R-04-38

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– the building of a database of quantitative data collected by SCUBA divers, its use and some GIS applications in the Gräsö area

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Keywords: Biomass, Shore displacement, Salinity change, Community change, Millennial time scale.

Abstract

The aim of the project was to compile a single database with quantitative data collected by SCUBA divers from the whole Swedish Baltic Sea coast. Data of plant and animal biomass, together with position, depth and type of substrate from 19 areas along the Swedish coast from the county of Blekinge to Kalix in the Bothnian Bay were compiled in a single database. In all, the database contains 2,170 records (samples) from 179 different stations where in total 161 plant and 145 animal species have been found. The data were then illustrated by the geographical distribution of plant and animal biomass and by constructing a model to estimate future changes of the plant and animal communities in the Gräsö area in the Åland Sea applying GIS-techniques.

To illustrate the opportunities of the database the change of the composition of benthic plant and animal biomass with salinity was calculated. The proportion of marine species increased with increasing salinity and the benthic biomass was at its highest in the southern Baltic proper.

Quantitative data from Grepen and the Gräsö-Singö area were used to calculate present biomass in the Gräsö area. A scenario of the change in biomass distribution and total biomass caused by shore displacement was created using data from Råneå and Kalix in the Bothnian Bay. To map the biomass distribution the material was divided into different depth intervals. The change of biomass with time was calculated as a function of salinity change and reduction of the available area, caused by shore displacement. The total biomass for all plants and animals in the investigated area was 50,500 tonnes at present. In 2,000 years the total biomass will be 25,000 tonnes and in 4,000 years 3,600 tonnes due to shore displacement causing a decrease in both salinity and available substrate.

To make an estimate of the species distribution and a rough estimate of their biomass in an unknown geographic area, the type of substrate, the depth and the wave exposure have to be known. Near future and future aspects are the compilation of substrate and species depth distribution and coverage into a database. Also the addition of substrate and wave exposure as GIS layers for the estimate of plant and animal biomass, in given geographic areas has to be evaluated.

Sammanfattning

Syftet med detta projekt har varit att sammanställa kvantitativa data som samlats in vid dykinventeringar på grunda hårdbottensamhällen längs hela den svenska Östersjökusten. Vi har också använt dessa data dels för att illustrera utbredningen av växter och djur längs den svenska kusten och dels för att förutsäga förändringen i biomassafördelning i Gräsöområdet på 4 000 års sikt. Kunskap om fördelningen av växt- och djurbiomassa behövs vid modellering av ekosystem samt när omloppstiden för miljögifter och radioaktiva ämnen skall beräknas.

Biomassan av växter och djur tillsammans med position, djup och bottentyp har samlats i en gemensam databas. Data är insamlade i 19 områden längs den svenska Östersjökusten, från Kalix i norr till Blekinge i söder. Allt som allt innehåller databasen 2 170 prover från 179 olika stationer där sammanlagt 161 växt- och 145 djurarter påträffats. En sammanställning av tillgängliga data visar att sammansättningen av bentisk växt- och djurbiomassa förändras längs salthaltsgradienten. Andelen marina arter ökar med ökad salthalt och biomassan är som högst i södra delen av egentliga Östersjön.

Datamaterialet har sedan använts för att med hjälp av GIS konstruera en modell för att uppskatta framtida förändringar av växt- och djursamhällena i Gräsöområdet. Landhöjningen påverkar storleken på den yta som i framtiden kommer att finnas tillgänglig för växt- och djursamhällen i Bottenhavet. Även den storskaliga cirkulationen kommer att påverkas, vilket vi här antar kommer att leda till minskad salthalt. Salthalten påverkar biomassan och artsammansättningen i växt- och djursamhällen och är en av de faktorer som styr utbredningen av olika växt- och djurarter längs den svenska kusten.

Kvantitativa data från Grepen och Gräsö-Singö-området användes för att beräkna biomassan i Gräsöområdet idag. Salthalten i området är ca 5.5 psu. Ett scenario för att beskriva förändringen av biomassans fördelning samt totalbiomassan till följd av strandförskjutning, skapades med hjälp av data från Råneå och Kalix, där salthalten är ca 2 psu. Materialet delades in i djupintervall för att ge en bild av fördelningen av biomassa. Biomassans förändring över tiden beräknades som en funktion av salthaltsförändring och minskning av yta till följd av landhöjningen. Den nuvarande totala biomassan för alla växt- och djurarter i karteringsområdet beräknades till 50 500 ton. Enligt modellen kommer den totala biomassan att vara 25 000 ton om 2 000 år och 3 600 ton om 4 000 år. Användandet av data från Bottenviken för att förutsäga utvecklingen kommer troligen att underskatta biomassan. Andra faktorer än salthalt påverkar biomassafördelningen i Bottenviken, t ex solinstrålning och temperatur, vilket påverkar växtsäsongens längd.

För att kunna göra en bra uppskattning av arternas utbredning samt en grov uppskattning av deras biomassa i ett icke undersökt geografiskt område behövs uppgifter om substat, djup och vågexponering. Nära förestående och framtida uppgifter blir att sammanställa en databas med bottentypsdata och arternas djuputbredning och täckningsgrad. Nyttan av att tillföra substrat och vågexponering som GIS-lager, för uppskattningen av växt- och djurbiomassa, i givna geografiska områden i hela Östersjön, bör också utvärderas.

Contents

1 Introduction

The knowledge of biomass distribution is of importance to estimate the circulation time of environmental toxins or radioactive substances. The biomass of plant and animal communities has been used in ecosystem modelling /cf Kumblad et al. 2003/.

Geographic distribution and depth zonation of biota are set by biotic and abiotic factors. In the Baltic Sea, usually the abiotic factors are the most important /Kautsky and van der Maarel, 1990/. The change in environmental parameters with time will alter species composition and biomass, and may thus alter the function of the system. Apart from estuaries, on a large scale (hundreds of km) salinity is one of the dominating factors controlling the distribution of plants and animals along the Swedish coast /Kautsky, 1995/. The salinity influences the biomass and species composition /see for example Remane and Schlieper, 1971; Sjörs, 1971; Kautsky, 1995/.

On a local scale /Kautsky and van der Maarel, 1990/ listed depth (i.e. light penetration) together with substrate and wave exposure as the main structuring factors The brown alga *Fucus vesiculosus* is contributing to a large part of the total plant biomass in the Baltic Sea /cf Kautsky, 1995/. In the Baltic proper, periods of low water levels determines the upper limit of *Fucus*, while the lower limit usually is set by light penetration. In the Bothnian Sea, especially the northern part, ice scouring can structure the substrates down to 4–6 m depth, depending on exposure /Kautsky et al. 1992/.

The distribution of benthic biomass in local areas of the Baltic Sea was described by e.g. /Kornfeldt, 1984/, /Olenin, 1997/ or /Westerbom et al. 2002/. Few articles deal with the Baltic Sea coast of Sweden /cf Kautsky, 1995/, but none of them used GIS tools. In the assessment of circulation time of for example radioactive substances, modelling biomass as a function of environmental variables changing over time is important.

The shore level displacement will determine the area available for the plant and animal communities in the Bothnian Sea. Also the circulation of the Baltic Sea will change, which in turn decreases the salinity /Gustavsson, 2004/. The shore displacement is a combined effect of two vertical movements: the glacio-isostatic uplift and the eustatic sea level rise that counteracts the uplift. A mathematical function for the course of events has been described by /Påsse, 1996/. Today, the shore displacement rate in the area is positive, and at present approximately 6 mm/year /Brydsten, 1999/.

This study aimed to compile biomass data of phytobenthic plant and animal communities from diving surveys along the whole Baltic Sea gradient, which were collected by Hans Kautsky. The investigations include depth distribution and cover degree as well as quantitative samples. The data were then used in a model to picture changes in biomass distribution for a given species or group of species with depth, and salinity as a function of shore displacement for the next 4,000 years in the Grepen area. The long-term change of the phytobenthic system in the Grepen area is dependent on the change in the hypsography of the area, influencing the species depth distribution as well as the predicted change in salinity may change the species composition. Both change in depth and salinity will alter the biomass production and the function of the ecosystem.

2 Methods

Data from spreadsheets or database files for given areas, as well as older, not computerized material, was put together in a database. The species lists were updated concerning nomenclature, and missing environmental data were added when possible. To ensure that the biomass values for different species were reasonable, a quality control was made by plotting the biomass for each species. In several cases corrections had to be performed, often by comparison with the original field protocols.

