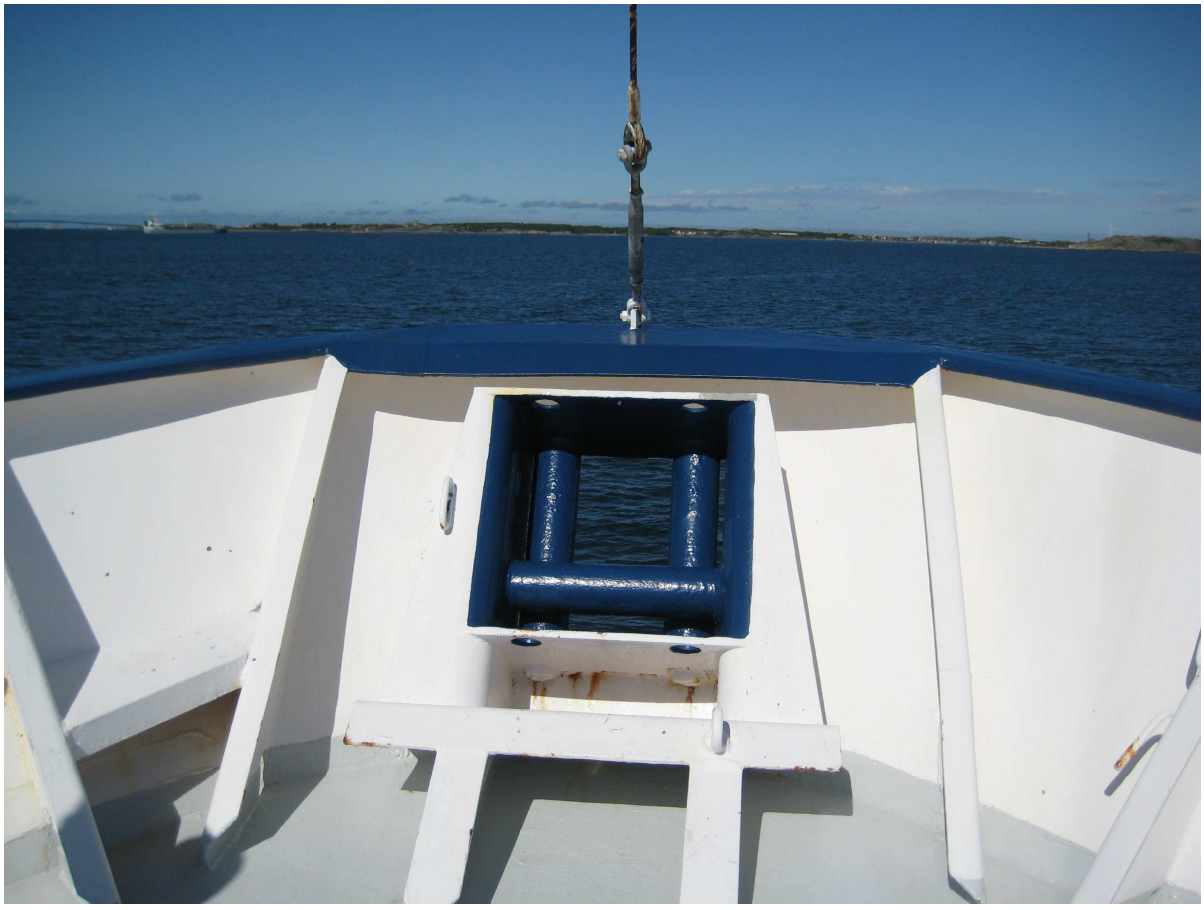
SMHI

Kristin I.M. Andreasson
Johan Wikner
Berndt Abrahamsson
Chris Melrose
Svante Nyberg

OCEANOGRAFI Nr 100/2009

Primary production measurments

-an intercalibration during a cruise in the Kattegat and the Batic Sea



Cover picture.
The bow of U/F Argos on a sunny day.

OCEANOGRAFI Nr 100/2009

Primary production measurments

-an intercalibration during a cruise in the Kattegat and the Batic Sea

Kristin I.M. Andreasson, Swedish Meteorological and Hydrological Institute (SMHI)
Johan Wikner, Umeå Marine Sciences Centre (UMSC)
Berndt Abrahamsson, Department of Systems Ecology, Stockholm University (SISU)
Chris Melrose, National Oceanic and Atmospheric Administration (NOAA)
Svante Nyberg, Department of Systems Ecology, Stockholm University (SISU)

Contents

ACKNOWLEDGEMENTS

The workshop was funded by the Swedish Environmental Protection Agency. Thanks to the SMHI crew on Argos, who did the additional samplings and measurements: Martin Hansson, Sara Johansson, Jenny Lycken, Anna-Kerstin Thell and Bodil Thorstensson. Also thanks to the crew on Argos with Captain Niklas Lund who got us to the stations. Thanks to Elisabeth Sahlsten who critically read the text before publication.

SUMMARY

In an effort to compare the primary production (PP) measurements in the Baltic Sea, four institutes got together in an intercalibration exercise with the aim to obtain similar values and a common method protocol. The strategy was to compare different methods on the same water sample and to identify sources to any differences.

The four methods showed different results and the differences were systematic. This was due to that the methods measured different things and to that there were differences in the manuals followed as well as to differences in the measurements. The manuals gave also possibilities to choose different variations of the method.

We have now managed to list all the differences and have a plan to investigate each step further with the aim to agree on a common method. This needs however to be tested to find the best method. The first step is to carefully measure the spectral composition of our incubators. We will see to that we get proper spectra and enough light. Other differences to be tested are the incubation time, the quality of ^{14}C added and the end addition of hydrochloric acid, HCl.

We think that the measurement of primary production is important and want to do it in the best possible way. To do this we need to have intercalibrations or a regular basis. We also need to test all the steps to find the most suitable method. The discussions will continue until a common manual is agreed upon. We also need to invite institutes from around the Baltic Sea to agree on a change in the common manuals.

INTRODUCTION

The primary production is the base for the production on earth. A big and measurable part of it is carried out by planktonic microalgae in the photic zone, i.e. the illuminated part of the ocean. A good estimate of the rate of the primary production (PP) is important if we want to estimate possible production in higher trophic levels. An estimation of the ecosystems capacity to assimilate and permanently store CO_2 from the atmosphere is also important.

A common way to measure primary production is to let the assembly of algae incubate *in situ* or in an incubator with ^{14}C labelled $H^{14}CO_3^-$; this method was described by Steeman Nielsen in 1952 and has been commonly used since then. Coming as a useful tool is the fluorescence method FRRF where the fluorescence from chlorophyll a is measured *in situ*. The ^{14}C method has the advantage of being used for many years and it has a proper detection limit. The FRRF method has the advantage of being clean, it works *in situ* with little stress on the algae and there is no laboratory work to be done afterwards.

Steeman Nielsen wrote already in 1975 that the PP measurements had an error of 30% so some variation was to be expected. This uncertainty is composed of natural variation as well as of analytical errors in the technique, from sample collection to the final calculation.

