

The image is a full-page background photograph of a coastal scene. In the foreground, a person with blonde hair, wearing a red jacket, white pants, and a backpack, stands on a dark, wet, reddish-brown rock formation. They are looking out towards a vast body of water. The water is a deep blue-green color with small, white-capped waves. In the distance, there are several small, forested islands or peninsulas under a bright blue sky with scattered white clouds. The overall mood is serene and natural.

The Baltic Sea

Environment and Ecology

Editors: Eeva Furman, Mia Pihlajamäki,
Pentti Välipakka & Kai Myrberg

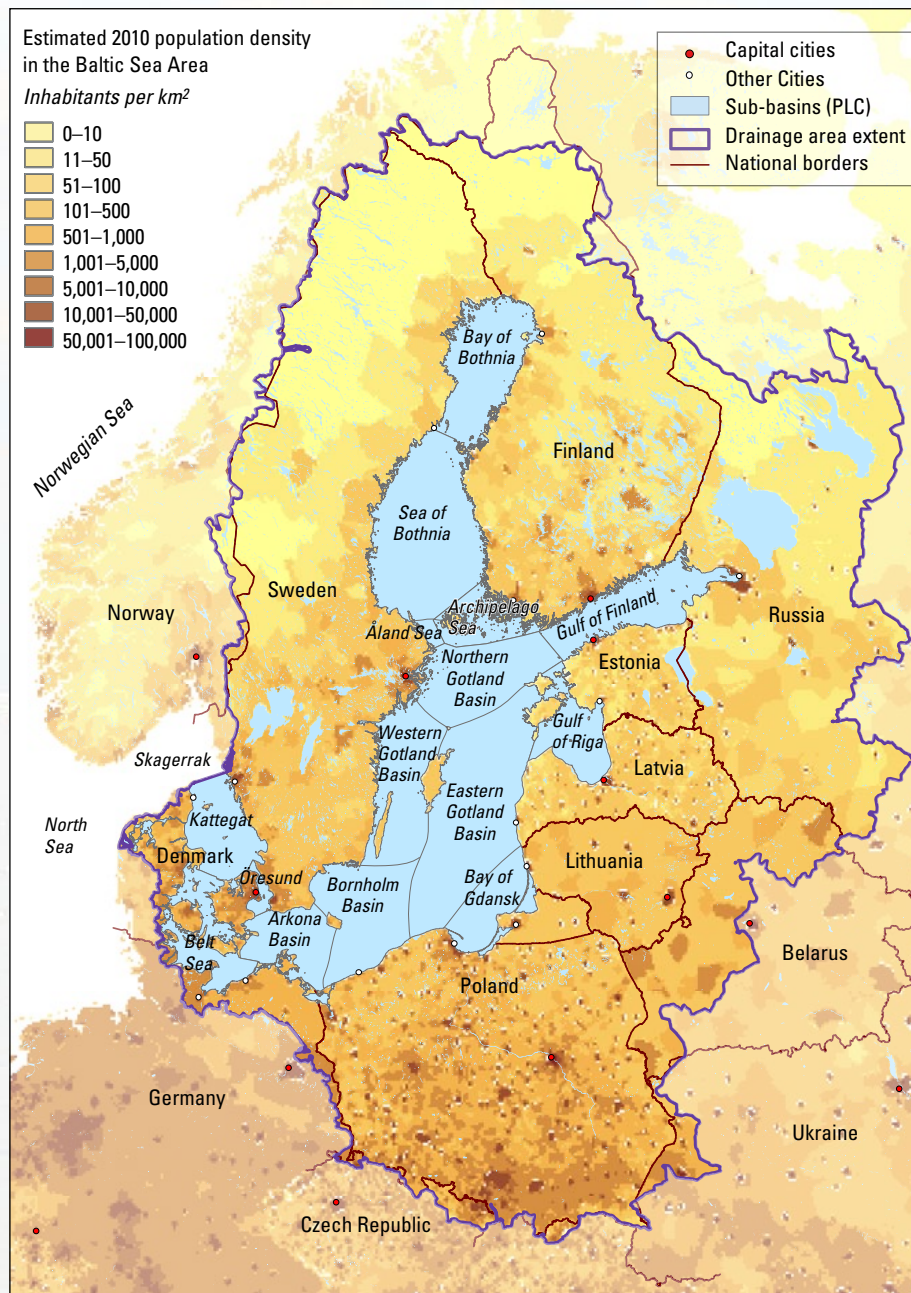
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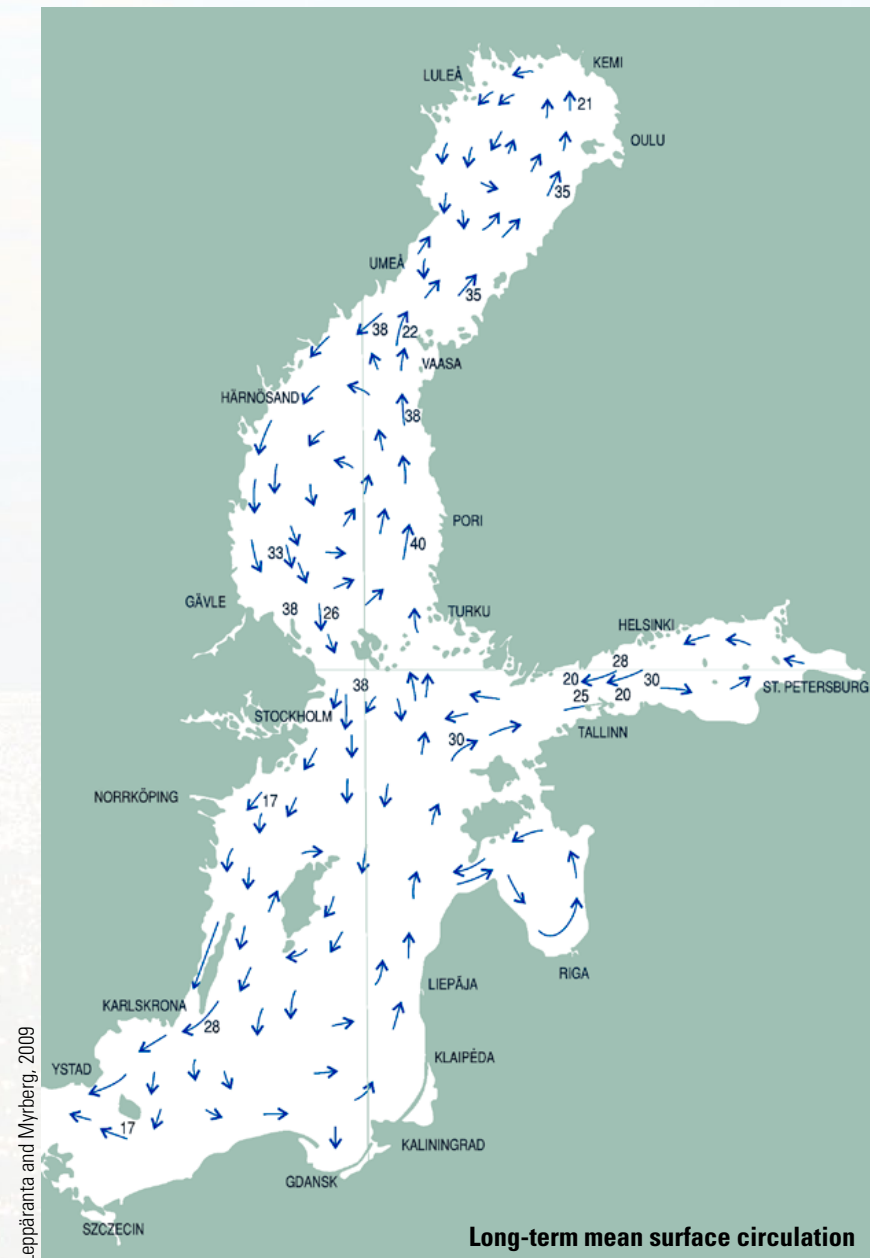
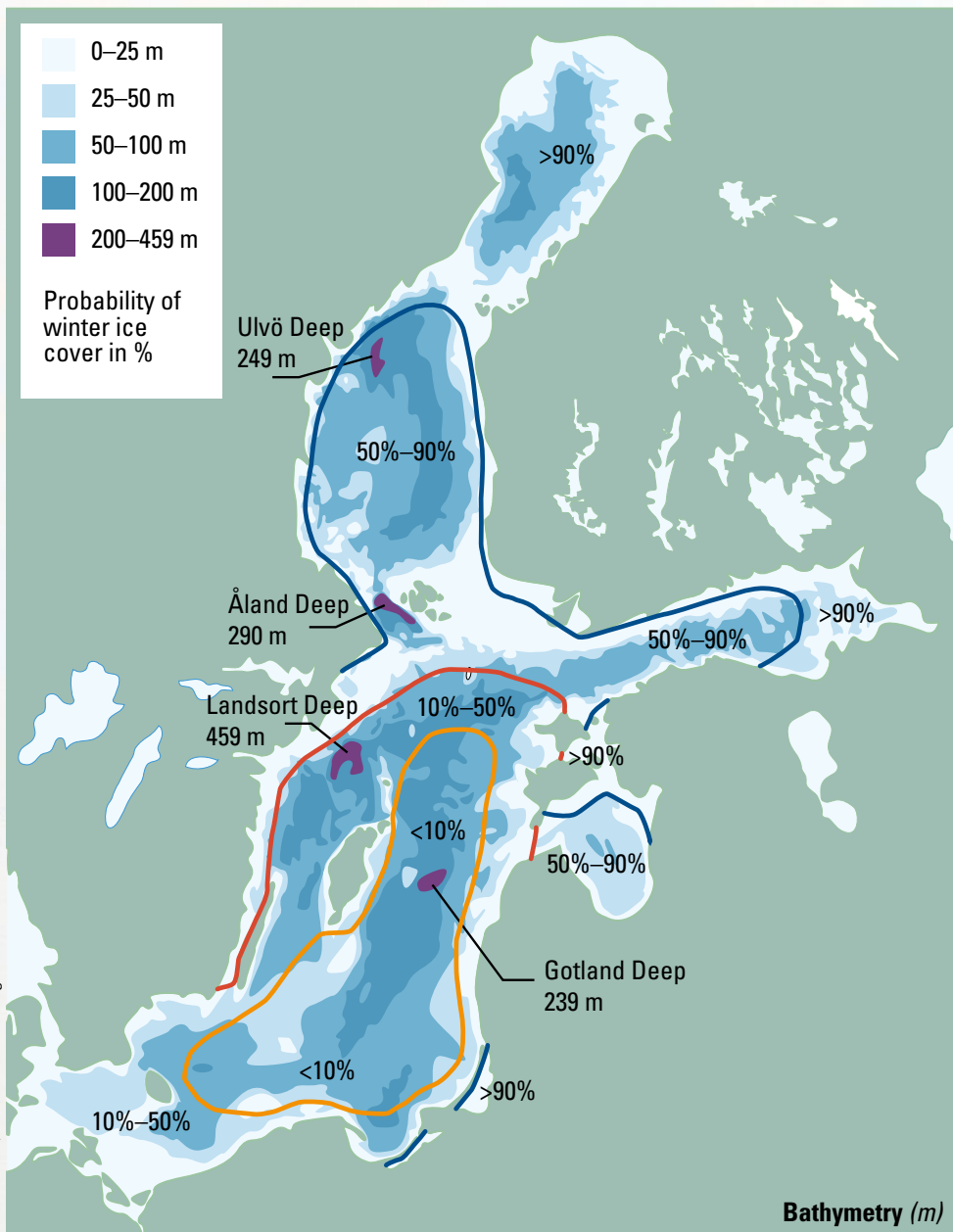


PHOTOS: PETRI KUOKKA

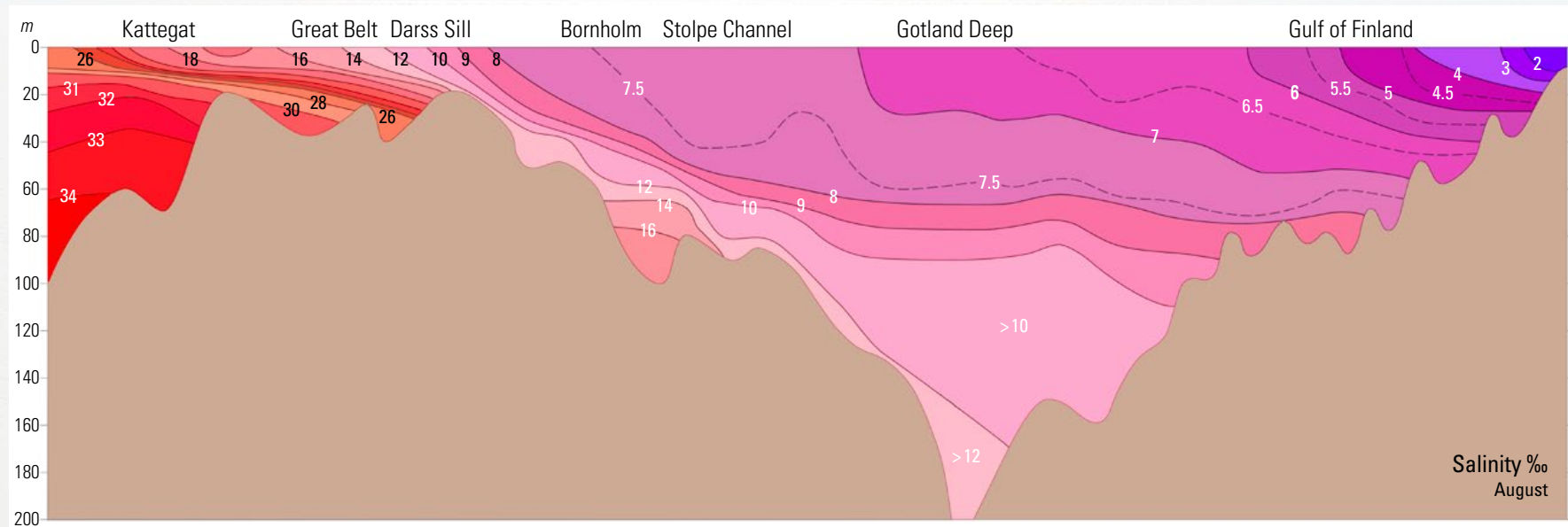
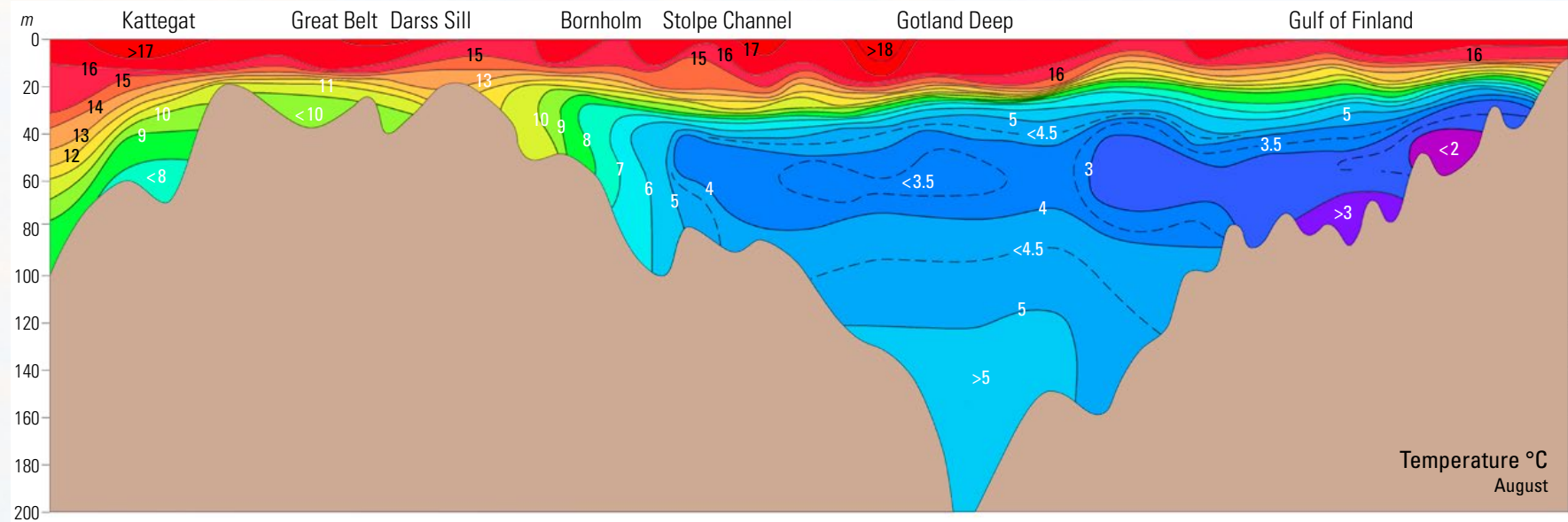


