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Forsmark site investigation

Production and respiration measurements in Lake Bolundsfjärden 2005

Sara Karlsson, Svensk Kärnbränslehantering AB

February 2006

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

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Abstract

The objective of the investigation was to estimate biological production and respiration at bottoms with different vegetation types in Lake Bolundsfjärden; bottoms with *Chara* stands and bottoms with only microbial mat. The data will be used in a system ecological model for the lakes of the Forsmark area which is part of the site description. The measurements were performed during one day (2005-06-09). The change in oxygen concentration over time was measured in plexiglass cylinders and these values were used to estimate primary production and respiration. To achieve only respiration, black hoods were placed over the cylinders to prevent radiation to reach the vegetation inside.

The estimated average net primary productions were similar for the two different sites; about 150 mg $O_2 \cdot m^{-2} \cdot h^{-1}$ (oxygen yield) or 50 mg $C \cdot m^{-2} \cdot h^{-1}$ (carbon assimilation). This is in agreement with earlier primary production measurements in nearby Lake Eckarfjärden. The respiration measurements did not perform very well though and this may have lead to somewhat underestimated net primary production values.

Sammanfattning

Syftet med undersökningen var att uppskatta biologisk produktion och respiration på bottnar med olika vegetationstyper i sjön Bolundsfjärden; dels på bottnar med kransalger och dels bottnar med enbart den mikrobiella mattan. Data kommer att användas i en systemekologisk modell för sjöarna i Forsmarksområdet som är en del av platsbeskrivningen. Mätningarna utfördes under en dag (2005-06-09). Syrekoncentrationerna i plexiglascylindrar följdes under dagen och dessa värden användes för att uppskatta primärproduktion och respiration. För att erhålla enbart respiration placerades svarta huvor över cylindrarna så att strålning inte kunde nå vegetationen innanför.

Medelvärdet för den uppskattade nettoprimärproduktionen var lika stor för de två platserna; cirka 150 mg $O_2 \cdot m^{-2} \cdot timme^{-1}$ (syreproduktion) eller 50 mg $C \cdot m^{-2} \cdot timme^{-1}$ (kolassimilering). Dessa värden stämmer överens med resultat från tidigare primärproduktionsmätningar i den närliggande sjön Eckarfjärden. Respirationsmätningarna fungerade dock inte särskilt bra vilket kan ha gjort att nettoprimärproduktionsvärdena underskattats något.

Contents

1 Introduction

This document reports the data gained by the measurements of production and respiration in Lake Bolundsfjärden in June 2005, which is one of the activities performed within the site investigation at Forsmark. The work was carried out in accordance with activity plan AP PF 400-05-065, see Table 1-1. Activity plans are SKB's internal controlling documents.

Measurements of production and respiration have been performed in aquatic environments. Lake Bolundsfjärden which was selected for the computing represents the most common lake type in the Forsmark area. The lake is very shallow and has no profundal. Large parts of its bottoms are covered by Stoneworths (*Chara sp.*) /Huononen 2005/. Earlier studies have shown that the upper part of the sediments consists of a layer with microalgae. This green part is clearly visible in sediment cores and is often called microbial mat /i.e. Brunberg and Blomqvist 2000/. That term will be used in this report. Measurements of biomass and production of the microbial mat have been performed in a nearby lake (Lake Eckarfjärden) by /Andersson 2005/.

The average depth in Lake Bolundsfjärden, excluding the reed belts, is about 0.9 m. Two study areas with approximately this water depth were chosen; one area with *Chara* (SKB idcode PFM004510) and one with the microbial mat only (SKB idcode PFM004511), see Figure 1-1 and 1-2.

The measurements were performed during one day (2005-06-09). The water was sunny, with a weak wind (1–2 m/s, mostly SSW). The air temperature was about 9°C at 6:00, rising to maximum 23°C at 13:30 and slowly decreasing (22°C at 18:00). The water temperature was about 15°C at 8:00 at the site with microbial mat and rose to about 17.5°C at 17:30. The water temperature at the *Chara* site was about 1°C higher during the whole day. The global radiation measured at a location nearby is shown in Figure 1-3 below.

Table 1-1. Controlling document for the performance of the activity.