In an earlier comparison exercise 24 laboratories from 15 countries compared their scintillation counting and their calculations (Richardson 1991). The four institutes in this comparison also participated in the earlier exercise. The old results showed that there was much variation in the results even if it was filters to be counted in a scintillation counter or results to be calculated. There was also a comparison of field measurements where differences in results were shown.

Our aim was to again estimate inter-laboratory differences when applying the HELCOM guidelines using our in-house method protocols with all our regular equipment. As a further comparison the FRRF method was used at the same time.

METHODS

Location

The intercalibration took place onboard U/F Argos during the week May 11-16, 2009. Samples were taken at seven stations: N14 Falkenberg, Anholt E, BY 5, BY 15, BY 32, RefM1V1 and finally Anholt E again (Fig. 1). Three stations were sampled in the Kattegat and four in the Baltic Sea. Most of the stations were sampled during daytime except BY 32, which was sampled in the middle of the night. The stations used are part of the Swedish monitoring programme under the Swedish Environmental Protection Agency (SEPA), and are sampled once a month by SMHI. In all stations except BY 32 the PP is measured regularly.

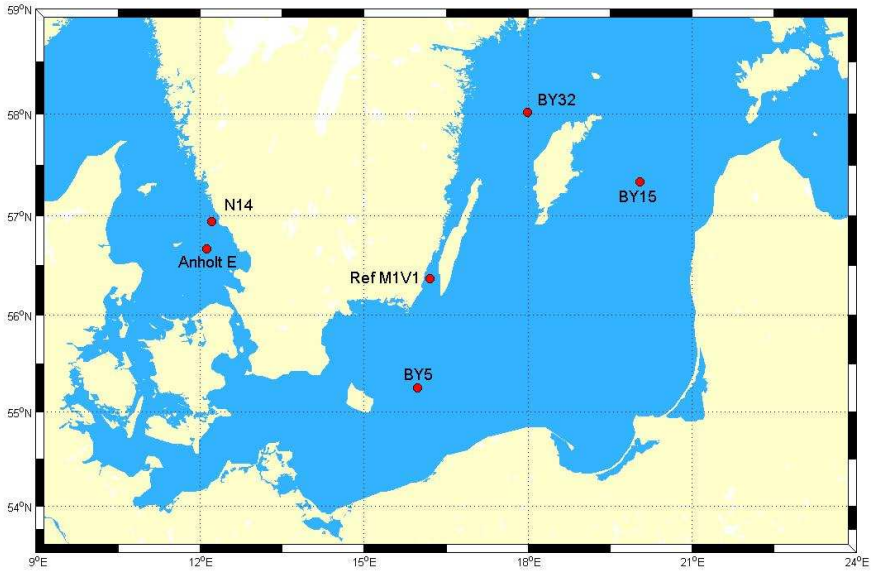


Figure 1. The sampled stations. The station Anholt E was sampled twice with four days between the occasions.

The participants and their methods

Participating were the three intitutes responsible for the Swedish monitoring of PP in the Baltic Sea: Department of Systems Ecology, Stockholm University – (SISU), Umeå Marine Sciences Centre, Umeå University – (UMSC) and Swedish Meteorological and Hydrological Institute – (SMHI). In addition National Oceanographic and Atmospheric Administration – (NOAA), USA, participated. The Swedish institutes worked with incubation techniques with artificial light and the addition of $H^{14}CO_3$, while NOAA participated with a fluorescence method, Fast Repetition Rate Fluorescence (FRRF), carried out in natural light.

Sampling

For the incubations two samples were taken with a hose 10 m long and 25 mm wide. The two samples were mixed in a dark bucket. After mixing subsamples were distributed to the participants. From the bucket were also taken samples for pH, alkalinity, salinity and chlorophyll a measurements. The water was gently stirred during the subsampling to avoid sedimentation in the bucket. Meanwhile the incubations took place the FRRF was run in the water column.

Light measurements

The spectra of the incubator light sources where compared using a spectroradiometer, Ocean optics USB 2000 with an optical fibre P-400-2-UV/VIS and a CC3-UV cosine corrector sensor. It was calibrated using a set of lamps also from Ocean optics, DH-2000 Deuterium Tungsten Halogen Light Source. The photosynthetic active radiation (PAR) in the flasks was measured with a submersible light meter from Biospherical instruments QSL 2100 with a spherical sensor small enough to fit in the incubation flasks. The PAR in the water column was measured during the CTD measurements, with a Biospherical instruments QSP-2300 with a spherical sensor attached to the CTD. The FRRF had an additional light meter built in. The data for irradiance in air was taken from the SMHI STRÅNG database.

Incubations

The incubations were made according to the HELCOM Combine and the SEPA manuals with modifications. Two different incubator models were used: two of the model from Hydrobios and one from Danish Hydrological Institute (DHI). The Hydrobios incubator works with 12 individually shaded 50 ml bottles. The rotation is propelled by the cooling medium. The DHI incubator works with 11 40 ml clear bottles that are placed in a row to shade each other with the help of a black mesh, tulle. The rotation is propelled by a motor. The cooling medium for SMHI and SISU was seawater pumped from 4m depth and for UMSC a temperature controlled cooling bath with water with polyethylene glycol (± 0.5 °C). The incubation time varied between 2 (SMHI) and 3 hours (the others). The incubations were terminated and the samples were either filtered as a whole onto a GF/F filter or a 5 or 10ml subsample was taken out and the whole water was measured in a scintillation counter after addition of scintillation fluids.

FRRF

Fast Repetition Rate Fluorescence, FRRF, measurements were performed at 1 m intervals. The FRRF values were linearly interpolated between neighbouring points to obtain values at depths corresponding to the light readings. Productivity was integrated to the deepest light reading (approx 31 m). FRRF measurements were only performed to 21

m or less depth. It was assumed that all FRRF productivity model parameters except light (chlorophyll, absorption cross section and photosynthetic efficiency) did not change below 21 m and the 21 m values were used in the productivity model for all deeper calculations. During daylight hours, the FRRF could not sample above approx 3 m due to contamination of the fluorescence signal by ambient red light so the FRRF values from the shallowest usable reading were used near surface.

Productivity estimates were made using an FRRF based productivity model developed by Chris Melrose and tuned using C14 data from Narragansett Bay. It uses only dark chamber data unlike traditional FRRF models that require light and dark measurements. Traditional FRRF models (Kolber and Falkowski 1993 or Smyth et al 2004) require a series of measurements throughout the day to estimate daily production. This type of data was not collected. For the comparison values from 0-10 m were calculated.

Table 1 Oceanographical data for the stations.