Based on HELCOM 2011

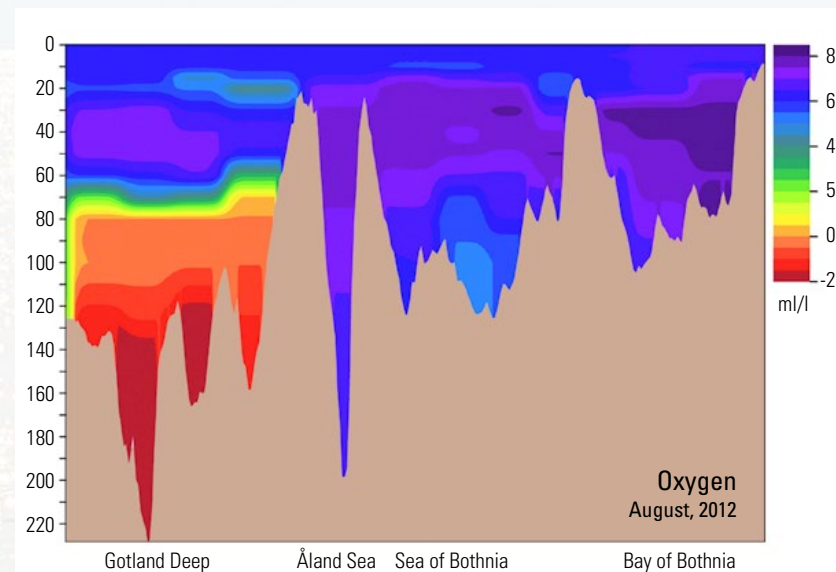
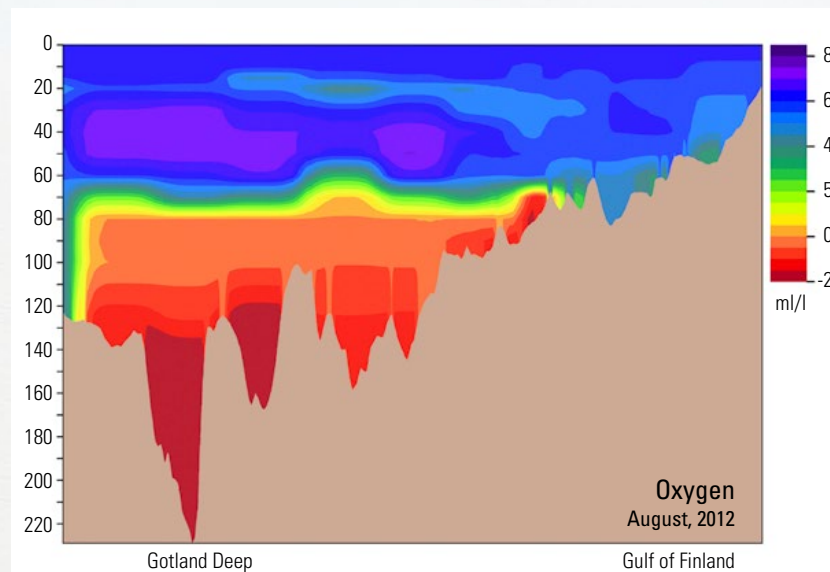
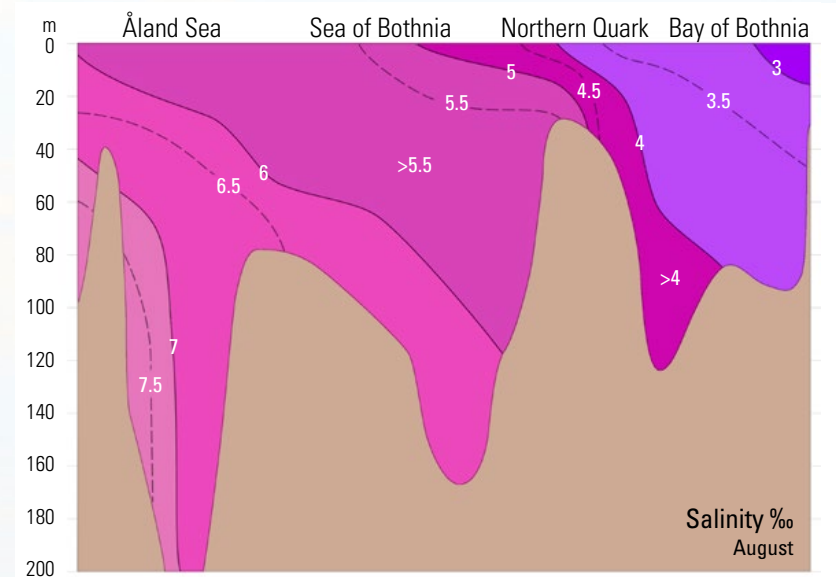
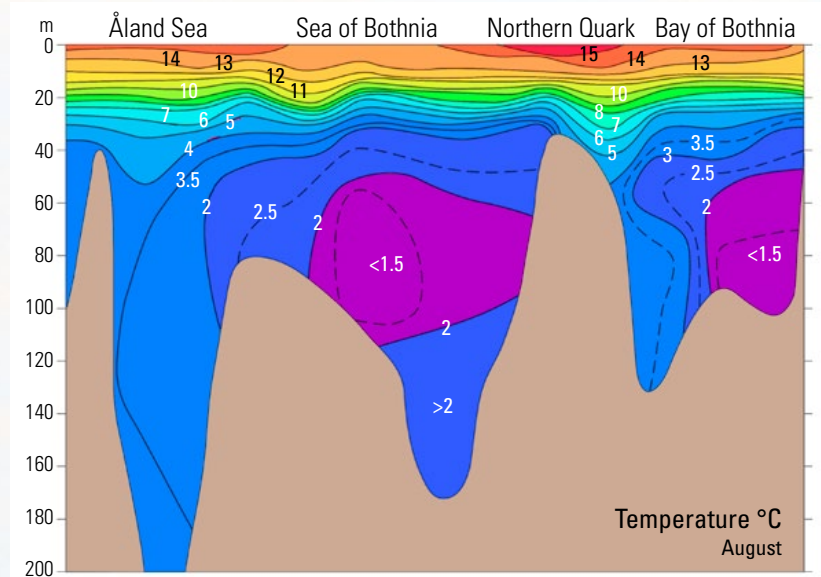


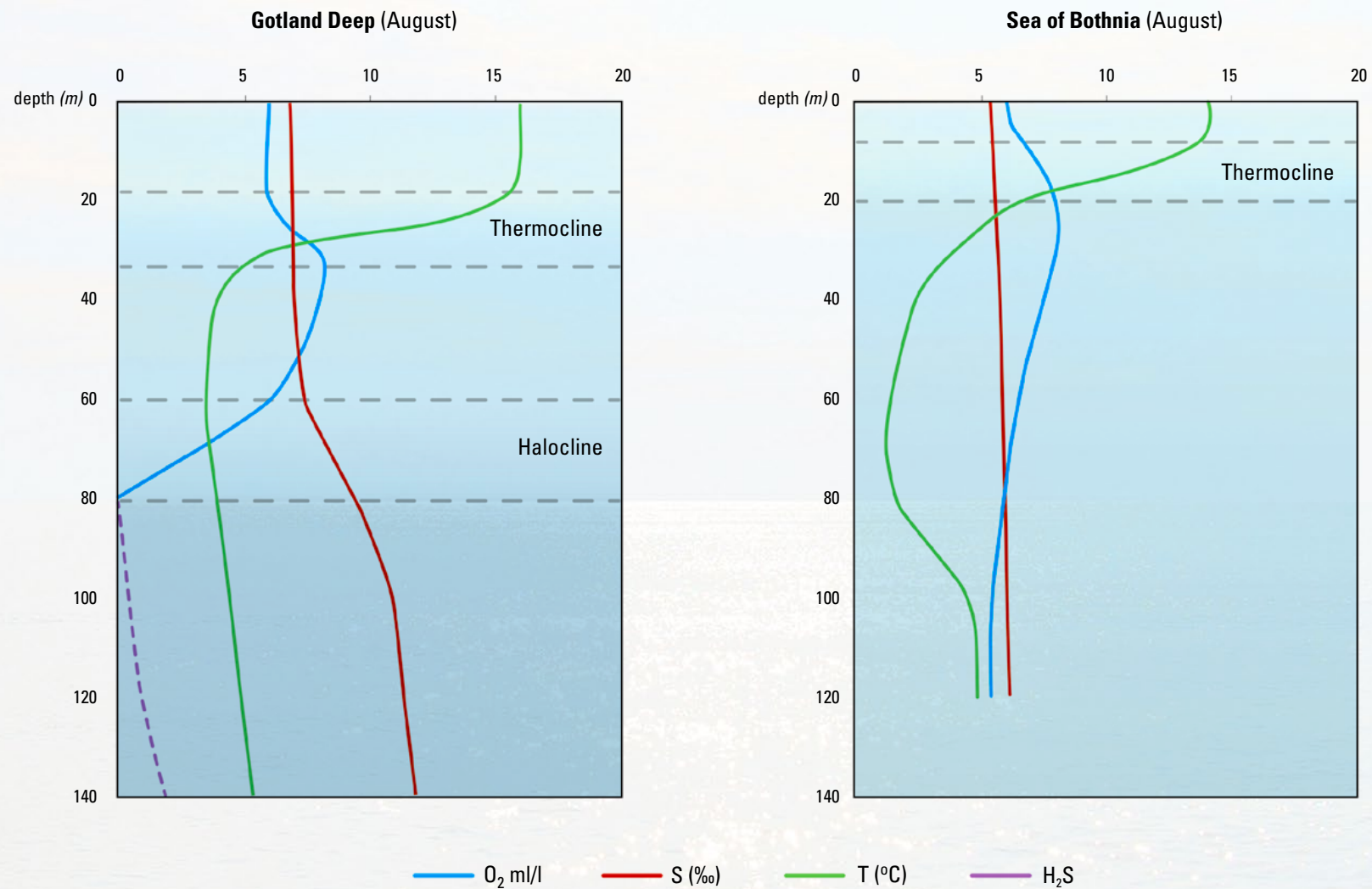


3A The Baltic Sea hydrography: horizontal profile

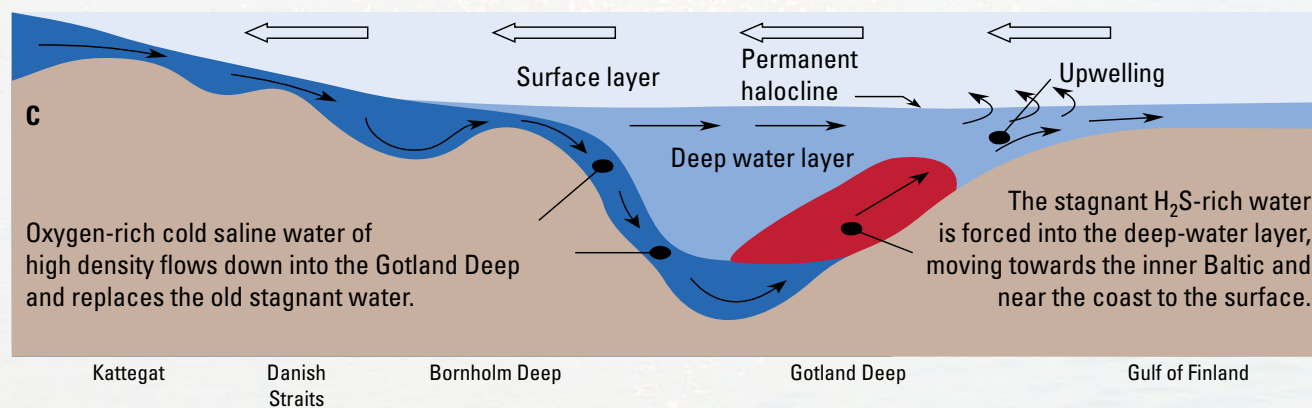
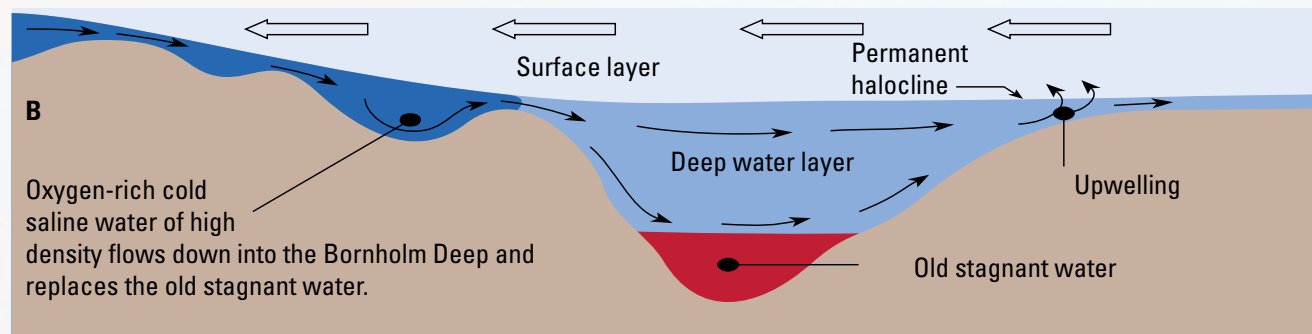
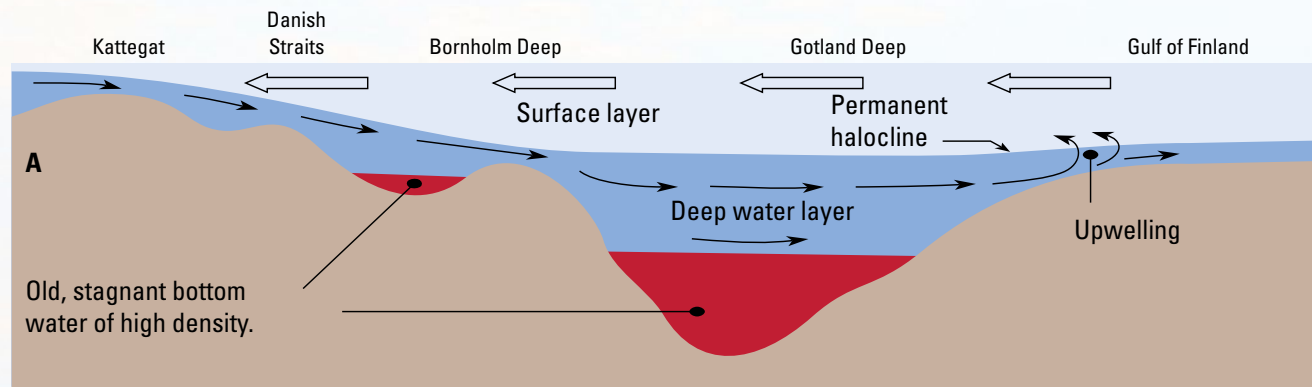


