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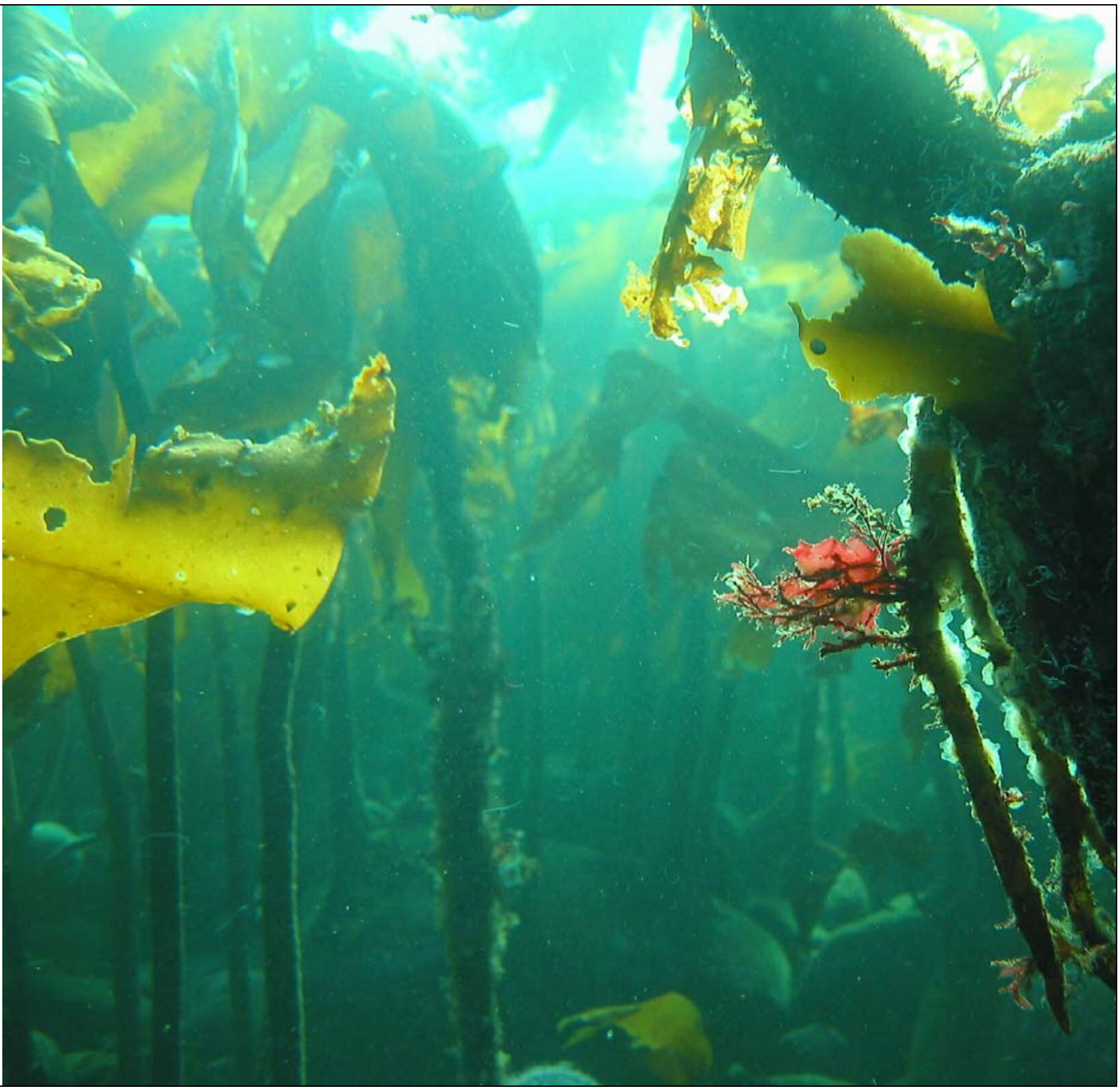
Spatial predictions of *Laminaria hyperborea* at the Norwegian Skagerrak coast



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REPORT

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Summary. The overall aim of the study was to investigate to what extent the distribution of L. hyperborea in Skagerrak has changed during the last 10-15 years. To do this, we first needed to test to what extent available data, i.e. data from the National monitoring program (KYO) are representative enough and could be used to for predicting spatial changes in the L. hyperborea distribution. Three models were compared. The first model, referred to as the "Full model", included registrations from the National program for mapping of prioritised nature types, and 2004 data from KYO. The second model, called KYO 2004, used only recordings from KYO 2004. The third model using KYO data from 1995 was also compared to the other two. If the predictions from the KYO 2004 model were approximately similar to the predictions of the Full model, we would assume that comparing KYO models from different years would give information about temporal differences in the distribution of L. hyperborea. The results showed that there were generally larger differences in the prediction between the full model and the model including KYO data from 2004, than between the two KYO models including data from 1995 and 2004. The KYO models underestimated the distribution of kelp compared to the Full model. The data used in KYO models did not cover the whole exposure gradient which is the main reason for the less accurate predictions. While time series data from KYO represent a very important tool for monitoring community changes in the Skagerrak, they are not designed to analyse spatial changes in the distribution of species. To do so, specific monitoring programs are needed.

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1. Laminaria hyperborea	1. Laminaria hyperborea
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4. Kystplanering	4. Coastal management

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Stockholm 01.05.2007

Front page: *Laminaria hyperborea* kelp forest at Finnøy on the west coast of Norway. Photo Martin Isæus

Preface

This project was a part of the NIVA project DYNAMOD and the EU Interreg III B project "BALANCE – Baltic Sea management, nature conservation and sustainable development in the marine ecosystem through spatial planning". This particular project is part of work package 2 "The marine landscapes and habitats of the Baltic Sea" which aims to provide spatial descriptions of the sea floor useful for management purposes.

Field data used in the report were provided from the National Coastal Monitoring Program (Kystoveråkningen, a national monitoring program funded by The Pollution Control Authorities SFT) and the National Program for Mapping of prioritised nature types (funded by Ministry of Fishery and Coastal affairs (FKD), Ministry of Environment (MD) and Ministry of Defence (FD). The project was funded by the Danish Forest and Nature Agency (SNS) and by Norwegian institute for water research (NIVA) within Kystovervåkningen.

Stockholm, 01.05.2007

Martin Isæus
Project leader

Content

Summary

The overall aim of the study was to investigate to what extent the distribution of *L. hyperborea* in Skagerrak has changed during the last 10-15 years. To do this, we first needed to test to what extent available data, i.e. data from the National monitoring program (KYO) are representative enough and could be used to for predicting spatial changes in the *L. hyperborea* distribution. Three models were compared. The first model, referred to as the "Full model", included registrations from the National program for mapping of prioritised nature types, and 2004 data from KYO. The second model, called KYO 2004, used only recordings from KYO 2004. The third model using KYO data from 1995 was also compared to the other two. If the predictions from the KYO 2004 model were approximately similar to the predictions of the Full model, we would assume that comparing KYO models from different years would give information about temporal differences in the distribution of L. hyperborea.

The results showed that there were generally larger differences in the prediction between the full model and the model including KYO data from 2004, than between the two KYO models including data from 1995 and 2004. The KYO models underestimated the distribution of kelp compared to the Full model. The data used in KYO models did not cover the whole exposure gradient which is the main reason for the less accurate predictions. While time series data from KYO represent a very important tool for monitoring community changes in the Skagerrak, they are not designed to analyse spatial changes in the distribution of species. To do so, specific monitoring programs are needed.

1. Background and aim

Results from an ongoing investigation along the Norwegian Skagerrak coast shows that major changes occurr in the phytobenthic community along the Norwegian Skagerrak coast. The kelp *Saccharina latissima* (former *Laminaria saccharina*) has disappeared from many sites and been exchanged by a filamentous turf, and has then recolonised again at some sites (Moy et al. 2003, 2007) Changes in the distribution of the kelp *Laminaria hyperborea* has also occurred, but the changes are not as drastic as for *S. latissima*. *L. hyperborea* is a habitat forming species with a highly diverse community associated with its stands, and the habitat is therefore pointed out as a prioritised nature type by Norwegian authorities (Anon. 2001).