Biomass data from the environmental monitoring programme and surveys from 1974 to present were compiled in a relational database. The database contains 2,170 samples from 179 different stations (Table 2-1) (in total 244, some of the stations have been revisited), in 19 areas ranging from Kalix in the Bothnian Bay to Torhamn in Blekinge (see Figure 4-1). In total, 161 plant and 145 animal species have been included in the database.

In all areas similar, comparable methods were used. The samples were collected along transects where the SCUBA divers noted the depth distribution of the plants and animals recognized under water and their cover degree of the substrate, as well as the type of substrate and siltation. Quantitative samples were collected using square frames, which were randomly tossed within given belts /cf Jansson and Kautsky, 1977/ or /Kautsky, 1993/. If the species had no biomass a value of 0.001 g was attributed to the species in order to mark the presence in the sample. For the samples from the monitoring programme, also the abundance of animal species was included.

In the database the plants and animal species were coded into groups based on function, taxonomy, life span or whether they were marine, freshwater or brackish water species in order to illustrate the composition and distribution of biomass. To show the possibilities of the database, some applications were performed. Averages per area, the functional plant and animal groups, and the species limnic, brackish water or marine origin were plotted in order to illustrate the use of the whole data set, (Figure 4-1, 4-2).

The shore level displacement was modelled in ESRI software ArcGIS and total coastal biomass in the map area was calculated by multiplying the biomass per m^2 for each depth interval with the total amount of seafloor available within that interval. This calculation was made for the present conditions as well as for 2,000 and 4,000 years into the future. The total biomass was also calculated as an arithmetic mean method, [average biomass] * [the total available seafloor area], for the same years. See Appendix 1 for details.

The elevation data used was a digital elevation model (DEM) with a raster (ESRI Grid) resolution of 10 m ranging from 58.58 m below sea level to 43.15 m above sea level. For further information on the elevation model, see /Brydsten, 1999/.

The biomass data used in this study came from quantitative investigations of benthic flora and fauna in two parts of the Baltic Sea – the Bothnian Bay (Råneå and Kalix) and the Gräsö area (Figure 4-1). The Bothnian Bay data was sampled in the archipelagos of Råneå and Kalix during the summer of 1991 (hereafter referred to as Bothnian Bay). The average surface salinity in the area was c 2 psu /Foberg and Kautsky, 1992/. The data from the Gräsö area were from two different investigations, one from the eastern (outer) side of the island of Gräsö in 1984, and one from the inner side, in Grepen, in 1998 (referred to as Gräsö) /Kautsky et al. 1999/. The surface salinity in the area was calculated to c 5.5 psu /Engqvist and Andrejev, 1999/.

Table 2-1. Number of diving transects in different areas. Hoburgs and Midsjö bankar refers to Hoburgs bank, Norra Midsjöbanken and Södra Midsjöbanken, as these areas were investigated as one area, cf Figure 5-1.

Area	Year	Number of transects
Askö	1974	16
Askö	1975	16
Luleå	1976	12
Gotland	1979	6
Källskären	1982	9
Holmöarna	1982	10
Salvorev	1983	9
Gräsö	1984	9
Norrsundet	1984	7
Hartsö	1988	10
Iggesund	1988	7
Torhamn	1989	4
Kvädö	1989	4
Askö	1990	3
Västervik	1990	4
Mönsterås	1990	6
Gotland	1990	4
Kalix	1991	10
Råneå	1991	9
Salvorev	1993	7
Askö	1993	6
Askö	1994	6
Askö	1995	6
Askö	1996	6
Askö	1997	6
Knolls grund	1998	4
Öregrundsgrepen	1998	6
Askö	1998	6
Råneå	1999	8
Askö	1999	6
Gotland	2000	4
Hoburgs and Midsjö bankar	2000	2
Askö	2000	6
Gotland	2001	4
Askö	2001	6

3 Database structure

The main structure of the database is described in Table 3-1. The records include sampling date (*date*), area (*område*), station name (*stationname*), transect number (*profile no*), sample number (*sample no*), distance from shore (*distance*), compass direction of transect (*compassdir*), *depth* and *substrate* (Tables 3-1 to 3-4). For all samples the *biomass* (g dry weight/m^2, including shells when present) of the species recorded in the sample were included. In most cases also *salinity*, water level (*waterlevel*) and secchi depth (*secchidepth*) were available.

ProfileID, SampleID, Sampledata and Speclist are different tables in the relational database, and they are linked to each other through the key fields (🔑) – the *profile no* in ProfileID is equivalent to the *profile no* in the SampleID and Sampledata tables.

Table 3-1. Structure of the relational database containing four coupled sets of data.

ProfileID – describes the location of the station and some general environmental factors.

	Field name	Data type	Description
🔑	Date	D	(m/d/yyyy)
🔑	Profile no	S	Transect number
	Område	A30	Area according to Figure 4-1
	Latitude	N	
	Longitude	N	
	Stationname	A30	Name of transect, or station
	Compassdir	N	Compass direction of transect from shore
	Wave exp	N	
	Salinity	N	Surface salinity, psu (available from late 1990's)
	Waterlevel	N	
	Secchidepth	N	

SampleID – describes the sample location.

	Field name	Data type	Description
🔑	Date	D	(m/d/yyyy)
🔑	Profile no	S	Transect number
🔑	Sample no	S	Number of the sample
	Distance	N	Distance from shore
	Depth	N	Sample depth (m)
	Frame size	S	Size of sampling frame
	Frame no	S	
	Substrate	N	Bottom type according to Table 3-2
	Parallel sample	S	Samples taken as replicates
	Sampling unit no	S	Parallel sample number
	Year	S	

Sampledata – contains the biomass and abundance of each species within the sample.

	Field name	Data type	Description
🔑	Date	D	(m/d/yyyy)
🔑	Profile no	S	Transect number
🔑	Sample no	S	Number of the sample
🔑	Sortcode	N	Numerical code for species
	Latnm	A30	Scientific name of species
	Biomass	N	g/m^2
	Abundance	N	Number of e.g. animals in a sample
	Year	S	

Speclist – lists all species found in all areas and their ecological role.

	Field name	Data type	Description
🔑	Sortcode	N	Numerical code for species
	Latnm	A30	Scientific name of species
	Txgrp	A30	Taxonomic group
	Trophic level	S	Trophic level according to Table 3-3
	Functional group	S	Functional group according to Table 3-4
	Salinity requirement	S	Marine (M), brackish water (B) or limnic (L) species
	Annual/Perennial	S	

🔑 Key field (determines the relations between the tables in the database)

Data types:

D	Date
S	Short
A30	Alpha, 30 characters
N	Number

Table 3-2. Substrate codes used in the database. Mixed substrate code number 6 also includes stones only and number 8 includes gravel only. For the odd hard substrates 13 and 14 the sand can be exchanged for soft bottom.

Substrate codes							
description	**code**	**rock**	**boulders**	**stones**	**gravel**	**sand**	**soft bottom**
hard	1	■					
	2	■	■				
	3	■	■	■			
	4		■	■			
mixed	5		■	■	■		
	6			■	■		
	7			■	■	■	
	8				■	■	
	9		■	■		■	
sand	10					■	
soft	11					■	■
	12						■
odd hard	13		■			■	
substrates	14	■				■	

Table 3-3. Trophic level of plants.

Trophic level	
1	cyanobacteria
2	green algae
3	charophyta
4	cryptophyceae
5	diatomees
6	brown algae
7	red algae
8	bryophyta
9	vascular plants
10	filter feeders
11	herbivores
12	carnivores
13	detritivores
14	omnivores

Table 3-4. Functional groups of plants and animals.

Functional category	
1	sheet group
2	filamentous group
3	coarsly branched group
4	thick, leathery group
5	jointed calcareous group
6	crustose group
10	filter feeders
11	herbivores
12	carnivores
13	detritivores
14	omnivores

4 Applications based on the database

4.1 Composition and distribution of benthic biomass

The composition of benthic plant and animal biomass changed with the salinity gradient. In the Bothnian Bay, where the salinity was low, freshwater (limnic) species dominated the biomass. The proportion of marine species increased with increasing salinity, and in the Baltic proper they dominated both plant and animal biomass (Figure 4-1). Brackish water species were found along the entire coastline.

