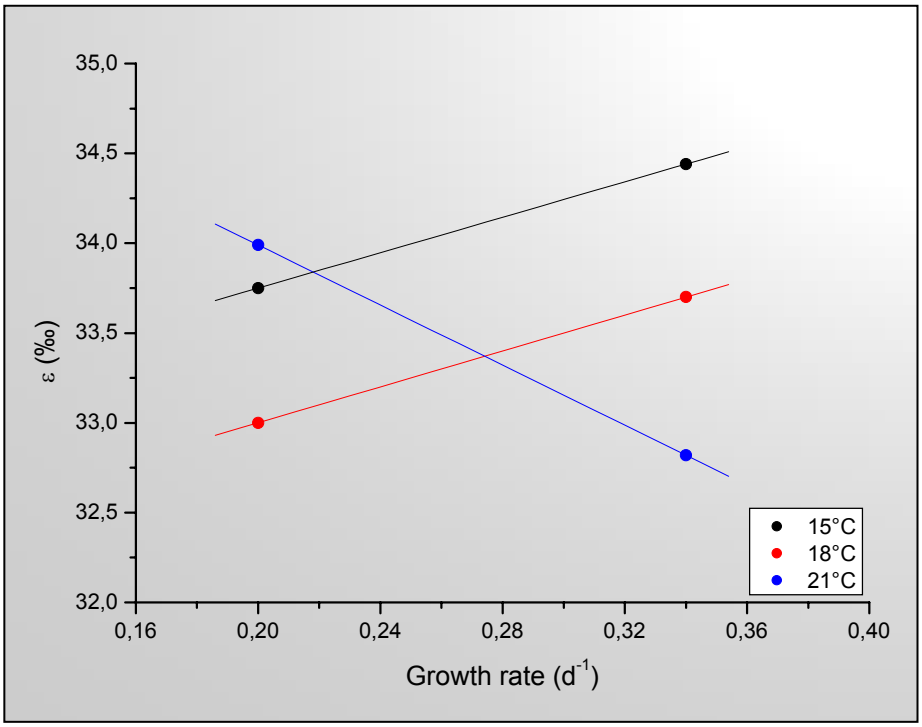


Figure 40: The functional relationship between the growth rate and the isotope fractionation ε.

The oxygen isotope fractionation of *Fragilaria crotonensis* and *Cyclotella meneghiniana*, which grew at the growth rate of 0.34 d^{-1}, exhibit also distinct differences between these species. The diatom *Fragilaria crotonensis* had a higher fractionation at temperatures 15 – 21°C, whereas at 24°C the higher fractionation was noted for *Cyclotella meneghiniana* (see Table 22). These findings point to a certain species-specific fractionation in diatoms.

From this study arises that the rate at which the diatoms grow plays an important role influencing the magnitude of the fractionation of a single species. Thus, the hypothesis of Brandriss et al. (1998) and Schmidt et al (2001) that the fast growing diatoms fractionate less is only partly confirmed experimentally. From Table 22 it has to be followed, that from the magnitude of the fractionations it can be difficult to calculate the temperature coefficient for a multi species assemblage, e.g. sampled from a lake. For example, if the fractionation of *Fragilaria crotonensis* at temperature of 15°C will be compared with the fractionation of *Cyclotella meneghiniana* at 9°C there exists almost no difference in the magnitude of fractionation (see Table 22 and Figure 36), however the temperature difference 6°C.

As was mentioned in Chapter 5.2, the study of Moschen et al. (2005) on valves of living diatoms sampled from a lake almost excluded the possibility of species specific fractionations according to measurements on three size fractions. In nature it is often observed, that with an increase of temperature accompanied by a rise in growth rate, the cell size of many diatoms decreases. But also diatoms which do not change their dimension are very common. Thus, the cell size is not useful in the determination of possible species specific fractionations and in estimation of the growth rate in natural ecosystems.

Schmidt et al. (2001) postulated that the oxygen isotope fractionation is related to the water temperature in cases when diatoms grow slowly, suggesting a non-equilibrium fractionation in the case of rapidly growing diatoms. This study showed that the fractionation was related to the temperature both in *Fragilaria* and *Cyclotella*, although the magnitude of the fractionation was different for these species. In this situation, more experiments with various diatom species are needed for further interpretation of the stable oxygen isotope behaviour in diatoms. Continuous culture experiments as used in this study permit an examination of single parameter studies, but under natural conditions growth changes both during a day and a season. Brandriss et al. (1998) used batch cultures which simulate growth of natural diatom populations, where the growth conditions change during various phases of growth. These values will, therefore, represent integral values as compared to the values received with steady state cultures. Presumably this is the reason for differences between temperature coefficients from these two different culturing systems.

5.6 Complexity of continuous cultures

As mentioned in Chapter 2.6 the continuous culture method is suited for studies on diatom populations with regard to particular environmental conditions over a long time period. It should be noted that the procedure of continuous culture provides constant growth conditions and is rather efficient. Though, the method is very promising there exist several limitations for this method in the laboratory, which was also observed during this study. Firstly, success of the experiments depended on the organisms cultured in the fermenter system. Secondly, problems with the laboratory equipment may appear which can influence the period of the experiments. Thirdly, contamination with bacteria is a serious problem for monospecific cultures.

1. A choice of suitable diatom species for the culture experiments was fundamental in this study because not all diatom species proved to be useful for the investigations. For this purpose preliminary tests in batch cultures were conducted, where the growth of several diatom species was tested in synthetic growth media under continuous aeration conditions. These tests showed that from all diatom species available during the test period only two diatom species were suited for the continuous culture experiments. Both species grown in the fermenter system tolerated continuous stirring and mixing. Important was also that the diatoms did not grow on the walls of the culture vessel.
2. The requirement for constant temperature runs mostly restricts continuous systems. The thermostats used in this study were able to maintain a constant temperature of the culture vessel down to 9°C provided the room temperature was less or about 20°C. During summer months with partly much higher temperatures in the laboratory; it was often realized that it was not possible to keep the temperature of the culture vessel constant. Thus, the experiments were not successful and had to be repeated.
3. The most common sources of contamination with bacteria originated from the culture medium, the air (from the air supply), the culture vessel, and the starter culture. It should be noted, however, that all components of the fermenter system were properly sterilised. Problems with bacteria most often appeared when the components were assembled in the laboratory under non-sterile conditions. The most serious consequences of cell culture contamination

during these studies were the loss of time, money spent (for cells, media) and efforts spent in cultivating new cultures and setting up new experiments.

The three problems outlined above influenced considerably the duration of all experiments of this study. Of all the problems encountered the main difficulty concerned the contamination with bacteria.

6 Resume and outlook

For the first time, the influence of single environmental parameters such as temperature, nitrate concentration, light intensity and growth rate was studied on the oxygen isotope fractionation between biogenic silica and water in freshwater diatoms. The oxygen isotope fractionation appeared to be temperature dependent for both diatom species studied. The corresponding temperature coefficients [τ] from this dependency are not species-specific. For *Fragilaria crotonensis* the temperature coefficient measured was -0.28‰/°C*,* within the temperature range of 15-24°C. The temperature coefficients obtained for *Cyclotella meneghiniana* were: -0.27‰/°C for the temperature range of 15 - 21°C using a growth rate of 0.34 d^{-1} and -0.27‰/°C for the temperature range of 9 - 18°C at growth rates of 0.2 d^{-1}.

As was proven, varying nitrate concentrations do not influence the oxygen isotope fractionation of diatomaceous silica which is important for temperature reconstructtions using diatom valves from different lakes which differ in the nutrient concentrations.

Investigations demonstrated that the light intensity has an influence on the oxygen isotope fractionation during the diatom valve morphogenesis and the cell division. Moreover, the effect of light intensity on the oxygen isotope fractionation in diatoms is opposite to the effect of temperature. An increase in light intensity causes an increase in the oxygen isotope fractionation, while an increase in temperature leads to a decrease of the oxygen isotope fractionation. Therefore, reconstructions of the water temperature using the oxygen isotope fractionation as derived from diatom valves, should keep the effect of the light intensity in mind.

Different growth rates and species-specific effects are distinctly expressed by the magnitude of the oxygen isotope fractionation despite equal water temperature. Thus, for reconstructions of the water temperature, it is important to separate the valves of single diatom species from plankton samples or sediment samples. The size of the diatom frustules does not seem to be useful for the estimation of the growth rate.

As this study shows the oxygen isotope fractionation between diatomaceous silica and water is more complex than was believed before. There are more factors responsible for variations of the oxygen isotope fractionation than temperature alone which have to be considered in the interpretation of environmental changes. Thus, in order to make use of the oxygen isotope ratio stored in diatom valves, a better understanding of factors controlling the oxygen isotope fractionation is needed. With respect to this requirement, it will be important in the future to examine:

- more diatom species over a broad temperature range.
  Although the temperature coefficients of diatom species examined in this study are very similar, it is possible that other species might have to be characterized by different temperature coefficients. In addition it should be clarified to what extent the magnitude of fractionation factors of different species may vary
- the influence of changing light intensities on diatom growth at different temperatures because the light-temperature interactions seem to be important.
- diatoms grown at various growth rates, as this study showed the growth rate to be responsible for differences in the magnitude of the fractionation, which makes it difficult to interpret a multi species assemblage.

Answers to these problems should provide a basis for better and more reliable reconstructions of the water temperature using the oxygen isotope ratios stored in diatom valves.

7. Summary

The oxygen isotopes of diatomaceous silica from marine and freshwater sediments are frequently used as indicators of the palaeotemperature development, particularly in cases where calcareous microfossils are rare or absent. With regard to terrestrial waters it is unknown whether or not palaeotemperature scale can be used in a limnic ecosystem. Due to the fact that the seasonal variations in lakes are larger than in oceans, specific problems arise when working with freshwater sediments. Thus, an understanding of the contribution of the various factors (e.g. temperature, light, nutrients, competition) influencing the formation of isotope signals in biogenic opal is a prerequisite for the accurate interpretation of environmental processes. Since it is impossible to examine the influence of a single parameter under natural ecosystem conditions due to permanent changes of the environment, laboratory experiments with single diatom species are needed.

Therefore, the aim of this study was to investigate the correlation between the oxygen isotope variations in biogenic opal and different environmental parameters using steady state cultures with diatoms. It should be examined whether or not the different diatom species grown under identical conditions show equal oxygen isotope ratios (species relationship), if variations of the water temperature induce variations of the oxygen isotope ratio (relationship with temperature), variable parameters such as light intensity and nitrate concentration influence the isotope ratio, and if vital effects (e.g. growth rate) lead to variations of the oxygen isotope ratio.

The experiments with diatoms were carried out using two fermenter systems. An illumination unit, constructed especially for the experiments, produced the necessary natural light spectrum. For the study two diatom species were chosen, which were morphologically different. These were the pennate form *Fragilaria crotonensis* and the centric form *Cyclotella meneghiniana*. The diatoms were grown at temperatures of 9, 12, 15, 18, 21 and 24°C. Subsequently, the influence of various nitrate concentrations of the medium (10.5, 21, 52.5 and 105 mg/l) was examined. Moreover experiments with various natural light intensities (200, 500, 1100 and 1700 µmol photons $m^{-2}s^{-1}$) were performed.

Based on the data obtained from the experiments, a negative linear correlation between the oxygen isotope ratio and the water temperature was found for both diatom species. The temperature coefficients obtained in this study were not species-

specific. The temperature coefficient determined for *Fragilaria crotonensis* within the temperature range of 15 - 24°C was ≈ -0.28‰/°C. For *Cyclotella meneghiniana* grown at a growth rate of 0.34 d^{-1} employing temperatures in the range of 15 - 21°C, the temperature coefficient was ≈ -0.27‰/°C. The same species grown at a growth rate of 0.2 d^{-1} and operating in a temperature range of 9 - 18°C also resulted in a temperature coefficient of ≈ -0.27‰/°C.

Varying nitrate concentrations examined in this study did not influence the oxygen isotope fractionation between diatomaceous silica and water. This finding is very important for further applications of the oxygen isotope ratio of diatom valves for reconstruction of the water temperature, since varying nitrate concentrations in lakes will not mask the temperature effect.

It was also found, that variations in the light intensity influence the oxygen isotope fractionation during diatom valve morphogenesis. The light coefficient (φ) was ≈0.05‰/100 µmol photons $m^{-2}s^{-1}$. The effect of the light intensity is opposite to the effect of the temperature and leads to a partial suppression of the fractionation effect induced by temperature. Thus, the effect of the light intensity should be taken into consideration in reconstructions of the water temperature.

Species-specific effects found on the basis of this study are distinctly expressed in the amount of the oxygen isotope fractionation despite equal water temperature. On the one hand, different growth rates caused differences in the fractionation of a single diatom species. On the other hand, there were also differences in the fractionation between diatom species grown with the same growth rate. Thus, for reconstructions of the water temperature, it is important to separate the valves of single diatom species from e.g. a plankton sample.

The results of this study increase hitherto existing information about the relationship of the oxygen isotope fractionation between diatomaceous silica and water. The new findings from this study should help in the interpretation of the stable oxygen isotope ratios of diatom valves.

8 References

Blackman, F.F. (1905): Optima and limiting factors. - Ann. Bot. 19, 281-298.

Brandriss, M.E., O'Neil, J.R., Edlund, M.B. & Stoermer, E.F. (1998): Oxygen isotope fractionation between diatomaceous silica and water. - Geochimica et Cosmochimica Acta 62, 1119-1125.

Brown, C.M. & Rose, H. (1969): Effects of temperature on composition and cell volume of *Candida utilis.*- Journal of Bacteriology 97, 261-272.

Brzezinski, M.A. (1985): The Si:C:N ratio of the marine diatoms: interspecific variability and the effect of some environmental variables. – Journal of Phycology 21, 347-357.

Brzezinski, M.A. (1992): Cell-cycle effects on kinetics of silicic acid uptake and resource competition among diatoms. - Journal of Plankton Research 14: 1511-39.

Brzezinski, M.A. & Conley, D.J. (1994): Silicon deposition during the cell cycle of *Thalassiosira weissflogii* (Bacillariophyceae) determined using dual rhodamine 123 and propidium iodide staining. - Journal of Phycology 30: 45-55.

Brzezinski, M.A., Olson, R.J. & Chisholm, S.W. (1990): Silicon availability and cell-cycle progression in marine diatoms. - Marine Ecology Progress Series 67: 83-96.

Campbell, W.H. (1988): Nitrate reductase and its role in nitrate assimilation in plants. - Physiologia Plantarum 74, 214-219.

Claquin, P., Martin-Jézéquel, V., Kromkamp, J.C., Veldhuis, M.J.W. & Kraay, G.W. (2002): Uncoupling of silicon compared with carbon and nitrogen metabolism and the role of the cell cycle in continuous cultures of *Thalassiosira pseudonana* (Bacillariophyceae) under light, nitrogen and phosphorus control. - Journal of Phycology 38, 922-930.

Craig, H. (1957): Isotopic standards for carbon and oxygen and correction factors for mass spectrometric analysis of carbon dioxide. - Geochimica te Cosmochimica Acta 12, 133-149.

Dansgaard, W., **Johnsen, S.J., Clausen, H.B., Dahl-Jensen, D., Gundestrup, N.S., Hammer, C.U., Hvidberg, C.S., Steffensen, J.P., Sveinbjörnsdottir, A.E., Jouzel, J., Bond, G.** (1993): Evidence for general instability of past climate from a 250-kyr ice-core record. - Nature364, 218-220.

Degens, E.T., Behrendt, M., Gotthard, B., Reppman, E. (1968): Metabolic fractionation of carbon isotopes in marine plankton – I: temperature and respiration experiments. - Deep Sea Research 15, 1-9.

Del Amo, Y., Brzezinski, M.A. (1999): The chemical form of dissolved Si taken up by marine diatoms. - Journal of Phycology 35, 1162-1170.

Dugdale, R.C. (1967): Nutrient limitation in the sea: dynamics, identification and significance. - Limnology and Oceanography 12, 685-695.

Dutkiewicz, A., **Herczeg, A.L., Dighton, J.C.** (2000): Past changes to isotopic and solute balances in a continental playa: clues from stable isotopes of lacustrine carbonates. - Chemical Geology 165, 309-329.

Elrifi, I.R. & Turpin, D.H. (1987): The path of carbon flow during NO_3^- induced photosynthetic suppression in N-limited *Selenastrum minutum*. - Plant Physiol. 83, 97-104.

Falkowski, P.G., Dubinsky, Z. & Wyman, K. (1985): Growth-irradiance relationships in phytoplankton. - Limnology and Oceanography 30, 311-321.

Farquhar, G.D., Ehlenringer, J.R., Hubick, K.T. (1989): Carbon isotope discrimination and photosynthesis. - Annual Review of Plant Physiology and Plant Molecular Biology 40, 503-537.

Flynn, K.J. & Martin-Jézéquel, V. (2000): Modelling Si-N-limited growth of diatoms. - Journal of Plankton Research 22: 447-472.

Forsberg, C. & Ryding, S.O. (1980): Eutrophication parameters and trophic state indices in 30 Swedish waste-receiving lakes. - Arch. Hydrobiology 89, 189-207.

Gallinari, M., **Ragueneau, O., Corrin, L., DeMaster, D.J., Tréguer, P.** (2002): The importance of water column process on the dissolution properties of biogenic silica in deep-sea sediments I. Solubility. - Geochimica et Cosmochimica Acta 66, 2701-2717.

Gibson, C.E. & Foy, R.H. (1989): On temperature-independent growth of phytoplankton.- Journal of Plankton Research 11, 605-607.

Goldman, C.R. & Horne, A.J. (1983): Limnology. - McGraw Hill, Inc., New York.

Golterman, H.L. (1969): Methods for chemical analysis of fresh waters. - Int. Biol. Program Handbook 8. Blackwell Scientific Publications, Oxford, 172 pp.

Gotham, I.J. & Rhee, G. (1981): Comparative kinetic studies of nitrate-limited growth and nitrate uptake in phytoplankton in continuous culture. - Journal of Phycology 17, 309-314.

Harris, G.P. (1986): Phytoplankton ecology: structure, function and fluctuation. - Chapman and Hall.

Hartig, J.H. & Wallen, D.G. (1986): The influence of light and temperature on growth and photosynthesis of *Fragilaria crotonensis* Kitton. - Journal of Freshwater Ecology 3, 371-382.

Hattori, A. (1962): Light-induced reduction of nitrate, nitrite and hydroxylamine in a blue-green alga *Anabacena cylindrica*. - Plant & Cell Physiology 3, 355-369.

Haug, G.H., Pedersen, T.F., Sigman, D.M., Calvert, S.E., Nielsen, B. & Peterson, L.C. (1998): Glacial/interglacial variations in production and nitrogen fixation in the Cariaco Basin during the last 580 kyr. - Paleoceanography 13, 427-432.

Hazelaar, S., van der Strate, H.J., Gieskes, W.W.C. & Vrieling, E.G. (2005): Monitoring rapid valve formation in the pennate diatom *Navicula salinarum* (Bacillariophyceae). - Journal of Phycology 41, 354-358.

Healey, F.P. & Hendzel, L.L. (1980): Physiological indicators of nutrient deficiency in lake phytoplankton. - Can. J. Fish. Aquat. Sci. 37, 442-453.

Hecky, R.E., Campbell, P. & Hendzel, L.L. (1993): The stoichiometry of carbon, nitrogen and phosphorus in particulate matter of lakes and oceans. – Limnology and Oceanography 39, 709-724.

Hildebrand, M. (2000): Silicic acid transport and its control during cell wall silification in diatoms. - *In* Bauerlein, E. [Ed.] *Biomineralisation of nano-and micro-structures.* Wiley-VCH, Weinheim, Germany, pp. 171-188.

Hinga, K.R., Arthur, M.A., Pilson, M.E.Q., Whitaker, D. (1994): Carbon isotope fractionation by marine phytoplankton in culture: the effects of CO_2 concentration, pH, temperature and species. - Global Biogeochemical Cycles 8, 91-102.

Janssen, M., Bathke, L., Marquardt, J., Krumbein, W.E., Rhhiel, E. (2001): Changes in the photosynthetic apparatus of diatoms in response to low and high light intensities. - International Microbiology 4, 27-33.

Jørgensen, E.G. (1969): The adaptation of plankton algae. IV. Light adaptation in different species. - Physiologia Plantarum 22, 920-926.

Juillet, A. (1980): Structure de la silice biogénique: nouvelles données approtées par l`analyse isotopique de l`oxygène. - C.R. Acad. Sc. Paris, t 290 Séries D, 1237-1240.

Juillet-Leclerc, A.J. & Labeyrie, L.D. (1987): Temperature dependence of the oxygen isotopic fractionation between diatom silica and water. - Earth and Planetary Science letters 84, 69-74.

Juillet-Leclerc, A.J., Labeyrie, L.D., Reyss, J.L. & Schrader, H. (1991): Temperature variability in the Gulf of California during the last century: a record of the recent strong El Niño. - Geophysical Research Letters 18, 10, 1889-1892.

Katamani, A. (1982): Dissolution rates of silica from diatoms decomposing at various temperatures. - Marine Biology 68, 91-96.

Kiefer, D.A. (1983): Chlorophyll a fluorescence in marine centric diatoms: response of chloroplast to light and nutrient stress.- Marine Biology 23, 39-46.

Kilham, P. (1990): Mechanisms controlling the chemical composition of lake and rivers: data from Africa.- Limnology and Oceanography 35, 80-83.

Knauth, L.P. (1973): Oxygen and hydrogen isotope ratio in cherts and related rocks.- Ph.D. thesis California Institute of Technology.

Korb, R.E., Raven, J.A., Johnston, A.M. & Leftley, J.W. (1996): Effect of cell size and specific growth rate on stable carbon isotope discrimination by two species of marine diatoms. - Marine Ecology Progress Series 143, 283-288.

Krammer, K. & Lange-Bertalot, H. (1991): Bacillariophyceae 2/3. - In: Ettl, H., Gerloff, J., Heynig, H. & Mollenhauer, D. (Hrsg): Süsswasserflora von Mitteleuropa.- Gustav Fischer, Stuttgart.

Kröger, N., Deutzmann, R. & Sumper, M. (1999): Polycationic peptides from diatom biosilica that direct silica nanosphere formation. - Science 286, 1129-1132.

Kröger, N., Deutzman, R., Bergsdorf, C. & Sumper, M. (2000): Species-specific polyamines from diatoms control silica morphology. - Proc. Natl. Acad. Sci. USA 97: 14133-8.

Labeyrie, L. Jun. (1974): New approach to surface seawater palaeotemperatures using $^{18}O/^{16}O$ ratios in silica of diatom frustules. - Nature 248, 40-42.

Labeyrie, L. & Juillet, A. (1980): Échangeabilité isotopique de l`oxygène de la silice biogénique. - C.R. Acad. Sc. Paris, D, t.290, 1185-1188.

Labeyrie, L. & Juillet, A. (1982): Oxygen isotopic exchangeability of diatom valve silica: interpretation and consequences for paleoclimatic studies. - Geochimica et Cosmochimica Acta 46, 967-975.

Laws, E.G., Popp, B.N., Bidigare, R.R., Kennicutt, M.C. & Macko, S.A. (1995): Dependence of phytoplankton carbon isotopic composition on growth rate and $[CO_2]_{aq.}$: theoretical considerations and experimental results. - Geochimica et Cosmochimica Acta 59, 1131-1138.

Lewin, J.C. (1961): The dissolution of silica from diatom walls. - Geochimica et Cosmochimica Acta 21, 182-198.

Lücke, A., Moschen, R. & Schleser, G.H. (2005): High-temperature carbon reduction of silica: A novel approach for oxygen isotope analysis of biogenic opal. - Geochimica et Cosmochimica Acta 69, 1423-1433.

Lund, J.W.G. (1949): Studies on *Asterionella* 1. - Journal of Ecology 37, 389-419.

Mariotti, A., **Germon, J.C., Hubert, P., Kaiser, P., Letolle, R., Tardieux, A. & Tardieux, P.** (1981): Experimental determination of nitrogen kinetic isotope fractionation: some principles; illustration for the denitrification and nitrification processes.- Plant Soiol 62, 413-430.

Martin-Jézéquel, V., Hildebrand, M., Brzezinski, M.A. (2000): Silicon metabolism in diatoms: implications for growth. - Journal of Phycology 36, 821-840.

Matheney, R.K. & Knauth, L.P. (1989): Oxygen isotope fractionation between marine biogenic silica and seawater. - Geochimica et Cosmochimica Acta 53, 3207-3214.

McCrea, J.M. (1950): On the isotopic chemistry of carbonates and palaeo-temperature scale. - Journal of Chemical Physics 18, 849-857.

Monod, J. (1950): La technique de culture continue: theorie et applications. - Ann. Inst. Pasteur 79, 390-410.

Montoya, J.P. (1990): Natural abundance of ^{15}N in marine and estuarine plankton: studies of biological isotopic fractionation and plankton processes.- Harvard University, Cambridge.

Mook, W.G., Bommerson, J.C., Staverman, W.H. (1974): Carbon isotope fractionation between dissolved bicarbonate and gaseous carbon dioxide. - Earth and Planetary Science Letters 22, 169-176.

Moschen, R., **Lücke, A & Schleser, G.H.** (2005): Sensitivity of biogenic silica oxygen isotopes to changes in surface water temperature and palaeoclimatology. - Geophysical Research Letters 32.

Mulitza, S., **Boltovskoy, D., Donner, B., Meggers, H., Paul, A., Wefer, G.** (2003): Temperature: $\delta^{18}O$ relationships of planktonic foraminifera collected from surface waters. - Palaeogeography, Palaeoclimatology, Palaeoecology 202, 143-152.

Needoba, J.A. & Harrison, P.J. (2004): Influence of low light and a light:dark cycle on NO_3^- uptake, intracellular NO_3^-, and nitrogen isotope fractionation by marine phytoplankton.- Journal of phycology 40, 505-516.

Negendank, J.F.W., Brauer, A., Zolitschka, B. (1990): Die Eifelmaare als erdgeschichtliche Fallen und Quellen zur Rekonstruktion des Paläoenvironments. - Mainzer geowissenschaftliche Mitteilungen 11, 235-262.

Niyogi, K.K. (1999): Photoprotection revisited: genetic and molecular approaches. - Annual Review of Plant Physiology and Plant Molecular Biology 50, 333-359.

Niyogi, K.K. (2000): Safety valves for photosynthesis. - Current Opinion in Plant Biology 3, 455-460.

Norton, T.A., Melkonian, M., Andersen, R.A. (1996): Algal biodiversity. - Phycologia 35, 353-365.

Novick, A & Szilard, L. (1950): Description of the chemostat. - Science 112, 715-716.

Osborne, B.A. & Geider, R.J. (1986): Effect of nitrate-nitrogen limitation on photosynthesis of the diatom *Phaeodactylum tricornutum* Bohlin (Bacillariophyceae). - Plant Cell Environ. 9, 617-625.

Paasche, E. (1973): Silicon and the ecology of marine plankton diatoms. I. *Thalassiosira pseudonana* (*Cyclotella nana*) growth in a chemostat with silicate as limiting nutrient. - Marine Biology 19:117-126.

Perry, M.J., Talbot, M.C. and Alberte, R.S. (1981): Photoadaptation in marine phytoplankton: response of the photosynthetic unit. - Marine Biology 62, 91-101.

Rahmstorf, S. (2002): Ocean circulation and climate during the past 120,000 years. - Nature 419, 207-213.

Raven, J.A. & Geider, R.J. (1988): Temperature and algal growth. - New Phytologist 110, 441-461.

Redfield, A.C., Ketchum, B.H. & Richards, F.A. (1963): The influence of organisms on the composition of seawater*. In:* Hill, M.N. [Ed.] *The sea*. Vol.2 Wiley Interscience, New York, pp. 26-77.

Rhee, G. & Gotham, I.J. (1981): The effect of environmental factors on phytoplankton growth: Temperature and the interactions of the temperature with nutrient limitation. – Limnology and Oceanography 26(4), 635-638.

Rickert, D., **Schlüter, M., Wallmann, K.** (2002): Dissolution kinetics of biogenic silica from the water column to the sediments. - Geochimica et Cosmochimica Acta 66, 439-455.

Rimstidt, J.D., Barnes, H.L. (1980): The kinetics of silica-water reactions. - Geochimica er Cosmochimica Acta 44, 1683-1669.

Rosen, B.H. & Lowe, R.L. (1984): Physiological and ultrastructural responses of *Cyclotella meneghiniana* (Bacillariophyta) to light intensity and nutrient limitation. - Journal of Phycology 20, 173-183.

Round, F.E., Crawford, R.W., Mann, D.G. (1990): The diatoms, biology and morphology of the genera. - Cambridge University Press, Cambridge.

Schmid, A.-M. M., Borowitzka, M.A. & Volcani, B.E. (1981): Morphogenesis and biochemistry of diatom cell walls. - *In* Kiermayer, O. [Ed.] *Cytomorphogenesis in plants.* Vol.8. Springer-Verlag, New York, pp: 63-97.

Schmid, A.-M. M., & Volcani, B.E. (1983): Wall morphogenesis in *Coscinodiscus wailesii*. I. Valve morphology and development of its architecture. - Journal of Phycology 19: 387-402.

Schmidt, M., **Botz, R., Stoffers, P., Anders, T., Bohrmann, G.** (1997): Oxygen isotopes in marine diatoms: A comparative study of analytical techniques and new results on the isotope composition of recent marine diatoms. - Geochimica et Cosmochimica Acta 61, 2275-2280.

Schmidt, M., **Botz, R., Rickert, G., Hall, S.R., Mann, S.** (2001): Oxygen isotopes of marine diatoms and relations to opal-A maturation. - Geochimica et Cosmochimica Acta 65, 201-211.

Schwoerbel, J. (1993): Einführung in die Limnologie. - Gustav Fischer Verlag, Stuttgart, Jena.

Shackleton, N.J. (1987): Oxygen isotopes, ice volume and sea level. - Quaternary Science Reviews 6(3-4), 183-190.

Shearer, G., **Schneider, J.D. & Kohl, D.H.** (1991): Separating the efflux and influx components of net nitrate uptake by *Synechococcus* R2 under steady-state conditions. - Journal of General Microbiology 137, 1179-1184.

Shemesh, A., Charles, C.D. & Fairbanks, R.G. (1992): Oxygen isotopes in biogenic silica. Global changes in ocean temperature and isotopic composition. - Science 256, 1434-1436.

Shemesh, A., Rosqvist, G., Rietti-Shati, M., Rubensdotter, L., Bigler, C., Yam, R. & Karlen, W. (2001): Holocene climate change in Swedish Lapland inferred from an oxygen isotope record of lacustrine silica. - The Holocene 11, 447-454.

Solomonson, L.P. & Barber, M.J. (1990): Assimilatory nitrate reductase: functional properties and regulation. - Annu. Rev. Plant Physiol. Plant Mol. Biol. 41, 225-253.

Stenseth, N.C., Mysterud, A., Ottersen, G., Hurrell, J.W., Chan, K., Lima, M. (2002): Ecological effects of climate flucuations. - Science 297, 1292-1296.

Stuiver, M., **Grootes, P.M., Braziunas, T.F.** (1995): The GISP2 $\delta^{18}O$ climate record of the past 16,500 years and the role of the sun, oean and volcanoes. - Quaternary Science 44(3), 341-354.

Sullivan, C.W. (1976): Diatom mineralization of silicic acid. I. $Si(OH)_4$ transport characteristics in *Navicula pelliculosa*. - Journal of Phycology 12, 390-396.

Sullivan, C.W. (1977): Diatom mineralization of silicic acid. II. Regulation of $Si(OH)_4$ transport rates during the cell cycle of *Navicula pelliculosa*. - Journal of Phycology 13: 96-91.

Sullivan, C.W. (1986): Silification by diatoms. - *In* Evered, D. & O'Connor, M. [Eds.] *Silicon biochemistry*. Ciba foundation Symposium 121. Wiley Interscience, Chichester, pp.59-89.

Sullivan, C.W. & Volcani, B.E. (1981): Silicon in the cellular metabolism of diatoms.- *In* Simpson, T.L. & Volcani, B.E. [Eds.] *Silicon and siliceous structures in biological systems.* Springer-Verlag, New York, pp. 15-42.

Takahashi, K., Wada, E. & Sakamoto, M. (1991): Relationship between carbon isotope discrimination and the specific growth rate of green alga *Chlamydomonas reinhardtii*.- Japanese Journal of Limnology 52, 105-112.

Thompson, P. (1999): The response of growth and biochemical composition to variations in daylenght, temperature, and irradiance in the marine diatom *Thalassiosira pseudonana* (Bacillariophyceae). - Journal of Phycology 35, 1215-1223.

Thompson, P. & Calvert, S. (1994): Carbon isotope fractionation by a marine diatom: the influence of irradiance, daylength, pH and nitrogen source. - Limnology and Oceanography 39, 1835-1844.

Thorleifson, J.T. & Knauth, L.P. (1984): An improved stepwise fluorination procedure for the oxygen isotopic analysis of hydrous silica (abstract). - Geol. Soc. Am. Abstr. Progr. 16, 675-676.

Treydte, K., Schleser, G.H., Schweingruber, F.H. & Winiger, M. (2001): The climatic significance of $\delta^{13}C$ in subalpine spruces (Lötschental, Swiss Alps) – A case study with respect to altitude, exposure and soil moisture. - Tellus 53B (5), 593-611.

Turpin, D.H., Elrifi, I.R., Birch, D.G., Weger, H.G. & Holmes, J.J. (1988): Interactions between photosynthesis, respiration and nitrogen assimilation in microalgae. - Canadian Journal of Botany 66, 2083-2097

Urey, H.C., Lowenstam, H.A., Epstein, S., McKinney, C.R. (1951): Measurement of palaeotemperatures and temperatures of the upper cretaceous of England, Denmark and south-eastern United States. - Geological Society of America Bulletin 62, 399-416.

Van Dam, H., Mertens A. & Sinkeldam J. (1994): A coded checklist and ecological indicator values of freshwater diatoms from the Netherlands. - Netherlands Journal of Aquatic Ecology 28 (1), 117-133.

Van den Hoek, C., Mann, D.G., Johns, H.M. (1997): Algae: An introduction to phycology. - Cambridge University Press, Cambridge, UK.

Vrieling, E.G., Gieskes, W.W.C., Beelen, T.P.M. (1999): Silicon deposition in diatoms: control by the pH inside the silicon deposition vesicle. - Journal of Phycology 35: 548-559.

Wada, E. & Hattori, A. (1976): Natural abundance of ^{15}N in particulate organic matter in the North Pacific Ocean. - Geochimica et Cosmochimica Acta 40: 249-251.

Wada, E. & Hattori, A. (1978): Nitrogen isotope effects in the assimilation of inorganic nitrogenous compounds by marine diatoms. - Geomicrobiology Journal 1: 85-101.

Wang, C.-H- & Yeh, H.-W. (1984): Oxygen isotopic analysis of marine diatoms. - Bull. Inst. Earth Sci. Acad. Sinica 4, 131-140.

Werner, D. (1977): Silicate metabolism. - *In* Werner, D. [Ed.] *The biology of diatoms. Botanical monograph.* University of California Press, Berkeley, Vol 13, 110-149.

Wetzel, R.G. (2001): Limnology. Lake and river ecosystem. - Academic press.

Wong, W.W., Sackett, W.M. (1978): Fractionation of stable carbon isotope by marine phytoplankton. - Geochimica et Cosmochimica Acta 42, 1809-1815.

Zachos, J., Pagani, M., Sloan, L., Thomas, E., Billups, K. (2001): Trends, rhythms and aberrations in global climate 65 Ma to present. - Science 292, 686-692.

Zhang, J., **Quay, P.D., Wilbur, D.O.** (1995): Carbon isotope fractionation during gas-water exchange and dissolution of CO_2. - Geochimica et Cosmochimica Acta 59, 107-114.

Zimmermann, B., Schleser, G.H. & Bräuning, A. (1997): Preliminary results of a Tibetan stable C-isotope chronology dating from 1200 to 1994. - Isotopes in Environmental and Health Studies 33, 157-165.

Zurzolo, C., Bowler, C. (2001): Exploring bioinorganic pattern formation in diatoms. A story of polarised trafficking. - Plant Physiology 127: 1339-1345.

Danksagung

Diese Arbeit entstand im Institut für Chemie und Dynamik der Geosphäre V, Sedimentäre Systeme, des Forschungszentrums Jülich GmbH (FZJ) in Zusammenarbeit mit dem Geographischen Institut der Universität zu Köln. Sie wurde von der Mathematisch-Naturwissenschaftlichen Fakultät der Universität zu Köln als Dissertation angenommen. Die Referenten der Arbeit waren Herr Prof. Dr. U. Radtke vom Geographischen Institut der Universität zu Köln und Herr Prof. Dr. G.H. Schleser vom Institut für Chemie und Dynamik der Geosphäre V: Sedimentäre Systeme des Forschungszentrums Jülich GmbH. Die Disputation fand am 08. Februar 2006 statt.