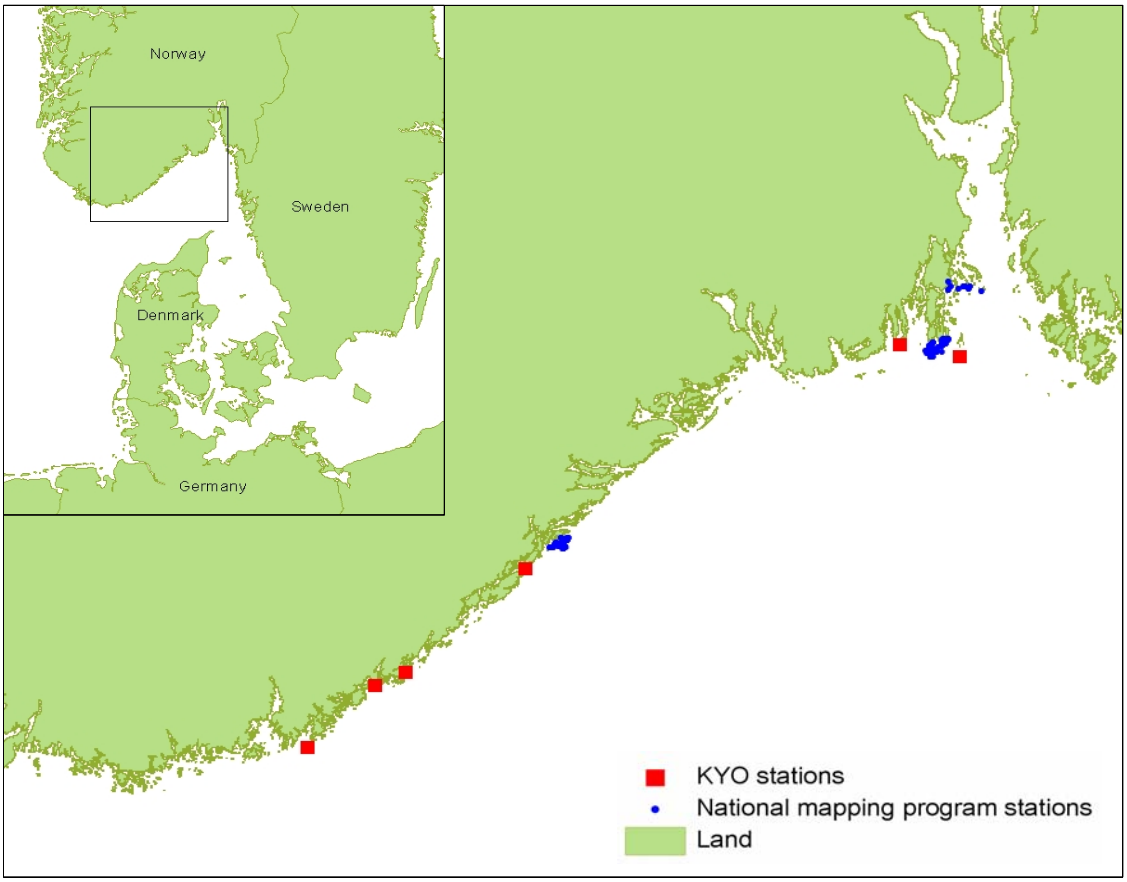

Figure 1. Field stations of the national monitoring program (KYO) and national mapping program 2005-2006.

Dive transect data from national coastal monitoring (Kystovervåkningen or KYO) provides time series data with information about the occurrence of sessile organisms, including *L. hyperborea* on monitoring stations in the Skagerrak in the period 1990-2006. These data may be used to model changes in the distribution of *L. hyperborea* if the stations are representative with respect to the distribution of *L. hyperborea* within intervals of the factors that are used in the model.

The aim of the study was to investigate to what extent the distribution of *L. hyperborea* in Skagerrak has changed during the last 10-15 years. Available data included yearly registrations (0-30 m depth, 6 stations) from KYO, and registrations from the National program for mapping of prioritised nature types (Fig 1). (KYO stations from which data was not available for all years were excluded, and are not shown in fig 1.)

First, we needed to test if the data set from the National monitoring program (KYO) was large enough be used to predict the spatial distribution of *L. hyperborea*. If so, we use predictive modelling for estimating the spatial changes of *L. hyberborea* over time. If the KYO-data was not sufficient, we use all data for spatial modelling to make the best possible prediction of *L. hyperborea* distribution along the Norwegian Skagerrak coast.

2. Material & Methods

The test if the data set from the National monitoring program (KYO) was large enough be used to predict the spatial distribution of *L. hyperborea* was done by comparing the results of three spatial models; one based on all data from the National program for mapping of prioritised nature types plus KYO data from 2004 (Full model), one based only on KYO data from 2004 (KYO 2004 model), and one based only on KYO data from 1995 (KYO 1995 model). It was assumed that the Full model would be able to predict *L. hyperborea* distribution better than the KYO models. If predictions from the Full model and the KYO model 2004 were approximately similar, we would conclude that KYO data was sufficient to construct models for predicting the distribution of *L. hyperborea* in Skagerrak. KYO models from different years could then be used to analyse changes in the distribution of *L. hyperborea* between years. To use the years 2004-2006 together in the Full model, it was assumed that the change during these three years was not significant.

2.1 Available data

The National Mapping Program included approximately 200 drop camera registrations in three areas in the Skagerrak Sea from 2005 and 2006. The KYO datasets included yearly registrations from 1990-2005 at 6 stations that were monitored during the whole period. Registrations of all visible sessile organisms were made by divers along transects from 30 to 0 m depth.

2.2 Modelling

Generalized Additive Models (GAM) in the GRASP extension to the S-PLUS software package were used for statistical analyses of the data, and Akaike's Information Criterion (AIC) was used for model selection. GRASP (Lehmann 2002) has proved to be a good tool for predictive modelling in both aquatic (Francis 2005, Garza-Pérez 2004, Schmeider 2004) and terrestrial environments (Zaniewski 2002).

Predictors in the models were wave exposure (SWM, Isæus 2004, 25 m resolution), depth (from a 25 m resolution digital elevation model), curvature (500 m resolution, analysed from the depth model), slope (25 m resolution, analysed from the depth model) and light exposure (light exposure in respect to the optimal angle, calculated from slope and aspect). Response variable was presence or absence of *L. hyperborea.*

Spatial predictions based on the GAM models were made in ArcView. Predictions result in grid-based maps showing the probability of presence of *L. hyperborea* in each grid cell. Predictions were classified in four probability classes, 0-0.25, 0.25-0.5, 0.5-0.75 and 0.75-1. All grids had a resolution of 25 m. The prediction grids were then compared using the Spatial Analyst extension.

To build a model of species distribution that accurately describes the variation of the target species, it is necessary that the collected field data covers the whole gradient of the environmental variables used as predictors. For example, if the model should be valid from 5-50 meters depth, this whole gradient should be present in the field data, even though the target species is only present between 10-15 meters. If part of the gradient is missing from the field data, the model and hence the predictions in this span will likely be inaccurate. In this case, this meant that predictions were restricted to areas where environmental predictors (primarily wave exposure) were inside the span covered in the field data. For the full model, predictions were made in the exposure interval 2.900-627.000 swm, while the KYO data predictions were made in the exposure interval 124.000-554.000 swm.

3. Results

3.1 The Full model

The predicted distribution of *Laminaria hyperborea* (LAMHY) along environmental gradients in the Full model is shown in Fig. 2. All available data from the National program for mapping (registrations from 2005-2006) and KYO (National monitoring program, registrations from 2004) were used. As can be seen in Fig. 2, field data in this case covered almost the whole gradient of the different environmental predictors.

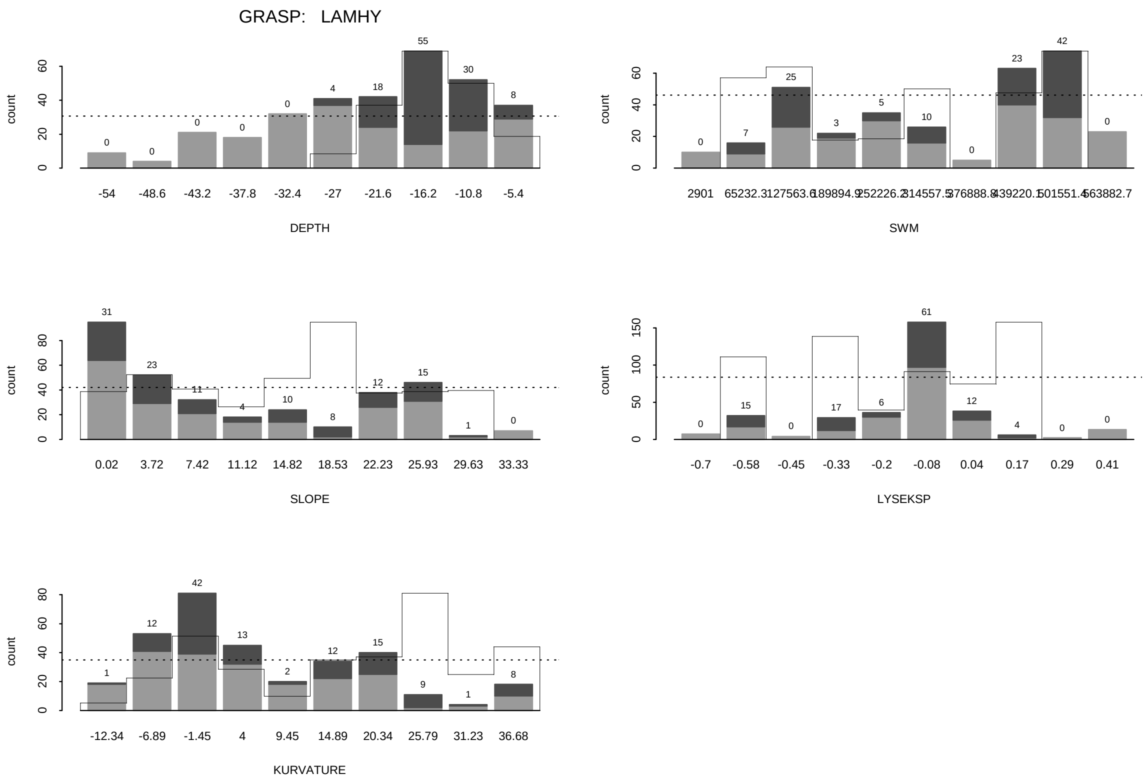

Fig. 2. Distribution of *L. hyperborea* (LAMHY) along environmental gradients in the full model: Depth, wave exposure (SWM), slope, light exposure (LYSEKSP) and curvature (500 m scale) The entire bars represent distribution of all data, and dark areas represent presence of LAMHY. The plain line is the ratio between presence and absence data and the dashed line corresponds to the overall mean proportion of presence data.

