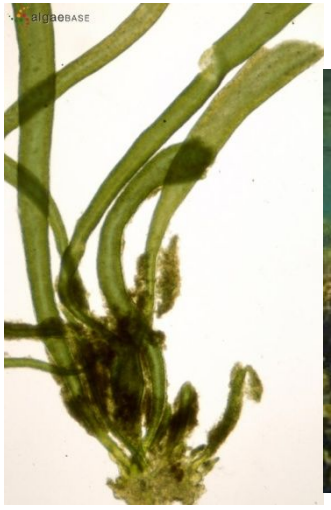
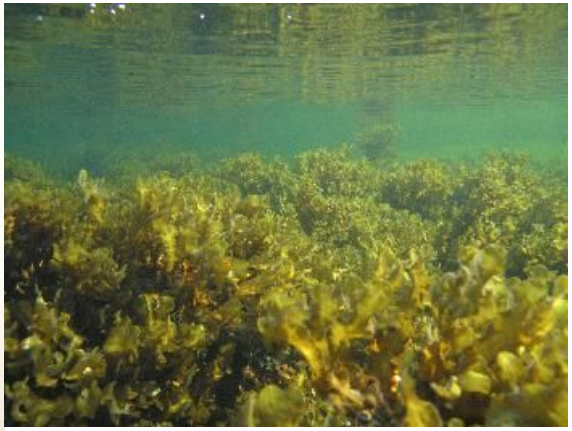
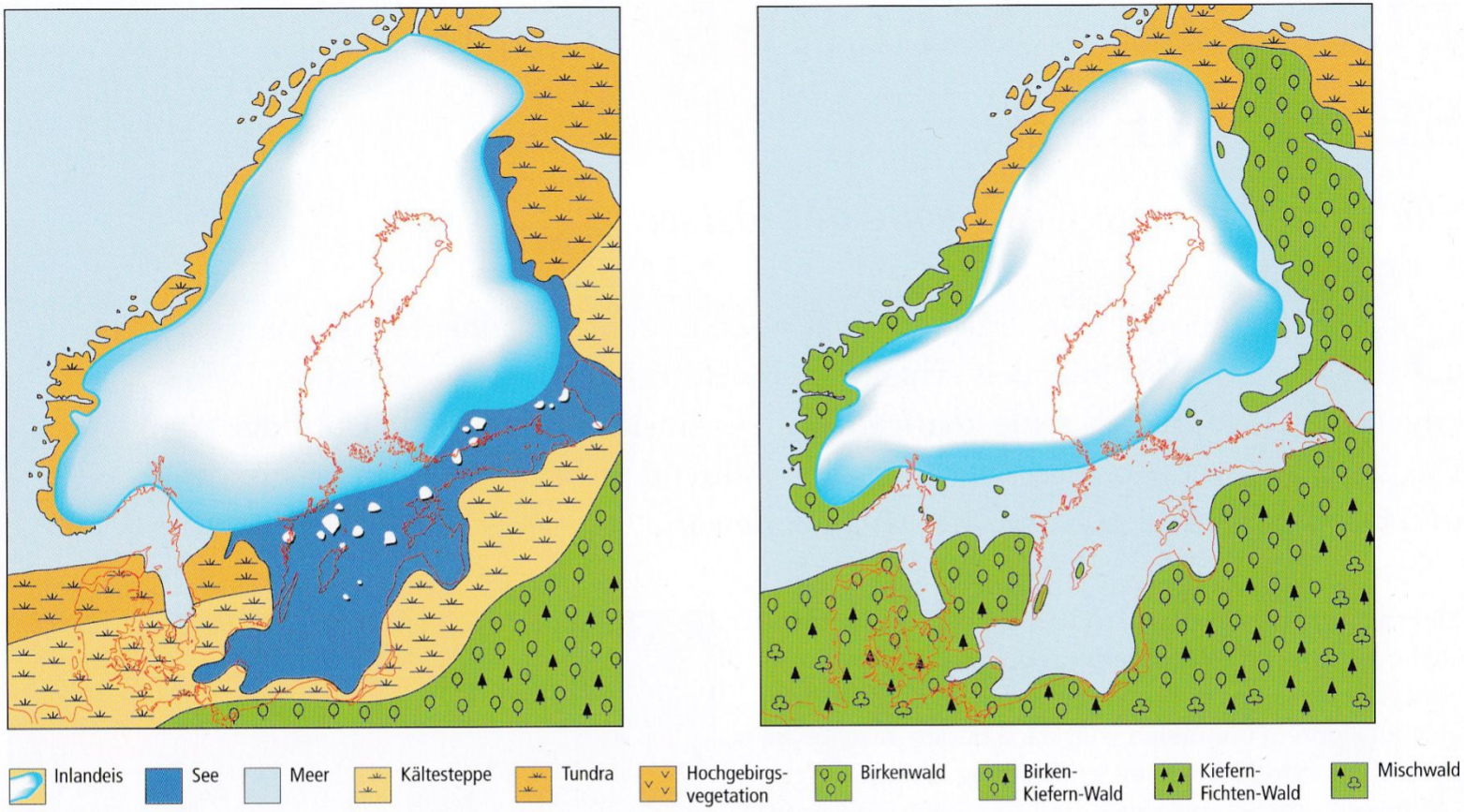
Brackish areas of the European cold temperate region – fjords, estuaries, **Baltic Sea**

eutrophication – tubular *Ulva*
mesohalinne conditions – *F. vesiculosus, F. serratus, Blidingia minima, Ulothrix, Ulva, Enteromorpha*

Baltic Sea
-no tides = no eulittoral
- before 12000 years – freshwater lake; nowadays brackish; low seaweeds diversity
- *Prasiola, Cladophora spp., Ceramium tenuicorne, Monostroma grevillei, Bangia atropurpurea, Blidingia minima, Rhodomela confervoides, F. vesiculosus*







Der Baltische Eissee ▲

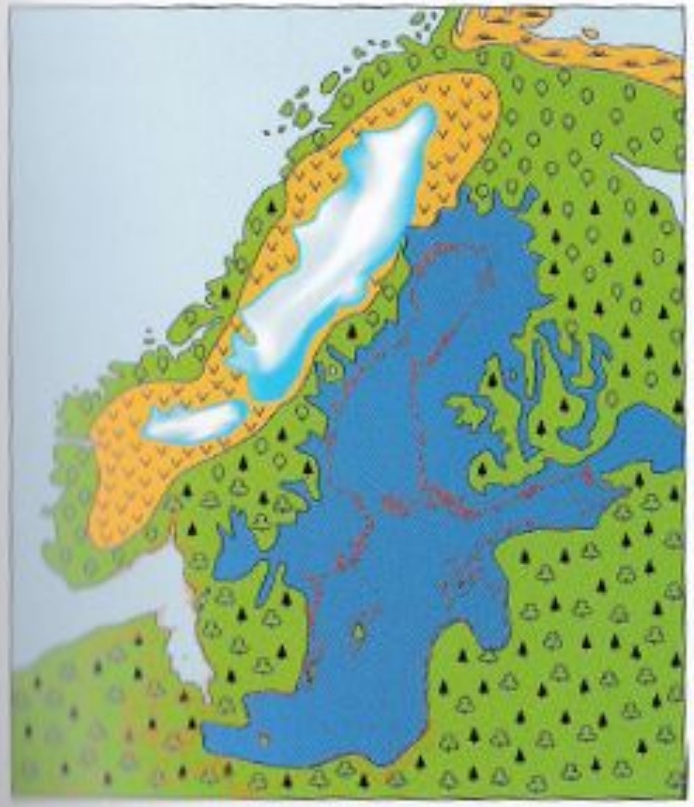
(11.000 bis 10.000 Jahre vor heute)

Als die Gletscher der letzten Vereisung schmolzen, bildete sich in der Ostsee-Senke ein gewaltiger Süßwassersee. Die längste Zeit des Jahres trug dieser See, der vom Inlandeis im Nordwesten angestaut wurde, eine feste Eisdecke. Im Sommer trieben zahlreiche Eisberge vom Inlandeis nach Süden und verfrachteten dabei zahlreiche „Findlinge" - große Gesteinsbrocken.

Das Yoldia-Meer ▲

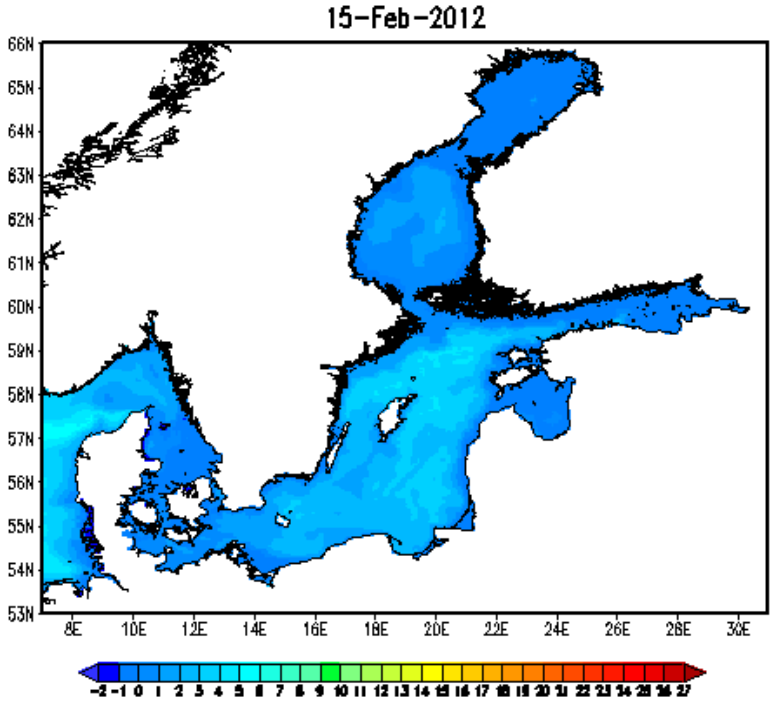
(10.000 bis 9.000 Jahre vor heute)

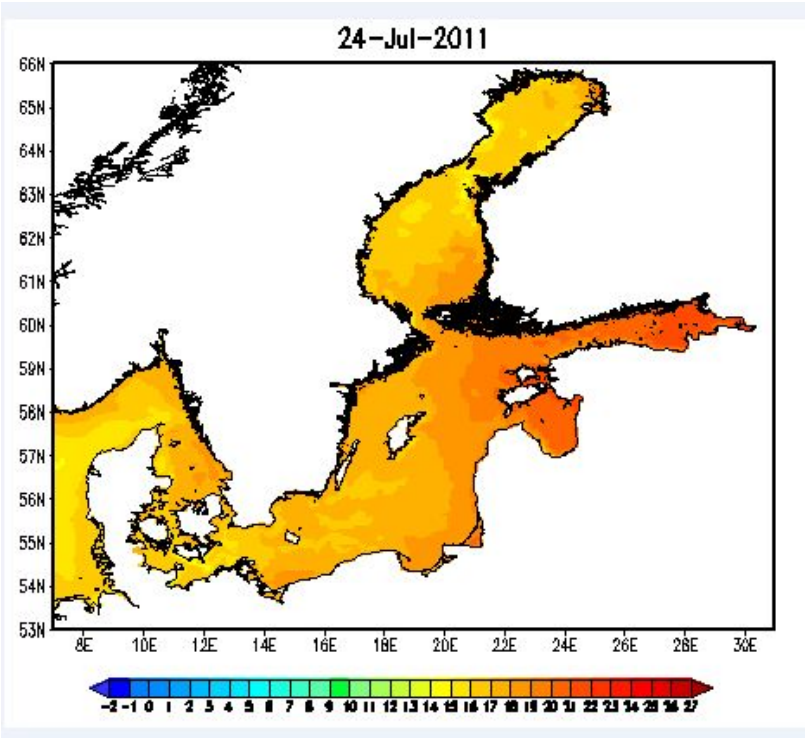
Als das Eis im Gebiet der Mittelschwedischen Senke abschmolz, lag deren Grund noch so tief, dass Nordseewasser in die Ostsee-Senke eindringen konnte. So wurde der See zum Meer - zum Yoldia-Meer, sogenannt nach der dickschaligen Islandmuschel Yoldia arctica.



Der Ancylus-See ▲
(9.000 bis 8.000 Jahre vor heute)
Durch die fortlaufende Landhebung lief die Mittelschwedische Senke trocken. Damit ging die Verbindung zwischen Yoldia-Meer und Weltmeer verloren. Das Meer wurde wieder zum See, der seinen Namen von der für ihn charakteristischen Süßwasserschnecke Ancylus fluviatilis erhielt.