	Lat	**Long**	**Temp**	**Salinity**	**pH**	**Alkalinity**	**Calculated Inorganic carbon**	**Chlorophyll**
			°C	psu		mmol/l	mg /l	mg/l
N 14	56.94	12.21	10.59	21.16	8.32	2.12	21.03	1.4
Anholt E	56.67	12.12	11.01	18.99	8.30	1.96	20.58	1.2
BY 5	55.25	15.98	7.52	7.50	8.40	1.66	17.47	5.1
BY 15	57.33	20.05	6.92	7.17	8.63	1.67	17.09	1.4
BY 32	58.02	17.98	7.32	6.69	8.51	1.58	16.16	1.6
RefM1V1	56.37	16.20	9.14	7.07	8.26	1.63	17.35	1.0
Anholt E	56.67	12.12	11.27	18.70	8.31	1.95	20.36	0.8

Additional measurements

Together with the PP other oceanographic parameters were measured at the stations. The nutrients were measured using colorimetric methods with an ALPKEM auto analyzer except for ammonium which was measured manually with a spectrophotometer Hitachi U-1800. The chlorophyll was measured with extraction in ethanol and measured with a fluorometer Hitachi F-2500, pH was measured with pH electrode Orion Ross 8102BNUWP, alkalinity with Gran titration using a Metrohm 665 Dosimat and salinity with Mini Sal lab salinometer. All parameters were measured using accredited (SWEDAC) methods.

*Table 2 Differences in the regular incubator methods. Differences also occurring during the workshop marked with an *. UMSC and SMHI also made 1 and 3 comparisons with filtered and whole water samples.*

	SISU	UMSC	SMHI
Sampling	19mm hose 0-10m for incubator. for in-situ - water from incubation depth	Hose 0-10 m	25mm hose 0-10 m
Incubation time	Always in daytime	Always in daytime, though dark during winter	Anytime; depends on when the ship comes to station
Incubator	Hydrobios*	Hydrobios*	DHI*
Light source	Light tubes Philips TL8W/33*	Light tubes (Aura. T5. 8 W. 840)*[a]	Phillips HPI-T Plus lamp*
^{14}C distributor	Amersham*	^{14}C- central. DHI*	^{14}C- central. DHI*
^{14}C specific activity (µCi/ml)	5*	50*	10*
^{14}C solvent	Water and Borax*	Water*	Water*
^{14}C volume added (µl)	500 in 59ml*	64 in 59ml*	200 in 38 ml*
Incubation time (h)	3 incubator* -4 in-situ	3 *	2 *
End sample volume (ml)	10ml whole water*	5ml whole water*	38ml on a Whatman GF/F filter*
HCl added to remove the excess inorganic ^{14}C	500 µl 10 % to 10 ml sample*	300 µl 5 M to 5ml sample*	200 µl 0.1 M on the filter*
Mean light (µE m^{-2} s^{-1})	470*	415*	808*
SD light (µE m^{-2} s^{-1})	80*	123*	481*
Light variation	Individually shaded bottles*	Individually shaded bottles*	Stacked clear bottles shaded with tulle*
Rotation	With the cooling medium*	With the cooling medium*	Motor*
Rotation rate (rpm)	~10*	10-12*	10*
Cooling medium	Water from 4m depth*	Water bath with 30 % polypropyleneglycol*	Water from 4m depth*
Flask wash prior to sample	One flask sample water*	One flask sample water*	One flask sample water*
Flask wash after incubation	3 flasks deionised water*	2 flasks tap water. One flask 1 M HCl. one flask Milli-Q*	New flask each incubation*
Flask wash after expedition	10% HCl now and then	2 flasks tap water. One flask 1 M HCl. one flask Milli-Q	HCl, 3 flasks deionised water
Scintillation	TriCarb 1600 TR*	*	DHI accredited by DANAC*
Scintillation liquid	LumaGel Safe*	OptiPhase High Safe 3*	OptiPhase High Safe 2*
Calculations	Respiration 6% and temperature in the equation Uses Öström 1975 for inorganic carbon	Respiration 6% and temperature in the equation Uses Gargas 1975 for inorganic carbon	Uses Zeebe and Wolf-Gladrow 2005 for inorganic carbon

[a] Prior to 2009-01-01 Light tubes Philips TL8W/33 were used.

Variations

Light irradiance spectra varied markedly between the different light sources. The Aure light tubes used by UMSC in this comparison had undetectable light at some wavelengths. In addition the DHI incubator used by SMHI had 808 µE m^{-2} s^{-1} as average light irradiance, while both SISU and UMSC were about half of this value.

The amount of HCl added to remove inorganic $^{14}CO_3^-$ from incubated samples also varied markedly. SISU used a final concentration of 50 mM while SMHI and UMSC used final concentrations 2 and 6 times higher, respectively.

Isotope final concentrations were fairly similar, but the pre-handling varied between SISU and the other laboratories. SISU dilute their stock solution in borax buffered distilled water, while the other laboratories withdraw the aliquots directly from the stock vial. In the latter case the volume is chosen to last for one incubation.

We found differences in the HELCOM Combine manual and in the SEPA manual. In the SEPA manual there is a temperature correction for differences in temperature between in-situ and incubator. This correction is not in the HELCOM Combine. There is a respiration factor of 1.06 in SEPA but not in HELCOM.

There are also some different ways to calculate the amount of inorganic carbon available for the algae. SISU and UMSC use the tables from Buch 1945, in SISUs case with modifications by Öström 1975. SMHI uses equations from Zeebe and Wolf-Gladrow 2005. The equations use measurements of pH, salinity and temperature in the calculations and in Zeebe and Wolf-Gladrow 2005 measured alkalinity is used as well.

The differences between the incubator handling can be seen in Table 2. The differences that occur during the cruise are marked with an asterisk.

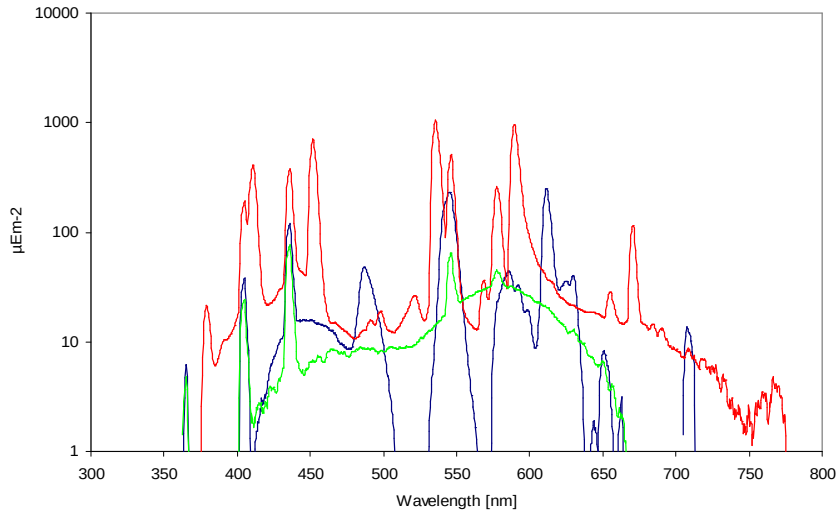


Figure 2 The irradiance from the light sources. Measurements in air. UMSC – blue. SMHI – Red and SISU – Green.

