National Environmental Research Institute
University of Aarhus · Denmark

NERI Technical Report No. 663, 2008

Tools to assess conservation status on open water reefs in Nature-2000 areas

[Blank page]

National Environmental Research Institute
University of Aarhus · Denmark

NERI Technical Report No. 663, 2008

Tools to assess conservation status on open water reefs in Nature-2000 areas

Karsten Dahl
Jacob Carstensen

Data sheet

Series title and no.:	NERI Technical Report No. 663
Title:	Tools to assess conservation status on open water reefs in Nature-2000 areas
Authors:	Karsten Dahl & Jacob Carstensen
Department:	Department of Marine Ecology
Publisher:	National Environmental Research Institute © University of Aarhus - Denmark
URL:	http://www.neri.dk
Year of publication:	April 2008
Editing completed:	March 2008
Referees:	Stig Asger Helmig and Lone Reersø Hansen, Agency for Spatial and Environmental Planning
Financial support:	Agency for Spatial and Environmental Planning
Please cite as:	Dahl, K. & Carstensen, J. 2008: Tools to assess conservation status on open water reefs in Nature-2000 areas. National Environmental Research Institute, University of Aarhus. 25 pp. – NERI Technical Report No. 663. http://www.dmu.dk/Pub/FR663.pdf

Reproduction permitted provided the source is explicitly acknowledged

Abstract: This work shows that total and cumulative vegetation covers are excellent indicators of the ecological quality of reefs in open waters. Total nitrogen load to inner Danish waters from January to July as well as solar radiation from May to July and presence of sea urchins are important anthropogenic and natural factors controlling the two indicators. Furthermore, there are significant differences between most reef locations. Based on parameter estimates from the statistical analysis, predictive models for both indicators have been established for a number of reef locations with good data coverage. Such models can be used to set targets for the vegetation covers using input targets on nitrogen load set by other indicators or measurements.

Keywords:	Macroalgal vegetation, modelling, the Habitats Directive, boulder reefs
Layout:	Anne van Acker
Cover photo:	Algae at Læsø Trindel. Photo: Karsten Dahl
ISBN:	978-87-7073-038-9
ISSN (electronic):	1600-0048
Number of pages:	25
Internet version:	The report is available in electronic format (pdf) at NERI's website http://www.dmu.dk/Pub/FR663.pdf

Contents

[Blank page]

Summary

This work shows that total and cumulative vegetation covers are excellent indicators of the ecological quality of reefs in open waters.

Total nitrogen load to inner Danish waters from January to July, solar radiation from May to July, depth and grazing pressure caused by sea urchins are important anthropogenic and natural factors controlling the two indicators. Furthermore, there are significant differences between most reef locations used in the analyses.

Based on parameter estimates from the statistical analyses, predictive models for both indicators have been established for a number of reef locations with good data coverage. Scenarios were made for reefs with high data sampling giving the best description of variables controlling the vegetation. In Danish waters there is a general lack of knowledge on the quality of biological variables before eutrophication, fishery and extraction of boulders and stone became a problem. Use of models to set targets for the vegetation covers is a way to establish a quality assessment tool. A precondition in this case is targeted nitrogen loads based on other indicators, measurements or models.

Sammenfatning

Rapportens analyser viser, at algernes samlede dækning og den kumulative dækning af de enkelte algearter begge er fine indikatorer for den økologiske tilstand på stenrev i åbne farvande.

Den samlede kvælstoftilførsel til indre danske farvande i forårshalvåret (januar-juli), solindstrålingen fra maj til juli, vanddybden og græsningstrykket fra søpindsvin udtrykt ved deres dækningsprocent på det hårde substrat er væsentlige signifikante antropogene og naturlige faktorer, som kontrollerer de to indikatorer. Yderligere er der en signifikant forskel mellem de fleste rev, der indgik i analyserne.

På baggrund af estimerede værdier af de strukturerende faktorer fra de statistiske analyser blev forskellige scenarier modelleret for dækning af makroalger. Scenarierne blev lavet for de rev, hvor datagrundlaget var godt og modellerne derfor fungerede bedst. I mangel på viden om naturkvaliteten på stenrev før eutrofiering, fiskeri og råstofindvinding for alvor blev et problem, kan modellerne anvendes til at opstille målsætninger for algevegetationen. Forudsætningen er målsatte kvælstoftilførsler baseret på andre indikatorer, målinger eller modeller.

1 Background

Most hard bottom areas in the open inner parts of Danish waters are reef like structures rising from the surrounding sandy seabed. The reef formations have a glacial and postglacial origin and consist of stones and boulders with varying cover of sand and gravel in between. Most reefs are found in the depth range of 4-24 m.

The distribution and composition of macroalgal communities on hard bottom habitats depend on chemical, physical and biological factors controlling growth and mortality.

The changing salinities in Danish waters are known to have a strong influence on the biodiversity in seaweed forests. The number of registered species is reduced threefold from Kattegat through the Danish straits to the western Baltic Sea (*Nielsen et al. 1995*). Salinity also influences the ratio between opportunistic and per-annual algal species found in the Danish coastal areas favouring the fast growing species in less saline waters (*Carstensen et al. in prep.*).

Light is another important factor reducing the macroalgal cover not just with increasing water depth but also as a result of eutrophication (*Krause-Jensen et al. 2007*). Results from studies in Danish waters using large datasets demonstrated positive relationships between nutrient and chlorophyll concentrations (*Nielsen et al. 2002*; *Carstensen et al. 2003*). Reduction in water clarity as a result of increased chlorophyll concentration is also well documented (*Petersen et al. 2005*).

The stability of substrate is also important controlling the species composition and cover on hard substrate. Stable substrate hosts a higher degree of per-annual species with more developed cover, compared to unstable substrate at the same depth that hosts more opportunistic algal communities (*Dahl et al. 2001*).

Grazing by crustaceans and sea urchins affects the growth rates of algal species, causes mortality and overall reduces the vegetation cover. Grazing can be so intensive that it is the most important controlling factor for the submerged vegetation. Devastating grazing caused mass occurrence of the northern sea urchin (*Strongylocentrotus droebachiensis)* changing seaweed forest to "barren grounds" is documented from several areas on the northern hemisphere as reviewed by *Steneck et al. 2002* and it is also an increasing problem in some Danish reef areas (*Ærtebjerg et al. 2007*).

Crustforming macroalgal species need low levels of light for survival and growth (*Markager & Sand-Jensen 1992*) while algal species with a leaf or a filamentous morphology have higher light requirements. Calcareous crusts cover most hard substrate on deep waters in inner Danish waters whereas erect forms have only scattered covers below depths of 20-25 m.

According to the Water Framework Directive and the Habitats Directive it is required to identify suitable biological indicators describing the quality of a given water body and habitat. Total cover of erect algal vegetation and cumulative cover of erect algal vegetation are two variables that are simple and integrative over time. At the same time these two indicators are highly relevant in an ecological perspective as benthic macroalgal vegetation is an important factor structuring hard bottom habitats and constitutes an important part of the primary production.