According to AIC selection, the best model (AIC=181.3) explaining presence of *L. hyperborea* (LAMHY) includes depth, exposure (swm), light exposure (LYSEKSP) and curvature. Cross validation showed a cvROC (5-fold)=0.95. In Figure 3 partial response curves for each predictor in the selected model is shown.

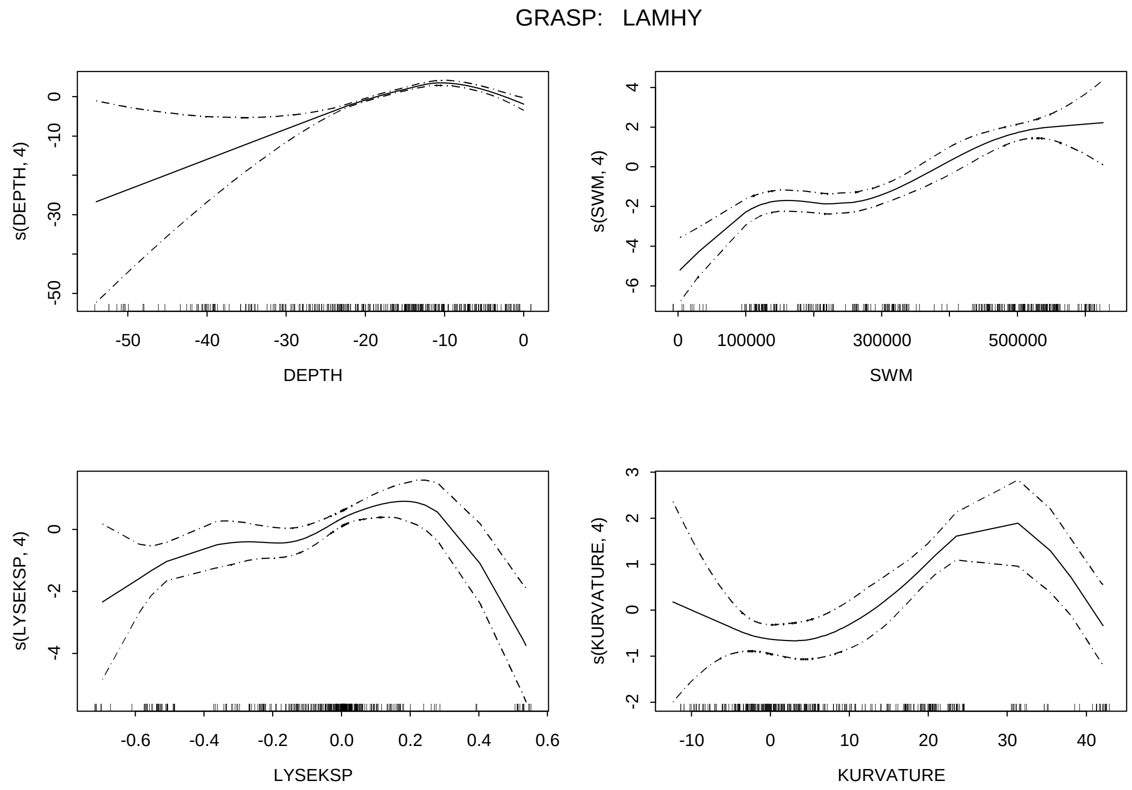

Figure 3. Partial response curves (±2 x S.E.) of LAMHY presence for each predictor in the selected model.

Spatial predictions of *L. hyperborea* (LAMHY, probability of presence) from the Full model is shown in Fig. 4. *L. hyperborea* is found at exposed sites in the sub-litoral down to a depth of approximately 25 m.

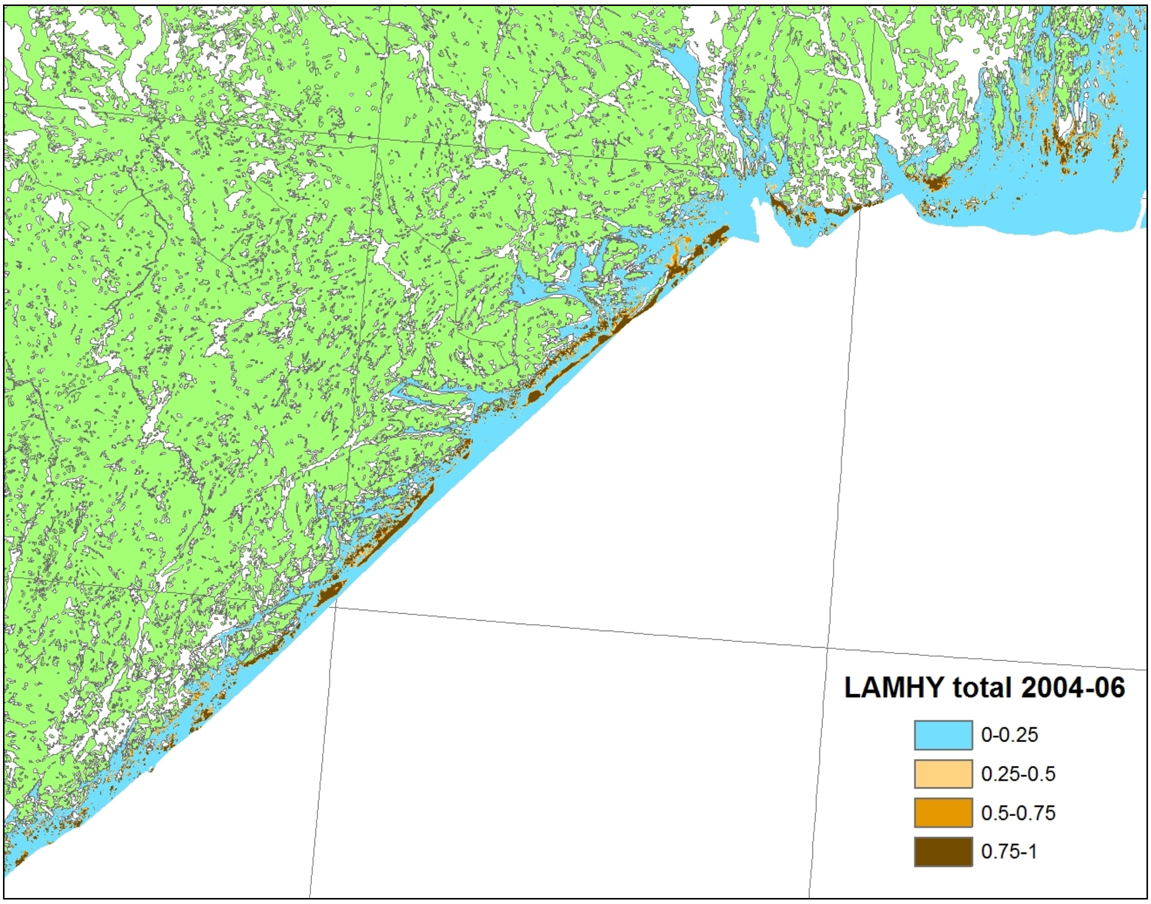

Fig. 4. Probability of presence of *Laminaria hyperborea* in four classes, as predicted by the full model. White areas have swm outside the span 2900-627000, and are outside the area in which the model can reliably predict *L. hyperborea* distribution. Green areas are land area.

In a smaller segment of the map, the predicted distribution of *L. hyperborea* on the outside (the exposed side) of skerries can be seen (Fig. 5).