Mein besonderer Dank gilt Herrn Prof. Dr. G.H. Schleser, Leiter des Instituts für Sedimentäre Systeme (ICG V) und der Projektgruppe Isotopengeochemie und Paläoklima sowie Herrn Prof. Dr. U. Radtke vom Geographischen Institut der Universität zu Köln für die Betreuung und wissenschaftliche Unterstützung bei der Anfertigung dieser Arbeit.

Herrn Dr. A. Lücke und Herrn Dr. H. Vos danke ich für die Hilfestellungen bei fachlichen Problemen und für die konstruktiven Diskussionen.

Ein besonderes Dankeschön gilt allen Mitarbeiterinnen und Mitarbeitern der Gruppe Isotopengeochemie und Paläoklima. Ohne sie hätte die Arbeit nicht durchgeführt werden können.

Mein größter Dank gilt meinen Eltern Wanda und Kazimierz Kowalczyk, von denen ich jederzeit Unterstützung erhielt.

Appendix

STABLE OXYGEN ISOTOPES OF BIOGENIC SILICA

Stable oxygen isotope ratios of biogenic silica from *Cyclotella meneghiniana* grown at various temperatures at two growth rates.

Growth rate μ (d^{-1})	Temperature (°C)	Sample	$\delta^{18}O_{SiO2}$ vs. V-SMOW (‰)				
	9	V14/D82	28.42	28.44	28.38	-	-
		V14/D91	28.42	28.89	29.35*	-	-
		V8/D89	26.8	27.12	26.75	-	-
		V8/D90	27.46	27.01	26.11*	-	-
0.2	12	V8/D91	27.56	-	-	-	-
		V8/D92	27.57	28.05	27.74	27.77	-
.		V14/D55	26.78	26.95	27.6	-	-
		V8/D80	26.21	26.4	26.27	26.51	-
		V8/D81	26.47	26.71	26.61	26.49	26.7
0.2	15	V8/D82	26.51	26.5	26.72	-	-
		V8/D83	26.92	26.56	26.42	27.16	-
		V14/D29	26.31	26.46	26.68	26.43	26.65
		V14/D31	26.84	26.87	26.69	26.51	-
		V15/D14	25.79	25.58	25.08*	-	-
0.2	18	V15/D15	25.63	25.85	26.11	-	-
		V15/D16	25.49	26.0	25.96	-	-
		V15/D17	25.98	26.23	25.86	25.72	-
		V8/D67	26.73	26.84	26.62	-	-
0.2	21	V8/D68	26.96	26.7	-	-	-
		V8/D69	26.25	25.92	25.38*	-	-
		V8/D71	26.02	26.38	26.97	-	-
		V8/D35	26.53	26.58	26.73	-	-
		V8/D36	26.7	26.83	26.8	26.89	-
0.34	15	V8/D37	26.49	26.6	26.46	26.56	26.82
		V8/D39	28.66	28.63	28.54	-	-
		V8/D19	26.4	26.3	26.8	-	-
		V8/D22	26.02	26.29	26.42	-	-
0.34	18	V8/D23	26.29	26.27	26.32	26.41	26.29
		V6/D11	26.15	26.25	26.85*	-	-
		V6/D14	26.39	26.22	26.54	26.48	26.29
		V8/D54	25.46	25.23	24.58*	-	-
		V8/D55	25.68	25.31	25.61	25.3	25.63
		V8/D56	25.37	25.43	25.28	-	-
		V8/D57	25.35	25.39	25.01	-	-
0.34	21	V8/D58	25.75	25.62	25.62	-	-
		V8/D59	26.1	25.6	26.7*	-	-
		V8/D60	25.49	25.22	25.5	-	-
		V8/D61	25.32	25.58	-	-	-
		V8/D62	25.89	25.87	25.53	25.79	25.49
0.34	24	V8/D7	26.0	26.3	26.2	-	-
		V8/D13	26.26	26.21	-	-	-

Stable oxygen isotope ratios of biogenic silica from *Fragilaria crotonensis* grown at various temperatures.

Growth rate μ (d^{-1})	Temperature (°C)	Sample	$\delta^{18}O_{SiO2}$ vs. V-SMOW (‰)				
0.34	15	V7/D31	28.77	28.47	28.37	-	-
		V7/D34	28.84	28.57	26.22*	-	-
0.34	18	V5/D40	26.83	26.68	25.92*	-	-
		V5/D41	26.82	26.8	26.76	26.77	26.42
0.34	21	V7/D12	26.25	26.45	26.55	-	-
0.34	24	V5/D28	25.62	25.69	25.58	24.83*	-
		V5/D30	25.7	25.8	-	-	-

Stable oxygen isotope ratios of biogenic silica from experiment Nr 5 with *Fragilaria crotonensis* grown at various nitrate concentrations of the medium.

Growth rate μ (d^{-1})	Temperature (°C)	Nitrate concentration of the medium (mg/l)	Sample	$\delta^{18}O_{SiO2}$ vs. V-SMOW (‰)			
0.34	24	10.5	V5/D3	26.18	25.78	-	-
			V5/D4	26.24	25.94	-	-
			V5/D5	25.67	25.37	26.67*	-
			V5/D6	26.01	26.21	26.01	-
0.34	24	21	V5/D10	25.87	25.77	25.77	-
			V5/D11	26.24	26.24	26.14	-
			V5/D12	26.32	26.32	-	-
			V5/D13	25.75	25.45	26.7*	-
0.34	24	52.5	V5/D22	26.56	26.46	-	-
			V5/D23	25.55	25.55	-	-
			V5/D25	26.17	25.91	26.15	26.35
0.34	24	105	V5/D28	25.62	25.69	25.58	24.83*
			V5/D30	25.7	25.8	-	-

Stable oxygen isotope ratios of biogenic silica from experiment Nr 15 with *Cyclotella meneghiniana* grown at various light intensities.

Growth rate μ (d^{-1})	Temperature (°C)	Light intensity (µmol photons $m^{-2}s^{-1}$)	Sample	$\delta^{18}O_{SiO2}$ vs. V-SMOW (‰)				
0.2	18	200	V15/D104	25.57	25.56	24.8*	-	-
			V15/D106	25.93	25.98	25.70	25.67	-
			V15/D108	25.65	25.65	25.33	25.60	24.23*
0.2	18	500	V15/D14	25.79	25.58	25.08*	-	-
			V15/D15	25.63	25.85	26.11	-	-
			V15/D16	25.49	26.00	25.96	-	-
			V15/D17	25.98	26.23	25.86	25.72	-
0.2	18	1100	V15/D54	26.29	26.48	26.01	25.75	25.96
			V15/D56	26.16	26.15	26.00	23.43*	-
			V15/D58	25.90	26.07	26.08	25.17*	-
0.2	18	1700	V15/D70	26.43	26.54	26.70	26.53	-
			V15/D73	26.60	26.34	26.40	26.19	-
			V15/D77	26.32	26.42	26.44	26.43	26.32

- non-existent

* outlier, not taken into consideration in this study

Results of the experiment Nr 5 with *Fragilaria crotonensis* grown at various temperatures and nitrate concentrations of the medium.

Temperature (°C)	Nitrate concentration of the medium (mg/l)	Growth rate μ (d^{-1})	Days	Date	Extinction 560nm	Dry mass (mg/l)	Sample	$\delta^{18}O$ medium from fermenter vs. V-SMOV (‰)	$\delta^{18}O$ medium 1 vs. V-SMOV (‰)	$\delta^{18}O$ medium 2 vs. V-SMOV (‰)	$\delta^{18}O$ laboratory water vs. V-SMOV (‰)	ε_{13C} (‰)	ε_{15N} (‰)	Ca^{2+} medium (mg/l)
			1	15.01.2002	0.173	124.2	D1	-	-	-	-7.51	-	-0.2	-
			2	16.01.2002	0.551	220.8	D2	-7.31	-	-	-	-25.24	0	-
24	**21**	**0.34**	3	17.01.2002	0.585	243.3	D3	-7.33	-	-	-7.53	-25.58	0	-
			4	18.01.2002	0.583	236	D4	-7.39	-7.45	-7.54	-	-25.72	0	3.5
			7	21.01.2002	0.599	246.1	D5	-6.77	-	-	-	-25.78	-0.2	-
			8	22.01.2002	0.566	206.3	D6	-7.59	-	-	-7.53	-26.06	-0.1	-
			9	23.01.2002	0.573	211	D7	-7.43	-7.50	-7.49	-	-25.8	-0.1	7
			10	24.01.2002	0.552	219.3	D8	-7.22	-	-	-	-25.91	-0.1	-
24	**10.5**	**0.34**	11	25.01.2002	0.515	199	D9	-7.63	-	-	-7.43	-25.75	-0.2	-
			14	28.01.2002	0.408	175.9	D10	-6.77	-7.29	-7.43	-	-25.54	-0.2	3.5
			15	29.01.2002	0.427	186	D11	-7.55	-	-	-	-25.52	-0.2	-
			16	30.01.2002	0.408	172.3	D12	-7.34	-	-	-	-25.3	-0.3	-
			17	31.01.2002	0.393	169.8	D13	-7.13	-	-	-	-25.6	-0.2	-
			18	01.02.2002	0.402	-	-	-	-7.43	-7.51	-7.52	-	-	-
			19	02.02.2002	-	-	-	-6.95	-	-	-	-	-	16.9
			21	04.02.2002	0.671	190.5	D14	-7.26	-	-	-	-26.1	-0.2	-
			22	05.02.2002	0.704	250.5	D15	-6.89	-	-	-	-26.43	0	-
			23	06.02.2002	0.77	278.6	D16	-7.04	-7.44	-7.43	-7.47	-26.44	0	8.3
			24	07.02.2002	0.763	256.6	D17	-7.54	-7.45	-7.44	-7.59	-26.97	0	16.5
24	**52.5**	**0.34**	25	08.02.2002	0.796	-	-	-	-	-	-	-	-	-
			28	10.02.2002	0.798	277.2	D18	-	-7.34	-7.44	-7.59	-26.67	-0.1	16.3
			29	12.02.2002	0.798	282.4	D19	-7.35	-	-	-	-26.37	-0.3	-
			30	13.02.2002	0.793	316.1	D20	-7.14	-	-	-	-26.08	-0.2	-
			31	14.02.2002	0.789	296.5	D21	-7.21	-	-	-	-26.18	0	-
			32	15.02.2002	0.795	296.8	D22	-7.32	-7.53	-7.45	-7.41	-26.18	-0.1	17
			35	18.02.2002	0.777	285	D23	-7.42	-	-	-	-26.14	-0.2	-
			36	19.02.2002	0.768	298.7	D24	-7.30	-	-	-	-25.98	-0.1	-
			37	20.02.2002	0.769	285.7	D25	-7.33	-7.38	-7.56	-	-26.03	-0.1	33.8
			38	21.02.2002	0.813	-	D26	-7.25	-	-	-	-25.86	-0.1	-
			39	22.02.2002	0.843	-	D27	-7.24	-	-	-	-25.76	0	-
24	**105**	**0.34**	42	25.02.2002	0.877	306.8	D28	-7.18	-7.43	-	-	-25.71	-0.4	17.7
			43	26.02.2002	0.874	320.8	D29	-7.37	-7.43	-7.48	-7.59	-25.8	-0.3	34.7
			44	27.02.2002	0.871	305.4	D30	-7.11	-	-	-	-25.79	0	-
			45	28.02.2002	0.827	288.8	D31	-7.09	-7.39	-7.35	-7.51	-25.76	-0.3	33.8
			46	01.03.2002	0.828	227.7	D32	-7.16	-	-	-	-26.41	-0.4	-
			49	04.03.2002	0.76	236.8	D33	-	-	-	-	-26.31	-0.5	-
			50	05.03.2002	0.781	281.8	D34	-7.04	-7.33	-7.37	-7.69	-26.43	-0.5	32.7
			51	06.03.2002	0.78	285.5	D35	-7.21	-	-	-	-26.37	-0.6	-
18	**105**	**0.34**	52	07.03.2002	0.766	287.6	D36	-7.55	-	-	-	-26.49	-0.6	-
			53	08.03.2002	0.799	280.1	D37	-7.15	-	-	-	-26.48	-0.7	-
			56	10.03.2002	-	-	-	-	-7.35	-7.36	-7.67	-	-	32.3
			57	11.03.2002	0.772	283.4	D38	-7.15	-	-	-	-26.6	-0.8	-
			58	12.03.2002	0.777	287.7	D39	-7.28	-	-	-	-26.42	-1	-
			59	13.03.2002	0.779	277.3	D40	-7.14	-	-	-	-26.66	-0.8	-
			60	14.03.2002	0.778	285.9	D41	-7.72	-	-	-	-26.64	-0.8	-
			61	15.03.2002	0.704	284.7	D42	-7.47	-7.46	-7.33	-7.76	-26.62	-0.8	33.1
			64	18.03.2002	0.665	256.3	D43	-7.23	-	-	-	-26.67	-0.8	-
12	**105**	**0.34**	65	19.03.2002	0.639	244.8	D44	-7.48	-	-	-	-26.65	-1.3	-
			66	20.03.2002	0.667	223.2	D45	-7.36	-7.44	-7.45	-7.5	-	-1.3	33.1
			67	21.03.2002	0.658	267.9	D46	-	-	-	-	-	-1.4	-
			68	22.03.2002	-	259.4	D47	-7.12	-	-	-	-	-1.4	-

steady state
- non-existent

Results of the experiment Nr 5 with *Fragilaria crotonensis* grown at various temperatures and nitrate concentrations of the medium. (For temperatures see previous page).

Days	Ca^{2+} susp. (mg/l)	Fe^{2+} medium (mg/l)	Fe^{2+} susp. (mg/l)	K^{+} medium (mg/l)	K^{+} susp. (mg/l)	Mg^{2+} medium (mg/l)	Mg^{2+} susp. (mg/l)	Na^{+} medium (mg/l)	Na^{+} susp. (mg/l)	Si^{2+} medium (mg/l)	Si^{2+} susp. (mg/l)	Chloride medium (mg/l)	Chloride susp. (mg/l)	Nitrate medium (mg/l)	Nitrate susp. (mg/l)	Phosphate medium (mg/l)	Phosphate susp. (mg/l)	Sulphate medium (mg/l)	Sulphate susp. (mg/l)
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	-	10.5	-	10	-	2.4	-	50	-	42	-	0.25	-	22	-	9.54	-	28.6	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	7.2	10.6	8.3	9.5	9.8	2.4	2.1	50.5	56.5	39.5	1.7	0.39	2.28	10.3	0.17	9.63	2.12	28.3	19.3
10	5.9	-	9.8	-	9	-	1.9	-	52	-	1.9	-	1.4	-	0.15	-	2.64	-	18.5
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	4.4	10.8	10.7	9.8	9	2.6	2.2	50	51	40.5	2.3	0.24	1.76	10.7	1.76	9.32	4.51	28.6	21.1
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	4	-	10	-	9.5	-	2.2	-	51.5	-	1.9	-	1.5	-	1.5	-	5.69	-	22.2
18	-	-	-	-	-	-	-	-	-	-	-	0.37	-	54.8	-	8.8	-	28.9	-
19	-	10.4	-	9.1	-	2.5	-	49.5	-	40.5	-	-	-	-	-	-	-	-	-
21	11	-	11.2	-	8.9	-	2.3	-	50.4	-	2.6	-	1.33	-	1.33	-	4.35	-	17.8
22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23	-	10.4	-	8.3	-	2.7	-	47.5	-	37.5	-	0.26	-	26.6	-	8.46	-	30.3	-
24	-	10.4	-	9.9	-	2.5	-	46.4	-	37.7	-	0.28	-	53.3	-	9.8	-	28.8	-
25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
28	13.8	10.5	8.5	9.9	8.3	2.5	1.9	47.1	46.7	36.5	1.7	0.31	1.13	52.6	0.11	9.6	1.21	29.1	10.8
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
31	15.2	-	8.6	-	8.3	-	1.9	-	45.4	-	1.8	-	1.11	-	0.16	-	1.97	-	12.1
32	-	10.6	-	9.8	-	2.5	-	47.7	-	36.8	-	0.26	-	54.1	-	10.3	-	29.5	-
35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
37	13.5	10.8	6	9.9	7.3	2.6	1.6	50.1	41.7	38.3	1.4	0.36	1.71	105	0.15	7.07	2.09	31.7	11.6
38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
39	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
42	29	10.8	3.6	9.8	9.2	2.5	2.2	48.8	53	37.8	0.56	0.25	1.36	54.2	13.8	11	1.82	30.3	13.7
43	-	10.4	-	9.6	-	2.5	-	47.6	-	37.3	-	0.24	-	106	-	6	-	30.5	-
44	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
45	31	10	6.5	9.8	9.5	2.6	2.3	49.6	51.9	36.9	1	0.27	1.25	106	9.23	6.2	3.23	30.3	14.1
46	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
49	29.5	-	2.9	-	8.4	-	2.2	-	50.4	-	0.59	-	1.35	-	14	-	1.36	-	13
50	-	10		9.6	-	2.5	-	48	-	37.5	-	0.24	-	107	-	6.8	-	28.2	-
51	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
52	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
53	30.2	-	3.8	-	8.9	-	2	-	54.3	-	0.75	-	1.74	-	11	-	0.21	-	12.5
56	-	10	-	9.5	-	2.5	-	48.6	-	39.4		0.24	-	107	-	6.8	-	28.6	-
57	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
58	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
59	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
60	31.6	-	2.8	-	8.8	-	2.1	-	52	-	0.85	-	1.21	-	29.6	-	1.33	-	14.4
61	-	10.2	-	9.7	-	2.5	-	49.3	-	39.1	-	0.26	-	107		5.52	-	28.7	-
64	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
65	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
66	31.4	10	4.1	9.5	8.5	2.5	2	49	50.8	39.4	1.2	0.27	0.43	106	42.7	6.93	0.05	28	17.4
67	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
68	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

susp. = suspension
- non-existent

Results of the experiment Nr 6 with *Cyclotella meneghiniana* grown at various temperatures.

Temperature (°C)	Growth rate μ (d^{-1})	Days	Date	Extinction 560nm	Dry mass (mg/l)	Sample	$\delta^{18}O$ medium 1 vs. V-SMOV (‰)	$\delta^{18}O$ medium 2 vs. V-SMOV (‰)	$\delta^{18}O$ laboratory water vs. V-SMOV (‰)	$\delta^{18}O$ medium from fermenter vs. V-SMOV (‰)	ε_{13C} (‰)	Ca^{2+} medium (mg/l)
		1	23.04.2002	0.114			-	-	-	-	-	17.4
		2	24.04.2002	0.23	41.5	D1	-	-	-	-7.34	-23.59	-
		3	25.04.2002	0.372	85.3	D2	-	-	-	-7.56	-22.83	18.1
		4	26.04.2002	0.489	122.9	D3	-7.42	-7.44	-7.8	-7.5	-22.77	-
		7	29.04.2002	0.631	210.9	D4	-	-	-	-	-22.92	-
		8	30.04.2002	0.659	258.7	D5	-	-	-	-7.51	-22.52	-
		9	01.05.2002		282.4	D6	-7.41	-7.38	-7.91	-	-22.49	17.5
		10	02.05.2002	0.644	278.1	D7	-	-	-	-7.59	-22.8	-
		11	03.05.2002	0.694	279.7	D8	-	-	-	-7.57	-22.94	-
18	**0.34**	14	06.05.2002	0.702			-7.4	-7.53	-7.73	-7.58	-	26.4
		15	07.05.2002	0.726	292.8	D9	-	-	-	-7.59	-22.63	-
		16	08.05.2002	0.706	313	D10	-	-7.37	-	-7.44	-22.58	29.1
		21	13.05.2002	0.729			-7.41	-7.37	-	-7.55	-	17.5
		22	14.05.2002	0.714	304.9	D11	-	-	-	-7.71	-22.8	-
		23	15.05.2002	0.717	312.1	D12	-	-	-	-7.61	-22.79	-
		24	16.05.2002	0.733	292.8	D13	-7.33	-7.44	-	-7.52	-22.99	17.6
		25	17.05.2002	0.737	317.8	D14	-7.53	-7.36	-7.69	-7.48	-22.72	17
		29	21.05.2002	0.717			-	-	-	-7.5	-	-
		30	22.05.2002	0.711	282	D15	-7.43	-7.4	-7.69	-7.41	-22.98	16.8
		31	23.05.2002	0.704	292.4	D16	-	-	-	-7.49	-22.8	-
		32	24.05.2002	0.654	295.9	D17	-	-	-	-7.68	-23.04	-
		33	25.05.2002				-7.48	-	-7.72	-	-	16.7
		35	27.05.2002	0.64			-	-	-	-7.45	-	-
		36	28.05.2002	0.607	262.2	D18	-	-	-	-7.4	-22.98	-
		37	29.05.2002	0.596	256.4	D19	-7.51	-7.48	-7.78	-7.5	-23.73	17
		42	03.06.2002	0.551			-7.42	-7.49	-7.8	-7.55	-	16.7
15	**0.34**	43	04.06.2002	0.546	219.9	D20	-	-	-	-7.35	-23.66	-
		44	05.06.2002	0.531	211.9	D21	-	-	-	-7.45	-24	-
		45	06.06.2002	0.526	207.4	D22	-7.5	-	-7.76	-7.28	-23.81	17.2
		46	07.06.2002	0.514	217.7	D23	-	-	-	-7.51	-23.75	-
		49	10.06.2002	0.483			-	-	-	-7.45	-	-
		50	11.06.2002	0.484	179.1	D24	-7.43	-7.44	-7.79	-7.36	-24.08	16.3
		51	12.06.2002	0.424	165.7	D25	-	-	-	-7.51	-23.99	-
		52	13.06.2002	0.394	146.4	D26	-	-	-	-7.44	-23.97	-
		53	14.06.2002	0.345	135.7	D27	-7.48	-	-7.86	-	-23.85	17.3
		56	17.06.2002	0.2			-	-	-	-7.55	-	-

steady state
- non-existent

Results of the experiment Nr 6 with *Cyclotella meneghiniana* grown at various temperatures. (For T see previous page).

Days	Ca^{2+} susp. (mg/l)	Fe^{2+} medium (mg/l)	Fe^{2+} susp. (mg/l)	K^{+} medium (mg/l)	K^{+} susp. (mg/l)	Mg^{2+} medium (mg/l)	Mg^{2+} susp. (mg/l)	Na^{+} medium (mg/l)	Na^{+} susp. (mg/l)	Si^{2+} medium (mg/l)	Si^{2+} susp. (mg/l)	Chloride medium (mg/l)	Chloride susp. (mg/l)	Nitrate medium (mg/l)	Nitrate susp. (mg/l)	Phosphate medium (mg/l)	Phosphate susp. (mg/l)	Sulphate medium (mg/l)	Sulphate susp. (mg/l)
1	-	10.1	-	10.1	-	2.7	-	48.1	-	40.9	-	13.66	-	54.2	-	8.75	-	28.8	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	17.9	10	10	8.4	10	2.5	2.4	46	55.2	37.9	26.4	16.97	2.87	55.8	0.06	7.2	3.23	28.9	26.9
4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	-	10.4	-	8.8	-	2.5	-	48.4	-	40.8	-	55.23	-	54.2	-	8.1	-	29.2	-
10	17.2	-	6.1	-	6.3	-	2.1	-	45.1	-	1.1	-	1.2	-	0.23	-	<0.05	-	21.2
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	16.7	9.7	6	8.5	6.2	2.6	2.1	48.3	49.5	39.5	1.4	0.1	0.99	53.8	0.31	7.3	<0.05	27.5	20.4
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	17.3	10.1	8.2	9	6.2	2.5	2.1	48.7	49.4	39.3	1.6	56.6	0.82	-	0.21	7.6	<0.05	28.3	20
21	22.5	9.7	9.1	9.1	7.8	2.5	2.3	45	47.4	40.6	2.4	-	0.68	53.4	0.28	-	0.05	-	20.8
22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23	17.6	-	5.1	-	6	-	2.2	-	43.9	-	1.2	-	1.74	-	0.59	-	0.18	-	20.5
24	-	10.4	-	8.2	-	2.5	-	46.3	-	39.2	-	0.16	-	52.6	-	9.3	-	27.8	-
25	-	10.1	-	9	-	2.5	-	44.2	-	44	-	0.08	-	52.6	-	11.1	-	28.6	-
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	17.8	8.9	10.2	8.4	6.5	2.4	2.4	44.2	45.4	38	3.2	0.15	1.11	52.2	0.48	9.07	0.24	26.4	22.2
31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
32	18.2	-	9	-	6.7	-	2.3	-	47.1	-	2.6	-	1.21	-	0.72	-	0.34	-	21.6
33	-	10	-	8.6	-	2.5	-	45.2	-	41	-	0.09	-	54.1	-	11.3	-	28.7	-
35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
36	17.4	-	9.6	-	6.8	-	2.2	-	46.5	-	1.9	-	0.85	-	0.49	-	0.04	-	22.7
37	-	9.8	-	7.7	-	2.4	-	37.8	-	15.3	-	0.09	-	55.6	-	10.9	-	28.9	-
42	16.6	9.2	6	7.9	6.5	2.5	2	42.8	39.7	18.9	0.85	0.15	0.62	54	0.53	10.6	0.22	27.3	23.3
43	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
44	16.4	-	5.6	-	6.5	-	2	-	41.6	-	3.3	-	0.57	-	0.28	-	<0.05	-	21.9
45	-	9.9	-	8.4	-	2.4	-	45.9	-	29	-	0.19	-	56.1	-	10.8	-	28.5	-
46	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
49	17.1	-	6.8	-	7.1	-	2	-	44.7	-	6.4	-	0.65	-	0.31	-	<0.05	-	23.8
50	-	9.1	-	8	-	2.3	-	34.3	-	34.7	-	0.22	-	52.4	-	8.9	-	28.4	-
51	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
52	17	-	7.1	-	7.8	-	2.1	-	41.9	-	17	-	0.7	-	0.8	-	2.45	-	24.6
53	-	9.8	-	8.7	-	2.4	-	45.2	-	36.1	-	0.19	-	53.6	-	9.2	-	29.3	-
56	17.4	-	7.3	-	8.6	-	2.3	-	44.4	-	25.8	-	0.8	-	24.1	-	6.4	-	27.8

susp. = suspension
- non-existent

Results of the experiment Nr 7 with *Fragilaria crotonensis* grown at various temperatures.

Temperature (°C)	Growth rate μ (d^{-1})	Days	Date	Extinction 560nm	Dry mass (mg/l)	Sample	ε_{13C} (‰)	$\delta^{18}O$ medium from fermenter vs. V-SMOV (‰)	$\delta^{18}O$ medium 1 vs. V-SMOV (‰)	$\delta^{18}O$ medium 2 vs. V-SMOV (‰)	$\delta^{18}O$ water vs. V-SMOV (‰)	$\delta^{18}O_{org}$ vs. V-SMOV (‰)	ε_{15N} (‰)	Ca^{2+} medium (mg/l)
		1	25.04.2002	0.228			-	-	-	-	-	-	-	16.8
		2	26.04.2002	0.539		D1	-24.39	-6.90	-	-	-	18.57	-	-
		5	29.04.2002	0.748			-	-	-	-7.55	-7.72	-	-	33.1
		6	30.04.2002	0.695	293.3	D2	-25.99	-7.00	-	-	-	18.63	-	-
		7	01.05.2002		298.9	D3	-25.81	-	-7.24	-	-	17.81	-	-
		8	02.05.2002	0.736	296.9	D4	-25.76	-6.99	-7.68	-	-7.64	16.68	-	34.1
		9	03.05.2002	0.772	295.7	D5	-25.94	-7.01	-	-	-	16.54	-	-
21	**0.34**	12	06.05.2002	0.775			-	-	-7.24	-	-	-	-	-
		13	07.05.2002	0.805	287.9	D6	-26.05	-7.19	-7.38	-	-7.68	16.9	-	35.3
		14	08.05.2002	0.782	311.3	D7	-25.77	-7.11	-7.44	-7.45	-	16.91	-	35.5
		19	13.05.2002	0.779			-	-7.18	-7.51	-7.39	-	-	-	34.3
		20	14.05.2002	0.781	307.5	D8	-25.84	-7.15	-	-	-	16.38	4.78	-
		21	15.05.2002	0.725	321.4	D9	-25.89	-7.16	-	-	-	15.68	4.83	-
		22	16.05.2002	0.749	305.7	D10	-25.78	-7.14	-	-7.51	-7.73	16.46	4.73	32.4
		23	17.05.2002	0.728	306.7	D11	-25.85	-7.04	-7.5	-7.53	-7.73	17.38	4.74	33.1
		27	21.05.2002	0.687			-	-6.94	-	-	-	-	-	-
		28	22.05.2002	0.671	261.3	D12	-26.02	-6.96	-	-7.47	-7.65	17.12	4.59	37.5
		29	23.05.2002	0.631	271.8	D13	-25.72	-7.17	-	-	-	17.27	-	-
		30	24.05.2002	0.602	258.5	D14	-25.68	-6.94	-	-	-	17.07	-	-
		31	25.05.2002				-	-	-7.59	-7.69	-7.65	-	-	32.7
		33	27.05.2002	0.626			-	-7.25	-	-	-	-	-	-
		34	28.05.2002	0.654	253.3	D15	-26.06	-7.44	-	-	-	16.62	-	34
		35	29.05.2002	0.682	269.6	D16	-26.02	-7.34	-7.56	-7.42	-7.85	17.58	-	-
		40	03.06.2002	0.715			-	-7.33	-7.55	-7.63	-7.65	-	-	36.1
		41	04.06.2002	0.733	292.9	D17	-26.34	-7.28	-	-	-	16.75	-	-
		42	05.06.2002	0.743	291.2	D18	-26.05	-7.30	-	-	-	16.74	-	-
		43	06.06.2002	0.721	318.9	D19	-26.02	-7.20	-7.53	-7.42	-7.69	17.07	-	32.8
		44	07.06.2002	0.734	311.3	D20	-26.02	-7.30	-	-	-	16.96	-	-
		47	10.06.2002	0.737			-	-7.32	-	-	-	-	-	-
		48	11.06.2002	0.742	308.8	D21	-26.05	-7.47	-7.41	-7.49	-7.6	17.02	-	33.4
15	**0.34**	49	12.06.2002	0.753	311.7	D22	-26.11	-7.44	-	-	-	17.49	4.81	-
		50	13.06.2002	0.757	316.1	D23	-26.14	-7.17	-	-	-	17.32	4.53	-
		51	14.06.2002	0.759	310.1	D24	-26.08	-7.41	-7.45	-	-7.67	17.08	4.88	33.2
		54	17.06.2002	0.729			-	-7.30	-	-	-	-	-	-
		55	18.06.2002	0.705	304.2	D25	-26.09	-7.21	-	-	-	16.73	4.67	-
		56	19.06.2002	0.697	268.8	D26	-26.55	-7.39	-7.63	-7.5	-7.64	17.2	4.94	32.4
		57	20.06.2002	0.718	272.4	D27	-26.44	-	-	-	-	16.85	4.43	-
		58	21.06.2002	0.719	286.7	D28	-26.31	-7.48	-	-	-	16.83	4.51	-
		61	24.06.2002	0.75			-	-7.17	-7.39	-7.56	-7.69	-	-	32.9
		62	25.06.2002	0.74	302.2	D29	-	-7.50	-	-	-	16.68	4.82	-
		63	26.06.2002	0.723	293.9	D30	-26.4	-7.20	-	-	-	16.97	4.88	-
		64	27.06.2002	0.723	303.2	D31	-26.34	-	-	-	-	-	4.63	-
		65	28.06.2002	0.715	306.4	D32	-26.36	-7.38	-7.49	-7.59	-7.7	-	4.83	35.1
		68	01.07.2002	0.747			-	-7.16	-	-	-	-	-	-
		69	02.07.2002	0.731	287.6	D33	-26.41	-7.04	-	-	-	-	4.67	-
		70	03.07.2002	0.742	284.9	D34	-26.39	-7.01	-	-	-	-	4.81	-
		71	04.07.2002	0.766	294.1	D35	-26.32	-7.20	-7.58	-7.5	-7.62	-	4.58	33.4
		72	05.07.2002	0.759	323.9	D36	-25.94	-6.92	-	-	-	-	4.84	-

steady state
- non-existent

Results of the experiment Nr 7 with *Fragilaria crotonensis* grown at various temperatures. (For T see previous page).

Days	Ca^{2+} susp. (mg/l)	Fe^{2+} medium (mg/l)	Fe^{2+} susp. (mg/l)	K^{+} medium (mg/l)	K^{+} susp. (mg/l)	Mg^{2+} medium (mg/l)	Mg^{2+} susp. (mg/l)	Na^{+} medium (mg/l)	Na^{+} susp. (mg/l)	Si^{2+} medium (mg/l)	Si^{2+} susp. (mg/l)	Chloride medium (mg/l)	Chloride susp. (mg/l)	Nitrate medium (mg/l)	Nitrate susp. (mg/l)	Phosphate medium (mg/l)	Phosphate susp. (mg/l)	Sulphate medium (mg/l)	Sulphate susp. (mg/l)
1	-	9.7	-	8.1	-	2.4	-	47.8	-	38.1	-	25.2	-	55.2	-	6	-	29.4	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	9.1	-	8	-	2.4	-	48	-	38.9	-	28.86	-	108	-	5.9	-	27.3	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	25.6	10	4.5	8.7	8.3	2.5	2.1	39.7	49.2	40.6	0.79	0.11	2.95	107	5.9	9.5	1.18	28.6	18.8
9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	29.5	-	5	-	7.5	-	2	-	47.7	-	1.1	-	1.24	-	12	-	0.5	-	12.4
13	-	9.8	-	8.6	-	2.5	-	45.5	-	37.9	-	0.2	-	111	-	6.9	-	28.1	-
14	31.8	9.8	6	9.1	7.7	2.5	2.1	48.4	47.6	40.2	1.2	51.06	1.29	107	15.2	4.3	0.41	29.1	11.4
19	32.1	9.5	3.5	9.4	8.4	2.5	2.1	48.5	46.6	40.1	0.52	-	1.4	-	21.8	-	1.29	-	14.5
20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.1	-	27.2	-
21	34.2	-	4.6	-	8.9	-	2.2	-	50.6	-	0.82	-	1.21	-	-	-	<0.05	-	13.4
22	-	7.9	-	8.5	-	2.4	-	46.3	-	38.6	-	0.2	-	108	-	5.4	-	26.9	-
23	-	8.9	-	8.3	-	2.5	-	48	-	39	-	0.3	-	104	-	5.7	-	28.9	-
27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
28	33.3	11.2	4.4	8.8	8.1	2.6	2.3	49.2	50.3	38.9	0.77	0.1	1.78	106	-	5.6	2.2	26.8	22.2
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	33.3	-	3.4	-	9	-	2.3	-	49.9	-	0.57	-	1.12	-	50.5	-	2.86	-	20.5
31	-	9.6	-	8.3	-	2.4	-	40.2	-	18.6	-	0.1	-	115	-	7.7	-	28.8	-
33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
34	33.7	9.7	4.5	8.3	8.7	2.4	2.8	42	45.5	18.1	0.78	0.1	1.11	113	30.6	4.1	1	28.9	19.4
35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
40	31.4	9.4	2.7	8.2	7.7	2.4	2.1	42.6	42.5	18.9	0.44	0.1	0.86	117	36	3.5	1.72	26.5	16.7
41	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
42	31.2	-	2.3	-	7.5	-	2	-	42.9	-	0.38	-	0.86	-	29.5	-	1.37	-	15.2
43	-	9.8	-	8.6	-	2.4	-	39.7	-	35.3	-	0.1	-	106	-	6.4	-	29	-
44	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
47	31.9	-	8.7	-	7.3	-	2.1	-	39.9	-	1.4	-	0.76	-	30.1	-	1.14	-	14.5
48	-	9.5	-	8.1	-	2.4	-	33.5	-	34.4	-	0.3	-	107	-	6.29	-	29.9	-
49	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
50	32.8	-	4.3	-	7.2	-	2.1	-	42.4	-	0.52	-	0.98	-	30.5	-	0	-	16.1
51	-	9.8	-	9.3	-	2.3	-	44.5	-	36.2	-	0.2	-	104	-	6.6	-	29.8	-
54	33	-	3.5	-	7.9	-	2	-	47.5	-	0.44	-	1.01	-	30.4	-	0.49	-	16.4
55	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
56	-	9.9	-	9.2	-	2.5	-	44.2	-	40.4	-	0.4	-	105	-	4.6	-	31	-
57	32.9	-	3.4	-	7.9	-	2	-	56.5	-	0.45	-	1.06	-	29.7	-	0.39	-	17.7
58	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
61	-	9.8	-	8.9	-	2.5	-	45.7	-	36.9	-	0.3	-	103	-	5.7	-	30.4	-
62	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
63	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
64	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
65	32.1	9.9	3.1	8.6	7.8	2.6	2.1	45.9	56.5	36.4	0.47	0.3	1.08	110	29.9	5.6	0.4	29.7	17.5
68	32.4	-	2.6	-	7.6	-	2.2	-	47.5	-	0.34	-	1.14	-	32.3	-	0.39	-	19
69	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
71	-	8.7	-	9.1	-	2.5	-	43.7	-	36.8	-	0.2	-	105	-	4.4	-	27.4	-
72	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

susp. = suspension
- non-existent

Results of the experiment Nr 8 with *Cyclotella meneghiniana* grown at various temperatures at two growth rates.