Unfortunately no "historic" data are available describing the conditions of the sea weed forests at the reefs in a quantitative manner from a period where human impact in the marine areas was a minor problem. A way to solve this problem of setting biological relevant target for favourable conservation status is to use models. This procedure needs first of all knowledge about cause-relationships between the chosen indicator and important anthropogenic and natural controlling factors and secondly that relevant "historic" information is available describing previous levels of the controlling factors.

One model has already been developed for open water reef areas in the Kattegat (*Dahl et al. 2005*). This model could successfully predict the development of total erect macroalgal cover on three out of six reefs with long time series of macroalgal data. All three reefs had in common that they had a deep distribution on hard substrate (>15 m) which gives the best opportunity to identify changes in the total vegetation coves.

Models describing different algal vegetation variables in the costal zone in Danish waters are also in progress (*Carstensen et al. in prep.*). These models are more general in nature describing the vegetation along large gradients of salinity and eutrophication whereas data from the reef areas in open waters allow a site specific modelling.

2 Aims

This work aims to develop tools to assess the conservation status on reef areas in open waters. The work is focused on two macroalgal indicators: "*total cover of erect macroalgal vegetation*" and "*cumulative cover of erect macroalgal vegetation*".

Previous work with "total cover of erect vegetation" (*Dahl et al. 2005*) will be improved by including a larger dataset from more sites and more years as well as analysing the structuring effect of important biotic components.

The indicator "cumulative cover of erect macroalgal vegetation" is developed and tested as an indicator working on more shallow water compared to total cover.

For both indicators important abiotic and biotic factors are identified and quantified. The resulting model can be used to make different scenarios for the indicators, including one describing the boundary condition for favourable/unfavourable conservation status.

3 Data and statistical methods

3.1 Reef locations and algal data

Algal data used in modelling

Macroalgae have been monitored at selected stations (point samples) along a depth gradient on stone reefs in Danish waters since 1993 using the same methodology. Some reefs have been visited 1-2 times annually and a few reefs only once in the period. All monitoring cruises were carried out between June and August. Taxonomic skilled divers visually judged the species specific percent cover of erect algae and the cover percent of the total erect macroalgal community on hard stable substrate. The selected stations had at least 10% cover of hard stable substrate and 10-25 m^2 of the stone reef was inspected. A few datasets where cumulative species cover constituted <80% of the estimated total algal covers were excluded, because either species registration must be incomplete in those cases or estimated species cover much to low. Along with the collection of algal data, divers visually recorded the cover of 4 species of sea urchins present in Danish waters: northern sea urchin (*Strongylocentrotus droebachiensis*), green sea urchin (*Psammechinus miliaris*), common sea urchin (*Echinus esculentus*), and long spine sea urchin (*Echinus acutus*) as well as the cover of floating algae and blue mussels (*Mytilus edulis*).

During the study period, seven different divers carried out a total of 838 point samples; three of these divers did fields sampling throughout the entire study period, whereas the other divers were involved in sampling activities in a limited number of years (≤ 3). A total of 17 stone reefs (*Figure 3.1*, *table 3.1*) were selected because they had at least 4 point samples representing at least 2 depth intervals. For cumulative cover analysis the number of reefs was limited to 15. These reef sites represent large gradients in salinity as well as geographic distance from nutrient sources. Point samples from depths more shallow than 6 m were discarded to eliminate observations with reduced algal cover mainly due to physical exposure, which resulted in 764 observations of total algal cover. This depth limit was established by identifying the highest cumulative vegetation cover (*figure 3.2*) using a non-parametric LOESS adjustment (*Cleveland 1979*). Species-specific algal cover was recorded for 649 of these 764 observations, representing 19 stone reefs and 5 divers only.

Algal data used for model validation

The total algal cover model was validated using an independent dataset collected in the BALANCE project (*Dahl et al. 2008*). Estimated total cover was collected at a few dives and a lot of transects using submerged video equipment at stable hard bottom reef areas in the vicinity of Kim's Top in June 2006.

Figure 3.1 Reef locations with vegetation data included in the analysis. Circles include data with both total and cumulative cover of erect macroalgal vegetation. Squares indicate location where only total cover was available in a sufficient number of observations.

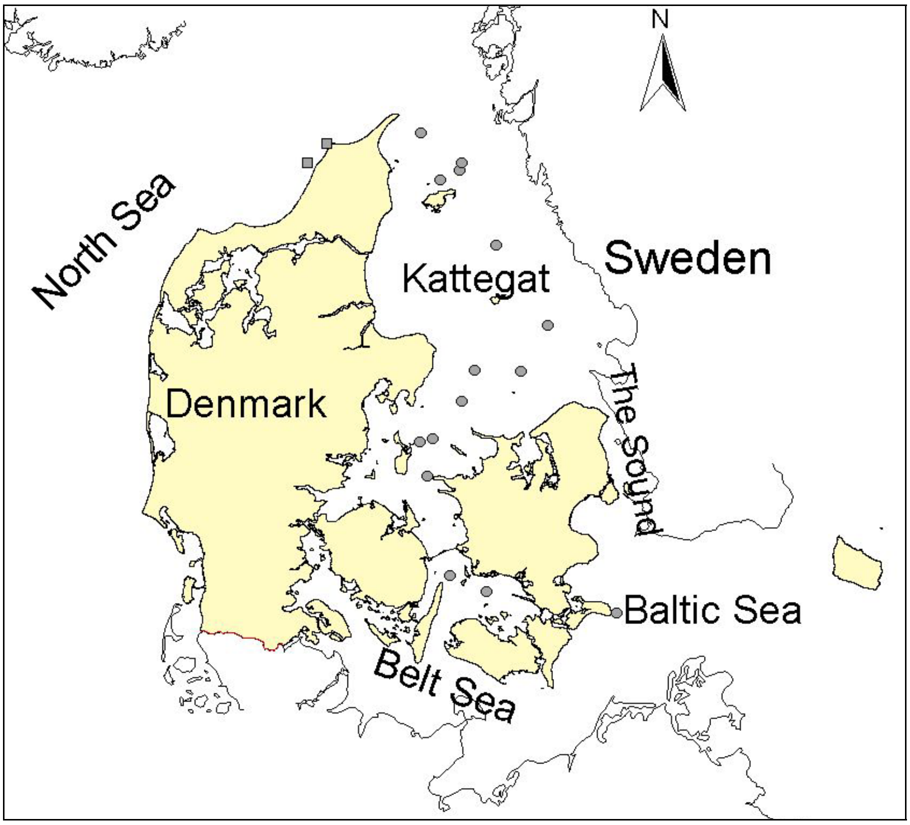
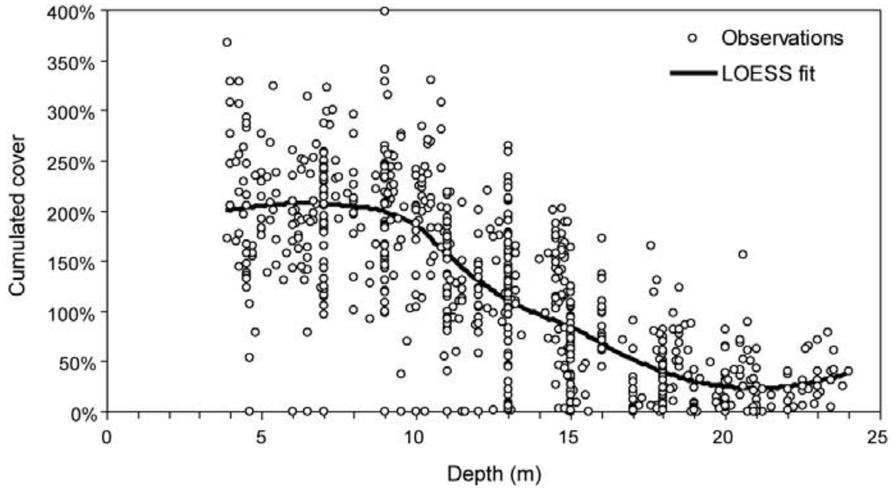


Table 3.1 Investigated stone reefs characterised by number of observations used in study and their depth range. Reefs marked with * are not included in the cumulative cover analysis.