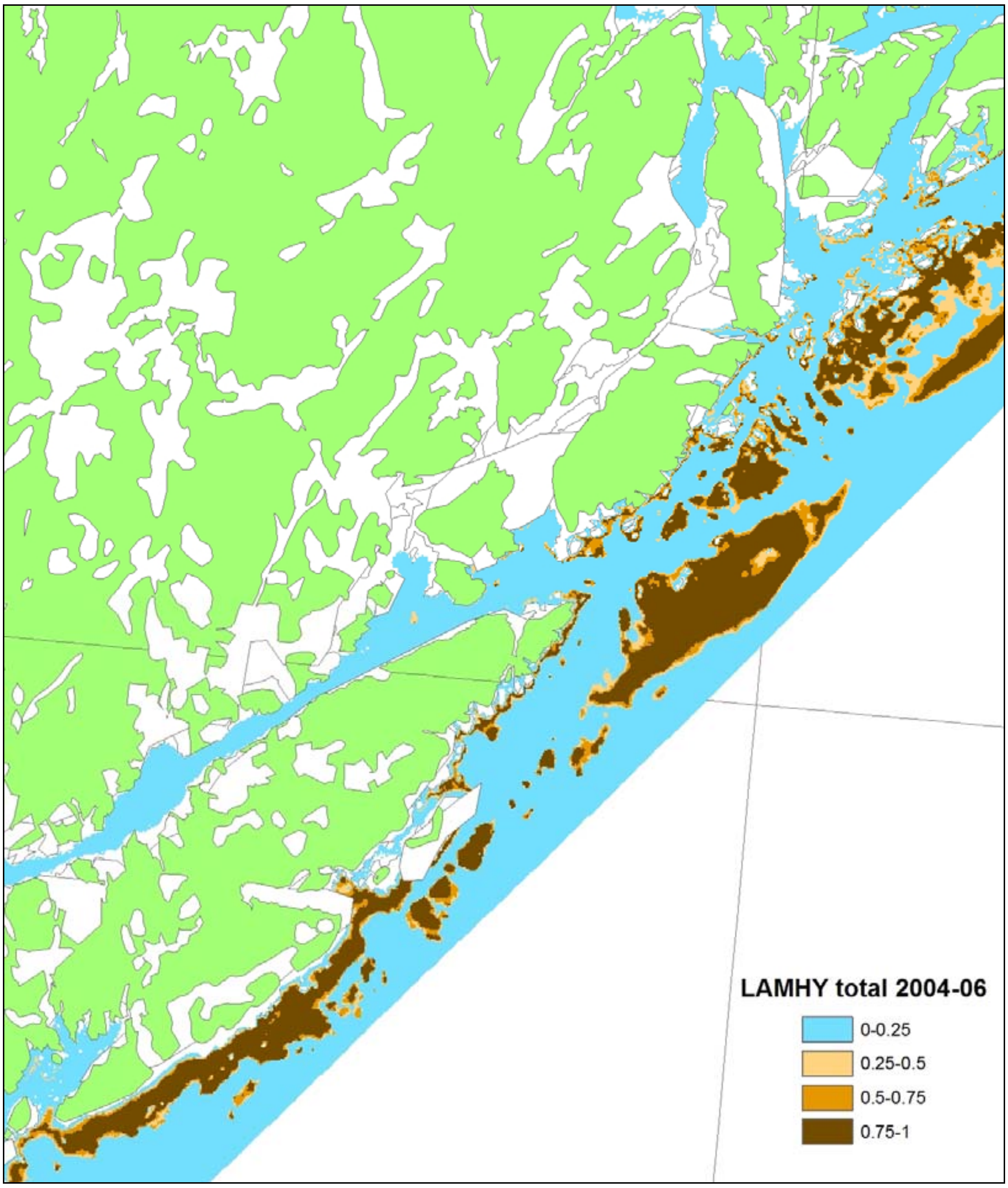

Figure 5. Probability of presence of *Laminaria hyperborea*, as predicted by the full model. Map segment from a smaller part of the Skagerrak. White areas have swm outside the span 2900-627000, and are outside the area in which the model can reliably predict *L. hyperborea* distribution. Green areas are land area.

3.2 Model KYO 2004

The distribution of *Laminaria hyperborea* (LAMHY) along environmental gradients in the model based on KYO 2004 data only, is shown in Fig. 6. As can be seen in this figure, field data in this case did not cover the whole gradients of environmental predictors, perhaps most obvious for SWM and slope. This is due to the fact that the model is based on data from only six sites, and the variation in horizontally varying parameters, such as wave exposure at surface level, is low. On the other hand, the description of the variation of kelp along the depth gradient is well described (Fig. 6, “DEPTH”) since all six stations have registrations at each meter of depth in the phytobenthic zone.

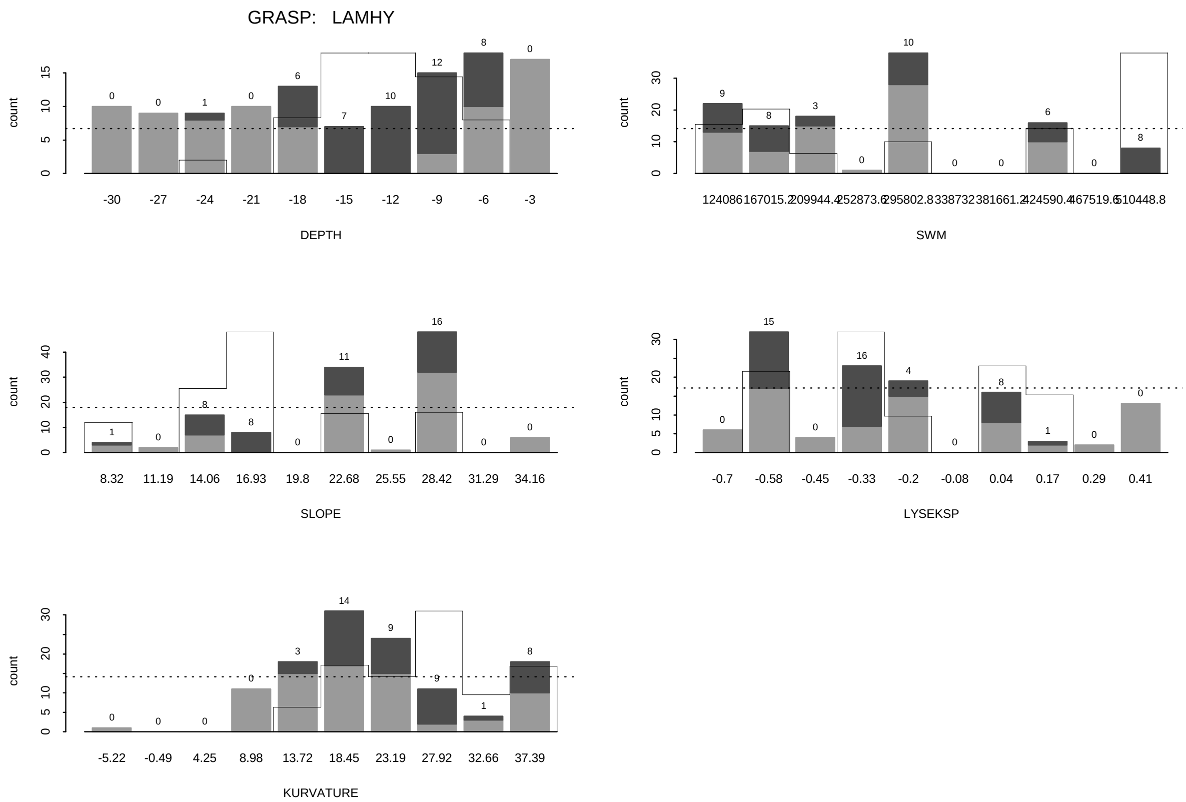

Figure 6. Distribution of *L. hyperborea* along environmental gradients in the KYO 2004 model. The entire bars represent distribution of all data, and dark areas represent presence of LAMHY. The plain line is the ratio between presence and absence data and the dashed line corresponds to the overall mean proportion of presence data.

According to AIC selection, the best model (AIC=72.0) to explain presence of *L. hyperborea* (LAMHY) includes depth, wave exposure (SWM), and curvature. Light exposure (LYSEKSP) and slope was excluded as a predictor from the model. Cross validation showed a cvROC (5-fold) for the selected model 0.93. In Figure 7 partial response curves for each predictor in the selected model are shown.

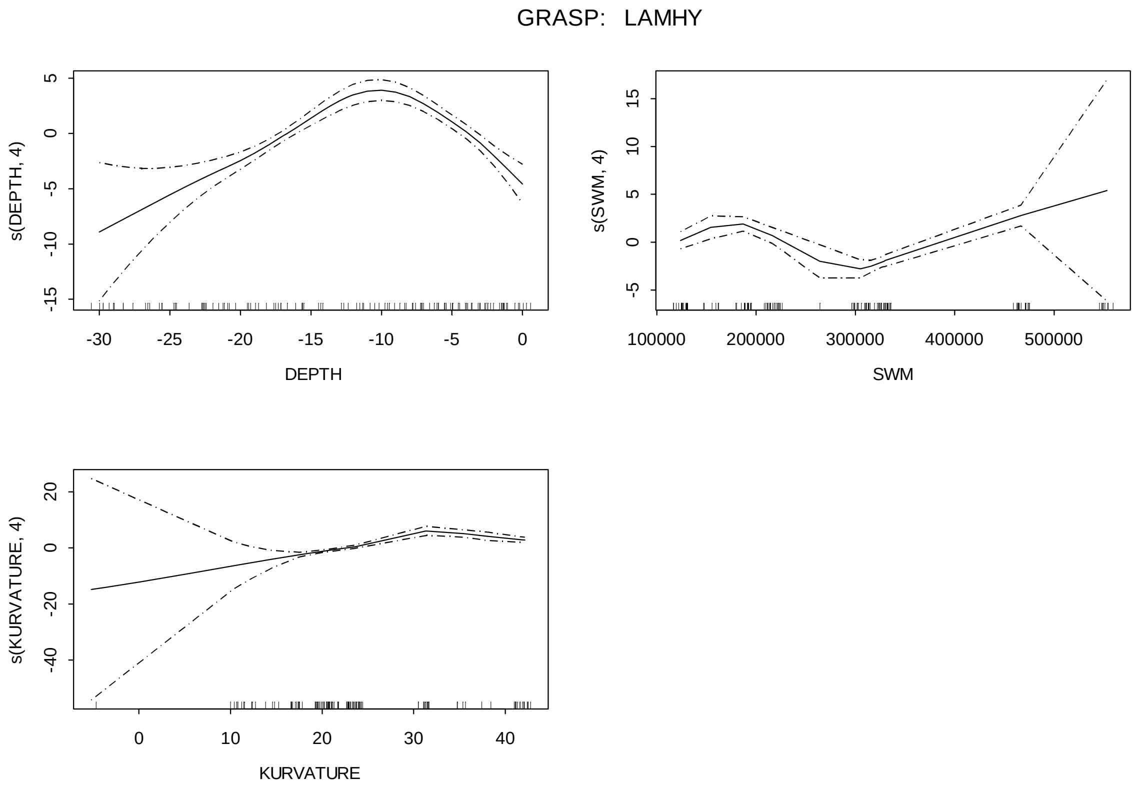

Fig. 7. Partial response curves (±2 x S.E.) of LAMHY presence for each predictor in the selected model.