The benthic biomass was highest in the southern Baltic proper /Kautsky, 1995/. The total mean biomass for plants and animals decreased northward. The decrease was stepwise with major changes in the Åland Sea and the Northern Quark (Holmöarna). Salinity changed with depth, but due to the water movement at a given site, it was usually fairly constant within the photic zone /cf Kautsky, 1989/ (Figure 4-2).

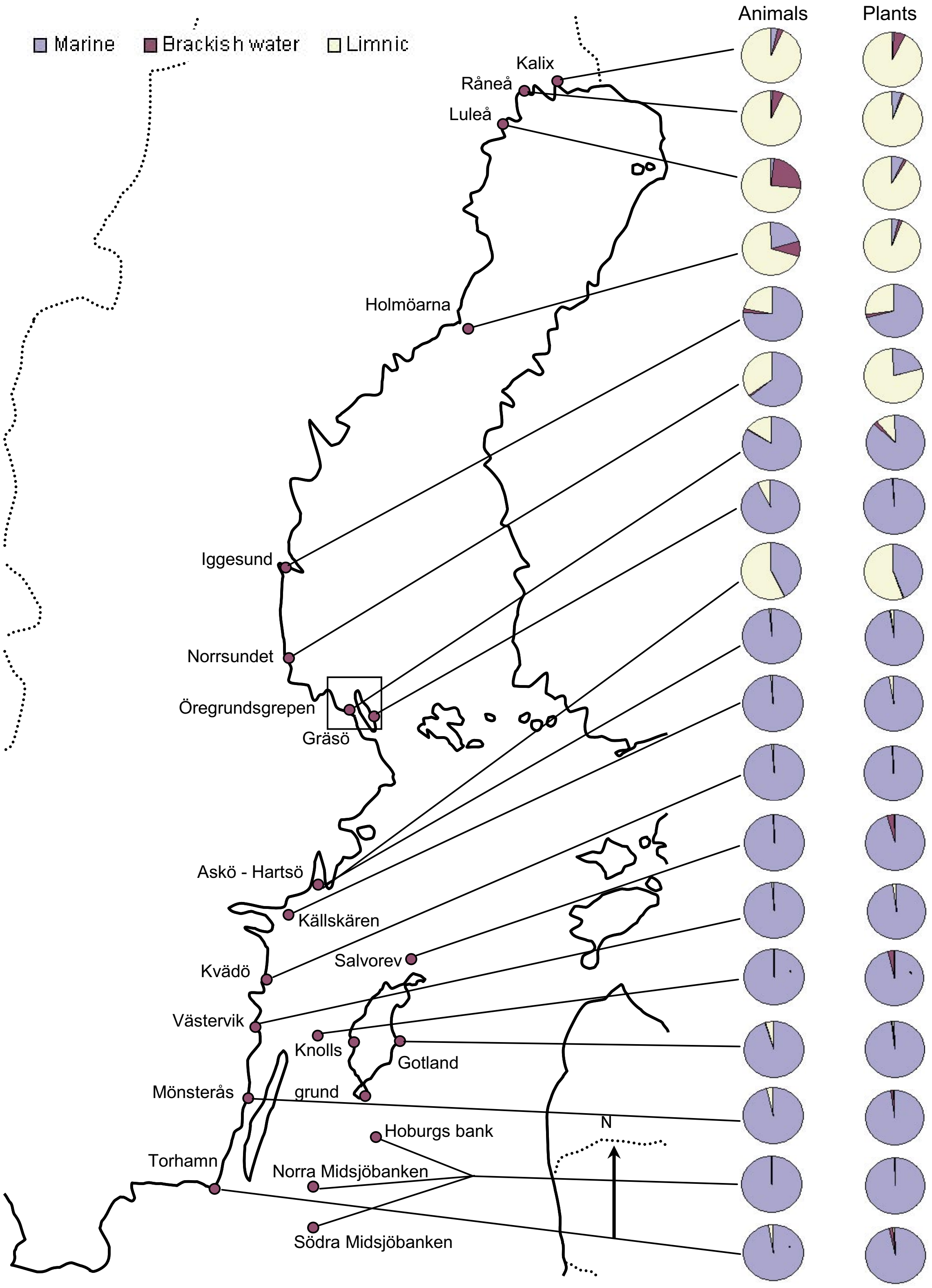

Figure 4-1. *Proportion of marine, brackish water and freshwater (limnic) species along the Baltic Sea salinity gradient.*

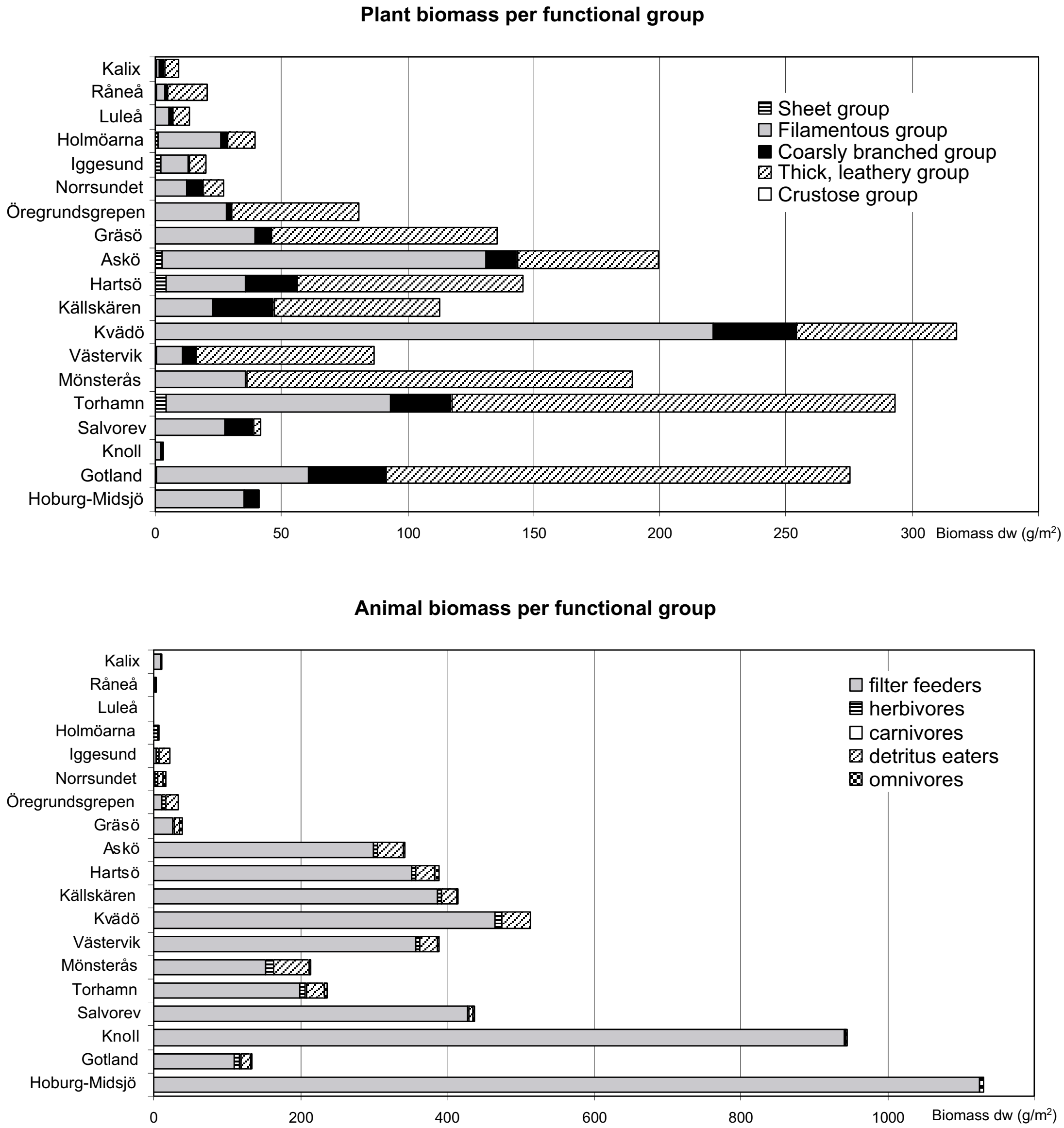

Figure 4-2. *Average biomass (g dry weight m^{-2}) for plants and animals in different areas, divided into functional groups.*

4.2 A GIS application

Data from the database were used in a model to estimate changes of the ecosystem in a 4,000 years future perspective. The database model included the decrease in available substrate for the plants and animals due to the land uplift and the predicted salinity decrease in the area, changing the species composition. The GIS application has been published as a degree project thesis at the Dept. Physical Geography and Quaternary Geology, Stockholm University /Sandman, 2004/.