Das Litorina-Meer ▲
(8.000 bis 2.000 Jahre vor heute)
Durch den weiteren raschen Anstieg des Meeresspiegels überflutete das Nordseewasser Belte und Sund. Der See wurde erneut zum Meer - zum Litorina-Meer, sogenannt nach der Gemeinen Strandschnecke Litorina litorea. Vor ungefähr 4.000 Jahren erreichte der Wasserspiegel seinen heutigen Stand. Seither unterliegt er nur geringfügigen Schwankungen.





s. m.: 18 až 22°C, w.m.: -2 až 4°C

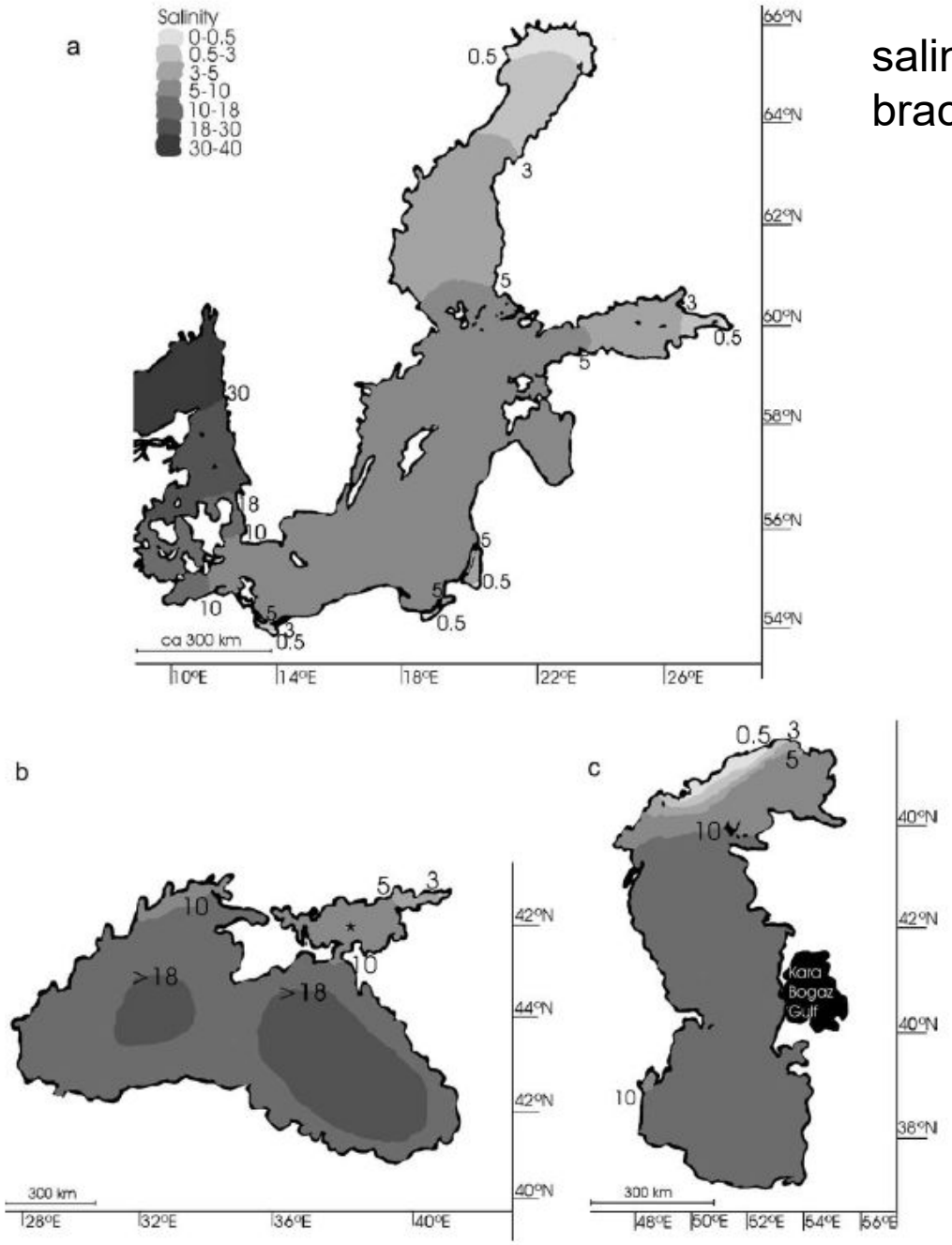
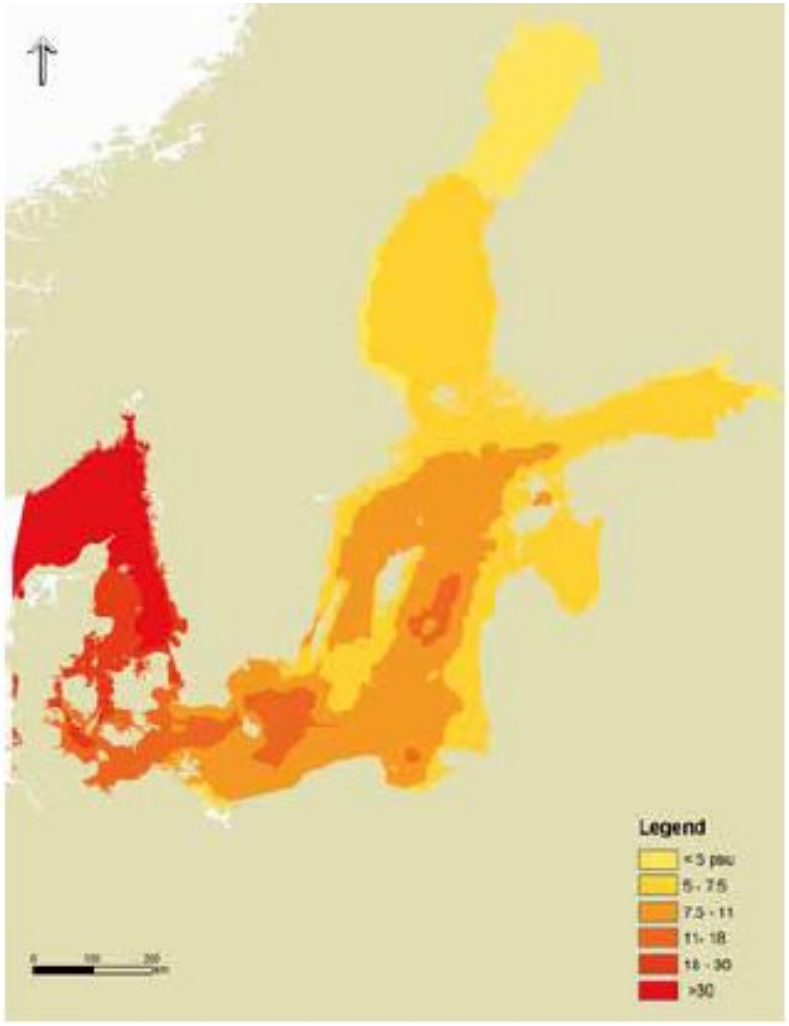


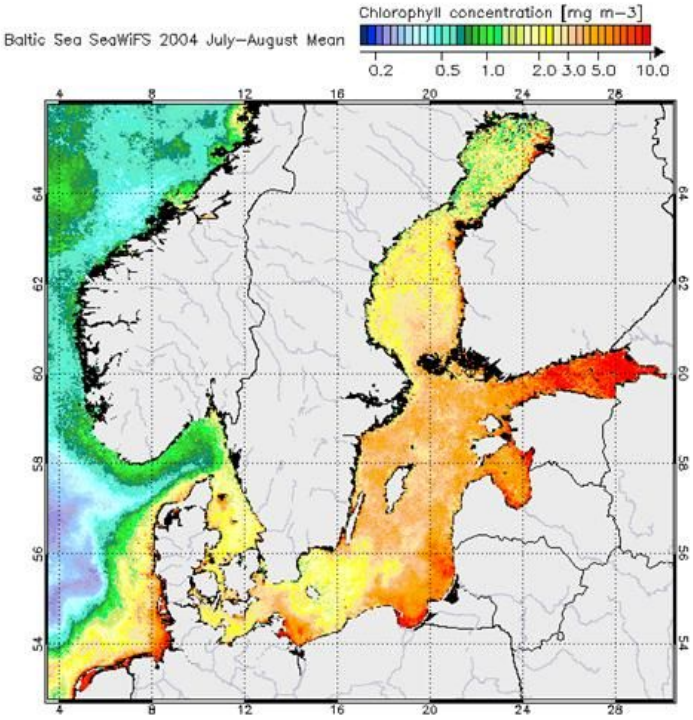
Fig. 2. The Baltic Sea (a), the Black Sea and the Sea of Azov (*) (b) and the Caspian Sea (c) with salinity zones according to the Venice system (zone border salinities as in Table 1). The salinity zone coloration as given in (a).

salinity gradients in major European brackish habitats

Paavola et al., 2005,
Est Coast Shelf Sci 64: 738-750

- Baltic is the single largest brackish habitat in the world
- it is atidal, but there are non-periodic fluctuations
- anaerobic benthic zones
- eutrophication since 1950s, peaking in 1970s to 1980s
- occasional inflows of oceanic saltwater
- decrease of competition from Kattegat to N and E regions (decreasing salinity)
- brackish submergence
- regular seasonal partial freezing





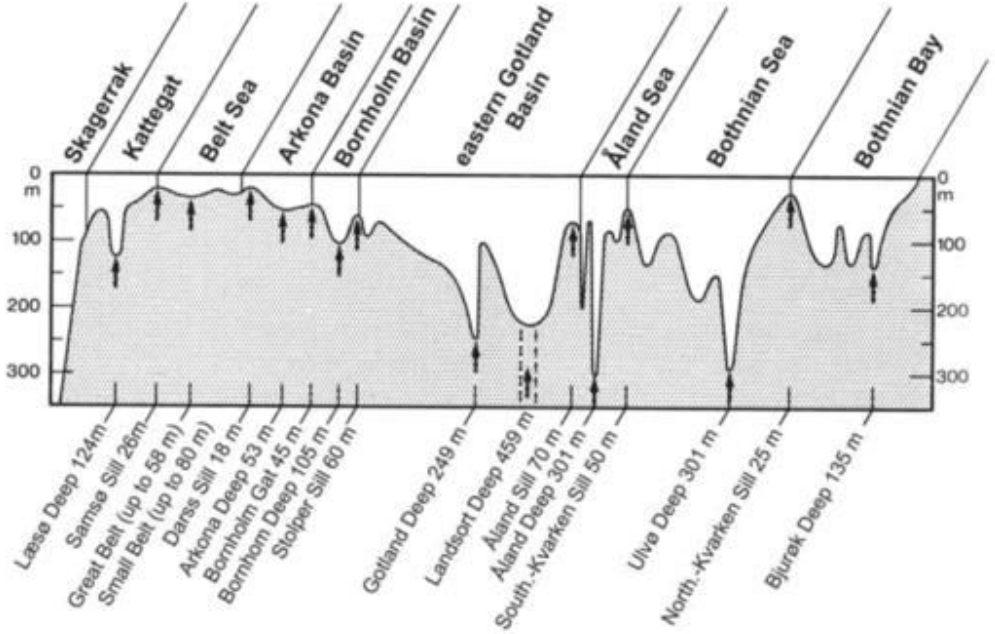
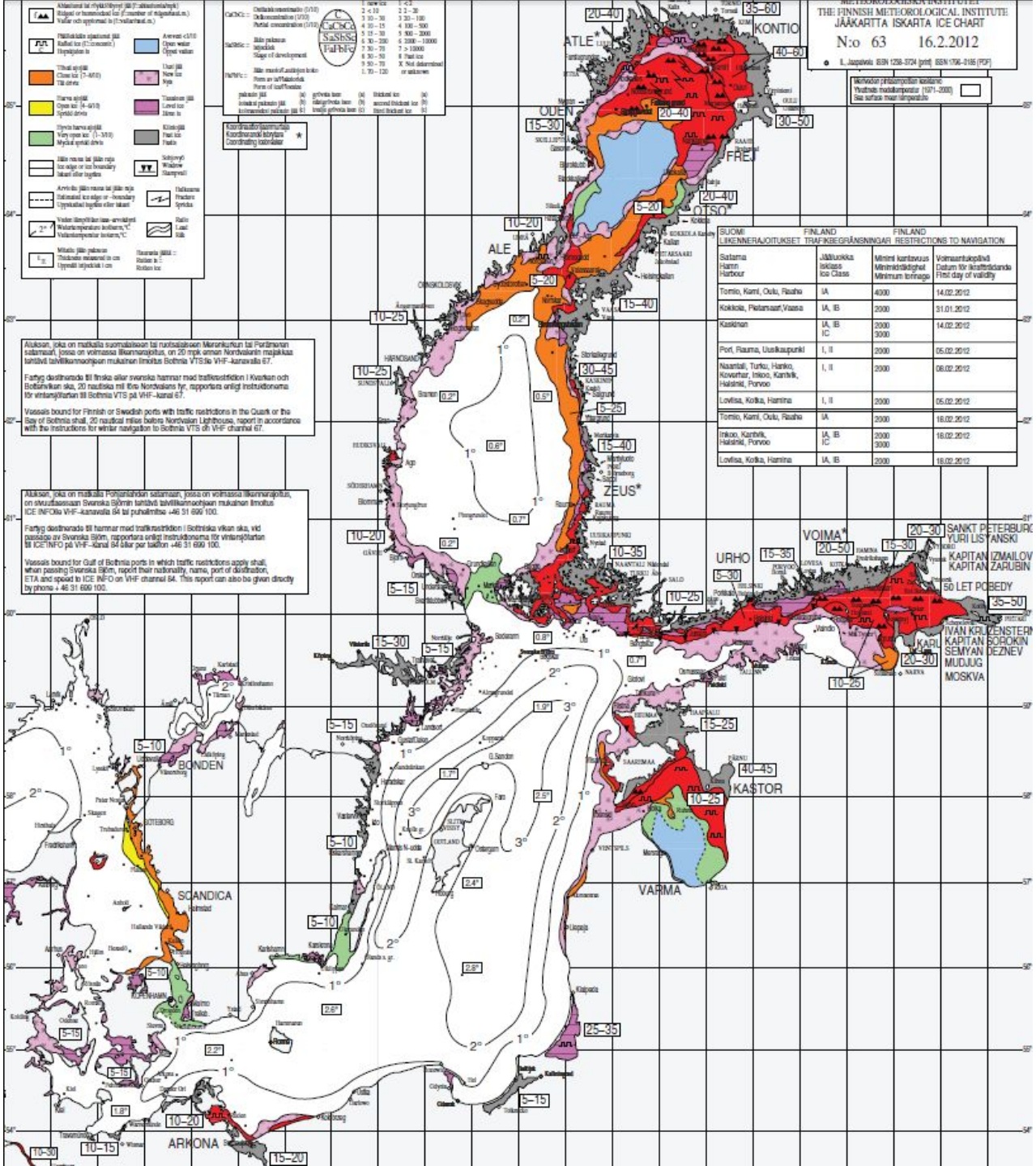


Fig. 1.2 Depth profile in longitudinal axis. Depth of basins and sills in metres (Rheinheimer 1995)

Abbildung 8.11 Salzgehaltgradient in der Ostsee[1]