Stone reef		Number of point samples	Depths analysed (m)
1.	Briseis Flak	40	6.1 - 9.4
2.	Broen	10	8.7 - 17.1
3.	Herthas Flak	108	10.0 - 20.5
4.	Kim's Top	86	14.3 - 22.9
5.	Kirkegrund	12	6.4 - 12.7
6.	Knudegrund *	5	9.5 - 20.0
7.	Lysegrund	8	6.3 - 13.0
8.	Læsø Trindel	28	11.0 - 18.4
9.	Lønstrup Rødgrund *	9	8.0 - 14.9
10.	Munkegrunde	7	7.0 - 13.0
11.	Møns Klint	12	9.7 - 20.7
12.	Per Nilen	30	6.1 - 11.0
13.	Røsnæs	4	9.5 - 12.0
14.	Schultz's Grund	90	7.0 - 18.3
15.	Store Middelgrund	80	8.5 - 24.0
16.	Tønneberg Banke	63	10.0 - 15.0
17.	Vejrø	145	6.8 - 21.2

Figure 3.2 LOESS fit to observed cumulative vegetation cover in the whole dataset.



3.2 Physical-chemical data

For this part of the work physical-chemical data from monitoring stations in the vicinity of the stone reefs were extracted from the Danish National Marine Database (MADS). This dataset included salinity, temperature, dissolved inorganic nitrogen (DIN), dissolved inorganic phosphorus (DIP), total nitrogen (TN), total phosphorus (TP), chlorophyll-a (CHLA) and Secchi depths. Sampling and chemical analyses were performed according to common standard guidelines (*Andersen et al. 2004*). Average concentrations of nutrients and chlorophyll-a were calculated for the upper mixed layer (0-15 m), whereas temperature and salinity were average over depths ranging from 10 to 20 m representing the typical depths of macroalgae point samples.

Nutrient inputs (total nitrogen and total phosphorus) to the Kattegat, the Sound, and the Belt Sea from Denmark and Sweden were compiled from the Danish National Aquatic Monitoring and Assessment Program (DNAMAP) and the Swedish Agricultural University (www.slu.se). Nutrient inputs were aggregated for two periods prior to the macroalgae sampling: 1) January-June and 2) July-December in the previous year. Wind speed observations were obtained from two separate and partly overlapping time series at Sprogø located in the middle of the Great Belt (data source: Sund & Bælt Holding A/S) and Risø near Roskilde Fjord (data source: Dept. of Wind Energy, Risø National Laboratory). Irradiance data were obtained from the HC Ørsted Institute, Copenhagen University. Wind speed and irradiance observations were averaged for May-July, i.e. the primary productive period prior to monitoring.

Dahl et al. 2005 gave a rough estimate of nitrogen load to the Kattegat in a reference situation for a whole year. The load in this context is set to 10,000 tons for the period January-June.

3.3 Statistical methods

Statistical analyses have been done to establish cause-relationships between the response in macroalgae vegetation on hard substrate and

- water quality elements like water concentrations of DIN, DIP,TN, TP and Secchi depth, nutrient load of nitrogen and phosphorous,
- biological factors like drifting algal mats and presence of sea urchins (grazing) and
- climatic factors like radiation and physical stress induced by wind on the remaining dataset below depths of 6 m.

Based on these analyses, which will be reported in *Carstensen et al. in prep*, two habitat models have been developed, both dealing with vegetation cover on hard stable substrate. In both cases, empirical relationships were identified between the development of benthic macroalgae vegetation and a number of important factors controlling this vegetation. Large variations in pressure and response both in space and time registered in the period 1993-2006 have facilitated the development of the models. Both models were based on General Linear Models framework with an appropriate transformation of data.

Model for describing total vegetation cover

The first model describes total vegetation cover of erect macroalgae vegetation as a function of location, water depth, nutrient load (from January to July) diver and cover of sea urchins. This model is a further development of a previous work by *Dahl & Carstensen (2005)* but also includes important biotic elements such as sea urchin grazing and drifting algal mats in the analysis. The model is presumed to be the most robust as total cover is relatively easy to collect. However, the model has the disadvantage that it is in general restricted to reef areas with water depth deeper than 12-14 m where total erect macroalgal covers are less than 100%.

Model for describing cumulated vegetation cover

Cumulated vegetation cover was first investigated with a similar model as for total vegetation cover assuming a maximum attainable cover of 300%. However, cumulated vegetation cover does not show the same tendency to reduced variation around 300% as total cover does close to the maximum value of 100%.

Therefore, cumulated vegetation cover is described using a linear model. The second model describes the cumulative erect macroalgal cover as function of the same variables as the first model. The data for this model are presumably more variable due to the more difficult task describing multi-layered vegetation. On the other hand, the advantage of the cumulative model is that it also works on shallow water until wave exposure becomes an important factor.

4 Results

4.1 Controlling factors

The models describing total and cumulative cover of erect macroalgal vegetation were both significant ($p < 0.001$) for the overall dataset including reefs from the Skagerrak, the Kattegat, the Belt Sea area and the western Baltic explaining more than 80% of the variation ($r^2 = 0,835$ and 0,801 respectively). Reef site, depth of seabed, global radiation from May-June, load of total nitrogen (TN) from January-June, presence of sea urchins and the diver carrying out the investigation all contributed significantly ($p < 5\%$) to describe both total and cumulative erect algal cover. The effect of depth was site specific on each locality and the effect of nutrient was site specific on both locality and depth. Parameter estimates and levels of significance for the two models are given in *tables 4.1* and *4.2*.

In both models there is an overall site specific effect on the development of the vegetation. This effect is significant at specific reef sites in many cases and especially pronounced where data sampling behind the estimation are numerous.

Vegetation decreases overall with depth but in a different manner from reef to reef. The effect was significant at site level in many cases and not surprising more pronounced for cumulative vegetation cover compared to total cover.

Although there was a good overall effect of nitrogen load on both total and cumulative erect algal vegetation cover, the effect was statistically significant ($p < 5\%$) on only 5 and 4 reefs sites for total cover and cumulative cover respectively and in 8 and 6 cases if 10% confidence level is accepted. However, data from cumulative cover at Kirkegrund ($p = 6.51\%$) show a very odd distribution pattern in the model and the result must be regarded as an artefact due to few sampling points.