Activity plan	Number	Version
Mätning av produktion och respiration i Bolundsfjärden 2005	AP PF 400-05-065	1.0

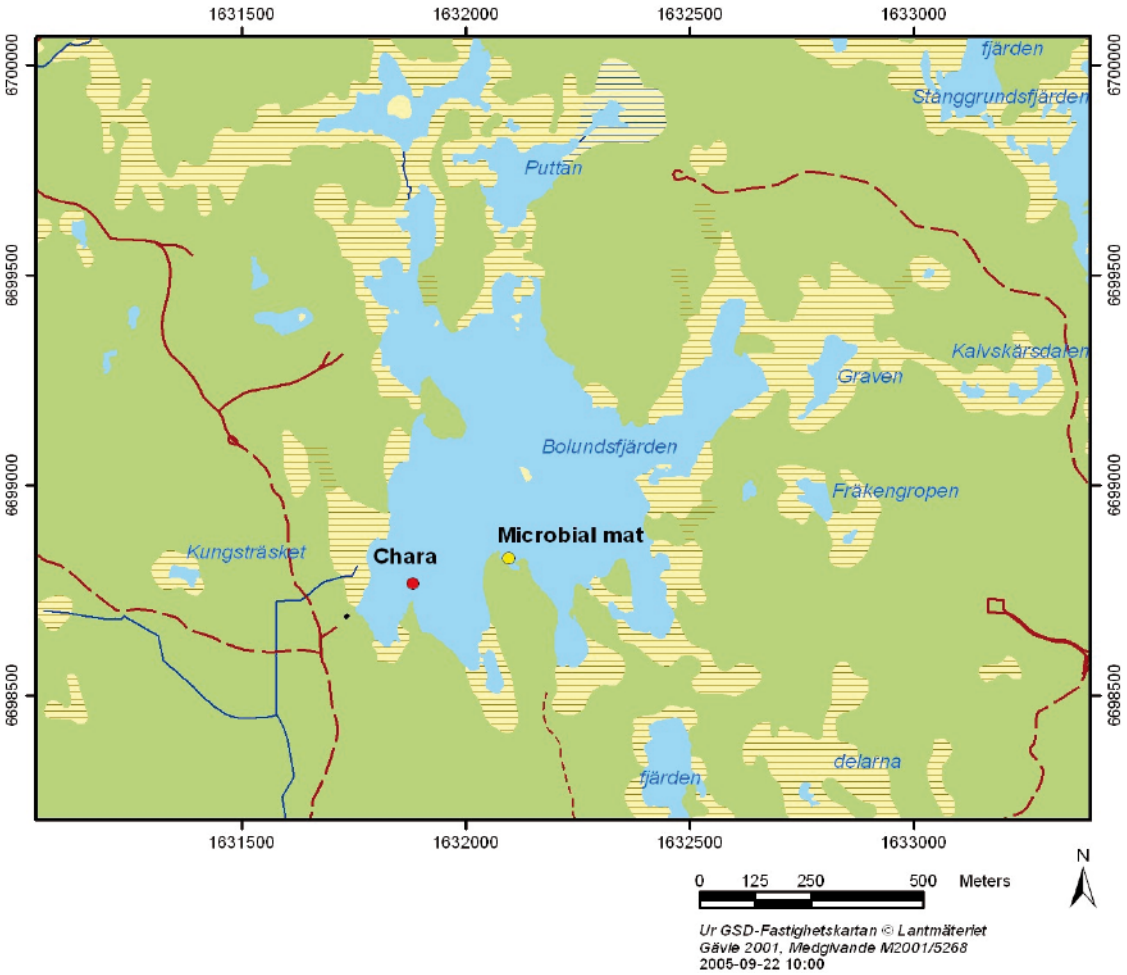

Figure 1-1. *Measurement sites (5 replicates at each site), Chara = PFM004510, Microbial mat = PFM004511.*