February
2012

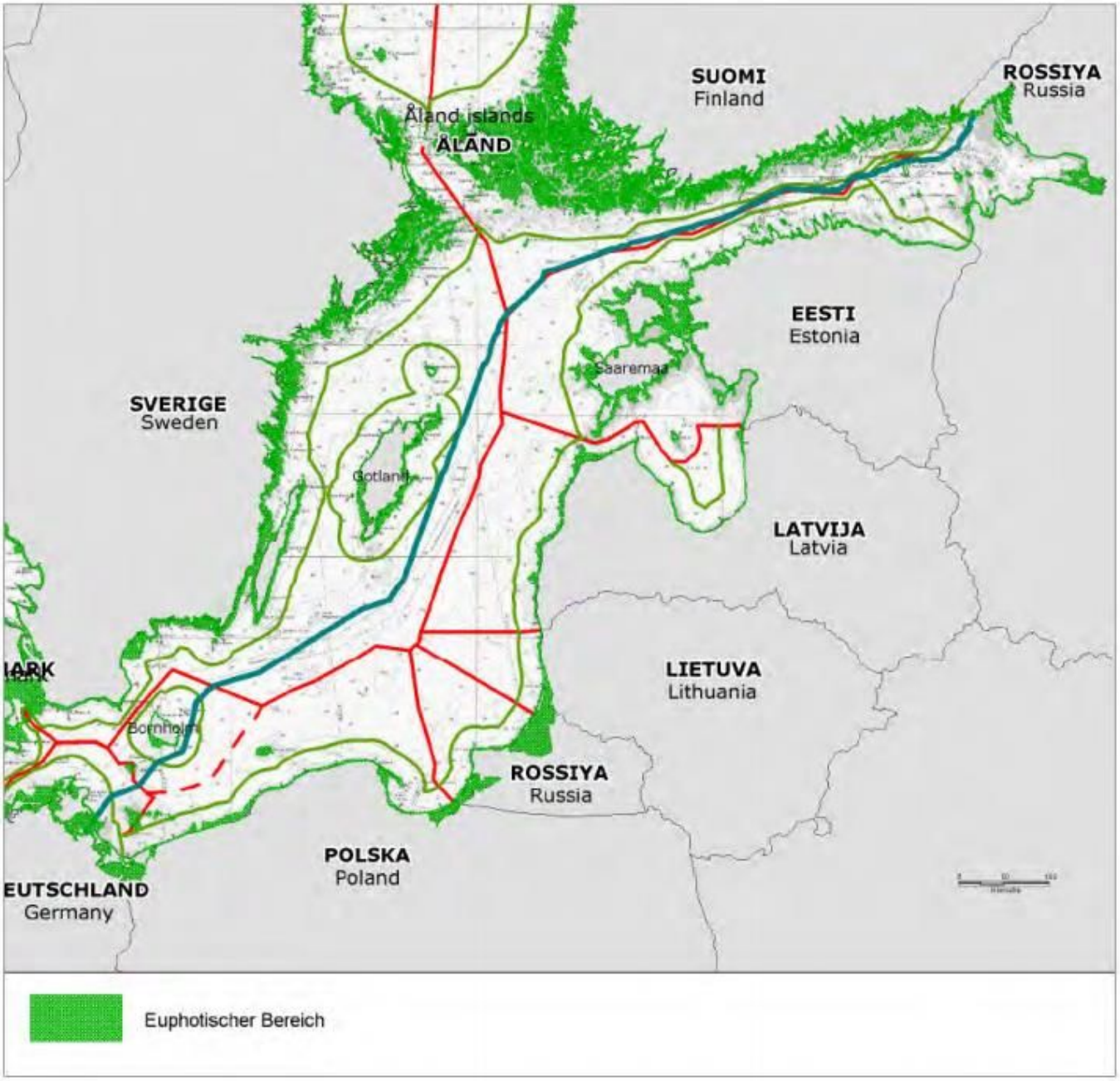
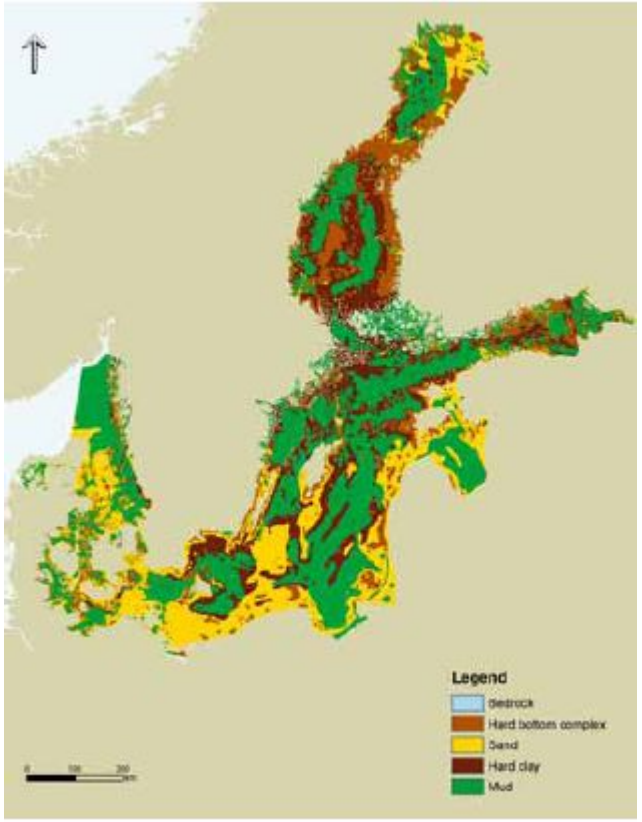
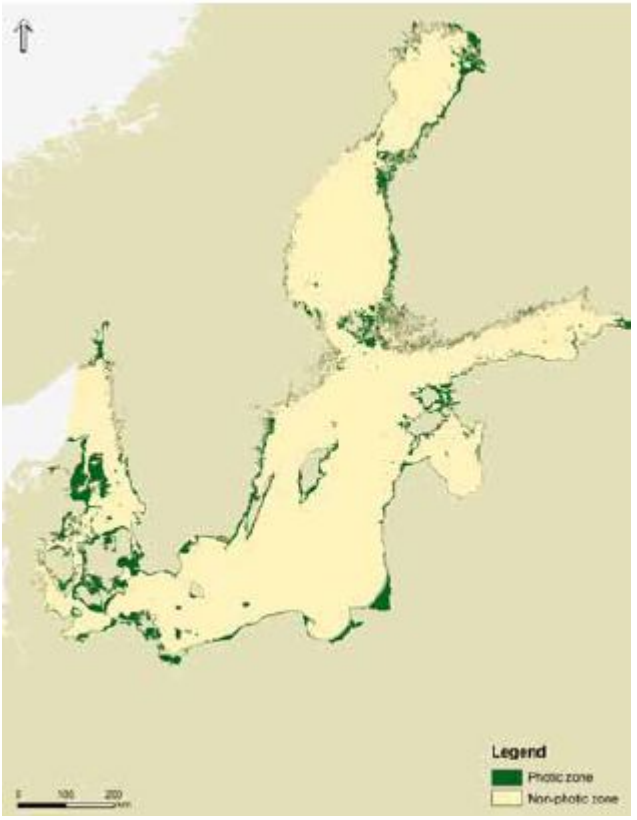
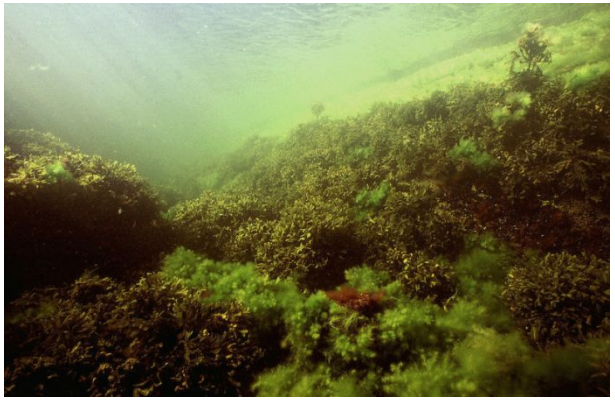
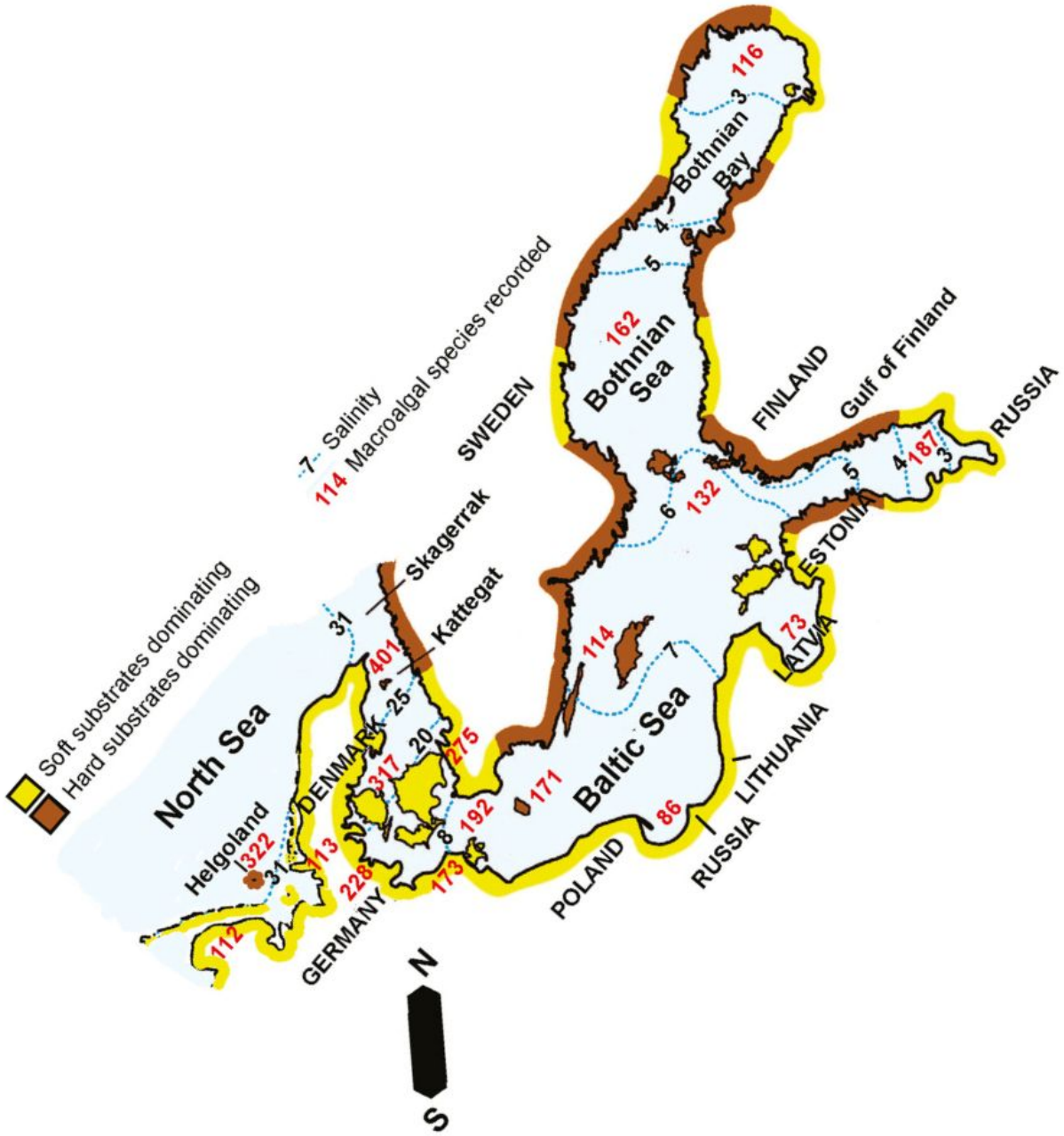


Abbildung 8.13 Gebiete in denen mindestens 1 % des nutzbaren Lichts den Meeresboden erreicht (euphotischer Bereich)(1)


Legend
Bedrock
Hard bottom complex
Sand
Hard clay
Mud


Legend
Photic zone
Non-photic zone




Soft substrates dominating
Hard substrates dominating
7 Salinity
114 Macroalgal species recorded
North Sea
Helgoland
322
31
113
112
GERMANY
DENMARK
Skagerrak
Kattegat
401
31
25
20
317
275
228
192
173
SWEDEN
Bothnian Sea
162
Bothnian Bay
116
3
4
5
6
132
114
171
Baltic Sea
FINLAND
Gulf of Finland
187
RUSSIA
ESTONIA
LATVIA
73
LITHUANIA
RUSSIA
POLAND
86
N
S