Temperature (°C)	Growth rate μ (d^{-1})	Days	Date	Extinction 560nm	Dry mass (mg/l)	Sample	ε_{15N} (‰)	$\delta^{18}O$ medium from fermenter vs. V-SMOV (‰)	$\delta^{18}O$ water vs. V-SMOV (‰)	$\delta^{18}O$ medium 1 vs. V-SMOV (‰)	$\delta^{18}O$ medium 2 vs. V-SMOV (‰)	ε_{13C} (‰)	Ca^{2+} medium (mg/l)
		1	27.06.2002	0.713			-	-	-7.71	-7.27	-	-	16.5
		6	02.07.2002	0.732	337.7	D1	-	-7.28	-	-	-	-22.48	-
		7	03.07.2002	0.782	362.4	D2	-	-7.44	-	-	-	-22.52	-
		8	04.07.2002	0.792	381.5	D3	-	-7.34	-7.53	-	-	-22.7	-
		9	05.07.2002	0.811	309.1	D4	-	-7.46	-	-7.37	-7.47	-23.84	16.4
		13	09.07.2002	0.8	377.5	D5	-	-7.37	-	-	-	-23.26	-
		14	10.07.2002	0.793	386.6	D6	-	-7.39	-7.58	-7.25	-7.50	-23.18	16.5
24	**0.34**	15	11.07.2002	0.784	365.1	D7	-0.75	-7.43	-	-	-	-23.3	-
		16	12.07.2002	0.789	310.4	D8	-0.69	-7.14	-	-	-	-23.49	-
		20	16.07.2002	0.815	345.7	D9	-0.75	-7.32	-7.77	-7.38	-7.42	-23.51	16.9
		21	17.07.2002	0.81		D10	-0.56	-7.37	-	-	-	-23.32	-
		22	18.07.2002	0.809	339.6	D11	-0.70	-7.50	-	-	-	-23.57	-
		23	19.07.2002	0.809	348.5	D12	-0.64	-7.42	-	-	-	-23.38	-
		25	21.07.2002				-	-	-7.55	-7.42	-7.45	-	17.3
		26	22.07.2002	0.778			-	-7.38	-	-	-	-	-
		27	23.07.2002	0.761	373.8	D13	-0.56	-7.34	-	-	-	-22.94	-
		28	24.07.2002	0.75	326.9	D14	-	-7.30	-	-	-	-23.35	-
		29	25.07.2002	0.723	340.5	D15	-	-7.33	-	-	-	-23.48	-
		30	26.07.2002	0.67	313.2	D16	-	-7.36	-7.63	-7.46	-7.38	-23.66	17.3
		33	29.07.2002				-	-7.24	-	-	-	-	-
		34	30.07.2002	0.681	306.4	D17	-	-7.41	-	-	-	-23.31	-
18	**0.34**	35	31.07.2002	0.682	306	D18	-	-7.45	-7.78	-7.33	-7.39	-23.32	16
		36	01.08.2002	0.695	305.1	D19	-0.41	-7.49	-	-	-	-23.28	-
		40	05.08.2002	0.727			-	-7.41	-7.69	-7.36	-7.45	-	16.4
		41	06.08.2002	0.728	303.7	D20	-0.39	-7.45	-	-7.31	-	-23.22	-
		42	07.08.2002	0.724	304.5	D21	-0.49	-7.34	-	-	-	-23.21	-
		43	08.08.2002	0.697	303.5	D22	-	-7.45	-7.63	-7.43	-7.45	-23.23	16.7
		44	09.08.2002	0.709	301.2	D23	-0.59	-7.43	-	-	-	-23	-
		47	12.08.2002	0.71			-	-7.42	-	-	-	-	-
		48	13.08.2002	0.721	275.9	D24	-	-7.48	-7.63	-7.46	-7.38	-23.08	16.4
		49	14.08.2002	0.727	307.1	D25	-	-7.50	-	-	-	-23.23	-
		50	15.08.2002	0.705	296.3	D26	-	-7.45	-	-	-	-23.47	-
		51	16.08.2002	0.668	262.9	D27	-	-7.39	-	-	-	-23.82	-
		54	19.08.2002	0.639			-	-7.51	-7.73	-7.47	-7.48	-	17
		55	20.08.2002	0.64	253.1	D28	-	-7.23	-	-	-	-24.39	-
		56	21.08.2002	0.648	237.6	D29	-	-7.29	-	-	-	-24.46	-
		57	22.08.2002	0.604	252	D30	-	-7.25	-	-	-	-24.43	-
		58	23.08.2002	0.619	246.9	D31	-0.22	-7.48	-	-	-	-24.39	-
		59	24.08.2002				-	-	-7.52	-7.49	-7.5	-	16.4
		61	26.08.2002	0.606			-	-7.37	-	-	-	-	-
		62	27.08.2002	0.62	242.5	D32	-0.26	-7.43	-	-	-	-24.47	-
15	**0.34**	63	28.08.2002	0.606	232.6	D33	-0.22	-7.33	-	-	-	-24.73	-
		64	29.08.2002	0.565	239.8	D34	-0.25	-7.33	-7.62	-7.41	-7.40	-24.49	17.2
		68	02.09.2002	0.552			-	-7.33	-	-	-	-	-
		69	03.09.2002	0.507	211.8	D35	-0.29	-7.34	-7.72	-7.35	-7.46	-24.66	17.2
		70	04.09.2002	0.475	230.5	D36	-0.30	-	-	-	-	-24.42	-
		71	05.09.2002	0.485	228.9	D37	-	-7.33	-	-	-	-24.1	-
		72	06.09.2002	0.497	221.2	D38	-	-7.28	-7.78	-7.51	-7.43	-24.1	17.6
		75	09.09.2002	0.48			-	-7.36	-	-	-	-	-
		76	10.09.2002	0.426	188.9	D39	-	-7.23	-	-	-	-24.03	-
		77	11.09.2002	0.388	179.8	D40	-	-7.65	-7.60	-7.44	-7.43	-24.06	16.7
		78	12.09.2002	0.35	166.2	D41	-	-	-	-	-	-24.97	-
		79	13.09.2002	0.301	149.9	D42	-	-7.39	-	-	-	-24.59	-
		82	16.09.2002	0.166			-	-7.34	-7.61	-7.56	-7.35	-	16.6
		83	17.09.2002	0.231			-	-7.31	-	-	-	-	-
		84	18.09.2002	0.216	98.2	D43	-	-6.99	-	-	-	-24.31	-
		85	19.09.2002	0.226	99.9	D44	-	-7.18	-	-	-	-24.13	-
		86	20.09.2002	0.222	101.9	D45	-	-7.30	-	-	-	-23.8	-
		87	21.09.2002				-	-	-7.61	-7.27	-7.41	-	16.8
		89	23.09.2002	0.216			-	-7.2	-	-	-	-	-
		90	24.09.2002	0.23	104.9	D46	-	-7.25	-	-	-	-23.56	-
		91	25.09.2002	0.246	71.7	D47	-	-7.40	-	-	-	-23.23	-
		92	26.09.2002	0.301	127.8	D48	-	-7.29	-7.70	-7.52	-7.37	-23.16	16.8
		93	27.09.2002	0.358	152.5	D49	-	-7.24	-	-	-	-22.93	-
		96	30.09.2002	0.543			-	-	-	-	-	-	-
		97	01.10.2002	0.583	256.4	D50	-	-7.36	-	-	-	-22.64	-
		98	02.10.2002	0.611	275.9	D51	-	-	-7.67	-7.37	-	-22.56	18.5
		99	07.10.2002	0.741			-	-	-7.83	-	-	-	17.3
21	**0.34**	100	08.10.2002	0.737	331.9	D52	-	-7.52	-	-	-	-22.54	-
		101	09.10.2002	0.746	327.1	D53	-	-7.50	-	-	-	-22.61	-
		102	10.10.2002	0.74	330.5	D54	-0.41	-7.20	-	-7.29	-7.48	-22.7	-
		103	11.10.2002	0.746	316.8	D55	-0.49	-7.36	-7.77	-7.34	-7.44	-22.69	16.9
		106	14.10.2002	0.742			-	-7.37	-	-	-	-	-
		107	15.10.2002	0.738	315.8	D56	-0.62	-7.28	-	-	-	-22.78	-
		108	16.10.2002	0.731	317.8	D57	-0.54	-7.26	-7.62	-7.34	-7.31	-22.83	17.5
		109	17.10.2002	0.729	317.3	D58	-0.57	-7.15	-	-	-	-22.82	-
		110	18.10.2002	0.729	318.1	D59	-0.30	-7.39	-	-	-	-22.89	-
		113	21.10.2002	0.707			-	-7.35	-7.43	-7.37	-7.32	-	17.8
		114	22.10.2002	0.712	299.3	D60	-	-7.25	-	-	-	-23.41	-
		115	23.10.2002	0.699	312.7	D61	-0.36	-7.20	-	-	-	-23.07	-
		116	24.10.2002	0.699	299.7	D62	-0.52	-7.10	-	-	-	-23.05	-
		117	25.10.2002	0.722	285.2	D63	-	-7.19	-	-	-	-22.97	-
		120	28.10.2002	0.717			-	-7.14	-	-	-	-	-
		121	29.10.2002	0.709	296.7	D64	-	-7.08	-7.34	-7.67	-7.24	-23.02	19.4
		122	30.10.2002	0.706	307.7	D65	-	-7.01	-	-	-	-22.98	-
		123	31.10.2002	0.685	285.5	D66	-	-6.98	-	-	-	-22.92	-
21	**0.2**	127	04.11.2002	0.687			-	-	-	-	-	-	-
		128	05.11.2002	0.69	301.2	D67	-0.36	-6.91	-	-	-	-23.07	-
		129	06.11.2002	0.702	299.9	D68	-0.60	-7.66	-	-	-	-23.09	-
		130	07.11.2002	0.673	300.7	D69	-0.47	-7.05	-7.46	-7.29	-7.68	-23.16	17.5
		131	08.11.2002	0.678	282.3	D70	-0.58	-7.30	-	-	-	-23.35	-
		134	11.11.2002	0.688			-	-6.96	-	-	-	-	-
		135	12.11.2002	0.655	302.6	D71	-0.38	-6.94	-	-	-	-23.42	-
		136	13.11.2002	0.639	287.4	D72	-	-6.90	-	-	-	-23.46	-
		137	14.11.2002	0.585	253.9	D73	-	-6.95	-	-	-	-23.42	-
		138	15.11.2002	0.594	256.5	D74	-	-6.86	-	-	-	-23.58	-
		141	18.11.2002	0.592			-	-7.16	-7.55	-7.31	-	-	17.3
		142	19.11.2002	0.598	260.3	D75	-	-7.22	-	-	-	-23.92	-
		143	20.11.2002	0.596	261.5	D76	-	-7.18	-	-	-	-23.91	-
15	**0.2**	144	21.11.2002	0.613	256.5	D77	-	-7.18	-	-	-	-23.93	-
		145	22.11.2002	0.615	260.3	D78	-	-7.21	-7.64	-7.26	-7.21	-23.82	17.9
		148	25.11.2002	0.643			-	-7.05	-	-	-	-	-
		149	26.11.2002	0.656	205.9	D79	-	-7.04	-	-	-	-22.91	-
		150	27.11.2002	0.676	281.1	D80	-0.30	-7.15	-	-	-	-23.89	-
		151	28.11.2002	0.655	281	D81	-0.39	-6.94	-7.66	-7.29	-7.30	-24.11	17.5
		152	29.11.2002	0.655	280.3	D82	-0.48	-	-	-	-	-23.98	-
		155	02.12.2002	0.675			-	-7.21	-	-	-	-	-
		156	03.12.2002	0.675	295.1	D83	-0.44	-7.20	-	-	-	-24.08	-
		157	04.12.2002	0.674	295.2	D84	-	-7.30	-	-	-	-24.17	-
		158	05.12.2002	0.651	280.2	D85	-	-7.20	-	-	-	-24.29	-
		159	06.12.2002	0.642	269.7	D86	-	-7.22	-7.56	-7.29	-7.49	-24.54	17.8
		162	09.12.2002	0.606			-	-7.29	-	-	-	-	-
12	**0.2**	163	10.12.2002	0.592	254.9	D87	-	-7.26	-	-	-	-25.05	-
		164	11.12.2002	0.596	255	D88	-0.42	-7.32	-	-	-	-25.2	-
		165	12.12.2002	0.595	254.2	D89	-0.52	-7.30	-	-	-	-25.22	-
		166	13.12.2002	0.58	252.1	D90	-0.35	-6.81	-7.85	-7.34	-7.46	-25.26	17.1
		169	16.12.2002	0.565			-	-6.89	-	-	-	-	-
		170	17.12.2002	0.568	237.6	D91	-	-7.04	-	-	-	-25.67	-
		171	18.12.2002	0.563	233.4	D92	-0.46	-6.98	-	-	-	-25.63	-

steady state
- non-existent

Results of the experiment Nr 8 with *Cyclotella meneghiniana* grown at various temperatures at two growth rates. (For T see previous page).

Days	Ca^{2+} susp. (mg/l)	Fe^{2+} medium (mg/l)	Fe^{2+} susp. (mg/l)	K^{+} medium (mg/l)	K^{+} susp. (mg/l)	Mg^{2+} medium (mg/l)	Mg^{2+} susp. (mg/l)	Na^{+} medium (mg/l)	Na^{+} susp. (mg/l)	Si^{2+} medium (mg/l)	Si^{2+} susp. (mg/l)	Chloride medium (mg/l)	Chloride susp. (mg/l)	Nitrate medium (mg/l)	Nitrate susp. (mg/l)	Phosphate medium (mg/l)	Phosphate susp. (mg/l)	Sulphate medium (mg/l)	Sulphate susp. (mg/l)
1	-	9.6	-	8.2	-	2.5	-	30.2	-	35.6	-	0.2	-	52.8	-	8.8	-	29.7	-
6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	17.9	-	7.5	-	6.4	-	2.2	-	39.2	-	1.2	-	2.8	-	1.04	-	0.05	-	23.1
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	-	9.8	-	9	-	2.4	-	43.4	-	37.5	-	0.3	-	52.9	-	10.3	-	28.5	-
13	16.7	-	6	-	6	-	2	-	40.3	-	2.1	-	1	-	0.09	-	0.05	-	19.2
14	-	9.4	-	8.4	-	2.4	-	39	-	38.1	-	0.4	-	53.1	-	10.4	-	30.8	-
15	17.1	-	8.8	-	7.3	-	2.2	-	44.5	-	2.5	-	0.9	-	0.05	-	0.62	-	20
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20	-	10.3	-	9.1	-	2.5	-	48	-	38.8	-	0.4	-	52.5	-	9.5	-	31.5	-
21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
23	16.7	-	5.1	-	6.3	-	2.2	-	48.2	-	1.1	-	1.1	-	0.05	-	0.05	-	23.66
25	-	10	-	8.8	-	2.3	-	45.1	-	36.2	-	0.3	-	51.4	-	9.2	-	31	-
26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
28	18.2	-	6.8	-	6.2	-	2.5	-	47.2	-	1.9	-	2.2	-	2.05	-	0.05	-	25.26
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	-	9.6	-	8.3	-	2.5	-	44.2	-	36.5	-	1	-	53.2	-	8.7	-	32.7	-
33	18.5	-	8.2	-	6.3	-	2.4	-	46.3	-	5.2	-	1.7	-	5.26	-	0.53	-	25.89
34	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
35	-	8.9	-	8.5	-	2.3	-	45.3	-	37.3	-	0.3	-	52.2	-	8.6	-	30.8	-
36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
40	-	8	-	9.3	-	2.4	-	44.8	-	34.8	-	0.4	-	52.7	-	9.4	-	27.9	-
41	17.8	-	7.2	-	6.3	-	2.3	-	46.6	-	4.1	-	1.7	-	4.46	-	0.05	-	24.85
42	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
43	-	8.8	-	8.3	-	2.5	-	42.4	-	20.3	-	0.3	-	53.1	-	7.6	-	29.1	-
44	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
47	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
48	17.9	8.6	6.5	8.5	5.6	2.5	2.3	37.8	44.4	14	1.1	0.3	1.4	54	1.04	8.1	0.05	29	21.3
49	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
51	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
54	-	8.8	-	8.1	-	2.5	-	42.1	-	18.4	-	0.3	-	52.7	-	7.5	-	29	-
55	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
56	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
57	17.2	-	**4.7**	-	**6.6**	-	**2.3**	-	**42.3**	-	**0.8**	-	**2**	-	**1.29**	-	**0.05**	-	**22.7**
58	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
59	-	9.7	-	8.2	-	2.4	-	41.9	-	17.7	-	0.2	-	53.6	-	7.7	-	31.1	-
61	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
62	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
63	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
64	-	9.8	-	8.7	-	2.5	-	44.9	-	19.4	-	0.2	-	52.9	-	8.3	-	31.2	-
68	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
69	-	9.5	-	8.7	-	2.5	-	47.8	-	20.9	-	0.3	-	53.1	-	8.5	-	30.1	-
70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
72	-	9.6	-	8.8	-	2.6	-	42	-	16.3	-	0.3	-	54.3	-	7.9	-	31.4	-
75	16.7	-	6.9	-	8.7	-	2.2	-	44.6	-	4.2	-	1.3	-	0.8	-	0.05	-	24.2
76	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
77	-	9.8	-	8.2	-	2.5	-	41.4	-	17.8	-	0.2	-	53.6	-	7.4	-	29.8	-
78	16.8	-	7.1	-	8	-	2.3	-	42.8	-	6.7	-	1	-	10	-	1.4	-	25.9
79	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
82	-	9.9	-	8.1	-	2.5	-	42.7	-	18.4	-	0.2	-	52.7	-	8.8	-	29.6	-
83	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
84	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
85	18.1	-	8.9	-	8.2	-	2.5	-	41.8	-	11.4	-	2.4	-	23.9	-	6.18	-	27.1
86	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
87	-	9.6	-	8.3	-	2.4	-	41.6	-	18.5	-	0.2	-	53.7	-	10.3	-	28.4	-
89	17	-	7.8	-	9.2	-	2.5	-	44.3	-	12.2	-	0.8	-	22.2	-	6.15	-	26.7
90	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
91	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
92	-	9.9	-	8.2	-	2.5	-	39.9	-	17.9	-	0.1	-	53.7	-	10.3	-	29.9	-
93	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
96	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
97	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
98	-	10.1	-	8	-	2.3	-	40.8	-	19.9	-	0.1	-	57.8	-	10	-	28.5	-
99	-	10.1	-	8.3	-	2.4	-	39.5	-	19.6	-	0.1	-	52.9	-	10.2	-	28.3	-
100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
101	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
102	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
103	-	10.1	-	8	-	2.6	-	39.9	-	19.1	-	0.2	-	52.6	-	9.7	-	29.3	-
106	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
107	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
108	-	10	-	8.3	-	2.4	-	38.6	-	18.2	-	0.1	-	53.7	-	10.1	-	28.5	-
109	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
110	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
113	-	9.6	-	8.3	-	2.5	-	28.4	-	18.6	-	0.1	-	55.4	-	10.1	-	28.3	-
114	20	-	5.6	-	6.4	-	2.8	-	41.2	-	0.63	-	2.3	-	1.67	-	0.26	-	25.4
115	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
116	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
117	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
120	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
121	-	10	-	8	-	2.3	-	41.4	-	28.1	-	0.1	-	58.7	-	9.7	-	27.1	-
122	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
123	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
127	19.3	-	5.5	-	6.4	-	2.4	-	41.1	-	0.6	-	1.5	-	1.02	-	0.09	-	21.9
128	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
129	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
130	-	10.9	-	8.7	-	2.3	-	47.5	-	38.4	-	0.2	-	52	-	10.4	-	27.2	-
131	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
134	18.5	-	4.4	-	6.8	-	2	-	49.5	-	0.78	-	1.2	-	0.16	-	0.1	-	18
135	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
136	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
137	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
138	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
141	-	9.6	-	7.8	-	2.3	-	45.7	-	36.8	-	0.2	-	50.4	-	8.7	-	24	-
142	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
143	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
144	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
145	19.6	10.4	5.2	8.6	6.9	2.3	2.2	45.8	47.3	38.2	2.3	0.3	4	52.3	2.19	9.7	0.05	25.4	23.5
148	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
149	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
150	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
151	-	10.4	-	8.5	-	2.2	-	45.5	-	39.5	-	0.1	-	51.7	-	9.5	-	24.7	-
152	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
155	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
156	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
157	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
158	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
159	18.7	10.5	6.1	8.7	6.6	2.3	2.1	44.8	48.3	38.5	2.5	0.1	2.2	52.1	1.27	9.6	0.05	24.7	21.6
162	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
163	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
164	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
165	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
166	19.4	10.7	7.1	8.7	7.1	2.3	2.3	46.1	45.6	37.8	2.8	0.2	3.3	49.9	1.83	9.67	0.05	25.1	22.5
169	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
170	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
171	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

susp. = suspension
- non-existent

Results of the experiment Nr 14 with *Cyclotella meneghiniana* grown at various temperatures.

Temperature (°C)	Growth rate μ (d^{-1})	Days	Date	Extinction 560nm	Dry mass (mg/l)	Sample	ε_{13C} (‰)	$\delta^{18}O$ medium from fermenter vs. V-SMOV (‰)	$\delta^{18}O$ water vs. V-SMOV (‰)	$\delta^{18}O$ medium 1 vs. V-SMOV (‰)	$\delta^{18}O$ medium 2 vs. V-SMOV (‰)	Ca^{2+} medium (mg/l)
		1	06.05.2003	0.196	72.2	D1	-23.43	-	-7.75	-7.38	-	17
		2	07.05.2003	0.227		D2	-	-	-	-	-	-
		3	08.05.2003	0.175	71.4	D3	-23.02	-	-	-	-	-
		4	09.05.2003	0.154	69.5	D4	-23.21	-	-7.68	-7.33	-7.31	17.4
		7	12.05.2003	0.188			-	-	-	-	-	-
		8	13.05.2003	0.234	87	D5	-22.88	-	-	-	-	-
		9	14.05.2003	0.234	88.4	D6	-22.9	-	-	-	-	-
		10	15.05.2003	0.236	120.7	D7	-22.89	-	-	-	-	-
		11	16.05.2003	0.242	96.3	D8	-22.87	-	-	-	-	-
		13	18.05.2003	0.263			-	-	-7.54	-7.34	-7.36	17.3
		14	19.05.2003	0.381			-	-7.57	-	-	-	-
		15	20.05.2003	0.343	139.1	D9	-22.64	-7.40	-	-	-	-
		16	21.05.2003	0.369	145.8	D10	-22.79	-6.99	-	-	-	-
		17	22.05.2003	0.385	154.3	D11	-22.88	-7.08	-	-	-	-
		18	23.05.2003	0.402	160.4	D12	-22.96	-6.96	-	-	-	-
		20	25.05.2003				-	-	-	-	-	-
		21	26.05.2003	0.494			-	-6.91	-	-	-	-
		22	27.05.2003	0.513	227.8	D13	-22.45	-6.98	-7.59	-7.28	-7.31	17.8
		23	28.05.2003	0.523	237.7	D14	-22.7	-7.06	-	-	-	-
		27	02.06.2003	0.754			-	-7.04	-	-	-	-
		28	03.06.2003	0.777			-	-6.88	-	-	-	-
		29	04.06.2003	0.737			-	-7.02	-	-	-	-
		30	05.06.2003	0.714			-	-7.00	-7.54	-7.4	-7.43	18
		31	06.06.2003	0.708	315.5	D15	-23.19	-7.00	-	-	-	-
		36	11.06.2003	0.688			-	-7.35	-	-	-	-
		37	12.06.2003	0.671	292.1	D16	-23.74	-7.27	-7.66	-7.2	-7.41	17.7
		38	13.06.2003	0.681	321.6	D17	-23.76	-7.32	-	-	-	-
		41	16.06.2003	0.692			-	-7.36	-	-	-	-
		42	17.06.2003	0.73			-	-7.28	-	-	-	-
		43	18.06.2003	0.718	341.7	D18	-23.66	-7.23	-7.58	-7.32	-7.31	17.6
		48	23.06.2003	0.712			-	-7.41	-	-	-	-
		49	24.06.2003	0.692	318.9	D19	-23.91	-7.34	-	-	-	-
		50	25.06.2003	0.692	342.1	D20	-23.96	-7.35	-7.52	-7.25	-7.36	35.8
		51	26.06.2003	0.64	299.8	D21	-24.15	-7.19	-	-	-	-
15	**0.2**	52	27.06.2003	0.705	285.1	D22	-25.14	-7.18	-7.64	-7.24	-7.26	26.8
		55	30.06.2003	0.802			-	-7.24	-	-	-	-
		56	01.07.2003	0.776	347.6	D23	-24.28	-7.34	-	-	-	-
		57	02.07.2003	0.789	345.4	D24	-24.53	-7.31	-	-	-	-
		58	03.07.2003	0.761	349.6	D25	-24.16	-7.57	-	-	-	-
		59	04.07.2003	0.763	350.7	D26	-24.12	-7.27	-7.77	-7.29	-7.33	17.6
		62	07.07.2003	0.762			-	-7.31	-	-	-	-
		63	08.07.2003	0.737	309.6	D27	-24.06	-7.27	-	-	-	-
		64	09.07.2003	0.719	345.5	D28	-24.01	-7.16	-	-	-	-
		65	10.07.2003	0.712	304.8	D29	-24.27	-7.33	-	-	-	-
		66	11.07.2003	0.72	351.3	D30	-23.95	-7.33	-7.68	-7.25	-7.33	17.6
		69	14.07.2003	0.704			-	-7.18	-	-	-	-
		70	15.07.2003	0.693	300.1	D31	-24.35	-7.13	-	-	-	-
		71	16.07.2003	0.727	336.8	D32	-24.15	-7.17	-	-	-	-
		72	17.07.2003	0.737	351.8	D33	-23.77	-7.07	-	-	-	-
		73	18.07.2003	0.714	316.3	D34	-24.15	-7.19	-7.63	-	-7.24	17.8
		76	21.07.2003	0.774			-	-6.97	-	-	-	-
		77	22.07.2003	0.729	332.1	D35	-24.47	-7.15	-	-	-	-
		78	23.07.2003	0.716	325.3	D36	-24.48	-7.05	-	-	-	-
		79	24.07.2003	0.696	298.4	D37	-24.64	-7.22	-	-	-	-
		80	25.07.2003	0.687	270.3	D38	-24.95	-7.29	-	-	-	-
		83	28.07.2003	0.639			-	-7.26	-7.72	-7.42	-7.33	19.6
		84	29.07.2003	0.628	275.3	D39	-25.31	-7.18	-	-	-	-
		85	30.07.2003	0.607	275.3	D40	-25.02	-7.13	-	-	-	-
		86	31.07.2003	0.599	268.1	D41	-25.12	-7.31	-	-	-	-
		87	01.08.2003	0.589	253.6	D42	-25.25	-	-	-	-	-
		90	04.08.2003	0.617			-	-7.40	-	-	-	-
		91	05.08.2003	0.593	262.8	D43	-25.09	-7.19	-	-	-	-
		92	06.08.2003	0.597	290.7	D44	-24.96	-7.12	-7.75	-7.31	-7.35	17.6
		93	07.08.2003	0.603	285.6	D45	-25.16	-7.14	-	-	-	-
		94	08.08.2003	0.591	288.6	D46	-25.15	-7.27	-	-	-	-
12	**0.2**	97	11.08.2003	0.608			-	-7.20	-	-	-	-
		98	12.08.2003	0.597	283.1	D47	-25.08	-7.44	-	-	-	-
		99	13.08.2003	0.61	287.4	D48	-25.21	-7.19	-	-	-	-
		100	14.08.2003	0.602	283.9	D49	-24.96	-7.45	-	-	-	-
		101	15.08.2003	0.618	292.1	D50	-24.98	-7.43	-7.72	-7.36	-7.24	18.8
		104	18.08.2003	0.602			-	-7.34	-	-	-	-
		105	19.08.2003	0.62	288.8	D51	-25.12	-7.45	-	-	-	-
		106	20.08.2003	0.606	288.7	D52	-25.11	-7.52	-	-	-	-
		107	21.08.2003	0.607	282.4	D53	-25.31	-7.34	-	-	-	-
		108	22.08.2003	0.6	285.7	D54	-25.11	-7.36	-	-	-	-
		111	25.08.2003	0.608			-	-7.24	-7.63	-7.34	-7.31	18.6
		112	26.08.2003	0.592	285.7	D55	-25.09	-7.42	-	-	-	-
		113	27.08.2003	0.61	284.4	D56	-25.27	-7.23	-	-	-	-
		114	28.08.2003	0.577	290.5	D57	-24.98	-7.11	-	-	-	-
		118	01.09.2003	0.383			-	-7.33	-	-	-	-
		119	02.09.2003	0.331	162.9	D58	-24.27	-	-7.65	-7.31	-7.28	17
		120	03.09.2003	0.294	135.5	D59	-23.93	-7.32	-	-	-	-
		121	04.09.2003	0.248	106.9	D60	-23.74	-7.42	-	-	-	-
		122	05.09.2003	0.226		D61	-23.6	-	-	-	-	-
		125	08.09.2003	0.173			-	-	-	-	-	-
9	**0.2**	126	09.09.2003	0.155	49.3	D62	-23.55	-	-	-	-	-
		127	10.09.2003	0.133	42.5	D63	-23.56	-	-	-	-	-
		128	11.09.2003	0.125	34	D64	-23.54	-	-	-	-	-
		132	15.09.2003	0.093			-	-	-	-	-	-
		133	16.09.2003	0.082			-	-	-	-	-	-
		134	17.09.2003	0.088			-	-	-	-	-	-
		135	18.09.2003	0.116			-	-	-	-	-	-
		136	19.09.2003	0.071			-	-	-	-	-	-
		139	22.09.2003				-	-	-	-	-	-
		140	23.09.2003				-	-	-	-	-	-
		141	24.09.2003				-	-	-7.79	-	-	18.35
		142	25.09.2003				-	-	-	-	-	-
		143	26.09.2003				-	-	-	-	-	-
		146	29.09.2003				-	-	-	-	-	-
		147	30.09.2003				-	-	-	-	-	-
		148	01.10.2003				-	-	-	-	-	-
9	**Batch conditions**	149	02.10.2003				-	-	-	-	-	-
		153	06.10.2003				-	-	-	-	-	-
		155	08.10.2003				-	-	-	-	-	-
		156	09.10.2003				-	-	-	-	-	-
		157	10.10.2003				-	-	-	-	-	-
		160	13.10.2003				-	-	-	-	-	-
		161	14.10.2003				-	-	-	-	-	-
		162	15.10.2003				-	-	-	-	-	-
		163	16.10.2003				-	-	-	-	-	-
		164	17.10.2003				-	-	-	-	-	-

steady state
- non-existent

Results of the experiment Nr 14 with *Cyclotella meneghiniana* grown at various temperatures. (For T see previous page).

Days	Ca^{2+} susp. (mg/l)	Fe^{2+} medium (mg/l)	Fe^{2+} susp. (mg/l)	K^{+} medium (mg/l)	K^{+} susp. (mg/l)	Mg^{2+} medium (mg/l)	Mg^{2+} susp. (mg/l)	Na^{+} medium (mg/l)	Na^{+} susp. (mg/l)	Si^{2+} medium (mg/l)	Si^{2+} susp. (mg/l)	Chloride medium (mg/l)	Chloride susp. (mg/l)	Nitrate medium (mg/l)	Nitrate susp. (mg/l)	Phosphate medium (mg/l)	Phosphate susp. (mg/l)	Sulphate medium (mg/l)	Sulphate susp. (mg/l)
1	21.5	9.9	8.8	8	9.9	2.5	2.8	47.3	48.9	31.5	29.3	0.18	2.64	62.3	41.5	8.77	7.4	24.1	23.6
2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	-	10.6	-	7.9	-	2.5	-	47.5	-	40.6	-	0.14	-	63.4	-	6.7	-	23.7	-
7	19.4	-	9.2	-	9.1	-	2.7	-	49.6	-	27.6	-	1.8	-	28.7	-	7	-	23.6
8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	18.7	-	9.3	-	8.7	-	2.4	-	49.9	-	24.3	-	0.9	-	20.4	-	6.2	-	22
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	-	10.5	-	8.1	-	2.5	-	47.1	-	40.7	-	0.16	-	62.7	-	7.11	-	23.7	-
14	19.7	-	8.4	-	3.4	-	2.3	-	50.4	-	19.2	-	0.9	-	1.7	-	3.8	-	20.5
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	17.7	-	8.2	-	7.7	-	2.3	-	50.7	-	12.6	-	1	-	0.24	-	2.7	-	19.6
18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
22	-	10.5	-	8.8	-	2.5	-	47.2	-	34.2	-	0.11	-	71.4	-	14.4	-	31.4	-
23	17.8	-	7.7	-	7.3	-	2.1	-	50.9	-	3.9	-	0.57	-	0.19	-	0.35	-	23.9
27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	-	10.2	-	8.8	-	2.5	-	47	-	37.6	-	0.11	-	72	-	15.2	-	30.4	-
31	17.5	-	5.5	-	6.4	-	2.1	-	50.8	-	0.9	-	0.55	-	0.1	-	0.05	-	22.2
36	17.6	-	6.2	-	5.9	-	2.1	-	49.5	-	1.1	-	0.5	-	0.12	-	0.05	-	21.5
37	-	10.4	-	8.9	-	2.5	-	47.4	-	38.3	-	0.11	-	70.9	-	17	-	30.4	-
38	17.3	-	6	-	4.3	-	2	-	37.1	-	1.2	-	0.54	-	0.2	-	0.05	-	21.7
41	17.7	-	5.5	-	5.8	-	2.1	-	49.5	-	0.9	-	0.53	-	0.31	-	0.05	-	21
42	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
43	-	10.3	-	8.8	-	2.5	-	47.1	-	38.1	-	0.22	-	72.2	-	17.4	-	30.8	-
48	18.2	-	6.3	-	5.8	-	2.3	-	49.6	-	1.3	-	1.36	-	1	-	0.05	-	22.4
49	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
50	18	9	6.7	9.1	5.5	2.5	2.1	87	49.3	41.1	1.5	0.1	0.5	153.5	0.22	1.47	0.05	28.6	21.5
51	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
52	23.1	10.1	4	8.6	5.8	2.5	2.2	46.5	59.9	37.1	0.6	0.11	0.7	97.9	0.25	11.1	0.05	30.1	20.2
55	20.5	-	4.6	-	5.2	-	2.1	-	55.1	-	0.8	-	0.63	-	0.28	-	0.05	-	20.4
56	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
57	19.8	-	4.9	-	5.4	-	2.2	-	53.9	-	0.8	-	0.61	-	0.07	-	0.05	-	21.4
58	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
59	-	10.4	-	8.3	-	2.6	-	47.7	-	38.8	-	0.12	-	69.1	-	12.2	-	32.6	-
62	19.5	-	6.1	-	5.3	-	2.3	-	52.6	-	1.1	-	0.6	-	0.22	-	0.05	-	21.7
63	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
64	19.8	-	6.2	-	5.3	-	2.4	-	53.3	-	1.2	-	0.72	-	0.45	-	0.05	-	22.5
65	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
66	-	10.4	-	8.8	-	2.6	-	48.2	-	39.1	-	0.1	-	74.5	-	12.3	-	32.5	-
69	18.6	-	6.4	-	5.2	-	2.3	-	50.9	-	1.3	-	0.82	-	0.18	-	0.05	-	22
70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
71	17.8	-	6.1	-	5.1	-	2.1	-	48.7	-	1.3	-	0.77	-	0.14	-	0.05	-	22.1
72	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
73	-	10.8	-	8.8	-	2.6	-	48.2	-	40.2	-	0.13	-	71.5	-	13.8	-	33.5	-
76	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
77	17.9	-	5.8	-	5.4	-	2.2	-	48.9	-	1.1	-	0.79	-	0.07	-	0.05	-	23
78	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
79	18	-	6.3	-	5.4	-	2.2	-	50	-	1.4	-	0.7	-	0.06	-	0.05	-	23.3
80	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
83	-	11.1	-	9.1	-	2.7	-	49.3	-	41.6	-	0.13	-	76.8	-	14.8	-	32.9	-
84	17.8	-	7.1	-	5.1	-	2.2	-	48.7	-	1.6	-	0.67	-	0.06	-	0.05	-	23.3
85	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
86	19.1	-	7.7	-	5.7	-	2.4	-	52.7	-	1.7	-	0.57	-	0.01	-	0.13	-	23.4
87	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
90	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
91	16.9	-	6.9	-	5.4	-	2.1	-	48.4	-	1.8	-	0.55	-	0.57	-	0.42	-	23.3
92	-	10.4	-	8.7	-	2.6	-	47	-	41.8	-	0.17	-	71	-	16.35	-	32	-
93	18.5	-	6.9	-	5.8	-	2.5	-	49.3	-	1.6	-	1.62	-	1.45	-	0.18	-	25.2
94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
97	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
98	17.2	-	6.8	-	5.4	-	2.2	-	48.2	-	1.8	-	0.85	-	0.3	-	0.05	-	22.9
99	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
100	18.4	-	6.7	-	5.5	-	2.5	-	48.5	-	2	-	1.57	-	1.12	-	0.05	-	25.3
101	-	10.2	-	8.7	-	2.5	-	46.4	-	40.3	-	0.22	-	74.85	-	15.4	-	31.5	-
104	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
105	19	-	6.9	-	5.6	-	2.6	-	48.2	-	1.8	-	1.99	-	1.37	-	0.08	-	24.6
106	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
107	19.3	-	7.1	-	5.5	-	2.6	-	47.9	-	1.8	-	1.81	-	1.5	-	0.2	-	24
108	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
111	-	10.2	-	8.6	-	2.7	-	46.1	-	40.4	-	0.2	-	75.05	-	19.35	-	31.6	-
112	19.6	-	6.8	-	5.6	-	2.7	-	47.9	-	1.7	-	2.21	-	1.75	-	0.14	-	25.2
113	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
114	18.3	-	7.2	-	5.3	-	2.3	-	47.6	-	1.9	-	1	-	0.53	-	0.93	-	23.2
118	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
119	22.5	10.1	7.5	9.4	7.4	2.5	3.7	47.8	49.8	43.7	11.4	0.22	5.64	70.4	14	25.4	0.98	31.2	31.7
120	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
121	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
122	18.9	-	7.4	-	8.4	-	3	-	52.3	-	17	-	2.87	-	33.3	-	8.23	-	33
125	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
126	18.6	-	7.4	-	9	-	3	-	52.8	-	27.1	-	2.28	-	52.8	-	16.2	-	35
127	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
128	18.3	-	1.1	-	10	-	2.9	-	55	-	15.6	-	2.35	-	60.2	-	16.1	-	35.3
132	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
133	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
134	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
135	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
136	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
139	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
140	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
141	-	10.2	-	9.15	-	2.2	-	47.15	-	37.3	-	0.21	-	75.9	-	15.05	-	31.85	-
142	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
143	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
146	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
147	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
148	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
149	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
153	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
155	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
156	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
157	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
160	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
161	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
162	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
163	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
164	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

susp. = suspension
- non-existent

Results of the experiment Nr 14 with *Cyclotella meneghiniana* grown at various temperatures.