Spatial predictions from the KYO 2004 model of probability of presence of *L. hyperborea* in a larger part of the Skagerrak area is shown in figure 8.

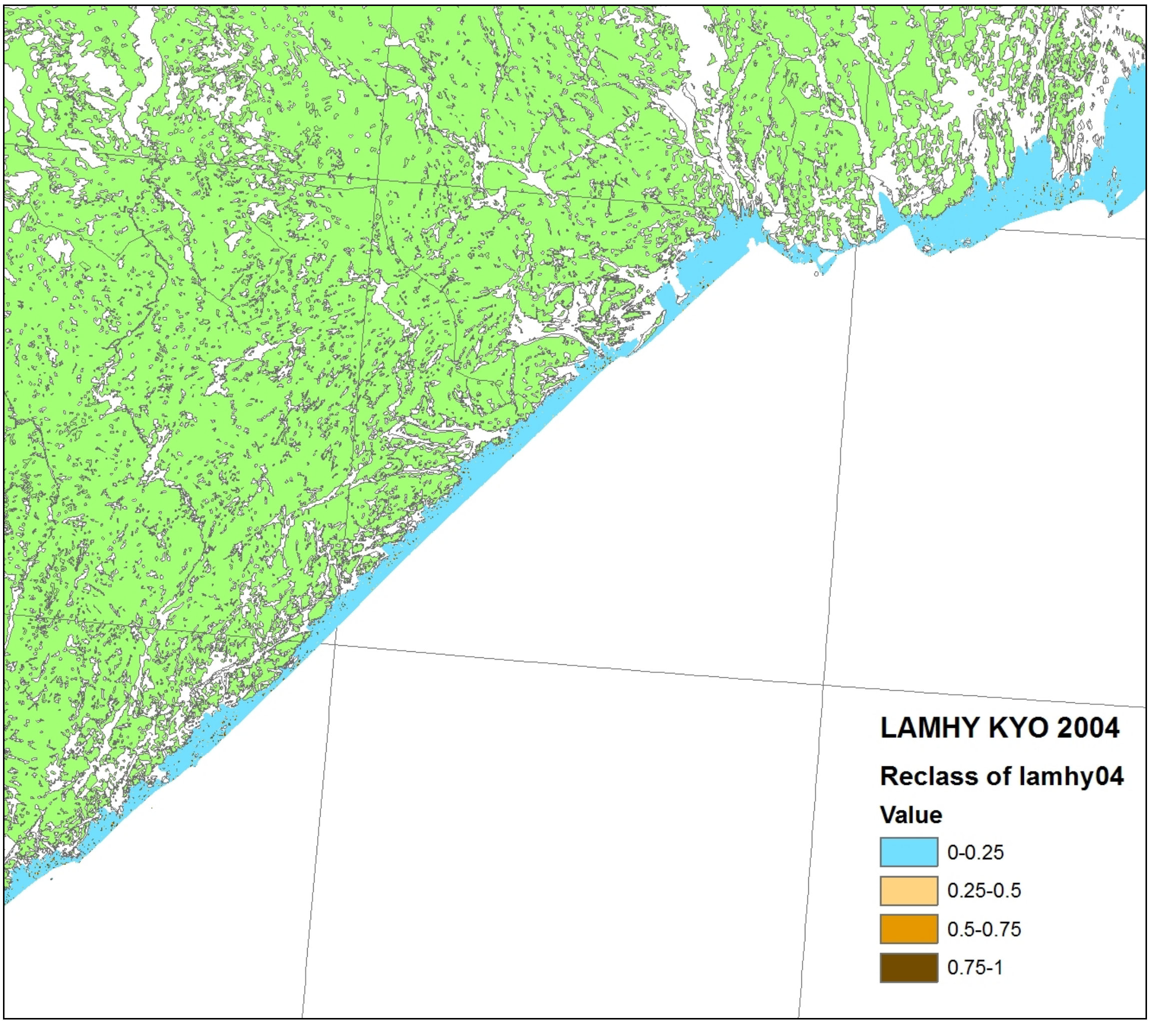

Fig. 8. Probability of presence of *Laminaria hyperborea* in four classes, as predicted by the KYO 2004 model. White areas have have swm outside the span 124000-554000, and are outside the area in which the model can reliably predict *L. hyperborea* distribution. Green areas are land area.

In a smaller segment of the map (the same area showed in Fig. 5), the distribution of *L. hyperborea* on the outside (the exposed side) of skerries can be seen (Fig. 9).

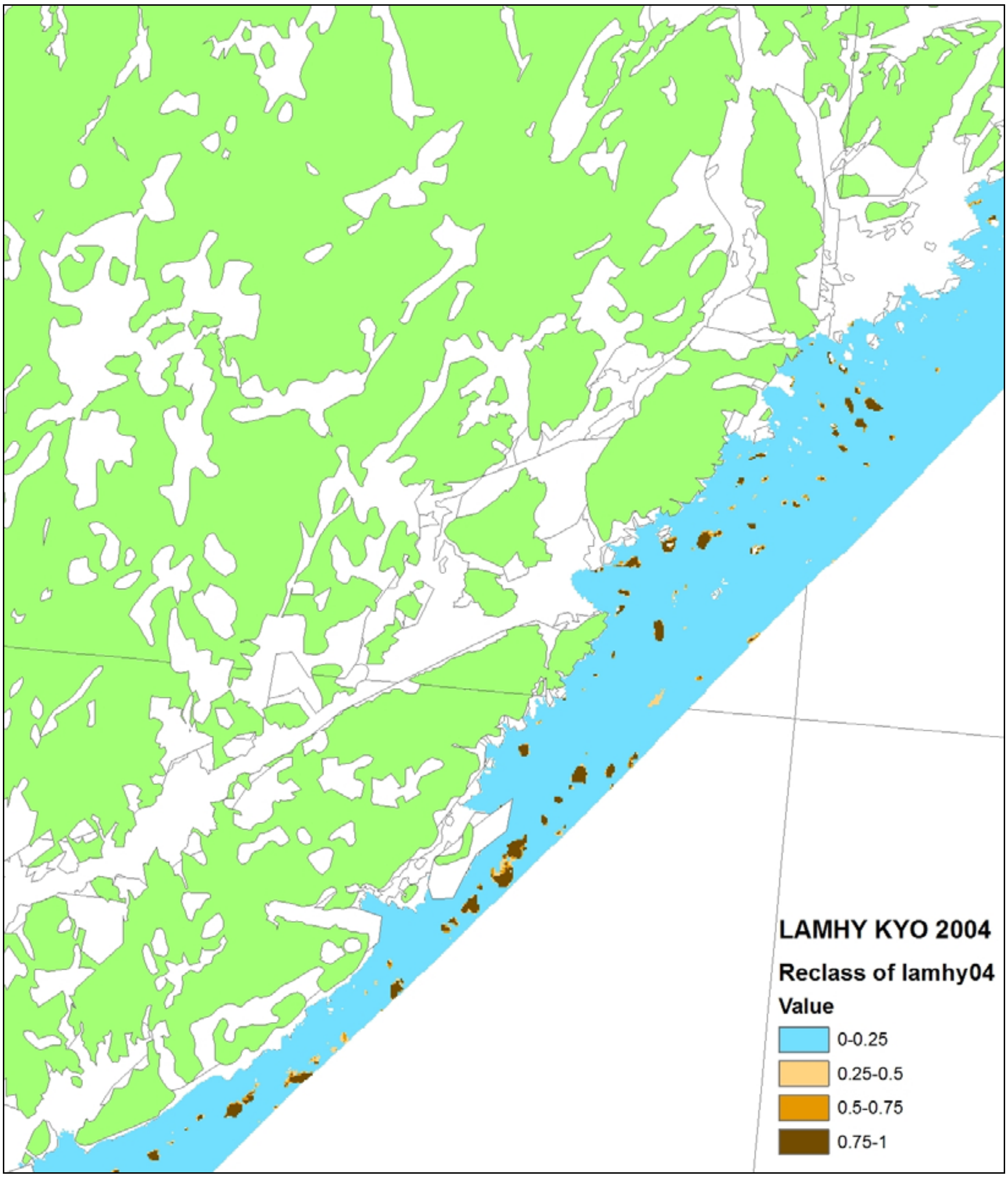

Fig. 9. Probability of presence of *Laminaria hyperborea*, as predicted by the KYO 2004 model. Map segment from a smaller part of the Skagerrak. White areas have swm outside the span 124000-554000, and are outside the area in which the model can reliably predict *L. hyperborea* distribution. Green areas are land area.