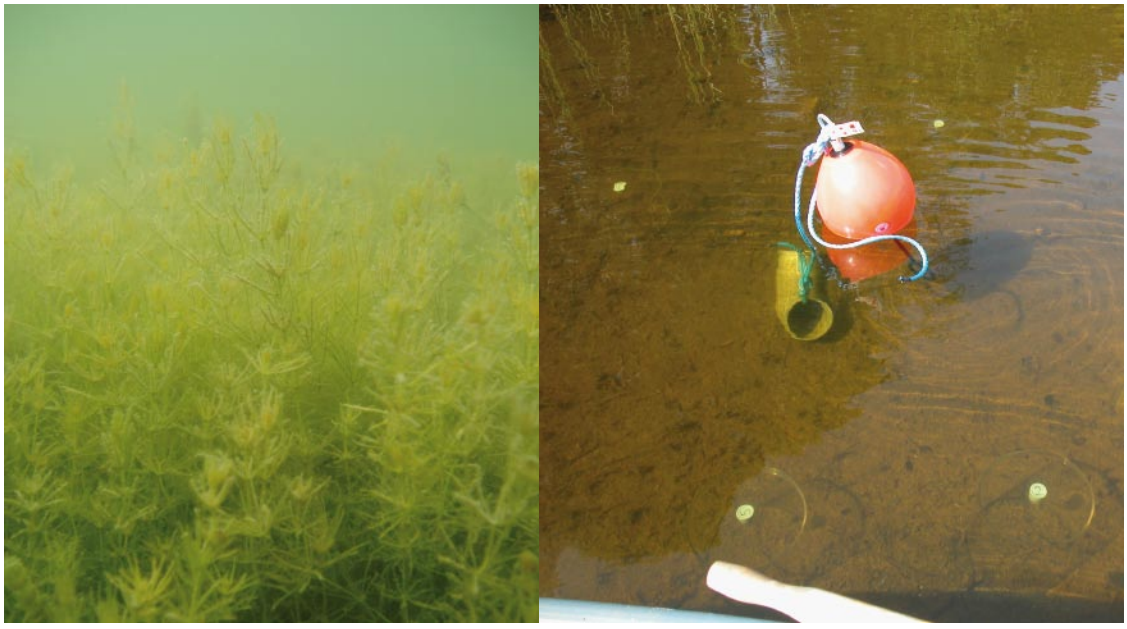

Figure 1-2. *Photo of Chara (PFM004510) and the site with the microbial mat (PFM004511).*

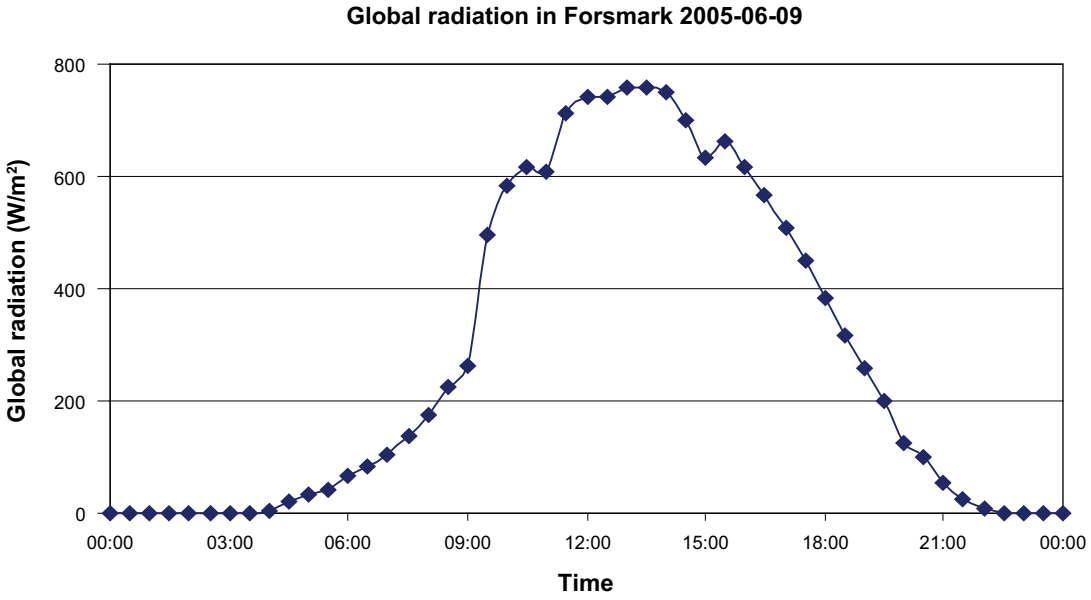

Figure 1-3. *Global radiation at the meteorological station in Forsmark (PFM010700) during the day when the measurements were performed (2005-06-09).*

2 Objective and scope

The objective of the investigation was to estimate production and respiration at two different bottom types in Lake Bolundsfjärden. The data will be used in a system ecological model for the lakes of the Forsmark area which is part of the site description.