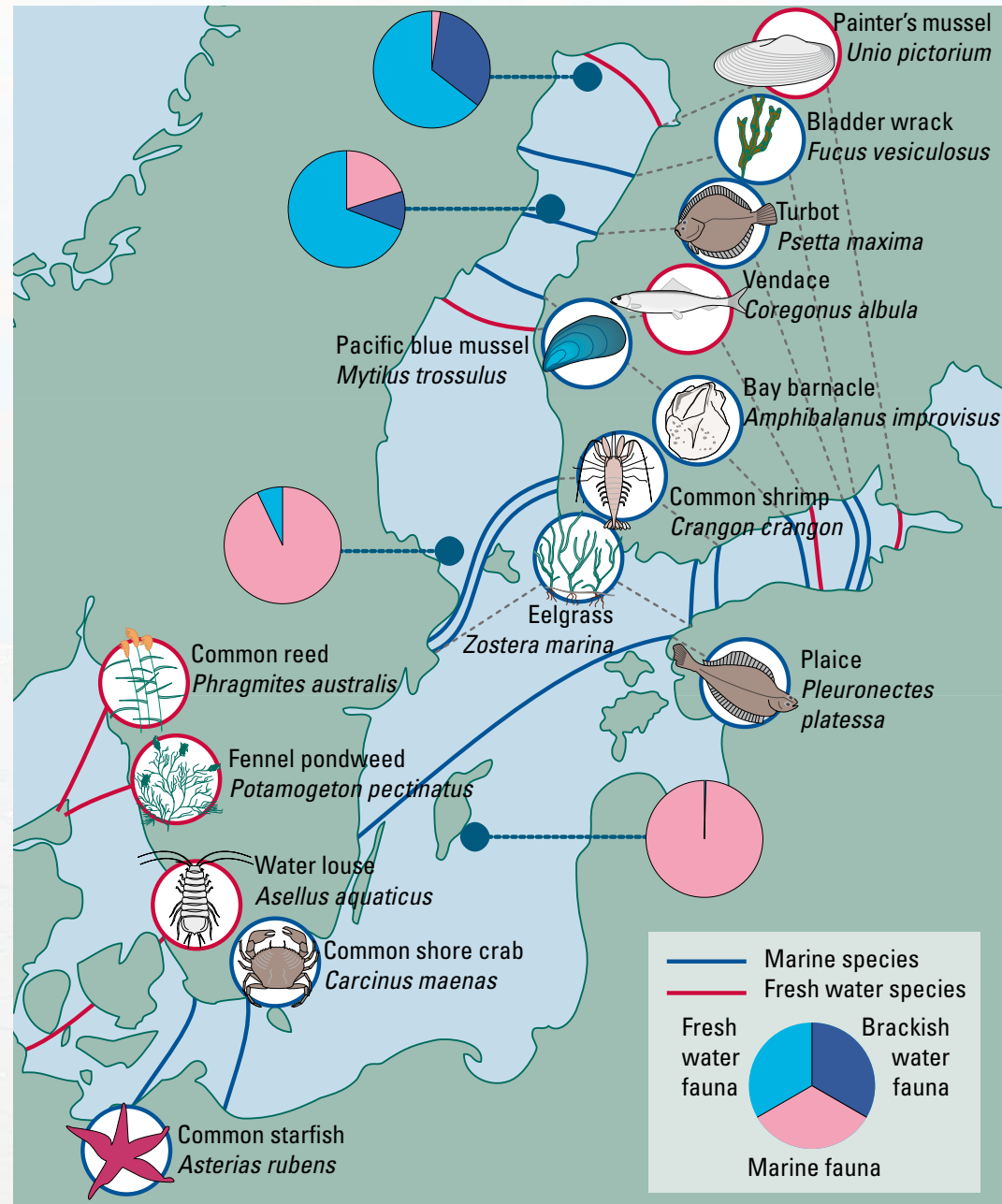
3B The Baltic Sea hydrography: horizontal profile