Future salinity change

The shore level displacement in the Bothnian Sea will change the large scale water circulation, and thus the salinity. Projections of salinity change over time in the area were not available. However, the salinity was estimated to decrease with 1 psu in 2,600 years and with 2 psu in 4,000 years /Gustavsson, 2003 pers comm/. These estimates were based on the assumption that there will be no changes in river runoff and that the shore displacement will not affect the exchange between the Baltic Sea and the North Sea and that the shore displacement in the Gräsö area was set to 5 mm/year.

The predicted salinities were used to create a curve for salinity change with time. The decrease in area of a cross section through the Southern Quark and the Åland Sea, caused by shore displacement, was not linear. Therefore, the assumption is that the salinity change will be non-linear. The salinity change used in the further analysis was thus expressed as a regression function:

$$s = -8*10^{-8}*t^2 - 0.0002*t + 5.5$$

where s is salinity in psu and t is time in years.

Shore displacement and digital elevation model

The shore displacement rates used in the further analysis followed two linear models of 5 mm elevation/year and 6 mm elevation/year as well as a non-linear model (equation 1, Figure 4-3) /Påsse, 1996/. The different functions resulted in shore displacements of 10–12 m elevation in 2,000 years and 20–24 m elevation in 4,000 years (Table 4-5).

$$U = 0.6366 * 275 * [\arctan (12{,}500 / 8{,}000) - \arctan ((12{,}500 - t) / 8{,}000)]$$

$$+ 0.6366 * 80 * [\arctan (10{,}400 / 700) - \arctan ((10{,}400 - t) / 700)] - E \qquad (1)$$

$$E = 0.6366 * 50 * [\arctan (9{,}350 / 1{,}375) - \arctan ((9{,}350 - t) / 1{,}375)]$$

where U is the shore displacement rate, t is the time in years and E is the eustatic sea level rise.

Table 4-5. Shore displacement (m) in the Gräsö area calculated with three different functions.

	6 mm/year	equation (1)	5 mm/year
2,000 years	12	11.1	10
4,000 years	24	20.2	20

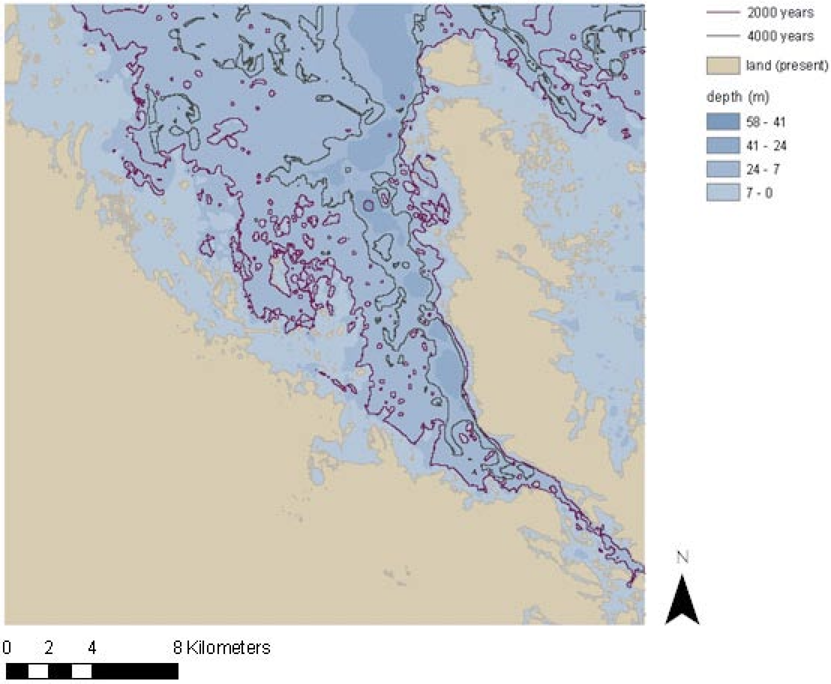

Figure 4-3. *Shoreline displacement in the Gräsö area at 2,000 and 4,000 years following equation 1. Location of the area is shown in Figure 4-1.*

4.2.1 GIS applications results

Samples from Gräsö and Öregrundsgrepen (Figure 4-1) were chosen to represent current conditions (5.5 psu) and samples from Råneå and Kalix in the Bothnian Bay were chosen to predict the biomass and its distribution at 2 psu.

In the Gräsö samples the biomass was dominated by *Fucus vesiculosus* (62% of the plant biomass) and *Mytilus edulis* (43% of the animal biomass) (Table 4-7). The two species were removed from the samples, in order to find out if they alone determined the difference in biomass. However, although *F. vesiculosus* and *M. edulis* constituted half of the biomass in the Gräsö area, the differences in biomass for both plants and animals remained higher in the Gräsö area after the removal (Table 4-6).

Table 4-6. Differences in biomass (g dry weight m^{-2}) between Gräsö and Bothnian Bay.

	Bothnian Bay Average g/m^2	Gräsö Average g/m^2
plants	9.25	113.11
excl Fucus		43.42
animals	7.01	36.35
excl Mytilis		20.70
all	16.25	149.46
excl Fucus		79.77
excl Mytilis		133.81
excl Mytilis or Fucus		64.13

Table 4-7. Biomass (g dry weight m^{-2}) of plant and animal species in both areas – The plants are divided into limnic (L), brackish water (B) or marine (M) species.

Plants	Bothnian Bay	Gräsö		Animals	Bothnian Bay	Gräsö	
Bluegreen	0.45			Cordylophora	0.20		B
Rivularia atra	0.41			Bithynia tentaculata	0.14		L
Furcellaria lumbricalis		3.50	M	Lymnaea peregra	0.18	0.45	L
Ceramium tenuicorne		7.18	M	Theodoxus fluviatilis	0.80	2.76	L
Polysiphonina fucoides		7.99	M	Hydrobia spp		0.86	M
Rhodomela confervoides		1.24	M	Mytilus total		15.65	M
Pilayella littoralis		12.14	M	Cardium sp		3.66	M
Pilayella/Ectocarpus		2.22	M	Macoma baltica		8.99	M
Fucus vesiculosus		69.69	M	Anodonta cygnea/complana	4.76		L
Mougeotia sp	0.34		L	Pisidium sp	0.22		L
Ulothrix spp	0.15		L	Valvata macrostoma	0.08		L
Cladophora aegagrophila	1.73		L	Balanus improvisus		0.99	M
Cladophora glomerata	0.15		L	Mesidothea entomon	0.21		L
Cladophora rupestris		2.07	M	Gammarus spp		0.56	M
Chara baltica	0.31		B	Gammarus zaddachi		0.95	M
Diatomea	0.98			Chironomidae	0.08		L
Octodiceras fontanum	0.68		L				
Fontinalis dalecarlica	0.78		L				
Isoetes echinospora	0.10		L				
Nuphar lutea	0.36		L				
Potamogeton gramineus	0.86		L				
Potamogeton filiformis		1.38	L				
Potamogeton perfoliatus	1.24		L				
Ruppia maritima		1.12	M				

Depth intervals and biomass distribution

The datasets were divided into depth intervals of 0–0.5 m, 0.5–1 m, 1–2 m, 2–3 m, 3–4 m, 4–6 m, 6–10 m, 10–15 m and 15–20 m depth. The intervals were shorter near the surface in order to catch the rapid decrease in biomass caused by the decrease in light attenuation.

The distribution of plant, animal and total biomass with depth are shown in Figure 4-4 (a–f). The spatial distribution of biomass for plants, animals and total biomass at present, in 2,000 years and in 4,000 years is shown in Figures 4-5, 4-6 and 4-7.