Temperature (°C)	Growth rate μ (d^{-1})	Days	Date	Extinction 560nm	Dry mass (mg/l)	Sample	ε_{13C} (‰)	$\delta^{18}O$ medium from fermenter vs. V-SMOV (‰)	$\delta^{18}O$ water vs. V-SMOV (‰)	$\delta^{18}O$ medium 1 vs. V-SMOV (‰)	$\delta^{18}O$ medium 2 vs. V-SMOV (‰)	Ca^{2+} medium (mg/l)
		167	20.10.2003	0.423			-	-	-	-	-	-
		168	21.10.2003	0.509	253.9	D65	-23.72	-6.73	-	-	-	-
		169	22.10.2003	0.495	238.1	D66	-24.1	-6.66	-	-	-	-
		170	23.10.2003	0.468	231.5	D67	-23.99	-6.58	-	-	-	-
		171	24.10.2003	0.439	224.7	D68	-24	-6.76	-	-	-	-
		174	27.10.2003	0.413			-	-6.57	-	-	-	-
		175	28.10.2003	0.376	192.8	D69	-23.61	-6.57	-	-	-	-
		176	29.10.2003	0.354	178	D70	-23.62	-6.49	-	-	-	-
		177	30.10.2003	0.327	142.4	D71	-23.46	-6.51	-	-	-	-
		178	31.10.2003	0.314	154.5	D72	-23.5	-7.01	-	-	-	-
		181	03.11.2003	0.303	139.3	D73	-23.71	-7.55	-	-	-	-
		182	04.11.2003	0.315	142.7	D74	-23.83	-6.86	-	-	-	-
		183	05.11.2003	0.3	143.3	D75	-24.06	-6.92	-7.74	-7.29	-7.45	19.3
		184	06.11.2003	0.304	150.6	D76	-24.23	-7.15	-	-	-	-
		185	07.11.2003	0.291	138.9	D77	-24.15	-6.88	-	-	-	-
		188	10.11.2003	0.298			-	-7.08	-	-	-	-
		189	11.11.2003	0.298	140.8	D78	-24.58	-7.06	-	-	-	-
		190	12.11.2003	0.303	129.1	D79	-	-6.75	-	-	-	-
		191	13.11.2003	0.302	145.9	D80	-24.55	-7.18	-	-	-	-
		192	14.11.2003	0.298	138.5	D81	-24.88	-7.71	-	-	-	-
		195	17.11.2003	0.292			-	-7.13	-	-	-	-
		196	18.11.2003	0.32			-	-	-	-	-	-
		197	19.11.2003	0.31	126.6	D82	-25.17	-7.22	-	-	-	-
		198	20.11.2003	0.31	138.9	D83	-25.58	-7.03	-	-	-	-
		199	21.11.2003	0.313	136.6	D84	-25.49	-7.13	-	-	-	-
		202	24.11.2003	0.304			-	-7.03	-7.67	-7.31	-7.32	18.1
		203	25.11.2003	0.321	132.4	D85	-25.35	-7.00	-	-	-	-
		204	26.11.2003	0.333	137.6	D86	-25.46	-7.20	-	-	-	-
9	**0.14**	205	27.11.2003	0.311	151.9	D87	-25.6	-7.10	-	-	-	-
		206	28.11.2003	0.317	143.8	D88	-25.64	-7.15	-	-	-	-
		209	01.12.2003	0.366			-	-	-	-	-	-
		210	02.12.2003	0.325	117	D89	-25.64	-6.94	-	-	-	-
		211	03.12.2003	0.336	145.8	D90	-25.7	-7.06	-	-	-	-
		212	04.12.2003	0.334	142.6	D91	-25.7	-6.95	-	-	-	-
		213	05.12.2003	0.349	146.9	D92	-25.84	-7.07	-	-	-	-
		216	08.12.2003	0.365			-	-6.89	-	-	-	-
		217	09.12.2003	0.366	160.8	D93	-25.84	-7.16	-	-	-	-
		218	10.12.2003	0.398	158.3	D94	-25.77	-6.99	-	-	-	-
		219	11.12.2003	0.408	170.3	D95	-26.09	-7.14	-	-	-	-
		220	12.12.2003	0.408	176	D96	-25.8	-7.04	-7.93	-7.42	-7.41	17.9
		223	15.12.2003	0.456			-	-6.89	-	-	-	-
		224	16.12.2003	0.463	198.7	D97	-26.5	-7.12	-	-	-	-
		225	17.12.2003	0.491			-	-	-	-	-	-
		226	18.12.2003	0.52	195.3	D98	-26.7	-6.96	-	-	-	-
		227	19.12.2003	0.521			-	-	-	-	-	-
		229	21.12.2003	0.498			-	-	-	-	-	-
		230	22.12.2003				-	-6.91	-	-	-	-
		235	27.12.2003	0.548			-	-7.25	-	-	-	-
		239	31.12.2003	0.537			-	-7.10	-7.72	-7.33	-	18.3
		243	04.01.2004	0.56			-	-7.01	-	-	-	-
		244	05.01.2004	0.585			-	-	-	-	-	-
		245	06.01.2004	0.566			-	-7.12	-	-	-	-
		246	07.01.2004	0.553	244.6	D99	-26.56	-7.38	-	-	-	-
		247	08.01.2004	0.57	258.2	D100	-26.29	-7.05	-	-	-	-
		248	09.01.2004	0.57	255.1	D101	-26.19	-7.27	-	-	-	-
		251	12.01.2004	0.534			-	-7.05	-	-	-	-
		252	13.01.2004	0.533			-	-	-	-	-	-
		253	14.01.2004	0.496	223.2	D102	-26.55	-7.22	-	-	-	-
		254	15.01.2004	0.476	197.9	D103	-26.51	-6.83	-	-	-	-
		255	16.01.2004	0.459	186.9	D104	-26.46	-6.90	-7.8	-7.33	-	18.4
		258	19.01.2004	0.39	158.1	D105	-26.17	-7.22	-	-	-	-
		259	20.01.2004	0.38			-	-6.47	-	-	-	-
		260	21.01.2004	0.365	159.3	D106	-26.27	-6.5	-	-	-	-
		261	22.01.2004	0.353	156.7	D107	-26.33	-6.97	-	-	-	-
		262	23.01.2004	0.345	154.1	D108	-26.38	-7.01	-	-	-	-
		265	26.01.2004	0.322			-	-7.14	-	-	-	-
		266	27.01.2004	0.295	125.5	D109	-26.29	-6.87	-	-	-	-
		267	28.01.2004	0.275	119.5	D110	-26.15	-6.86	-	-	-	-
		268	29.01.2004	0.264	115.1	D111	-26.21	-6.81	-	-	-	-
		269	30.01.2004	0.242	115.5	D112	-26.09	-	-	-	-	-
		272	02.02.2004	0.244	112.9	D113	-25.86	-6.69	-	-	-	-
		273	03.02.2004	0.218	107.8	D114	-25.88	-6.91	-7.83	-7.34	-	18.3
		274	04.02.2004	0.222	101.2	D115	-25.87	-7.12	-	-	-	-
		275	05.02.2004	0.211	101.6	D116	-25.87	-7.23	-	-	-	-
		276	06.02.2004	0.208	92.7	D117	-25.96	-7.1	-	-	-	-
		279	09.02.2004	0.184			-	-7.12	-	-	-	-
		280	10.02.2004	0.185	87.4	D118	-25.3	-6.97	-	-	-	-
		281	11.02.2004	0.189	84.2	D119	-25.61	-6.75	-	-	-	-
		282	12.02.2004	0.184	82	D120	-25.62	-7.04	-	-	-	-
		283	13.02.2004	0.2	82.5	D121	-25.78	-7.16	-	-	-	-
		286	16.02.2004	0.196	78.6	D122	-25.68	-6.92	-	-	-	-
		287	17.02.2004	0.206	89.7	D123	-25.68	-6.66	-	-	-	-
		288	18.02.2004	0.21	89.6	D124	-25.43	-6.7	-	-	-	-
		289	19.02.2004	0.208	75	D125	-25.61	-6.85	-	-	-	-
		290	20.02.2004	0.219			-	-	-	-	-	-
		291	21.02.2004	0.207			-	-	-	-	-	-
		294	24.02.2004	0.213	91.8	D126	-24.96	-6.6	-	-	-	-
		295	25.02.2004	0.215	86.5	D127	-25.56	-6.57	-7.82	-7.49	-	18
		296	26.02.2004	0.229			-	-6.62	-	-	-	-
		297	27.02.2004	0.211	89	D128	-25.79	-	-	-	-	-
		300	01.03.2004	0.211	92.8	D129	-25.81	-7.08	-	-	-	-
		301	02.03.2004	0.187	88.3	D130	-25.36	-6.4	-	-	-	-
		302	03.03.2004	0.199	83.3	D131	-25.63	-6.79	-	-	-	-
		303	04.03.2004	0.19	81.9	D132	-25.56	-6.83	-	-	-	-
		304	05.03.2004	0.197	76.6	D133	-25.64	-6.69	-	-	-	-
		307	08.03.2004	0.184	87.3	D134	-25.79	-6.57	-	-	-	-
9	**0.13**	308	09.03.2004	0.159	74.6	D135	-25.6	-6.44	-	-	-	-
		309	10.03.2004	0.156	88.3	D136	-25.54	-6.55	-	-	-	-
		310	11.03.2004	0.167			-	-	-	-	-	-
		311	12.03.2004	0.144			-	-	-	-	-	-
		314	15.03.2004	0.135	65.8	D137	-18.17	-6.47	-	-	-	-
		315	16.03.2004	0.114	61.9	D138	-25.23	-6.62	-	-	-	-
		316	17.03.2004	0.112	61.9	D139	-25.01	-6.71	-	-	-	-
		317	18.03.2004	0.115	48.6	D140	-25.42	-7.04	-	-	-	-
		318	19.03.2004	0.11	72.1	D141	-25.4	-6.55	-	-	-	-
		321	22.03.2004	0.121			-	-	-7.69	-7.24	-	17.7
		322	23.03.2004	0.112	54.1	D142	-25.07	-6.45	-	-	-	-
		323	24.03.2004	0.092	32.3	D143	-24.77	-6.48	-	-	-	-
		324	25.03.2004	0.121	49.6	D144	-24.99	-6.47	-	-	-	-
		325	26.03.2004	0.141	67.8	D145	-24.09	-6.62	-	-	-	-
		328	29.03.2004	0.21	73.6	D146	-23.75	-6.94	-	-	-	-
21	**0.14**	329	30.03.2004	0.239	90.8	D147	-23.9	-6.88	-	-	-	-
		330	31.03.2004	0.173	84.6	D148	-23.64	-7.07	-	-	-	-
		331	01.04.2004	0.17	77.4	D149	-23.52	-6.99	-	-	-	-
		332	02.04.2004	0.156	70.4	D150	-23.45	-6.99	-	-	-	-
		335	05.04.2004	0.107			-	-	-	-	-	-

steady state
- non-existent

Results of the experiment Nr 14 with *Cyclotella meneghiniana* grown at various temperatures. (For T see previous page).

Days	Ca^{2+} susp. (mg/l)	Fe^{2+} medium (mg/l)	Fe^{2+} susp. (mg/l)	K^{+} medium (mg/l)	K^{+} susp. (mg/l)	Mg^{2+} medium (mg/l)	Mg^{2+} susp. (mg/l)	Na^{+} medium (mg/l)	Na^{+} susp. (mg/l)	Si^{2+} medium (mg/l)	Si^{2+} susp. (mg/l)	Chloride medium (mg/l)	Chloride susp. (mg/l)	Nitrate medium (mg/l)	Nitrate susp. (mg/l)	Phosphate medium (mg/l)	Phosphate susp. (mg/l)	Sulphate medium (mg/l)	Sulphate susp. (mg/l)
167	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
168	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
169	17.4	-	7.5	-	9.5	-	2.1	-	50.2	-	5.2	-	2.92	-	0.03	-	0.05	-	25
170	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
171	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
174	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
175	19.3	-	7.8	-	8.8	-	2.5	-	49.9	-	8.5	-	3.53	-	2.19	-	0.06	-	27.9
176	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
177	19	-	8.4	-	7.9	-	2.2	-	46.5	-	9.3	-	1.94	-	0.07	-	0.05	-	24.5
178	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
181	19	-	7.9	-	8.3	-	2.3	-	46.2	-	12.7	-	2.18	-	2.95	-	1.65	-	26.5
182	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
183	18.1	10.8	8.7	9	8	2.5	2.1	48.15	45.7	36.7	14.9	0.15	1.3	67.2	2.45	9.25	2.59	29.15	25.2
184	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
185	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
188	18.5	-	8.4	-	8.3	-	2.1	-	48.7	-	6.6	-	1.32	-	1.12	-	2.21	-	20.7
189	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
190	18.5	-	8.4	-	8.4	-	2.2	-	49.9	-	6.9	-	1.09	-	1.2	-	2.3	-	20.8
191	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
192	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
195	18.1	-	7.8	-	8.3	-	2.2	-	48.7	-	8	-	1.06	-	1.75	-	2.71	-	20.8
196	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
197	18.2	-	7.7	-	8.4	-	2.2	-	49.2	-	8	-	1	-	1.52	-	2.66	-	20.7
198	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
199	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
202	18.4	10.5	7.8	8.9	8.7	2.4	2.2	44	51.3	29.2	9.4	0.15	1.02	51	1.55	5.7	2.79	25.5	21.5
203	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
204	18.6	-	6.8	-	8.4	-	2.3	-	49.2	-	12.2	-	0.9	-	1.55	-	2.75	-	21.4
205	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
206	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
209	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
210	17.9	-	6.3	-	9.8	-	2.1	-	43.6	-	10.1	-	0.95	-	0.76	-	2.66	-	21
211	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
212	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
213	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
216	17.7	-	5.4	-	8.9	-	2.1	-	48.2	-	10.4	-	1.32	-	0.03	-	1.66	-	20.5
217	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
218	17.5	-	5	-	8.2	-	2	-	47.5	-	9.5	-	1.25	-	0.07	-	1.11	-	20.5
219	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
220	-	10.6	-	8.8	-	2.4	-	47	-	35.1	-	0.2	-	52.7	-	6.75	-	26.4	-
223	17.7	-	5.7	-	7.9	-	1.9	-	48.7	-	7.8	-	0.91	-	0.03	-	0.04	-	20.1
224	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
225	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
226	17.9	-	6.4	-	8.1	-	1.9	-	50.3	-	6.2	-	0.96	-	0.04	-	0.34	-	21.5
227	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
229	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
230	19	-	6.7	-	7.8	-	2.3	-	49.5	-	4.7	-	1.87	-	0.75	-	0.05	-	22.1
235	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
239	-	10.8	-	9.1	-	2.5	-	47.8	-	36.4	-	0.25	-	54.9	-	8	-	27.8	-
243	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
244	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
245	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
246	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
247	17.8	-	6.9	-	7.3	-	1.9	-	50.3	-	4.1	-	1.17	-	0.15	-	0.05	-	19.7
248	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
251	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
252	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
253	17.9	-	7	-	8.5	-	2	-	51.5	-	8.1	-	1.16	-	0.08	-	0.05	-	21.3
254	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
255	-	10.7	-	9.1	-	2.5	-	47.5	-	36.4	-	0.22	-	56	-	8.2	-	28.1	-
258	17.7	-	1.4	-	9.1	-	2.1	-	53.1	-	6.1	-	7.69	-	2.1	-	0.74	-	22.7
259	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
260	18.1	-	7.1	-	9	-	2.2	-	52.1	-	6.1	-	0.98	-	5.73	-	1.81	-	23
261	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
262	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
265	34.9	-	1.5	-	8.3	-	2.1	-	49.5	-	1.3	-	1.65	-	52.9	-	3.38	-	22.9
266	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
267	19.1	-	9.9	-	9	-	2.4	-	53	-	14.1	-	1.34	-	14.6	-	4.21	-	25.1
268	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
269	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
272	18.3	-	8	-	9.2	-	2.3	-	52.2	-	19.2	-	1.27	-	19.9	-	5.26	-	25.4
273	-	10.8	-	9.3	-	2.6	-	48.2	-	35.2	-	0.27	-	56	-	7.77	-	28.3	-
274	18.3	-	7.9	-	9.3	-	2.4	-	52.1	-	21.4	-	0.87	-	22.3	-	5.76	-	26.1
275	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
276	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
279	18.3	-	8.2	-	9	-	2.3	-	52.4	-	13.4	-	0.94	-	26.6	-	6.42	-	26.2
280	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
281	18.7	-	8.2	-	9.6	-	2.5	-	51.6	-	13.3	-	-	-	-	-	-	-	-
282	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
283	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
286	19.1	-	8.8	-	10.1	-	2.6	-	52.3	-	11.7	-	-	-	-	-	-	-	-
287	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
288	18.2	-	7.5	-	9.8	-	2.4	-	52.3	-	14.2	-	-	-	-	-	-	-	-
289	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
290	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
291	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
294	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
295	19.3	11	8.9	9.3	10	2.6	2.5	48.1	52.9	33.1	16.4	-	-	-	-	-	-	-	-
296	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
297	18.7	-	7.7	-	10.1	-	2.5	-	52.1	-	16.7	-	-	-	-	-	-	-	-
300	18.8	-	8.4	-	10.2	-	2.5	-	52.2	-	18	-	-	-	-	-	-	-	-
301	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
302	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
303	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
304	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
307	19.7	-	7.6	-	10.9	-	2.7	-	54.2	-	22.5	-	-	-	-	-	-	-	-
308	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
309	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
310	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
311	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
314	20.1	-	8.6	-	11.5	-	2.8	-	56	-	24	-	-	-	-	-	-	-	-
315	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
316	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
317	19.5	-	8	-	11.1	-	2.7	-	53.7	-	27.9	-	-	-	-	-	-	-	-
318	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
321	-	10.3	-	9.3	-	2.6	-	47.1	-	38	-	-	-	-	-	-	-	-	-
322	19.6	-	8.4	-	11.3	-	2.7	-	54.2	-	29.6	-	-	-	-	-	-	-	-
323	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
324	19.2	-	8.2	-	10.9	-	2.7	-	53.2	-	29.4	-	-	-	-	-	-	-	-
325	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
328	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
329	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
330	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
331	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
332	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
335	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

susp. = suspension
- non-existent

Results of the experiment Nr 15 with *Cyclotella meneghiniana* grown at various light intensities.

Temperature (°C)	Light intensity (µmol photons $m^{-2}s^{-1}$)	Growth rate µ (d^{-1})	Days	Date	Extinction 560nm	Dry mass (mg/l)	Sample	ε_{13C} (‰)	ε_{15N} (‰)	$\delta^{18}O$ medium from fermenter vs. V-SMOV (‰)	$\delta^{18}O$ water vs. V-SMOV (‰)	$\delta^{18}O$ medium 1 vs. V-SMOV (‰)	$\delta^{18}O$ medium 2 vs. V-SMOV (‰)	Ca^{2+} medium (mg/l)
			1	23.05.2003				-	-	-	-7.55	-7.34	-	17.6
			4	26.05.2003	0.604			-	-	-6.81	-	-	-	-
			5	27.05.2003	0.643	316.7	D1	-21.36	-	-6.83	-	-	-	-
			6	28.05.2003	0.653	332.1	D2	-21.48	-	-6.81	-7.51	-7.51	-7.36	18.2
			11	02.06.2003	0.733			-	-	-6.98	-	-	-	-
			12	03.06.2003	0.732	357.5	D3	-22.72	-	-7.05	-	-	-	-
			13	04.06.2003	0.754	301.7	D4	-24.06	-	-6.97	-	-	-	-
			14	05.06.2003	0.75	367.9	D5	-22.82	-	-6.84	-	-	-	-
			15	06.06.2003	0.77	334.6	D6	-23.07	-	-6.90	-7.49	-7.38	-7.53	18.2
			20	11.06.2003	0.744			-	-	-6.95	-	-	-	-
			21	12.06.2003	0.747	342.9	D7	-23.61	-	-7.06	-	-	-	-
			22	13.06.2003	0.74	310.1	D8	-	-0.61	-7.12	-7.49	-7.41	-7.43	17.9
18	**500**	**0.2**	25	16.06.2003	0.729			-	-	-6.85	-	-	-	-
			26	17.06.2003	0.763			-	-	-7.08	-	-	-	-
			27	18.06.2003	0.753	392.7	D9	-	-0.47	-7.05	-	-	-	-
			30	21.06.2003	0.748			-	-	-	-7.55	-7.32	-7.41	17.8
			32	23.06.2003	0.742			-	-	-6.91	-	-	-	-
			33	24.06.2003	0.719	374.3	D10	-23.32	-0.62	-7.11	-	-	-	-
			34	25.06.2003	0.732	369.1	D11	-23.5	-0.49	-7.22	-	-	-	-
			35	26.06.2003	0.735	354.3	D12	-23.75	-0.43	-7.22	-	-	-	-
			36	27.06.2003	0.754	303.3	D13	-24.31	-0.64	-7.21	-7.60	-7.31	-7.38	18.1
			39	30.06.2003	0.723			-	-	-7.11	-	-	-	-
			40	01.07.2003	0.741	362.6	D14	-23.71	-0.80	-7.29	-	-	-	-
			41	02.07.2003	0.752	362	D15	-23.57	-0.78	-7.20	-	-	-	-
			42	03.07.2003	0.742	354.6	D16	-23.69	-0.59	-7.22	-	-	-	-
			43	04.07.2003	0.748	334.1	D17	-23.87	-0.64	-7.24	-	-	-	-
			46	07.07.2003	0.765			-	-	-7.13	-7.51	-7.29	-7.38	18.7
			47	08.07.2003	0.735	322.1	D18	-23.65	-	-7.20	-	-	-	-
			48	09.07.2003	0.695	368.9	D19	-23.51	-	-7.11	-	-	-	-
			49	10.07.2003	0.687	310.5	D20	-23.9	-	-7.27	-	-	-	-
			50	11.07.2003	0.622	322.2	D21	-23.58	-	-7.16	-	-	-	-
			53	14.07.2003	0.616			-	-	-7.26	-	-	-	-
			54	15.07.2003	0.619	268	D22	-24.11	-	-7.27	-	-	-	-
			55	16.07.2003	0.615	271.4	D23	-23.78	-	-7.18	-7.51	-7.20	-7.41	18.1
			56	17.07.2003	0.644	293.1	D24	-23.55	-	-7.24	-	-	-	-
			57	18.07.2003	0.617	260.7	D25	-23.92	-	-7.24	-	-	-	-
			60	21.07.2003	0.595	271.6	D26	-24.14	-	-7.27	-	-	-	-
			61	22.07.2003	0.586	270.1	D27	-24.11	-	-7.19	-	-	-	-
			62	23.07.2003	0.579	272.6	D28	-24.05	-	-7.04	-	-	-	-
			63	24.07.2003	0.567	271.1	D29	-24.11	-	-7.16	-	-	-	-
			64	25.07.2003	0.565	248	D30	-24.25	-	-7.37	-7.67	-7.28	-7.42	18.2
			67	28.07.2003	0.592			-	-	-7.32	-	-	-	-
18	**1100**	**0.2**	68	29.07.2003	0.591	257	D31	-24.36	-	-7.11	-	-	-	-
			69	30.07.2003	0.598	251.6	D32	-24.23	-	-7.10	-	-	-	-
			70	31.07.2003	0.595	258	D33	-24.28	-	-7.25	-	-	-	-
			71	01.08.2003	0.575	268.4	D34	-24.43	-	-7.18	-	-	-	-
			74	04.08.2003	0.63			-	-	-7.20	-7.46	-7.29	-	16.7
			75	05.08.2003	0.634	301.3	D35	-24	-	-7.15	-	-	-	-
			76	06.08.2003	0.643	297	D36	-24.15	-	-7.30	-	-	-	-
			77	07.08.2003	0.64	308.9	D37	-23.97	-	-7.19	-	-	-	-
			78	08.08.2003	0.66	307	D38	-24.04	-	-7.16	-	-	-	-
			81	11.08.2003	0.67			-	-	-7.12	-	-	-	-
			82	12.08.2003	0.677	315	D39	-24.15	-0.91	-7.07	-	-	-	-
			83	13.08.2003	0.686	307.9	D40	-24.35	-0.78	-7.08	-	-	-	-
			84	14.08.2003	0.682	324.8	D41	-24.15	-0.91	-7.11	-7.51	-7.23	-7.38	17.2
			85	15.08.2003	0.675	311.7	D42	-24.36	-0.86	-7.13	-	-	-	-
			88	18.08.2003	0.669			-	-	-7.21	-	-	-	-
			89	19.08.2003	0.665	301.5	D43	-24.26	-0.59	-7.22	-	-	-	-
			90	20.08.2003	0.652	315.5	D44	-24.01	-1.02	-7.14	-	-	-	-
			91	21.08.2003	0.642	305.6	D45	-24.44	-	-7.09	-	-	-	-
			92	22.08.2003	0.663	314.7	D46	-24.4	-0.94	-7.04	-	-	-	-
			95	25.08.2003	0.649			-	-	-7.27	-7.63	-7.33	-7.50	17.6
			96	26.08.2003	0.649	302.2	D47	-24.28	-	-7.23	-	-	-	-
			97	27.08.2003	0.652	307	D48	-24.19	-	-7.21	-	-	-	-
			98	28.08.2003	0.656	309.8	D49	-24.25	-	-7.20	-	-	-	-
			102	01.09.2003	0.649			-	-	-7.34	-	-	-	-
			103	02.09.2003	0.603	296.6	D50	-24.25	-0.80	-7.45	-	-	-	-
			104	03.09.2003	0.631	286.8	D51	-24.11	-	-7.33	-7.61	-7.35	-7.46	17.4
			105	04.09.2003	0.65	297	D52	-24.12	-0.79	-7.22	-	-	-	-
			106	05.09.2003	0.655	291.4	D53	-23.94	-0.93	-7.25	-	-	-	-
			109	08.09.2003	0.663			-	-	-7.14	-	-	-	-
			110	09.09.2003	0.673	305.5	D54	-23.8	-0.49	-7.15	-	-	-	-
			111	10.09.2003	0.67	317.9	D55	-23.78	-0.78	-7.13	-	-	-	-
			112	11.09.2003	0.654	303.3	D56	-23.94	-0.75	-7.16	-7.69	-7.34	-7.41	17.6
			113	12.09.2003	0.636	311.3	D57	-23.81	-	-7.28	-	-	-	-
			115	15.09.2003	0.575			-	-	-7.26	-	-	-	-
			116	16.09.2003	0.587	273.1	D58	-24.34	-0.64	-7.21	-	-	-	-
			117	17.09.2003	0.564	292	D59	-24.65	-	-7.14	-	-	-	-
			118	18.09.2003	0.533	279.9	D60	-24.59	-	-7.21	-	-	-	-
			119	19.09.2003	0.523	242.6	D61	-25.18	-	-7.18	-	-	-	-
			122	22.09.2003	0.559	198.9	D62	-25.26	-	-7.09	-7.53	-7.30	-7.38	18.1
			123	23.09.2003	0.559	243	D63	-24.39	-	-7.15	-	-	-	-
			124	24.09.2003	0.545	220.5	D64	-24.73	-	-7.32	-	-	-	-
			125	25.09.2003	0.521	226.2	D65	-24.66	-	-7.11	-	-	-	-
			126	26.09.2003	0.541	241	D66	-24.54	-	-7.20	-	-	-	-
			129	29.09.2003	0.521			-	-	-7.19	-	-	-	-
			130	30.09.2003	0.507	234.4	D67	-24.35	-0.59	-7.36	-7.58	-7.32	-7.39	17.8
			131	01.10.2003	0.526	224.7	D68	-24.31	-0.57	-7.31	-	-	-	-
			132	02.10.2003	0.514	241.3	D69	-24.12	-0.39	-7.24	-	-	-	-
18	**1700**	**0.2**	136	06.10.2003	0.532			-	-	-7.27	-	-	-	-
			137	07.10.2003	0.533	208.2	D70	-24.49	-0.59	-7.41	-	-	-	-
			138	08.10.2003	0.529			-	-	-7.34	-	-	-	-
			139	09.10.2003	0.525	231.2	D71	-24.14	-0.67	-7.16	-7.60	-7.35	-7.34	17.6
			140	10.10.2003	0.527	240.4	D72	-23.91	-0.74	-7.25	-	-	-	-
			143	13.10.2003	0.54			-	-	-7.33	-	-	-	-
			144	14.10.2003	0.498	211.2	D73	-24.14	-0.67	-7.22	-	-	-	-
			145	15.10.2003	0.506	234.4	D74	-23.88	-0.69	-7.18	-	-	-	-
			146	16.10.2003	0.494	231.3	D75	-23.91	-0.70	-7.21	-	-	-	-
			147	17.10.2003	0.502	206.7	D76	-24.02	-0.57	-7.23	-7.66	-7.26	-7.34	17.6

steady state
- non-existent

Results of the experiment Nr 15 with *Cyclotella meneghiniana* grown at various light intensities. (For T see previous page).

Days	Ca^{2+} susp. (mg/l)	Fe^{2+} medium (mg/l)	Fe^{2+} susp. (mg/l)	K^{+} medium (mg/l)	K^{+} susp. (mg/l)	Mg^{2+} medium (mg/l)	Mg^{2+} susp. (mg/l)	Na^{+} medium (mg/l)	Na^{+} susp. (mg/l)	Si^{2+} medium (mg/l)	Si^{2+} susp. (mg/l)	Chloride medium (mg/l)	Chloride susp. (mg/l)	Nitrate medium (mg/l)	Nitrate susp. (mg/l)	Phosphate medium (mg/l)	Phosphate susp. (mg/l)	Sulphate medium (mg/l)	Sulphate susp. (mg/l)
1	-	10.3	-	8.4	-	2.6	-	47.3	-	30.5	-	0.68	-	62	-	8.11	-	23.7	-
4	18.1	-	5.6	-	8.1	-	2.2	-	54.7	-	1.6	-	1.56	-	0.11	-	0.05	-	24.3
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	17.7	10.9	7.8	8.9	7.1	2.6	2.1	47.5	51.3	38.8	1.7	0.1	1.33	100.35	0.03	10.3	0.05	31	22.6
11	17.3	-	6.5	-	5.7	-	2.1	-	50.2	-	1.3	-	1.1	-	1.14	-	0.05	-	22.3
12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	17.2	-	5	-	5.6	-	2.1	-	51.2	-	0.9	-	1	-	0.17	-	0.05	-	21.6
14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	-	10.5	-	9	-	2.6	-	47.1	-	35.4	-	0.31	-	70.25	-	17	-	30.8	-
20	17.2	-	6.1	-	5.1	-	2.2	-	49.4	-	1.1	-	0.9	-	0.24	-	0.05	-	20.2
21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
22	17.1	10.2	6.3	8.8	5.1	2.6	2.1	46.8	49.3	35.8	1.1	0.14	0.8	70.35	0.05	13.7	0.05	30.5	20.2
25	17.5	-	4.6	-	5.3	-	2.1	-	50.2	-	0.7	-	0.83	-	0.05	-	0.05	-	21.7
26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
27	17.8	-	4.4	-	5	-	2.3	-	49.4	-	0.8	-	0.88	-	0.21	-	0.05	-	20.5
30	-	10.3	-	8.9	-	2.5	-	47.1	-	39	-	0.16	-	71.3	-	15.25	-	30.4	-
32	16.4	-	4.3	-	4.6	-	2	-	46	-	0.7	-	0.81	-	0.15	-	0.05	-	20.1
33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
34	17.3	-	5.2	-	4.9	-	2.1	-	49.5	-	1	-	0.84	-	0.18	-	0.05	-	19.8
35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
36	16.2	10.3	4.9	9.1	4.7	2.6	2	48	46.4	42	0.9	0.11	0.84	73.9	0.05	11.9	0.05	31	19.7
39	17.3	-	5	-	4.8	-	2.1	-	49.3	-	-	-	0.75	-	0.06	-	0.05	-	21.5
40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
41	18.9	-	5	-	5.2	-	2.4	-	53.6	-	0.9	-	0.94	-	0.67	-	0.05	-	21.3
42	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
43	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
46	-	10.3	-	8.8	-	2.5	-	48.4	-	35.4	-	0.14	-	75.6	-	7.9	-	31.9	-
47	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
48	18.2	-	4.8	-	4.7	-	2.3	-	51.9	-	0.8	-	1.28	-	0.06	-	0.05	-	20.9
49	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
50	17.7	-	5.8	-	4.3	-	2.2	-	49.5	-	1.6	-	0.76	-	0.16	-	0.09	-	21.6
53	16.9	-	5.7	-	4.5	-	2.1	-	47.6	-	1.4	-	0.64	-	0.02	-	0.3	-	20
54	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
55	-	10.2	-	8.8	-	2.6	-	47.3	-	37.5	-	0.14	-	79.9	-	5.48	-	32.3	-
56	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
57	17.6	-	6.4	-	4.8	-	2.2	-	48.6	-	1.5	-	0.7	-	0.05	-	0.05	-	21.6
60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
61	17.9	-	5.6	-	4.8	-	2.1	-	47.9	-	1.3	-	0.8	-	0.19	-	0.21	-	21.5
62	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
63	17	-	6.2	-	4.8	-	2.1	-	47.6	-	1.7	-	0.72	-	0.01	-	0.2	-	20.6
64	-	10.3	-	8.9	-	2.5	-	48	-	41.1	-	0.11	-	72.4	-	5.13	-	28.6	-
67	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
68	17	-	6	-	4.9	-	2.1	-	48	-	1.4	-	0.86	-	0.02	-	0.33	-	21.2
69	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
70	17	-	6	-	5.1	-	2.1	-	48	-	1.5	-	0.75	-	0.01	-	0.11	-	21.3
71	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
74	-	10.1	-	8.8	-	2.5	-	47.5	-	40.4	-	0.32	-	70.5	-	14.25	-	32.5	-
75	16.6	-	5.8	-	4.6	-	2.1	-	48.1	-	1.4	-	0.62	-	0.4	-	0.86	-	20.8
76	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
77	15.6	-	5.6	-	5.1	-	2.1	-	49.4	-	1.4	-	0.94	-	0.47	-	1.12	-	21.7
78	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
81	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
82	19.2	-	6.7	-	4.7	-	2.9	-	46.9	-	2.1	-	3.25	-	2.91	-	1.02	-	24.4
83	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
84	19.2	10.2	6.4	8.5	4.5	2.5	2.9	45.6	46.2	39.6	2.2	0.18	2.93	68.5	2.45	15.5	1.02	31.55	23.8
85	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
88	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
89	18.6	-	7.2	-	4.5	-	2.8	-	45.4	-	2.2	-	2.34	-	1.72	-	1.25	-	23.6
90	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
91	18.6	-	6.9	-	4.5	-	2.8	-	45.7	-	2	-	2.46	-	2.03	-	1.17	-	23
92	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
95	-	10.3	-	8.6	-	2.5	-	45.1	-	39.3	-	0.17	-	69.4	-	19.1	-	31	-
96	19.4	-	6.8	-	4.5	-	3.1	-	44.5	-	2	-	3.67	-	3.01	-	1.12	-	24.9
97	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
98	18	-	7.1	-	4.7	-	2.7	-	45.3	-	2	-	2.67	-	1.83	-	1.11	-	22.4
102	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
103	19.5	-	7.4	-	5.3	-	2.8	-	45.8	-	5.5	-	2.67	-	3.57	-	0.81	-	26.2
104	-	9.8	-	8.7	-	2.5	-	45.8	-	44.4	-	0.2	-	70	-	17.2	-	30.9	-
105	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
106	20.3	-	6.6	-	5.5	-	3.2	-	45.5	-	5.5	-	3.87	-	8.23	-	0.86	-	25.8
109	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
110	17.6	-	7.4	-	5.7	-	2.4	-	47.5	-	6.9	-	0.91	-	8.2	-	1.74	-	21.7
111	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
112	18.1	10	9.4	8.7	5.9	2.5	2.6	45.1	48.2	39.6	8.3	0.18	1.13	70.95	10.09	20.15	0.48	31.3	22.6
113	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
115	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
116	18.1	-	8.9	-	5.6	-	2.7	-	50.6	-	2.2	-	2.49	-	1.39	-	0.9	-	24.4
117	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
118	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
119	23.5	-	7.2	-	6.7	-	4.3	-	52.5	-	1.9	-	9.12	-	8.83	-	0.77	-	37.6
122	-	9.4	-	8.7	-	2.7	-	46.1	-	37.3	-	0.12	-	73.5	-	13.4	-	30.4	-
123	19.3	-	5.8	-	6.1	-	3	-	51.8	-	1.6	-	3.83	-	3.69	-	1.01	-	26.7
124	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
125	17.5	-	5.8	-	5.6	-	2.3	-	50.4	-	1.2	-	1	-	0.49	-	0.05	-	23.1
126	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
129	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
130	17.7	10.5	6.1	8.8	5.8	2.6	2.2	47.3	49.9	37.4	1.5	0.11	0.89	74	0.53	12.3	0.05	32.3	22.2
131	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
132	19.4	-	6.2	-	7.5	-	3.3	-	55.2	-	1.4	-	7.55	-	0.82	-	0.05	-	31
136	16.7	-	6.5	-	6.2	-	2.3	-	52.7	-	1.5	-	1.19	-	0.29	-	0.05	-	25.2
137	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
138	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
139	18.1	10.4	5.9	8.8	6.1	2.5	2.6	47.6	50.3	40.2	1.5	0.14	1.72	73	1.25	12.2	0.05	32	25.5
140	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
143	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
144	16.9	-	6.4	-	6.1	-	2.2	-	50.1	-	1.5	-	0.77	-	0.21	-	0.05	-	23.5
145	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
146	16.8	-	6.7	-	5.9	-	2.1	-	49.9	-	1.6	-	0.67	-	0.04	-	0.05	-	23.2
147	-	10.4	-	8.8	-	2.5	-	47.6	-	41.2	-	0.12	-	73.6	-	13.2	-	32.2	-

susp. = suspension
- non-existent

Results of the experiment Nr 15 with *Cyclotella meneghiniana* grown at various light intensities.