4.2 Scenarios

The results of the analysis of structuring factors can be used to model the total and cumulative cover of erect vegetation. *Figures 4.1* and *4.2* present four different scenarios for selected reefs where TN was found to have a significant effect on the total and cumulative algal cover. The scenarios describe the depth dependent development of total and cumulative algal cover at different loads of nitrogen to the Kattegat keeping the solar radiation on an average level (213.3 W m^{-2}), using an "average" diver and with a sea urchin cover of 0.1%. The chosen load scenarios are a reference like situation with 10,000 tons, an average load from 1993-2005 (48,000 tons) and loads equal to a dry and a wet year in the same period (23,000 and 79,000 tons).

Appendix 1 shows an example of the calculation of expected total cover value for the reef Kim's Top at one depth using average conditions of nutrient load and solar radiation in the appendix.

Table 4.1 Parameter estimates and levels of significance on factors describing the total logistic transformed cover of erect macroalgal vegetation. Nitrogen load (TN) is given in tons for January-June, depth in metre, sea urchins in percent cover of suitable hard substrate and solar radiation as W m^{-2} for the period January-June.

Parameter estimates

Variable	Reef locality	Estimates	Significance level
Solar radiation		**0.0093**	**0.0177**
Sea urchins (log)		**-0.9769**	**<0.0001**
Locality	**All together:**		**<0.0001**
	For each locality:		
	- Briseis Flak	1.0387	0.5419
	- Broen	9.7540	0.0097
	- Herthas Flak	6.8224	<0.0001
	- Kim's Top	6.3550	<0.0001
	- Kirkegrund	-1.2406	0.6189
	- Knudegrund	-4.0980	0.1419
	- Lysegrund	-1.3489	0.5799
	- Læsø Trindel	-0.5586	0.8342
	- Lønstrup Rødgrund	3.8175	0.2621
	- Munkegrunde	3.6629	0.2744
	- Møns Klint	-4.3572	0.0409
	- Per Nilen	4.3038	0.0065
	- Røsnæs	8.8327	0.3104
	- Schultz's Grund	5.6482	<0.0001
	- Store Middelgrund	3.1667	0.0015
	- Tønneberg Banke	3.4725	0.0328
	- Vejrø	5.2835	<0.0001
Depth * locality	**All together:**		**<0.0001**
	For each locality:		
	- Briseis Flak	0.1245	0.5409
	- Broen	-1.1404	0.0047
	- Herthas Flak	-0.6123	<0.0001
	- Kim's Top	-0.3967	<0.0001
	- Kirkegrund	2.7971	0.6479
	- Knudegrund	-1.5351	0.0477
	- Lysegrund	0.3755	0.2264
	- Læsø Trindel	-0.1208	0.4165
	- Lønstrup Rødgrund	-0.4085	0.2533
	- Munkegrunde	-0.4273	0.2365
	- Møns Klint	-0.7180	0.8492
	- Per Nilen	-0.3948	0.0610
	- Røsnæs	-1.0966	0.1804
	- Schultz's Grund	-0.5956	<0.0001
	- Store Middelgrund	-0.2732	<0.0001
	- Tønneberg Banke	-0.2332	0.0453
	- Vejrø	-0.5050	<0.0001
TN * depth * locality	**All together:**		**0.0008**
	For each locality:		
	- Briseis Flak	-0.000005871	0.0016
	- Broen	0.000005115	0.1496
	- Herthas Flak	-0.000001107	0.0524
	- Kim's Top	-0.000002984	<0.0001
	- Kirkegrund	-0.000064314	0.6744
	- Knudegrund	0.000030695	0.1276
	- Lysegrund	-0.000004875	0.4280
	- Læsø Trindel	-0.000001901	0.0705
	- Lønstrup Rødgrund	-0.000006871	0.0847
	- Munkegrunde	0.000000309	0.9078
	- Møns Klint	0.000022077	0.8142
	- Per Nilen	-0.000001792	0.5707
	- Røsnæs	0.000003710	0.3425
	- Schultz's Grund	-0.000001031	0.2233
	- Store Middelgrund	-0.000001892	0.0034
	- Tønneberg Banke	-0.000002253	0.0204
	- Vejrø	-0.000001456	0.0036
Diver	**All together:**		**0.0234**
	For each diver:		
	- Diver 1	-2.2021	0.1210
	- Diver 2	-0.2954	0.6952
	- Diver 3	-0.3799	0.0691
	- Diver 4	-0.4397	0.0019
	- Diver 5	0.1036	0.8061
	- Diver 6	0	0

Table 4.2 Parameter estimates and levels of significance on factors describing the cumulative cover of erect macroalgal vegetation. Nitrogen load (TN) is given in tons for January-June, depth in metre, sea urchins in percent cover of suitable hard substrate and solar radiation as W m^{-2} for the period January-June.

Parameter estimates			
Variable	Reef locality	Estimates	Significance level
Solar radiation		**0.2263**	**<0.0363**
Sea urchins (log)		**-14.7670**	**<0.0001**
Locality	**All together:**		**<0.0001**
	For each locality:		
	- Briseis Flak	176.25	0.0002
	- Broen	323.64	0.0017
	- Herthas Flak	269.89	<0.0001
	- Kim's Top	279.52	<0.0001
	- Kirkegrund	57.22	0.4024
	- Lysegrund	19.84	0.7647
	- Læsø Trindel	152.56	0.0417
	- Munkegrunde	367.47	<0.0001
	- Møns Klint	-20.67	0.7238
	- Per Nilen	165.61	0.0001
	- Røsnæs	732.28	0.0020
	- Schultz's Grund	166.85	<0.0001
	- Store Middelgrund	212.97	<0.0001
	- Tønneberg Banke	300.81	<0.0001
	- Vejrø	244.42	<0.0001
Depth * locality	**All together:**		**<0.0001**
	For each locality:		
	- Briseis Flak	-3.17	0.5657
	- Broen	-27.47	0.0127
	- Herthas Flak	-16.48	<0.0001
	- Kim's Top	-12.53	<0.0001
	- Kirkegrund	311.33	0.0620
	- Lysegrund	17.40	0.0391
	- Læsø Trindel	-8.19	0.0469
	- Munkegrunde	-25.60	0.0092
	- Møns Klint	154.36	0.1749
	- Per Nilen	-2.36	0.6792
	- Røsnæs	-63.75	0.0042
	- Schultz's Grund	-9.96	<0.0001
	- Store Middelgrund	-8.85	<0.0001
	- Tønneberg Banke	-12.35	0.0002
	- Vejrø	-13.02	<0.0001
TN * depth * locality	**All together:**		**0.0008**
	For each locality:		
	- Briseis Flak	-0.0000903	0.0726
	- Broen	0.0001276	0.1861
	- Herthas Flak	-0.0000121	0.4967
	- Kim's Top	-0.0000585	0.0013
	- Kirkegrund	-0.0076923	0.0651
	- Lysegrund	-0.0000693	0.6783
	- Læsø Trindel	-0.0000480	0.1052
	- Munkegrunde	-0.0000245	0.7357
	- Møns Klint	-0.0037479	0.1867
	- Per Nilen	-0.0000821	0.3388
	- Røsnæs	0.0001356	0.2015
	- Schultz's Grund	-0.0000247	0.3017
	- Store Middelgrund	-0.0000534	0.0024
	- Tønneberg Banke	-0.0000664	0.0137
	- Vejrø	-0.0000297	0.0325
Diver	**All together:**		**0.0131**
	For each diver:		
	- Diver 1	-16.12	0.4555
	- Diver 2	-5.76	0.3494
	- Diver 3	-5.86	0.1455
	- Diver 4	-40.53	0.0008
	- Diver 5	0	-

Figure 4.1 Estimated total erect vegetation cover (thick lines) and 95% confidence intervals (between thin lines) at different depths at 8 different reefs. The chosen scenarios are based on a nitrogen load from January to June of 10,000 tons (blue colour), 48,000 tons (black colour), 23,000 tons (green colour) and 79,000 tons (red colour). Solar radiation is an average value for 1993-2006 from May-July at 213.3 W m^{-2} and presence of sea urchins is 0.1 percent cover.