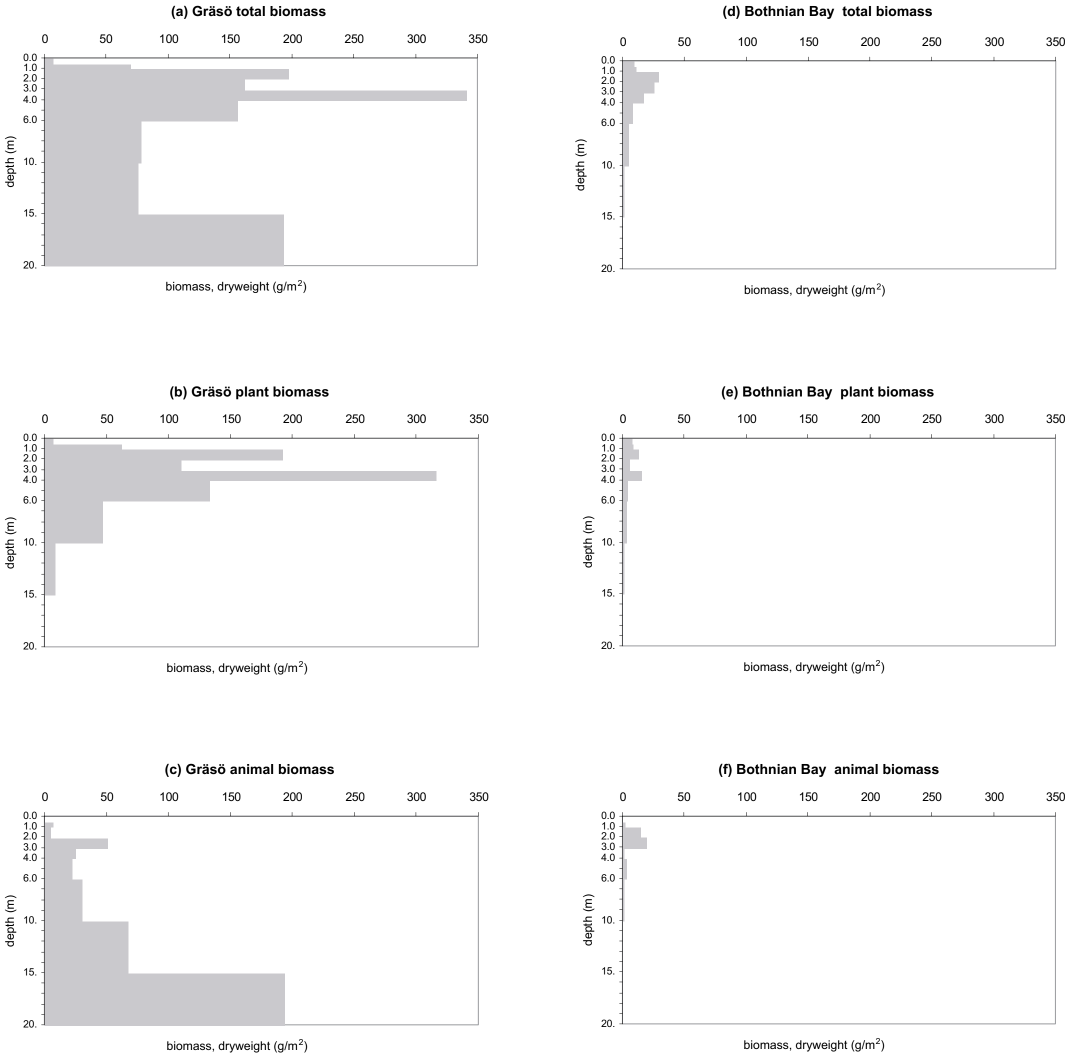

Figure 4-4. *Distribution of total biomass (a), plants (b) and animals (c) in the Gräsö area and total biomass (d), plants (e) and animals (f) in the Bothnian Bay. The depth intervals are 0–0.5 m, 0.5–1 m, 1–2 m, 2–3 m, 3–4 m, 4–6 m, 6–10 m, 10–15 m and 15–20 m.*

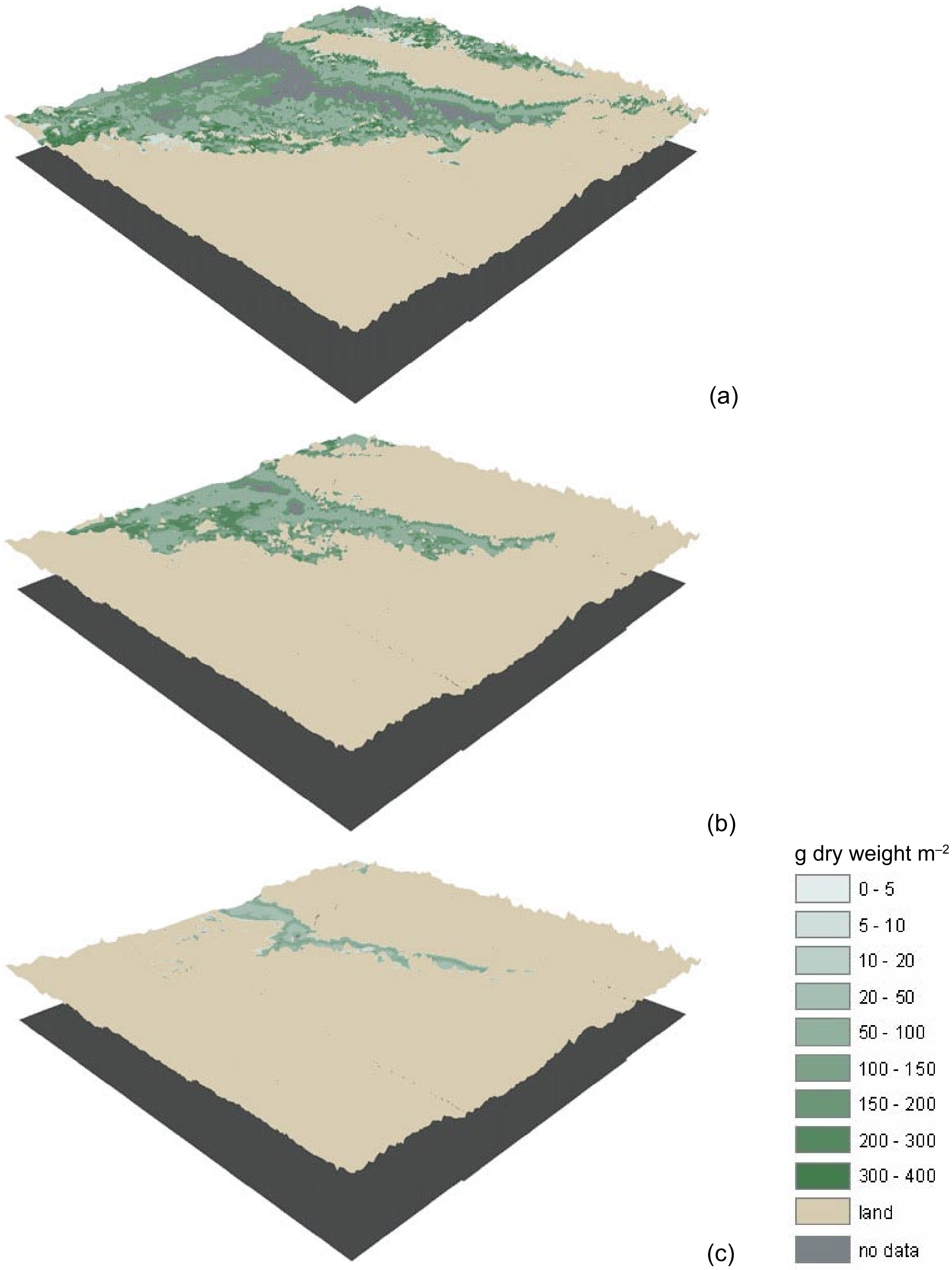

Figure 4-5. *Total biomass distribution in the Gräsö area (a) at present, (b) in 2,000 years and (c) in 4,000 years.*