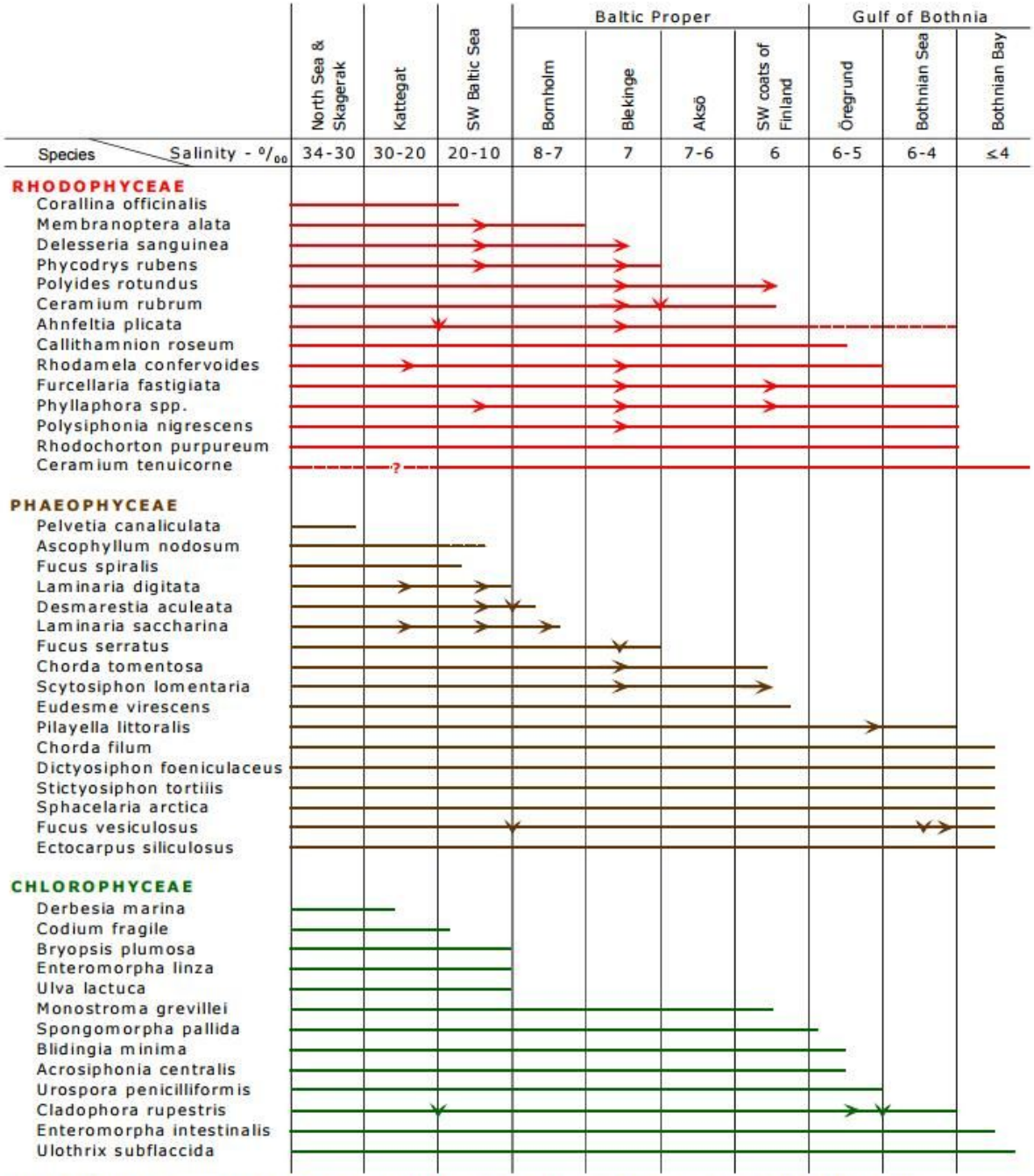
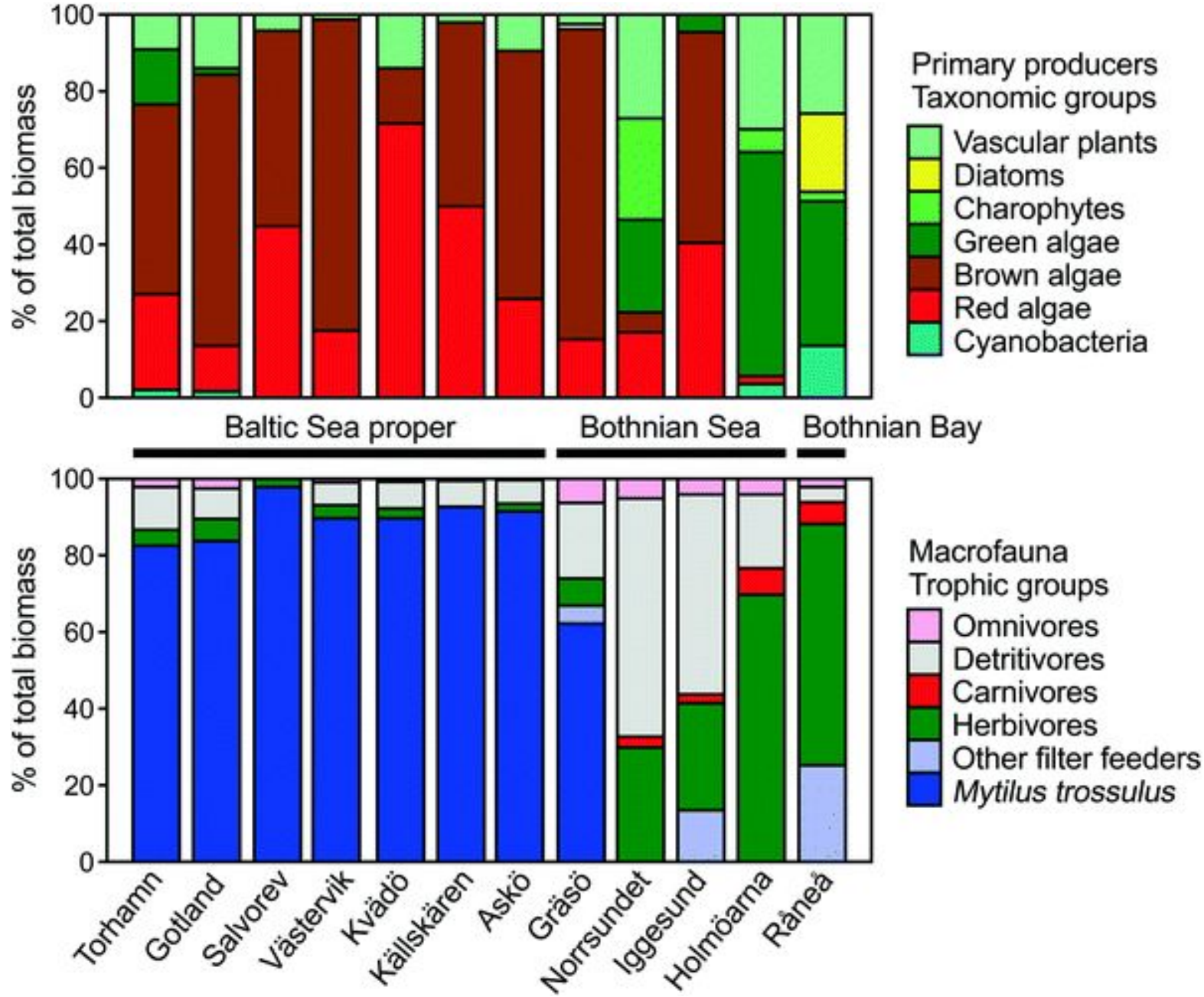
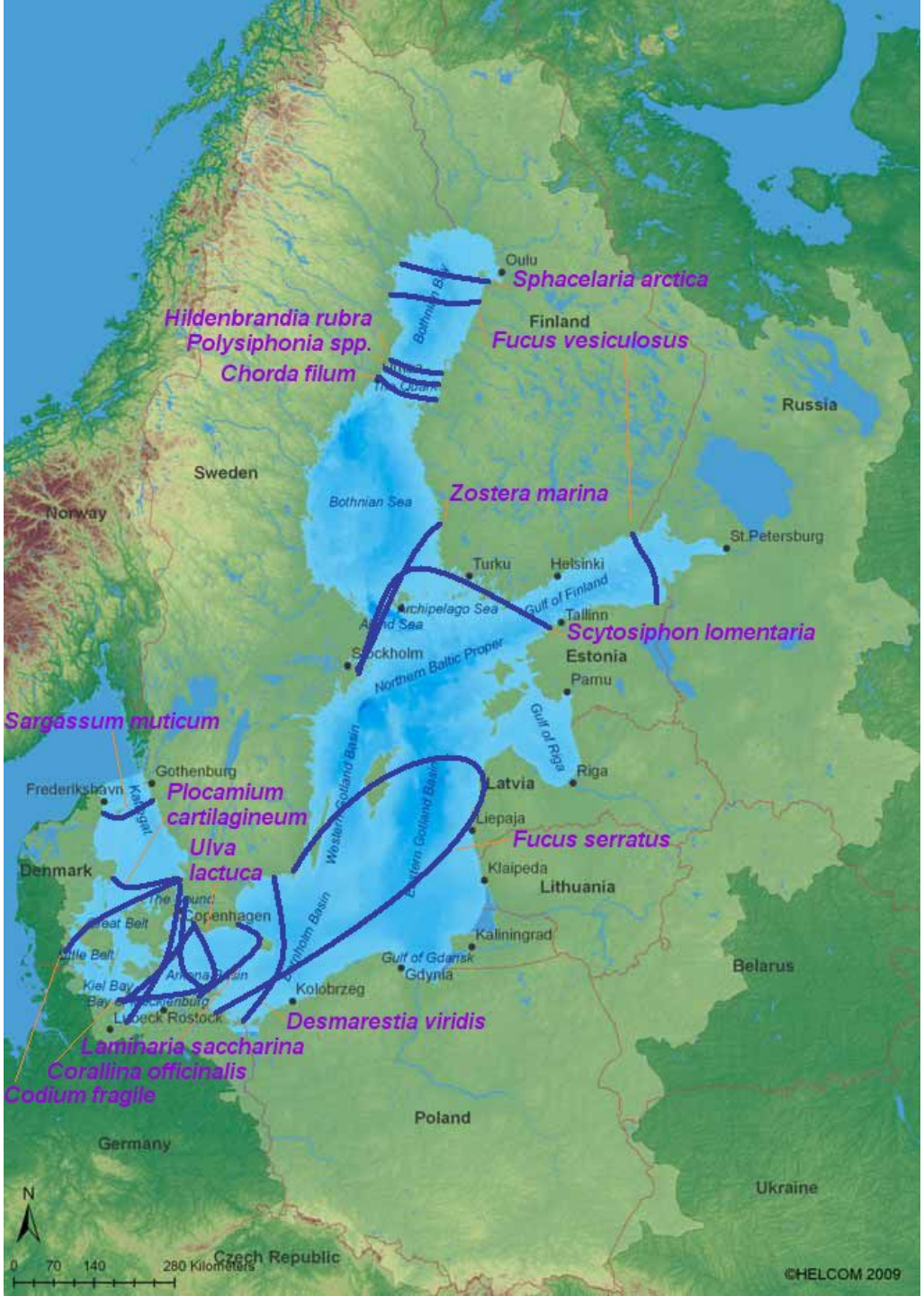
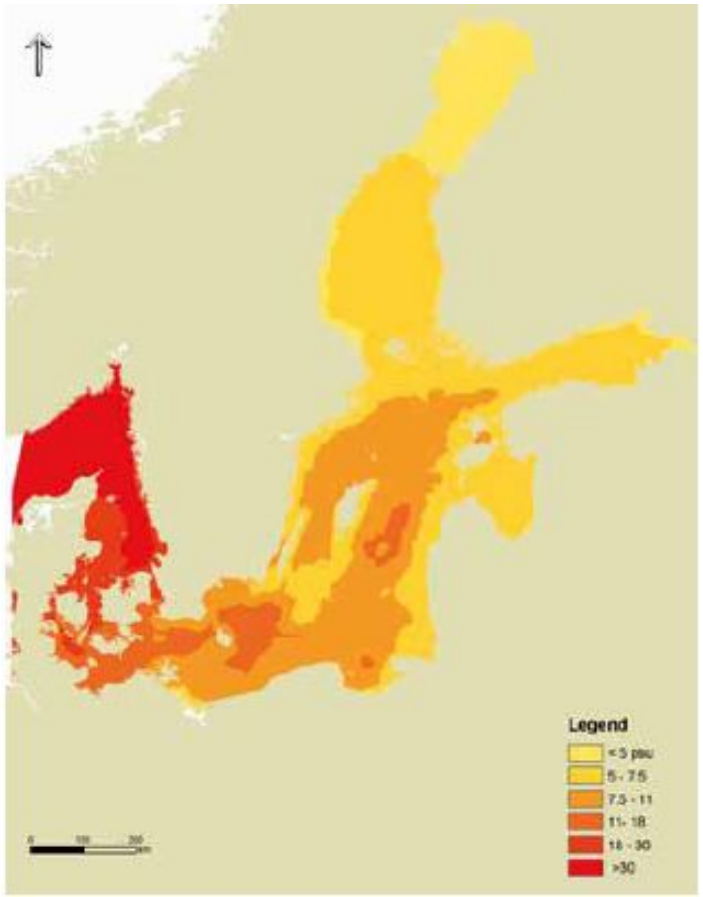


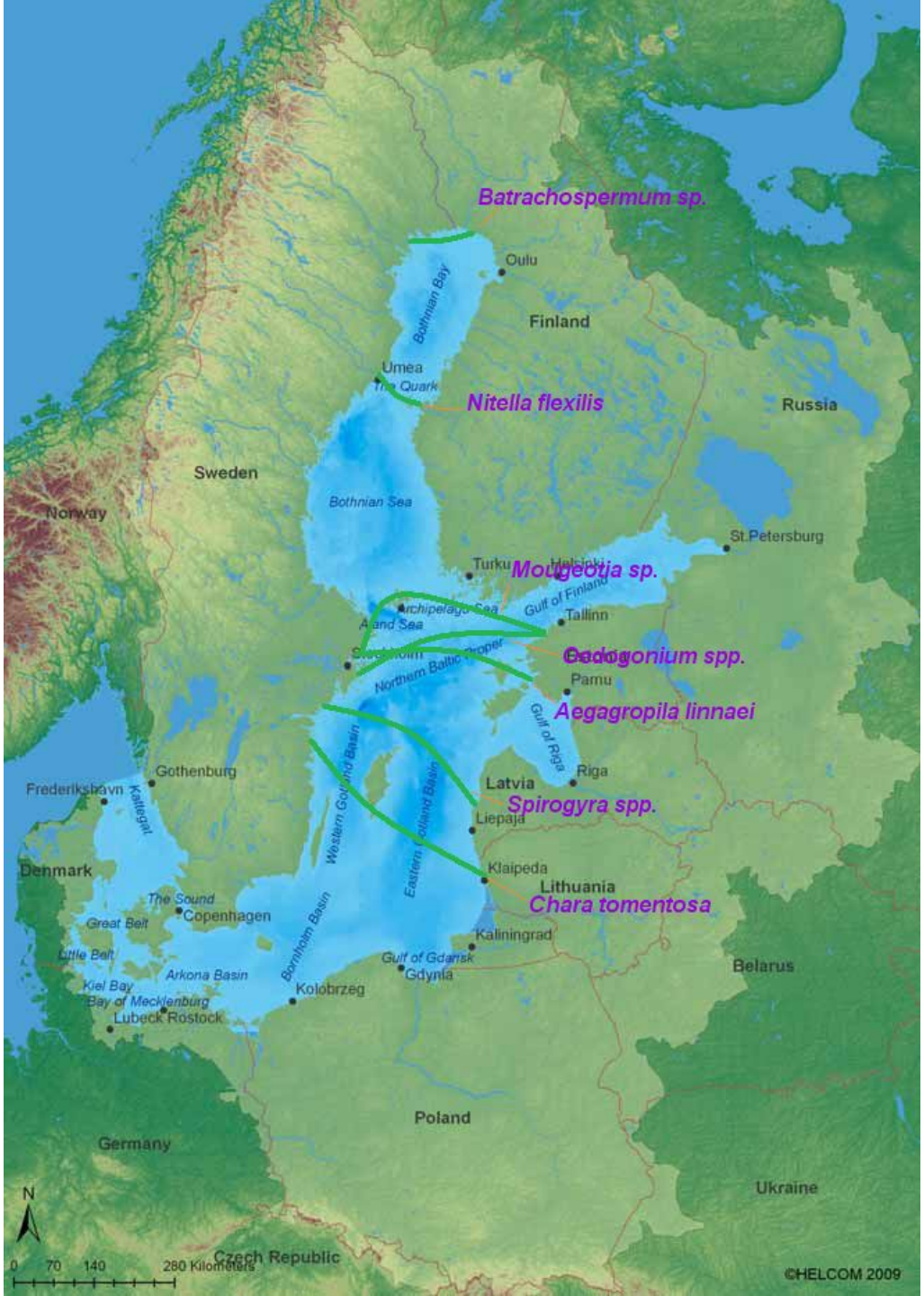
Abbildung 8.14 Verbreitung von Makroalgen in der Ostsee, mit Ausnahme des Finnischen Meerbusens[1]