Temperature (°C)	Light intensity (µmol photons $m^{-2}s^{-1}$)	Growth rate µ (d^{-1})	Days	Date	Extinction 560nm	Dry mass (mg/l)	Sample	ε_{13C} (‰)	ε_{15N} (‰)	$\delta^{18}O$ medium from fermenter vs. V-SMOV (‰)	$\delta^{18}O$ water vs. V-SMOV (‰)	$\delta^{18}O$ medium 1 vs. V-SMOV (‰)	$\delta^{18}O$ medium 2 vs. V-SMOV (‰)	Ca^{2+} medium (mg/l)
			150	20.10.2003	0.65			-	-	-7.33	-	-	-	-
			151	21.10.2003	0.638	294.9	D77	-23.82	-	-7.26	-	-	-	-
			152	22.10.2003	0.706	292.8	D78	-23.83	-	-7.19	-	-	-	-
			153	23.10.2003	0.717	282.8	D79	-24.46	-	-7.18	-	-	-	-
			154	24.10.2003	0.73	335.8	D80	-23.71	-	-7.10	-7.67	-7.32	-7.40	17.6
			157	27.10.2003	0.766			-	-	-7.11	-	-	-	-
			158	28.10.2003	0.759	343.6	D81	-24.02	-	-6.98	-	-	-	-
			159	29.10.2003	0.755	326.1	D82	-24.01	-	-7.35	-	-	-	-
			160	30.10.2003	0.765	314.9	D83	-24.09	-	-7.13	-	-	-	-
			161	31.10.2003	0.764	331.3	D84	-24.08	-	-7.14	-7.62	-7.33	-7.39	17.75
			164	03.11.2003	0.779			-	-	-7.25	-	-	-	-
			165	04.11.2003	0.768	294.6	D85	-23.69	-	-7.32	-	-	-	-
			166	05.11.2003	0.783	340.2	D86	-23.88	-	-7.25	-	-	-	-
			167	06.11.2003	0.775	330.1	D87	-24.22	-	-7.19	-	-	-	-
			168	07.11.2003	0.782	310.5	D88	-24.63	-	-7.25	-	-	-	-
			171	10.11.2003	0.781			-	-	-7.10	-7.59	-7.29	-7.38	18.9
			172	11.11.2003	0.787	367.1	D89	-24.13	-	-7.00	-	-	-	-
			173	12.11.2003	0.782	333.1	D90	-24.69	-	-7.07	-	-	-	-
			174	13.11.2003	0.78	351.3	D91	-24.44	-	-7.24	-	-	-	-
18	**200**	**0.2**	175	14.11.2003	0.789	306.7	D92	-24.74	-	-7.18	-	-	-	-
			178	17.11.2003	0.782			-	-	-6.98	-	-	-	-
			179	18.11.2003	0.802			-	-	-	-	-	-	-
			180	19.11.2003	0.795	343.7	D93	-24.05	-	-7.10	-7.63	-7.36	-7.22	17.3
			181	20.11.2003	0.806	366	D94	-23.7	-	-7.02	-	-	-	-
			182	21.11.2003	0.806	361.8	D95	-23.89	-	-7.00	-	-	-	-
			185	24.11.2003	0.803			-	-	-7.00	-	-	-	-
			186	25.11.2003	0.817	363.6	D96	-23.83	-0.80	-7.03	-	-	-	-
			187	26.11.2003	0.829	376.4	D97	-23.9	-0.41	-7.11	-	-	-	-
			188	27.11.2003	0.82	375.1	D98	-23.98	-0.69	-7.04	-	-	-	-
			189	28.11.2003	0.822	327.1	D99	-24	-0.76	-7.14	-7.67	-7.38	-7.37	18
			192	01.12.2003	0.842			-	-	-	-	-	-	-
			193	02.12.2003	0.834	375.1	D100	-24.11	-0.90	-7.03	-	-	-	-
			194	03.12.2003	0.829	392.9	D101	-24	-0.70	-7.20	-	-	-	-
			195	04.12.2003		357.3	D102	-24.2	-0.95	-7.18	-	-	-	-
			196	05.12.2003	0.835	365	D103	-24.15	-0.80	-7.13	-	-	-	-
			199	08.12.2003	0.836			-	-	-6.92	-7.64	-7.50	-7.29	18
			200	09.12.2003	0.825	351.7	D104	-24.26	-0.64	-7.01	-	-	-	-
			201	10.12.2003	0.825	367.4	D105	-24.16	-0.75	-7.13	-	-	-	-
			202	11.12.2003	0.813	358.6	D106	-24.29	-1.04	-7.17	-	-	-	-
			203	12.12.2003	0.815	356.6	D107	-24.05	-0.77	-7.18	-	-	-	-
			205	15.12.2003	0.807			-	-	-6.91	-	-	-	-
			206	16.12.2003	0.813	369.4	D108	-23.85	-0.81	-7.06	-	-	-	-
			207	17.12.2003	0.821	373.4	D109	-24.04	-	-	-7.62	-7.14	-7.39	17.8
			208	18.12.2003	0.83		D110	-23.04	-	-7.10	-	-	-	-
			209	19.12.2003	0.837			-	-	-	-	-	-	-
			211	21.12.2003	0.785			-	-	-6.96	-	-	-	-
21	**500**	**0.2**	218	27.12.2003	0.761			-	-	-7.28	-7.71	-7.22	-7.26	17.4
			222	31.12.2003	0.754			-	-	-6.86	-	-	-	-
			226	04.01.2004	0.564			-	-	-6.74	-	-	-	-
			227	05.01.2004	0.509			-	-	-6.63	-	-	-	-
			228	06.01.2004	0.424			-	-	-6.82	-	-	-	-

steady state
- non-existent

Results of the experiment Nr 15 with *Cyclotella meneghiniana* grown at various light intensities. (For T see previous page).

Days	Ca^{2+} susp. (mg/l)	Fe^{2+} medium (mg/l)	Fe^{2+} susp. (mg/l)	K^{+} medium (mg/l)	K^{+} susp. (mg/l)	Mg^{2+} medium (mg/l)	Mg^{2+} susp. (mg/l)	Na^{+} medium (mg/l)	Na^{+} susp. (mg/l)	Si^{2+} medium (mg/l)	Si^{2+} susp. (mg/l)	Chloride medium (mg/l)	Chloride susp. (mg/l)	Nitrate medium (mg/l)	Nitrate susp. (mg/l)	Phosphate medium (mg/l)	Phosphate susp. (mg/l)	Sulphate medium (mg/l)	Sulphate susp. (mg/l)
150	16.6	-	6.9	-	6.7	-	2.1	-	52.9	-	1.4	-	0.77	-	0.05	-	0.05	-	24.7
151	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
152	17.1	-	7.3	-	6.9	-	2.1	-	53.8	-	1.7	-	0.81	-	0.07	-	0.05	-	24.4
153	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
154	-	10.4	-	8.8	-	2.4	-	47.15	-	38.45	-	0.14	-	72.9	-	17.8	-	32.5	-
157	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
158	18.4	-	6	-	7.2	-	2.1	-	52	-	2	-	1.17	-	0.36	-	0.05	-	23.1
159	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
160	20.3	-	5.7	-	8.6	-	2.8	-	57.9	-	1.1	-	3.46	-	2.44	-	0.05	-	28.7
161	-	10.4	-	8.7	-	2.4	-	47.75	-	37.95	-	0.13	-	72.8	-	15.1	-	32.2	-
164	17.8	-	6.1	-	6.7	-	2.1	-	50.5	-	1.2	-	0.72	-	0.05	-	0.05	-	21.5
165	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
166	18.3	-	6.3	-	6.8	-	2.1	-	51.9	-	1.2	-	1.01	-	0.07	-	0.05	-	22.2
167	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
168	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
171	17.9	10.5	6.5	8.9	6.7	2.4	2.1	47.65	51.3	33	1.4	0.16	0.77	64.5	0.07	10.9	0.2	28.7	17.4
172	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
173	18.2	-	6.8	-	6.6	-	2.1	-	51.2	-	1.2	-	0.72	-	0.06	-	0.28	-	17.1
174	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
175	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
178	18.2	-	6.8	-	7.2	-	2.1	-	50.1	-	1.3	-	1.27	-	0.04	-	0.05	-	16.8
179	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
180	18.1	10.6	6.7	8.8	6.6	2.4	2.1	47.2	50.2	32.8	1.3	18.5	0.76	51.05	0.05	7.19	0.05	25.8	16.8
181	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
182	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
185	18.5	-	6.9	-	6.6	-	2.2	-	52.2	-	1.4	-	0.88	-	0.05	-	0.05	-	17.1
186	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
187	17.9	-	6.8	-	6.4	-	2.1	-	51	-	1.4	-	0.69	-	0.04	-	0.05	-	17.2
188	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
189	-	10.5	-	8.7	-	2.4	-	45.85	-	34.35	-	0.15	-	51.5	-	6.78	-	25.55	-
192	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
193	19	-	5.9	-	6.8	-	2.3	-	52.2	-	0.8	-	1.53	-	1.68	-	0.05	-	18.9
194	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
195	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
196	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
199	18.6	10.6	5.6	9.1	6.6	2.5	2.2	47.1	50	30	0.8	0.17	1.19	53.9	0.02	6.31	0.05	26.3	17.5
200	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
201	18.6	-	5.3	-	6.4	-	2.2	-	49.2	-	0.9	-	0.88	-	0.13	-	0.05	-	17.5
202	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
203	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
205	18.6	-	5.7	-	6.5	-	2.1	-	50.2	-	1	-	0.82	-	0.03	-	0.05	-	17.7
206	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
207	-	10.7	-	9.1	-	2.4	-	46.8	-	24.8	-	-	-	-	-	-	-	-	-
208	19.1	-	5.5	-	6.9	-	2.3	-	51.3	-	0.78	-	0.76	-	0.07	-	0.05	-	18.4
209	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
211	18.4	-	5.4	-	6.8	-	2.3	-	50	-	0.76	-	0.86	-	0.07	-	0.05	-	18
218	-	10.5	-	9.5	-	2.4	-	48.3	-	30.8	-	-	-	-	-	-	-	-	-
222	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
226	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
227	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
228	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

susp. = suspension
- non-existent

Experiment Nr 5. Optical density of *Fragilaria crotonensis* culture determined by extinction measurements using three different wavelengths.

Date	Ext. 440 nm	Ext. 535 nm	Ext. 560 nm	Temperature (°C)	pH
15.01.2002 16:00			0.173	24	6.75
16.01.2002 10:00			0.567	24.2	6.76
16.01.2002 16:30			0.536	24.2	6.74
17.01.2002 10:00			0.559	24.2	6.75
17.01.2002 14:00			0.593	24.3	6.76
17.01.2002 17:00			0.603	24.2	6.73
18.01.2002 08:30			0.596	24.2	6.72
18.01.2002 12:30			0.571	24.2	6.72
18.01.2002 16:00			0.582	24.2	6.72
21.01.2002 08:00			0.593	24.6	6.72
21.01.2002 12:00			0.605	24	6.7
21.01.2002 16:00			0.597	24	6.69
22.01.2002 08:30			0.554	24	6.7
22.01.2002 10:30			0.58	24	6.69
22.01.2002 14:00			0.566	24	6.7
23.01.2002 07:30			0.575	24	6.7
23.01.2002 09:30			0.561	24	6.7
23.01.2002 12:30			0.582	24	6.68
23.01.2002 14:30			0.586	24	6.7
23.01.2002 16:30			0.567	24	6.68
24.01.2002 08:00			0.549	24	6.68
24.01.2002 10:30			0.555	24	6.67
24.01.2002 17:00			0.554	24	6.67
25.01.2002 08:00			0.5	24	6.66
25.01.2002 09:00			0.521	24	6.65
25.01.2002 13:00			0.524	24	6.65
25.01.2002 15:00			0.516	24	6.64
28.01.2002 09:00			0.378	24	6.61
28.01.2002 11:30			0.42	24	6.61
28.01.2002 13:00			0.427	24	6.61
29.01.2002 08:30			0.436	24	6.6
29.01.2002 10:00			0.42	24	6.6
29.01.2002 11:00			0.426	24	6.6
29.01.2002 16:30			0.44	24	6.6
30.01.2002 08:00			0.412	24	6.6
30.01.2002 10:00			0.409	24	6.6
30.01.2002 11:00			0.406	24	6.59
30.01.2002 14:00			0.4	24	6.58
30.01.2002 16:00			0.413	24	6.6
31.01.2002 08:00			0.382	24	6.6
31.01.2002 10:00			0.4	24	6.59
31.01.2002 12:00			0.397	24	6.59
01.02.2002 08:00			0.405	24	6.59
01.02.2002 10:00			0.404	24	6.59
01.02.2002 12:00			0.4	24	6.59
01.02.2002 14:00			0.399	24	6.6
04.02.2002 08:00			0.654	24	6.9
04.02.2002 10:00			0.675	24	6.9
04.02.2002 11:00			0.669	24	6.91
04.02.2002 12:00			0.664	24	6.91
04.02.2002 14:00			0.691	24	6.91
04.02.2002 16:00			0.674	24	6.92
05.02.2002 08:00			0.712	24	6.96
05.02.2002 10:00			0.697	24	6.96
06.02.2002 08:00			0.775	24	7
06.02.2002 10:00			0.773	24	7
06.02.2002 12:00			0.768	24	7
06.02.2002 14:00			0.778	24	7
06.02.2002 16:00			0.76	24	7
07.02.2002 08:00			0.761	24	6.97
07.02.2002 10:00			0.794	24	6.96
07.02.2002 12:00			0.751	24	6.97
07.02.2002 14:30			0.749	24	6.98
08.02.2002 10:00			0.783	24	7.02
08.02.2002 14:00			0.81	24	6.99
10.02.2002 09:00			0.821	24	7.05
10.02.2002 09:30			0.795	24	7.06
10.02.2002 12:00			0.779	24	7.05
12.02.2002 10:00			0.805	24	7.07
12.02.2002 13:00			0.799	24	7.07
12.02.2002 16:00			0.79	24	7.05
13.02.2002 08:00			0.8	24	7.06
13.02.2002 10:00			0.773	24	7.07
13.02.2002 12:00			0.792	24	7.07
13.02.2002 14:00			0.789	24	7.06
13.02.2002 16:00			0.814	24	7.08
14.02.2002 08:00			0.803	24	7.06
14.02.2002 10:00			0.792	24	7.07
14.02.2002 12:00			0.787	24	7.07
14.02.2002 14:00			0.789	24	7.07
14.02.2002 16:00			0.778	24	7.07
15.02.2002 08:00			0.777	24	7.08
15.02.2002 10:00			0.806	24	7.08
15.02.2002 12:00			0.811	24	7.07
15.02.2002 14:00			0.798	24	7.12
15.02.2002 16:00			0.804	24	7.09
15.02.2002 18:00			0.801	24	7.09
15.02.2002 20:00			0.773	24	7.07
18.02.2002 08:00			0.774	24	7.1
18.02.2002 10:00			0.76	24	7.1
18.02.2002 10:30			0.785	24	7.1
18.02.2002 12:00			0.772	24	7.1
18.02.2002 15:00			0.794	24	7.1
19.02.2002 08:00			0.784	24	7.11
19.02.2002 10:00			0.757	24	7.12
19.02.2002 12:00			0.76	24	7.11
19.02.2002 14:00			0.778	24	7.11
19.02.2002 16:00			0.762	24	7.12
20.02.2002 08:00	1.002	0.77	0.777	24	7.12

Date	Ext. 440 nm	Ext. 535 nm	Ext. 560 nm	Temperature (°C)	pH
20.02.2002 10:00	0.978	0.786	0.775	24	7.11
20.02.2002 12:00	0.984	0.768	0.776	24	7.11
20.02.2002 14:00	0.985	0.769	0.771	24	7.12
20.02.2002 16:00	0.946	0.714	0.75	24	7.11
21.02.2002 08:00	1.04	0.76	0.799	24	7.22
21.02.2002 10:00	1.047	0.808	0.805	24	7.22
21.02.2002 12:00	1.02	0.786	0.801	24	7.21
21.02.2002 14:00	1.076	0.821	0.812	24	7.23
21.02.2002 16:00	1.074	0.841	0.851	24	7.25
22.02.2002 08:00	1.123	0.847	0.839	24	7.29
22.02.2002 10:00	1.119	0.858	0.846	24	7.3
22.02.2002 12:00	1.132	0.861	0.86	24	7.28
22.02.2002 14:30	1.145	0.855	0.846	24	7.29
22.02.2002 17:00	1.121	0.856	0.827	24	7.29
25.02.2002 08:00	1.209	0.891	0.885	24	7.35
25.02.2002 10:00	1.195	0.899	0.88	24	7.34
25.02.2002 12:00	1.204	0.894	0.872	24	7.35
25.02.2002 14:00	1.173	0.882	0.875	24	7.35
25.02.2002 16:00	1.17	0.885	0.881	24	7.35
26.02.2002 08:00	1.195	0.897	0.877	24	7.34
26.02.2002 10:00	1.145	0.848	0.835	24	7.34
26.02.2002 12:00	1.205	0.904	0.892	24	7.33
26.02.2002 14:00	1.196	0.905	0.868	24	7.34
26.02.2002 16:30	1.234	0.921	0.901	24	7.35
27.02.2002 08:00	1.188	0.892	0.881	24	7.35
27.02.2002 10:30	1.209	0.896	0.866	24	7.35
27.02.2002 12:00	1.2	0.883	0.856	24	7.35
27.02.2002 14:00	1.175	0.857	0.876	24	7.35
27.02.2002 16:30	1.181	0.872	0.88	24	7.35
28.02.2002 08:00	1.142	0.847	0.864	24	7.35
28.02.2002 10:00	1.101	0.825	0.806	24	7.37
28.02.2002 12:00	1.146	0.847	0.845	24	7.35
28.02.2002 14:00	1.116	0.86	0.826	24	7.35
01.03.2002 08:00	1.075	0.819	0.808	24	7.37
01.03.2002 09:30	1.144	0.878	0.864	18.6	7.38
01.03.2002 11:30	1.181	0.876	0.855	18	7.32
01.03.2002 13:30	1.101	0.822	0.811	18	7.29
01.03.2002 15:30	1.074	0.825	0.803	18	7.29
04.03.2002 08:00	1.141	0.859	0.839	18	7.32
04.03.2002 10:00	1.108	0.813	0.813	18	7.32
04.03.2002 12:00	1.147	0.851	0.808	18	7.32
04.03.2002 14:00	1.133	0.846	0.825	18	7.32
04.03.2002 16:00	1.173	0.853	0.851	18	7.31
05.03.2002 08:00	1.158	0.863	0.864	18	7.31
05.03.2002 10:00	1.15	0.854	0.85	18	7.31
05.03.2002 12:00	1.154	0.876	0.865	18	7.31
05.03.2002 16:00	1.137	0.84	0.827	18	7.32
06.03.2002 08:00	1.177	0.848	0.859	18	7.31
06.03.2002 10:00	1.131	0.838	0.843	18	7.31
06.03.2002 12:00	1.15	0.869	0.86	18	7.31
06.03.2002 14:00	1.133	0.857	0.837	18	7.33
06.03.2002 16:00	1.149	0.857	0.857	18	7.31
07.03.2002 09:00	1.095	0.847	0.852	18	7.31
07.03.2002 12:00	1.136	0.829	0.831	18	7.31
07.03.2002 14:00	1.079	0.819	0.818	18	7.31
07.03.2002 16:00	1.129	0.846	0.849	18	7.31
08.03.2002 08:00	1.132	0.902	0.906	18	7.32
08.03.2002 10:00	1.173	0.875	0.852	18	7.32
08.03.2002 12:00	1.171	0.874	0.869	18	7.32
08.03.2002 14:00	1.167	0.876	0.861	18	7.3
08.03.2002 16:00	1.185	0.896	0.866	18	7.3
11.03.2002 08:00	1.115	0.824	0.824	18	7.3
11.03.2002 10:00	1.13	0.877	0.838	18	7.3
11.03.2002 12:00	1.132	0.885	0.837	18	7.3
11.03.2002 14:00	1.113	0.847	0.839	18	7.3
12.03.2002 09:00	1.144	0.846	0.84	18	7.31
12.03.2002 12:00	1.111	0.832	0.826	18	7.31
12.03.2002 14:00	1.138	0.835	0.851	18	7.28
13.03.2002 08:00	1.122	0.843	0.84	18	7.28
13.03.2002 10:00	1.129	0.872	0.846	18	7.28
13.03.2002 11:30	1.121	0.854	0.839	18	7.29
14.03.2002 08:00	1.166	0.857	0.849	18	7.31
14.03.2002 10:00	1.107	0.838	0.842	18	7.31
14.03.2002 11:30	1.11	0.84	0.831	13.4	7.22
15.03.2002 08:00	1.04	0.803	0.792	13.3	
15.03.2002 11:00	1.056	0.789	0.804	14.7	
15.03.2002 13:00	1.027	0.77	0.766	13.9	
15.03.2002 15:00	1.053	0.802	0.804	23.4	
18.03.2002 08:00	1.023	0.761	0.754	12	7.19
18.03.2002 10:00	1.005	0.757	0.753	12	7.19
18.03.2002 11:30	1.004	0.758	0.75	12	7.19
19.03.2002 08:00	0.941	0.683	0.693	12	7.19
19.03.2002 10:00	0.971	0.739	0.735	12	7.19
19.03.2002 12:00	0.942	0.73	0.723	12	7.19
19.03.2002 14:00	0.965	0.743	0.738	12	7.19
19.03.2002 16:00	0.965	0.747	0.741	12	7.2
20.03.2002 08:00	0.95	0.718	0.71	12	7.19
20.03.2002 10:00	0.955	0.749	0.725	12	7.19
20.03.2002 11:00	0.972	0.737	0.736	12	7.18
20.03.2002 13:00	0.966	0.724	0.728	12	7.18
20.03.2002 15:00	0.972	0.737	0.74	12	7.18
21.03.2002 07:30	0.929	0.7	0.704	12	7.19
21.03.2002 10:00	0.921	0.71	0.717	12	7.18
21.03.2002 12:00	0.973	0.727	0.734	12	7.18
21.03.2002 17:00	0.976	0.731	0.749	12	7.19
22.03.2002 09:00	0.926	0.709	0.707	12	7.19
22.03.2002 12:00	0.936	0.722	0.715	12	7.19
25.03.2002 09:30	0.94	0.718	0.732	12	7.19

Experiment Nr 6. Optical density of *Cyclotella meneghiniana* culture determined by extinction measurements using three different wavelengths.

Date	Ext. 440nm	Ext. 535nm	Ext. 560nm	Temperature (°C)	pH
23.04.2002 11:00	0.199	0.12	0.114	18	6.7
24.04.2002 09:00	0.328	0.223	0.215	18	6.7
24.04.2002 11:00	0.36	0.233	0.231	18	6.8
24.04.2002 14:00	0.351	0.243	0.244	18	6.76
25.04.2002 11:00	0.529	0.355	0.364	18	6.76
25.04.2002 14:00	0.519	0.382	0.372	18	6.87
25.04.2002 16:00	0.557	0.39	0.382	18	6.82
26.04.2002 11:00	0.668	0.486	0.487	18	6.8
26.04.2002 13:00	0.676	0.5	0.488	18	6.9
26.04.2002 15:00	0.679	0.499	0.493	18	6.9
29.04.2002 12:00	0.685	0.595	0.625	18	6.9
29.04.2002 16:00	0.725	0.62	0.637	18	6.9
30.04.2002 10:00	0.715	0.62	0.638	18	6.9
30.04.2002 14:00	0.745	0.656	0.68	18	6.9
02.05.2002 10:00	0.722	0.64	0.647	18	6.9
02.05.2002 12:00	0.76	0.625	0.641	18	6.9
03.05.2002 10:00	0.758	0.658	0.673	18	6.9
03.05.2002 12:00	0.769	0.688	0.704	18	6.9
03.05.2002 16:00	0.778	0.68	0.705	18	7
06.05.2002 10:00	0.785	0.663	0.674	18	6.9
06.05.2002 12:00	0.787	0.69	0.693	18	6.9
06.05.2002 16:00	0.821	0.707	0.74	18	6.96
07.05.2002 11:00	0.803	0.694	0.715	18	7
07.05.2002 16:30	0.82	0.717	0.737	18	6.95
08.05.2002 09:30	0.793	0.666	0.688	18	7
08.05.2002 13:00	0.784	0.68	0.713	18	7
08.05.2002 16:00	0.775	0.689	0.718	18	6.97
13.05.2002 09:00	0.782	0.711	0.729	18	7
14.05.2002 09:00	0.746	0.681	0.709	18	7
14.05.2002 11:00	0.795	0.666	0.689	18	7
14.05.2002 14:00	0.773	0.765	0.734	18	7
14.05.2002 16:00	0.786	0.702	0.724	18	6.98
15.05.2002 09:00	0.778	0.688	0.718	18	7
15.05.2002 12:30	0.776	0.693	0.717	18	7
15.05.2002 16:00	0.765	0.693	0.716	18	6.99
16.05.2002 10:00	0.805	0.702	0.719	18	7
16.05.2002 16:00	0.854	0.72	0.748	18	7
17.05.2002 09:30	0.822	0.726	0.743	18	7
17.05.2002 13:00	0.799	0.709	0.731	18	6.99
21.05.2002 08:30	0.734	0.661	0.688	18	6.99
21.05.2002 14:00	0.808	0.708	0.727	18	6.98
21.05.2002 16:00	0.796	0.702	0.737	18	7
22.05.2002 10:00	0.77	0.663	0.677	18	7
22.05.2002 12:00	0.801	0.679	0.712	18	7
22.05.2002 14:00	0.805	0.692	0.722	18	7
22.05.2002 16:00	0.797	0.715	0.733	18	7
23.05.2002 10:00	0.772	0.675	0.702	15	7
23.05.2002 14:00	0.776	0.678	0.699	15	6.95
23.05.2002 16:00	0.795	0.709	0.713	15	6.93
24.05.2002 09:00	0.698	0.611	0.615	15	7
24.05.2002 13:00	0.756	0.632	0.681	15	7
24.05.2002 16:00	0.748	0.643	0.667	15	6.9
27.05.2002 10:00	0.724	0.63	0.641	15	7
27.05.2002 14:00	0.722	0.617	0.64	15	6.98
28.05.2002 09:00	0.701	0.597	0.612	15	7
28.05.2002 12:00	0.716	0.613	0.631	15	7
28.05.2002 14:00	0.701	0.605	0.579	15	7
29.05.2002 10:00	0.717	0.614	0.629	15	7
29.05.2002 14:00	0.704	0.6	0.564	15	7
03.06.2002 09:00	0.621	0.515	0.547	15	6.9
03.06.2002 11:30	0.62	0.494	0.508	15	6.9
03.06.2002 17:00	0.635	0.542	0.599	16.1	7
04.06.2002 08:30	0.617	0.505	0.529	15	7
04.06.2002 14:00	0.681	0.552	0.563	15	7
05.06.2002 09:00	0.608	0.501	0.523	15	7
05.06.2002 16:00	0.642	0.525	0.54	15.5	7
06.06.2002 12:30	0.631	0.515	0.526	15	7
07.06.2002 10:00	0.604	0.501	0.513	15	7
07.06.2002 14:00	0.613	0.505	0.515	15	7
10.06.2002 09:00	0.554	0.456	0.492	15	7
10.06.2002 11:00	0.589	0.461	0.468	15	6.97
10.06.2002 14:00	0.587	0.479	0.484	15	6.98
10.06.2002 16:30	0.589	0.484	0.489	15	7
11.06.2002 09:00	0.567	0.452	0.454	15	7
11.06.2002 12:00	0.589	0.468	0.515	15	6.9
12.06.2002 11:30	0.537	0.415	0.423	15	6.96
12.06.2002 16:00	0.567	0.425	0.425	15	6.92
13.06.2002 10:00	0.521	0.397	0.401	15	6.92
13.06.2002 12:00	0.526	0.381	0.38	15	9.61
13.06.2002 16:00	0.519	0.387	0.401	15	6.88
14.06.2002 12:00	0.424	0.345	0.345	15	6.8
17.06.2002 09:00	0.276	0.198	0.205	15.1	6.8
17.06.2002 11:30	0.28	0.201	0.196	16.1	6.8

Experiment Nr 7. Optical density of *Fragilaria crotonensis* culture determined by extinction measurements using three different wavelengths.