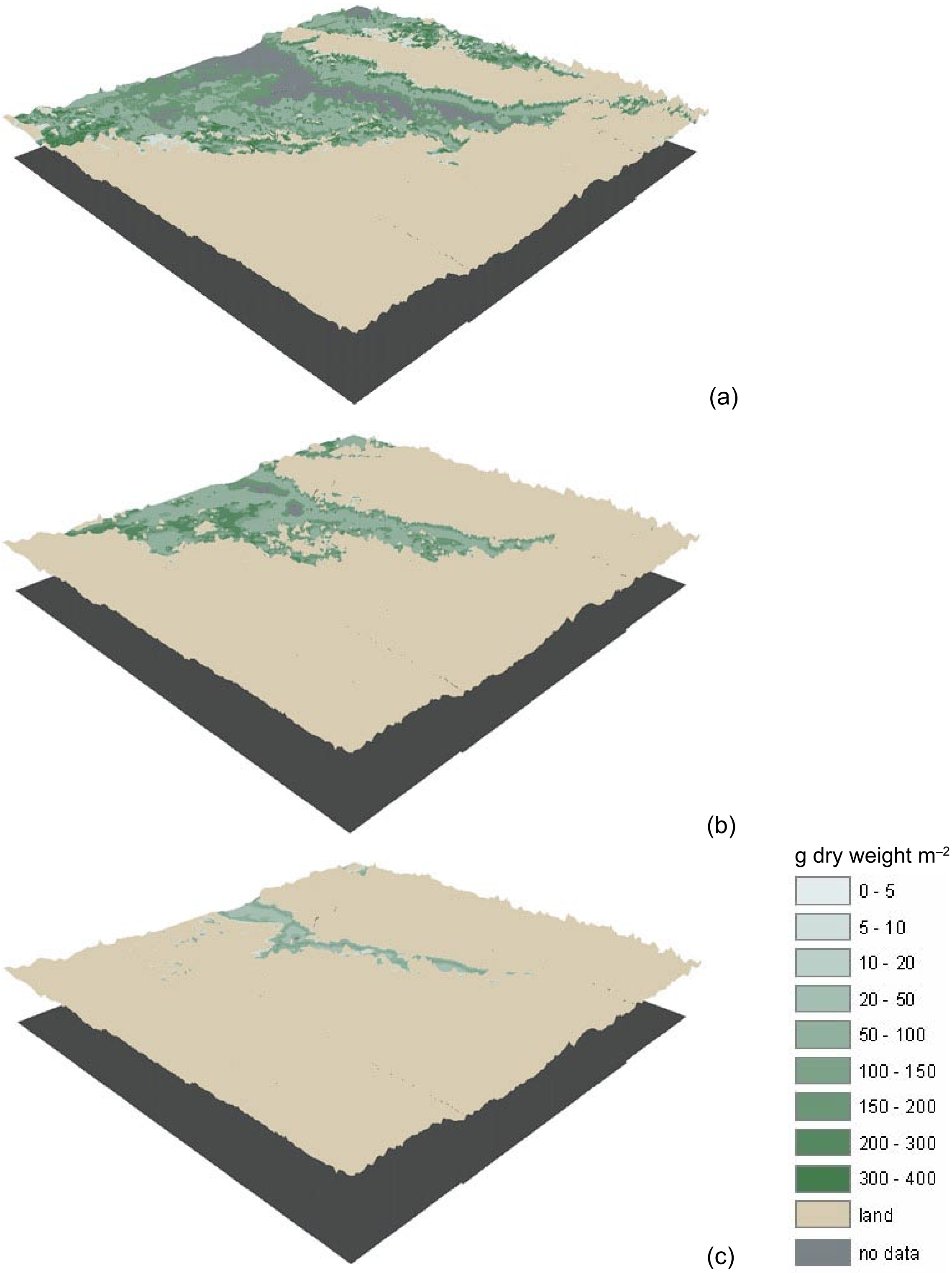

Figure 4-6. *Plant biomass distribution in the Gräsö area (a) at present, (b) in 2,000 years and (c) in 4,000 years.*

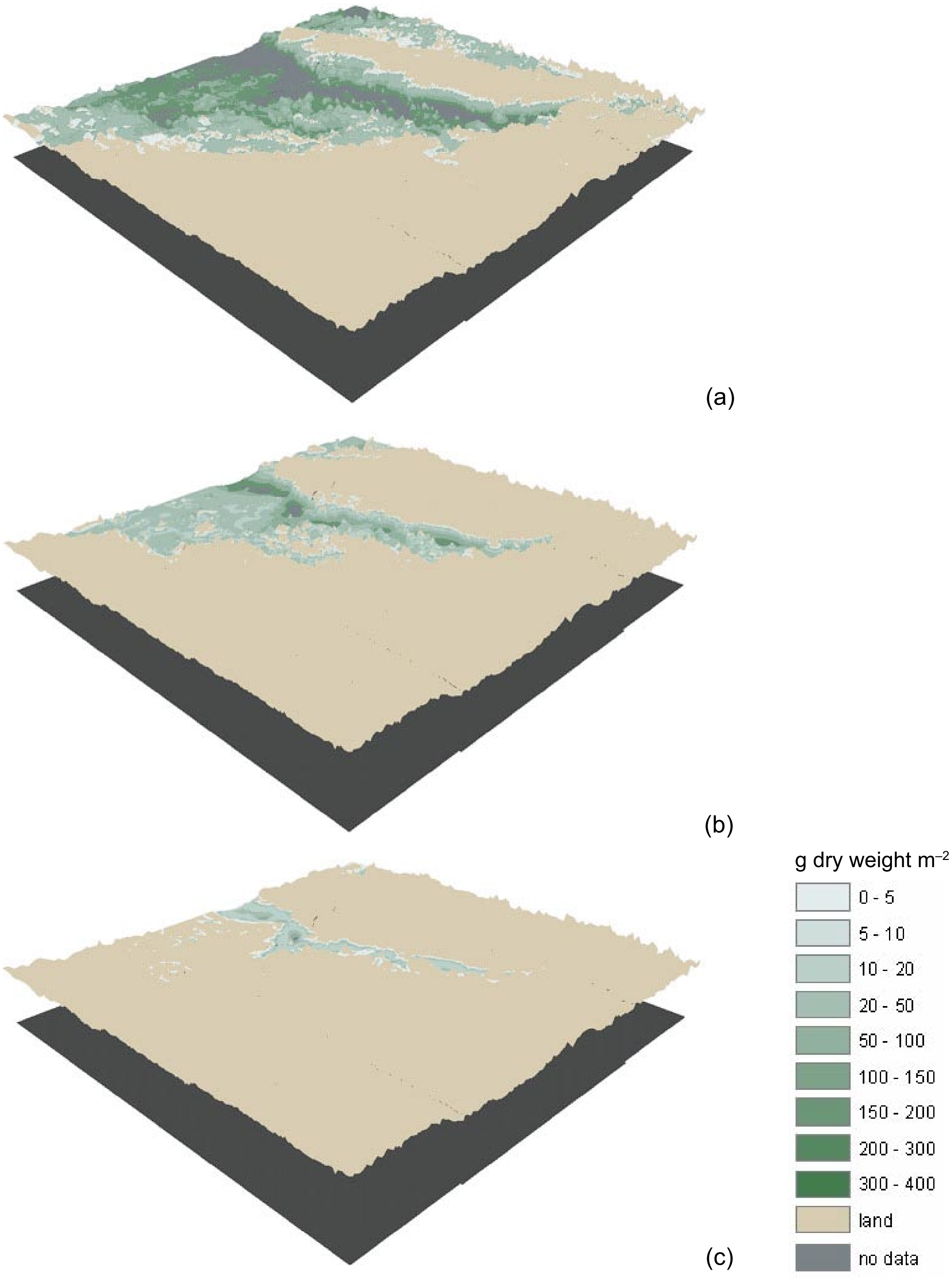

Figure 4-7. Animal biomass distribution in the Gräsö area (a) at present, (b) in 2,000 years and (c) in 4,000 years.

Total biomass

The changes in biomass per m² due to change in salinity were assumed to be linear, and were based on the biomass for 5.5 psu and 2 psu (Figure 4-4).

The biomass was calculated for each depth interval as [biomass (g/m²)] * [available area] and then added to receive the total biomass, biomass and depth intervals were according to Figure 4-4. The total biomass for all species in the map area at present was 50,500 tonnes. When the shoreline displacement was calculated according to equation (1), the total biomass in 2,000 years was 25,000 tonnes and in 4,000 years 3,600 tonnes. When the shoreline displacement was calculated as 6 mm/year, the total biomass counted up to 29,000 tonnes in 2,000 years and to 1,800 tonnes in 4,000 years, and for 5 mm/year it was 27,000 tonnes in 2,000 years and 5,000 tonnes in 4,000 years (Figure 4-8).