3 Equipment

3.1 Description of experiment set-up and equipment

The measurements were performed within transparent cylinders of plexiglass placed on the lake sediment the day before the measurements. When the measurements started a transparent lid with a small hole (and a cork) was placed on top of each cylinder to prevent water exchange, see Figure 3-1.

The measurement equipment used was an oxygen measurement device from WTW called Oxi 330i (sensor Cellox 325*)*. Light measurements at the lake bottom were performed with a multiparameter system for water measurements from YSI. Geographical positions were estimated using a GPS device of type Garmin (accuracy about ± 10 m).

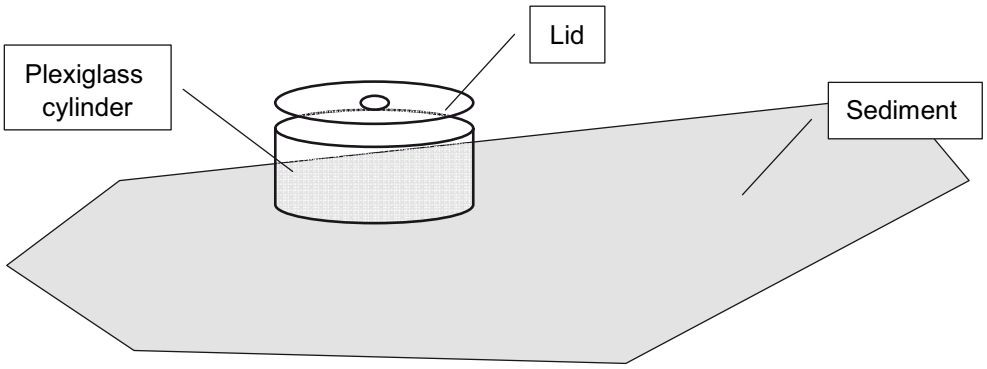

Figure 3-1. *Outline of the experiment set-up.*

3.2 Calibration of the dissolved oxygen meter

The dissolved oxygen meter was calibrated in water vapour-saturated air with the OxiCal-SL air calibration vessel according to the operating manual /WTW 2004/.

When the calibration was completed the relative slope value and sensor evaluation was checked.

4 Execution

The biological processes primary production and respiration both involve oxygen. During primary production oxygen is released from the producer, whereas oxygen is taken up during respiration. For primary production to occur light is needed, whereas respiration occurs during both light and dark conditions. The method used in this study aims at measuring the oxygen concentration in the water inside plexiglass cylinders. The change in oxygen concentration will be used to estimate primary production and respiration. To achieve only respiration, black hoods are placed over the cylinders to prevent radiation to reach the vegetation inside (this is hereafter called “Dark measurements”).

4.1 Preparations

The day before the measurements the cylinders were set out at the chosen sites. The coordinates of the sites were recorded.

Before measurements started the oxygen device was calibrated according to standard routines (see Chapter 3.2).

The bottles used for the water samples were marked in advance.

4.2 Execution of field work

Just before measurement started a lid of transparent glass was placed on top of each cylinder. The lids contain a small hole in which a cork is placed. Through this hole the measuring device is put and measures the oxygen concentration in the cylinder (as mg/l and as %) and water temperature. The same measurements are also performed in the surrounding water. The times for measurements are presented in Table 4-1.

In connection to the measurements the light at the bottom of the lake was measured as Photosynthesis Active Radiation (PAR). Water samples from each of the cylinders and the surrounding water were also taken (see Table 4-1). These were placed in cooling baskets and later sent to a laboratory (Department of systems ecology, Stockholm University) for analyses of some parameters which can be used when evaluating the measurement results.

Table 4-1. Approximate times for measurements.

Measurement	Light 1* (start)	Light 2	Light 3/Dark 1*, (black hood was placed on cylinder after measurement)	Dark 2*
Chara (PFM004510)	7:30	10:00	13:00	17:00
Microbial mat (PFM004511)	8:00	11:00	14:00	17:30

* water sampling for chemical analyses were performed.