Date	Ext. 440 nm	Ext. 535 nm	Ext. 560 nm	Temperature (°C)	pH
01.07.2002 13:00	0.829	0.725	0.713	24	7
02.07.2002 09:00	0.8	0.693	0.73	24	7
02.07.2002 11:00	0.761	0.689	0.71	24	7
02.07.2002 14:30	0.813	0.74	0.749	24	7
02.07.2002 17:00	0.835	0.74	0.74	24	7
03.07.2002 09:00	0.832	0.754	0.765	24	7
03.07.2002 11:00	0.828	0.734	0.758	24	7
03.07.2002 14:30	0.841	0.768	0.804	24	7
03.07.2002 17:00	0.846	0.766	0.804	24	7
04.07.2002 09:00	0.828	0.758	0.777	24	7
04.07.2002 11:00	0.827	0.764	0.772	24	7
04.07.2002 14:00	0.87	0.785	0.824	24	7
04.07.2002 16:00	0.852	0.771	0.796	24	7
05.07.2002 09:00	0.86	0.774	0.805	24	7
05.07.2002 11:00	0.853	0.769	0.809	24	7
05.07.2002 14:00	0.852	0.747	0.816	24	7
05.07.2002 16:30	0.879	0.785	0.813	24	7
08.07.2002 09:00	0.785	0.786	0.738	24	7
08.07.2002 11:00	0.838	0.732	0.765	24	7
08.07.2002 14:30	0.832	0.764	0.79	24	7
08.07.2002 17:00	0.879	0.787	0.821	24	7
09.07.2002 09:00	0.851	0.774	0.773	24	7
09.07.2002 11:00	0.842	0.77	0.8	24	7
09.07.2002 14:00	0.836	0.783	0.814	24	7
09.07.2002 17:00	0.862	0.793	0.815	24	7
10.07.2002 09:00	0.843	0.748	0.771	24	7
10.07.2002 14:00	0.858	0.775	0.802	24	7
10.07.2002 16:00	0.869	0.777	0.805	24	7
11.07.2002 09:00	0.732	0.681	0.728	24	7
11.07.2002 11:00	0.846	0.755	0.792	24	7
11.07.2002 14:00	0.871	0.784	0.798	24	7
11.07.2002 16:00	0.847	0.775	0.819	24	7
12.07.2002 09:00	0.896	0.737	0.731	24	7
12.07.2002 11:00	0.856	0.739	0.768	24	7
12.07.2002 14:00	0.861	0.781	0.808	24	7
12.07.2002 16:00	0.888	0.789	0.83	24	7
15.07.2002 09:00	0.86	0.774	0.795	24	7
15.07.2002 11:00	0.846	0.75	0.78	24	7
15.07.2002 17:00	0.875	0.778	0.792	24	7
16.07.2002 09:00	0.87	0.797	0.807	24	7
16.07.2002 14:00	0.872	0.784	0.824	24	7
16.07.2002 16:00	0.881	0.799	0.815	23.4	7
17.07.2002 09:00	0.893	0.791	0.821	24	7
17.07.2002 11:30	0.88	0.788	0.801	24	7
17.07.2002 14:00	0.873	0.783	0.804	24	7
17.07.2002 16:00	0.877	0.771	0.816	24	7
18.07.2002 09:00	0.899	0.803	0.831	24	7
18.07.2002 12:00	0.896	0.773	0.802	24	7
18.07.2002 14:00	0.858	0.762	0.797	24	7
18.07.2002 16:00	0.889	0.784	0.809	24	7
19.07.2002 09:00	0.815	0.713	0.806	24	7
19.07.2002 11:00	0.889	0.798	0.83	24	7
19.07.2002 14:00	0.901	0.791	0.829	24	7
19.07.2002 16:00	0.833	0.757	0.773	24	7
22.07.2002 10:00	0.803	0.766	0.776	24	7
22.07.2002 13:00	0.83	0.722	0.78	24	7
22.07.2002 15:00	0.781	0.722	0.779	24	7
22.07.2002 17:30	0.758	0.771	0.777	24	7
23.07.2002 09:30	0.792	0.732	0.771	24	7.1
23.07.2002 12:00	0.779	0.725	0.736	24	7.1
23.07.2002 14:00	0.775	0.744	0.778	24	7.1
24.07.2002 09:00	0.735	0.698	0.74	18	7.1
24.07.2002 12:30	0.787	0.719	0.76	18	7.1
24.07.2002 15:00	0.776	0.72	0.754	18	7.1
24.07.2002 16:30	0.755	0.722	0.747	18	7.1
25.07.2002 09:00	0.756	0.711	0.726	18	7.1
25.07.2002 12:00	0.737	0.683	0.666	18	7.1
25.07.2002 14:00	0.733	0.715	0.714	18	7.1
26.07.2002 09:00	0.721	0.672	0.71	18	7.1
26.07.2002 12:00	0.736	0.68	0.728	18	7.1
26.07.2002 14:00	0.724	0.669	0.699	18	7.1
26.07.2002 16:00	0.819	0.738	0.754	18	7.1
29.07.2002 09:30	0.704	0.693	0.681	18	7.1
29.07.2002 12:00	0.719	0.654	0.682	18	7.1
29.07.2002 14:00	0.723	0.657	0.638	18	7.1
29.07.2002 16:00	0.72	0.65	0.681	18	7
30.07.2002 09:00	0.733	0.67	0.665	18	7
30.07.2002 12:00	0.726	0.651	0.676	18	7
30.07.2002 14:00	0.732	0.672	0.679	18	7
30.07.2002 16:00	0.751	0.68	0.706	18	7
31.07.2002 09:00	0.724	0.643	0.688	18	7
31.07.2002 12:00	0.724	0.669	0.696	18	7
31.07.2002 14:00	0.762	0.677	0.69	18	7
31.07.2002 16:00	0.713	0.652	0.678	18	7
01.08.2002 09:00	0.709	0.655	0.685	18	7
01.08.2002 11:30	0.73	0.668	0.708	18	7
01.08.2002 16:00	0.73	0.659	0.692	18	7
05.08.2002 09:00	0.762	0.681	0.721	18	7
05.08.2002 12:00	0.759	0.694	0.734	18	7
05.08.2002 14:00	0.771	0.694	0.733	18	7

Date	Ext. 440 nm	Ext. 535 nm	Ext. 560 nm	Temperature (°C)	pH
05.08.2002 16:00	0.76	0.707	0.722	18	7
06.08.2002 09:00	0.804	0.716	0.732	18	7
06.08.2002 13:00	0.756	0.702	0.733	18	7
06.08.2002 15:00	0.778	0.7	0.721	18	7
07.08.2002 09:00	0.766	0.684	0.733	18	7
07.08.2002 12:00	0.744	0.688	0.712	18	7
07.08.2002 14:00	0.782	0.703	0.723	18	7
07.08.2002 16:00	0.763	0.703	0.73	18	7
08.08.2002 09:00	0.78	0.71	0.721	18	7
08.08.2002 12:00	0.752	0.699	0.636	18	7.1
08.08.2002 14:00	0.777	0.679	0.72	18	7.1
08.08.2002 16:00	0.775	0.691	0.712	18	7.1
09.08.2002 09:00	0.737	0.673	0.681	18	7.1
09.08.2002 12:00	0.761	0.691	0.73	18	7.1
09.08.2002 14:00	0.781	0.7	0.702	18	7.1
09.08.2002 15:30	0.765	0.691	0.725	18	7.1
12.08.2002 09:00	0.796	0.714	0.725	18	7.1
12.08.2002 12:30	0.746	0.714	0.679	18	7.1
12.08.2002 14:00	0.809	0.727	0.705	18	7.1
12.08.2002 16:00	0.78	0.704	0.733	18	7.1
13.08.2002 09:00	0.761	0.697	0.741	18	7.1
13.08.2002 12:00	0.775	0.673	0.702	15	7.1
13.08.2002 14:00	0.773	0.73	0.73	15	7
13.08.2002 15:30	0.816	0.737	0.712	15	7
14.08.2002 08:30	0.762	0.696	0.715	15	7
14.08.2002 12:00	0.778	0.652	0.735	15	7
14.08.2002 14:00	0.753	0.694	0.728	15	7
14.08.2002 16:00	0.789	0.699	0.731	15	7
15.08.2002 09:00	0.722	0.667	0.699	15	7
15.08.2002 12:00	0.741	0.657	0.707	15	7
15.08.2002 14:00	0.719	0.664	0.712	15	7
15.08.2002 16:00	0.735	0.687	0.705	15	7
16.08.2002 09:00	0.708	0.628	0.626	15	7
16.08.2002 12:00	0.712	0.633	0.685	15	7
16.08.2002 15:00	0.721	0.634	0.694	15	7
19.08.2002 10:00	0.711	0.631	0.604	15	7
19.08.2002 12:00	0.721	0.62	0.651	15	7
19.08.2002 14:00	0.693	0.617	0.649	15	7
19.08.2002 16:00	0.726	0.649	0.652	15	7
20.08.2002 09:00	0.686	0.615	0.643	15	7
20.08.2002 12:00	0.68	0.606	0.62	15	7
20.08.2002 14:00	0.677	0.592	0.634	15	7
20.08.2002 16:00	0.702	0.613	0.664	15	7
21.08.2002 09:00	0.71	0.598	0.652	15	7
21.08.2002 16:00	0.683	0.617	0.644	15	7
22.08.2002 09:00	0.674	0.618	0.629	15	7
22.08.2002 12:00	0.674	0.593	0.608	15	7
22.08.2002 14:00	0.687	0.605	0.569	15	7
22.08.2002 16:00	0.659	0.587	0.61	15	7
23.08.2002 09:00	0.699	0.596	0.625	15	7
23.08.2002 12:00	0.682	0.531	0.626	15	7
23.08.2002 14:00	0.608	0.602	0.613	15	7
23.08.2002 16:00	0.695	0.591	0.615	15	7
26.08.2002 09:00	0.7	0.587	0.617	15	7
26.08.2002 13:00	0.7	0.586	0.601	15	7
26.08.2002 17:00	0.685	0.482	0.602	15	7
27.08.2002 08:00	0.622	0.59	0.608	15	7
27.08.2002 16:00	0.679	0.66	0.633	15	7
28.08.2002 08:00	0.679	0.595	0.607	15	7
28.08.2002 16:00	0.666	0.573	0.604	15	7
29.08.2002 09:00	0.662	0.573	0.54	15	7
29.08.2002 13:00	0.669	0.565	0.591	15	7
02.09.2002 09:00	0.625	0.557	0.538	15	7
02.09.2002 14:00	0.671	0.564	0.555	15	7
02.09.2002 17:00	0.642	0.55	0.563	15	7
03.09.2002 11:30	0.522	0.46	0.506	15	7
03.09.2002 17:00	0.561	0.49	0.508	15	7.1
04.09.2002 09:00	0.521	0.44	0.441	15	7.1
04.09.2002 12:00	0.523	0.478	0.494	15	7.1
04.09.2002 17:00	0.527	0.47	0.492	15	7.1
05.09.2002 09:00	0.539	0.467	0.487	15	7.1
05.09.2002 11:30	0.518	0.47	0.477	15	7.1
05.09.2002 16:30	0.506	0.485	0.491	15	7.1
06.09.2002 09:00	0.557	0.444	0.485	15	7.1
06.09.2002 11:00	0.493	0.433	0.479	15	7.1
06.09.2002 13:00	0.515	0.468	0.474	15	7.1
09.09.2002 09:00	0.591	0.488	0.492	15	7
09.09.2002 11:00	0.537	0.458	0.468	15	7
10.09.2002 09:00	0.47	0.404	0.424	15	7
10.09.2002 11:00	0.483	0.418	0.428	15	7
11.09.2002 09:00	0.451	0.383	0.391	15	7
11.09.2002 11:00	0.403	0.374	0.385	15	7
12.09.2002 09:00	0.417	0.355	0.363	15	7
12.09.2002 11:00	0.404	0.334	0.337	15	7
13.09.2002 09:00	0.362	0.304	0.307	15	6.9
13.09.2002 11:00	0.358	0.288	0.296	15	7
16.09.2002 09:00	0.189	0.165	0.167	15	6.9
16.09.2002 11:00	0.165	0.157	0.164	15	6.9
17.09.2002 09:00	0.365	0.268	0.262	21	6.9
17.09.2002 11:00	0.205	0.199	0.21	21	7

Experiment Nr 7. Optical density of *Fragilaria crotonensis* culture determined by extinction measurements using three different wavelengths.

Date	Ext. 440 nm	Ext. 535 nm	Ext. 560 nm	Temperature (°C)	pH
18.09.2002 09:00	0.204	0.186	0.2	21	7
18.09.2002 11:00	0.222	0.194	0.2	21	6.9
18.09.2002 17:00	0.282	0.232	0.25	21	6.95
19.09.2002 09:00	0.214	0.21	0.206	21	7
19.09.2002 11:00	0.229	0.205	0.215	21	7
19.09.2002 16:00	0.261	0.235	0.259	21	7
20.09.2002 09:00	0.239	0.229	0.22	21	7
20.09.2002 11:00	0.241	0.236	0.224	21	7
23.09.2002 09:00	0.264	0.226	0.223	21	7
23.09.2002 11:00	0.237	0.203	0.21	21	7
24.09.2002 09:00	0.235	0.207	0.219	21	7
24.09.2002 11:00	0.241	0.209	0.221	21	7
25.09.2002 09:00	0.261	0.226	0.227	21	7
25.09.2002 11:00	0.282	0.236	0.247	21	7
25.09.2002 16:00	0.305	0.251	0.264	21	7
26.09.2002 09:00	0.335	0.264	0.289	21	7
26.09.2002 11:00	0.315	0.268	0.286	21	7.1
26.09.2002 16:00	0.347	0.306	0.328	21	7.1
27.09.2002 09:00	0.417	0.325	0.345	21	7.1
27.09.2002 11:00	0.464	0.465	0.353	21	7.1
27.09.2002 13:00	0.456	0.373	0.376	21	7.1
30.09.2002 09:00	0.59	0.497	0.528	21	7.1
30.09.2002 11:00	0.645	0.535	0.541	21	7.1
30.09.2002 15:30	0.655	0.542	0.562	21	7.1
01.10.2002 09:30	0.665	0.562	0.58	21	7.1
01.10.2002 14:00	0.651	0.57	0.587	21	7.1
02.10.2002 11:30	0.664	0.596	0.611	21	7.1
07.10.2002 09:00	0.806	0.716	0.739	21	7.1
07.10.2002 14:00	0.794	0.708	0.743	21	7.1
08.10.2002 09:30	0.817	0.711	0.744	21	7.1
08.10.2002 12:00	0.807	0.703	0.73	21	7.1
09.10.2002 09:00	0.815	0.713	0.748	21	7.1
09.10.2002 14:00	0.792	0.711	0.745	21	7.1
09.10.2002 17:00	0.796	0.724	0.745	21	7.1
10.10.2002 09:00	0.807	0.71	0.744	21	7.1
10.10.2002 12:00	0.824	0.687	0.731	21	7.1
10.10.2002 15:00	0.818	0.728	0.745	21	7.1
11.10.2002 09:00	0.81	0.712	0.742	21	7.1
11.10.2002 12:30	0.804	0.703	0.749	21	7.1
11.10.2002 16:30	0.837	0.73	0.748	21	7.1
14.10.2002 09:30	0.794	0.709	0.726	21	7.1
14.10.2002 13:30	0.824	0.718	0.756	21	7.1
14.10.2002 17:00	0.809	0.719	0.744	21	7.1
15.10.2002 09:00	0.808	0.715	0.739	21	7.1
15.10.2002 14:00	0.807	0.714	0.742	21	7.1
15.10.2002 16:30	0.8	0.717	0.733	21	7.1
16.10.2002 09:00	0.79	0.708	0.737	21	7.1
16.10.2002 16:00	0.792	0.686	0.726	21	7.1
17.10.2002 09:00	0.806	0.71	0.738	21	7.1
17.10.2002 15:30	0.775	0.704	0.712	21	7.1
17.10.2002 17:30	0.802	0.703	0.739	21	7.1
18.10.2002 09:30	0.783	0.697	0.729	21	7.1
21.10.2002 09:30	0.781	0.685	0.703	21	7.1
21.10.2002 14:00	0.797	0.683	0.712	21	7.1
22.10.2002 09:00	0.829	0.73	0.752	21	7.1
22.10.2002 12:00	0.771	0.672	0.7	21	7.1
22.10.2002 15:00	0.774	0.678	0.684	21	7.1
23.10.2002 09:00	0.779	0.672	0.707	21	7.1
23.10.2002 12:00	0.776	0.666	0.694	21	7.1
23.10.2002 14:30	0.766	0.656	0.696	21	7.1
23.10.2002 17:00	0.78	0.678	0.702	21	7.1
24.10.2002 09:00	0.751	0.677	0.698	21	7.1
24.10.2002 13:30	0.764	0.673	0.693	21	7.1
24.10.2002 17:00	0.798	0.689	0.707	21	7.1
25.10.2002 09:30	0.701	0.704	0.729	21	7.2
25.10.2002 14:30	0.802	0.699	0.715	21	7.2
28.10.2002 12:00	0.81	0.698	0.726	21	7.2
28.10.2002 16:00	0.767	0.671	0.708	21	7.2
29.10.2002 09:30	0.752	0.677	0.706	21	7.2
29.10.2002 12:30	0.774	0.696	0.711	21	7.2
29.10.2002 15:30	0.778	0.699	0.71	21	7.2
30.10.2002 09:30	0.777	0.677	0.706	21	7.2
30.10.2002 12:00	0.788	0.667	0.709	21	7.2
30.10.2002 15:30	0.769	0.65	0.704	21	7.2
31.10.2002 09:00	0.767	0.733	0.661	21	7.2
31.10.2002 12:00	0.786	0.681	0.698	21	7.2
31.10.2002 13:30	0.781	0.677	0.697	21	7.2
04.11.2002 09:00	0.773	0.667	0.682	21	7.2
04.11.2002 11:00	0.794	0.674	0.675	21	7.2
04.11.2002 14:00	0.795	0.7	0.706	21	7.2
05.11.2002 09:00	0.77	0.669	0.692	21	7.2
05.11.2002 11:00	0.768	0.671	0.672	21	7.2
05.11.2002 15:00	0.813	0.697	0.708	21	7.2
06.11.2002 09:00	0.778	0.67	0.696	21	7.2
06.11.2002 11:00	0.786	0.665	0.709	21	7.2
07.11.2002 09:00	0.77	0.677	0.686	21	7.2
07.11.2002 11:00	0.762	0.647	0.661	21	7.2
08.11.2002 09:00	0.767	0.654	0.671	21	7.2
08.11.2002 11:00	0.771	0.667	0.685	21	7.2
11.11.2002 09:00	0.805	0.689	0.701	21	7.2

Date	Ext. 440 nm	Ext. 535 nm	Ext. 560 nm	Temperature (°C)	pH
11.11.2002 11:00	0.781	0.664	0.676	21	7.2
12.11.2002 09:00	0.722	0.64	0.663	21	7.2
12.11.2002 11:00	0.728	0.628	0.659	21	7.2
12.11.2002 14:00	0.693	0.645	0.645	15	7.1
13.11.2002 09:00	0.681	0.601	0.639	15	7.1
14.11.2002 09:30	0.662	0.58	0.585	15	7.1
15.11.2002 10:30	0.658	0.577	0.594	15	7.1
18.11.2002 10:00	0.674	0.585	0.597	15	7.1
18.11.2002 12:00	0.665	0.562	0.59	15	7.1
18.11.2002 14:00	0.664	0.577	0.596	15	7.1
18.11.2002 16:00	0.717	0.588	0.584	15	7.1
19.11.2002 09:00	0.66	0.58	0.601	15	7.1
19.11.2002 17:00	0.658	0.58	0.595	15	7.1
20.11.2002 09:00	0.666	0.589	0.585	15	7.1
20.11.2002 12:00	0.667	0.581	0.6	15	7.1
20.11.2002 14:00	0.672	0.589	0.607	15	7.1
20.11.2002 16:00	0.645	0.584	0.593	15	7.1
21.11.2002 09:30	0.664	0.59	0.611	15	7.1
21.11.2002 12:00	0.683	0.58	0.611	15	7.1
21.11.2002 15:00	0.697	0.579	0.617	15	7.1
21.11.2002 16:30	0.698	0.594	0.613	15	7.1
22.11.2002 09:30	0.661	0.583	0.617	15	7.1
22.11.2002 12:30	0.69	0.581	0.616	15	7.1
22.11.2002 14:30	0.687	0.585	0.614	15	7.1
25.11.2002 09:30	0.71	0.58	0.649	15	7.1
25.11.2002 16:00	0.701	0.518	0.638	15	7.1
26.11.2002 09:30	0.724	0.627	0.658	15	7.1
26.11.2002 12:00	0.714	0.623	0.659	15	7.1
26.11.2002 15:00	0.723	0.617	0.651	15	7.1
27.11.2002 09:00	0.716	0.628	0.693	15	7.1
27.11.2002 12:00	0.756	0.649	0.669	15	7.1
27.11.2002 14:00	0.731	0.639	0.667	15	7.1
28.11.2002 09:30	0.754	0.652	0.678	15	7.1
28.11.2002 11:30	0.735	0.645	0.647	15	7.1
28.11.2002 14:00	0.707	0.628	0.638	15	7
28.11.2002 16:00	0.746	0.633	0.66	15	7
29.11.2002 09:00	0.713	0.625	0.654	15	7
29.11.2002 12:00	0.733	0.639	0.666	15	7
29.11.2002 14:00	0.714	0.631	0.645	15	7
02.12.2002 09:00	0.733	0.645	0.672	15	7
02.12.2002 12:00	0.714	0.646	0.676	15	7
02.12.2002 16:00	0.752	0.656	0.679	15	7
03.12.2002 09:30	0.759	0.65	0.679	15	7
03.12.2002 12:00	0.753	0.647	0.671	13.6	7
03.12.2002 16:00	0.717	0.646	0.675	12.6	7
04.12.2002 09:00	0.744	0.64	0.667	12.1	7
04.12.2002 12:00	0.763	0.67	0.697	12.1	7
04.12.2002 14:00	0.737	0.655	0.668	12.1	7
04.12.2002 16:00	0.729	0.635	0.665	12.1	7
05.12.2002 09:00	0.715	0.622	0.645	12	7
05.12.2002 11:30	0.725	0.625	0.667	12	7
05.12.2002 14:00	0.702	0.625	0.641	12	7
05.12.2002 16:00	0.729	0.622	0.652	12	7
06.12.2002 09:00	0.724	0.63	0.648	12	7
06.12.2002 12:00	0.737	0.616	0.64	12	7
06.12.2002 14:00	0.732	0.63	0.652	12	7
06.12.2002 16:00	0.703	0.622	0.628	12	7
09.12.2002 09:00	0.703	0.624	0.606	12	7
09.12.2002 12:00	0.661	0.585	0.611	12	7
09.12.2002 14:00	0.682	0.587	0.614	12	7
09.12.2002 16:00	0.644	0.575	0.594	12	7
10.12.2002 09:00	0.649	0.578	0.596	12	7
10.12.2002 12:00	0.687	0.633	0.588	12	7
10.12.2002 14:00	0.657	0.581	0.591	12	7
10.12.2002 16:00	0.678	0.577	0.593	12	7
11.12.2002 09:30	0.669	0.577	0.591	12	7
11.12.2002 12:30	0.677	0.581	0.602	12	7
11.12.2002 14:00	0.679	0.568	0.602	12	7
11.12.2002 16:00	0.683	0.576	0.592	12	7
12.12.2002 09:30	0.691	0.572	0.601	12	7
12.12.2002 12:00	0.669	0.562	0.593	12	7
12.12.2002 14:00	0.687	0.582	0.605	12	7
12.12.2002 16:00	0.692	0.584	0.583	12	7
13.12.2002 09:30	0.661	0.558	0.587	12	7
13.12.2002 12:30	0.664	0.574	0.574	12	7
13.12.2002 14:30	0.681	0.557	0.581	12	7
13.12.2002 16:00	0.666	0.566	0.579	12	7
16.12.2002 09:00	0.654	0.55	0.558	12	7
16.12.2002 12:00	0.656	0.558	0.581	12	7
16.12.2002 14:00	0.634	0.543	0.564	12	7
16.12.2002 16:00	0.63	0.54	0.56	12	7
17.12.2002 09:30	0.644	0.553	0.573	12	7
17.12.2002 12:30	0.648	0.542	0.562	12	7
17.12.2002 14:00	0.655	0.546	0.566	12	7
17.12.2002 16:00	0.617	0.544	0.573	12	7
18.12.2002 09:00	0.654	0.539	0.563	12	7

Experiment Nr 8. Optical density of *Cyclotella meneghiniana* culture determined by extinction measurements using three different wavelengths.

Date	Ext. 440 nm	Ext. 535 nm	Ext. 560 nm	Temperature (°C)	pH
01.07.2002 13:00	0.829	0.725	0.713	24	7
02.07.2002 09:00	0.8	0.693	0.73	24	7
02.07.2002 11:00	0.761	0.689	0.71	24	7
02.07.2002 14:30	0.813	0.74	0.749	24	7
02.07.2002 17:00	0.835	0.74	0.74	24	7
03.07.2002 09:00	0.832	0.754	0.765	24	7
03.07.2002 11:00	0.828	0.734	0.758	24	7
03.07.2002 14:30	0.841	0.768	0.804	24	7
03.07.2002 17:00	0.846	0.766	0.804	24	7
04.07.2002 09:00	0.828	0.758	0.777	24	7
04.07.2002 11:00	0.827	0.764	0.772	24	7
04.07.2002 14:00	0.87	0.785	0.824	24	7
04.07.2002 16:00	0.852	0.771	0.796	24	7
05.07.2002 09:00	0.86	0.774	0.805	24	7
05.07.2002 11:00	0.853	0.769	0.809	24	7
05.07.2002 14:00	0.852	0.747	0.816	24	7
05.07.2002 16:30	0.879	0.785	0.813	24	7
08.07.2002 09:00	0.785	0.786	0.738	24	7
08.07.2002 11:00	0.838	0.732	0.765	24	7
08.07.2002 14:30	0.832	0.764	0.79	24	7
08.07.2002 17:00	0.879	0.787	0.821	24	7
09.07.2002 09:00	0.851	0.774	0.773	24	7
09.07.2002 11:00	0.842	0.77	0.8	24	7
09.07.2002 14:00	0.836	0.783	0.814	24	7
09.07.2002 17:00	0.862	0.793	0.815	24	7
10.07.2002 09:00	0.843	0.748	0.771	24	7
10.07.2002 14:00	0.858	0.775	0.802	24	7
10.07.2002 16:00	0.869	0.777	0.805	24	7
11.07.2002 09:00	0.732	0.681	0.728	24	7
11.07.2002 11:00	0.846	0.755	0.792	24	7
11.07.2002 14:00	0.871	0.784	0.798	24	7
11.07.2002 16:00	0.847	0.775	0.819	24	7
12.07.2002 09:00	0.896	0.737	0.731	24	7
12.07.2002 11:00	0.856	0.739	0.768	24	7
12.07.2002 14:00	0.861	0.781	0.808	24	7
12.07.2002 16:00	0.888	0.789	0.83	24	7
15.07.2002 09:00	0.86	0.774	0.795	24	7
15.07.2002 11:00	0.846	0.75	0.78	24	7
15.07.2002 17:00	0.875	0.778	0.792	24	7
16.07.2002 09:00	0.87	0.797	0.807	24	7
16.07.2002 14:00	0.872	0.784	0.824	24	7
16.07.2002 16:00	0.881	0.799	0.815	23.4	7
17.07.2002 09:00	0.893	0.791	0.821	24	7
17.07.2002 11:30	0.88	0.788	0.801	24	7
17.07.2002 14:00	0.873	0.783	0.804	24	7
17.07.2002 16:00	0.877	0.771	0.816	24	7
18.07.2002 09:00	0.899	0.803	0.831	24	7
18.07.2002 12:00	0.896	0.773	0.802	24	7
18.07.2002 14:00	0.858	0.762	0.797	24	7
18.07.2002 16:00	0.889	0.784	0.809	24	7
19.07.2002 09:00	0.815	0.713	0.806	24	7
19.07.2002 11:00	0.889	0.798	0.83	24	7
19.07.2002 14:00	0.901	0.791	0.829	24	7
19.07.2002 16:00	0.833	0.757	0.773	24	7
22.07.2002 10:00	0.803	0.766	0.776	24	7
22.07.2002 13:00	0.83	0.722	0.78	24	7
22.07.2002 15:00	0.781	0.722	0.779	24	7
22.07.2002 17:30	0.758	0.771	0.777	24	7
23.07.2002 09:30	0.792	0.732	0.771	24	7.1
23.07.2002 12:00	0.779	0.725	0.736	24	7.1
23.07.2002 14:00	0.775	0.744	0.778	24	7.1
24.07.2002 09:00	0.735	0.698	0.74	18	7.1
24.07.2002 12:30	0.787	0.719	0.76	18	7.1
24.07.2002 15:00	0.776	0.72	0.754	18	7.1
24.07.2002 16:30	0.755	0.722	0.747	18	7.1
25.07.2002 09:00	0.756	0.711	0.726	18	7.1
25.07.2002 12:00	0.737	0.683	0.666	18	7.1
25.07.2002 14:00	0.733	0.715	0.714	18	7.1
26.07.2002 09:00	0.721	0.672	0.71	18	7.1
26.07.2002 12:00	0.736	0.68	0.728	18	7.1
26.07.2002 14:00	0.724	0.669	0.699	18	7.1
26.07.2002 16:00	0.819	0.738	0.754	18	7.1
29.07.2002 09:30	0.704	0.693	0.681	18	7.1
29.07.2002 12:00	0.719	0.654	0.682	18	7.1
29.07.2002 14:00	0.723	0.657	0.638	18	7.1
29.07.2002 16:00	0.72	0.65	0.681	18	7
30.07.2002 09:00	0.733	0.67	0.665	18	7
30.07.2002 12:00	0.726	0.651	0.676	18	7
30.07.2002 14:00	0.732	0.672	0.679	18	7
30.07.2002 16:00	0.751	0.68	0.706	18	7
31.07.2002 09:00	0.724	0.643	0.688	18	7
31.07.2002 12:00	0.724	0.669	0.696	18	7
31.07.2002 14:00	0.762	0.677	0.69	18	7
31.07.2002 16:00	0.713	0.652	0.678	18	7
01.08.2002 09:00	0.709	0.655	0.685	18	7
01.08.2002 11:30	0.73	0.668	0.708	18	7
01.08.2002 16:00	0.73	0.659	0.692	18	7
05.08.2002 09:00	0.762	0.681	0.721	18	7
05.08.2002 12:00	0.759	0.694	0.734	18	7

Date	Ext. 440 nm	Ext. 535 nm	Ext. 560 nm	Temperature (°C)	pH
05.08.2002 14:00	0.771	0.694	0.733	18	7
05.08.2002 16:00	0.76	0.707	0.722	18	7
06.08.2002 09:00	0.804	0.716	0.732	18	7
06.08.2002 13:00	0.756	0.702	0.733	18	7
06.08.2002 15:00	0.778	0.7	0.721	18	7
07.08.2002 09:00	0.766	0.684	0.733	18	7
07.08.2002 12:00	0.744	0.688	0.712	18	7
07.08.2002 14:00	0.782	0.703	0.723	18	7
07.08.2002 16:00	0.763	0.703	0.73	18	7
08.08.2002 09:00	0.78	0.71	0.721	18	7
08.08.2002 12:00	0.752	0.699	0.636	18	7.1
08.08.2002 14:00	0.777	0.679	0.72	18	7.1
08.08.2002 16:00	0.775	0.691	0.712	18	7.1
09.08.2002 09:00	0.737	0.673	0.681	18	7.1
09.08.2002 12:00	0.761	0.691	0.73	18	7.1
09.08.2002 14:00	0.781	0.7	0.702	18	7.1
09.08.2002 15:30	0.765	0.691	0.725	18	7.1
12.08.2002 09:00	0.796	0.714	0.725	18	7.1
12.08.2002 12:30	0.746	0.714	0.679	18	7.1
12.08.2002 14:00	0.809	0.727	0.705	18	7.1
12.08.2002 16:00	0.78	0.704	0.733	18	7.1
13.08.2002 09:00	0.761	0.697	0.741	18	7.1
13.08.2002 12:00	0.775	0.673	0.702	15	7.1
13.08.2002 14:00	0.773	0.73	0.73	15	7
13.08.2002 15:30	0.816	0.737	0.712	15	7
14.08.2002 08:30	0.762	0.696	0.715	15	7
14.08.2002 12:00	0.778	0.652	0.735	15	7
14.08.2002 14:00	0.753	0.694	0.728	15	7
14.08.2002 16:00	0.789	0.699	0.731	15	7
15.08.2002 09:00	0.722	0.667	0.699	15	7
15.08.2002 12:00	0.741	0.657	0.707	15	7
15.08.2002 14:00	0.719	0.664	0.712	15	7
15.08.2002 16:00	0.735	0.687	0.705	15	7
16.08.2002 09:00	0.708	0.628	0.626	15	7
16.08.2002 12:00	0.712	0.633	0.685	15	7
16.08.2002 15:00	0.721	0.634	0.694	15	7
19.08.2002 10:00	0.711	0.631	0.604	15	7
19.08.2002 12:00	0.721	0.62	0.651	15	7
19.08.2002 14:00	0.693	0.617	0.649	15	7
19.08.2002 16:00	0.726	0.649	0.652	15	7
20.08.2002 09:00	0.686	0.615	0.643	15	7
20.08.2002 12:00	0.68	0.606	0.62	15	7
20.08.2002 14:00	0.677	0.592	0.634	15	7
20.08.2002 16:00	0.702	0.613	0.664	15	7
21.08.2002 09:00	0.71	0.598	0.652	15	7
21.08.2002 16:00	0.683	0.617	0.644	15	7
22.08.2002 09:00	0.674	0.618	0.629	15	7
22.08.2002 12:00	0.674	0.593	0.608	15	7
22.08.2002 14:00	0.687	0.605	0.569	15	7
22.08.2002 16:00	0.659	0.587	0.61	15	7
23.08.2002 09:00	0.699	0.596	0.625	15	7
23.08.2002 12:00	0.682	0.531	0.626	15	7
23.08.2002 14:00	0.608	0.602	0.613	15	7
23.08.2002 16:00	0.695	0.591	0.615	15	7
26.08.2002 09:00	0.7	0.587	0.617	15	7
26.08.2002 13:00	0.7	0.586	0.601	15	7
26.08.2002 17:00	0.685	0.482	0.602	15	7
27.08.2002 08:00	0.622	0.59	0.608	15	7
27.08.2002 16:00	0.679	0.66	0.633	15	7
28.08.2002 08:00	0.679	0.595	0.607	15	7
28.08.2002 16:00	0.666	0.573	0.604	15	7
29.08.2002 09:00	0.662	0.573	0.54	15	7
29.08.2002 13:00	0.669	0.565	0.591	15	7
02.09.2002 09:00	0.625	0.557	0.538	15	7
02.09.2002 14:00	0.671	0.564	0.555	15	7
02.09.2002 17:00	0.642	0.55	0.563	15	7
03.09.2002 11:30	0.522	0.46	0.506	15	7
03.09.2002 17:00	0.561	0.49	0.508	15	7.1
04.09.2002 09:00	0.521	0.44	0.441	15	7.1
04.09.2002 12:00	0.523	0.478	0.494	15	7.1
04.09.2002 17:00	0.527	0.47	0.492	15	7.1
05.09.2002 09:00	0.539	0.467	0.487	15	7.1
05.09.2002 11:30	0.518	0.47	0.477	15	7.1
05.09.2002 16:30	0.506	0.485	0.491	15	7.1
06.09.2002 09:00	0.557	0.444	0.485	15	7.1
06.09.2002 11:00	0.493	0.433	0.479	15	7.1
06.09.2002 13:00	0.515	0.468	0.474	15	7.1
09.09.2002 09:00	0.591	0.488	0.492	15	7
09.09.2002 11:00	0.537	0.458	0.468	15	7
10.09.2002 09:00	0.47	0.404	0.424	15	7
10.09.2002 11:00	0.483	0.418	0.428	15	7
11.09.2002 09:00	0.451	0.383	0.391	15	7
11.09.2002 11:00	0.403	0.374	0.385	15	7
12.09.2002 09:00	0.417	0.355	0.363	15	7
12.09.2002 11:00	0.404	0.334	0.337	15	7
13.09.2002 09:00	0.362	0.304	0.307	15	6.9
13.09.2002 11:00	0.358	0.288	0.296	15	7
16.09.2002 09:00	0.189	0.165	0.167	15	6.9
16.09.2002 11:00	0.165	0.157	0.164	15	6.9

Experiment Nr 8. Optical density of *Cyclotella meneghiniana* culture determined by extinction measurements using three different wavelengths.

Date	Ext. 440 nm	Ext. 535 nm	Ext. 560 nm	Temperature (°C)	pH
17.09.2002 09:00	0.365	0.268	0.262	21	6.9
17.09.2002 11:00	0.205	0.199	0.21	21	7
18.09.2002 09:00	0.204	0.186	0.2	21	7
18.09.2002 11:00	0.222	0.194	0.2	21	6.9
18.09.2002 17:00	0.282	0.232	0.25	21	6.95
19.09.2002 09:00	0.214	0.21	0.206	21	7
19.09.2002 11:00	0.229	0.205	0.215	21	7
19.09.2002 16:00	0.261	0.235	0.259	21	7
20.09.2002 09:00	0.239	0.229	0.22	21	7
20.09.2002 11:00	0.241	0.236	0.224	21	7
23.09.2002 09:00	0.264	0.226	0.223	21	7
23.09.2002 11:00	0.237	0.203	0.21	21	7
24.09.2002 09:00	0.235	0.207	0.219	21	7
24.09.2002 11:00	0.241	0.209	0.221	21	7
25.09.2002 09:00	0.261	0.226	0.227	21	7
25.09.2002 11:00	0.282	0.236	0.247	21	7
25.09.2002 16:00	0.305	0.251	0.264	21	7
26.09.2002 09:00	0.335	0.264	0.289	21	7
26.09.2002 11:00	0.315	0.268	0.286	21	7.1
26.09.2002 16:00	0.347	0.306	0.328	21	7.1
27.09.2002 09:00	0.417	0.325	0.345	21	7.1
27.09.2002 11:00	0.464	0.465	0.353	21	7.1
27.09.2002 13:00	0.456	0.373	0.376	21	7.1
30.09.2002 09:00	0.59	0.497	0.528	21	7.1
30.09.2002 11:00	0.645	0.535	0.541	21	7.1
30.09.2002 15:30	0.655	0.542	0.562	21	7.1
01.10.2002 09:30	0.665	0.562	0.58	21	7.1
01.10.2002 14:00	0.651	0.57	0.587	21	7.1
02.10.2002 11:30	0.664	0.596	0.611	21	7.1
07.10.2002 09:00	0.806	0.716	0.739	21	7.1
07.10.2002 14:00	0.794	0.708	0.743	21	7.1
08.10.2002 09:30	0.817	0.711	0.744	21	7.1
08.10.2002 12:00	0.807	0.703	0.73	21	7.1
09.10.2002 09:00	0.815	0.713	0.748	21	7.1
09.10.2002 14:00	0.792	0.711	0.745	21	7.1
09.10.2002 17:00	0.796	0.724	0.745	21	7.1
10.10.2002 09:00	0.807	0.71	0.744	21	7.1
10.10.2002 12:00	0.824	0.687	0.731	21	7.1
10.10.2002 15:00	0.818	0.728	0.745	21	7.1
11.10.2002 09:00	0.81	0.712	0.742	21	7.1
11.10.2002 12:30	0.804	0.703	0.749	21	7.1
11.10.2002 16:30	0.837	0.73	0.748	21	7.1
14.10.2002 09:30	0.794	0.709	0.726	21	7.1
14.10.2002 13:30	0.824	0.718	0.756	21	7.1
14.10.2002 17:00	0.809	0.719	0.744	21	7.1
15.10.2002 09:00	0.808	0.715	0.739	21	7.1
15.10.2002 14:00	0.807	0.714	0.742	21	7.1
15.10.2002 16:30	0.8	0.717	0.733	21	7.1
16.10.2002 09:00	0.79	0.708	0.737	21	7.1
16.10.2002 16:00	0.792	0.686	0.726	21	7.1
17.10.2002 09:00	0.806	0.71	0.738	21	7.1
17.10.2002 15:30	0.775	0.704	0.712	21	7.1
17.10.2002 17:30	0.802	0.703	0.739	21	7.1
18.10.2002 09:30	0.783	0.697	0.729	21	7.1
21.10.2002 09:30	0.781	0.685	0.703	21	7.1
21.10.2002 14:00	0.797	0.683	0.712	21	7.1
22.10.2002 09:00	0.829	0.73	0.752	21	7.1
22.10.2002 12:00	0.771	0.672	0.7	21	7.1
22.10.2002 15:00	0.774	0.678	0.684	21	7.1
23.10.2002 09:00	0.779	0.672	0.707	21	7.1
23.10.2002 12:00	0.776	0.666	0.694	21	7.1
23.10.2002 14:30	0.766	0.656	0.696	21	7.1
23.10.2002 17:00	0.78	0.678	0.702	21	7.1
24.10.2002 09:00	0.751	0.677	0.698	21	7.1
24.10.2002 13:30	0.764	0.673	0.693	21	7.1
24.10.2002 17:00	0.798	0.689	0.707	21	7.1
25.10.2002 09:30	0.701	0.704	0.729	21	7.2
25.10.2002 14:30	0.802	0.699	0.715	21	7.2
28.10.2002 12:00	0.81	0.698	0.726	21	7.2
28.10.2002 16:00	0.767	0.671	0.708	21	7.2
29.10.2002 09:30	0.752	0.677	0.706	21	7.2
29.10.2002 12:30	0.774	0.696	0.711	21	7.2
29.10.2002 15:30	0.778	0.699	0.71	21	7.2
30.10.2002 09:30	0.777	0.677	0.706	21	7.2
30.10.2002 12:00	0.788	0.667	0.709	21	7.2
30.10.2002 15:30	0.769	0.65	0.704	21	7.2
31.10.2002 09:00	0.767	0.733	0.661	21	7.2
31.10.2002 12:00	0.786	0.681	0.698	21	7.2
31.10.2002 13:30	0.781	0.677	0.697	21	7.2
04.11.2002 09:00	0.773	0.667	0.682	21	7.2
04.11.2002 11:00	0.794	0.674	0.675	21	7.2
04.11.2002 14:00	0.795	0.7	0.706	21	7.2
05.11.2002 09:00	0.77	0.669	0.692	21	7.2
05.11.2002 11:00	0.768	0.671	0.672	21	7.2
05.11.2002 15:00	0.813	0.697	0.708	21	7.2
06.11.2002 09:00	0.778	0.67	0.696	21	7.2
06.11.2002 11:00	0.786	0.665	0.709	21	7.2
07.11.2002 09:00	0.77	0.677	0.686	21	7.2
07.11.2002 11:00	0.762	0.647	0.661	21	7.2