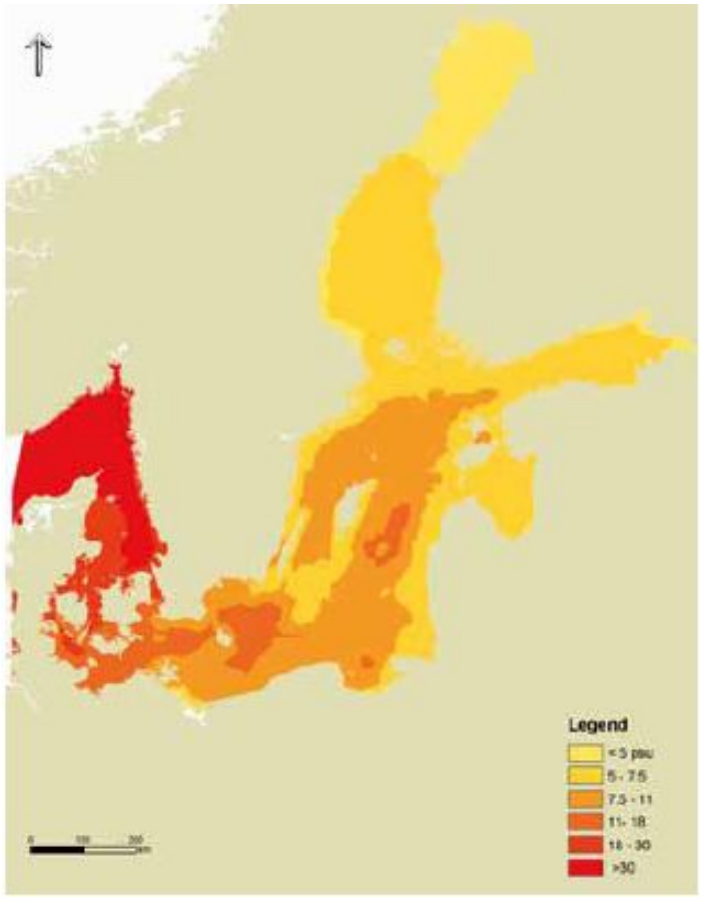

% of total biomass
100
80
60
40
20
0
Primary producers
Taxonomic groups
Vascular plants
Diatoms
Charophytes
Green algae
Brown algae
Red algae
Cyanobacteria
Baltic Sea proper
Bothnian Sea
Bothnian Bay
% of total biomass
Macrofauna
Trophic groups
Omnivores
Detritivores
Carnivores
Herbivores
Other filter feeders
Mytilus trossulus
Torhamn
Gotland
Salvorev
Västervik
Kvädö
Källskären
Askö
Gräsö
Norrsundet
Iggesund
Holmöarna
Råneå





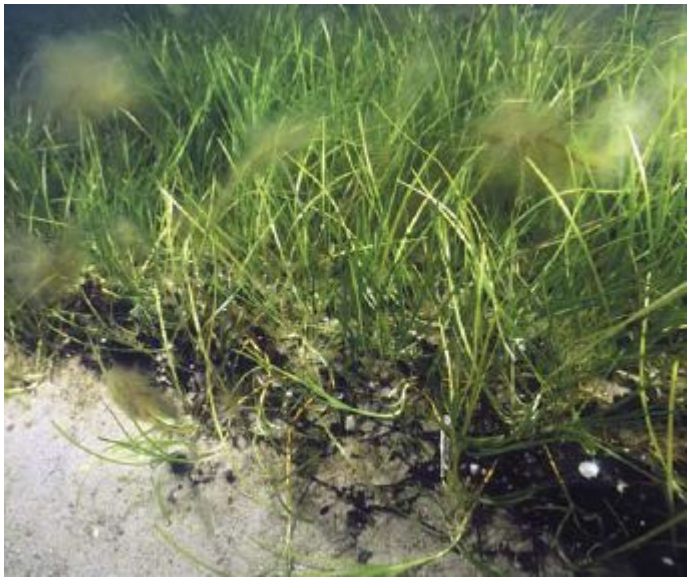
distribution limits of selected marine taxa





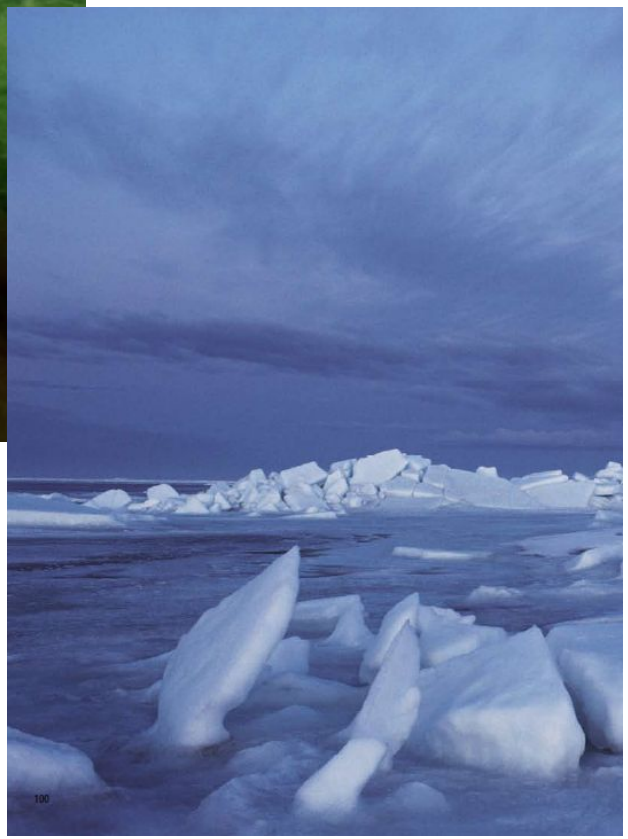
distribution limits of selected freshwater taxa

dominant marine landscapes of the Baltic sea



5 key vegetation types:
- **Zostera meadows**
- **ulvophyceans**
- **Fucus belt**
- **stoneworts meadows**
- **Furcellaria belt**

additional typical components:
a) brown epiphytes/ephemerals (*Ectocarpus, Pilayella*)
b) red epiphytes/ephemerals (*Ceramium, Polysiphonia*)
c) green epiphytes/ephemerals (*Cladophora*)



ice scraping (= absence of perennial macroalgae in the upper sublittoral of northern Baltic shores)

http://www.visayards.com/66

upper sublittoral of central Baltic (the Fucus belt)

http://www.visayards.com/66

mid-sublittoral assemblages – Fucus belt in Baltic sublittoral – as result of **brackish submergence**

http://www.visayards.com/66

Fucus belt

- primarily on hard substrates (rock, stones, immobile organic bottom)
- three species – F. vesiculosus, F. serratus, F. radicans
- F. serratus outcompetes F. vesiculosus in western and central Baltic; however, it does not tolerate disturbance (ice scraping, etc.) as it cannot regenerate from holdfasts; therefore, F. serratus only dominates in deeper parts of the belt
- endemic F. radicans is part of the belt in E and N parts with lower salinity (is never in direct contact with F. serratus)

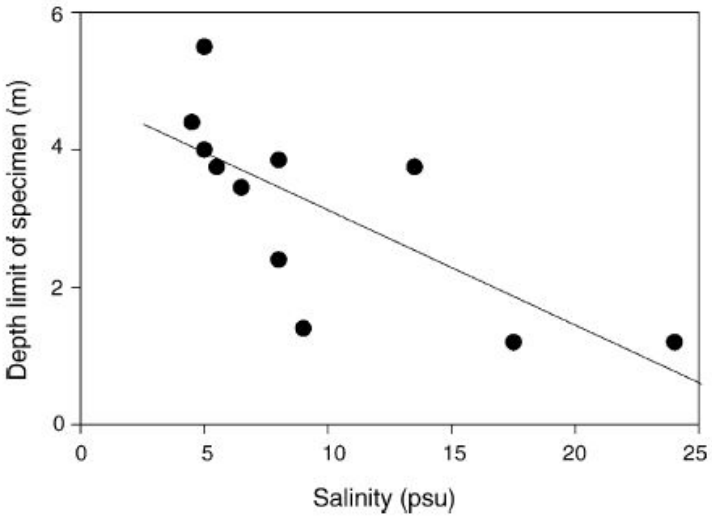
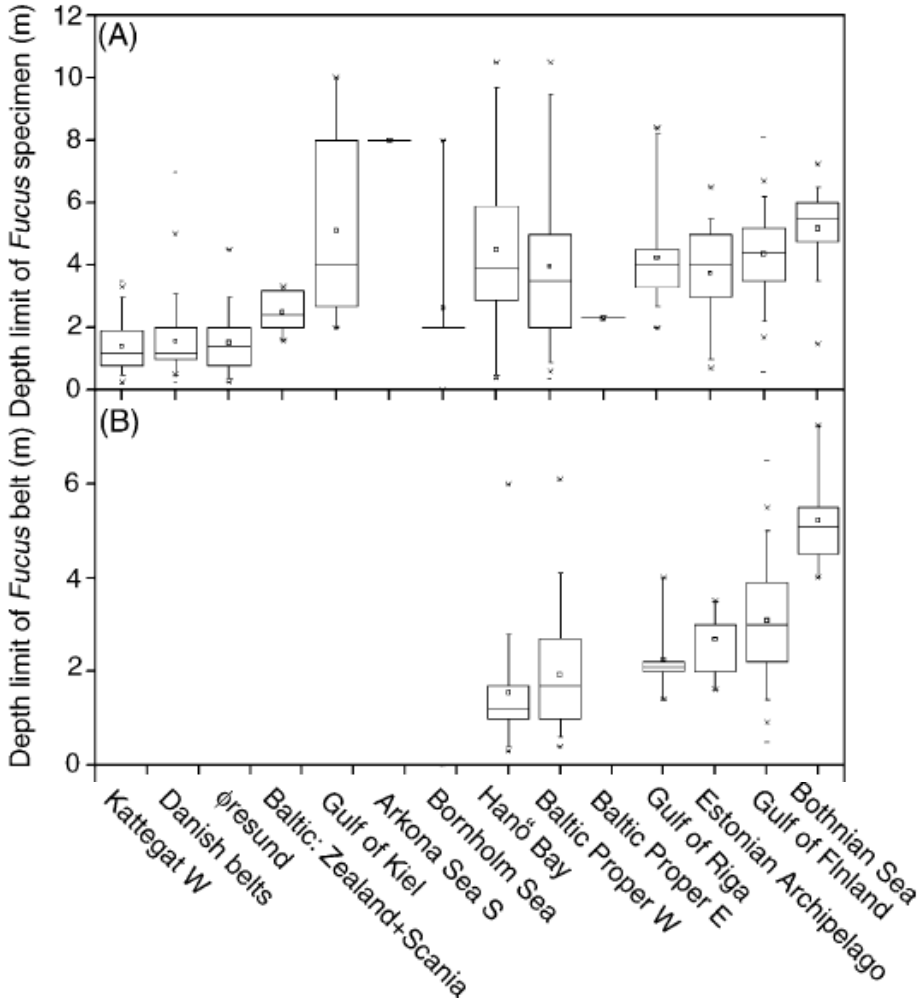


Fig. 4. Depth limit (medians) of *F. vesiculosus* specimen in various districts of the Baltic Sea as a function of the average salinity of the districts. Linear regression: $y = -0.14x + 4.7$, $R^2 = 0.53$, $p = 0.011$, $n = 11$. Data from 1989 to 2001.

F.v. lower depth limit is decreased in more saline areas (due to increased competition)



Torn et al, 2006, Aq. Bot.

eutrophication in the 2nd half of the 20th century generally shifted the limits of the *Fucus* belt upwards

(but there are newer data showing the recent reversal of this trend)

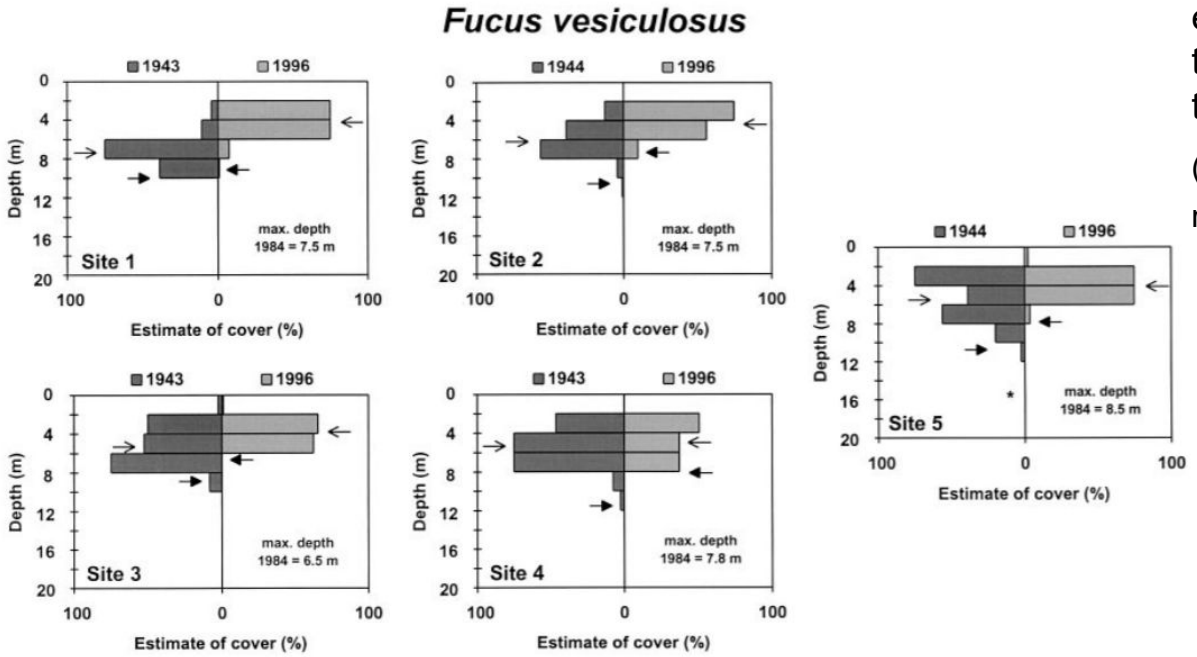
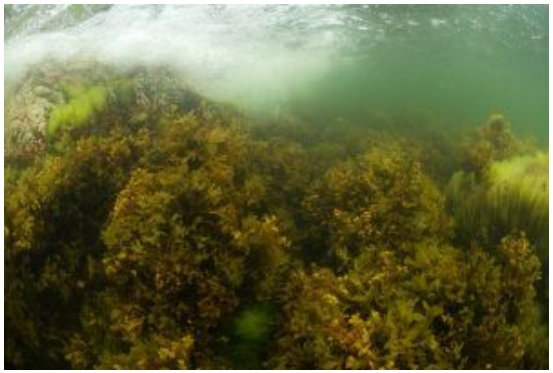


Fig. 2. Percentage cover for *Fucus vesiculosus* at the five sites investigated in the Öregrund archipelago in 1943–4 and 1996. Filled arrows indicate the deepest occurrence and open arrows show the weighted average depth. * denotes that for site 5 no data were available below 15 m depth in 1943–4.