3.3 Model KYO 1995

The distribution of *Laminaria hyperborea* (LAMHY) along environmental gradients in the model based on KYO data from 1995 is shown in Fig. 10. The figure indicates gaps in the gradients for several of the environmental predictors.

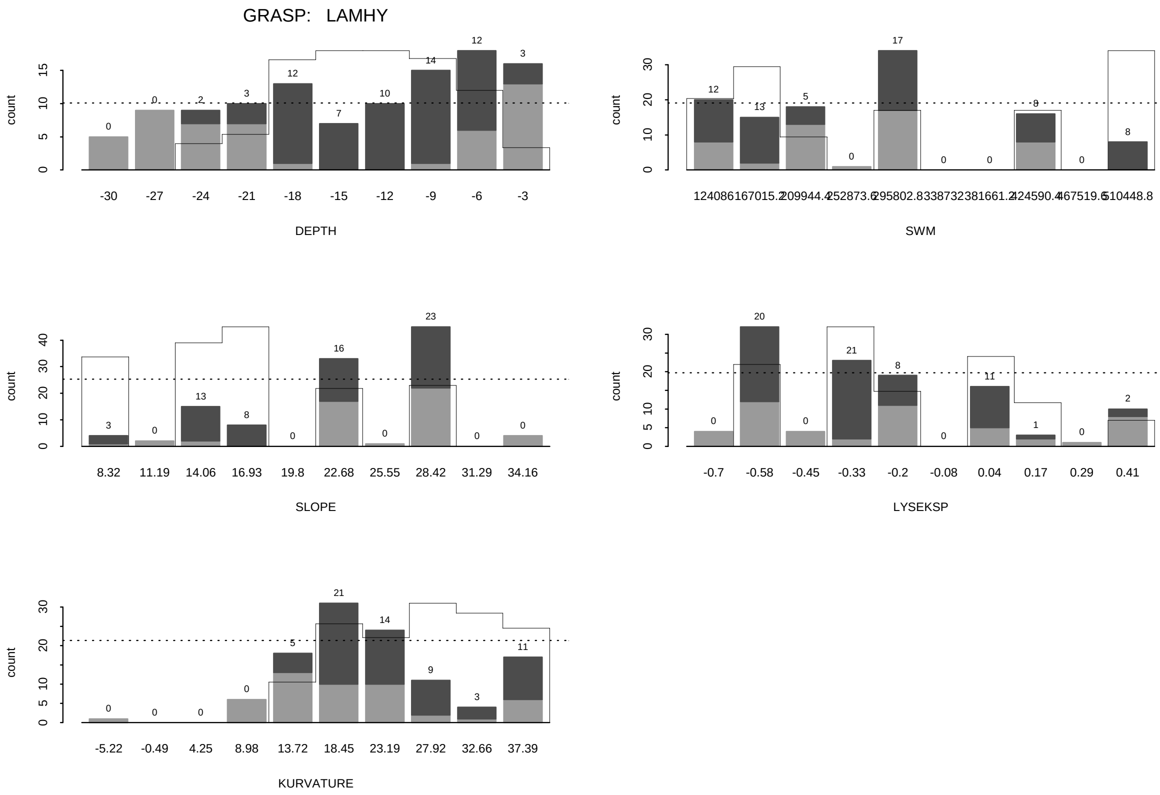

Figure 10. Distribution of LAMHY along environmental gradients in the KYO 1995 model. The entire bars represent distribution of all data, and dark areas represents presence of LAMHY. The plain line is the ratio between presence and absence data and the dashed line corresponds to the overall mean proportion of presence data.

According to AIC selection, the best model (AIC=66.0) to explain presence of *Laminaria hyperborea* (LAMHY) includes depth, exposure (swm) and Curvature. Similarly to the KYO 2004 model, Light exposure (LYSEKSP) and Slope was excluded as a predictor from the KYO 1995 model. Cross validation showed a cvROC (5-fold)=0.94 for the selected model.

In Fig. 11, partial response curves for each predictor in the selected model is shown.

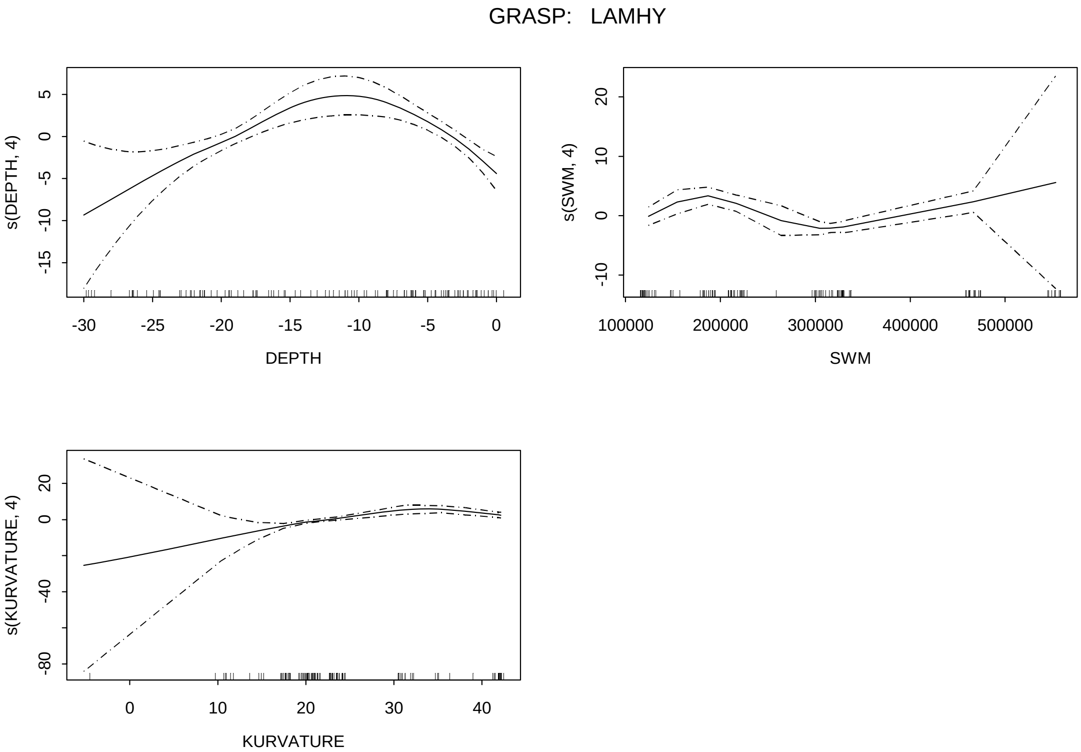

Figure 11. Partial response curves (±2 x S.E.) of *L. hyperborea* presence for each predictor in the selected model.

Spatial predictions of *Laminaria hyperborea* from the KYO 1995 model is shown in Fig. 12.