These kinds of measurements are usually performed by divers. An incautious diver may easily stir up sediment when approaching the cylinders which may influence the results of the measurements. As the water depth at the study sites was extremely shallow, it was decided that the measurements would be performed from a boat. One person was leaning over the side of the boat and holding the measuring device in place, whereas another person was reading the display of the device. One problem with the technique was the wind which made the boat drift during the measurements.

To be able to relate the measured processes to a biomass it was intended to sample the primary producers within each cylinder after the measurements were completed. That was however not performed, see Section 4.4 (Nonconformities).

4.3 Data handling/post processing

Changes in oxygen concentration are recalculated into gross primary production (GPP) or respiration (R) per square metre and hour (mg $O_2 \cdot m^{-2} \cdot h^{-1}$). Measurements during light give values of GPP whereas dark measurements provide values of R according to:

$$GPP = R = \left(\frac{\Delta C_{o_2} \cdot V}{A} \right) \cdot \frac{1}{T}$$

Co_2 = oxygen concentration (mg/l)

V = volume of cylinder (dm^3)

A = bottom area of cylinder (m^2)

T = time interval between measurements (h)

Net primary production (NPP) is calculated as:

NPP = GPP-R

Production expressed in oxygen yield, P_{oxygen}, (mg $O_2 \cdot m^{-2} \cdot h^{-1}$) can be recalculated to express carbon assimilation, P_{carbon}, (mg $C \cdot m^{-2} \cdot h^{-1}$) using the following formula:

$P_{carbon} = P_{oxygen} \cdot 0.334$ /Kautsky 1995/.

4.4 Nonconformities

Due to problems with equipment measurements the campaign planned for August could not be performed. The results from June can therefore not be compared with values from late summer.

No biomass sampling was performed. The values are presented as per unit area which may also be used in the ecosystem model. Transformation of production/respiration values per biomass can be performed using biomass values for *Chara* in Lake Bolundsfjärden from /Huononen 2005/ and for biomass values for the microbial mat from nearby Lake Eckarfjärden /Andersson and Brunberg submitted/, see Section 5.4.

The hoods used during the dark measurements were rather hard to get fit on the cylinders. At the *Chara* site one of the hoods floated away and at the other site one of the cylinders fell when the hood was placed on it. Because of this only four replicates are available at both sites for the respiration measurements. The results of the respiration measurements may have been of better quality if the measurements had been performed during a longer time period, i.e. over the night as discussed in Section 5.2.

The chemical analyses of the water samples were intended to be used as support parameters. The results of the chemical analyses are presented in Appendix B but not discussed somewhere else in this report.

5 Results

The original results are stored in the primary data base (SICADA) and these should be used for further interpretation (modelling). The data are traceable in SICADA by the Activity Plan number (AP PF 400-05-065).

5.1 Oxygen concentration measurements

Measured oxygen concentrations are presented in Table 5-1 and 5-2. Other data from the measurements can be found in Appendix A.

It was almost impossible to get the figures of the oxygen device staying on a stable level. Instead a value was recorded after about one minute. The accuracy of the values is therefore somewhat unsure.

The cylinder volumes differ somewhat as some of them sunk down into the sediment to some extent. The height of the cylinder walls above the sediment was therefore measured after the end of the campaign. Two measurements were performed at each cylinder (maximum and minimum) and an average value was used when calculating the cylinder volumes. Data for this can be found in Appendix A.

Table 5-1. Measured oxygen levels (mg/l), *Chara* stands, PFM004510. The last column shows the average difference in oxygen level between this measurement and the previous one. The row with figures for the "dark" measurements is grey. Figures in italic style indicate oxygen concentrations of higher levels than expected.

Time	Surr. water	Cyl. 1	Cyl. 2	Cyl. 3	Cyl. 4	Cyl. 5	Average Cyl. 1–5	Difference
7:30	11.57	11.52	11.23	11.52	11.24	11.46	11.39 ± 0.15	
10:00	11.77	12.59	12.50	12.67	12.75	12.6	12.62 ± 0.09	1.23 ± 0.17
13:00	14.98	13.76	13.64	14.3	14.78	16.73	14.64 ± 1.25	2.02 ± 1.24
17:00	14.43	*14.55*	*14.22*	–	14.32	15.37	14.62 ± 0.52	–0.11 ± 1.00

Table 5-2. Measured oxygen levels (mg/l), microbial mat, PFM004511. The last column shows the average difference in oxygen level between this measurement and the previous one. The row with figures for the "dark" measurements is grey. Figures in italic style indicate oxygen concentrations of higher levels than expected.