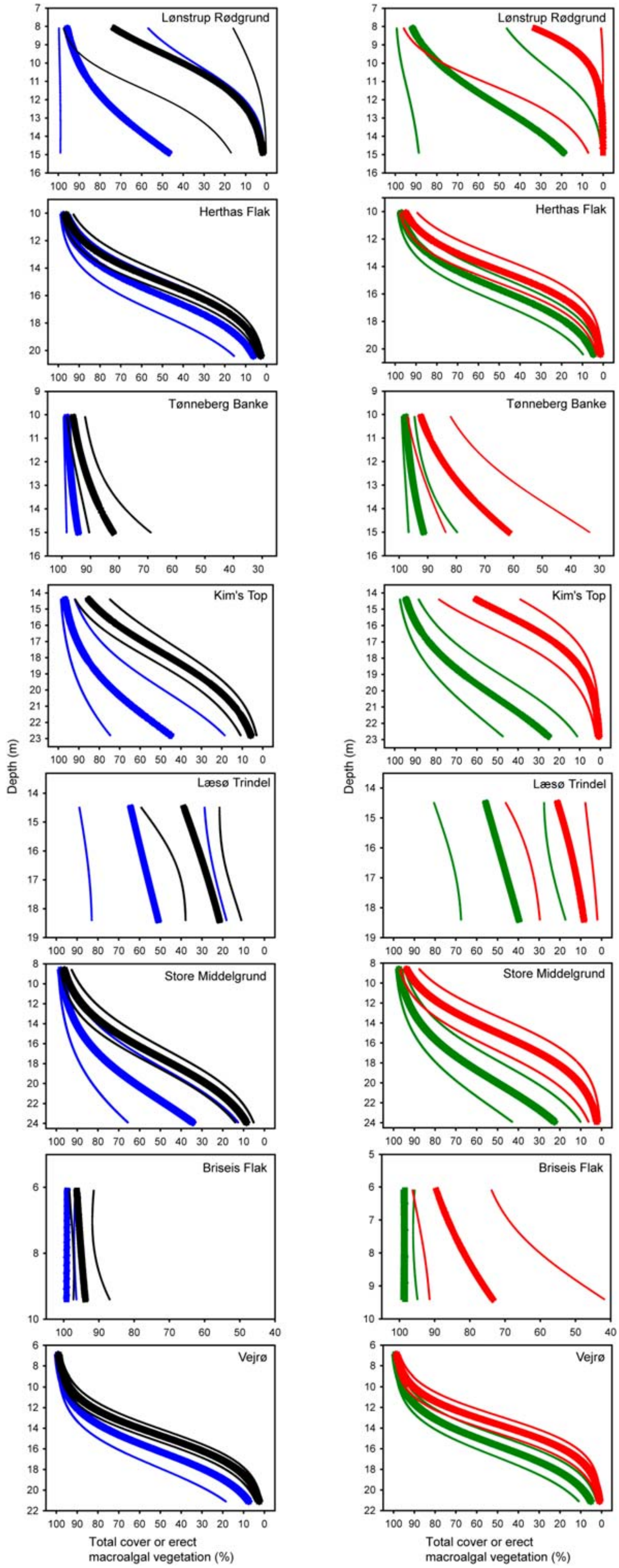
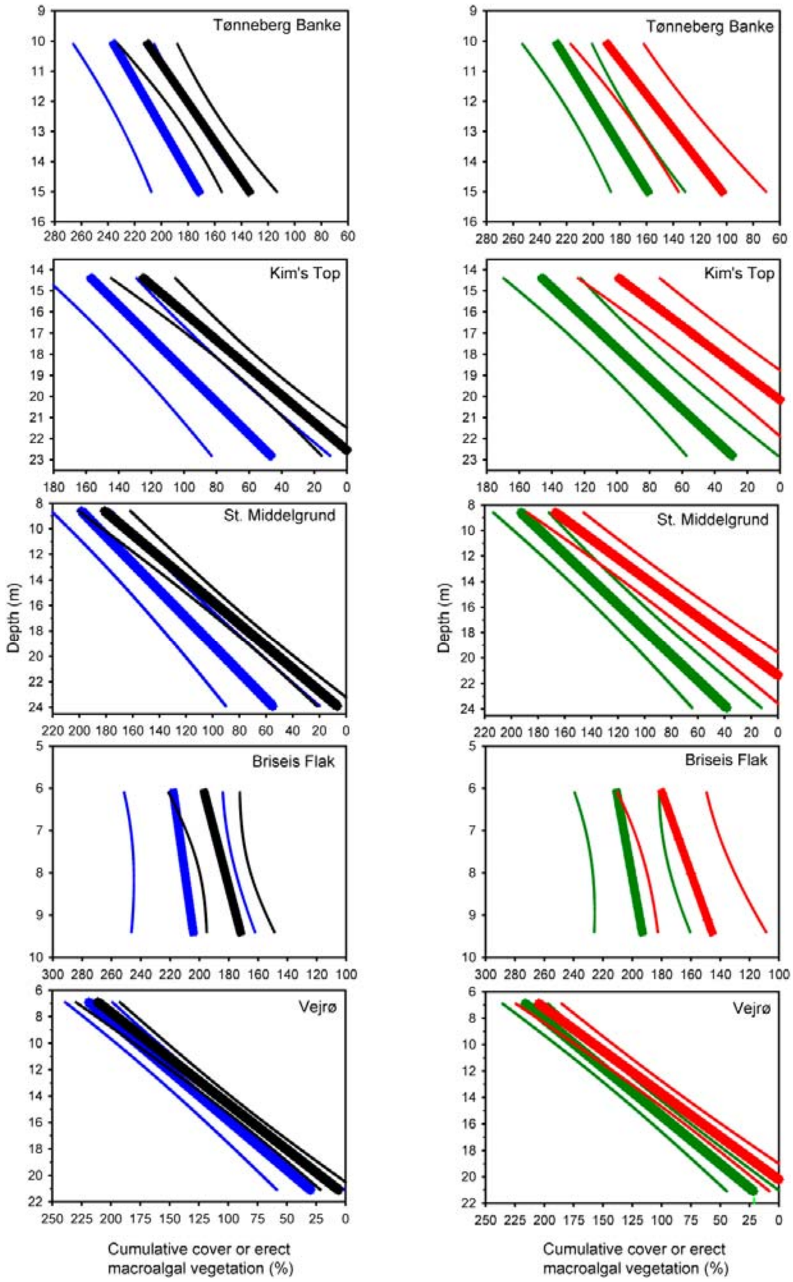