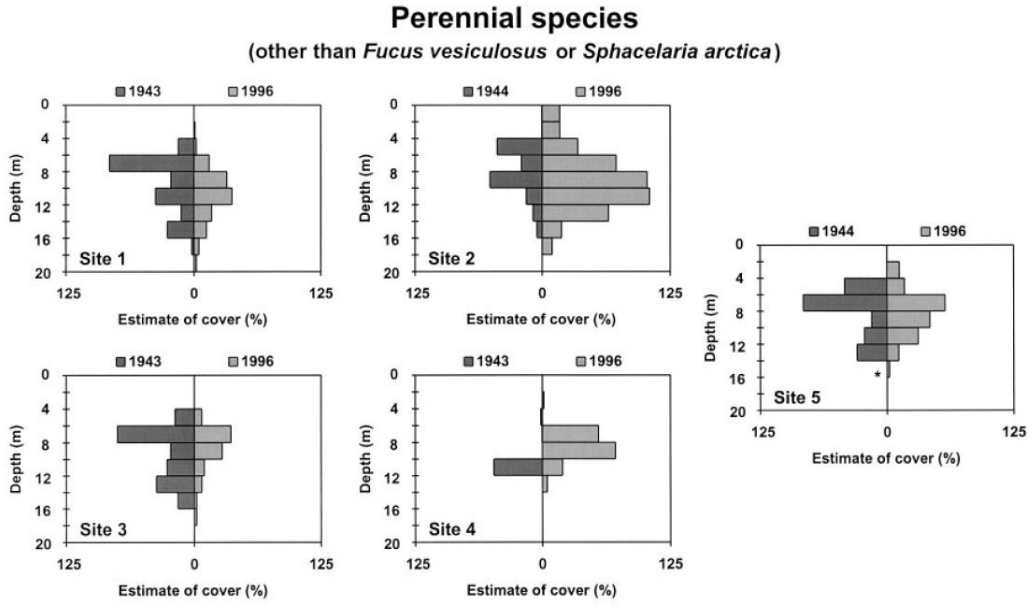


Fig. 4. Percentage cover for perennial algae other than *Fucus vesiculosus* or *Sphacelaria arctica* at the five sites investigated in the Öregrund archipelago in 1943–4 and 1996. * denotes that for site 5 no data were available below 15 m depth in 1943–4.

Eriksson et al., 1998, Eur. J. Phycol 33: 241-249

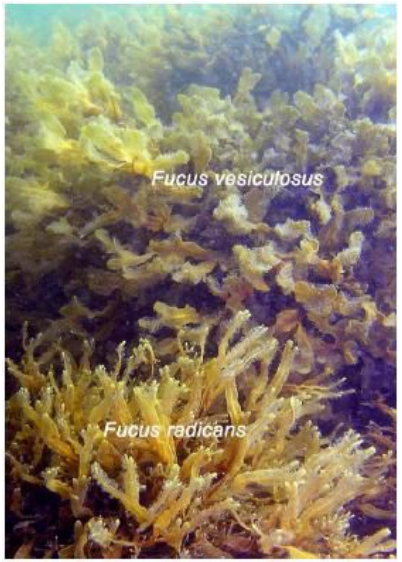
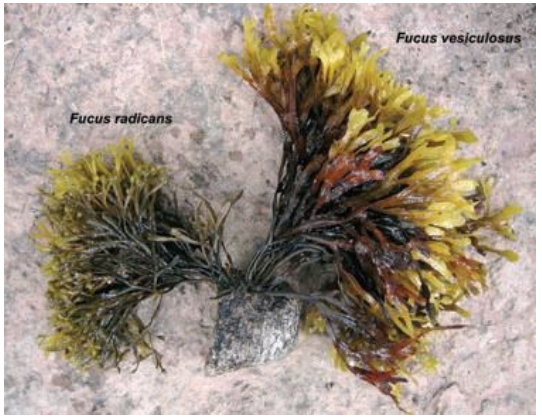


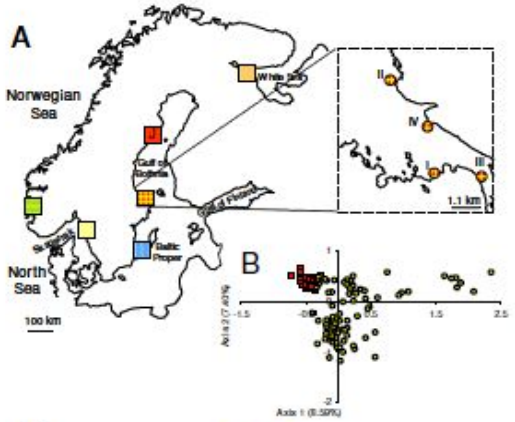
Figure 1
***Fucus radicans* and *F. vesiculosus*.** Picture showing both *Fucus* species living in sympatry without any environmental discontinuity in the SW Gulf of Bothnia (northern Baltic Se

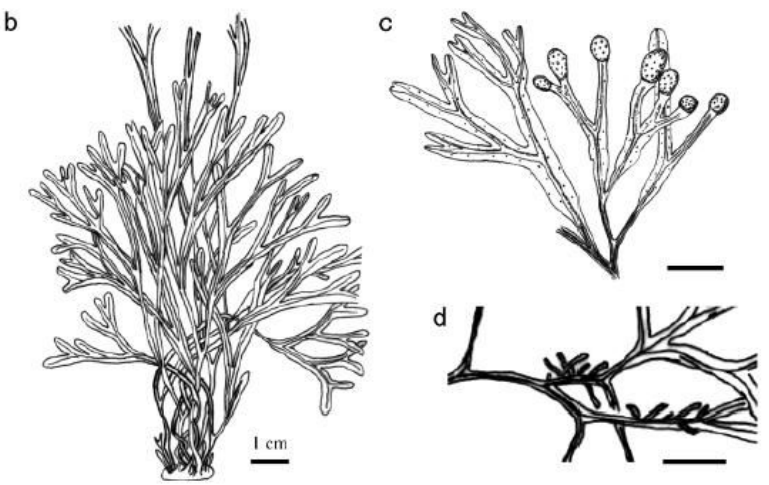


Bergstrom et al., 2005, J Phycol 41: 1025-1038
Pereyra et al. 2009, BMC Evol Biol 9: 70

Baltic Seaweed Blog

F. radicans evolved in the Baltic Sea from F. vesiculosus (possibly even "several" times)





F. radicans – no air vesicles

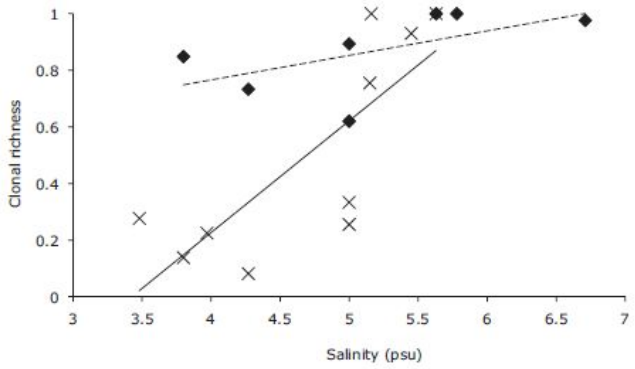
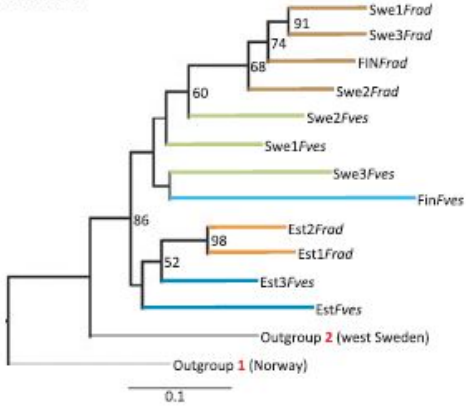


FIG. 2. Relationship between salinity and clonal richness of populations of *Fucus radicans* (crosses, dotted trend line, $R^2 = 0.62$, $P = 0.007$) and *F. vesiculosus* (diamonds, broken trend line, $R^2 = 0.34$, $P = 0.17$).



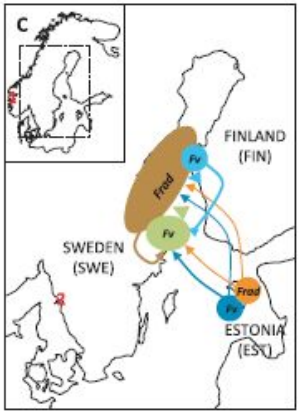
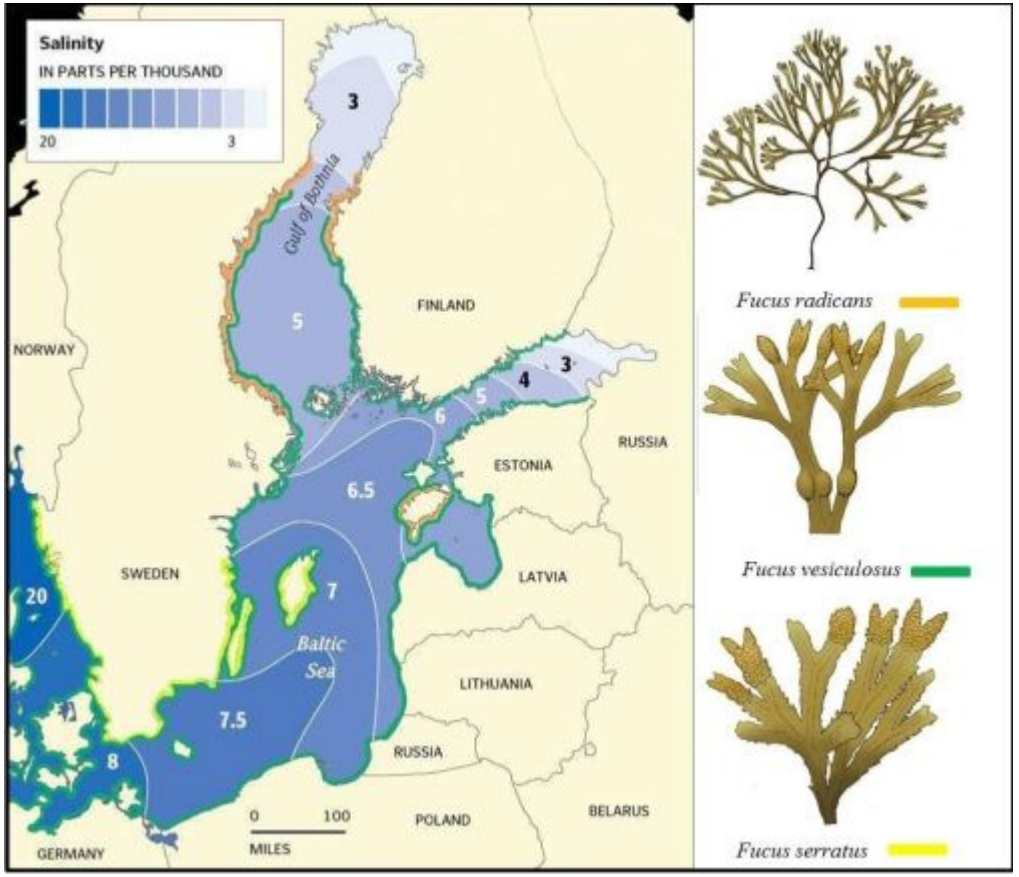
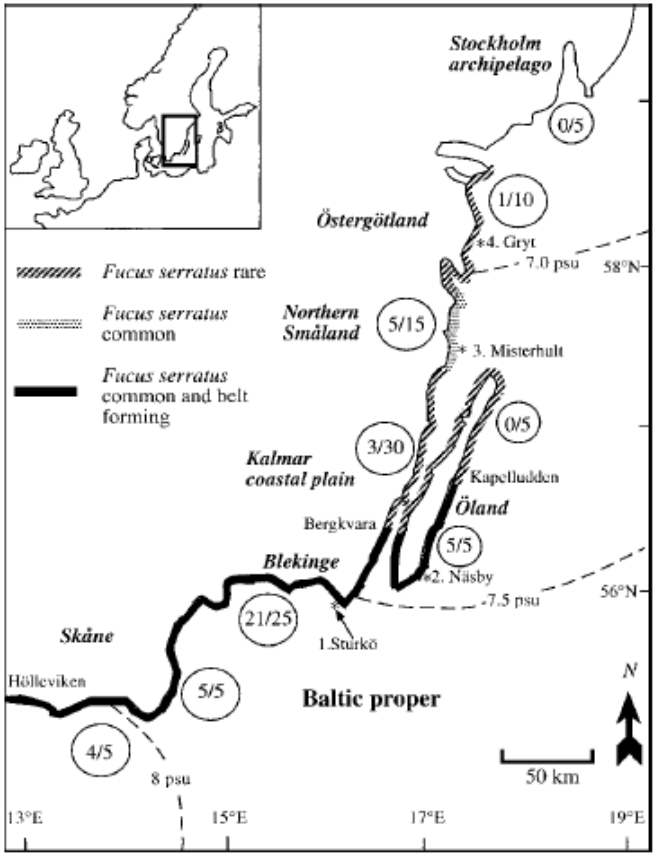


Fig. 4 Overall genetic differentiation between *Fucus* species in the Baltic Sea. (a) Combined histogram of Bayesian individual assignment test to illustrate the overall genotypic clustering of both species from all the sampling localities. Bars represent individual assignment probability into different genetic clusters depicted with colours, as in Fig. 2. (b) Neighbour-joining microsatellite-based population tree calculated with Cavalli-Sforza genetic distances. Out-group locations are indicated in Fig. 4c. (c) Map of the Baltic Sea with a superimposed gene flow network identifying the genetic sources among species and populations. Arrow thickness is proportional to the amount of gene flow to the indicated direction. Numbers 1 and 2 correspond to out groups *Fucus vesiculosus* from Eggholmen, Norway and Fiskebäckskil, west Sweden, respectively.

clonality of F.v. and F.r. populations increases with dereasing salinity (marginal habitats lead to low genetic diversity and asexual reproduction)

Pereyra et al. 2009, BMC Evol Biol 9: 70
Pereyra et al., 2013, J. Evol. Biol.
Johanesson et al., 2011, J. Phycol.