Time	Surr. water	Cyl. 1	Cyl. 2	Cyl. 3	Cyl. 4	Cyl. 5	Average Cyl. 1–5	Difference
8:00	11.04	11.00	10.8	11.26	11.15	11.04	11.05 ± 0.17	
11:00	11.12	11.48	11.38	11.8	11.63	11.57	11.57 ± 0.16	0.52 ± 0.04
14:00	13.61	14.45	13.84	13.77	14.37	14.28	14.14 ± 0.31	2.57 ± 0.38
17:30	14.92	13.90	–	*13.87*	14.13	*14.31*	14.05 ± 0.21	–1.17 ± 0.30

5.2 Production and respiration calculations

Calculated gross production and respiration values are presented in Table 5-3. To convert NPP into carbon assimilation, a conversion factor of 0.334 has been used /Kautsky 1995/.

The respiration measurements ("dark measurements") have not performed especially well. One of the hoods at the *Chara* site floated away between the two measurements and therefore only four replicates were measured. Two of these showed decreasing oxygen levels: the other two displayed increasing oxygen levels indicating a net primary production instead of respiration. At the microbial mat site one of the cylinders fell over when the last measurement should be performed which resulted in four replicates instead of five. Also here the oxygen levels increased in two of the remaining cylinders between the two measurements. This may indicate a delayed production which is "hiding" the effect on oxygen concentration due to respiration. If this delaying phase exists in reality, it is important to extend the "dark measurement" period so that the effect on the results is minimized. Using a too low respiration value entails a somewhat underestimated net primary production.

Table 5-3. Gross primary production (GPP), respiration (R) and net primary production (NPP), the latter expressed as oxygen yield (mg $O_2 \cdot m^{-2} \cdot h^{-1}$) as well as carbon assimilation (mg $C \cdot m^{-2} \cdot h^{-1}$). The two gross primary production values and figures calculated using those are presented separately and as a mean (in brackets). The last column shows the number of replicates at each site on which the estimation is based.

	Chara PFM004510	Microbial mat PFM004511	Replicates (n)
GPP (mg $O_2 \cdot m^{-2} \cdot h^{-1}$)	123/168 (145)	50/226 (138)	5
R (mg $O_2 \cdot m^{-2} \cdot h^{-1}$)	9	15	4
NPP (mg $O_2 \cdot m^{-2} \cdot h^{-1}$)	131/177 (154)	65/241 (153)	4
NPP (mg $C \cdot m^{-2} \cdot h^{-1}$)	44/59 (51)	22/80 (51)	4

5.3 Comparison with other measurements

/Andersson 2005/ has performed measurements of primary production in Lake Eckarfjärden in the Forsmark area during two years (2001 and 2002). Measurements were performed *in situ* with ^{14}C-incorporations at 14 occasions. The microbial mat produced 56 g $C \cdot m^{-2} \cdot year^{-1}$, and showed a clear seasonality with high summer values and low winter values. The production varied between 0.03–144 mg $C \cdot m^{-2} \cdot h^{-1}$. The measurements performed in June correlate very well with the production measured in Lake Bolundsfjärden in this study.

/Andersson 2005/ also measured the production of the heterotrophic bacteria within the microbial mat which ranged between 0.6 and 17 mg $C \cdot m^{2} \cdot h^{-1}$. The daily primary production was significantly higher than the benthic heterotrophic bacterial production.

5.4 Relations to biomass

The figures shown above are all related to an area. If the biomass within each cylinder was weighed the figures could be related to biomass instead. In this study no biomass sampling was performed. The biomass of *Chara* in Lake Bolundsfjärden has been investigated in another study though /Huononen 2005/. According to that study the biomass of submerged vegetation in littoral III in Lake Bolundsfjärden is about 680 g DW·m^{-2}. The clearly dominating species are *Chara* (2 different species which together made up 99.8% of the weight) which corresponds with the situation at the *Chara* site in this study. If this biomass value is used, a net primary production of 0.08 mg C·g DW^{-1}·h^{-1} is gained. The value can also been expressed per gram carbon using a transformation factor of 0.135 as proposed for *Chara* in /Kautsky 1995/. The net primary production is then 0.56 mg C·g C^{-1}·h^{-1}.