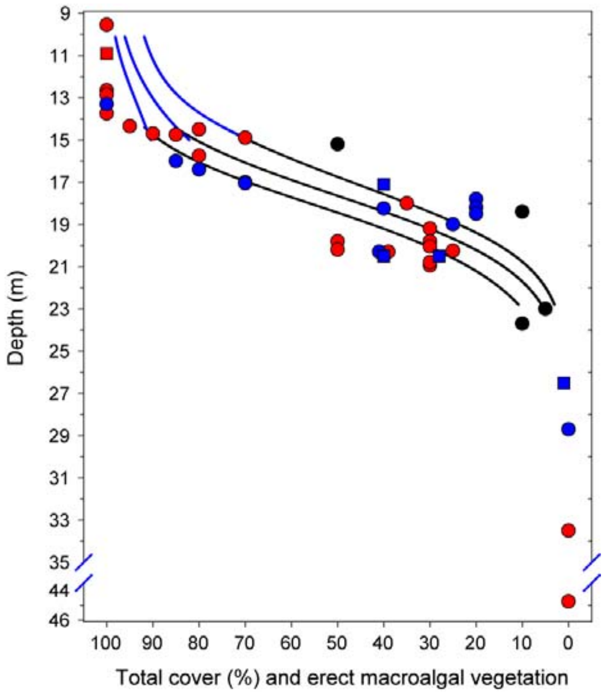
Figure 4.2 Estimated cumulative cover of erect vegetation (thick lines) and 95% confidence intervals (between thin lines) at different depths at 5 different reefs. The chosen scenarios are based on a nitrogen load from January to June of 10,000 tons (blue colour), 48,000 tons (black colour), 23,000 tons (green colour) and 79,000 tons (red colour). Solar radiation is an average value for 1993-2006 from May-July at 213.3 W m^{-2} and presence of sea urchins is 0.1 percent cover.



4.3 Model validation

The estimated total vegetation cover for reef areas in the open Kattegat was validated on data collected in the BALANCE project on several reefs in the central part of Kattegat and in the neighbourhood of Kim's Top (*Dahl et al. 2008*). The modelled vegetation cover used a scenario with an average nitrogen load from 1993-2006, an "average" diver and solar radiation as well as presence of 0.1% sea urchin cover. The majority of data have been collected by judging video sequences from a submerged camera to the seabed and not by divers and the depth accuracy on this dataset is not perfect. Anyway, the observations made in the BALANCE project fit reasonably well with the model from Kim's Top and not quiet as well with the model from the northern reef area Tønneberg Banke (*figure 4.3*).

Figure 4.3 Estimated total cover of erect macroalgal vegetation at Kim's Top (black line from 14-23 m) and Tønneberg Banke (blue line from 10-15 m) and actual observations using a submerged television camera. Red circle: data from videotransect and no sea urchins. Blue circle: data from videotransect and <0.1% sea urchins. Black circle: data from videotransect and 1-2% sea urchins. Red square: Data from diver and no sea urchins. Blue square: data from diver and <0.1% sea urchins (from *Dahl et al. 2008*).



5 Discussion

The period from 1993-2006 is characterised by huge fluctuations in nitrogen and phosphorus loads to the Kattegat and the Belt Sea as a result of changing dry and wet climatic conditions (*Ærtebjerg 2007*). Solar radiation also shows some changes and this is not well correlated with load data. Such data variations are excellent for development of empirical models.

The precondition for the present models that describe vegetation covers as function of nutrient load is the hypothesis that nutrient load regulates the light extinction in the water column by control of plankton biomasses in the surface water (*Nielsen et al. 2002*, *Carstensen et al. 2003*, *Carstensen et al. 2004*) and that light controls the development of macroalgal vegetation.

Both models describe the development of vegetation as a function of nutrient load to inner Danish waters instead of using the actual concentration on each site. The reason for this choice is that interannual variations in nutrient load correlate well with many biological indicators (e.g. *Carstensen et al. 2004*) and nutrients are not frequently monitored in the vicinity of the stone reefs. Differences in effect of nutrients caused by varying gradients in concentrations from sources are reflected in the site specific variable in the models.

Two reef sites are included in the statistical analysis although they are located in the Skagerrak. Nutrient load to this part of the Skagerrak is to a large extent governed by the same precipitation and freshwater discharge pattern as the Kattegat and the Belt Sea area, and therefore interannual variations in macroalgae cover show similar patters to localities in the Kattegat and the Belt Sea. Moreover, to obtain information on site specific governing factors for the localities in Skagerrak the interannual variation has to be resolved. Thus, including the two stone reefs in the Skagerrak improves the information on the governing factors for macroalgae cover.

Overall significant relationships with high correlations were established between the total and cumulative covers of erect vegetation at the investigated stone reefs and identified factors structuring the vegetation.

The total and cumulative vegetation covers differ significantly between reefs in combination with depth and nitrogen load. The site specific differences are likely caused by a combined effect of different nutrient concentrations and changing salinities. The number of species is known to be very sensitive to the changing salinity in Danish waters (*Nielsen et al. 1995*). *Pedersen & Snoeijs (2001)* found clear downward dislocation of algal species from the Skagerrak to the Kattegat and suggest that the wider depth distribution of several algal species is due to changed competition caused by lower salinity.

Solar radiation in the summer months had a positive effect on the development of the algal cover. This implies that natural variation in radiation significantly affects the present state of the vegetation cover and that a normalization procedure to an average radiation is recommendable using the tool in assessing the reef quality.

Sea urchins are important grazers affecting the algal vegetation and unfortunately mass occurrence of this species is observed in several Danish Natura-2000 sites with devastating results for the habitat (*Ærtebjerg et al. 2007*). The most important sea urchin species and the one responsible for the severe reduction in seaweed forests is northern sea urchin (*Strongylocentrotus droebachiensis*). This species is always observed below the pycnocline and is not observed at reefs south of Samsø Bælt, probably due to specific demands in salinity. The vertical distribution of the northern sea urchin at reefs with steep slopes in the Belt Sea area is observed to fluctuate 2-5 metres probably due to changing salinities. This also means that the actual presence of sea urchins not necessarily reflects the species impact on the local vegetation. However, the present model shows that it is possible to parameterize the effect of sea urchins on vegetation cover. It is widely discussed if the risk of outbreak of mass occurrence of sea urchins is linked to lack of biological control caused by the general worldwide reduction in predatory fish species due to overexploitation (*Steneck et al. 2002*). Scenarios made with this model enable us to estimate what is lost in some places and what can be expected to be lost in other places if sea urchins increase in numbers.

A reduction in total load of nitrogen to inner Danish waters (from January-June) will influence the vegetation cover in the following summer in a positive way both with regard to total and cumulative cover. The response seen on both indicators seems most pronounced in the open waters. The previous work with the total cover model (*Dahl et al. 2005*) was not able to distinguish nitrogen load from phosphorus load as the most important structuring nutrient factor. The present result identifying nitrogen as the only significant nutrient factor is in accordance with results from the coastal zone (*Carstensen et al. in prep.*).

