A landscape ecological approach to marine coastal zone applications

by

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Abstract: Because of the variety in water depth, terrain variation, sea-bed substrate, oceanography and weather conditions, the coastal zone of Norway has a great diversity of habitats and associated species. Differences in survival, growth, abundance, distribution and dispersal of species depend on quantity, quality, distribution and composition of habitats and resources. Hence, to obtain a holistic understanding of ecological processes, the traditional species-by-species approach to research, management and planning must be supplemented with an ecosystem approach. To adopt ecosystem approaches, procedures and techniques for identifying and classifying habitats, their spatial patterns and geographical distributions are needed. Studies on spatial patterns and geographical distributions of organisms and habitats have a long tradition in terrestrial ecology, and landscape theories and classification techniques are widely used in ecological studies of the terrestrial environment. As a commonly agreed typology for the Norwegian coastal zone habitats has yet to be implemented, it is necessary to develop effective techniques and procedures for reliable identification, classification and quantification of habitats. This paper shows how accessible data on bathymetry, terrain variation and weather conditions may be integrated into a seascape model applied to the heterogeneous marine coastal zone of Norway. We present a procedure for identifying, modelling and classifying marine habitats, and present the ongoing work on the development of a predictive model for the distribution of habitat classes according to the EUNIS habitat classification system. We discuss the usefulness of such an ecosystem approach to research, management and planning.

Keywords: GIS, integrated coastal zone management, landscape analysis, space use, spatial planning, terrain modelling, habitat classification.

Introduction

Because of the variety in water depth, terrain variation, sea-bed substrate, oceanography and weather conditions, the coastal zone of Norway has a great diversity of habitats and associated species (St. meld. 43, 1998-99). Differences in survival, growth, abundance, distribution and dispersal of species depend on quantity, quality, distribution and composition of habitats and resources. Hence, to obtain a holistic understanding of ecological processes, the traditional species-by-species approach to research and management must be supplemented with an ecosystem approach (McNeely 1999). Such approaches are, for the marine coastal zone, in focus at the national scale (e.g. AREALIS, SEAGIS and DN's "Seashore project"), as well as being an important aspect of interregional and international environmental policies (e.g. the "North Sea Interreg IIIB Programme" and EU's 5. Framework Program, "Sustainable marine ecosystems").

To adopt ecosystem approaches to research, management and planning, procedures and techniques for identifying and classifying habitats, their spatial patterns and geographical distributions are needed (Wiken and Ironside 1977, Swanson et al. 1988, Bailey 1996). Studies on spatial patterns and geographical distributions of organisms and habitats have a long tradition in terrestrial ecology, and landscape theories and classification techniques are widely used in ecological studies of the terrestrial environment (e.g. Fremstad 1997). However, the resolution of available spatial and temporal information in the marine environment is quite coarse compared to the terrestrial environment. The marine environment is also more difficult to survey, identify and monitor than the terrestrial
environment (due to *e.g.* wind and waves, depth and turbidity of the water column). Hence, even though the marine environment have much the same challenges as the terrestrial environment when it comes to the effects of landscape patterns, landscape ecological principles have not been widely applied to marine aquatic systems.

The overall aim of this paper is to show how accessible data on bathymetry, terrain variation and weather conditions may be integrated into a seascape model applied to the heterogeneous marine coastal zone of Norway. We show that by analysing a digital terrain model and using terrain variation algorithms and visibility analysis techniques, habitat types such as kelp forest areas, deep basins, deep plains and inter-tidal zones can be identified, modelled and classified. We will present the ongoing work on the development of a predictive model for the distribution of habitat classes according to the EUNIS habitat classification system. We will also discuss the usefulness of such an ecosystem approach to research, management and planning. This paper is based on the manuscript Bekkby *et al.* (subm.) and the thesis of Bekkby (2001).

**Study area**

Sandøy (62°N 6°E), on the West coast of Norway, was chosen as a model area. This area is typical for the archipelago of Central Norway, with numerous smaller islands and inter-tidal rocks inshore from the continental shelf waters (Fig. 1). In the wave exposed parts, submerged rocks down to 25-30 m are covered by kelp (*mainly Laminaria hyperborea*, Fosså and Sjøtun 1993). The kelp forest is intercepted by channels of sand and shell-sand. In the less wave exposed areas, *e.g.* the inshore side of the islands, the substrate is dominated by sand and silt. Sand, silt and clay are also covering larger parts of the deeper areas.

Topographic information was acquired from an existing digital topographic database (Norwegian Hydrographic Service, main chart series 31, 32 and 33, scale 1:50 000). Bathymetric information was digitised from nautical maps (scale 1:50 000), adding depth contours, small islands, inter-tidal rocks and depth point values. The contour interval on the topographic maps was 20 m. In total, 279 560 elevation points were digitised, with the highest point density in the rugged inshore areas and the lowest density in the deep areas further offshore. Coarse-scale information on the sea-bed sediment was obtained from local fishermen based on point characteristics on the nautical maps. The Norwegian Meteorological Institute provided the information on wind direction.

**Integrating and analysing data in a GIS**

We constructed an interpolated digital terrain model (Fig. 1), with a spatial resolution of 100 m. As a result, the about 40 km by 40 km large area were presented as an interpolated terrain model of 183 977 grid cells, 421 in the East-West direction and 437 in the North-South direction. The model was transferred to ArcView version 3.1 (ESRI 1996) for further analyses.

The digital terrain model was analysed to achieve information on terrain variations. We used relative relief (*Fig. 2, often named "range") as an indicator of slope. Plan and profile curvature (often called "ruggedness", Evans 1972, Evans 1990) was not adopted as indices of terrain variation, as they were strongly correlated with the relative relief index at the scale level of this study ($r^2 = 0.67$ and $r^2 = 0.72$, respectively). However, at other scale levels, these indices may provide useful information.