The biomass of the microbial mat has been studied within the nearby Lake Eckarfjärden during three years (2000–2002). The annual average biomass was 4,313 mg C·m^{-2} (/Andersson 2005/ and partly unpublished material). The biomass showed a seasonal variation with a maximum during summer both years. Average biomass value for June was 3,676 mg C·m^{-2}. Using this biomass value gives a net primary production of 14 mg C·g C^{-1}·h^{-1}.

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Appendix A

Primary data

***Chara* PFM004510**						
Date: 2005-06-09		**Coordinates:**	**6698766**	**1631883**		
Light I						
Start measurement:	**07:30**					
Cylinder no	**Time**	**mg O_2/l**	**% O_2**	**Temp**	**Light (PAR)**	Comments
1		11.52	113.1	16.0		
2		11.23	109.3	16.0		
3		11.52	112.6	16.0		
4		11.24	112.5	16.0		
5		11.46	114.2	16.0		
Average		11.394				
Surrounding water		11.57	114.8	16.0		
Light II						
Start measurement:	**09:55**					
Cylinder no	**Time**	**mg O_2/l**	**% O_2**	**Temp**	**Light (PAR)**	Comments
1		12.59	123.6	16.5	ca 450 (bottom value)	
2		12.50	122.7	16.5		
3		12.67	124.3	16.6		
4		12.75	124.5	16.7		
5		12.60	123.9	16.8		
Average		12.622				
Surrounding water		11.77	117.5	16.8		
Light III / Dark I						
Start measurement:	**12:50**					
Cylinder no	**Time**	**mg O_2/l**	**% O_2**	**Temp**	**Light (PAR)**	Comments
1		13.76	123.5	17.9	ca 650	
2		13.64	141.2	17.8		calibration of probe
3		14.30	169.3	17.9		
4		14.78	161.9	18.0		
5		16.73	162.1	18.0		
Average		14.642				
Surrounding water		14.98	155.8	18.1		
Dark II						
Start measurement:	**17:00**					
Cylinder no	**Time**	**mg O_2/l**	**% O_2**	**Temp**	**Light (PAR)**	Comments
1		14.55	153.5	18.6		
2		14.22	146.6	18.5		
3		–	–	–		Hood gone, no measurement performed
4		14.32	154.4	18.6		
5		15.37	159.6	18.4		
Average		14.615				
Surrounding water		14.43	151.8	19.0		

Microbial mat PFM004511

Date: 2005-06-09 **Coordinates: 6698826 1632097**

Light I

Start measurement: 07:55

Cylinder no	Time	mg O_2/l	% O_2	Temp	Light (PAR)	Comments
1	07:55	11.00	108.8	15.2		
2	08:10	10.80	107.5	15.3		Cylinder moving somewhat!
3	08:13	11.26	109.3	15.5		
4	08:16	11.15	109.7	15.4		
5	08:20	11.04	108.8	15.3		
Average		11.050				
Surrounding water	08:05	11.04	109.5	15.6		

Light II

Start measurement: 10:50

Cylinder no	Time	mg O_2/l	% O_2	Temp	Light (PAR)	Comments
1		11.48	112.3	16.0	ca 590 (bottom)	
2		11.38	113.3	16.1		
3		11.80	117.7	16.3		
4		11.63	115.5	16.3		
5		11.57	115.1	16.2		
Average		11.572				
Surrounding water		11.12	112.1	16.3		

Light III / Dark I

Start measurement: 14:10

Cylinder no	Time	mg O_2/l	% O_2	Temp	Light (PAR)	Comments
1	14:10	14.45	147.1	17.5	ca 170	
2		13.84	137.6	17.4		
3		13.77	139.7	17.4		
4		14.37	142.0	17.4		
5		14.28	142.4	17.4		
Average		14.142				
Surrounding water	14:32	13.61	138.0	17.0		

Dark II

Start measurement: 17:30

Cylinder no	Time	mg O_2/l	% O_2	Temp	Light (PAR)	Comments
1	17:30	13.90	134.3	17.4		
2		–	–	–		Cylinder overturned
3		13.87	142.5	17.4		
4		14.13	144.8	17.4		
5	17:45	14.31	143.9	17.4		
Average		14.053				
Surrounding water		14.92	147.0	17.7		

Cylinder heights

Two measurements of cylinder heights were performed at each cylinder (maximum and minimum) and an average value was used when calculating the cylinder volumes.