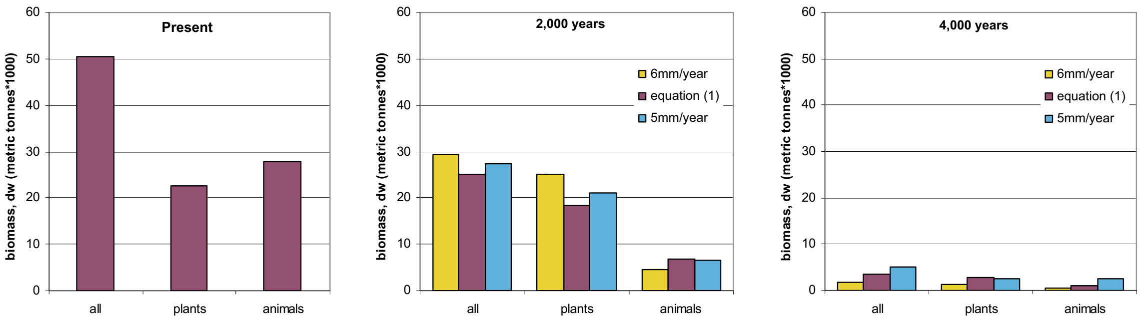

Figure 4-8. *Total biomass in the Gräsö area in metric tonnes * 10³, calculated with different shore displacement rates; the present rate of 6 mm/year, the displacement rate according to equation (1) and 5 mm/year.*

A simpler model to estimate total biomass for the entire area used the formula [average biomass (g/m²)] * [available area] (0 m – maximum depth (20 m)). Based on shore displacement according to equation (1), this estimation resulted in 55,400 metric tonnes at present, 26,000 in 2,000 years and 4 300 tonnes in 4,000 years (Figure 4-9).

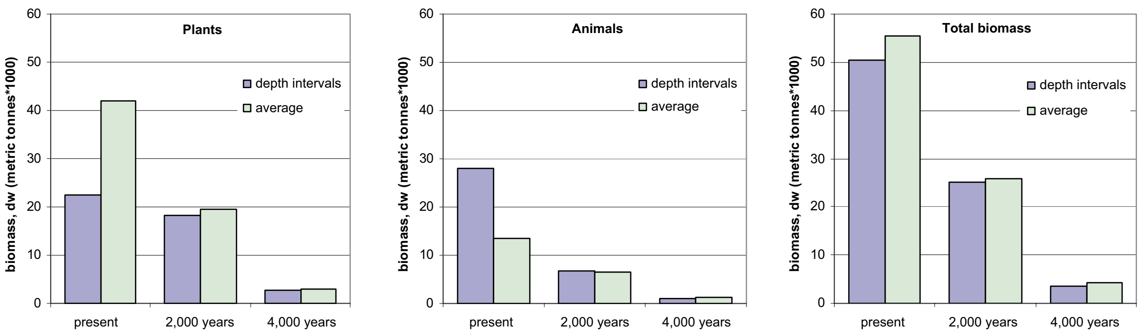

Figure 4-9. *Total biomass in the Gräsö area in metric tonnes * 10³, calculated as depth intervals and as arithmetic mean.*

Difference in total biomass for three rates of shore displacement

For fastest rate of shore displacement (6 mm/year) the total biomass in 2,000 years was 8% higher (for all species) than for the slowest (5 mm/year). For plants it was 20% higher with a faster shore displacement, but the animal biomass decreased by 31%. The difference increased with time and in 4,000 years the total biomass for all species at a shore displacement rate of 6 mm/year was 65% lower than for a shore displacement rate of 5 mm/year. Plant biomass was 52% lower and animal biomass was 80% lower with the fastest shore displacement rate than with the slowest (Figure 4-8).

Differences in total biomass of two methods

Biomass estimates were calculated in two ways, using area of the depth intervals in Figure 4-3 multiplied by the biomass/m^2 for each interval (alternative 1), or using the total available area from 0 to maximum depth (20 m) times the average biomass (alternative 2). The difference in biomass estimate of all species was at present 10% higher calculated as alternative 2. For plants it was 85% higher and for animals it was 51% lower. In 2,000 years, alternative 2 gave a biomass estimate for all species that was 4% higher than for alternative 1. For plants it was 7% higher and for animals 5% lower. In 4,000 years the differences in total, plant and animal biomass increased to 17%, 14% and 27% higher respectively (Figure 4-9).

5 Discussion

5.1 GIS application

Although the database contains over 2,000 samples, the number is small compared to the vast area the samples represent. However, we assume that the underwater environment is more predictable than the terrestrial. While the terrestrial environment is characterised by abiotic and biotic interactions forming intricate mosaic patterns, the rough structure of the Baltic Sea plant and animal communities is mainly determined by environmental factors. In a given area, the observed pattern mainly depends on the depth (light), the type of substrate and the wave exposure /Kautsky and van der Maarel, 1990/. On a larger geographical scale and in areas influenced by land runoff also salinity is important. This makes extrapolation of few sampling points to larger geographic areas of the Baltic Sea easier and more valid than equivalent terrestrial sampling. The predictability of the occurrence of a community is often high /Isæus, 2004/.

Estimations of the coastal biomass for Sweden have been made by /Kautsky and Kautsky, 1995/, who calculated the biomass per meter shoreline times the shore length for different sections of the coast. The total biomass was calculated to 2.0×10^8 kg C. Of the total biomass, 92% was found in the Baltic proper, 6% in the Bothnian Sea and only 2% in the Bothnian Bay. The plant biomass in the Baltic proper were composed to 61% of perennial macroalgae (mainly *Fucus vesiculosus*, *Furcellaria lumbricalis* and, in the south, *Fucus serratus*), while annual, filamentous algae dominated the biomass in the Bothnian Sea and the Bothnian Bay (64% and 73% respectively). In the Bothnian Sea and the Bothnian Bay phanerogames increased in importance. They made up 19% and 15% in respective area of the total biomass compared to only 5% in the Baltic proper. The blue mussel (*Mytilus edulis*) constituted more than 90% of the animal biomass in the Baltic proper. In the Bothnian Sea another bivalve, *Macoma baltica*, was found to be the dominating species with 61% of the total animal biomass. In the Bothnian Bay the bivalves were replaced by crustaceans and gastropods (45% and 35% respectively).

The possible changes in biomass as a result of lowered salinity have here been illustrated by using biomass values from the Bothinan Bay, in an area where the salinity is around 2 psu. The use of Bothnian Bay data to predict future development will underestimate the biomass. There are other factors except salinity that influence the biomass distribution in the Bothnian Bay, such as ice scouring, insolation and temperature /cf Snoeijs and Kautsky, 1989; Kautsky and Kautsky, 1995/. It is therefore likely that only lowered salinity would give a somewhat higher biomass than what is found in the Bothnian Bay samples. The estimates in this study did not take into consideration the effects of salinity on all species in the Gräsö material. The salinity requirements of the two major biomass contributors in the Gräsö area, *Fucus vesiculosus* and *Mytilus edulis*, which have their distribution limits at 4 and 4.5 psu respectively /cf Kautsky, 1989/, /Serrão et al. 1996/ and /Westerbom et al. 2002/, would exclude them from the area in 2,500 to 3,000 years time. The blue mussel *Mytilus edulis* is already less common in the Öregrundsgrepen samples than in the Gräsö samples, and the present animal biomass might thus be overestimated.

Production period

In the Bothnian Bay the deepest sample (13.2 m) is not as deep as in the Gräsö area (20 m). This difference in depth distribution is most likely not only an effect of salinity, but depends on other factors such as insolation or topography. Insolation, as a function of latitude and ice coverage, influences the length of the growth season for plants. This could be calculated as a correction function for latitude and ice cover /for details see Kautsky and Kautsky, 1995/. In the southern Baltic Sea the productive season is about 9–10 months, while it is only 4–5 months in the Bothnian Bay. The use of Bothinan Bay samples to represent the benthic community at 2 psu might therefore underestimate the estimated future biomass at the same salinity in the Gräsö area.

The maximum and minimum depths used in this study were based on the depths of individual samples. This is however a simplification, as these samples actually represent an interval that might go deeper than the sample itself. Thus, the biomass covers a larger area than the one used here, which will underestimate the total biomass.

The largest difference in biomass estimate due to method is at present time, where the plant biomass was 85% higher when calculated as [average biomass]*[available area] than when divided into depth intervals. In 2,000 years and 4,000 years, the choice of shore displacement function was more important when calculating total biomass than the input biomass value.