**Modelling marine habitats**

As marine habitats are difficult to identify and map environment (due to *e.g.* wind and waves, depth and turbidity of the water column), techniques for modelling habitat distribution are needed. In this study, we chose to identify and model land areas, inter-tidal zones, deep basins, deep plains and kelp forest areas. Land areas and inter-tidal zones were directly identified from the digital terrain model. The inter-tidal zone were defined as areas of between zero and one meter depth. A deep basin was characterised by a deep area surrounded by shallower, steeper areas (mean gradient >0.1, from map of
relative relief). These basins were always found at more than 100 m deep. A deep plain was characterised by an areas of > 100 m depth not surrounded by shallower, steeper areas.

The distribution of kelp forest areas depends on depth and the degree to which the area is exposed to wave and wind action. The kelp forest of this area is known to be located in exposed areas down to 25 m. We therefore modelled the distribution of the kelp forest by combining the areas of exposure with areas of depths down to 25 m (Fig. 3). To model kelp forest distribution, we used a visibility analysis (using the viewshed algorithm of ESRI in ArcView 3.2) to simulate the areas influenced by the most dominant winds.

The kelp model often predicted presence of kelp where there, according to the kelp harvesters, was none. This is most likely explained by the sea-bed sediment being unsuitable for kelp growth (the kelp grows only on solid rock, stones or large boulders, Kain 1971). We carried out an indicative analysis of the explanatory potential of information on sea-bed sediment. This improved the model drastically.

In some areas, the model did not predict kelp, though kelp was, according to the kelp harvesters, present. These areas may result from errors introduced by the choice of depth and areas of wind exposure suitable for kelp growth, especially related to the course resolution of the model. However, it may also be due to inaccuracies in the information provided by the harvesters. Parts of the area have too many inter-tidal rocks and too shallow water for the kelp harvest boats to enter; the boats are only allowed to harvest down to 20 m depth and they prefer to trawl in flat terrain. Hence, the observations should be expected to vary in quality and reliability. More detailed and systematic investigations and field validation are therefore needed to continue the development of this model.

Classifying marine habitats

To analyse and present the distribution of habitats and the landscape level, the area was classified into habitat types by dividing the digital terrain model into 1 by 1 km cells (Fig. 4), each of which was divided into 100 m by 100 m sub-cells. Depth classes, terrain structures (deep basins or plains) and presence of islands, inter-tidal zones and kelp (from the exposure model) were used to classify each cell as a habitat type. Depth categories were based on cell means derived from the digital terrain model. A cell was defined as a kelp forest habitat type if at least 50 % of the sub-cells included kelp.
Further/ongoing work

Even though studies have documented that terrain structures (such as depth) and environmental factors (such as sea-bed sediment and degree of exposure) influence the distribution of marine habitats (e.g. Lein et al. 1987, Pasquallini et al. 2001), no comprehensive and unified habitat classification system has been applied to the coastal zone of Norway. We believe that we can combine environmental information in a predictive model for the distribution of habitat classes, and thereby contribute to both science, with the goal to increase knowledge, and to the applied field, with the purpose of solving management and planning problems. The ongoing work will

- contribute to a holistic understanding of factors and processes structuring the distribution of marine coastal habitats and develop a predictive model for mapping marine coastal habitats,
- provide knowledge on the effect of scale on the predictability of habitat models, regarding both the input data and further use of such models in scientific and applied studies of the marine coastal zone,
- evaluate an internationally agreed habitat classification system applied to the Norwegian marine coastal environment,
- contribute with information relevant for projects such as MAREANO and DN's work on protection of marine biodiversity and habitats, and as input to the work carried out by conventions such as OSPAR and ICES.

The European Environment Agency (EEA, see Davies and Moss 1999) has developed a classification system in collaboration with the Council of Europe. The aim of this system is to develop a common parameter-based European classification frame. The classification system forms an integral part of the nature information system EUNIS of the European Topic Centre on Nature Protection and Biodiversity (ETC/NPB). The usefulness of EUNIS to the needs of ICES is currently under discussion (ICES 2000). As the EUNIS Habitat classification system is fully harmonised with important marine conventions (such as OSPAR), we will adopt this system as a basis for the analyses and the predictive modelling. The model will be refined and validated through seismic and echo sound surveys, as well as field samplings.

Discussion
Managing complex environments requires suitable tools to integrate data from a variety of sources and to efficiently analyse and present them within a geographical context. This paper shows how accessible data on bathymetry, terrain variation and weather conditions may be integrated into a seascape model applied to the heterogeneous marine coastal zone of Norway.

Movement and habitat use of species may vary with the distribution of resources. For instance, Bekkby (2001) shows how diving activity, movement, home range, habitat selection and haul-out behaviour of harbour seal pups depend on resource distribution. For management and planning purposes, knowledge on the effects of habitat loss, degradation, addition or restoration can be obtained by integrating information on movement and habitat use of species. Vulnerable areas can be mapped and integrated into plans for dynamic coastal zone management and potential areas of conflicts (between conservation, recreation and commercial interests, and between different commercial activities) can be identified.

At present, coastal habitat types are insufficiently identified, and techniques for identification and classification of marine habitats are needed to develop and refine procedures for coastal resource management. Although much work remains to be done before seascape models and landscape ecology indices can be fully integrated in general operational coastal zone management tools, this kind of work has large potential. As more information becomes accessible, e.g. on sea bed sediment, currents, temperature and degree of disturbance, the usefulness of landscape ecology as a tool in coastal environmental planning will increase further.

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