RESULTS AND DISCUSSION

In this study we covered stations that varied clearly in terms of phytoplankton composition and nutrient composition (Figs. 6 and 7). The station BY 5 had the highest amount of nutrients, chlorophyll a and number of algal cells. There was also a difference in the algal composition between the Kattegat and the Baltic Sea, with Kattegat (N 14 and Anholt E) containing more heterotrophs than the Baltic stations. These environmental factors have a potential impact on the PP measurements.

The results from the FRRF and ^{14}C assimilation differed in this study (Fig. 5). Four stations were much higher than the ^{14}C measurements, while two of the stations were in the same range and one of the stations was not measured. A reason can be that the FRRF measured higher productivity with lower light as opposite to the incubators where the opposite was seen lower productivity with lower light (Fig. 3). This depends on the higher chlorophyll a content at these depths. The high production in almost no light is still to be explained. The values in Fig. 5 are calculated from 0-10 m. If we have high production in the water deeper than 10m, we will miss it with our sampling method.

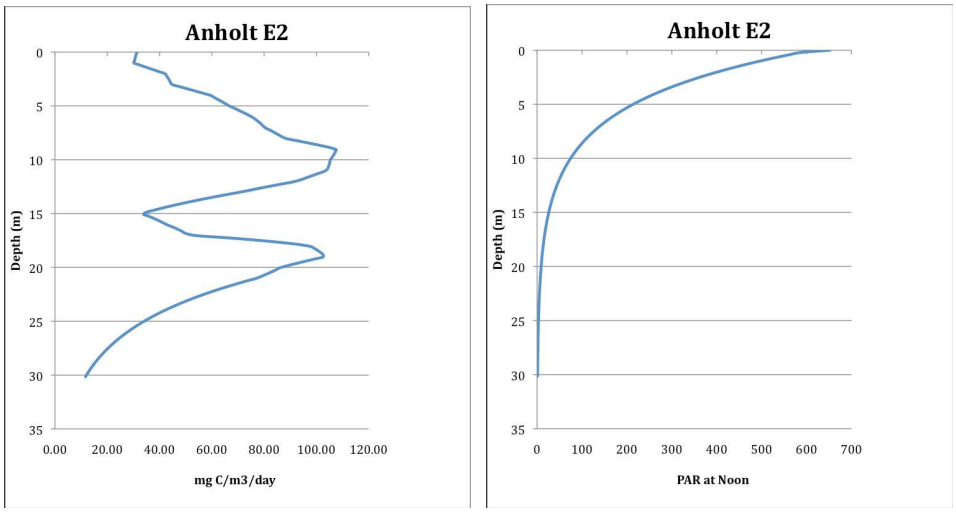


Figure 3 An example of the productivity pattern measured with the FRRF, together with the accompanying light measurement. This is the last Anholt E station and here the results differ a lot. NB. The incubators measure only down to 10 m.

Within the incubator experiments there were also differences. The first result we could see was that the light spectra varied a lot between the different incubators (Fig 2). The SMHI lamp had the most complete spectrum but the peaks were very high. The SISU spectrum was mostly in the green part and lacked wavelengths shorter than 445 (except for a peak at 430) and longer than 645. The UMSC spectrum showed gaps here and there. The light intensity was highest in the SMHI incubator (Table 2). The spectra inside the incubators showed signs to be even more different but they have to be measured again to make any certain conclusions. How much the spectrum affects the result is unknown, but it is

potentially a substantial source of differences. It is the most likely candidate to explain the main part of the measurement variation between the incubators seen in this exercise.

For the comparison all the incubator results were calculated in the same ways. Still there were differences (Table 3 and Figs 4 and 5). The SISU results are always the highest and UMSC approximately 50 % of SISU and SMHI 70 % of SISU (Fig. 4). The differences between SISU and SMHI are quite constant while UMSC have results that are lower than 50 % in the Baltic Sea and higher in the first Kattegat stations. This can be speculated to be due to a combination between different algal composition and the spectrum in the incubator, but for now it is only speculations.

The extra samples taken by SMHI and UMSC showed for SMHI higher results when the whole water was counted than when the sample was filtered. For UMSC single sample this was not found, the results were almost identical. Theoretically the result for whole water should be somewhat higher because the algae exude organic compounds to some extent. These compounds are not captured on the filter.

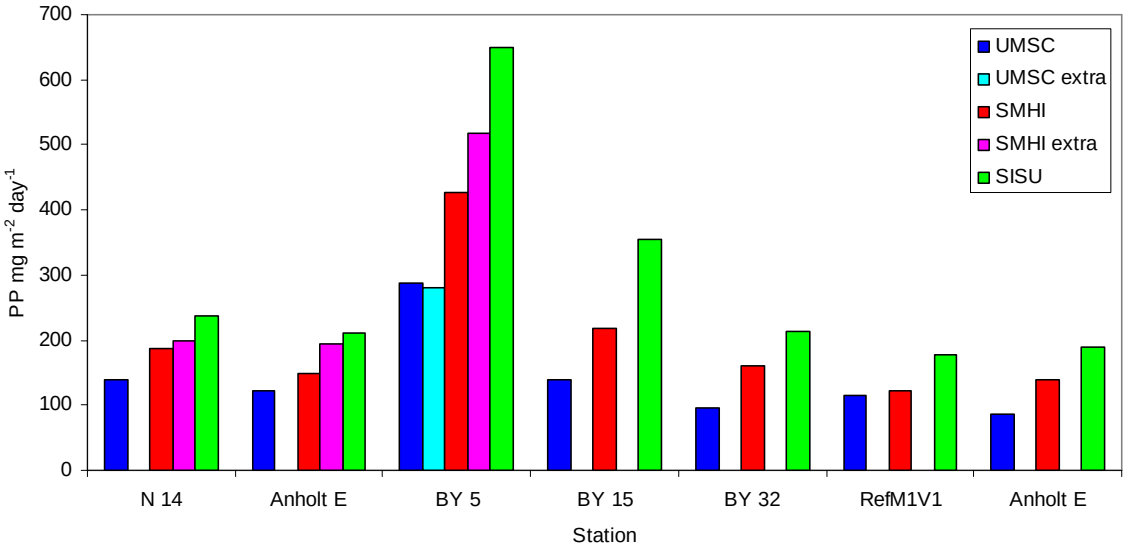


Figure 4 The daily production values measured with the incubators calculated. UMSC - blue and the extra measurement light blue. SMHI - red and the extra measurement pink and SISU – green.