Chara, PFM004510

Replicate	Cylinder height (cm)			volume (dm^3)
	max	min	mean	
1	26	20	23	16.25
2	24	21	22.5	15.90
3	25	20	22.5	15.90
4	29	27	28	19.78
5	26	22	24	16.96
			Mean:	*16.96*

Microbial mat, PFM004511

Replicate	Cylinder height (cm)			volume (dm^3)	Comments
	max	min	mean		
1	30	30	30	21.20	
2	–	–	–	–	Cylinder fell before measurements
3	30	26	28	19.78	
4	30	27	28.5	20.14	
5	30	28	29	20.49	
			Mean:	*20.40*	

Appendix B

Chemical data

Chara, PFM004510

Sample time and cylinder number	PO4-P µg/l	Tot-P µg/l	NH4-N µg/l	(NO2+3-N) µg/l	Tot-N µg/l	DIC mg/l	pH	Comments
7.30 surr. w.	2.2	10.8	5.7	0.5	805	16.1	8.8	
7.30 1	1.9	11.1	5.6	0.6	808	15.3	9.0	
7.30 2	3.2	12.7	6.9	0.7	880	15.1	9.2	
7.30 3	2.6	11.2	5.1	0.6	812	14.3	9.2	
7.30 4	2.7	11.1	5.1	0.5	814	16.1	9.0	
7.30 5	2.0	11.0	5.3	0.6	815	13.8	9.1	
13.00 surr. w.	2.7	10.8	5.8	0.7	809	14.5	9.1	
13.00 1	3.4	14.0	3.7	0.6	905	13.3	9.0	
13.00 2	3.5	14.4	5.0	0.6	878	14.7	8.7	
13.00 3	2.1	13.3	4.0	0.5	857	14.4	9.1	
13.00 4	3.0	10.9	6.4	0.7	811	15.1	9.1	
13.00 5	2.9	12.1	5.8	0.5	864	14.7	8.6	
17.00 surr. w.	2.8	10.9	4.2	0.6	804	15.6	8.4	
17.00 1	5.3	17.6	8.1	0.6	909	14.1	9.0	
17.00 2	6.9	21.6	6.6	0.6	944	13.8	9.0	
17.00 4	6.5	17.5	6.4	0.7	865	14.0	8.8	
17.00 5	7.4	52.5	14.1	0.8	1,774	13.7	8.5	Visible particles in the sample

Microbial mat, PFM004511

Sample time and cylinder number	PO4-P µg/l	Tot-P µg/l	NH4-N µg/l	(NO2+3-N) µg/l	Tot-N µg/l	DIC mg/l	pH
8.00 surr. w.	2.0	11.6	7.1	0.6	809	16.4	8.6
8.00 1	2.8	11.9	7.0	0.6	809	17.3	8.9
8.00 2	2.8	12.1	6.7	0.7	821	14.2	9.0
8.00 3	2.9	11.8	5.9	0.7	812	14.4	8.8
8.00 4	2.8	12.2	7.1	0.6	829	14.1	8.8
8.00 5	2.3	11.0	6.5	0.7	797	16.0	9.0
14.00 surr. w.	3.4	12.2	6.0	0.6	818	12.9	9.1
14.00 1	2.8	11.1	4.0	0.6	822	12.9	9.0
14.00 2	2.7	10.7	4.3	0.6	800	12.3	8.8
14.00 3	2.5	10.4	3.7	0.7	797	15.7	8.2
14.00 4	2.0	10.7	4.2	0.7	810	12.6	8.8
14.00 5	2.4	10.6	4.3	0.6	801	12.5	8.9
17.30 surr. w.	2.2	10.5	6.4	0.9	792	14.0	9.1
17.30 1	1.8	10.6	6.2	0.8	797	14.3	9.1
17.30 3	2.6	10.6	4.9	0.8	793	15.1	9.1
17.30 4	2.6	11.9	5.8	0.9	834	15.5	9.2
17.30 5	3.0	11.8	5.8	0.7	807	13.8	8.9