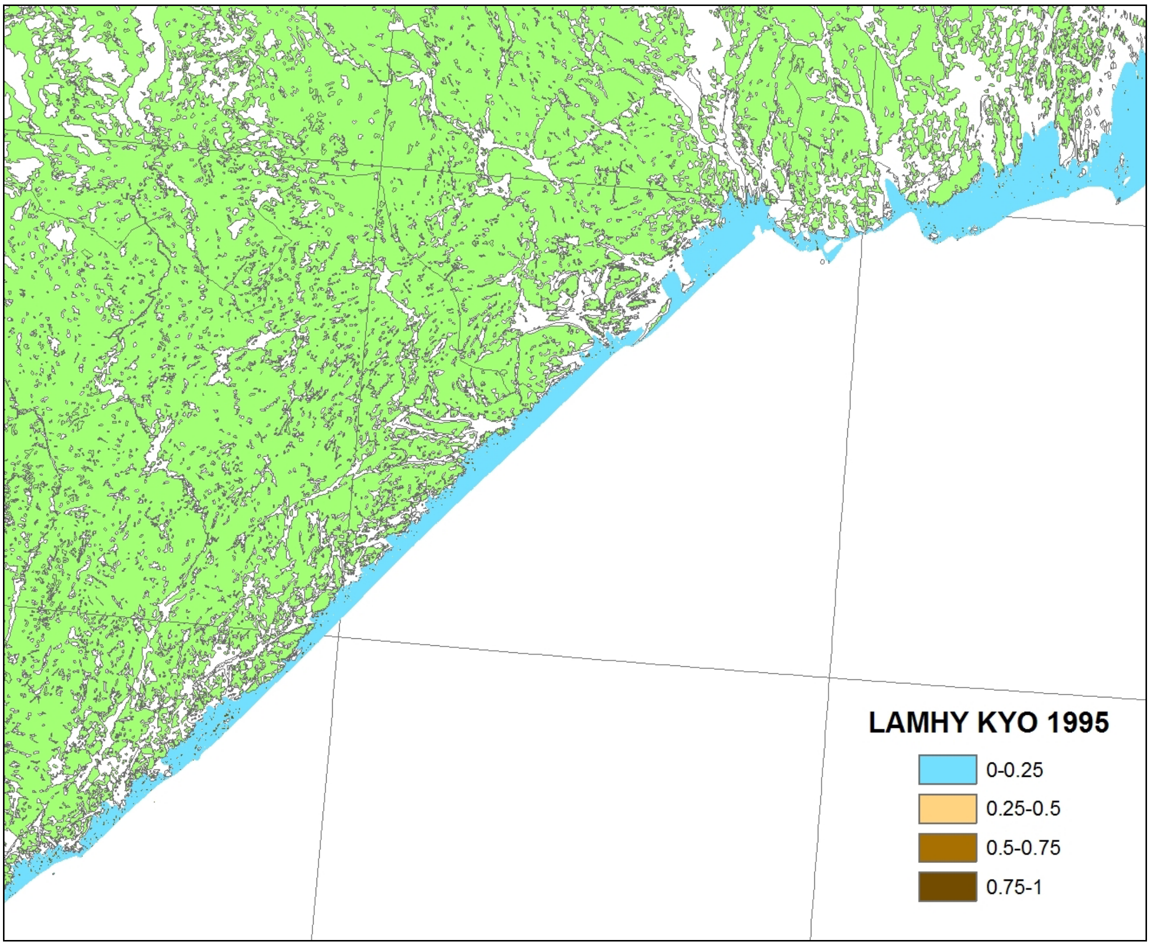

Figure 12. Probability of presence of *Laminaria hyperborea* in four classes, as predicted by the KYO 1995 model. White areas have swm outside the span 124000-554000, and are outside the area in which the model can reliably predict *L. hyperborea* distribution. Green areas are land area.

In a smaller segment of the map (the same area showed in Fig. 5 and 9), the distribution of *L. hyperborea* according to the KYO 1995 model can be seen (Fig. 13).

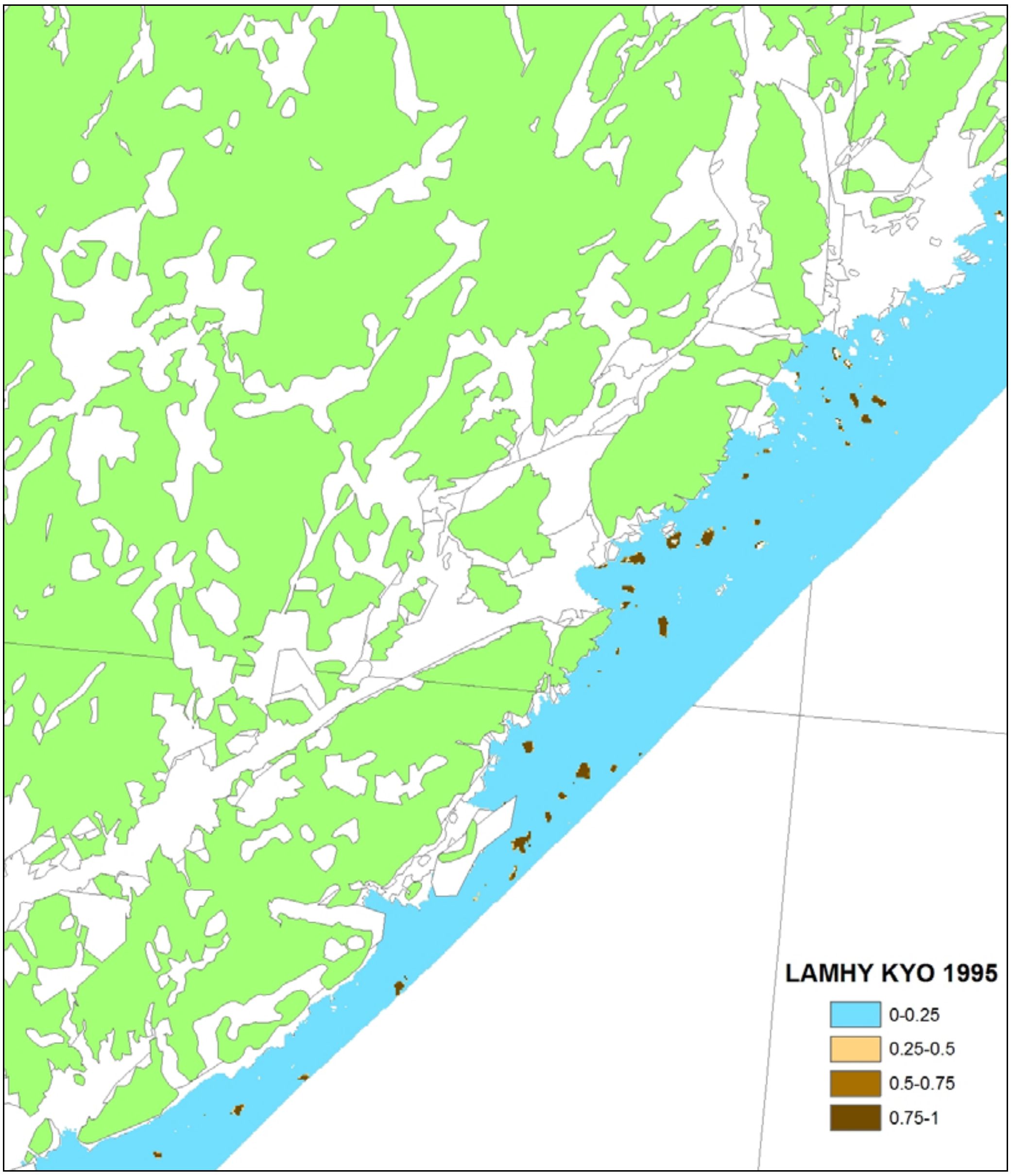

Fig. 13. Probability of presence of *Laminaria hyperborea*, as predicted by the KYO 1995 model. Map segment from a smaller part of the Skagerrak. White areas have swm outside the span 124000-554000, and are outside the area in which the model can reliably predict *L. hyperborea* distribution. Green areas are land area..

3.4 Comparison of models

There were generally larger differences in the prediction between the full model and the KYO 2004 model, than between the two KYO models. Both KYO models underestimated the distribution of kelp compared to the full model (Tab. 1).

Table 1. Distribution of data (counts and percentage of cells in the grid) between different probabilities according to the full model and the models including data from KYO in 1995 and 2004.

Probability of presence of *Laminaria hyperborea*		
Full model	**Counts**	**Percentage**
0-0.25	3 915 967	0.89
0.25-0.5	136 033	0.03
0.5-0.75	131 757	0.03
0.75-1	204 546	0.05
KYO 2004		
0-0.25	1 503 632	0.97
0.25-0.5	7 791	0.005
0.5-0.75	6 097	0.004
0.75-1	25 828	0.02
KYO 1995		
0-0.25	1 518 155	0.98
0.25-0.5	3 261	0.002
0.5-0.75	3 085	0.002
0.75-1	18 847	0.01

Differences in predictions between the full model and the model including KYO data from 2004 are shown in Fig. 14. The main difference between the models was in areas where the KYO 2004 model underestimated the distribution of kelp (blue areas), compared to the Full model.

There were generally small differences between the KYO 1995 model and the KYO 2004 model (Fig. 15). The models predicted larger distribution of kelp in 2004 than 1995, but the differences were small (and much smaller than differences between the full model and the KYO 2004 model, see the Discussion section).