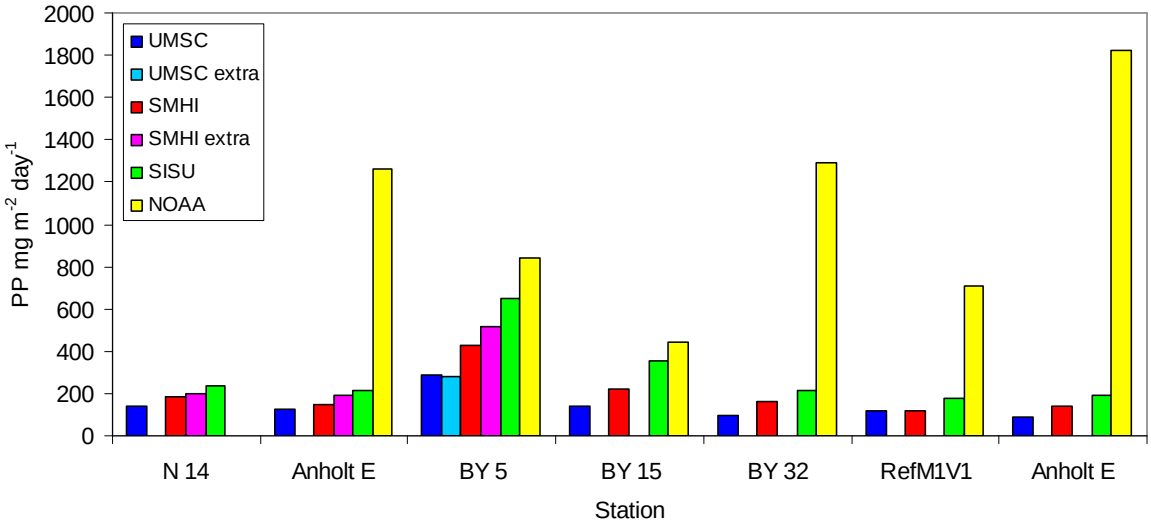


Figure 5 The same plot as Fig. 4 but with the values from FRRF added. The NOAA - yellow.

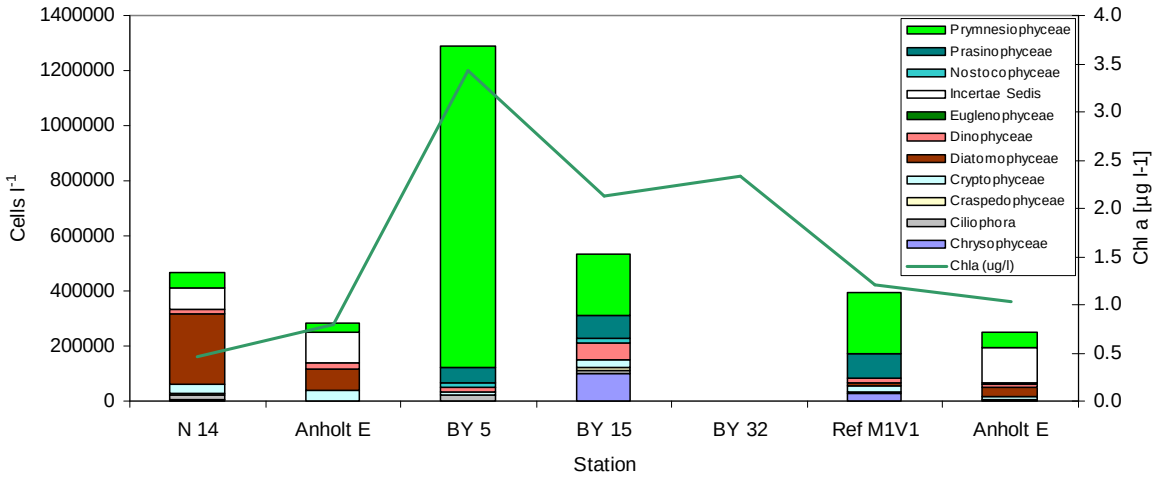


Figure 6 The composition of algal groups in the water. Incertae Sedis consists of heterotrophs. In BY 5 the most common species was the Chrysocromulina polylepis. The green line is the chlorophyll concentration in the water.

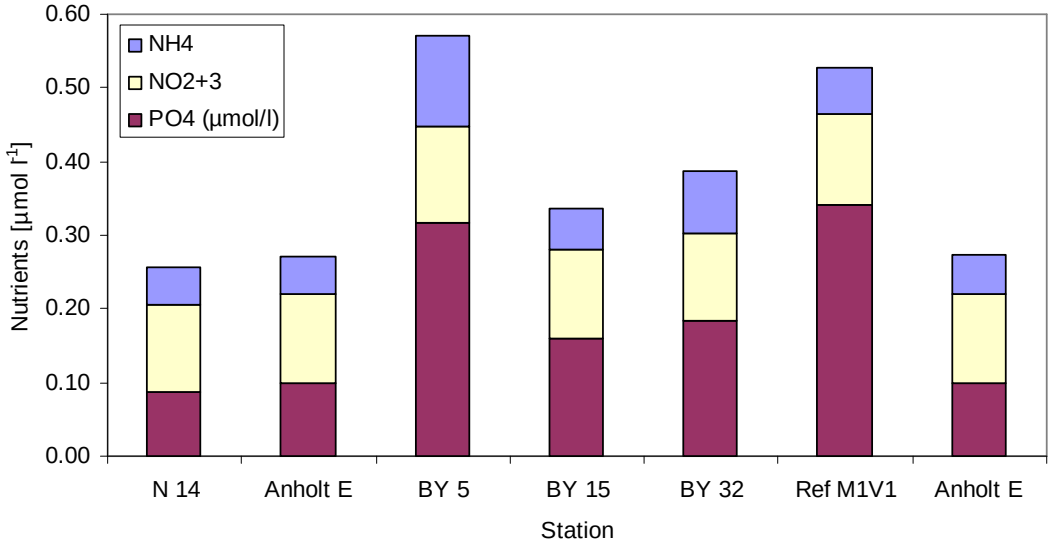


Figure 7 Concentrations of ammonium, nitrate + nitrite and phosphate in the water.

Table 3 The P_{max} and the α values. The extra samples are for UMSC one filter and for SMHI tree whole water samples.

	Pmax [µgCl^{-1}h^{-1}]			α [µgCl^{-1}h^{-1}]		
	SISU	**UMSC**	**SMHI**	**SISU**	**UMSC**	**SMHI**
N 14	2.04	1.127	1.466	0.011	0.006	0.008
N 14 Extra			1.754			0.007
Anholt E	1.88	1.054	1.345	0.009	0.004	0.005
Anholt E extra			1.557			0.008
BY 5	5.81	2.234	3.901	0.028	0.013	0.015
BY 5 extra		2.161	4.509		0.013	0.018
BY 15	3.10	1.247	2.080	0.018	0.005	0.008
BY 32	1.89	0.717	1.181	0.010	0.005	0.010
RefM1V1	1.45	1.040	0.963	0.009	0.004	0.005
Anholt E	1.93	0.810	1.221	0.010	0.004	0.008

CONCLUSIONS AND RECOMMENDATIONS

We found differences in the result from our incubation measurements. The FRRF technique suggested significant CO_2 fixation rates also at depths were light irradiance was low or undetectable. It further showed 3 times higher values than the ^{14}C-based techniques. Also the ^{14}C-based techniques differed by a factor of 2. We found it necessary to investigate why we got so different results. Some variation is of course expected but it should not be systematic.

The manuals from HELCOM Combine and from the SEPA allow marked deviations in practice (Table 2). The manuals need to be updated and where there are ambiguities the best procedure should be decided through tests. The aim should be a better harmonized method protocol.