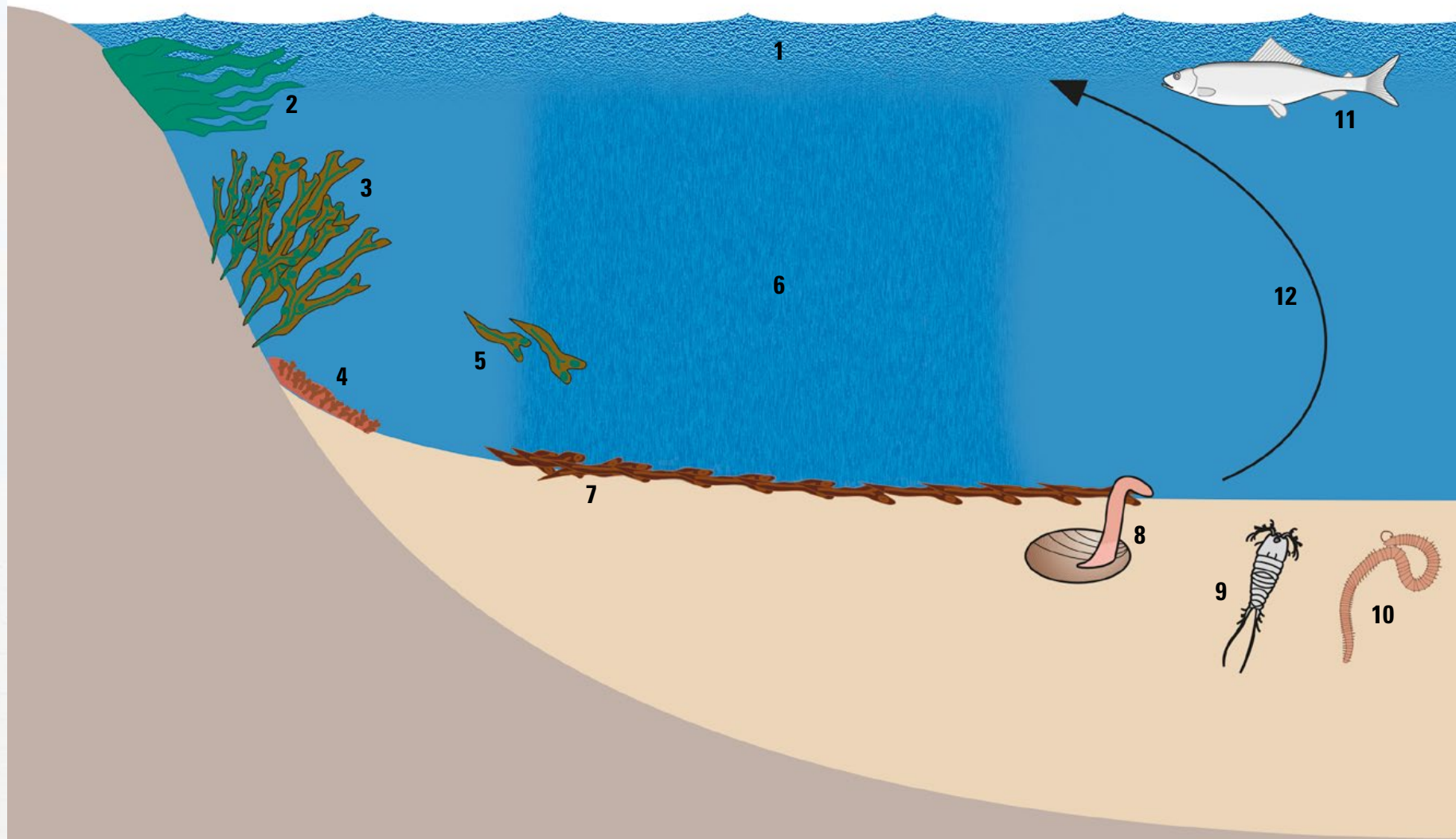


S & T: Leppäranta & Myrberg, 2009
 O_2 : Jan-Erik Bruun / SYKE





Characteristic organisms and processes



1 Plankton

2 Filamentous algal zone

3 Bladder wrack zone

4 Red algal zone

5 Loose macroalgae

6 Sedimentation

7 Bacterial decomposition

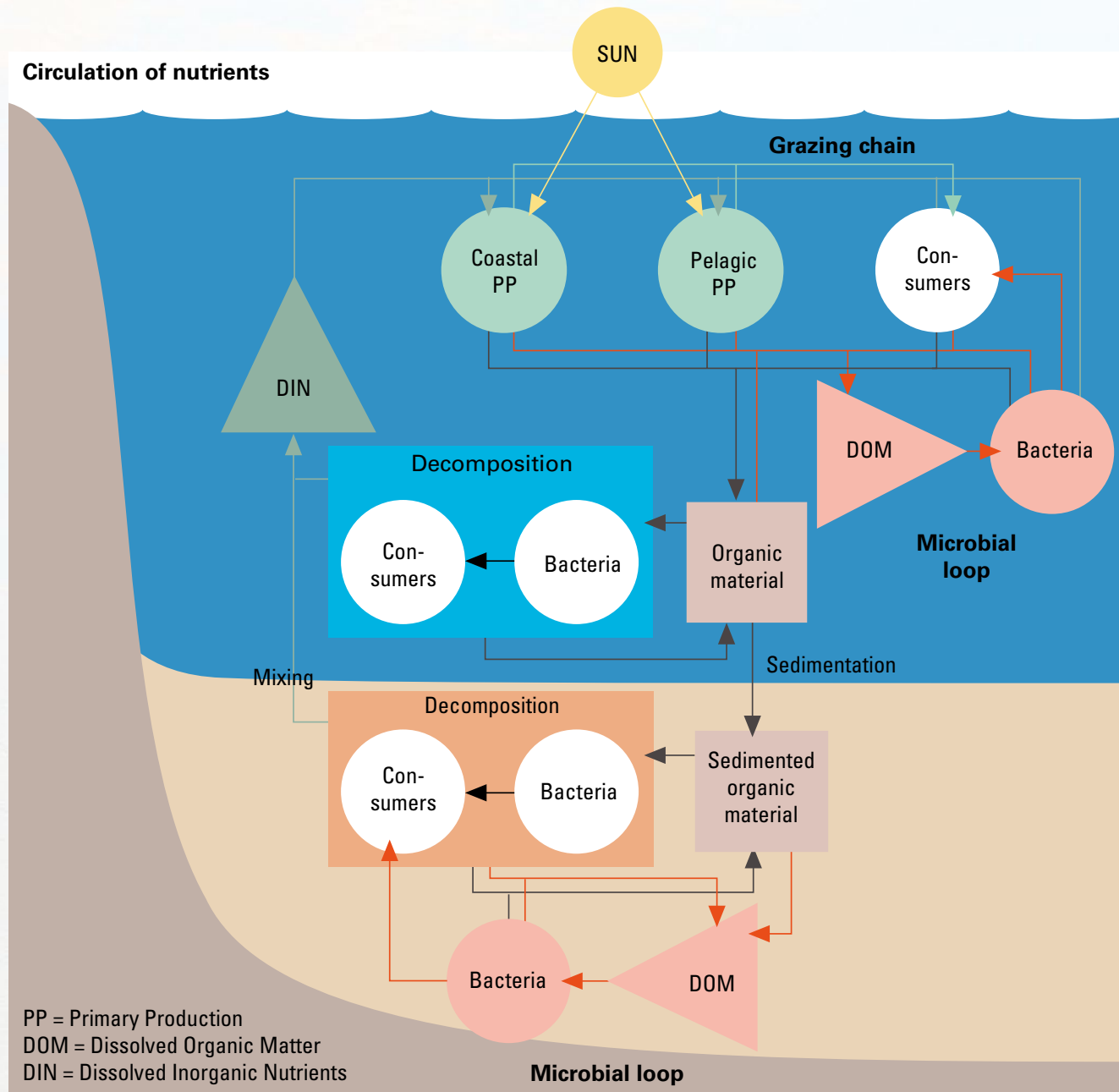
8 Macrofauna

9 Meiofauna

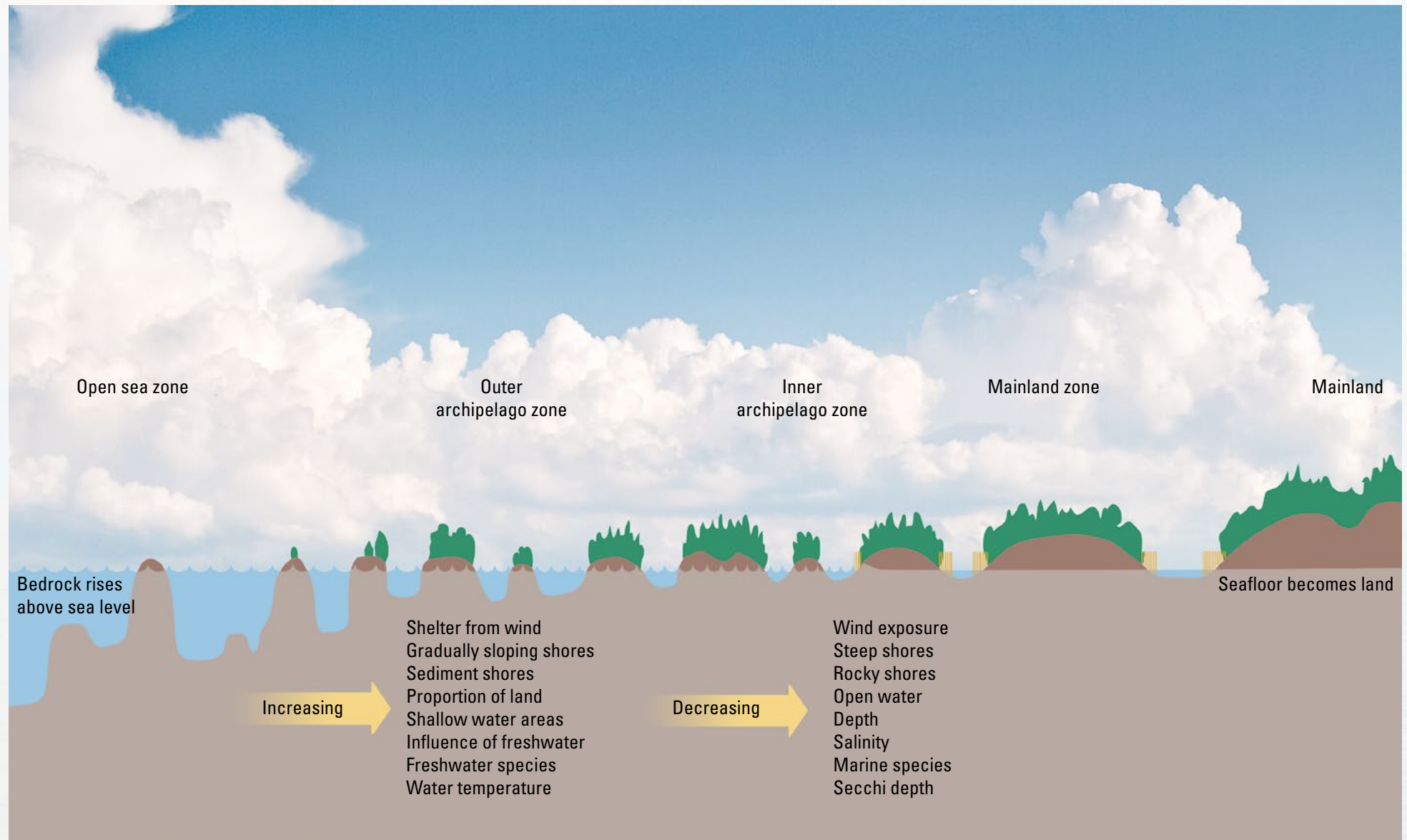
10 Marenzelleria

11 Fish

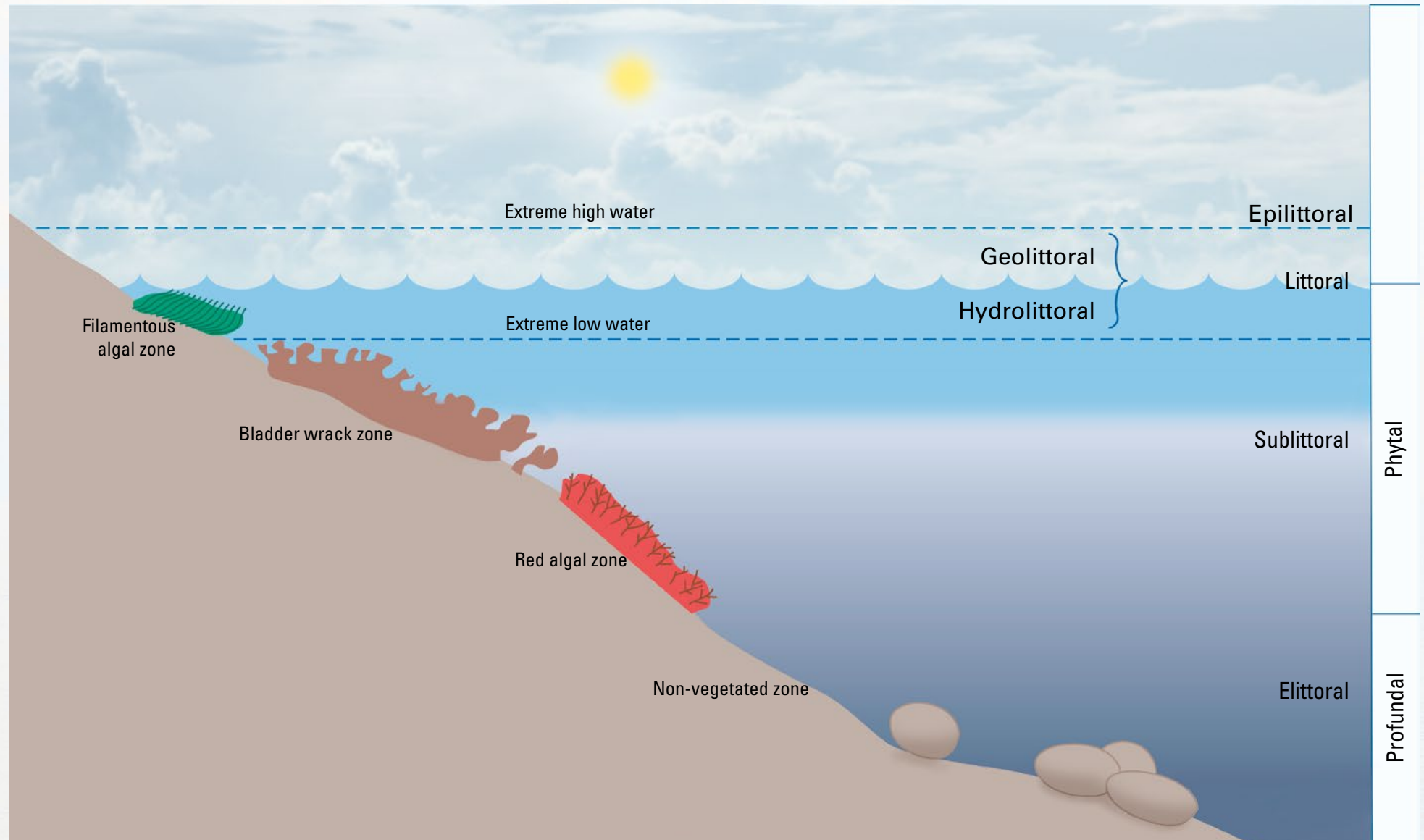
12 Circulation of nutrients

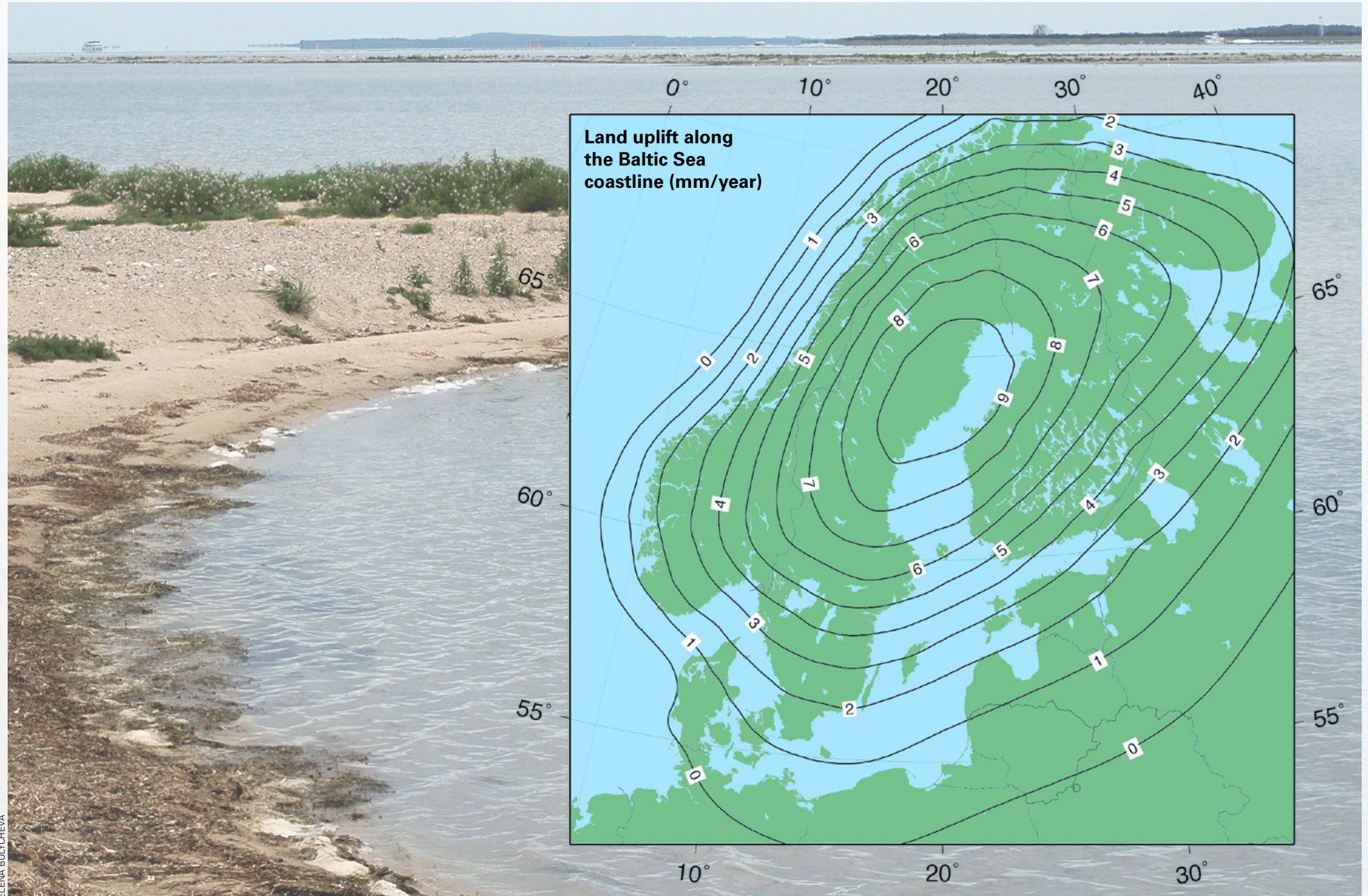


8A The archipelagos: topographic development and gradients



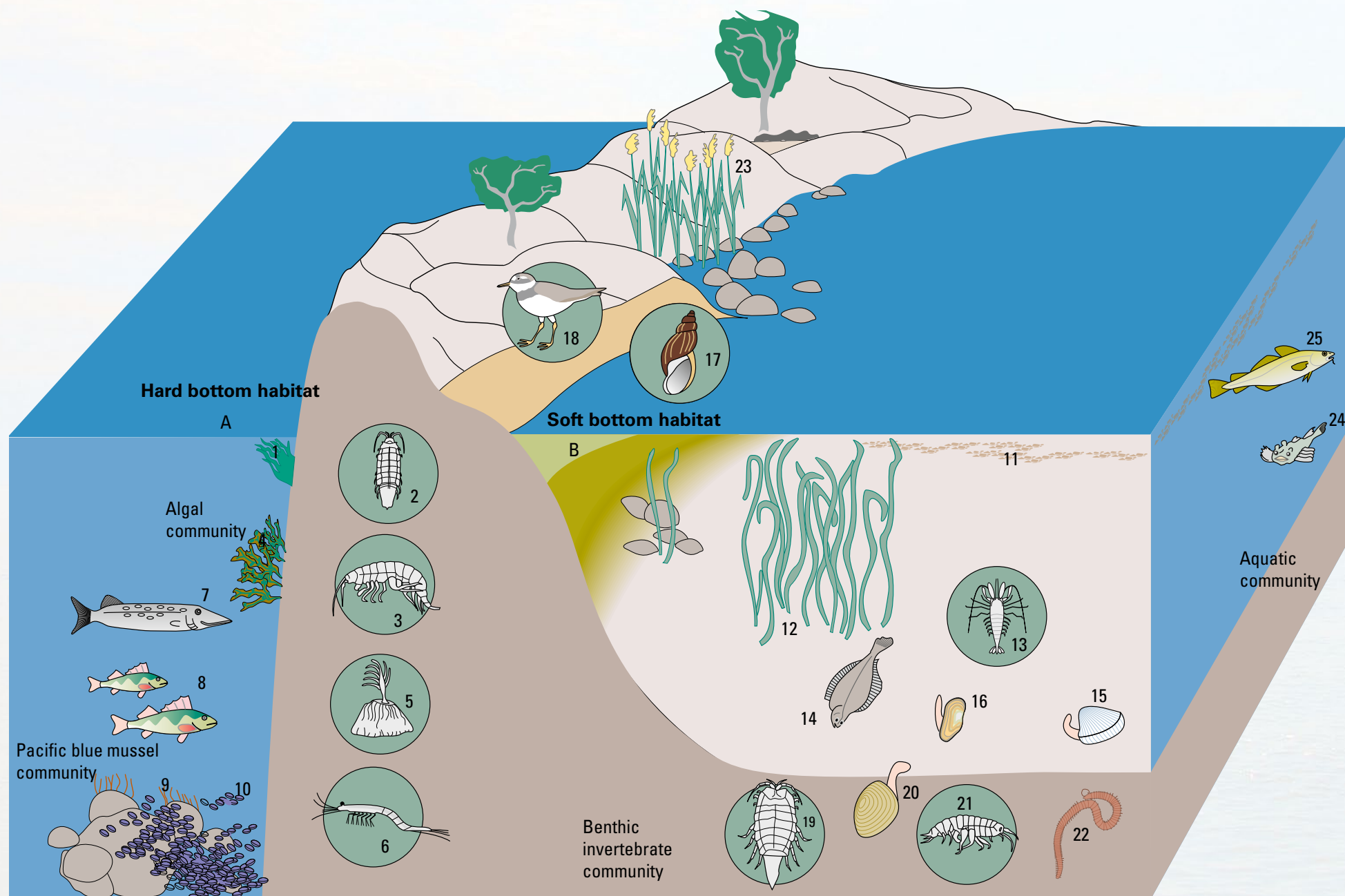
8B The zonation of shores

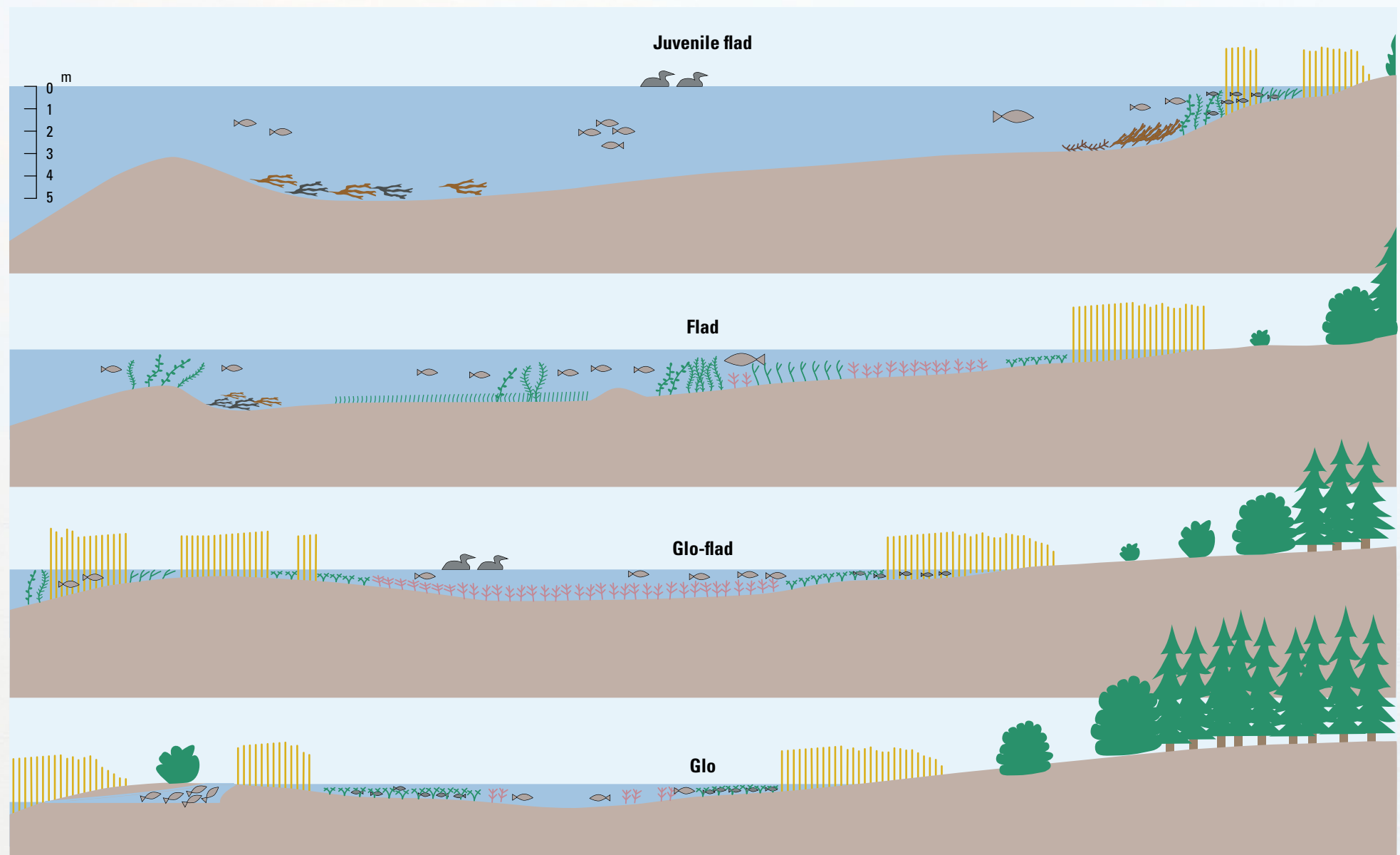


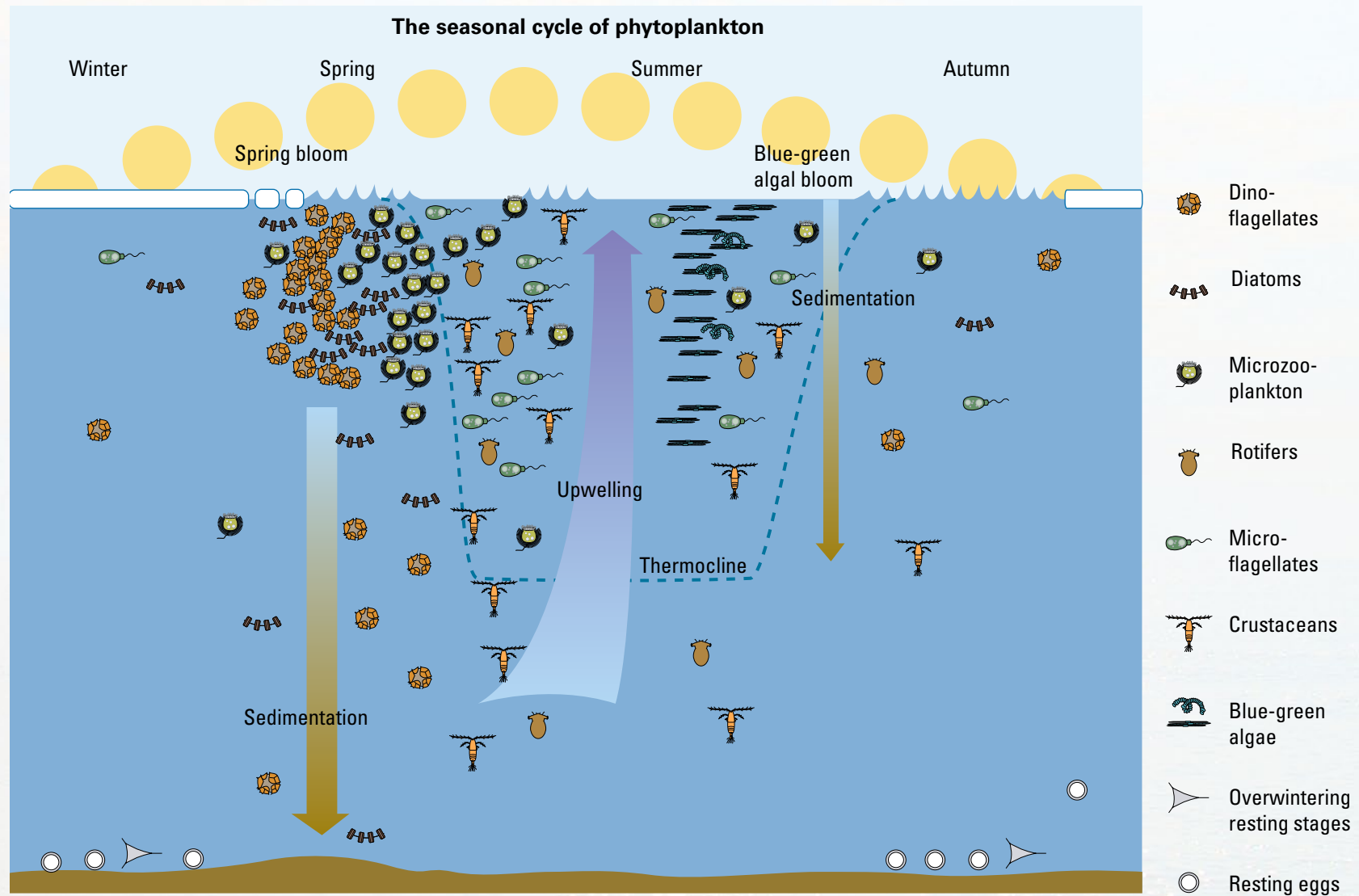


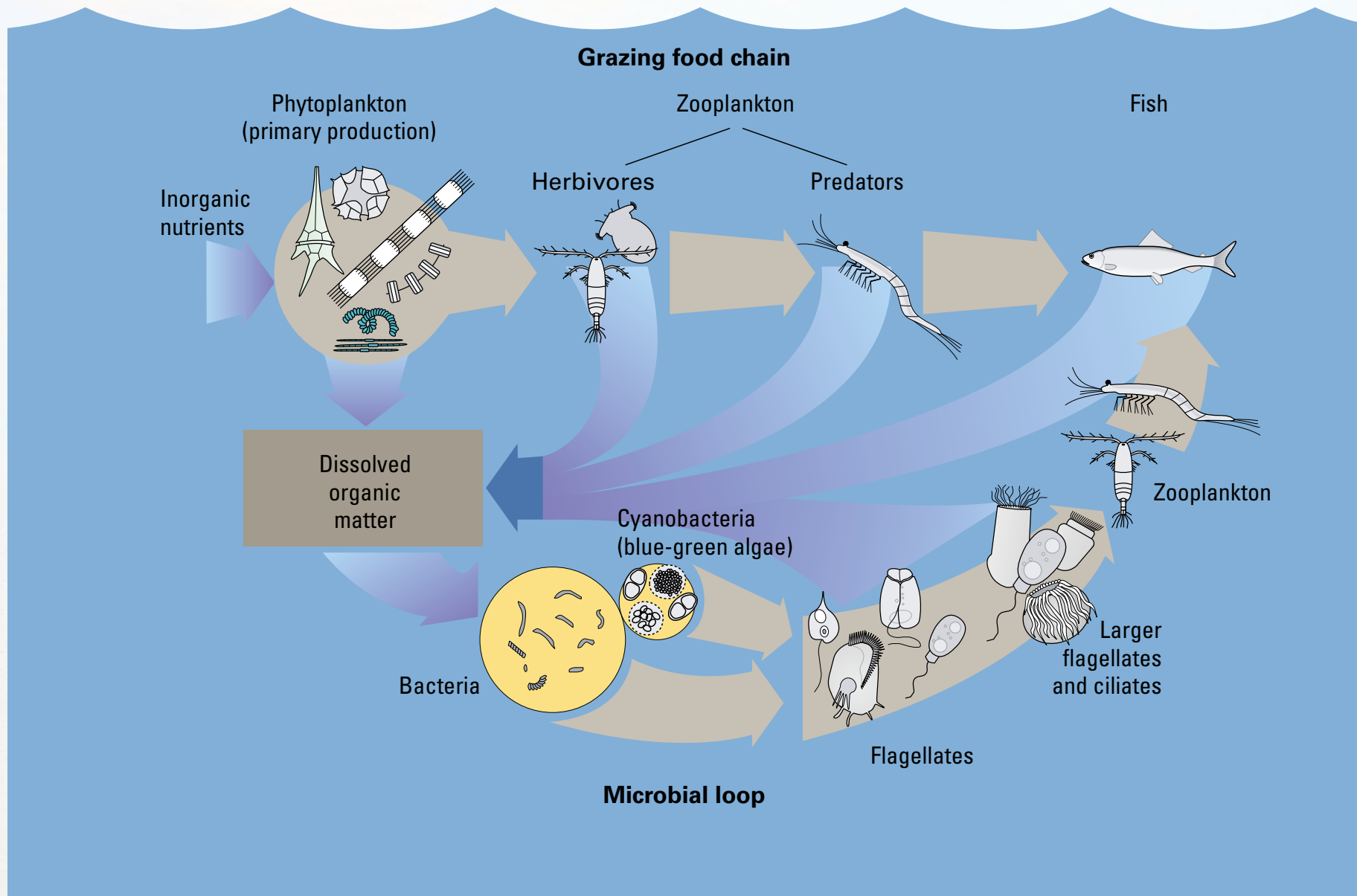
ELENA BULYCHEVA

Source: Vestøl, Ågren, Svensson









13 The open sea ecosystem: scales and proportions

AUTOTROPHS Primary producers



RELATIVE SCALE

From earth to moon
20,000 – 200,000 km



To the other side