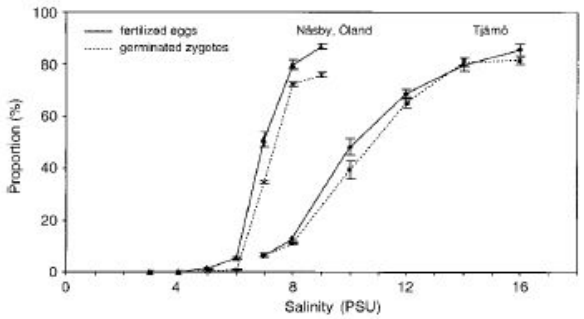


Fig. 4. Proportion of fertilised *Fucus serratus* eggs after 15 h and germination of zygotes (%) cultured at different salinities in natural seawater. The material from Näsby (Site

Malm et al., 2001, Bot Mar 44: 101-108

Bodden habitats

– coastal lagoons on southern shores,
soft bottom, local salinity gradients, eutrophication

unique communities composed of plants and algae originating from both freshwater and marine ecosystems (*Ruppia maritima, Fucus vesiculosus, Furcellaria lumbricalis, Chara baltica, Myriophyllum spicatum*)

Red algal meadows

– shallow soft bottom bays, coastal lagoons – E Baltic, Estonian coastal sea
Furcellaria lumbricalis, Coccotylus truncatus

Location of the Väinameri area in the Baltic sea

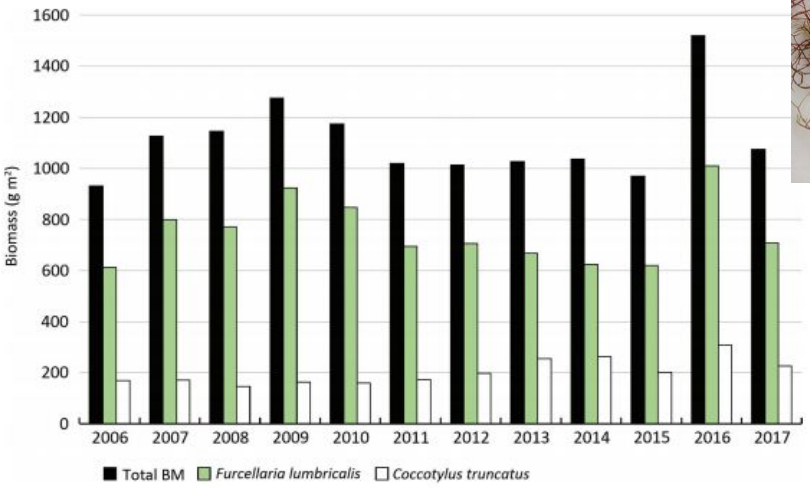


Figure 4: Interannual variation (2006–2017) of the share of *Furcellaria lumbricalis* and *Coccotylus truncatus* in the loose-lying red algal community biomass (BM) in the Kassari Bay, West Estonian Archipelago Sea.
Compiled results of annual monitorings 2006–2017; database of the Estonian Marine Institute.

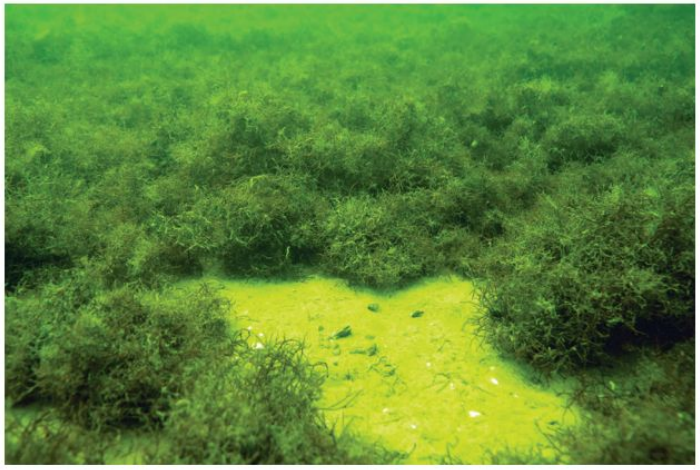


Figure 2: Loose-lying *Furcellaria lumbricalis-Coccotylus truncatus* community in the Kassari Bay, West Estonian Archipelago Sea (Photo: K. Kaljurand).

Weinberger et al., 2020, Bot. Mar.
The Väinameri Project, 2005

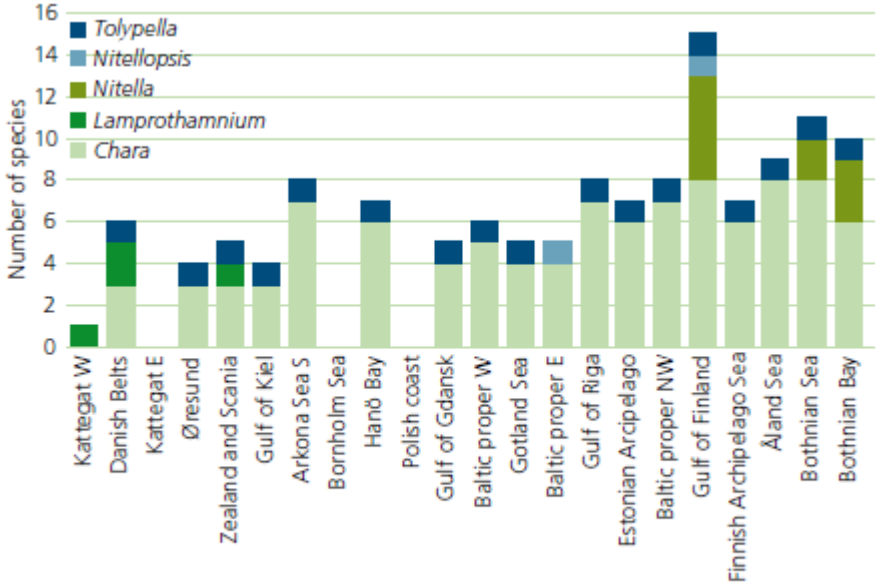


Figure 3.2.4. Number of Charophyte species in different areas of the Baltic Sea. Data from Schubert & Blindow 2003, Torn 2008. Division of the Baltic Sea after Nielsen et al. 1995.

Charophyte gradients

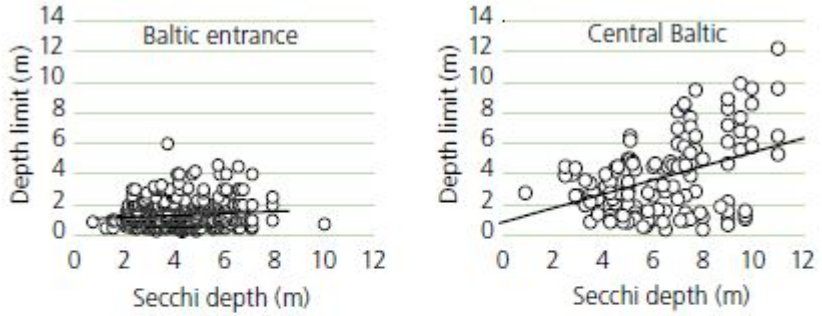


Figure 3.2.2. Relation between depth distribution of *Fucus vesiculosus* and water transparency in the Baltic Sea entrance area (including data from Kattegat, the Danish Belts Øresund and the Baltic between Zealand, Denmark and Scania, Sweden) and the central Baltic (including data from the Kiel Bight, Hanö Bay, the Arkona Sea, the Baltic Proper, the Gulf of Riga and the Gulf of Finland). Modified from Torn et al. 2006.

Fucus vesiculosus depth distribution dynamics

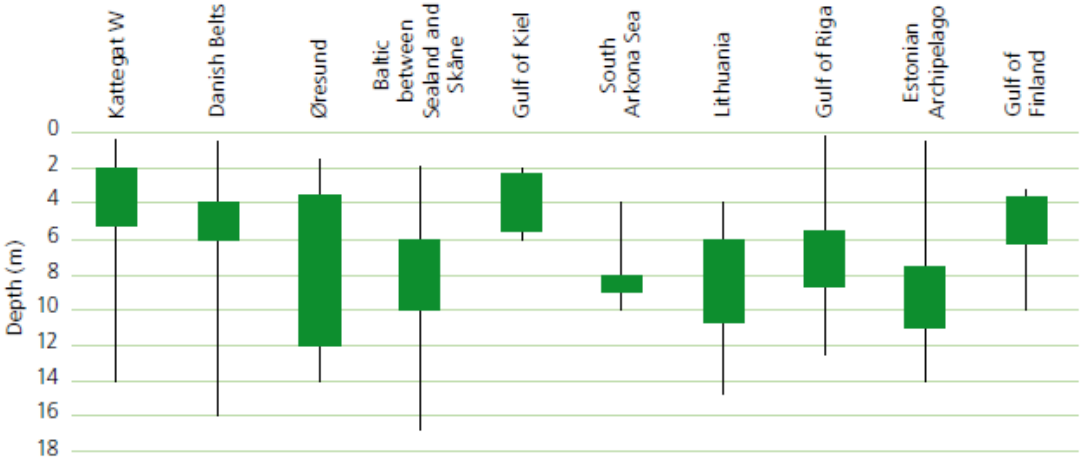


Figure 3.2.3. Maximum depth penetration of *Furcellaria lumbricalis* in different sea areas of the Baltic Sea. Boxes delimit the 25% and 75% percentiles and whiskers the minimum and maximum values. Data from 1989 to 2007 (CHARM database, national monitoring data).

Furcellaria dominated communities

The effect of salinity gradient of Furcellaria belt

the case study of *Furcellaria lumbricalis* – possible ongoing speciation due to salinity gradient and geographic isolation

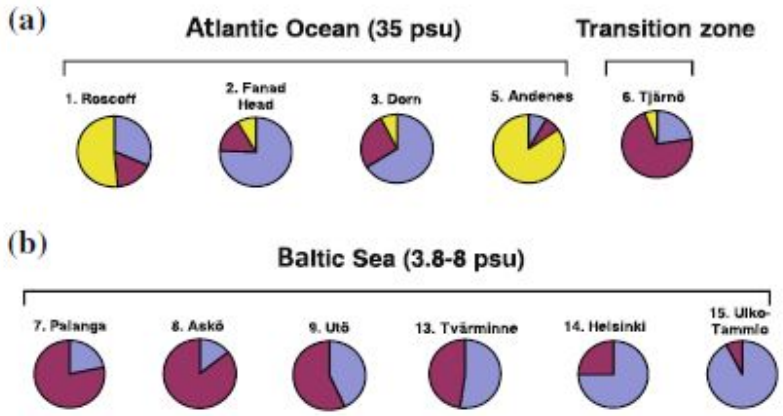


Fig. 4 Bayesian estimates of population structure of *Furcellaria lumbricalis* based on EST-derived microsatellites in **a** five populations grouped together as cluster A (populations 1–3 and 5 from the Atlantic Ocean and population 6 from the west coast of Sweden) in the first round of STRUCTURE analysis, and in **b** six populations grouped together as cluster B (populations 7–9 and 13–15 from the Baltic Sea). Each *shade* represents one of the clusters formed in the analysis ($K = 3$ in analysis (**a**) and $K = 2$ in analysis (**b**)). All populations examined using EST-derived microsatellites grouped to either cluster A or B. Results are based on ten replicate runs

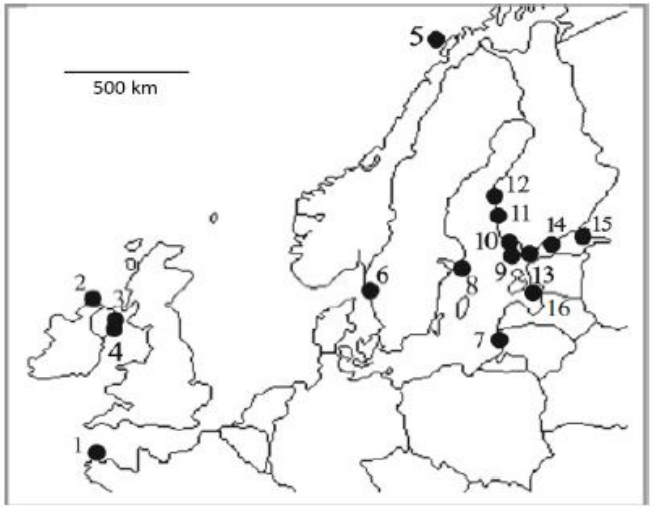
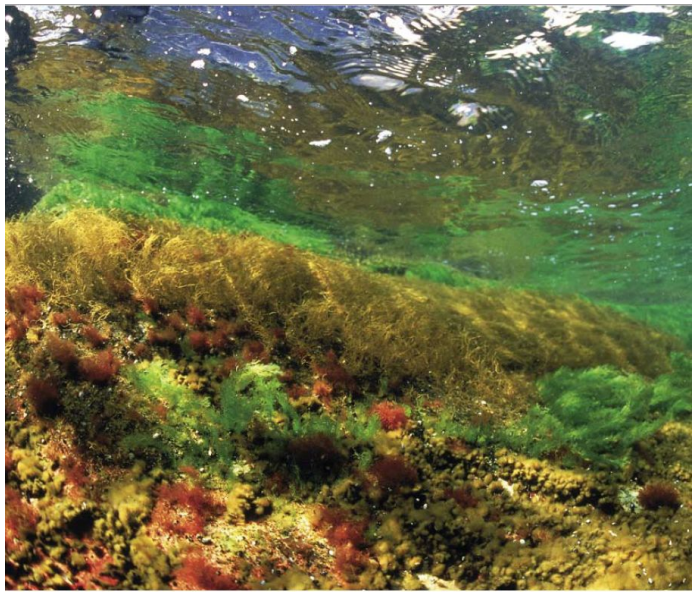


Fig. 1 Sixteen *Furcellaria lumbricalis* populations from the Atlantic Ocean and Baltic Sea included in the study. The names of the populations and additional sampling site information are given in Table 1

Kostamo et al., 2012, Mar. Biol. 159: 561-571.