We could frame the source of the differences between the ^{14}C-based techniques to some quality factor of the incubators, light quality, HCl treatment, isotope, or flask washing. This was because the differences were occurring already as dpm uptake in the incubation flasks.

The quality of light spectra could also influence the dpm differences found. The gaps in the UMSC spectra compared to SISU may explain the lower PP values observed in the latter case. However, the spectra measured outside the DHI incubator by SMHI does not fall into the same explaining pattern. The possibility of a compromised spectrum inside the DHI incubator has to be confirmed by further measurements.

Also the isotope quality could influence the $^{14}CO_2$ uptake in the incubation flasks. The borax buffered and diluted isotope of SISU could introduce some stimulating nutrient. Alternatively, the manufacturer's stock solution could contain some hampering substance explaining the lower PP values of SMHI. If the current isotope qualities have no effect on the measurements, direct use of the stock solution from the manufacturer provides the least laborious protocol for routine work.

These hypotheses need to be experimentally tested and the best practices for measurement quality and least laborious procedures adopted for a future standard operating procedure.

We think that the PP measurement is important for the understanding of the dynamics in the sea and we want to measure it in the best possible way. This means that more intercalibration is necessary. We argue also that the method should be possible to do during monitoring cruises, which means that the possible way is perhaps not the optimal way but good enough. The use of the FRRF could, if we can get it to work, be a valuable complement to incubations. It needs to be studied more though. The FRRF can if it is

calibrated easily give us more data points. The only draw back will in that case be that it uses more station time during the measurements.

How we continue:

1. Measure the light spectrum in the incubators. See to that it is as natural as possible.
2. Determine the optimal concentration of HCl to remove the extra $^{14}CO_2$.
3. Compare the effect of diluted and undiluted isotope.
4. Test the incubation time to get an optimal time span.
5. Test if we should use filter samples or whole water samples.
6. Discuss with experts in the area how to estimate inorganic carbon in the water.
7. We should remove the respiration factor from the SEPA manual (Marra 2009).
8. The FRRF needs to be investigated further.

This intercalibration has started a necessary discussion and comparison among the institutes that do the PP monitoring for SEPA. The work will continue at each ones lab, but the workshop participants found it important to do common exercises as well and wish to do them on a regular basis. Our recommendation for the future is to do intercalibration and ring tests preferably on land for efficiency and in the process we need to invite scientists from other institutes to participate. The *in situ* measurements should also be a part of the measurement.

REFERENCES

Gargas, E., 1975. A manual for phytoplankton primary production studies in the Baltic. Baltic Marine Biologists. Publ. No. 2. Water Quality Institute, Hørsholm, Denmark.

HELCOM Combine
http://www.helcom.fi/groups/monas/CombineManual/AnnexesC/en_GB/annex5/

Jassby, A.D. and Platt, T. 1976. Mathematical formulation of the relationship between photosynthesis and light for phytoplankton. Limnology and Oceanography 21(4):540-547

Kolber, Z. and Falkowski, P.G. 1993 Use of active fluorescence to estimate phytoplankton photosynthesis *in situ*. Limn. Oeanogr. 38(8) 1646-1665

Marra, J. 2009. Net and gross productivity: weighing in with ^{14}C. Aquatic Microb. Ecol. 56:123-131.

Naturvårdsverket
http://www.naturvardsverket.se/upload/02_tillstandet_i_miljon/Miljoovervakning/undersokn_typ/hav/primprod.pdf

Richardson, K. 1991. Comparison of ^{14}C primary production determinations made by different laboratories. Mar. Ecol. Prog Ser. Vol 72: 189-201

Smyth, T.J., Pemberton, K.L.. Aiken, J. and Geider, R.J.. 2004 A methodology to determine primary production and phytoplankton photosynthetic parameters from Fast Repetition Rate Fluorometry. J. of Plankton Res. 26(11) 1337-1350

Stemann Nielsen, E. 1952 The use of radio-active carbon (C^{14}) for measuring organic production in the sea. Organic production in the sea. P 117-140

Stemann Nielsen, E. 1975 Marine Photosynthesis: with special emphasis on the ecological aspects. Elsevier, Amsterdam.

STRÅNG database http://produkter.smhi.se/strang/extraction/index.php

Zeebe, R.E. and Wolf-Gladrow, D., 2005. CO_2 in seawater: equilibrium, kinetics, isotopes. Elsevier oceanography series 65, Series editor David Halpern, Pp 346

Öström, B. 1975. Formulae to calculate the solubility of CO_2, total CO_2 and primary production in sea water. Internal report IC/75/166, International Centre for theoretical physics.

APPENDIX

Calculations

The base for the calculations was the equation

PP = (Tot CO_2 * DPM measured * 1.05 * 60) / (DPM added * incubation time in minutes)

The amount of total CO_2 was calculated according to the equations by Öström 1975. DPM is the concentration of the added ^{14}C tracer, 1.05 accounts for ^{14}C lower uptake rate than ^{12}C. 60 is for converting the incubation time to hours. Additional calculations for sub sampling were used when needed. This PP is valid for the light intensity for the actual bottle.

An equation is fitted to the CO_2 uptake for each light intensity to get the values of the maximum possible production rate (P_{max}) and the efficiency of the algae to utilise the light (α). The equation used is a tangential curve fit proposed by Jassby and Platt 1976:

$$PP = P_{max} * (TANH (\alpha * E_{PAR}/P_{max})).$$

E_{PAR} is the actual light in the bottle.

This equation was used to calculate the production in the water column together with the light measured and /or calculated.

The light in the water column was calculated. The reflection on the water surface needs to be estimated. For this exercise we decided to use 7 % reflection. The attenuation coefficient in the water column was calculated from light measurements from the CTD profile. The upper meter was not accounted for because it mainly consisted of disturbances from the ship. From 1 m to the end of the illuminated zone the attenuation coefficient was estimated as

$$K_d = -\ln (I_1-I_0)/(D_1-D_0)$$

I is the irradiance at the depth. D is the depth.

The average K_d for all the data sets was used. The light at each meter from 0 to 10 meters was calculated.

SMHIs publiceringar

SMHI ger ut sju rapportserier. Tre av dessa, R-serierna är avsedda för internationell publik och skrivs därför oftast på engelska. I de övriga serierna används det svenska språket.