Calculated as depth intervals, the total benthic biomass in the map area is at present 10 to 29 times higher than the estimated biomass in 4,000 years depending on which shore displacement function is used. However, it is also 13 times higher when calculated as [average biomass]*[available area].

5.2 Future perspectives

The database

The major parts of the biomass database are complete. There are some minor details, for example substrate is missing for a few areas and available but not added for some other. In a small number of the samples distance to land, depth or frame size is missing. In most of those cases, the information was not clearly available in the original data due to minor differences in sampling techniques.

The positions of the profiles have not yet been added to the database. There are GPS coordinates available for some of the transects, but only reliable data for the most recent. For most of the areas the only positioning available is a mark on a paper map. We are waiting to obtain access to a good digital background map or sea chart covering the entire Baltic Sea coast in order to have all the positions in the same system.

The description of species depth distribution and coverage as well as a description of the substrate along the entire transect are not yet compiled in a database. Those data include several areas that have not been sampled quantitatively. In all areas where quantitative samples were collected, cover data are also available. The cover data will make a better estimate of the plant and animal distribution possible. For the areas with both quantitative samples and cover data, the correlation between biomass and cover degree should be performed. If such a correlation is found, a rough estimate of the biomass may be done in areas where no biomass data were collected.

The GIS application

The main structuring factors for the Baltic Sea are salinity, depth, wave exposure and substrate. All these factors should be included in the analysis. However, substrate maps for the area were not available. Although substrate records are available in (almost) all samples in the database, within the realms of this project we could not find a way to use the substrate data in the database to create such a map, and evaluate its possibilities. Even though there are 150 substrate samples along the 15 transects in the Gräsö area, the uneven spatial distribution of the samples makes them difficult to use as the only basis for substrate cover. The samples are aggregated along transects, with wide gaps in between. The loss of information for heterogeneous landscapes increases rapidly as data is aggregated and analysed at a coarser resolution /Cao and Lam, 1997/. Along transects substrate records in the samples changes within a few meters, thus making interpolation to 10 m pixels less meaningful. Wave exposure calculations have not been made. A model suitable for Swedish conditions is under construction /Isæus, manuscript/.

To make a good estimate of the species distribution and a rough estimate of their biomass in an unknown geographic area, the type of substrate, the depth and the wave exposure have to be known. Since neither substrate maps nor wave exposure calculations were available, the only factors that have been taken into consideration in the GIS application were salinity and depth. Adding information available in substrate maps and/or data on wave exposure would probably increase the reliability of the estimates. It is therefore advisable to try a smaller area for one or two of the additional variables, in order to see if the difference is large enough to be worth the effort.

Initially, statistical analyses were performed to test the homogeneity of the material. These tests showed that the two subareas of Råneå and Kalix were similar enough to be treated as the same area. However, a previous investigation found that although the total plant biomass for Råneå and Kalix was similar, the difference in species composition was pronounced /Foberg and Kautsky, 1992/. A multivariate analysis (MDS) clearly separated the areas into two distinct clusters. This stresses the importance of biological interpretation of the material together with the importance of relevant statistical methods. To only rely on standard statistical or numerical methods, like ANOVA and other popular applications, when handling the material is prone to produce results with no ecological relevance.

Near future and future aspects are the compilation of substrate and species depth distribution and coverage into a database. The possibility of creating a GIS map of the geology in an area based on substrate observations along the divers transects also needs to be investigated. The latter could be done by taking the wave exposure and depth into account, combined with declination of the shoreline and general geology of the area. Also the importance of substrate as a GIS layer for the estimate of plant and animal biomass in given geographic areas in the whole Baltic Sea has to be evaluated.

6 Acknowledgements

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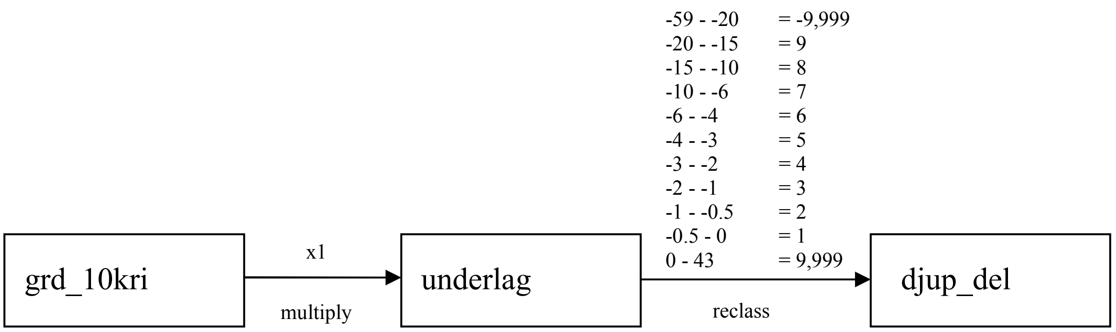
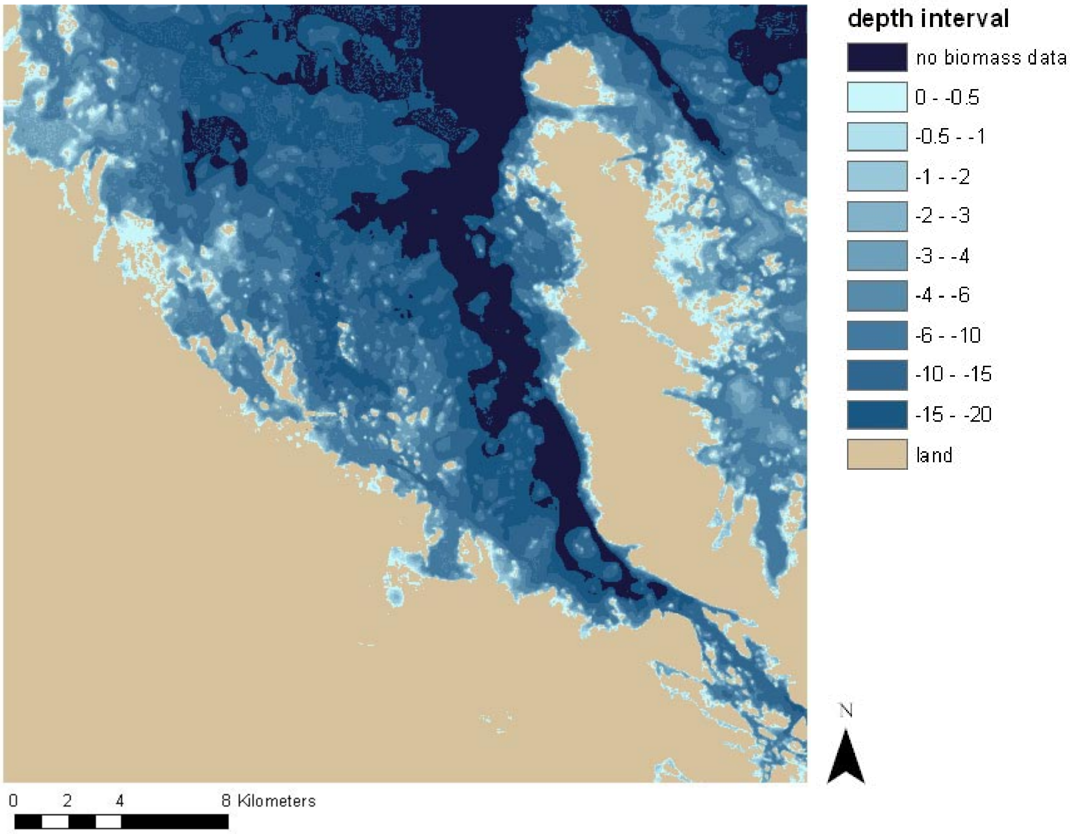
Appendix 1

The digital terrain model (ESRI grid file grd_10kri) was multiplied by [1] in order to create a file (underlag) that could be reclassed. The terrain model was then divided into depth intervals.



djup_del



Attribute table for djup_del

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2	2	112347
3	3	132051
4	4	166794
5	5	274988
6	6	334582
7	7	727688
8	8	810162
9	9	867070
10	9999	4353573

The pixel size is 100 m^2. Total biomass in grams is calculated as [the biomass per m^2 for each depth interval]*[the number of pixels for each interval]*100. Biomass is converted to metric tonnes with the conversion factor of 1,000,000.