of the planet
2,000 – 20,000 km



From St. Petersburg
to Copenhagen
200 – 2,000 km



From Helsinki
to Tallinn
20 – 200 km



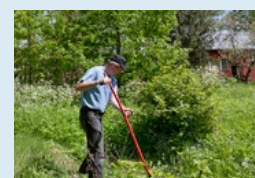
From the suburb
to the city centre
2 – 20 km



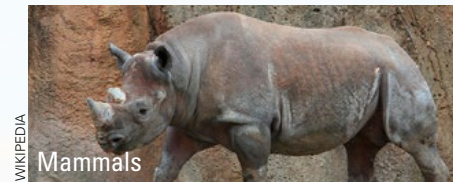
From home
to a local shop
200 m – 2 km



Across the
home yard
20 m – 200 m



HETEROTROPHS Decomposers & consumers



WIKIPEDIA

Mammals



WIKIPEDIA

Fish



WIKIPEDIA

Macrozooplankton > 2 mm



WIKIPEDIA

Mesozooplankton 200–2,000 µm



WIKIPEDIA

Microzooplankton 20–200 µm



DAVID J. PATTERSON

Nanozooplankton 2–20 µm



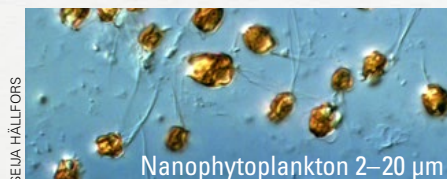
DAVID J. PATTERSON

Bacteria (Picozooplankton) < 2 µm



OUTI SETÄLÄ

Microphytoplankton 20–200 µm



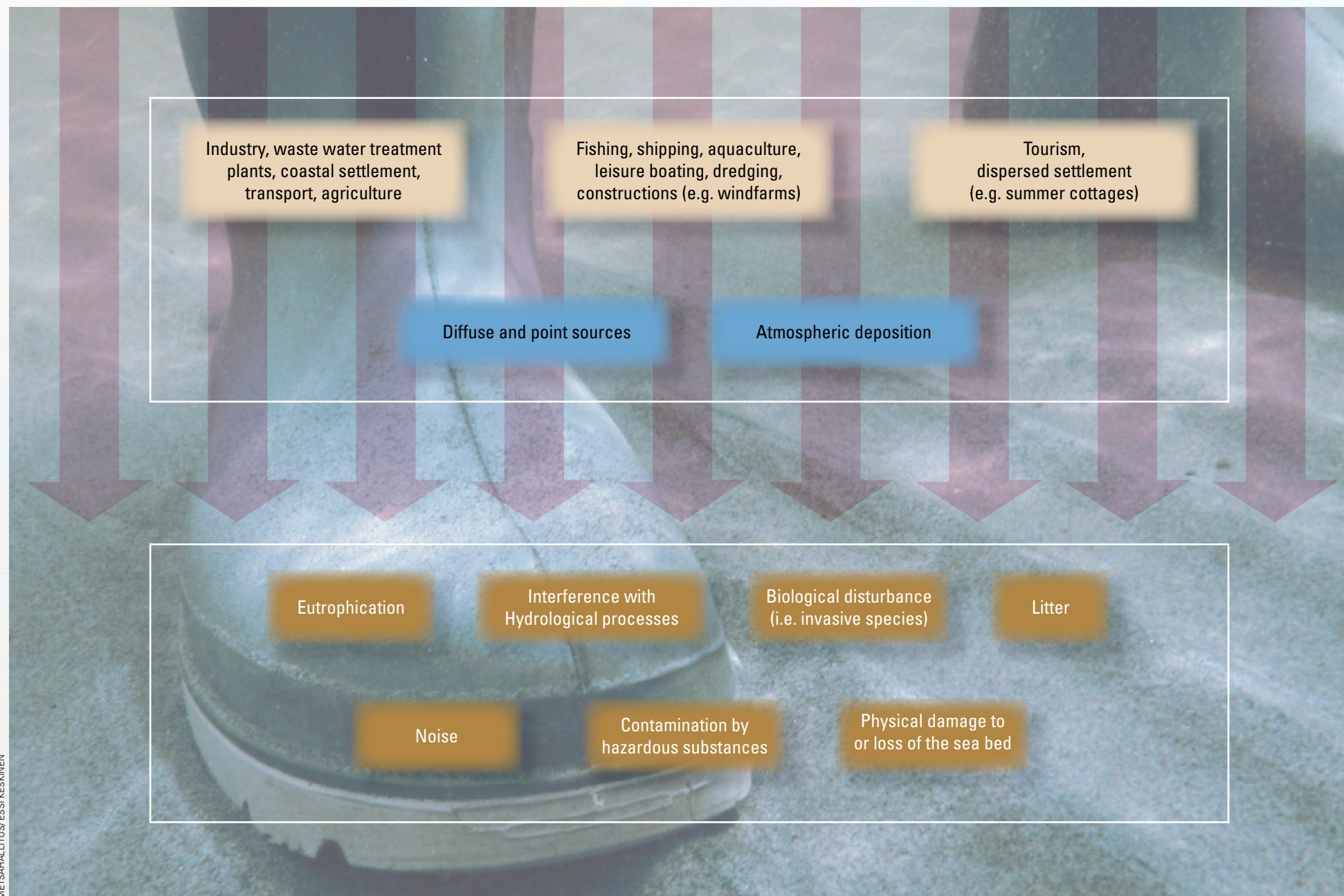
SEJLA HÄLLFORS

Nanophytoplankton 2–20 µm



DAVID J. PATTERSON

Picophytoplankton 0,2–2 µm



Impact of meal choice on health and environment



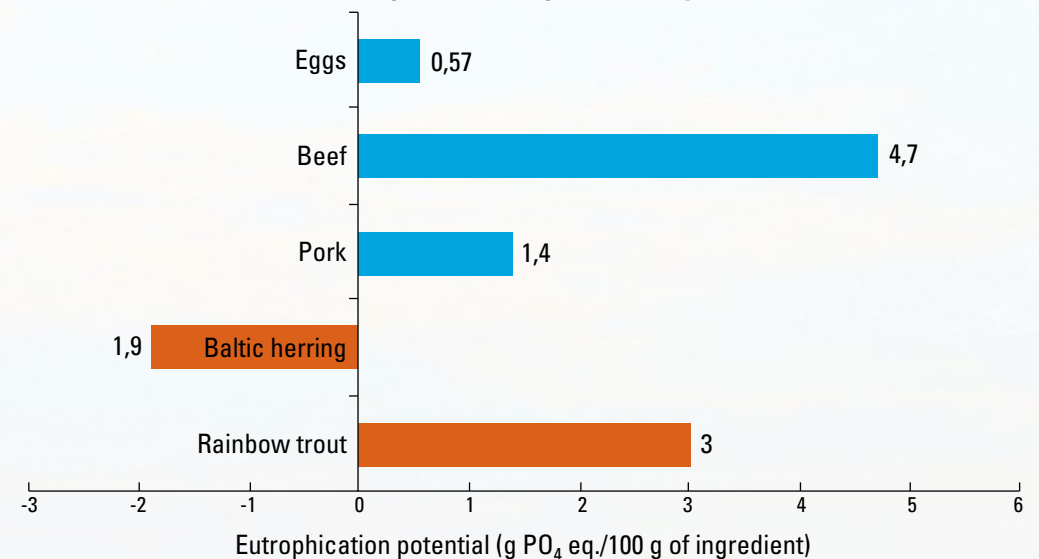
Environmental effects:
climate change
eutrophication
pesticide pollution