Seriernas namn	**Publiceras sedan**
RMK (Rapport Meteorologi och Klimatologi)	1974
RH (Rapport Hydrologi)	1990
RO (Rapport Oceanografi)	1986
METEOROLOGI	1985
HYDROLOGI	1985
OCEANOGRAFI	1985
KLIMATOLOGI	2009

I serien OCEANOGRAFI har tidigare utgivits:

1 Lennart Funkquist (1985)
En hydrodynamisk modell för spridnings- och cirkulationsberäkningar i Östersjön Slutrapport.

2 Barry Broman och Carsten Pettersson. (1985)
Spridningsundersökningar i yttre fjärden Piteå.

3 Cecilia Ambjörn (1986).
Utbyggnad vid Malmö hamn; effekter för Lommabuktens vattenutbyte.

4 Jan Andersson och Robert Hillgren (1986).
SMHIs undersökningar i Öregrundsgrepen perioden 84/85.

5 Bo Juhlin (1986)
Oceanografiska observationer utmed svenska kusten med kustbevakningens fartyg 1985.

6 Barry Broman (1986)
Uppföljning av sjövärmepump i Lilla Värtan.

7 Bo Juhlin (1986)
15 års mätningar längs svenska kusten med kustbevakningen (1970 - 1985).

8 Jonny Svensson (1986)
Vågdata från svenska kustvatten 1985.

9 Barry Broman (1986)
Oceanografiska stationsnät - Svenskt Vattenarkiv.

11 Cecilia Ambjörn (1987)
Spridning av kylvatten från Öresundsverket

12 Bo Juhlin (1987)
Oceanografiska observationer utmed svenska kusten med kustbevakningens fartyg 1986.

13 Jan Andersson och Robert Hillgren (1987)
SMHIs undersökningar i Öregrundsgrepen 1986.

14 Jan-Erik Lundqvist (1987)
Impact of ice on Swedish offshore lighthouses. Ice drift conditions in the area at Sydostbrotten - ice season 1986/87.

15 SMHI/SNV (1987)
Fasta förbindelser över Öresund - utredning av effekter på vattenmiljön i Östersjön.

16 Cecilia Ambjörn och Kjell Wickström (1987)
Undersökning av vattenmiljön vid utfyllnaden av Kockums varvsbassäng. Slutrapport för perioden 18 juni - 21 augusti 1987.

17 Erland Bergstrand (1987)
Östergötlands skärgård - Vattenmiljön.

18 Stig H. Fonselius (1987)
Kattegatt - havet i väster.

19 Erland Bergstrand (1987)
Recipientkontroll vid Breviksnäs fiskodling 1986.

20 Kjell Wickström (1987)
Bedömning av kylvattenrecipienten för ett kolkraftverk vid Oskarshamnsverket.

21 Cecilia Ambjörn (1987)
Förstudie av ett nordiskt modellsystem för kemikaliespridning i vatten.

22 Kjell Wickström (1988)
Vågdata från svenska kustvatten 1986.

23 Jonny Svensson, SMHI/National Swedish Environmental Protection Board (SNV) (1988)
A permanent traffic link across the Öresund channel - A study of the hydro-environmental effects in the Baltic Sea.

24 Jan Andersson och Robert Hillgren (1988)
SMHIs undersökningar utanför Forsmark 1987.

25 Carsten Peterson och Per-Olof Skoglund (1988)
Kylvattnet från Ringhals 1974-86.

26 Bo Juhlin (1988)
Oceanografiska observationer runt svenska kusten med kustbevakningens fartyg 1987.

27 Bo Juhlin och Stefan Tobiasson (1988)
Recipientkontroll vid Breviksnäs fiskodling 1987.

28 Cecilia Ambjörn (1989)
Spridning och sedimentation av tippat lermaterial utanför Helsingborgs hamnområde.

29 Robert Hillgren (1989)
SMHIs undersökningar utanför Forsmark 1988.

30 Bo Juhlin (1989)
Oceanografiska observationer runt svenska kusten med kustbevakningens fartyg 1988.

31 Erland Bergstrand och Stefan Tobiasson (1989)
Samordnade kustvattenkontrollen i Östergötland 1988.

32 Cecilia Ambjörn (1989)
Oceanografiska förhållanden i Brofjorden i samband med kylvattenutsläpp i Trommekilen.

33a Cecilia Ambjörn (1990)
Oceanografiska förhållanden utanför Vendelsöfjorden i samband med kylvattenutsläpp.

33b Eleonor Marmefelt och Jonny Svensson (1990)
Numerical circulation models for the Skagerrak - Kattegat. Preparatory study.

34 Kjell Wickström (1990)
Oskarshamnsverket - kylvattenutsläpp i havet - slutrapport.

35 Bo Juhlin (1990)
Oceanografiska observationer runt svenska kusten med kustbevakningens fartyg 1989.

36 Bertil Håkansson och Mats Moberg (1990)
Glommaälvens spridningsområde i nordöstra Skagerrak

37 Robert Hillgren (1990)
SMHIs undersökningar utanför Forsmark 1989.

38 Stig Fonselius (1990)
Skagerrak - the gateway to the North Sea.

39 Stig Fonselius (1990)
Skagerrak - porten mot Nordsjön.

40 Cecilia Ambjörn och Kjell Wickström (1990)
Spridningsundersökningar i norra Kalmarsund för Mönsterås bruk.

41 Cecilia Ambjörn (1990)
Strömningsteknisk utredning avseende utbyggnad av gipsdeponi i Landskrona.

42 Cecilia Ambjörn, Torbjörn Grafström och Jan Andersson (1990)
Spridningsberäkningar - Klints Bank.

43 Kjell Wickström och Robert Hillgren (1990)
Spridningsberäkningar för EKA-NOBELs fabrik i Stockviksverken.

44 Jan Andersson (1990)
Brofjordens kraftstation - Kylvattenspridning i Hanneviken.

45 Gustaf Westring och Kjell Wickström (1990)
Spridningsberäkningar för Höganäs kommun.

46 Robert Hillgren och Jan Andersson (1991)
SMHIs undersökningar utanför Forsmark 1990.

47 Gustaf Westring (1991)
Brofjordens kraftstation - Kompletterande simulering och analys av kylvattenspridning i Trommekilen.

48 Gustaf Westring (1991)
Vågmätningar utanför Kristianopel - Slutrapport.

49 Bo Juhlin (1991)
Oceanografiska observationer runt svenska kusten med kustbevakningens fartyg 1990.

50a Robert Hillgren och Jan Andersson (1992)
SMHIs undersökningar utanför Forsmark 1991.

50b Thomas Thompson, Lars Ulander, Bertil Håkansson, Bertil Brusmark, Anders Carlström, Anders Gustavsson, Eva Cronström och Olov Fäst (1992).
BEERS -92. Final edition.

51 Bo Juhlin (1992)
Oceanografiska observationer runt svenska kusten med kustbevakningens fartyg 1991.

52 Jonny Svensson och Sture Lindahl (1992)
Numerical circulation model for the Skagerrak - Kattegat.

53 Cecilia Ambjörn (1992)
Isproppsförebyggande muddring och dess inverkan på strömmarna i Torneälven.

54 Bo Juhlin (1992)
20 års mätningar längs svenska kusten med kustbevakningens fartyg (1970 - 1990).

55 Jan Andersson, Robert Hillgren och Gustaf Westring (1992)
Förstudie av strömmar, tidvatten och vattenstånd mellan Cebu och Leyte, Filippinerna.