Some effect of divers was observed and relates to different judgement of both total and cumulative vegetation covers, even though video and communication are used during cover judgement for on-line intercalibration between divers. Because the majority of data are collected by a team of the same three divers over the years, it is possible with this model to compensate for differences and harmonise the model output to an "average" diver as done in the scenarios.

The two models are both based on linear relationships between algal cover and factors controlling growth conditions for the algae. This might not necessarily be so at species level and might explain some of the variation found in the estimated parameters. The total algal cover includes typical short-living "annual" species and species that can survive for years. The "annual" species, which often peak in late spring and summer, depend on recruitment success and growth conditions in a rather short period. The cover of perennial species on the other hand may also depend on the growth and recruitment conditions the year before. Significant year to year changes in growth conditions can also result in loss of specific species at a given depth, and for some species with a slow colonisation rate it can take time to establish a population again. For this reason the estimated responses on the two chosen algal indicators based on year to year changes are probably conservative compared to expected changes caused by a general improvement in water quality over a longer time span.

Total cover of erect vegetation has a little higher correlation than cumulative cover probably due to the more robust judgement of one general parameter compared to the judgement of covers of several species often growing on top of each other. However, the two models complement each other as assessment tools. Total vegetation cover is only useful as indicator at water depths where the algal cover is less that 100% which is often below depths of 10-14 metres on reefs in open waters. Cumulative cover on the other hand is less dependent on water depth in the range where physical disturbance caused by waves is not an important structuring factor.

The same two indicators have been successfully tested on hard bottom areas in fjords and more exposed costal waters (*Carstensen et al. in prep.*). The coastal model is using a different set-up correlating the development of algal vegetation to spatial differences in total nitrogen and salinity concentrations whereas the present model is based on nutrient load and site specific changes.

6 Conclusions and perspectives

Total and cumulative vegetation covers are shown to be excellent indicators for the ecological quality of reefs in open waters and it is possible to set up targets for a large depth range using the two indicators. Exact targets for favourable conditions on reefs with regard to vegetation covers still need to be established and this should be done separately for each reef location. This task is, however, easily done for the reefs that are significant at site level using the present models, as soon as an agreement on the acceptable national nitrogen load level to inner Danish waters has been reached.

It is more problematic for the majority of the Nature-2000 reefs where significant relationships still need to be established between controlling factors and the indicators. To improve the models – both with respect to accuracy and the number of reef locations covered – more data are needed on vegetation covers. With the present reduction in sampling activities – on most reefs from every third to every sixth year within the NOVANA programme – progress will take a very long time.

Work on a more general model for open reefs sites has been carried out in parallel with this work following the same ideas as the work done on coastal vegetation (*Carstensen et al. in prep*). Further work creating output scenarios from this model could prove to be a useful substitute for site specific models until better data are available.

7 References

Andersen, J.H., Markager, S. & Ærtebjerg, G. (red.) 2004: Tekniske anvisninger for marin overvågning. - Teknisk rapport fra DMU (in Danish). http://m-fdc.dmu.dk

Carstensen, J., Conley, D.J. & Müller-Karulis, B. 2003: Spatial and temporal resolution of carbon fluxes in a shallow coastal ecosystem. - Marine Ecology Progress Series 252: 35-50.

Carstensen, J., Conley, D.J., & Henriksen, P. 2004: Frequency, composition and causes of summer phytoplankton blooms in a shallow coastal ecosystem, the Kattegat. - Limnology and Oceanography 49: 191-201.

Carstensen, J., Krause-Jensen, D., Dahl, K., & Henriksen, P. (*in prep.*): Macroalgae and phytoplankton as indicators of ecological status of Danish coastal waters. National Environmental Research Institute, University of Aarhus. - NERI Technical Report.

Cleveland, W.S. 1979: Robust locally weighted regression and smoothing scatterplots. - Journal of the American Statistical Association 74: 829-836.

Dahl, K., Hansen, J., Helmig, S., Nielsen, R. & Larsen, H.S. 2001: Naturkvalitet på stenrev. Hvilke indikatorer kan vi bruge? Danmarks Miljøundersøgelser. - Faglig rapport fra DMU 352: 130 s. http://www.dmu.dk/1_viden/2_Publikationer/3_fagrapporter/rapporter/FR352.pdf

Dahl, K. (red.), Andersen, J.H. (red.), Riemann, B.(red.), Carstensen, J., Christiansen, T., Krause-Jensen, D., Josefson, A.B., Larsen, M.M., Petersen, J.K., Rasmussen, M.B. & Strand, J. 2005: Redskaber til vurdering af miljø- og naturkvalitet i de danske farvande. Typeinddeling, udvalgte indikatorer og eksempler på klassifikation. Danmarks Miljøundersøgelser. - Faglig rapport fra DMU 535: 158 s. (elektronisk). http://www2.dmu.dk/1_viden/2_Publikationer/3_fagrapporter/rapporter/FR535.PDF

Dahl, K., Leth, J.O., Al-Hamdani, Z., Carstensen, J., Lundsteen, S. & Anthony, D. 2008: Mapping of marine habitats in the Kattegat - Balance Interim Report No. 21. http://balance-eu.org/xpdf/balance-interim-report-no-21.pdf

Krause-Jensen, D., Middelboe, A.L., Carstensen, J. & Dahl, K. 2007: Spatial patterns of macroalgal abundance in relation to eutrophication. - Marine Biology 152(1): 25-36. http://dx.doi.org/10.1007/s00227-007-0676-2

Markager S. & Sand-Jensen K. 1992: Light requirements and depth zonation of marine macroalgae. - Marine Ecology Progress Series 88: 83-92.

Nielsen, R., Kristiansen, A.A., Mathiesen, L., Mathiesen, H. 1995: Distributional index of the benthic macroalgae of the Baltic Sea area. - Acta Botanica Fennica 155: 1-51.

Nielsen, S.L., Sand-Jensen, K., Borum, J., Geertz-Hansen, O. 2002: Phytoplankton, nutrients, and transparency in Danish coastal waters. - Estuaries 25: 930-937.

Pedersen, M. & Snoeijs, P. 2001: Patterns of macroalgal diversity, community composition and long-term changes along the Swedish west coast. - Hydrobiologia 459:83-102.

Petersen, J.K., Hansen, O.S. (eds.), Henriksen, P., Carstensen, J., Krause-Jensen, D., Dahl, K., Josefson, A.B., Hansen, J.L.S., Middelboe, A.L. & Andersen, J.L. 2005: Scientific and technical background for intercalibration of Danish coastal waters. National Environmental Research Institute. - NERI Technical Report 563: 72 s. (electronic).
http://www2.dmu.dk/1_viden/2_Publikationer/3_fagrapporter/rapporter/FR563.PDF

Steneck, R.S., Graham, M.H., Bourque, B.J., Corbett, D., Erlandson, J.M., Estes, J.A. & Tegner, M.J. 2002: Kelp forest ecosystems: biodiversity, stability, resilience and future. - Environmental Conservation 29: 436-459.

Ærtebjerg, G. (red.) 2007: Marine områder 2005-2006 - Tilstand og udvikling i miljø- og naturkvaliteten. NOVANA. Danmarks Miljøundersøgelser, Aarhus Universitet. - Faglig rapport fra DMU 639: 95 s. (elektronisk).
http://www.dmu.dk/Pub/FR639.pdf

Appendix 1

Example on how to calculate the expected value for a given reef at a given depth and at given input values of TN load, solar radiation and sea urchin cover. Calculation of 95% confidence values needs statistical tools.