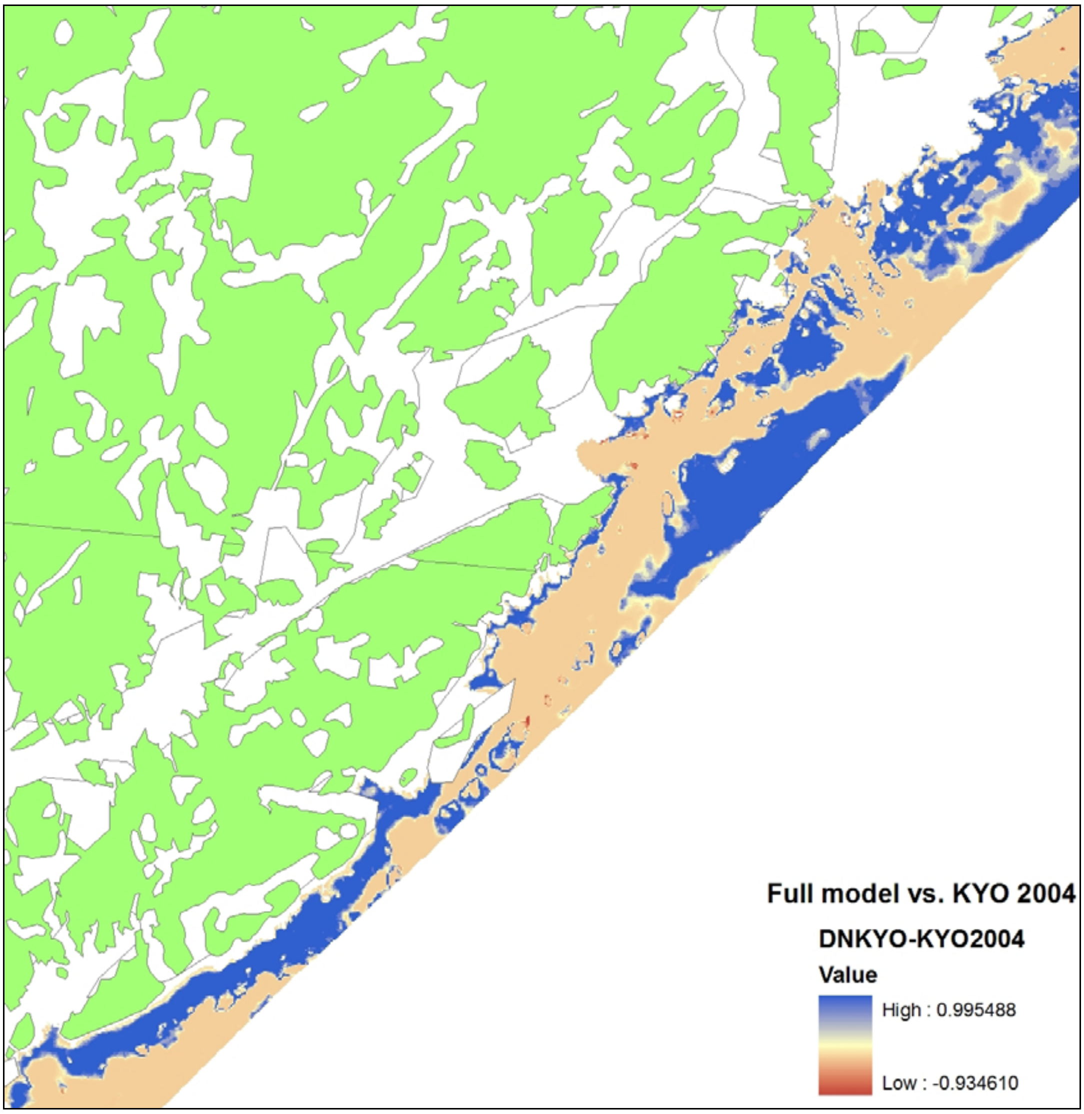

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Fig. 14. Differences in predictions between the full model and the KYO 2004 model (expressed as Prob(Full model) – Prob(KYO 2004 model)). In blue areas the full model predicts a higher probability of finding *Laminaria hyperborea* than the KYO 2004 model. In red areas the KYO 2004 model predicts higher probability. In brown areas the predictions of the two models are equal. White areas are outside the area in which one or both of the models can reliably predict *L. hyperborea.* Green areas are land area

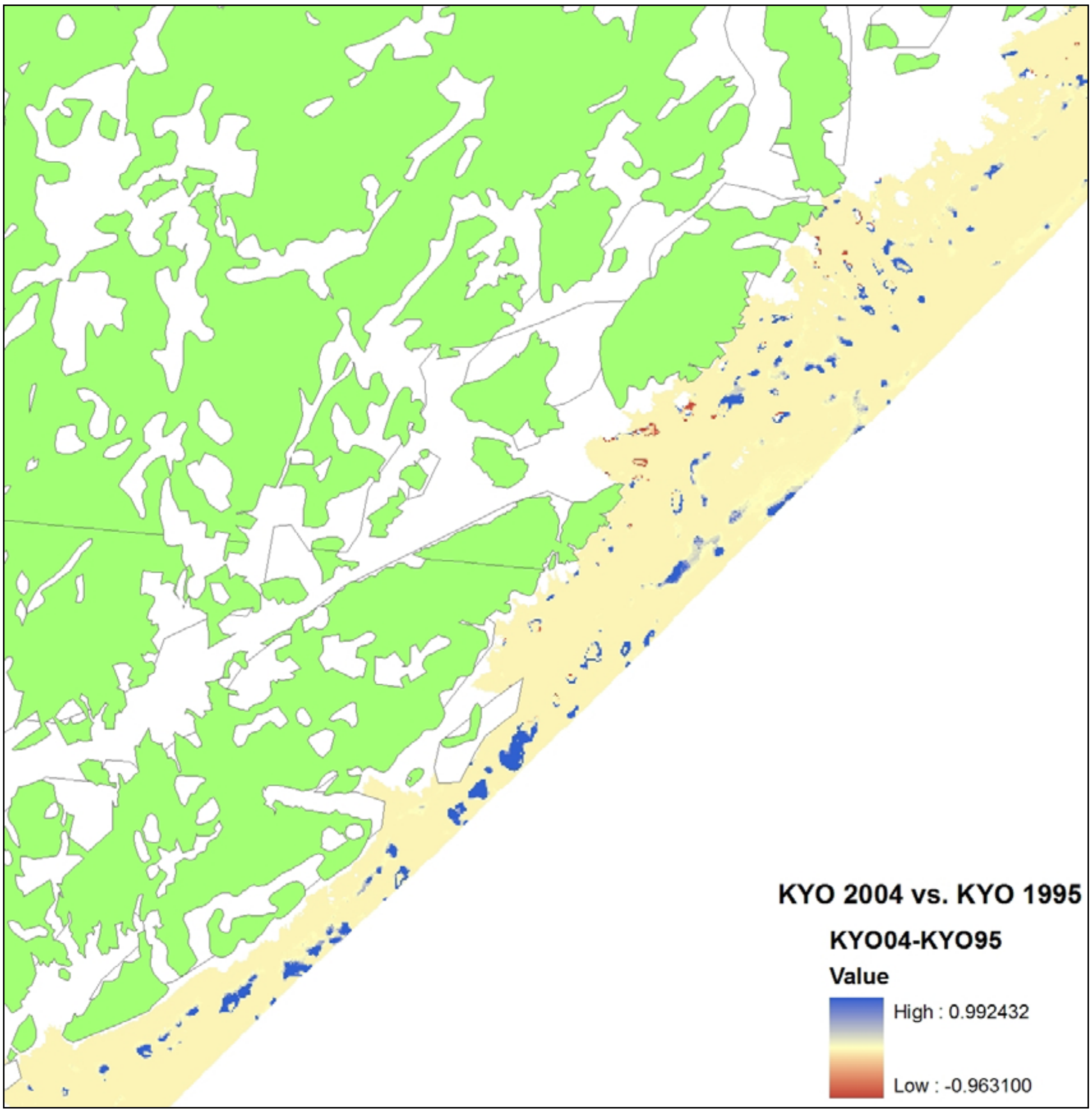

Fig. 15. Differences in predictions between the KYO 2004 and the KYO 1995 models (expressed as Prob(KYO 2004 – Prob(KYO 1995)). In blue areas the 2004 model predicts a higher probability of finding *Laminaria hyperborea* than the 1995 model. In red areas the 1995 model predicts higher probability. In brown areas the predictions of the two models are equal. White areas are outside the area in which one or both of the models can reliably predict *Laminaria hyperborea.* Green areas are land area.

4. Discussion

A comparison between all models showed that there where larger differences between the full model (including all available data from 2004-2006) and the KYO 2004 model, than between the 2004 and 1995 KYO models. The KYO models, including KYO data only, underestimated the distribution of *L. hyperborea* when compared to the full model. Because the full model is based on more data covering a larger part of the environmental gradients, it can be assumed that this model is more reliable in predicting the distribution of *L. hyperborea* in the investigated area.

None of the models used were validated with external data, but the Full model represents the status of the knowledge concerning *L. hyperborea* distribution in the Skagerrak. The results show that the KYO data alone cannot be used for predicting variation in the spatial distribution of *L. hyperborea* in the Skagerrak between years.

Significance for the predictor curvature in the model may reflect the importance of substrate, because curvature may indicate were rocky bottom is found. There is a general need for substrate information which is expected to increase the precision of benthic models. The lack of importance of slope as a factor in the model (excluded by AIC selection in all the GRASP models) probably reflects that there were few steep stations in the datasets (Fig. 2). It is known that kelp do not attach to very steep surfaces. The factor slope is also strongly dependent on scale and it may be that the resolution 25 m gridcell size does not sufficiently describe slope variation for this modelling purpose.

The prediction is limited to the range of wave exposure in which kelp data are available. Within this range there is a positive effect of exposure on kelp distribution, but this effect is expected to drop in areas with very high exposure (outside the range of this study).

The time series data from KYO represent a very important tool for monitoring community changes in the Skagerrak. Such time series data will be crucial in the future for analysing possible biological effects of large scale changes, e.g. climatic changes. The monitoring program is however not designed to analyse spatial changes in the distribution of species. To do this, specific monitoring programs are needed.

4.1 Conclusions and guidelines

The design for collecting field data is crucial for modelling and making spatial predictions. Dive transects are cost-effective since they describe the whole depth gradient in detail. To gather this information by using point inventories instead of transects takes much more effort. However, sampling sites must also cover gradients of other ecologically important parameters. Wave exposure is one of the most important factors structuring the shore community (Lewis 1964) and field data for a coastal model should therefore include the full range of wave exposure variation that occur in the model area. In the present study, KYO stations were not covering the whole exposure gradient, which is thought to be the main reason for the less accurate predictions based on this dataset.

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