Date	Ext. 440 nm	Ext. 535 nm	Ext. 560 nm	Temperature (°C)	pH
08.11.2002 09:00	0.767	0.654	0.671	21	7.2
08.11.2002 11:00	0.771	0.667	0.685	21	7.2
11.11.2002 09:00	0.805	0.689	0.701	21	7.2
11.11.2002 11:00	0.781	0.664	0.676	21	7.2
12.11.2002 09:00	0.722	0.64	0.663	21	7.2
12.11.2002 11:00	0.728	0.628	0.659	21	7.2
12.11.2002 14:00	0.693	0.645	0.645	15	7.1
13.11.2002 09:00	0.681	0.601	0.639	15	7.1
14.11.2002 09:30	0.662	0.58	0.585	15	7.1
15.11.2002 10:30	0.658	0.577	0.594	15	7.1
18.11.2002 10:00	0.674	0.585	0.597	15	7.1
18.11.2002 12:00	0.665	0.562	0.59	15	7.1
18.11.2002 14:00	0.664	0.577	0.596	15	7.1
18.11.2002 16:00	0.717	0.588	0.584	15	7.1
19.11.2002 09:00	0.66	0.58	0.601	15	7.1
19.11.2002 17:00	0.658	0.58	0.595	15	7.1
20.11.2002 09:00	0.666	0.589	0.585	15	7.1
20.11.2002 12:00	0.667	0.581	0.6	15	7.1
20.11.2002 14:00	0.672	0.589	0.607	15	7.1
20.11.2002 16:00	0.645	0.584	0.593	15	7.1
21.11.2002 09:30	0.664	0.59	0.611	15	7.1
21.11.2002 12:00	0.683	0.58	0.611	15	7.1
21.11.2002 15:00	0.697	0.579	0.617	15	7.1
21.11.2002 16:30	0.698	0.594	0.613	15	7.1
22.11.2002 09:30	0.661	0.583	0.617	15	7.1
22.11.2002 12:30	0.69	0.581	0.616	15	7.1
22.11.2002 14:30	0.687	0.585	0.614	15	7.1
25.11.2002 09:30	0.71	0.58	0.649	15	7.1
25.11.2002 16:00	0.701	0.518	0.638	15	7.1
26.11.2002 09:30	0.724	0.627	0.658	15	7.1
26.11.2002 12:00	0.714	0.623	0.659	15	7.1
26.11.2002 15:00	0.723	0.617	0.651	15	7.1
27.11.2002 09:00	0.716	0.628	0.693	15	7.1
27.11.2002 12:00	0.756	0.649	0.669	15	7.1
27.11.2002 14:00	0.731	0.639	0.667	15	7.1
28.11.2002 09:30	0.754	0.652	0.678	15	7.1
28.11.2002 11:30	0.735	0.645	0.647	15	7.1
28.11.2002 14:00	0.707	0.628	0.638	15	7
28.11.2002 16:00	0.746	0.633	0.66	15	7
29.11.2002 09:00	0.713	0.625	0.654	15	7
29.11.2002 12:00	0.733	0.639	0.666	15	7
29.11.2002 14:00	0.714	0.631	0.645	15	7
02.12.2002 09:00	0.733	0.645	0.672	15	7
02.12.2002 12:00	0.714	0.646	0.676	15	7
02.12.2002 16:00	0.752	0.656	0.679	15	7
03.12.2002 09:30	0.759	0.65	0.679	15	7
03.12.2002 12:00	0.753	0.647	0.671	13.6	7
03.12.2002 16:00	0.717	0.646	0.675	12.6	7
04.12.2002 09:00	0.744	0.64	0.667	12.1	7
04.12.2002 12:00	0.763	0.67	0.697	12.1	7
04.12.2002 14:00	0.737	0.655	0.668	12.1	7
04.12.2002 16:00	0.729	0.635	0.665	12.1	7
05.12.2002 09:00	0.715	0.622	0.645	12	7
05.12.2002 11:30	0.725	0.625	0.667	12	7
05.12.2002 14:00	0.702	0.625	0.641	12	7
05.12.2002 16:00	0.729	0.622	0.652	12	7
06.12.2002 09:00	0.724	0.63	0.648	12	7
06.12.2002 12:00	0.737	0.616	0.64	12	7
06.12.2002 14:00	0.732	0.63	0.652	12	7
06.12.2002 16:00	0.703	0.622	0.628	12	7
09.12.2002 09:00	0.703	0.624	0.606	12	7
09.12.2002 12:00	0.661	0.585	0.611	12	7
09.12.2002 14:00	0.682	0.587	0.614	12	7
09.12.2002 16:00	0.644	0.575	0.594	12	7
10.12.2002 09:00	0.649	0.578	0.596	12	7
10.12.2002 12:00	0.687	0.633	0.588	12	7
10.12.2002 14:00	0.657	0.581	0.591	12	7
10.12.2002 16:00	0.678	0.577	0.593	12	7
11.12.2002 09:30	0.669	0.577	0.591	12	7
11.12.2002 12:30	0.677	0.581	0.602	12	7
11.12.2002 14:00	0.679	0.568	0.602	12	7
11.12.2002 16:00	0.683	0.576	0.592	12	7
12.12.2002 09:30	0.691	0.572	0.601	12	7
12.12.2002 12:00	0.669	0.562	0.593	12	7
12.12.2002 14:00	0.687	0.582	0.605	12	7
12.12.2002 16:00	0.692	0.584	0.583	12	7
13.12.2002 09:30	0.661	0.558	0.587	12	7
13.12.2002 12:30	0.664	0.574	0.574	12	7
13.12.2002 14:30	0.681	0.557	0.581	12	7
13.12.2002 16:00	0.666	0.566	0.579	12	7
16.12.2002 09:00	0.654	0.55	0.558	12	7
16.12.2002 12:00	0.656	0.558	0.581	12	7
16.12.2002 14:00	0.634	0.543	0.564	12	7
16.12.2002 16:00	0.63	0.54	0.56	12	7
17.12.2002 09:30	0.644	0.553	0.573	12	7
17.12.2002 12:30	0.648	0.542	0.562	12	7
17.12.2002 14:00	0.655	0.546	0.566	12	7
17.12.2002 16:00	0.617	0.544	0.573	12	7
18.12.2002 09:00	0.654	0.539	0.563	12	7

Experiment Nr 14. Optical density of *Cyclotella meneghiniana* culture determined by extinction measurements using three different wavelengths.

Date	Ext. 440nm	Ext. 535nm	Ext. 560nm	Temperature (°C)	pH
06.05.2003 09:00	0.293	0.197	0.197	15	6.6
06.05.2003 16:30	0.257	0.196	0.195	15	6.6
07.05.2003 16:00	0.292	0.224	0.227	15	6.6
08.05.2003 09:00	0.229	0.165	0.162	15	6.6
08.05.2003 11:00	0.251	0.199	0.189	15.1	6.6
09.05.2003 09:00	0.191	0.147	0.167	15.1	6.6
09.05.2003 13:00	0.19	0.147	0.142	15	6.6
12.05.2003 09:00	0.243	0.187	0.188	15	6.6
13.05.2003 15:00	0.288	0.24	0.234	15	6.6
14.05.2003 09:00	0.31	0.23	0.238	15	6.6
14.05.2003 11:00	0.307	0.217	0.23	15	6.6
15.05.2003 09:00	0.318	0.252	0.241	15.1	6.6
15.05.2003 11:00	0.297	0.232	0.232	15.1	6.6
15.05.2003 16:00	0.308	0.231	0.253	15.1	6.6
16.05.2003 09:00	0.344	0.256	0.261	15.1	6.6
16.05.2003 11:00	0.342	0.265	0.276	15	6.5
16.05.2003 14:00	0.335	0.245	0.254	15	6.7
19.05.2003 09:00	0.442	0.334	0.41	15	6.7
19.05.2003 12:30	0.458	0.338	0.371	15	6.7
19.05.2003 16:00	0.445	0.358	0.363	15	6.7
20.05.2003 09:00	0.443	0.339	0.344	15	6.7
20.05.2003 11:00	0.444	0.343	0.343	15	6.7
21.05.2003 09:00	0.478	0.37	0.372	15	6.7
21.05.2003 11:00	0.486	0.368	0.364	15	6.7
21.05.2003 15:00	0.475	0.375	0.372	15	6.7
22.05.2003 09:00	0.461	0.366	0.377	15	6.7
22.05.2003 11:00	0.489	0.373	0.371	15	6.7
22.05.2003 15:30	0.493	0.394	0.407	15	6.7
23.05.2003 09:00	0.501	0.371	0.396	15	6.7
23.05.2003 11:00	0.491	0.379	0.397	15	6.7
23.05.2003 14:00	0.5	0.392	0.4	15	6.7
23.05.2003 16:00	0.514	0.412	0.417		6.7
25.05.2003 12:00				39.8	6.7
26.05.2003 09:00	0.577	0.474	0.491	15.1	6.7
26.05.2003 11:00	0.554	0.46	0.476	15.2	6.7
26.05.2003 14:00	0.593	0.503	0.501	15.3	6.7
26.05.2003 15:30	0.621	0.496	0.51	15.3	6.7
27.05.2003 09:00	0.579	0.481	0.493	15.3	6.7
27.05.2003 11:00	0.589	0.496	0.51	15.3	6.7
27.05.2003 15:00	0.629	0.523	0.537	15.3	6.7
28.05.2003 09:00	0.612	0.502	0.517	15.7	6.7
28.05.2003 11:00	0.623	0.515	0.529	15.8	6.7
02.06.2003 09:00	0.849	0.745	0.757	25.5	6.9
02.06.2003 11:00	0.84	0.717	0.752	24.8	6.9
03.06.2003 10:30	0.855	0.801	0.77	19.3	6.8
03.06.2003 15:00	0.866	0.754	0.785	15.1	6.8
04.06.2003 09:00	0.788	0.702	0.73	15	6.8
04.06.2003 14:30	0.803	0.71	0.734	15	6.8
04.06.2003 17:00	0.825	0.708	0.748	15	6.8
05.06.2003 09:00	0.802	0.685	0.714	15	6.8
05.06.2003 11:00	0.805	0.69	0.712	15	6.8
05.06.2003 16:00	0.797	0.698	0.715	15	6.8
06.06.2003 09:00	0.811	0.696	0.721	15	6.8
06.06.2003 14:00	0.804	0.672	0.701	18.5	6.8
06.06.2003 18:00	0.797	0.688	0.703	15	6.8
11.06.2003 09:00	0.76	0.659	0.694	15	6.8
11.06.2003 11:00	0.781	0.662	0.682	15	6.8
12.06.2003 09:00	0.733	0.636	0.669	15	6.8
12.06.2003 11:00	0.738	0.639	0.673	15	6.8
13.06.2003 09:00	0.736	0.649	0.683	15	6.8
13.06.2003 11:00	0.733	0.644	0.673	15	6.8
13.06.2003 16:00	0.753	0.66	0.686	15.3	6.8
16.06.2003 10:00	0.772	0.675	0.697	27.3	7
16.06.2003 12:00	0.764	0.656	0.686	16.7	6.8
16.06.2003 14:00	0.794	0.662	0.693	15.2	6.8
17.06.2003 10:00	0.792	0.704	0.742	15	6.8
17.06.2003 12:00	0.763	0.704	0.719	15	6.8
18.06.2003 09:00	0.769	0.676	0.713	15	6.8
18.06.2003 11:00	0.796	0.698	0.724	15	6.8
21.06.2003 22:00	0.78	0.678	0.709	15	6.8
23.06.2003 10:00	0.801	0.704	0.732	15	6.8
23.06.2003 12:00	0.769	0.661	0.692	15.2	6.8
24.06.2003 09:00	0.757	0.656	0.684	15	6.8
24.06.2003 11:00	0.76	0.67	0.701	15	6.8
25.06.2003 09:00	0.756	0.653	0.688	15	6.8
25.06.2003 11:00	0.789	0.67	0.697	15	6.8
26.06.2003 09:00	0.652	0.583	0.619	15	6.9
26.06.2003 09:30	0.685	0.615	0.665	15	6.9
26.06.2003 11:00	0.664	0.605	0.637	15	6.9
27.06.2003 09:00	0.732	0.644	0.683	15.1	7
27.06.2003 11:00	0.733	0.676	0.706	15.1	7
27.06.2003 15:00	0.732	0.666	0.726	15.1	7
30.06.2003 09:00	0.831	0.769	0.796	15	6.9
30.06.2003 11:00	0.834	0.758	0.808	15	6.9
01.07.2003 09:00	0.81	0.748	0.773	15.1	6.9
01.07.2003 11:00	0.821	0.746	0.78	15	6.9
02.07.2003 09:00	0.83	0.745	0.778	15	6.9
02.07.2003 11:00	0.782	0.747	0.798	15	6.9
02.07.2003 11:30	0.826	0.712	0.792	15	6.9
03.07.2003 09:00	0.79	0.721	0.763	15	6.9
03.07.2003 11:00	0.799	0.714	0.76	15	6.9
04.07.2003 09:00	0.811	0.738	0.767	15	6.8
04.07.2003 11:00	0.788	0.743	0.759	15	6.8
07.07.2003 09:00	0.816	0.717	0.763	15	6.8
07.07.2003 11:00	0.811	0.709	0.762	15	6.8
08.07.2003 09:00	0.771	0.69	0.737	15	6.8
08.07.2003 11:00	0.746	0.692	0.738	15	6.8
09.07.2003 09:00	0.772	0.683	0.71	15	6.8
09.07.2003 11:00	0.743	0.691	0.729	15	6.8

Date	Ext. 440nm	Ext. 535nm	Ext. 560nm	Temperature (°C)	pH
10.07.2003 09:00	0.714	0.663	0.71	15	6.8
10.07.2003 11:00	0.752	0.676	0.714	15	6.8
11.07.2003 09:30	0.741	0.689	0.727	15	6.8
11.07.2003 11:00	0.74	0.674	0.714	15	6.8
14.07.2003 09:00	0.735	0.678	0.706	15	6.8
14.07.2003 11:00	0.736	0.669	0.703	15	6.8
15.07.2003 09:00	0.701	0.641	0.682	15	6.8
15.07.2003 11:00	0.727	0.668	0.704	15	6.8
16.07.2003 09:00	0.76	0.685	0.735	15	6.8
16.07.2003 11:00	0.736	0.67	0.719	15	6.8
17.07.2003 10:30	0.766	0.7	0.739	15	6.8
17.07.2003 14:00	0.776	0.713	0.736	15	6.8
18.07.2003 09:00	0.743	0.673	0.717	15	6.8
18.07.2003 11:00	0.744	0.665	0.707	15	6.8
18.07.2003 11:30	0.736	0.698	0.718	15	6.8
21.07.2003 09:00	0.798	0.764	0.793	15	6.8
21.07.2003 11:30	0.818	0.734	0.755	15	6.8
22.07.2003 09:00	0.784	0.71	0.744	15	6.8
22.07.2003 11:00	0.784	0.697	0.715	15	6.8
23.07.2003 09:00	0.77	0.691	0.716	15	6.8
23.07.2003 11:00	0.771	0.696	0.717	15	6.8
24.07.2003 09:00	0.761	0.687	0.69	15	6.8
24.07.2003 11:00	0.765	0.673	0.703	15	6.8
25.07.2003 09:00	0.708	0.638	0.677	15	6.8
25.07.2003 11:00	0.734	0.66	0.697	15	6.8
25.07.2003 16:00	0.744	0.678	0.704	12	6.8
28.07.2003 09:00	0.658	0.599	0.639	12	6.8
28.07.2003 11:00	0.663	0.595	0.63	12	6.8
28.07.2003 15:00	0.684	0.603	0.649	12	6.8
29.07.2003 09:30	0.683	0.607	0.629	12	6.8
29.07.2003 11:30	0.669	0.592	0.624	12	6.8
29.07.2003 15:00	0.682	0.598	0.631	12	6.8
30.07.2003 09:00	0.649	0.577	0.602	12	6.7
30.07.2003 13:30	0.661	0.578	0.613	12	6.7
31.07.2003 09:00	0.642	0.563	0.593	12	6.8
31.07.2003 12:00	0.645	0.567	0.59	12	6.7
31.07.2003 15:00	0.662	0.596	0.615	12	6.7
01.08.2003 09:00	0.646	0.588	0.595	12	6.7
01.08.2003 11:30	0.635	0.559	0.584	12	6.7
04.08.2003 10:00	0.667	0.589	0.629	12	6.7
04.08.2003 12:30	0.657	0.584	0.606	12	6.7
05.08.2003 10:00	0.664	0.584	0.597	12	6.7
05.08.2003 13:00	0.649	0.562	0.59	12	6.7
05.08.2003 16:30	0.671	0.564	0.593	12	6.7
06.08.2003 10:00	0.657	0.566	0.589	12	6.7
06.08.2003 15:30	0.671	0.568	0.606	12	6.7
07.08.2003 10:00	0.674	0.574	0.603	12	6.7
08.08.2003 10:00	0.659	0.554	0.592	12	6.7
08.08.2003 12:30	0.66	0.559	0.591	12	6.7
11.08.2003 10:00	0.695	0.581	0.609	12	6.7
11.08.2003 11:30	0.662	0.573	0.595	12	6.7
11.08.2003 15:00	0.688	0.589	0.621	12	6.7
12.08.2003 10:00	0.672	0.581	0.607	12	6.7
12.08.2003 14:30	0.675	0.574	0.588	12	6.7
13.08.2003 10:00	0.688	0.574	0.619	12	6.7
13.08.2003 14:00	0.695	0.567	0.602	12	6.7
14.08.2003 10:30	0.686	0.579	0.603	12	6.7
14.08.2003 13:30	0.683	0.58	0.601	12	6.7
15.08.2003 08:30	0.692	0.593	0.618	12	6.7
18.08.2003 10:30	0.701	0.591	0.622	12	6.7
18.08.2003 15:30	0.702	0.594	0.618	12	6.7
19.08.2003 10:30	0.686	0.578	0.61	12	6.7
19.08.2003 13:00	0.675	0.59	0.603	12	6.7
20.08.2003 10:00	0.687	0.598	0.615	12	6.7
20.08.2003 15:00	0.684	0.582	0.599	12	6.7
21.08.2003 10:00	0.694	0.577	0.577	12	6.7
21.08.2003 14:00	0.666	0.56	0.585	12	6.7
22.08.2003 10:00	0.687	0.558	0.598	12	6.7
22.08.2003 14:00	0.687	0.563	0.602	12	6.7
25.08.2003 09:30	0.704	0.579	0.614	12	6.7
25.08.2003 13:30	0.693	0.582	0.602	12	6.7
26.08.2003 10:00	0.706	0.589	0.604	12	6.7
26.08.2003 13:30	0.697	0.581	0.581	12	6.7
27.08.2003 10:00	0.706	0.59	0.605	12	6.7
27.08.2003 13:30	0.7	0.602	0.615	12	6.7
28.08.2003 09:00	0.653	0.546	0.577	12	6.7
01.09.2003 10:30	0.457	0.37	0.383	9	6.7
01.09.2003 14:00	0.469	0.371	0.384	9	6.7
02.09.2003 10:00	0.398	0.321	0.324	9	6.7
02.09.2003 12:30	0.409	0.337	0.338	9	6.6
03.09.2003 10:00	0.388	0.333	0.296	9	6.6
03.09.2003 13:00	0.38	0.3	0.293	9	6.6
04.09.2003 11:00	0.332	0.239	0.249	9	6.6
04.09.2003 14:00	0.324	0.243	0.248	9	6.6
05.09.2003 10:00	0.287	0.212	0.224	9	6.6
05.09.2003 15:30	0.299	0.224	0.228	9	6.6
08.09.2003 10:00	0.246	0.163	0.165	9	6.5
08.09.2003 16:00	0.236	0.149	0.182	9	6.5
09.09.2003 10:00	0.21	0.146	0.15	9	6.5
09.09.2003 14:30	0.203	0.154	0.161	9	6.5
10.09.2003 10:00	0.194	0.178	0.131	9	6.4
10.09.2003 14:00	0.198	0.139	0.135	9	6.5
11.09.2003 10:00	0.195	0.125	0.125	9	6.5
15.09.2003 10:00	0.147	0.101	0.093	9	6.5
16.09.2003 10:00	0.146	0.087	0.082	9	6.5
17.09.2003 11:00	0.158	0.099	0.088	9	6.5
18.09.2003 09:00	0.205	0.137	0.116	9	6.5
19.09.2003 10:00	0.16	0.099	0.071	9	6.5
20.10.2003 09:00	0.639	0.418	0.414	9	6.7

Experiment Nr 14. Optical density of *Cyclotella meneghiniana* culture determined by extinction measurements using three different wavelengths.

Date	Ext. 440nm	Ext. 535nm	Ext. 560nm	Temperature (°C)	pH
20.10.2003 12:30	0.513	0.414	0.433	9	6.7
21.10.2003 09:00	0.671	0.529	0.502	9	6.7
21.10.2003 12:30	0.652	0.51	0.516	9	6.7
22.10.2003 09:00	0.626	0.482	0.485	9	6.7
22.10.2003 12:30	0.656	0.503	0.506	9	6.7
23.10.2003 09:00	0.583	0.448	0.47	9	6.7
23.10.2003 13:00	0.584	0.454	0.466	9	6.7
24.10.2003 09:00	0.545	0.413	0.437	9	6.7
24.10.2003 14:00	0.573	0.439	0.442	9	6.7
27.10.2003 10:00	0.532	0.39	0.413	9	6.7
28.10.2003 09:00	0.488	0.364	0.368	9	6.7
28.10.2003 13:00	0.531	0.38	0.384	9	6.7
29.10.2003 09:00	0.501	0.349	0.36	9	6.7
29.10.2003 13:30	0.489	0.341	0.349	9	6.7
30.10.2003 09:00	0.451	0.351	0.33	9	6.7
30.10.2003 13:00	0.456	0.329	0.324	9	6.7
31.10.2003 09:00	0.455	0.327	0.312	9	6.7
31.10.2003 13:30	0.454	0.334	0.317	9	6.7
03.11.2003 09:00	0.411	0.292	0.301	9	6.7
03.11.2003 13:00	0.436	0.293	0.306	9	6.7
04.11.2003 09:00	0.428	0.285	0.325	9	6.7
04.11.2003 12:30	0.429	0.298	0.305	9	6.7
05.11.2003 09:00	0.427	0.303	0.297	9	6.7
05.11.2003 13:00	0.421	0.314	0.303	9	6.7
06.11.2003 09:00	0.431	0.306	0.303	9	6.7
06.11.2003 13:00	0.423	0.301	0.306	9	6.7
07.11.2003 09:00	0.437	0.3	0.291	9	6.7
10.11.2003 09:00	0.43	0.294	0.304	9	6.7
10.11.2003 12:30	0.431	0.29	0.293	9	6.7
11.11.2003 09:00	0.419	0.286	0.296	9	6.7
11.11.2003 13:00	0.42	0.297	0.3	9	6.7
12.11.2003 09:00	0.4	0.304	0.292	9	6.7
12.11.2003 12:30	0.407	0.302	0.314	9	6.7
13.11.2003 09:00	0.41	0.301	0.306	9	6.7
13.11.2003 12:30	0.42	0.291	0.298	9	6.7
14.11.2003 09:00	0.406	0.295	0.307	9	6.7
14.11.2003 12:00	0.418	0.287	0.29	9	6.7
17.11.2003 09:00	0.406	0.298	0.29	9	6.7
17.11.2003 12:30	0.43	0.293	0.295	9	6.7
18.11.2003 10:00	0.436	0.323	0.311	9	6.7
18.11.2003 14:00	0.44	0.31	0.329	9	6.7
19.11.2003 09:00	0.422	0.321	0.313	9	6.7
19.11.2003 12:30	0.444	0.302	0.308	9	6.7
20.11.2003 09:00	0.415	0.309	0.309	9	6.7
20.11.2003 13:00	0.429	0.311	0.312	9	6.7
21.11.2003 09:00	0.425	0.303	0.313	9	6.7
24.11.2003 09:00	0.419	0.308	0.304	9	6.7
25.11.2003 09:00	0.431	0.308	0.323	9	6.7
25.11.2003 13:00	0.442	0.313	0.319	9	6.7
26.11.2003 09:00	0.446	0.331	0.333	9	6.7
27.11.2003 09:00	0.427	0.304	0.3	9	6.7
27.11.2003 13:00	0.443	0.328	0.323	9	6.7
28.11.2003 09:00	0.442	0.315	0.317	9	6.7
01.12.2003 10:30	0.458	0.348	0.366	9	6.7
02.12.2003 10:00	0.439	0.319	0.321	9	6.7
02.12.2003 14:00	0.442	0.314	0.33	9	6.7
03.12.2003 09:00	0.42	0.338	0.326	9	6.7
03.12.2003 13:00	0.43	0.339	0.347	9	6.7
04.12.2003 09:00	0.436	0.33	0.334	9	6.7
05.12.2003 09:00	0.452	0.328	0.347	9	6.7
05.12.2003 12:00	0.444	0.341	0.351	9	6.7
08.12.2003 09:00	0.464	0.363	0.364	9	6.7
08.12.2003 13:00	0.482	0.367	0.366	9	6.7
09.12.2003 09:00	0.484	0.368	0.355	9	6.7
09.12.2003 13:00	0.482	0.375	0.377	9	6.7
10.12.2003 09:00	0.484	0.395	0.388	9	6.7
10.12.2003 13:00	0.492	0.391	0.408	9	6.7
11.12.2003 09:00	0.49	0.395	0.394	9	6.7
11.12.2003 13:00	0.522	0.408	0.422	9	6.7
12.12.2003 09:00	0.494	0.395	0.4	9	6.7
12.12.2003 12:00	0.522	0.404	0.416	9	6.7
15.12.2003 09:00	0.561	0.436	0.45	9	6.7
15.12.2003 13:00	0.566	0.452	0.462	9	6.7
16.12.2003 09:00	0.591	0.457	0.458	9	6.7
16.12.2003 13:00	0.54	0.444	0.468	9	6.7
17.12.2003 19:30	0.618	0.484	0.491	9	6.7
18.12.2003 09:00	0.662	0.501	0.52	9	6.7
19.12.2003 10:30	0.619	0.502	0.521	9	6.7
21.12.2003 09:00	0.64	0.455	0.482	9	6.8
21.12.2003 14:00	0.645	0.507	0.515	9	6.8
27.12.2003 10:00	0.664	0.531	0.548	9	6.8
31.12.2003 10:00	0.631	0.532	0.537	9	6.8
04.01.2004 17:30	0.659	0.545	0.56	9	6.8
05.01.2004 14:00	0.702	0.58	0.585	9	6.8
06.01.2004 10:00	0.658	0.534	0.565	9	6.8
06.01.2004 13:00	0.662	0.557	0.567	9	6.8
07.01.2004 09:00	0.649	0.54	0.553	9	6.8
08.01.2004 09:00	0.656	0.545	0.567	9	6.8
08.01.2004 13:00	0.714	0.565	0.574	9	6.8
09.01.2004 09:00	0.659	0.55	0.57	9	6.8
12.01.2004 09:00	0.615	0.53	0.534	9	6.8
13.01.2004 11:00	0.567	0.501	0.533	9	6.8
14.01.2004 09:00	0.614	0.503	0.517	9	6.8
14.01.2004 13:00	0.603	0.47	0.476	9	6.8
15.01.2004 09:00	0.575	0.493	0.489	9	6.8
15.01.2004 13:00	0.583	0.439	0.464	9	6.8
16.01.2004 09:00	0.573	0.447	0.459	9	6.8
19.01.2004 09:00	0.462	0.383	0.39	9	6.8
20.01.2004 09:00	0.473	0.372	0.379	9	6.8
20.01.2004 13:00	0.436	0.37	0.382	9	6.8
21.01.2004 09:00	0.43	0.354	0.365	9	6.8
22.01.2004 09:00	0.416	0.338	0.353	9	6.8
22.01.2004 12:00	0.414	0.339	0.353	9	6.8
23.01.2004 09:00	0.385	0.325	0.345	9	6.8
23.01.2004 12:00	0.397	0.331	0.345	9	6.8
26.01.2004 09:00	0.396	0.305	0.317	9	6.8
26.01.2004 12:30	0.429	0.325	0.327	9	6.8
27.01.2004 09:00	0.373	0.284	0.298	9	6.8
27.01.2004 12:30	0.338	0.279	0.293	9	6.7
28.01.2004 09:00	0.33	0.273	0.275	9	6.8
29.01.2004 10:00	0.312	0.245	0.264	9	6.7
29.01.2004 13:00	0.327	0.26	0.265	9	6.7
30.01.2004 09:00	0.288	0.235	0.248	9	6.7
30.01.2004 12:00	0.284	0.23	0.237	9	6.7
02.02.2004 09:00	0.324	0.24	0.249	9	6.7
02.02.2004 13:00	0.292	0.223	0.237	9	6.7
02.02.2004 16:00	0.288	0.222	0.247	9	6.7
03.02.2004 09:00	0.26	0.207	0.215	9	6.7
03.02.2004 13:00	0.262	0.209	0.222	9	6.7
04.02.2004 09:00	0.259	0.21	0.214	9	6.7
04.02.2004 13:00	0.299	0.235	0.23	9	6.7
05.02.2004 09:00	0.251	0.198	0.209	9	6.7
05.02.2004 13:00	0.252	0.199	0.213	9	6.7
06.02.2004 09:00	0.251	0.203	0.219	9	6.7
06.02.2004 12:00	0.226	0.189	0.197	9	6.7
09.02.2004 09:00	0.219	0.177	0.177	9	6.7
09.02.2004 12:30	0.23	0.184	0.191	9	6.7
10.02.2004 09:00	0.217	0.177	0.181	9	6.7
10.02.2004 13:00	0.245	0.196	0.189	9	6.7
11.02.2004 09:00	0.212	0.174	0.182	9	6.7
11.02.2004 15:00	0.245	0.195	0.196	9	6.7
12.02.2004 09:00	0.213	0.175	0.187	9	6.7
12.02.2004 13:00	0.219	0.177	0.181	9	6.7
13.02.2004 09:00	0.218	0.179	0.192	9	6.7
13.02.2004 14:00	0.255	0.194	0.209	9	6.7
16.02.2004 09:00	0.232	0.192	0.19	9	6.7
16.02.2004 13:00	0.26	0.2	0.203	9	6.7
17.02.2004 09:00	0.272	0.202	0.208	9	6.7
17.02.2004 12:30	0.266	0.2	0.204	9	6.7
18.02.2004 09:00	0.253	0.2	0.21	9	6.7
19.02.2004 09:00	0.25	0.195	0.208	9	6.7
20.02.2004 10:30	0.281	0.218	0.219	9	6.7
21.02.2004 10:30	0.267	0.205	0.207	9	6.7
24.02.2004 09:00	0.26	0.201	0.203	9	6.7
24.02.2004 12:30	0.292	0.219	0.224	9	6.8
25.02.2004 09:00	0.291	0.213	0.213	9	6.8
25.02.2004 13:30	0.257	0.203	0.218	9	6.8
26.02.2004 09:30	0.271	0.222	0.229	9	6.8
27.02.2004 09:00	0.267	0.213	0.216	9	6.8
27.02.2004 14:00	0.248	0.202	0.206	9	6.8
01.03.2004 09:00	0.236	0.191	0.196	9	6.8
01.03.2004 13:00	0.247	0.204	0.226	9	6.8
02.03.2004 09:00	0.242	0.178	0.185	9	6.8
02.03.2004 13:00	0.234	0.18	0.19	9	6.8
03.03.2004 10:30	0.26	0.195	0.203	9	6.8
03.03.2004 15:00	0.24	0.185	0.196	9	6.8
04.03.2004 10:30	0.257	0.188	0.191	9	6.8
04.03.2004 15:00	0.231	0.18	0.189	9	6.8
05.03.2004 10:30	0.242	0.191	0.201	9	6.8
05.03.2004 14:00	0.266	0.189	0.193	9	6.8
08.03.2004 09:30	0.208	0.164	0.182	9	6.8
08.03.2004 13:00	0.257	0.187	0.187	9	6.8
09.03.2004 09:00	0.209	0.157	0.161	9	6.8
09.03.2004 12:30	0.218	0.153	0.158	9	6.7
10.03.2004 09:00	0.193	0.145	0.156	9	6.7
11.03.2004 10:00	0.208	0.168	0.167	9	6.7
12.03.2004 10:00	0.182	0.145	0.144	9	6.8
12.03.2004 12:30	0.175	0.143	0.145	9	6.8
15.03.2004 09:00	0.176	0.125	0.125	9	6.7
15.03.2004 12:30	0.196	0.149	0.145	9	6.7
16.03.2004 09:00	0.14	0.11	0.107	9	6.7
16.03.2004 12:30	0.157	0.124	0.122	9	6.7
17.03.2004 09:30	0.149	0.113	0.112	9	6.7
17.03.2004 13:00	0.142	0.11	0.113	9	6.7
18.03.2004 09:00	0.129	0.106	0.11	9	6.7
18.03.2004 13:00	0.146	0.122	0.12	9	6.7
19.03.2004 09:00	0.125	0.1	0.103	9	6.7
19.03.2004 13:00	0.15	0.114	0.118	9	6.7
22.03.2004 10:30	0.154	0.115	0.121	9	6.7
23.03.2004 11:30	0.14	0.106	0.108	9	6.7
23.03.2004 16:30	0.139	0.11	0.116	9	6.7
24.03.2004 09:00	0.1	0.09	0.092	9	6.7
25.03.2004 09:00	0.154	0.114	0.158	21	
25.03.2004 12:30	0.137	0.112	0.099	21	
25.03.2004 14:30	0.16	0.129	0.108	21	
26.03.2004 09:00	0.166	0.135	0.138	21	
26.03.2004 14:00	0.173	0.141	0.145	21	
29.03.2004 10:00	0.281	0.231	0.218	21	
29.03.2004 13:00	0.268	0.2	0.202	21	
30.03.2004 09:00	0.27	0.287	0.274	21	
30.03.2004 13:00	0.288	0.203	0.204	21	
31.03.2004 09:00	0.232	0.178	0.177	21	
31.03.2004 13:00	0.224	0.17	0.17	21	
01.04.2004 09:00	0.237	0.175	0.172	21	
01.04.2004 13:00	0.232	0.172	0.168	21	
02.04.2004 09:00	0.264	0.183	0.167	21	
02.04.2004 14:00	0.2	0.153	0.145	21	
05.04.2004 09:00	0.175	0.113	0.107	21	

Experiment Nr 15. Optical density of *Cyclotella meneghiniana* culture determined by extinction measurements using three different wavelengths.