Locality	**Kim's Top**	
Chosen input values:		
Depth (m)	18	
TN load (tons)	48000	
Solar radiation W m^{-2}	213.3	
Sea urchins (log)	0.1	
Estimates:		Calculation of contribution
Solar radiation	0.0093	1.98369
Sea urchin	-0.9769	1.572259897
Locality	6.355	6.355
Locality * depth	-0.3967	-7.1406
TN * depth * locality	-0.000002984	-2.578176
Diver (average)	-0.535583333	-0.535583333
SUM		-0.343409437
Back transforming from Logistic transformation		0.414981523
Expressed in % cover		41.49815226

NERI **National Environmental Research Institute**
DMU Danmarks Miljøundersøgelser

National Environmental Research Institute, NERI, is a part of University of Aarhus.

NERI's tasks are primarily to conduct research, collect data, and give advice on problems related to the environment and nature.

At NERI's website www.neri.dk you'll find information regarding ongoing research and development projects.

Furthermore the website contains a database of publications including scientific articles, reports, conference contributions etc. produced by NERI staff members.

Further information: www.neri.dk

National Environmental Research Institute
Frederiksborgvej 399
PO Box 358
DK-4000 Roskilde
Denmark
Tel: +45 4630 1200
Fax: +45 4630 1114

Management
Personnel and Economy Secretariat
Monitoring, Advice and Research Secretariat
Department of Policy Analysis
Department of Atmospheric Environment
Department of Marine Ecology
Department of Environmental Chemistry and Microbiology
Department of Arctic Environment

National Environmental Research Institute
Vejlsøvej 25
PO Box 314
DK-8600 Silkeborg
Denmark
Tel: +45 8920 1400
Fax: +45 8920 1414

Monitoring, Advice and Research Secretariat
Department of Marine Ecology
Department of Terrestrial Ecology
Department of Freshwater Ecology

National Environmental Research Institute
Grenåvej 14, Kalø
DK-8410 Rønde
Denmark
Tel: +45 8920 1700
Fax: +45 8920 1514

Department of Wildlife Ecology and Biodiversity

NERI Technical Reports

NERI's website www.neri.dk contains a list of all published technical reports along with other NERI publications. All recent reports can be downloaded in electronic format (pdf) without charge. Some of the Danish reports include an English summary.

Nr./No. **2008**

653 Control of Pesticides 2006. Chemical Substances and Chemical Preparations.
By Krongaard, T., Petersen, K.K. & Christoffersen, C. 25 pp.

652 A preliminary strategic environmental impact assessment of mineral and hydrocarbon activities on the Nuussuaq peninsula, West Greenland.
By Boertmann, D. et al. 66 pp.

651 Undersøgelser af jordhandler i forbindelse med naturgenopretning.
Af Jensen, P.L., Schou, J.S. & Ørby, P.V. 44 s.

650 Fuel consumption and emissions from navigation in Denmark from 1990-2005 – and projections from 2006-2030. By Winther, M. 108 pp.

2007

649 Annual Danish Emission Inventory Report to UNECE. Inventories from the base year of the protocols to year 2005. By Illerup, J.B. et al. 182 pp.

648 Optælling af agerhøns på Kalø Gods 2004-2007 – metodeafprøvning og bestandsudvikling.
Af Odderskær, P. & Berthelsen, J.P. 38 s.

647 Criteria for favourable conservation status in Denmark. Natural habitat types and species covered by the EEC Habitats Directive and birds covered by the EEC Birds Directive.
By Søgaard, b. et al. 92 pp.

646 Vandmiljø og Natur 2006. NOVANA. Tilstand og udvikling – faglig sammenfatning.
Af Boutrup, S. et al. 125 s.

645 Atmosfærisk deposition 2006. NOVANA. Af Ellermann, T. et al. 62 s.

644 Arter 2006. NOVANA. Af Søgaard, B., Pihl, S. & Wind, P. 88 s.

643 Terrestriske Naturtyper 2006. NOVANA. Af Bruus, M. et al. 70 s.

642 Vandløb 2006. NOVANA. Af Bøgestrand, J. (red.). 93 s.

641 Søer 2006. NOVANA. Af Jørgensen, T.B. et al. 63 s.

640 Landovevågningsoplande 2006. NOVANA. Af Grant, R. et al. 121 s.

639 Marine områder 2005-2006. Tilstand og udvikling i miljø- og naturkvaliteten. NOVANA.
Af Ærtebjerg, G. (red.). 95 s.

637 Forvaltningsmetoder i N-belastede habitatnaturtyper. Af Damgaard, C. et al. 46 s.

636 Sørestaurering i Danmark. Del 1: Tværgående analyser, Del 2: Eksempelsamling.
Af Liboriussen, L., Søndergaard, M. & Jeppesen, E. (red.). 86 s. + 312 s.

635 Håndbog om dyrearter på habitatdirektivets bilag IV – til brug i administration og planlægning.
Af Søgaard, B. et al. 226 s.

634 Skovenes naturtilstand. Beregningsmetoder for Habitatdirektivets skovtyper.
Af Fredshavn, J.R. et al. 52 s.

633 OML Highway. Phase 1: Specifications for a Danish Highway Air Pollution Model.
By Berkowicz, R. et al. 58 pp.

632 Denmark's National Inventory Report 2007. Emission Inventories – Submitted under the United Nations Framework Convention on Climate Change, 1990-2005. By Illerup, J.B. et al. 638 pp.

631 Biologisk vurdering og effektundersøgelser af faunapassager langs motorvejsstrækninger i Vendsyssel. Af Christensen, E. et al. 169 s.

630 Control of Pesticides 2005. Chemical Substances and Chemical Preparations.
By Krongaard, T., Petersen, K.K. & Christoffersen, C. 24 pp.

629 A chemical and biological study of the impact of a suspected oil seep at the coast of Marraat, Nuussuaq, Greenland. With a summary of other environmental studies of hydrocarbons in Greenland. By Mosbech, A. et al. 55 pp.

628 Danish Emission Inventories for Stationary Combustion Plants. Inventories until year 2004.
By Nielsen, O.-K., Nielsen, M. & Illerup, J.B. 176 pp.

627 Verification of the Danish emission inventory data by national and international data comparisons. By Fauser, P. et al. 51 pp.

[Blank page]

663 Tools to assess conservation status on open water reefs in Nature-2000 areas

This work shows that total and cumulative vegetation covers are excellent indicators of the ecological quality of reefs in open waters. Total nitrogen load to inner Danish waters from January to July as well as solar radiation from May to July and presence of sea urchins are important anthropogenic and natural factors controlling the two indicators. Furthermore, there are significant differences between most reef locations. Based on parameter estimates from the statistical analysis, predictive models for both indicators have been established for a number of reef locations with good data coverage. Such models can be used to set targets for the vegetation covers using input targets on nitrogen load set by other indicators or measurements.

National Environmental Research Institute
University of Aarhus · Denmark

978-87-7073-038-9
ISSN 1600-0048