Health effects:
Too much saturated fats,
salt and sugars

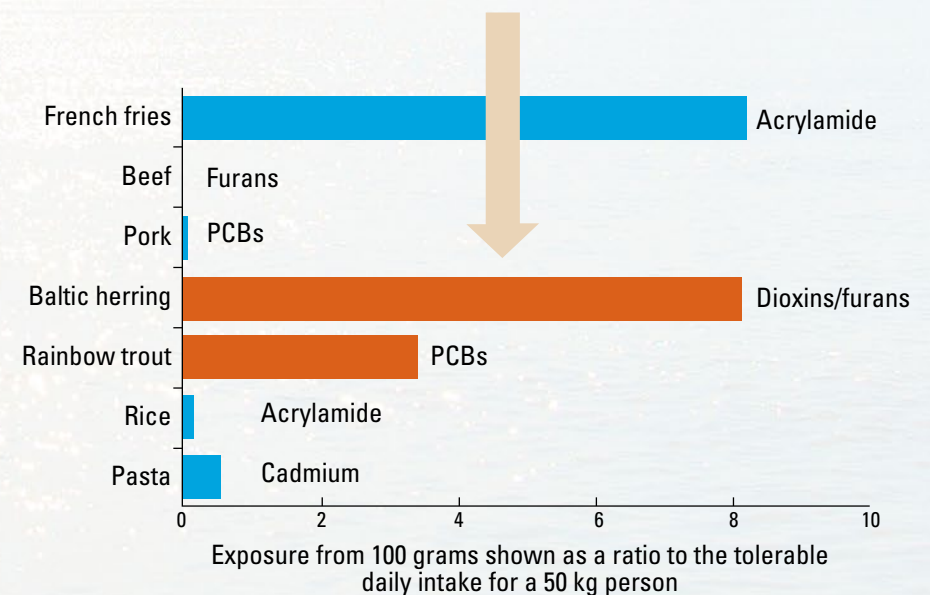
Compare:

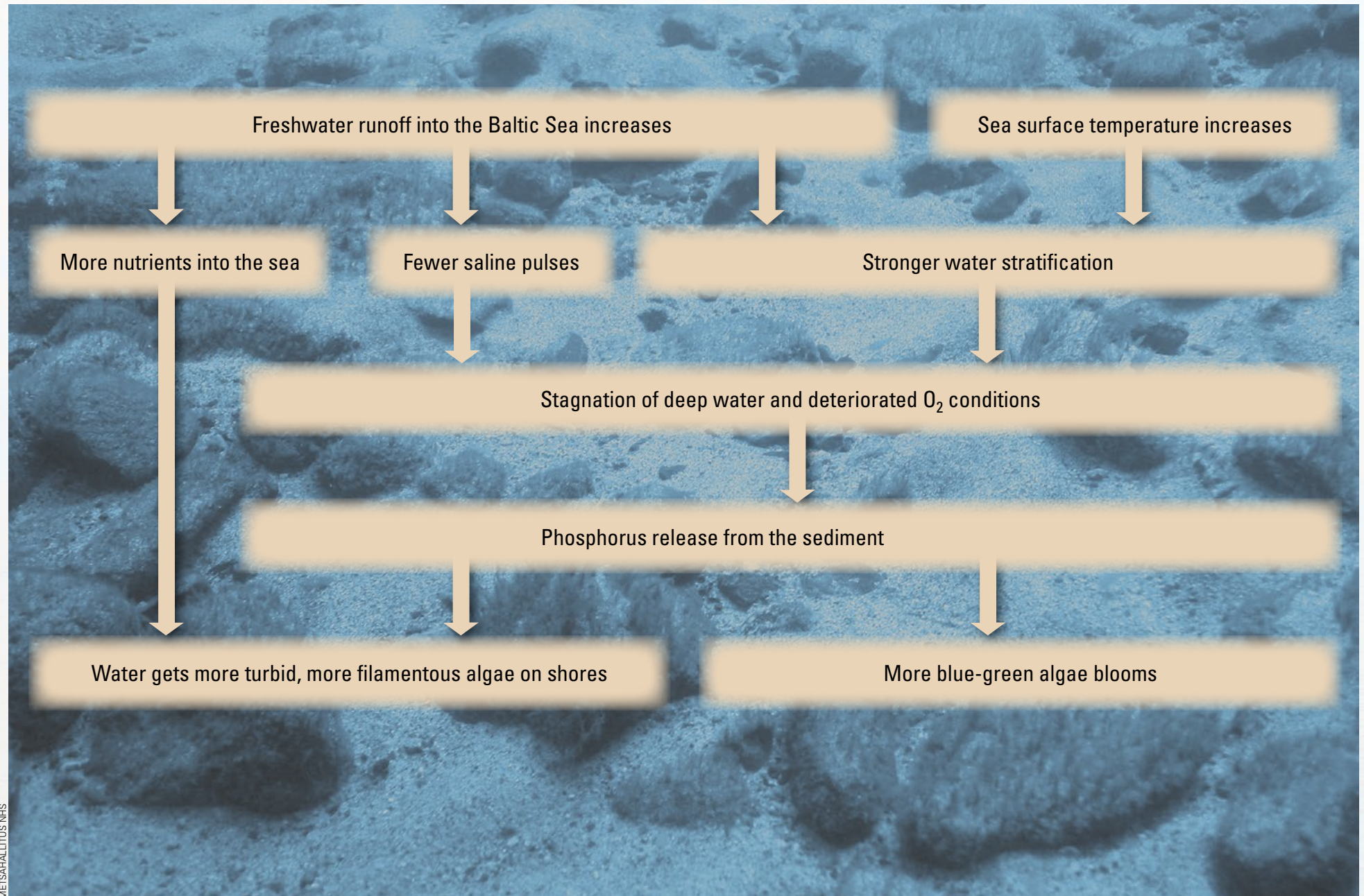
	CO ₂	PO ₄
French fries (oven), 50 g	0,03	0,01
Boiled potatoes, 165 g	0,09	0,04
Boiled rice, 70 g	1,4	2,27
Broad bean patty, 130 g	0,1	0,21
Hamburger (mincemeat patty), 100 g	1,08	0,97
Milk, 2 dl	0,27	0,66
Soft drink, 2 dl	0,22	0,02

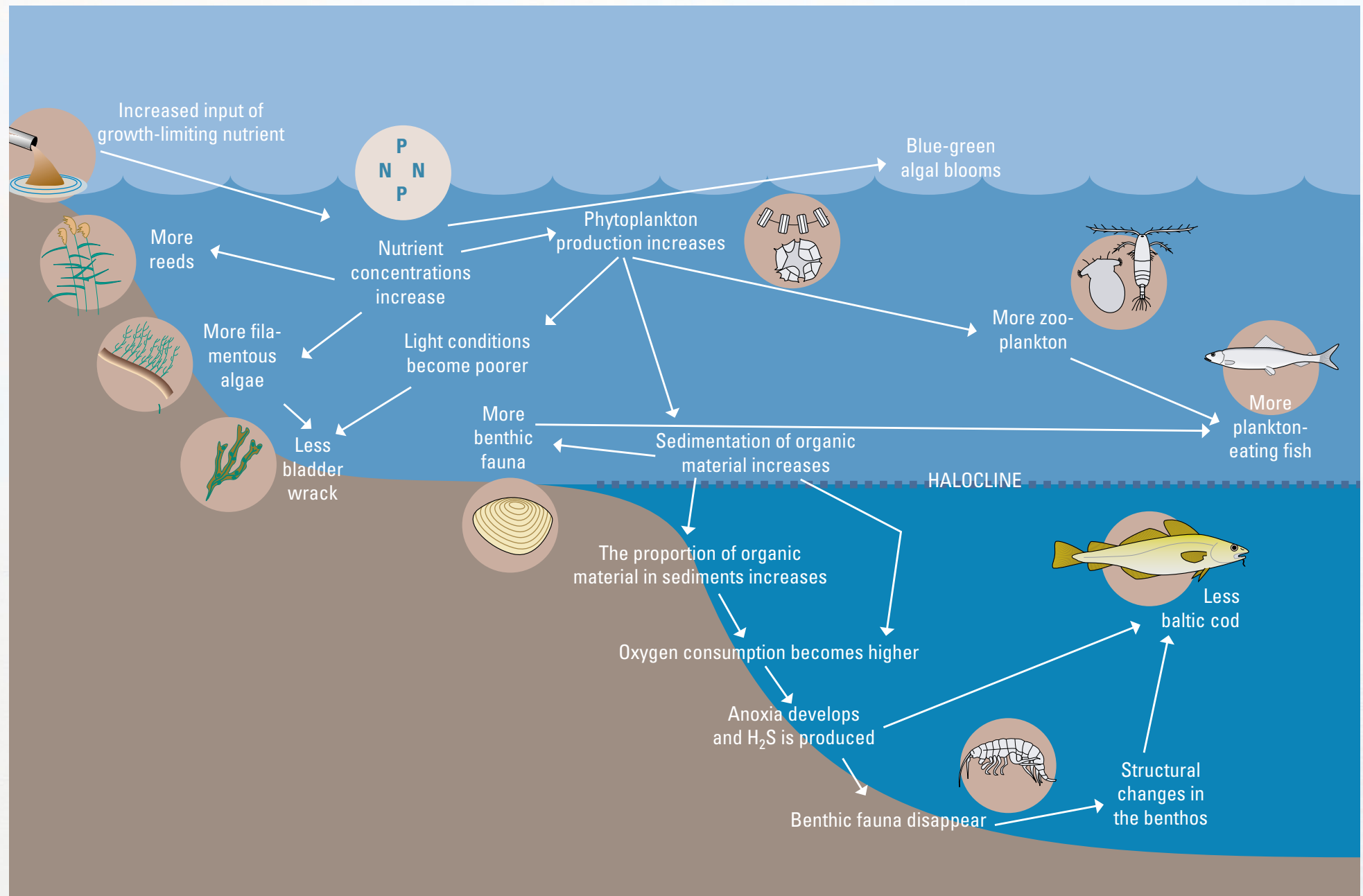
Wild caught fish mitigates eutrophication

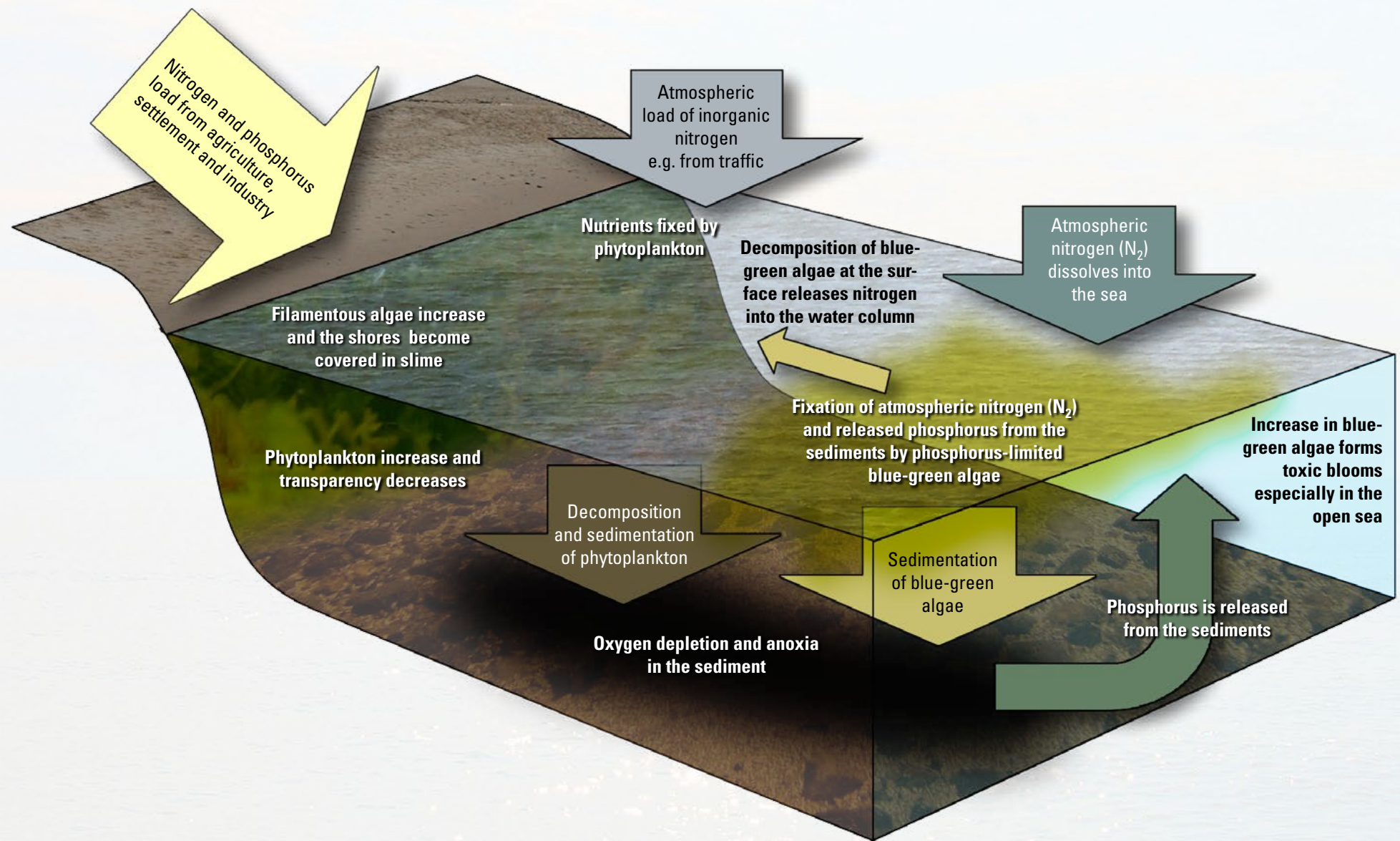


The state of the Baltic Sea affects human health







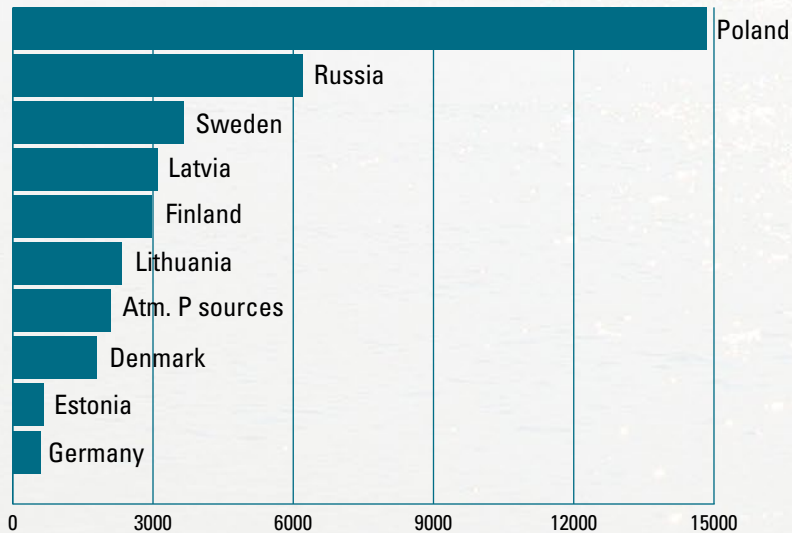


Non-normalized (=actual) waterborne and airborne inputs of phosphorus and nitrogen to the Baltic Sea in 2010