Date	Ext. 440nm	Ext. 535nm	Ext. 560nm	Temperature (°C)	pH
23.05.2003 14:00	0.378	0.284	0.286	18	6.7
26.05.2003 09:00	0.685	0.575	0.596	18	6.8
26.05.2003 12:00	0.7	0.579	0.593	18	6.8
26.05.2003 14:00	0.715	0.596	0.617	18	6.8
26.05.2003 15:30	0.71	0.603	0.61	18	6.8
27.05.2003 09:30	0.695	0.604	0.624	18	6.8
27.05.2003 11:00	0.687	0.611	0.641	18	6.8
27.05.2003 14:00	0.751	0.643	0.663	18	6.8
28.05.2003 09:00	0.681	0.616	0.651	18	6.8
28.05.2003 11:00	0.697	0.622	0.656	18	6.8
02.06.2003 09:00	0.751	0.693	0.729	18.1	6.7
02.06.2003 11:00	0.75	0.685	0.711	18	6.7
02.06.2003 14:00	0.776	0.711	0.747	18	6.7
02.06.2003 15:30	0.777	0.697	0.745	18	6.7
03.06.2003 10:30	0.722	0.694	0.726	18	6.7
03.06.2003 15:00	0.776	0.698	0.739	18	6.7
04.06.2003 09:00	0.782	0.705	0.736	18.1	6.7
04.06.2003 14:30	0.791	0.711	0.744	18	6.8
04.06.2003 17:00	0.836	0.758	0.782	18	6.8
05.06.2003 09:00	0.737	0.68	0.724	18	6.8
05.06.2003 11:00	0.79	0.71	0.741	18	6.8
05.06.2003 16:00	0.846	0.748	0.785	18	6.8
06.06.2003 09:00	0.815	0.73	0.766	18	6.7
06.06.2003 14:00	0.801	0.729	0.752	22	6.7
06.06.2003 18:00	0.827	0.767	0.793	18	6.7
11.06.2003 09:00	0.79	0.728	0.772	18	6.7
11.06.2003 11:00	0.763	0.678	0.717	18	6.7
12.06.2003 09:00	0.76	0.688	0.723	18	6.7
12.06.2003 11:00	0.797	0.73	0.772	18	6.7
13.06.2003 09:00	0.803	0.736	0.774	18	6.7
13.06.2003 11:00	0.798	0.693	0.719	18	6.7
13.06.2003 16:00	0.776	0.698	0.727	18	6.7
16.06.2003 10:00	0.781	0.699	0.726	26.8	6.7
16.06.2003 12:00	0.787	0.689	0.714	18	6.7
16.06.2003 14:00	0.776	0.697	0.746	18	6.7
17.06.2003 10:00	0.803	0.728	0.763	18	6.7
17.06.2003 12:00	0.785	0.721	0.764	18	6.7
18.06.2003 09:00	0.783	0.72	0.754	18	6.7
18.06.2003 11:00	0.805	0.717	0.752	18	6.7
21.06.2003 22:00	0.772	0.711	0.748	18	6.7
23.06.2003 10:00	0.792	0.723	0.752	18	6.7
23.06.2003 12:00	0.762	0.698	0.733	18	6.7
24.06.2003 09:00	0.756	0.692	0.724	18	6.7
24.06.2003 11:00	0.735	0.683	0.715	18	6.7
25.06.2003 09:00	0.736	0.694	0.731	18	6.7
25.06.2003 11:00	0.768	0.696	0.733	18	6.7
26.06.2003 09:00	0.755	0.687	0.729	18	6.7
26.06.2003 09:30	0.764	0.717	0.75	18	6.7
26.06.2003 11:00	0.752	0.684	0.727	18	6.7
27.06.2003 09:00	0.764	0.717	0.754	18	6.7
27.06.2003 11:00	0.773	0.729	0.766	18	6.7
27.06.2003 15:00	0.73	0.689	0.744	18	6.7
30.06.2003 09:00	0.746	0.689	0.73	18	6.7
30.06.2003 11:00	0.72	0.672	0.717	18	6.7
01.07.2003 09:00	0.75	0.709	0.762	18	6.7
01.07.2003 11:00	0.746	0.676	0.72	18	6.7
02.07.2003 09:00	0.753	0.724	0.765	18	6.7
02.07.2003 11:00	0.78	0.72	0.756	18	6.7
02.07.2003 11:30	0.72	0.685	0.736	18	6.7
03.07.2003 09:00	0.726	0.701	0.736	18	6.7
03.07.2003 11:00	0.744	0.702	0.748	18	6.7
04.07.2003 09:00	0.755	0.71	0.739	18	6.7
04.07.2003 11:00	0.78	0.71	0.758	18	6.7
07.07.2003 09:00	0.781	0.72	0.777	18	6.7
07.07.2003 11:00	0.769	0.7	0.753	18	6.7
08.07.2003 09:00	0.783	0.728	0.769	18	6.7
08.07.2003 11:00	0.725	0.656	0.702	18	6.7
09.07.2003 09:00	0.732	0.658	0.701	18	6.7
09.07.2003 11:00	0.692	0.655	0.689	18	6.7
10.07.2003 09:00	0.733	0.656	0.704	18	6.7
10.07.2003 11:00	0.711	0.63	0.67	18	6.7
11.07.2003 09:30	0.73	0.624	0.658	18.1	6.7
11.07.2003 11:00	0.657	0.569	0.587	18	6.7
14.07.2003 09:00	0.668	0.597	0.631	18	6.7
14.07.2003 11:00	0.651	0.568	0.601	18	6.7
15.07.2003 09:00	0.652	0.573	0.609	18	6.7
15.07.2003 11:00	0.663	0.586	0.629	18	6.7
16.07.2003 09:00	0.666	0.557	0.598	18	6.7
16.07.2003 11:00	0.683	0.585	0.632	18	6.7
17.07.2003 10:30	0.687	0.593	0.64	18	6.7
17.07.2003 14:00	0.672	0.604	0.648	18	6.7
18.07.2003 09:00	0.674	0.601	0.634	18	6.7
18.07.2003 11:00	0.661	0.573	0.611	18	6.7
18.07.2003 11:30	0.689	0.569	0.606	18	6.7
21.07.2003 09:00	0.662	0.57	0.592	18	6.7
21.07.2003 11:30	0.673	0.572	0.598	18	6.7
22.07.2003 09:00	0.684	0.581	0.59	18	6.7
22.07.2003 11:00	0.653	0.536	0.582	18	6.7

Date	Ext. 440nm	Ext. 535nm	Ext. 560nm	Temperature (°C)	pH
23.07.2003 09:00	0.645	0.55	0.579	18	6.7
23.07.2003 11:00	0.621	0.586	0.578	18	6.7
24.07.2003 09:00	0.64	0.555	0.578	18	6.7
24.07.2003 11:00	0.626	0.541	0.556	18	6.7
25.07.2003 09:00	0.639	0.545	0.561	18	6.7
25.07.2003 11:00	0.647	0.54	0.569	18	6.7
25.07.2003 16:00	0.659	0.576	0.587	18	6.7
28.07.2003 09:00	0.672	0.574	0.572	18	6.7
28.07.2003 11:00	0.656	0.565	0.595	18	6.7
28.07.2003 15:00	0.673	0.588	0.609	18	6.7
29.07.2003 09:30	0.678	0.58	0.611	18	6.7
29.07.2003 11:30	0.638	0.532	0.552	18	6.7
29.07.2003 15:00	0.675	0.581	0.611	18	6.7
30.07.2003 09:00	0.65	0.556	0.589	18	6.7
30.07.2003 13:30	0.659	0.567	0.607	18	6.7
31.07.2003 09:00	0.654	0.558	0.584	18	6.7
31.07.2003 12:00	0.67	0.574	0.592	18	6.7
31.07.2003 15:00	0.687	0.59	0.611	18	6.7
01.08.2003 09:00	0.649	0.562	0.591	18	6.7
01.08.2003 11:30	0.631	0.539	0.559	18	6.7
04.08.2003 10:00	0.719	0.605	0.638	18	6.7
04.08.2003 12:30	0.712	0.594	0.622	18	6.7
05.08.2003 10:00	0.708	0.621	0.637	18	6.7
05.08.2003 13:00	0.697	0.606	0.63	18	6.7
05.08.2003 16:30	0.728	0.616	0.635	18	6.7
06.08.2003 10:00	0.726	0.614	0.646	18	6.7
06.08.2003 15:30	0.738	0.624	0.641	18.2	6.7
07.08.2003 10:00	0.714	0.625	0.64	18	6.7
08.08.2003 10:00	0.749	0.639	0.674	18	6.7
08.08.2003 12:30	0.754	0.651	0.646	18	6.7
11.08.2003 10:00	0.759	0.655	0.68	18	6.6
11.08.2003 11:30	0.749	0.641	0.663	18	6.6
11.08.2003 15:00	0.752	0.643	0.667	18	6.6
12.08.2003 10:00	0.757	0.653	0.673	18	6.6
12.08.2003 14:30	0.768	0.651	0.681	18	6.6
13.08.2003 10:00	0.801	0.651	0.689	18	6.6
13.08.2003 14:00	0.755	0.654	0.684	18	6.6
14.08.2003 10:30	0.786	0.666	0.689	18	6.6
14.08.2003 13:30	0.759	0.651	0.675	18	6.6
15.08.2003 08:30	0.742	0.654	0.675	18	6.7
18.08.2003 10:30	0.749	0.642	0.67	18	6.6
18.08.2003 15:30	0.744	0.634	0.669	18	6.6
19.08.2003 10:30	0.728	0.622	0.658	18	6.6
19.08.2003 13:00	0.732	0.614	0.673	18	6.6
20.08.2003 10:00	0.734	0.639	0.65	18	6.6
20.08.2003 15:00	0.721	0.62	0.655	18	6.6
21.08.2003 10:00	0.747	0.628	0.631	18	6.6
21.08.2003 14:00	0.746	0.618	0.654	18	6.6
22.08.2003 10:00	0.736	0.641	0.673	18	6.6
22.08.2003 14:00	0.737	0.636	0.653	18	6.6
25.08.2003 09:30	0.714	0.624	0.652	18	6.6
25.08.2003 13:30	0.743	0.618	0.646	18	6.6
26.08.2003 10:00	0.735	0.637	0.654	18	6.6
26.08.2003 13:30	0.735	0.625	0.645	18	6.6
27.08.2003 10:00	0.738	0.631	0.658	18	6.6
27.08.2003 13:30	0.74	0.633	0.647	18	6.6
28.08.2003 09:00	0.743	0.626	0.656	18	6.6
01.09.2003 10:30	0.744	0.632	0.649	18	6.6
01.09.2003 14:00	0.764	0.632	0.649	18	6.5
02.09.2003 10:00	0.696	0.605	0.622	18	5.5
02.09.2003 12:30	0.755	0.582	0.584	18	6.6
03.09.2003 10:00	0.744	0.623	0.632	18	6.6
03.09.2003 13:00	0.734	0.625	0.63	18	6.6
04.09.2003 11:00	0.75	0.632	0.651	18	6.6
04.09.2003 14:00	0.746	0.639	0.65	18	6.6
05.09.2003 10:00	0.758	0.647	0.655	18	6.6
05.09.2003 15:30	0.762	0.65	0.656	18	6.6
08.09.2003 10:00	0.774	0.648	0.668	18	6.6
08.09.2003 16:00	0.774	0.639	0.659	18	6.6
09.09.2003 10:00	0.759	0.642	0.669	18	6.4
09.09.2003 14:30	0.768	0.655	0.678	18	6.6
10.09.2003 10:00	0.768	0.658	0.664	18	6.6
10.09.2003 14:00	0.766	0.652	0.676	18	6.6
11.09.2003 10:00	0.754	0.627	0.66	18	6.6
11.09.2003 16:00	0.756	0.641	0.649	18	6.6
12.09.2003 10:00	0.718	0.616	0.63	18	6.6
12.09.2003 13:30	0.758	0.648	0.642	18	6.6
15.09.2003 09:00	0.64	0.528	0.549	18	6.7
15.09.2003 13:00	0.674	0.577	0.602	18	6.7
16.09.2003 09:00	0.675	0.573	0.594	18	6.7
16.09.2003 12:30	0.667	0.56	0.58	18	6.7
17.09.2003 09:00	0.642	0.543	0.565	18	6.7
17.09.2003 12:30	0.654	0.537	0.564	18	6.7
18.09.2003 09:00	0.623	0.528	0.534	18	6.7
18.09.2003 12:30	0.609	0.51	0.533	18	6.7
19.09.2003 09:00	0.644	0.515	0.526	18	6.7
19.09.2003 12:00	0.621	0.501	0.521	18	6.7
22.09.2003 09:00	0.638	0.546	0.548	18	6.7

Experiment Nr 15. Optical density of *Cyclotella meneghiniana* culture determined by extinction measurements using three different wavelengths.

Date	Ext. 440nm	Ext. 535nm	Ext. 560nm	Temperature (°C)	pH
22.09.2003 12:30	0.672	0.544	0.57	18	6.7
23.09.2003 09:00	0.638	0.546	0.548	18	6.7
23.09.2003 12:30	0.672	0.544	0.57	18	6.7
24.09.2003 09:00	0.658	0.537	0.541	18	6.7
24.09.2003 12:30	0.639	0.531	0.549	18	6.7
25.09.2003 09:00	0.614	0.485	0.499	18	6.7
25.09.2003 12:30	0.632	0.521	0.543	18	6.7
26.09.2003 09:00	0.647	0.53	0.547	18	6.7
26.09.2003 12:00	0.65	0.517	0.536	18	6.7
29.09.2003 09:00	0.629	0.506	0.524	18	6.7
29.09.2003 12:30	0.612	0.507	0.518	18	6.7
30.09.2003 09:00	0.629	0.483	0.49	18	6.7
30.09.2003 12:30	0.638	0.505	0.525	18	6.7
01.10.2003 09:00	0.632	0.51	0.523	18	6.7
01.10.2003 12:30	0.647	0.521	0.53	18	6.7
02.10.2003 09:00	0.641	0.502	0.508	18	6.7
02.10.2003 11:30	0.65	0.502	0.52	18	6.7
06.10.2003 09:00	0.655	0.522	0.53	18	6.7
06.10.2003 12:30	0.651	0.523	0.535	18	6.7
07.10.2003 09:00	0.661	0.53	0.538	18	6.7
07.10.2003 12:00	0.653	0.519	0.528	18	6.7
08.10.2003 09:00	0.646	0.514	0.529	18	6.7
08.10.2003 12:30	0.634	0.506	0.529	18	6.7
09.10.2003 09:00	0.663	0.512	0.526	18	6.7
09.10.2003 12:30	0.635	0.506	0.525	18	6.7
10.10.2003 09:00	0.652	0.521	0.53	18	6.7
10.10.2003 12:00	0.613	0.519	0.524	18	6.7
13.10.2003 09:00	0.612	0.484	0.497	18	6.7
13.10.2003 12:00	0.584	0.46	0.584	18	6.7
14.10.2003 09:00	0.583	0.463	0.481	18	6.7
14.10.2003 12:30	0.6	0.5	0.516	18	6.7
15.10.2003 09:00	0.599	0.485	0.508	18	6.7
15.10.2003 12:30	0.582	0.499	0.504	18	6.7
16.10.2003 09:00	0.58	0.478	0.495	18	6.7
16.10.2003 12:30	0.584	0.485	0.494	18	6.7
17.10.2003 09:00	0.595	0.489	0.501	18	6.7
17.10.2003 12:00	0.586	0.483	0.503	18	6.7
20.10.2003 09:00	0.719	0.617	0.638	18	6.8
20.10.03 12.30	0.779	0.651	0.662	18	6.8
21.10.2003 09:00	0.76	0.662	0.685	18	6.7
21.10.2003 12:30	0.761	0.676	0.691	18	6.7
22.10.2003 09:00	0.789	0.685	0.702	18	6.8
22.10.2003 12:30	0.813	0.701	0.71	18	6.8
23.10.2003 09:00	0.798	0.691	0.714	18	6.8
23.10.2003 13:00	0.791	0.695	0.72	18	6.7
24.10.2003 09:00	0.793	0.69	0.717	18	6.7
24.10.2003 13:30	0.823	0.718	0.742	18	6.7
24.10.2003 15:00	0.814	0.713	0.733	18	6.8
27.10.2003 10:00	0.853	0.74	0.766	18	6.7
28.10.2003 09:00	0.842	0.725	0.752	18	6.7
28.10.2003 13:30	0.872	0.752	0.766	18	6.7
29.10.2003 09:00	0.868	0.746	0.752	18	6.7
29.10.2003 13:30	0.86	0.739	0.759	18	6.7
30.10.2003 09:00	0.855	0.747	0.764	18	6.7
30.10.2003 13:00	0.863	0.745	0.767	18	6.7
31.10.2003 09:00	0.861	0.739	0.766	18	6.7
31.10.2003 13:30	0.844	0.742	0.762	18	6.7
03.11.2003 09:00	0.85	0.744	0.772	18	6.8
03.11.2003 13:00	0.853	0.753	0.786	18	6.7
04.11.2003 09:00	0.853	0.759	0.771	18	6.7
04.11.2003 12:30	0.837	0.741	0.765	18	6.7
05.11.2003 09:00	0.872	0.469	0.788	18	6.7
05.11.2003 13:00	0.85	0.747	0.778	18	6.7
06.11.2003 09:00	0.847	0.763	0.78	18	6.7
06.11.2003 13:00	0.84	0.748	0.77	18	6.7
07.11.2003 09:00	0.866	0.768	0.782	18	6.7
10.11.2003 09:00	0.863	0.753	0.792	18	6.7
10.11.2003 12:30	0.853	0.75	0.771	18	6.7
11.11.2003 09:00	0.869	0.759	0.785	18	6.7
11.11.2003 13:00	0.865	0.758	0.79	18	6.7
12.11.2003 09:00	0.878	0.769	0.799	18	6.7
12.11.2003 12:30	0.845	0.74	0.766	18	6.7
13.11.2003 09:00	0.857	0.762	0.795	18	6.7
13.11.2003 12:30	0.842	0.733	0.766	18	6.7
14.11.2003 09:00	0.878	0.759	0.786	18	6.7
14.11.2003 12:00	0.863	0.762	0.792	18	6.7
17.11.2003 09:00	0.85	0.75	0.775	18	6.8
17.11.2003 12:30	0.876	0.769	0.79	18	6.7
18.11.2003 10:00	0.873	0.777	0.81	18	6.7
18.11.2003 14:00	0.89	0.786	0.795	18	6.7
19.11.2003 09:00	0.87	0.77	0.792	18	6.7
19.11.2003 12:30	0.869	0.774	0.799	18	6.7
20.11.2003 09:00	0.893	0.778	0.806	18	6.7
20.11.2003 13:00	0.9	0.772	0.807	18	6.7
21.11.2003 09:00	0.903	0.776	0.806	18	6.7
24.11.2003 09:00	0.878	0.773	0.807	18	6.7
24.11.2003 13:00	0.872	0.773	0.8	18	6.7
25.11.2003 09:00	0.897	0.778	0.809	18	6.7
25.11.2003 13:00	0.899	0.798	0.825	18	6.7
26.11.2003 09:00	0.911	0.809	0.841	18	6.7
26.11.2003 13:00	0.895	0.793	0.818	18	6.7
27.11.2003 09:00	0.926	0.805	0.825	18	6.7
27.11.2003 13:00	0.904	0.795	0.816	18	6.7
28.11.2003 09:00	0.915	0.799	0.822	18	6.6
01.12.2003 10:30	0.947	0.833	0.842	18	6.6
02.12.2003 10:00	0.936	0.818	0.831	18	6.8
02.12.2003 14:00	0.94	0.822	0.837	18	6.8
03.12.2003 09:00	0.921	0.817	0.831	18	6.7
03.12.2003 13:00	0.925	0.815	0.827	18	6.7
05.12.2003 09:00	0.909	0.805	0.832	18	6.6
05.12.2003 12:00	0.937	0.812	0.838	18	6.6
08.12.2003 09:00	0.928	0.823	0.837	18	6.6
08.12.2003 13:00	0.948	0.809	0.835	18	6.7
09.12.2003 09:00	0.924	0.803	0.832	18	6.6
09.12.2003 13:00	0.926	0.805	0.819	18	6.6
10.12.2003 09:00	0.916	0.812	0.821	18	6.7
10.12.2003 13:00	0.927	0.803	0.83	18	6.6
11.12.2003 09:00	0.907	0.793	0.822	18	6.7
11.12.2003 13:00	0.903	0.732	0.805	18	6.7
12.12.2003 09:00	0.901	0.739	0.8	18	6.7
12.12.2003 12:00	0.911	0.792	0.83	18	6.7
15.12.2003 09:00	0.9	0.789	0.802	18	6.8
15.12.2003 13:00	0.905	0.793	0.813	18	6.7
16.12.2003 09:00	0.903	0.79	0.812	18	6.7
16.12.03 13.00	0.899	0.795	0.814	21	6.7
17.12.03 19.30	0.916	0.79	0.821	21	
18.12.2003 09:00	0.923	0.809	0.83	21	
19.12.2003 10:30	0.922	0.811	0.837	21	
21.12.2003 09:00	0.866	0.764	0.776	21	
21.12.2003 14:00	0.889	0.759	0.795	21	
27.12.2003 10:00	0.839	0.747	0.761	21	
31.12.03 10.00	0.857	0.733	0.754	21	
04.01.2004 17:30	0.711	0.584	0.564	21	
05.01.2004 14:00	0.68	0.511	0.509	21	
06.01.2004 10:00	0.603	0.45	0.42	21	
06.01.2004 13:00	0.634	0.46	0.428	21	

Element composition and C:N:Si ratios of selected samples of *Fragilaria crotonensis* dry mass accumulated during steady state conditions of experiment 5 and 7. Diatoms were grown for various nitrate concentrations of the medium and temperatures. Si/P, C/P and N/P are accordingly the amounts of Si, C and N (mg $l^{-1}d^{-1}$) divided by the productivity (P) (mg $l^{-1}d^{-1}$)

Temp. (°C)	Growth rate μ (d^{-1})	Nitrate concentration of the medium (mg/l)	Sample	Dry mass (mg/l)	Productivity P (mg $l^{-1}d^{-1}$)	Si (wt-%)	Si (mg $l^{-1}d^{-1}$)	Si/P	C (wt-%)	C (mg $l^{-1}d^{-1}$)	C/P	H (wt-%)	H (mg $l^{-1}d^{-1}$)	H/P	N (wt-%)	N (mg $l^{-1}d^{-1}$)	N/P	S (wt-%)	S (mg $l^{-1}d^{-1}$)	S/P	O (wt-%)	O (mg $l^{-1}d^{-1}$)	O/P	C/N	Si/C	Si/N
24	0.34	10.5	V5 D12	172.3	58.6	20.1	11.76	0.2	20.7	12.14	0.21	3.7	2.18	0.04	1.2	0.71	0.012	0.6	0.34	0.006	26.9	15.74	0.27	17.5	0.95	16.7
24	0.34	21	V5 D4	236.0	80.2	16.5	13.23	0.16	29.3	23.49	0.29	5.0	4.01	0.05	1.6	1.29	0.016	0.8	0.65	0.008	24.8	19.89	0.25	18.1	0.55	10.0
			V5 D5	246.1	83.7	15.0	12.55	0.15	28.3	23.66	0.28	5.0	4.18	0.05	1.5	1.26	0.015	0.6	0.51	0.006	21.7	18.16	0.22	18.7	0.54	10.0
24	0.34	52.5	V5 D19	282.4	96.0	13.3	12.78	0.13	36.9	35.43	0.37	5.8	5.58	0.06	2.8	2.69	0.028	0.8	0.78	0.008	24.8	23.8	0.25	13.2	0.35	4.6
			V5 D22	296.8	100.9	11.7	11.8	0.12	35.7	36.04	0.36	5.9	5.95	0.06	2.7	2.72	0.027	0.7	0.71	0.007	21.1	21.28	0.21	13.3	0.33	4.4
24	0.34	105	V5 D29	320.8	109.7	10.3	11.22	0.1	37.1	40.46	0.37	6.0	6.53	0.06	3.6	3.91	0.036	0.7	0.75	0.007	20.9	22.78	0.21	10.3	0.27	2.8
			V5 D30	305.4	103.8	10.8	11.22	0.11	37.4	38.83	0.37	6.1	6.32	0.06	3.7	3.84	0.037	0.6	0.61	0.006	21.0	21.79	0.21	10.0	0.30	3.0
21	0.34	105	V7 D9	321.4	109.3	11.5	12.57	0.12	37.7	41.21	0.38	6.1	6.66	0.061	4.6	5.03	0.046	0.6	0.65	0.006	25.7	28.08	0.26	8.2	0.3	2.5
			V7 D11	306.7	104.3	11.3	11.79	0.11	38.4	40.10	0.38	5.9	6.15	0.059	4.0	4.20	0.04	0.5	0.51	0.005	22.0	22.95	0.22	9.6	0.3	2.8
			V5 D36	287.6	97.8	11.1	10.85	0.11	38.5	37.64	0.38	6.1	5.95	0.06	4.0	3.91	0.04	0.7	0.68	0.007	20.4	19.96	0.2	9.5	0.29	2.8
18	0.34	105	V5 D38	283.4	96.4	12.0	11.56	0.12	38.3	36.89	0.38	6.25	6.02	0.06	4.0	3.84	0.04	0.7	0.68	0.007	23.2	22.34	0.23	9.5	0.32	3.0
			V5 D41	285.9	97.2	11.5	11.19	0.12	38.3	37.23	0.38	6.1	5.92	0.06	3.8	3.71	0.04	0.6	0.58	0.006	20.6	20.03	0.21	9.5	0.32	3.0
15	0.34	105	V7 D29	302.2	102.7	11.9	12.22	0.12	36.8	37.79	0.37	5.6	5.75	0.056	4.1	4.21	0.04	0.4	0.41	0.004	22.8	23.43	0.23	9.0	0.3	2.9
			V7 D35	294.1	100.0	11.5	11.50	0.12	38.3	38.30	0.38	5.9	5.92	0.059	4.4	4.40	0.04	0.5	0.51	0.005	21.5	21.49	0.21	8.7	0.3	2.6
12	0.34	105	V5 D46	267.9	91.1	12.6	11.49	0.13	34.2	31.14	0.34	5.8	5.27	0.06	4.2	3.84	0.042	0.6	0.54	0.006	20.2	18.39	0.2	8.1	0.38	3.1
			V5 D47	259.4	88.2	12.4	10.95	0.12	34.6	30.53	0.35	5.8	5.1	0.06	4.2	3.71	0.042	0.6	0.54	0.006	19.8	17.48	0.2	8.3	0.34	2.9

Element composition and C:N:Si ratios of selected samples of *Cyclotella meneghiniana* dry mass accumulated during steady state conditions of experiment 15. Diatoms were grown for various light intensities. Si/P, C/P and N/P are accordingly the amounts of Si, C and N (mg $l^{-1}d^{-1}$) divided by the productivity (P) (mg $l^{-1}d^{-1}$)

Temp. (°C)	Growth rate μ (d^{-1})	Light intensity (μmol $m^{-2}s^{-1}$)	Sample	Dry mass (mg/l)	Productivity P (mg $l^{-1}d^{-1}$)	Si (wt-%)	Si (mg $l^{-1}d^{-1}$)	Si/P	C (wt-%)	C (mg $l^{-1}d^{-1}$)	C/P	H (wt-%)	H (mg $l^{-1}d^{-1}$)	H/P	N (wt-%)	N (mg $l^{-1}d^{-1}$)	N/P	S (wt-%)	S (mg $l^{-1}d^{-1}$)	S/P	O (wt-%)	O (mg $l^{-1}d^{-1}$)	O/P	C/N	Si/C	Si/N
			V15 D103	365.0	73.0	9.5	6.94	0.10	39.5	28.84	0.40	6.1	4.46	0.061	3.1	2.26	0.031	0.4	0.30	0.004	23.5	17.16	0.24	12.8	0.2	3.1
18	0.2	200	V15 D105	367.4	73.5	9.7	7.12	0.10	39.2	28.80	0.39	6.1	4.48	0.061	3.0	2.20	0.030	0.4	0.30	0.004	23.7	17.42	0.24	13.1	0.2	3.2
			V15 D107	356.6	71.3	9.9	7.06	0.10	39.6	28.24	0.40	6.2	4.42	0.062	3.0	2.14	0.030	0.4	0.28	0.004	23.3	16.62	0.23	13.2	0.3	3.3
18	0.2	500	V15 D15	362.0	72.4	10.4	7.52	0.10	38.1	27.58	0.38	5.9	4.28	0.059	2.6	1.88	0.026	0.3	0.22	0.003	25.4	18.38	0.25	14.7	0.3	4.0
			V15 D17	334.1	66.8	11.7	7.82	0.12	37.4	25.00	0.37	5.9	3.94	0.059	2.7	1.80	0.027	0.3	0.20	0.003	23.8	15.90	0.24	13.9	0.3	4.3
			V15 D53	291.4	58.3	11.9	6.94	0.12	34.1	19.88	0.34	5.4	3.14	0.054	3.2	1.86	0.032	0.4	0.24	0.004	24.5	14.28	0.25	10.7	0.3	3.7
18	0.2	1100	V15 D55	317.9	63.6	12.5	7.94	0.12	33.0	20.98	0.33	5.3	3.36	0.053	3.1	1.98	0.031	0.4	0.26	0.004	23.8	15.14	0.24	10.6	0.4	4.0
			V15 D57	311.3	62.3	12.5	7.78	0.12	32.8	20.42	0.33	5.3	3.30	0.053	3.1	1.94	0.031	0.4	0.24	0.004	24.4	15.20	0.24	10.5	0.4	4.0
			V15 D71	231.2	46.2	15.7	7.26	0.16	29.2	13.50	0.29	4.7	2.18	0.047	4.2	1.94	0.042	0.5	0.24	0.005	19.7	9.10	0.20	7.0	0.5	3.7
18	0.2	1700	V15 D74	234.4	46.9	14.5	6.80	0.15	30.6	14.34	0.31	4.9	2.30	0.049	4.2	1.96	0.042	0.5	0.24	0.005	20.7	9.70	0.21	7.3	0.5	3.5
			V15 D76	206.7	41.3	15.6	6.44	0.16	29.6	12.24	0.30	4.8	1.98	0.048	4.4	1.82	0.044	0.5	0.20	0.005	19.9	8.22	0.20	6.7	0.5	3.5

Element composition and C:N:Si ratios of selected samples of *Cyclotella meneghiniana* dry mass accumulated during steady state conditions of main experiment V8 and repetition experiments – V6, V14 and V15. Diatoms were grown at different temperatures and growth rates.

Temp. (°C)	Growth rate μ (d^{-1})	Sample	Dry mass (mg/l)	Productivity P (mg $l^{-1}d^{-1}$)	Si (wt-%)	Si (mg $l^{-1}d^{-1}$)	Si/P	C (wt-%)	C (mg $l^{-1}d^{-1}$)	C/P	H (wt-%)	H (mg $l^{-1}d^{-1}$)	H/P	N (wt-%)	N (mg $l^{-1}d^{-1}$)	N/P	S (wt-%)	S (mg $l^{-1}d^{-1}$)	S/P	O (wt-%)	O (mg $l^{-1}d^{-1}$)	O/P	C/N	Si/C	Si/N
15	0.34	V8 D32	242.5	82.5	12.2	10.06	0.12	32.4	26.72	0.32	5.4	4.45	0.054	3.9	3.23	0.039	0.4	0.34	0.004	23.1	19.04	0.23	8.3	0.4	3.1
		V8 D34	239.8	81.5	12.7	10.37	0.13	32.3	26.35	0.32	5.2	4.25	0.052	3.9	3.20	0.039	0.3	0.24	0.003	22.4	18.26	0.22	8.2	0.4	3.2
		V8 D18	306.0	104.0	10.6	11.02	0.11	34.4	35.80	0.34	5.5	5.71	0.055	3.2	3.33	0.032	0.3	0.31	0.003	27.8	28.93	0.28	10.7	0.3	3.3
18	0.34	V8 D20	303.7	103.3	10.7	11.05	0.11	34.2	35.33	0.34	5.5	5.71	0.055	3.2	3.30	0.032	0.4	0.41	0.004	26.1	26.96	0.26	10.7	0.3	3.4
		V8 D24	275.9	93.8	10.8	10.13	0.11	34.2	32.10	0.34	5.5	5.17	0.055	3.1	2.92	0.031	0.4	0.37	0.004	26.2	24.58	0.26	11.0	0.3	3.5
		V8 D53	327.1	111.2	10.6	11.80	0.11	33.4	37.16	0.33	5.4	6.02	0.054	3.3	3.67	0.033	0.3	0.34	0.003	26.7	29.68	0.27	10.1	0.3	3.2
21	0.34	V8 D57	317.8	108.1	10.7	11.56	0.11	33.6	36.31	0.34	5.5	5.95	0.055	3.3	3.57	0.033	0.3	0.34	0.003	27.3	29.51	0.27	10.2	0.3	3.2
		V8 D62	299.7	101.9	10.8	11.02	0.11	33.4	34.03	0.33	5.4	5.51	0.054	3.6	3.67	0.036	0.4	0.41	0.004	25.6	26.08	0.26	9.3	0.3	3.0
24	0.34	V8 D9	345.7	117.5	9.4	11.05	0.09	36.2	42.53	0.36	5.8	6.83	0.058	2.7	3.16	0.027	0.3	0.34	0.003	29.6	34.78	0.30	13.5	0.3	3.5
		V8 D12	348.5	118.5	9.5	11.25	0.09	36.2	42.91	0.36	5.8	6.87	0.058	2.6	3.09	0.026	0.3	0.34	0.003	29.1	34.48	0.29	13.9	0.3	3.6
12	0.2	V8 D91	237.6	47.5	12.6	5.98	0.13	33.3	15.82	0.33	5.4	2.56	0.054	4.2	2.00	0.042	0.4	0.20	0.004	20.6	9.78	0.21	7.9	0.4	3.0
15	0.2	V8 D80	281.1	56.2	11.6	6.52	0.12	32.9	18.50	0.33	5.3	2.98	0.053	3.6	2.02	0.036	0.4	0.22	0.004	24.9	14.00	0.25	9.2	0.4	3.2
		V8 D82	280.3	56.1	11.6	6.50	0.12	33.0	18.50	0.33	5.3	2.98	0.053	3.5	1.96	0.035	0.4	0.22	0.004	24.4	13.68	0.24	9.4	0.4	3.3
21	0.2	V8 D70	282.3	56.5	11.7	6.60	0.12	32.0	18.06	0.32	5.2	2.94	0.052	3.5	1.98	0.035	0.4	0.22	0.004	24.1	13.60	0.24	9.1	0.4	3.3
18	0.34	V6 D12	312.1	106.1	10.3	10.91	0.10	34.3	36.41	0.34	5.7	6.05	0.057	3.3	3.50	0.033	0.4	0.41	0.004	23.0	24.41	0.23	10.4	0.3	3.1
		V6 D14	317.8	108.1	11.0	11.90	0.11	34.0	36.75	0.34	5.7	6.15	0.057	3.3	3.57	0.033	0.4	0.44	0.004	23.8	25.70	0.24	10.3	0.3	3.3
		V14 D50	292.1	58.4	12.8	7.48	0.13	33.2	19.40	0.33	5.2	3.04	0.052	3.8	2.22	0.038	0.5	0.30	0.005	25.3	14.78	0.25	8.7	0.4	3.4
12	0.2	V14 D52	288.7	57.7	12.4	7.16	0.12	33.6	19.40	0.34	5.3	3.06	0.053	3.9	2.26	0.039	0.5	0.29	0.005	25.0	14.44	0.25	8.6	0.4	3.2
		V14 D54	285.7	57.1	12.5	7.14	0.12	33.7	19.26	0.34	5.3	3.02	0.053	3.9	2.22	0.039	0.5	0.28	0.005	24.3	13.88	0.24	8.7	0.4	3.2
		V14 D56	284.4	56.9	12.7	7.22	0.13	33.5	19.06	0.34	5.2	2.96	0.052	4.0	2.28	0.040	0.5	0.28	0.005	24.4	13.88	0.24	8.4	0.4	3.2
		V14 D28	345.5	69.1	11.0	7.60	0.11	37.5	25.92	0.38	5.7	3.94	0.057	3.1	2.14	0.031	0.4	0.28	0.004	27.3	18.86	0.27	12.1	0.3	3.6
15	0.2	V14 D30	351.3	70.3	10.7	7.52	0.11	37.3	26.20	0.37	5.7	4.00	0.057	3.1	2.18	0.031	0.4	0.28	0.004	27.4	19.26	0.27	12.0	0.3	3.4
		V14 D34	316.3	63.3	11.3	7.14	0.11	36.2	22.90	0.36	5.7	3.60	0.057	3.2	2.02	0.032	0.4	0.26	0.004	27.1	17.14	0.27	11.3	0.3	3.5
		V14 D38	270.3	54.1	12.8	6.92	0.13	37.2	20.12	0.37	5.8	3.14	0.058	3.3	1.78	0.033	0.4	0.22	0.004	23.5	12.70	0.23	11.3	0.3	3.9
18	0.2	V15 D15	362.0	72.4	10.4	7.52	0.10	38.1	27.58	0.38	5.9	4.28	0.059	2.6	1.88	0.026	0.3	0.22	0.003	25.4	18.38	0.25	14.7	0.3	4.0
		V15 D17	334.1	66.8	11.7	7.82	0.12	37.4	25.00	0.37	5.9	3.94	0.059	2.7	1.80	0.027	0.3	0.20	0.003	23.8	15.90	0.24	13.9	0.3	4.3

Erklärung Gemäß § Abs. 10 der Promotionsordnung der Mathematisch-Naturwissenschaftlichen Fakultät der Universität zu Köln

Ich versichere, dass ich die von mir vorgelegte Dissertation selbständig angefertigt, die benutzten Quellen und Hilfsmittel vollständig angegeben und die Stellen der Arbeit – einschließlich Tabellen, Karten und Abbildungen -, die anderen Werken im Wortlaut oder dem Sinn nach entnommen sind, in jedem Einzelfall als Entlehnung kenntlich gemacht habe; dass diese Dissertation noch keiner anderen Fakultät oder Universität zur Prüfung vorgelegen hat; dass sie - abgesehen von unten angegebenen Teilpublikationen – noch nicht veröffentlicht worden ist sowie, dass ich eine solche Veröffentlichung vor Abschluss des Promotionsverfahrens nicht vornehmen werde. Die Bestimmungen dieser Promotionsordnung sind mir bekannt. Die von mir vorgelegte Dissertation ist von Herrn Prof. Dr. Ulrich Radtke und Herrn Prof. Dr. Gerhard Hans Schleser betreut worden.

Forschungszentrum Jülich
in der Helmholtz-Gemeinschaft

Jül-4217
Mai 2006
ISSN 0944-2952