56 Gustaf Westring, Jan Andersson, Henrik Lindh och Robert Axelsson (1993)
Forsmark - en temperaturstudie.
Slutrapport.

57 Robert Hillgren och Jan Andersson (1993)
SMHIs undersökningar utanför Forsmark 1992.

58 Bo Juhlin (1993)
Oceanografiska observationer runt svenska kusten med kustbevakningens fartyg 1992.

59 Gustaf Westring (1993)
Isförhållandena i svenska farvatten under normalperioden 1961-90.

60 Torbjörn Lindkvist (1994)
Havsområdesregister 1993.

61 Jan Andersson och Robert Hillgren (1994)
SMHIs undersökningar utanför Forsmark 1993.

62 Bo Juhlin (1994)
Oceanografiska observationer runt svenska kusten med kustbevakningens fartyg 1993.

63 Gustaf Westring (1995)
Isförhållanden utmed Sveriges kust - isstatistik från svenska farleder och farvatten under normalperioderna 1931-60 och 1961-90.

64 Jan Andersson och Robert Hillgren (1995)
SMHIs undersökningar utanför Forsmark 1994.

65 Bo Juhlin (1995)
Oceanografiska observationer runt svenska kusten med kustbevakningens fartyg 1994.

66 Jan Andersson och Robert Hillgren (1996)
SMHIs undersökningar utanför Forsmark 1995.

67 Lennart Funkquist och Patrik Ljungemyr (1997)
Validation of HIROMB during 1995-96.

68 Maja Brandt, Lars Edler och Lars Andersson (1998)
Översvämningar längs Oder och Wisla sommaren 1997 samt effekterna i Östersjön.

69 Jörgen Sahlberg SMHI och Håkan Olsson, Länsstyrelsen, Östergötland (2000).
Kustzonsmodell för norra Östergötlands skärgård.

70 Barry Broman (2001)
En vågatlas för svenska farvatten.
Ej publicerad

71 ***Vakant – kommer ej att utnyttjas!***

72

73 Fourth Workshop on Baltic Sea Ice Climate Norrköping, Sweden 22-24 May, 2002 Conference Proceedings
Editors: Anders Omstedt and Lars Axell

74 Torbjörn Lindkvist, Daniel Björkert, Jenny Andersson, Anders Gyllander (2003)
Djupdata för havsområden 2003

75 Håkan Olsson, SMHI (2003)
Erik Årnefelt, Länsstyrelsen Östergötland
Kustzonssystemet i regional miljöanalys

76 Jonny Svensson och Eleonor Marmefelt (2003)
Utvärdering av kustzonsmodellen för norra Östergötlands och norra Bohusläns skärgårdar

77 Eleonor Marmefelt, Håkan Olsson, Helma Lindow och Jonny Svensson, Thalassos Computations (2004)
Integrerat kustzonssystem för Bohusläns skärgård

78 Philip Axe, Martin Hansson och Bertil Håkansson (2004)
The national monitoring programme in the Kattegat and Skagerrak

79 Lars Andersson, Nils Kajrup och Björn Sjöberg (2004)

Dimensionering av det nationella marina pelagialprogrammet

80 Jörgen Sahlberg (2005)
Randdata från öppet hav till kustzons-modellerna (Exemplet södra Östergötland)

81 Eleonor Marmefelt, Håkan Olsson (2005)
Integrerat Kustzonssystem för Hallandskusten

82 Tobias Strömgren (2005)
Implementation of a Flux Corrected Transport scheme in the Rossby Centre Ocean model

82 Martin Hansson (2006)
Cyanobakterieblomningar i Östersjön, resultat från satellitövervakning 1997-2005

83 Kari Eilola, Jörgen Sahlberg (2006)
Model assessment of the predicted environmental consequences for OSPAR problem areas following nutrient reductions

84 Torbjörn Lindkvist, Helma Lindow (2006)
Fyrskeppsdata. Resultat och bearbetnings-metoder med exempel från Svenska Björn 1883 – 1892

85 Pia Andersson (2007)
Ballast Water Exchange areas – Prospect of designating BWE areas in the Baltic Proper

86 Elin Almroth, Kari Eilola, M. Skogen, H. Søiland and Ian Sehested Hansen (2007)
The year 2005. An environmental status report of the Skagerrak, Kattegat and North Sea

87 Eleonor Marmefelt, Jörgen Sahlberg och Marie Bergstrand (2007)
HOME Vatten i södra Östersjöns vattendistrikt. Integrerat modellsystem för vattenkvalitetsberäkningar

88 Pia Andersson (2007)
Ballast Water Exchange areas – Prospect of designating BWE areas in the Skagerrak and the Norwegian Trench

89 Anna Edman, Jörgen Sahlberg, Niclas Hjerdt, Eleonor Marmefelt och Karen Lundholm (2007)
HOME Vatten i Bottenvikens vatten-distrikt. Integrerat modellsystem för vattenkvalitetsberäkningar

90 Niclas Hjerdt, Jörgen Sahlberg, Eleonor Marmefelt och Karen Lundholm (2007)
HOME Vatten i Bottenhavets vattendistrikt. Integrerat modellsystem för vattenkvalitets-beräkningar

91 Elin Almroth, Morten Skogen, Ian Sehsted Hansen, Tapani Stipa, Susa Niiranen (2008)
The year 2006
An Eutrophication Status Report of the North Sea, Skagerrak, Kattegat and the Baltic Sea
A demonstration Project

92 Pia Andersson, editor and co-authors Bertil Håkansson*, Johan Håkansson*, Elisabeth Sahlsten*, Jonathan Havenhand**, Mike Thorndyke**, Sam Dupont** * Swedish Meteorological and Hydrological Institute ** Sven Lovén, Centre of Marine Sciences (2008)
Marine Acidification – On effects and monitoring of marine acidification in the seas surrounding Sweden

93 Jörgen Sahlberg, Eleonor Marmefelt, Maja Brandt, Niclas Hjerdt och Karen Lundholm (2008)
HOME Vatten i norra Östersjöns vatten-distrikt. Integrerat modellsystem för vattenkvalitetsberäkningar.

94 David Lindstedt (2008)
Effekter av djupvattenomblandning i Östersjön – en modellstudie

95 Ingemar Cato*, Bertil Håkansson**, Ola Hallberg*, Bernt Kjellin*, Pia Andersson**, Cecilia Erlandsson*, Johan Nyberg*, Philip Axe** (2008)
*Geological Survey of Sweden (SGU)
**The Swedish Meteorological and Hydrological Institute (SMHI)
A new approach to state the areas of oxygen deficits in the Baltic Sea

96 Kari Eilola, H.E. Markus Meier, Elin Almroth, Anders Höglund (2008)
Transports and budgets of oxygen and phosphorus in the Baltic Sea

97 Anders Höglund, H.E. Markus Meier, Barry Broman och Ekaterini Kriezi (2009)
Validation and correction of regionalised ERA-40 wind fields over the Baltic Sea using the Rossby Centre Atmosphere model RCA3.0

98 Jörgen Sahlberg (2009)
The Coastal Zone Model

99 Kari Eilola (2009)
On the dynamics of organic nutrients, nitrogen and phosphorus in the Baltic Sea

Avsiktligt blank

SMHI

Sveriges meteorologiska och hydrologiska institut
601 76 NORRKÖPING
Tel 011-495 80 00 Fax 011-495 80 01

ISSN 0283-7714