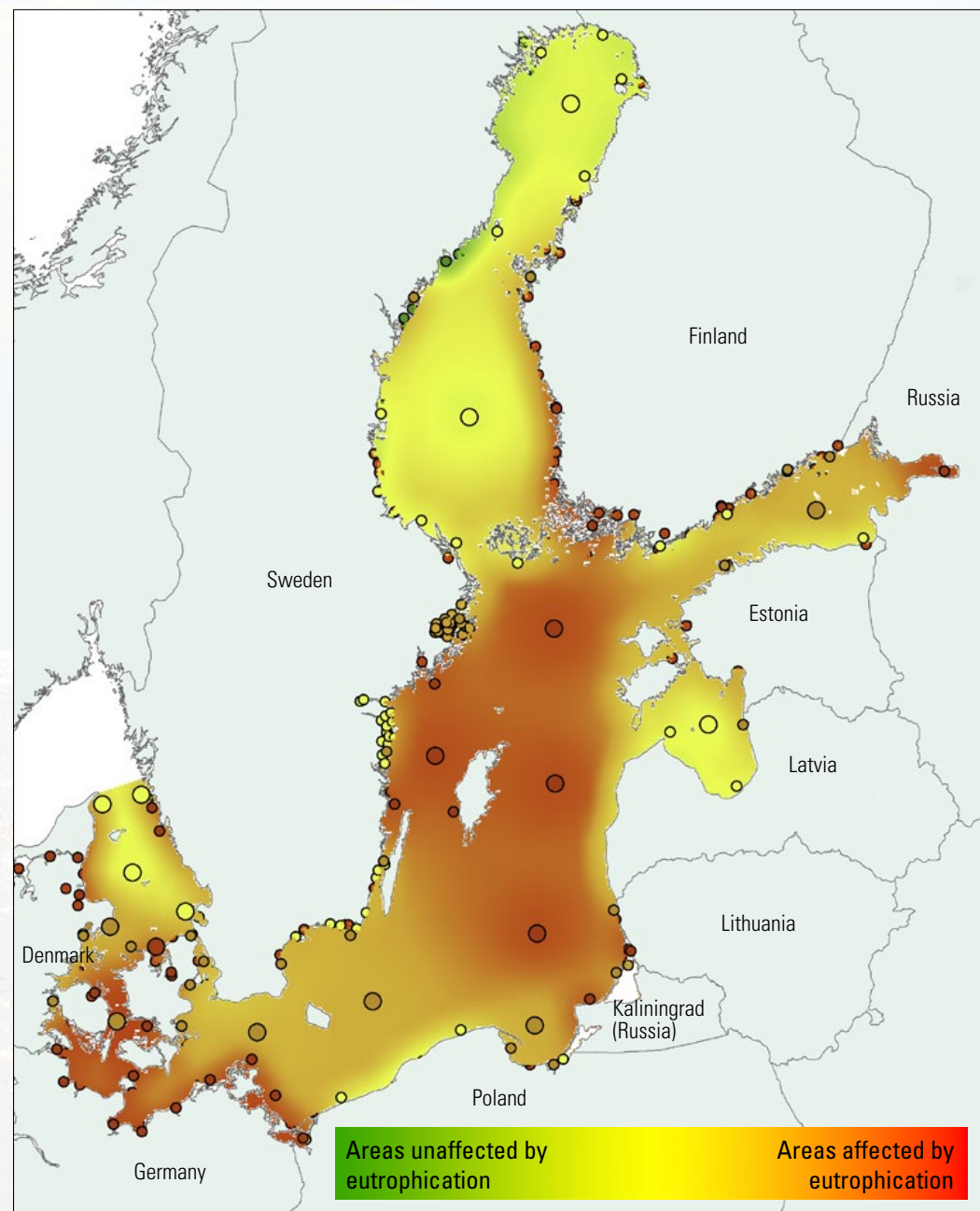
NITROGEN



PHOSPHORUS

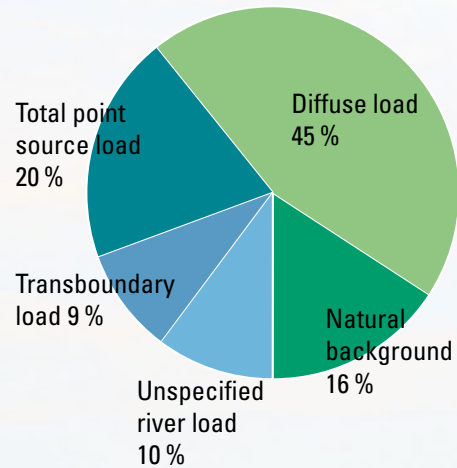


Source: HELCOM 2013



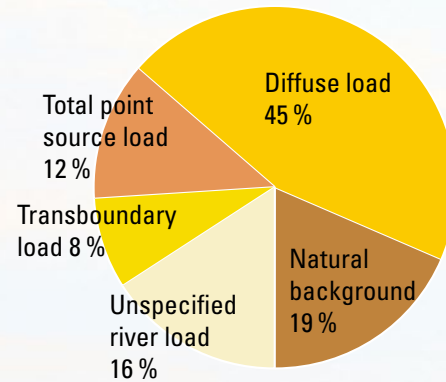
Source: HELCOM 2010a

Total waterborne phosphorus

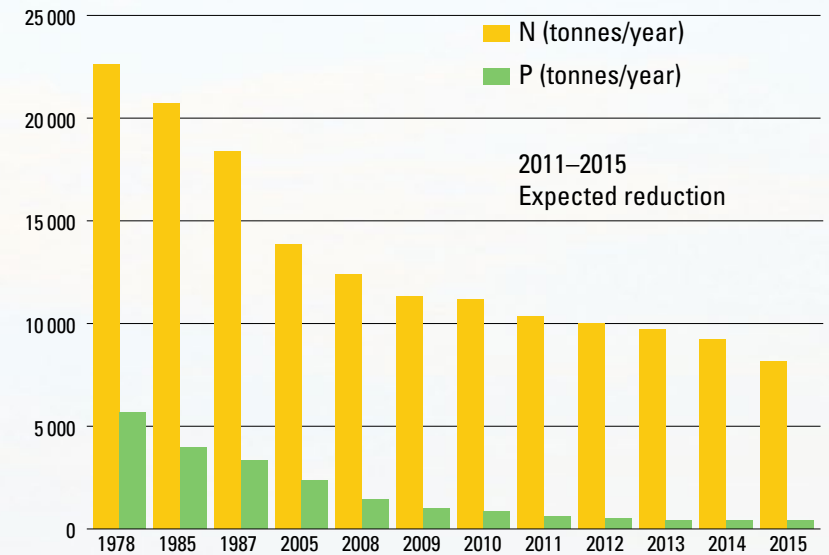


Source: HELCOM 2011

Total waterborne nitrogen load



Reduction of nutrient discharges at Vodokanal of St. Petersburg

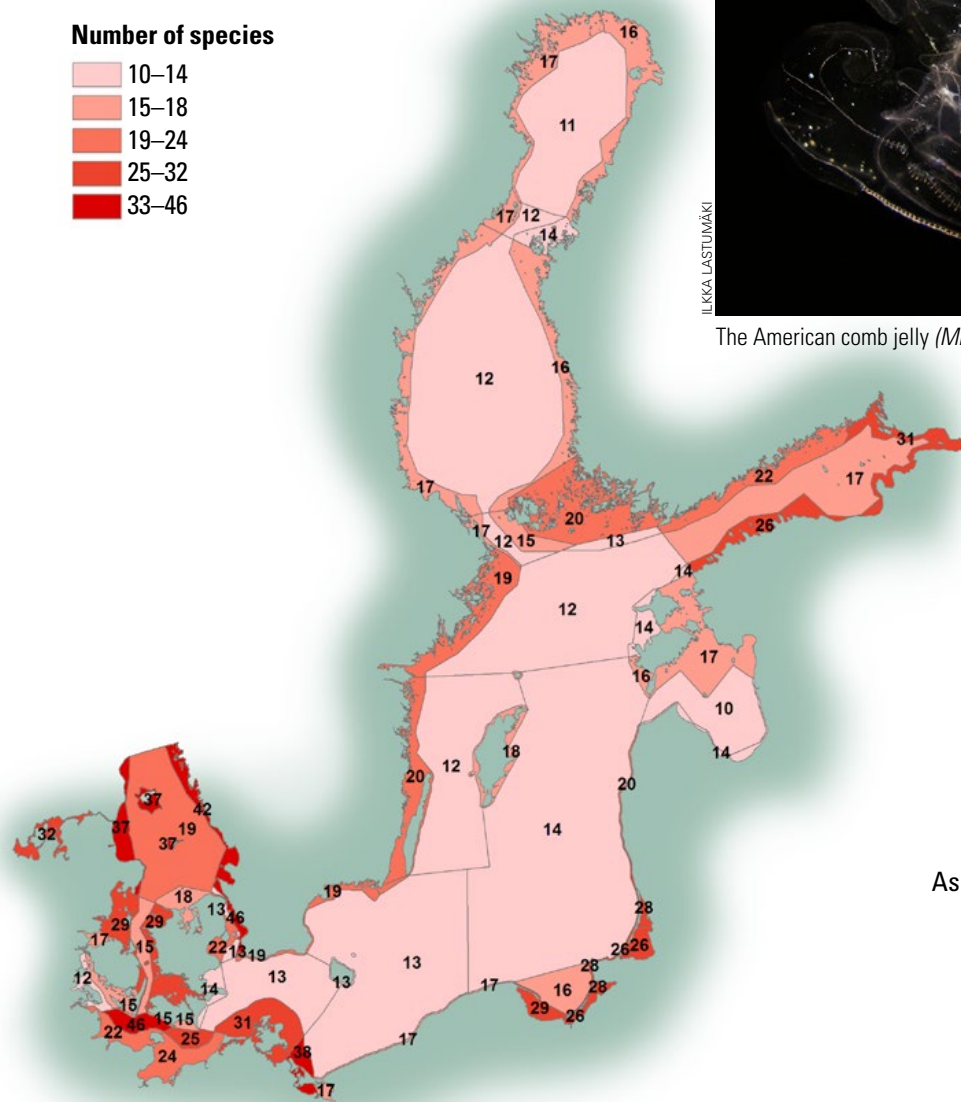
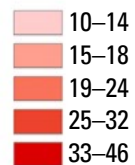


Source: SUE "VODOKANAL OF ST. PETERSBURG" 2010



PETRI KUOKKA

Number of species



Source: HELCOM 2012



ILKKA LASTUNÄKI

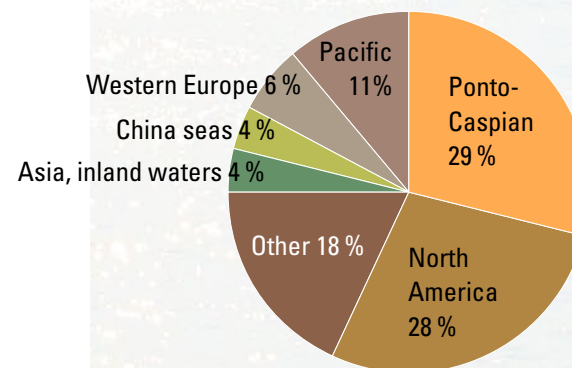
The American comb jelly (*Mnemiopsis leidyi*)



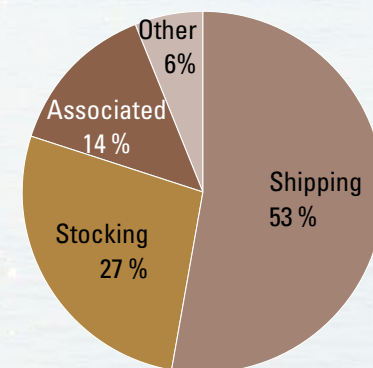
METSÄHALLITUS NHS / ESSI KESKINEN

Chinese mitten crab (*Eriocheir sinensis*)