Soft-bottom mid- and lower sublittoral and the *Battersia* belt

eutrophication-related increase in the proportion of the ephemeral vegetation during the 20th century



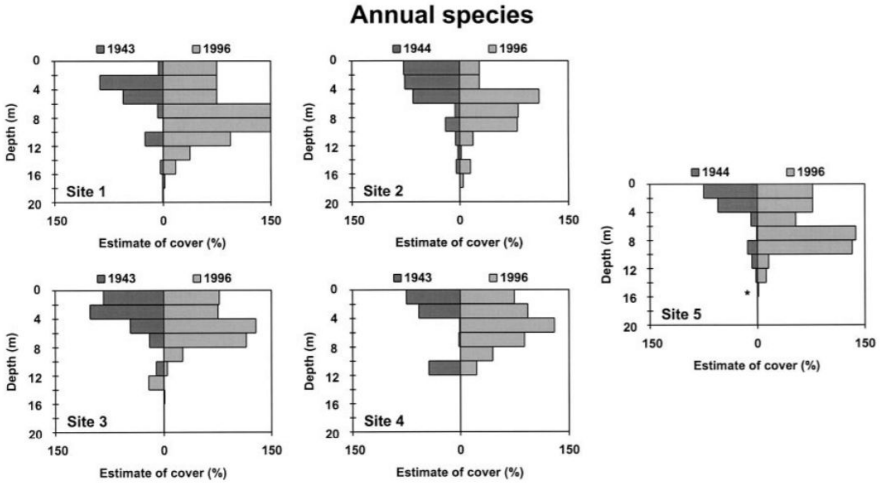


Fig. 5. Percentage cover for annual algae at the five sites investigated in the Öregrund archipelago in 1943–4 and 1996. * denotes that for site 5 no data were available below 15 m depth in 1943–4.

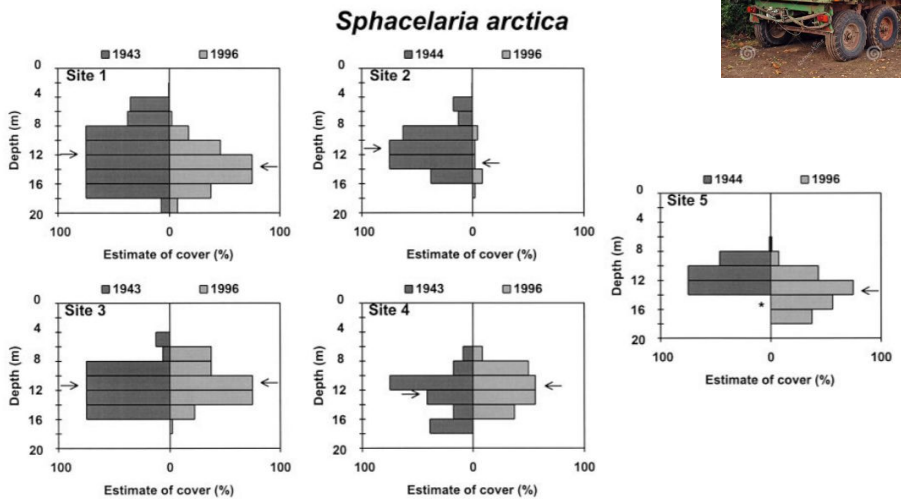


Fig. 3. Percentage cover for *Sphacelaria arctica* at the five sites investigated in the Öregrund archipelago in 1943–4 and 1996. Open arrows indicate the weighted average depth. * denotes that for site 5 no data were available below 15 m depth in 1943–4.

Eriksson et al., 1998, Eur. J. Phycol 33: 241-249

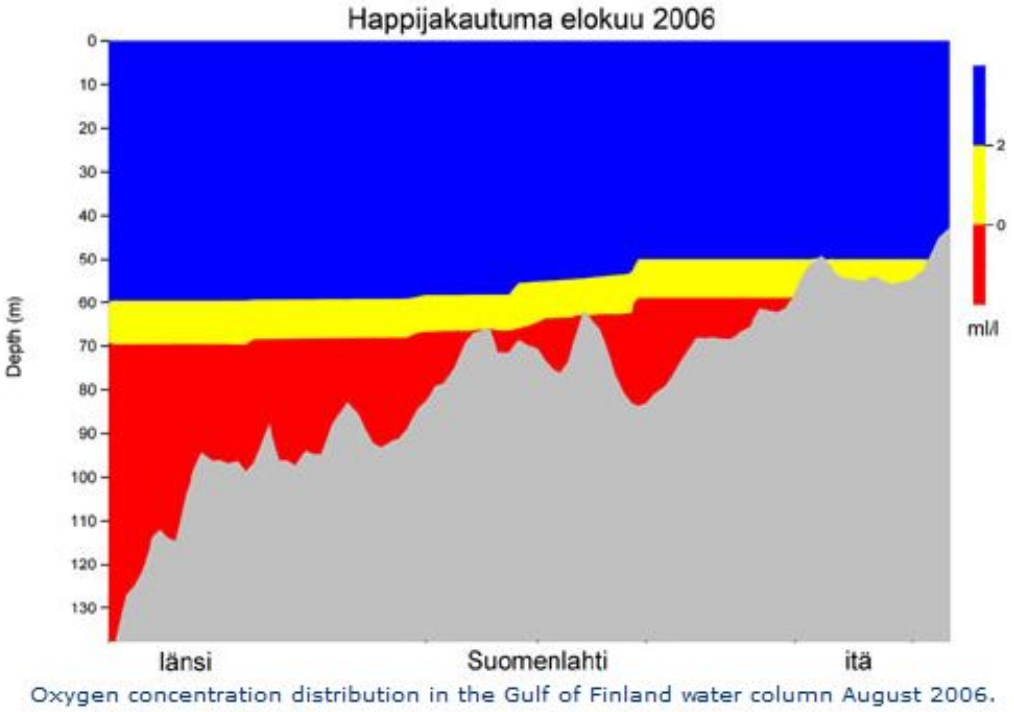
Baltic water blooms

- mostly formed by Cyanobacteria
- develops in summer (2nd half of July, August)
- non-periodic development (depends on combination of temperature and salinity)
- leads to extensive anoxic benthic zones

summer 2010

Nodularia spumigena

Aphanizomenon/Anabaena



Oxygen concentration distribution in the Gulf of Finland water column August 2006.

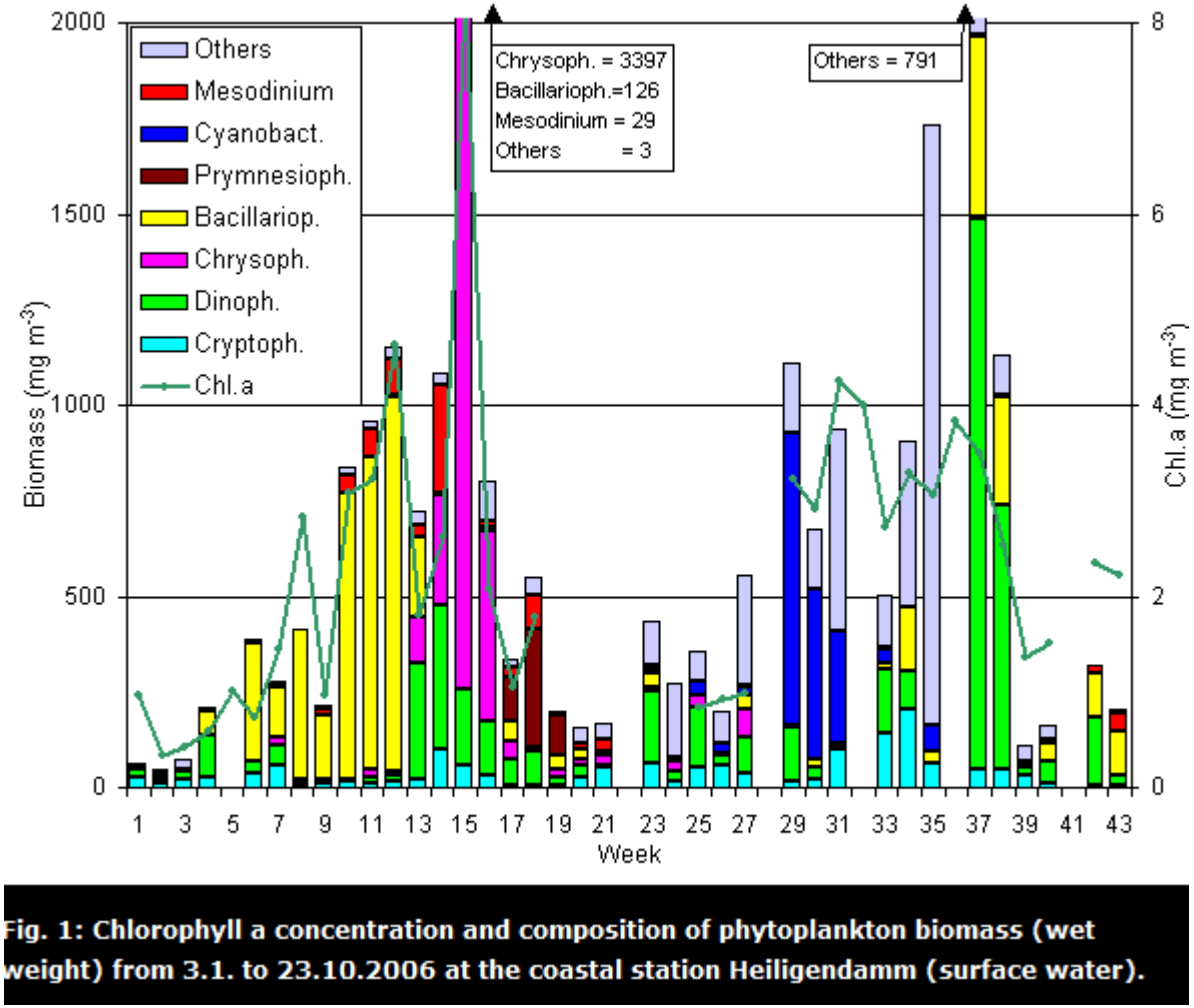


Fig. 1: Chlorophyll a concentration and composition of phytoplankton biomass (wet weight) from 3.1. to 23.10.2006 at the coastal station Heiligendamm (surface water).

phytoplankton in W Baltic (2006)

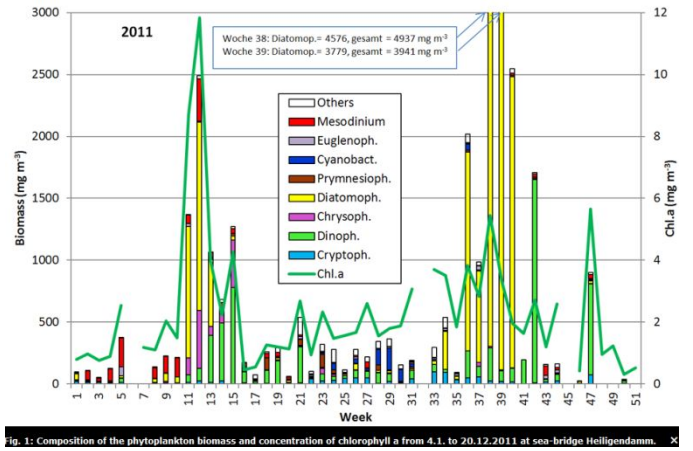


Fig. 1: Composition of the phytoplankton biomass and concentration of chlorophyll a from 4.1. to 20.12.2011 at sea-bridge Heiligendamm.

2011

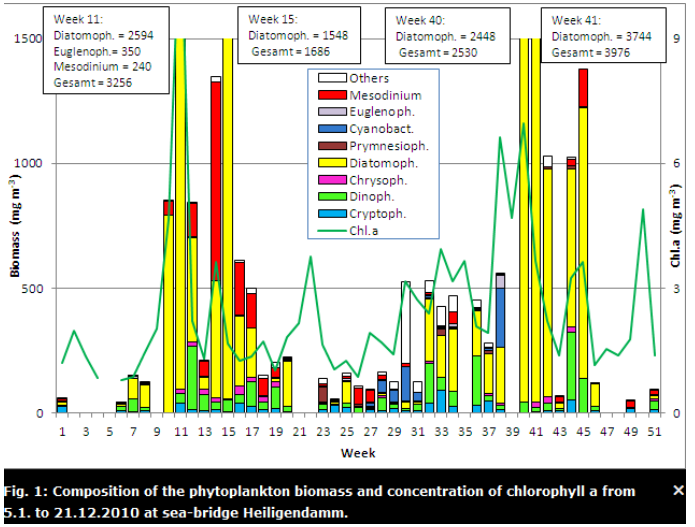


Fig. 1: Composition of the phytoplankton biomass and concentration of chlorophyll a from 5.1. to 21.12.2010 at sea-bridge Heiligendamm.

2010

typically two seasonal maxima:

spring diatoms/dictyocha bloom + **late summer** cyanobacteria/diatom bloom

(dominants may include even the phototrophic ciliates (*Mesodinium*), dinoflagellates, dictyoches, haptophytes or euglenoids)