Origin of species

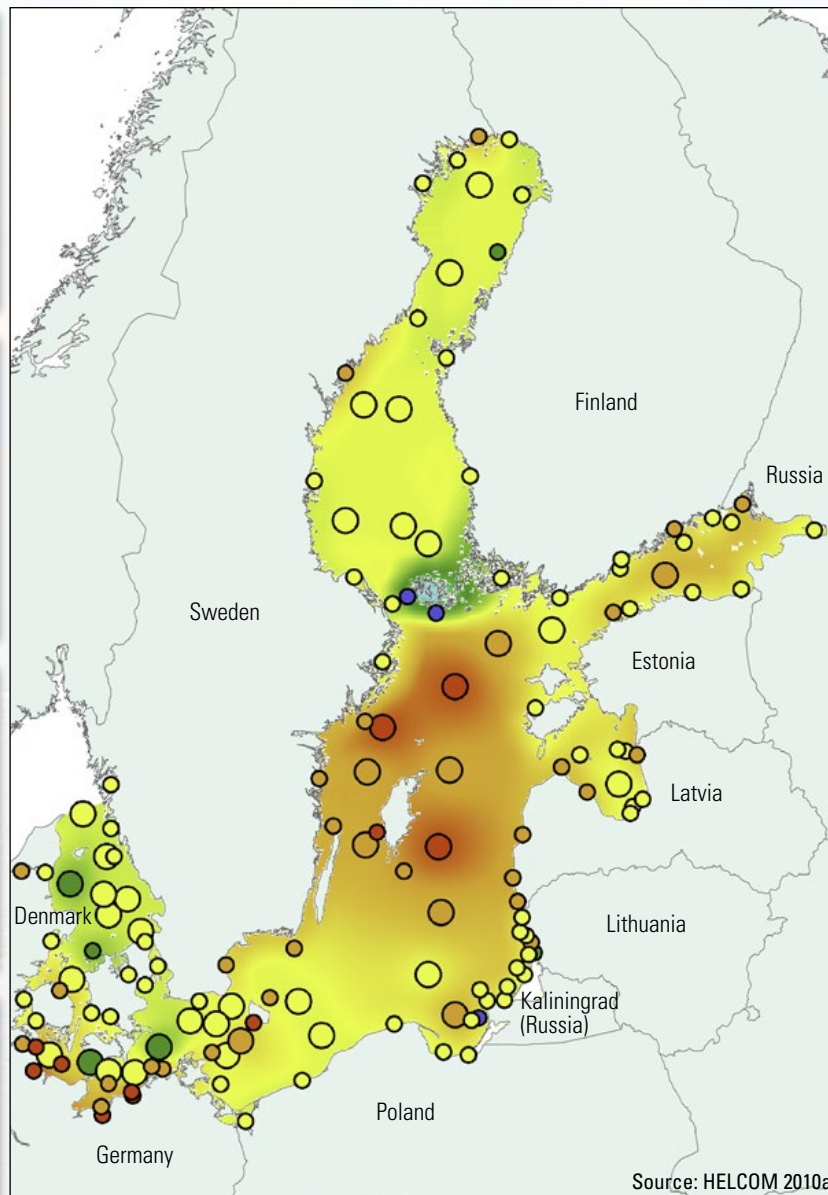


Method of introduction



Source: Zaiko et. al. 2011

21 Hazardous substances in the Baltic Sea

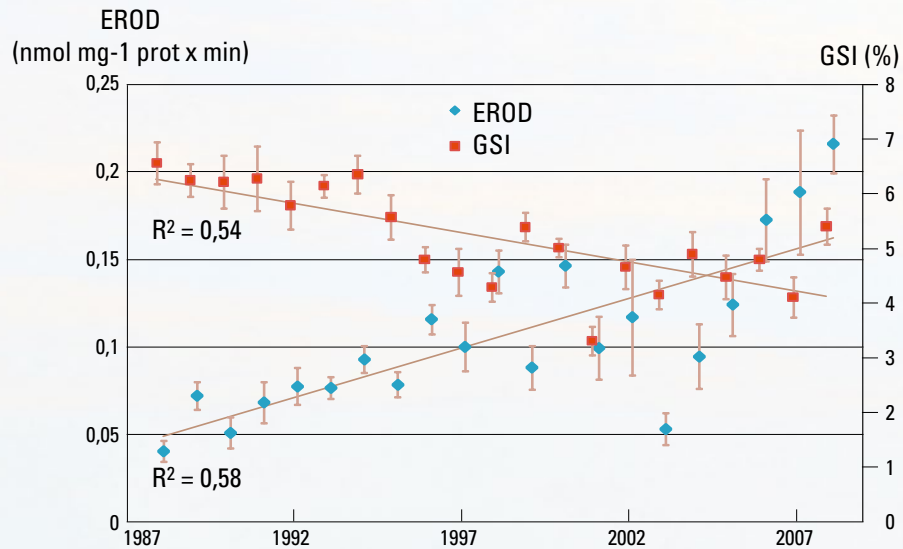


Areas not disturbed by hazardous substances

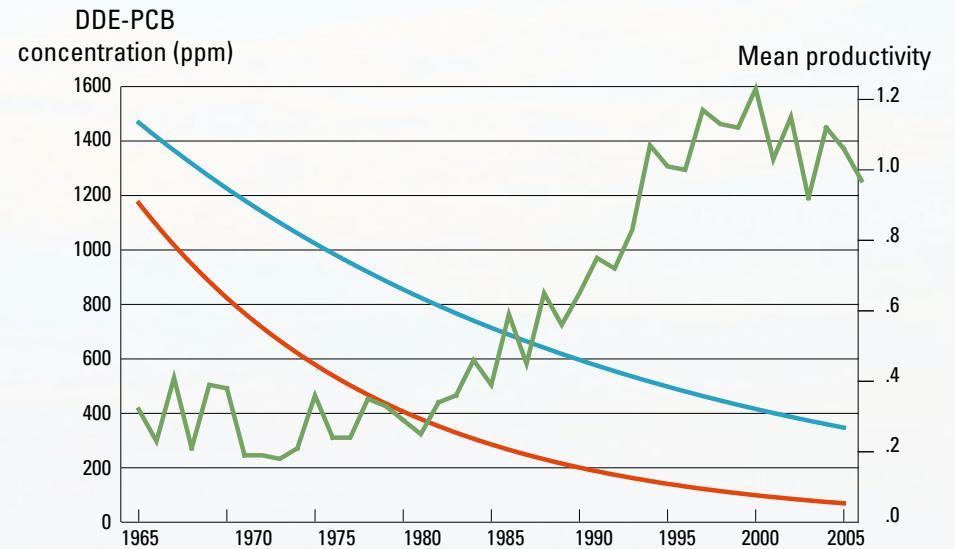
Areas disturbed by hazardous substances



EROD enzyme activity and gonadosomatic index (GSI) in perch (*Perca fluviatilis*) on the coast of the Swedish Baltic Proper from 1988–2008, indicating the linkage between exposure to organic contaminants and reproductive capacity in fish.



Mean productivity (green line) vs. egg lipid concentrations of DDE (red) and PCBs (blue) of the white-tailed sea eagle (*Haliaeetus albicilla*) on the Swedish Baltic Sea coast from 1965–2005.



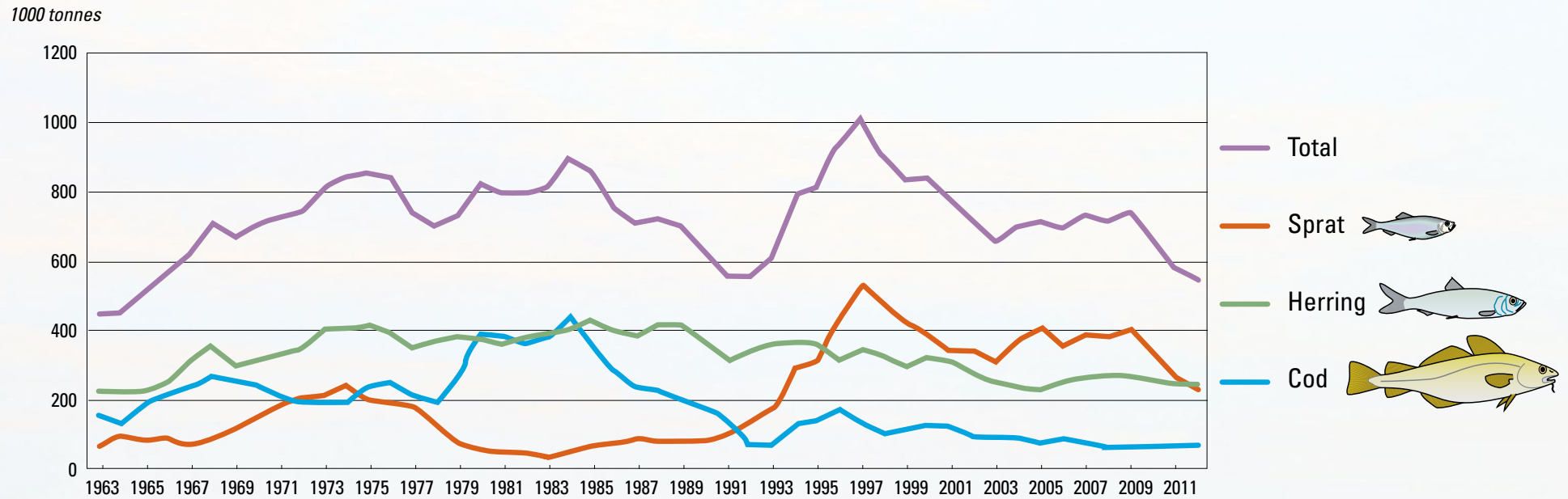
Source: HELCOM 2010b



LAURI RANTALA / WIKIPEDIA



EPRDOX / WIKIPEDIA



MARKKU LAHTINEN



RIKU LUMIARO / SYKE

Emissions:

- SO_x
- NO_x
- O_3
- PAH
- Particles

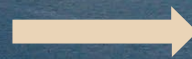
Greenhouse gases:

- Mainly CO_2

Ozone-depleting substances:

- Halon
- CFCs
- VOC

- Ballast water
- Hull fouling
- Accidental or illegal spills
- Sewage discharges
- Bilge water



- Oil, chemicals, anti-fouling paints and other hazardous substances
- Alien species
- Nutrients



Baltic Sea Action Plan (BSAP), 2007

The overall aim is “to restore the good ecological status of the Baltic marine environment by 2021”

What are the main issues?

Eutrophication

Hazardous
substances

Biodiversity

Maritime
activities

How are these issues tackled?

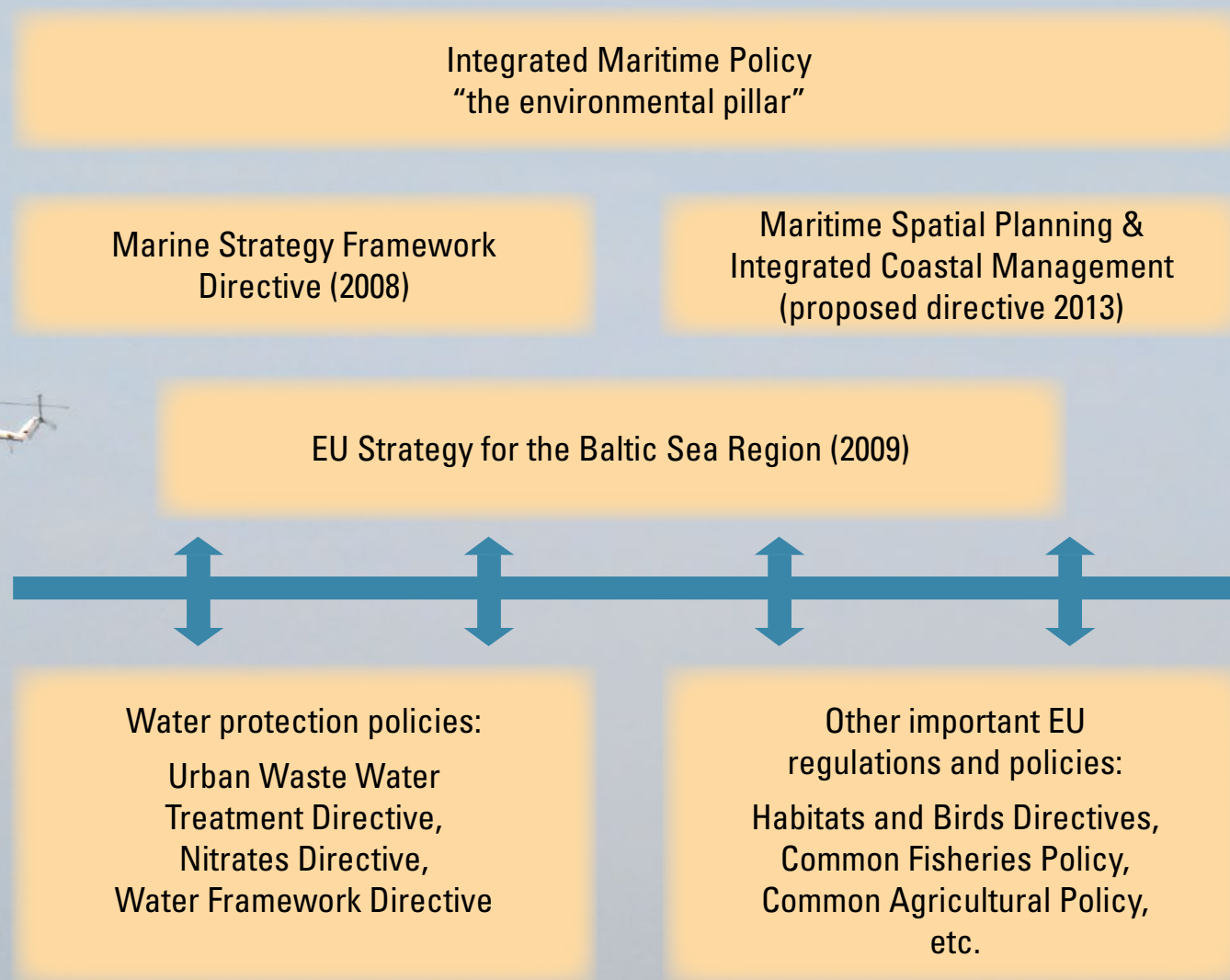
Reduction of
nitrogen and
phosphorus
input

Restrictions
on the use
of selected
substances

Developing Baltic
Sea Protected
Areas and
management plans
for threatened
species and
habitats

Enhancing
cooperation (e.g. to
influence IMO) and
the implementation
of existing
environmental
regulations

- Since 1972 the Helsinki Commission (HELCOM) has worked to protect the Baltic Sea from pollution
- The main tool is the BSAP
– *Based on ecosystem approach*
- HELCOM comprises all the coastal states and the EU
- HELCOM carries out environmental monitoring and assessment
- HELCOM also contributes to the implementation of the EU Maritime Strategy Framework Directive, EU Strategy for the Baltic Sea Region and Maritime Spatial Planning



- In the 21st century, the EU has taken a more significant role in the protection of the Baltic Sea
- Since 2004, eight out of the nine coastal countries have been members of the EU
- These countries implement EU policies and regulations – *Russia is the only coastal country that is not a member of the EU*

One of the most protected and yet most polluted seas in the world

New initiatives have emerged

Private funding

Concrete actions

Private-public
partnership

Engaging new actors



www.puhdasitameri.fi/en
www.balticsea2020.org/english/

Clean Baltic Sea
JOHN NURMINEN FOUNDATION

**BALTIC SEA 2020
FOR A LIVING COAST**

The way we:

move

eat

live



The development of this new edition of the Baltic Sea presentation package was inspired by the Gulf of Finland Year 2014, in order to contribute to the intensive work on augmenting the scientific knowledge base and awareness of the Baltic Sea. We hope that the Gulf of Finland Year 2014 will be successful and meaningful for the future of the Baltic Sea environment.

This presentation package, in the form of plastic transparencies and a paper booklet, was originally developed by a group of Baltic Sea scientists, mainly from Helsinki University, the Finnish Institute of Marine Research and the Environmental Administration of Finland. The first series was produced in English in 1993. Over the years Finnish, Swedish and Russian versions were produced, and in 2004 the English version was updated and transformed into digital format.

Over this period the hardcopy presentation package has been donated to schools in the Baltic region, to administration, politicians, research institutions, NGOs and to the industry. The www-version has been downloadable free of charge, and many parts of the material have been made freely available for use in other books, reports and the media, subject only to a copyright acknowledgement.

The content of the presentation package demonstrates, on one hand, the physical, chemical and biological characteristics of the Baltic Sea and, on the other hand, the challenges presented by the Baltic. The last parts of the presentation package demonstrate various ways in which society is already acting, and can in the future continue to act to influence the future of the Baltic Sea to ensure the sustainable use of its environment. At the end, the question is posed to all of us: *what can I personally do for the Baltic Sea?*

The idea of creating this Baltic Sea – Environment & Ecology slide series originally arose at a meeting of the Junior Cham-

bers (JC's) of South Eastern Finland in Kotka in the spring of 1992. Following this meeting a declaration was handed to Ms Sirpa Pietikäinen, the then Finnish Minister of the Environment. In their statement, the JCs expressed their firm desire to do something concrete to improve the condition of the Baltic Sea. As a result of this initiative, this slide series was produced.

Dr Eeva Furman, Dr Pentti Välipakka and Dr Heikki Salemaa were responsible for the scientific planning and editing of the first edition. Sadly, Dr Salemaa died in 2001; this present version has been edited by Dr Eeva Furman, Ms Mia Pihlajamäki, Dr Pentti Välipakka, and Dr Kai Myrberg. Mr Robin King improved the material by checking the English language. From the beginning Mr Petri Kuokka of Aarnipaja has been responsible for the graphic design, as also for this 2013 edition.

Over its lifetime, many people have contributed to the presentation package. The following scientists and experts provided invaluable information for the 1993 edition: Ms A.B. Andersin, Dr Erik Bondsdorff, Mr Jan Ekebom, Prof. Ilkka Hanski, Dr Jorma Kuparinen, Dr Juha-Markku Leppänen, Prof. Åke Niemi, Prof. Aimo Oikari, Ms Meeri Palosaari, Dr Raimo Parmanne, Dr Eeva-Liisa Poutanen, Prof. Kalevi Rikkinen, Dr Timo Tamminen, Ms Vappu Tervo and Dr Ilppo Vuorinen. Dr Riggert Munsterhjelm made a major contribution by revising the slides for the Swedish version in 2001. Ms. Anna Nöjd contributed to the content of the English version of 2004. The production of the presentation package has been sponsored over the years by various bodies, i.e.:

- The Nessling Foundation
- The Ministry of the Environment, Finland
- National Board of Education
- Economic Information Office of Finnish Industries

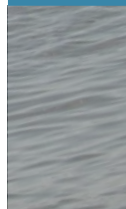
- City of Kotka
- University of Helsinki
- Finnish Environment Institute
- Southeast Finland Regional Environment Centre
- Junior Chamber Kotka
- The Nottbeck Foundation

The development of the 2013 edition of the presentation package has been funded by the Nessling Foundation and the Finnish Environment Institute, which has also been the home of the presentation package and its development since 1996. We have had irreplaceable help from the following institutions, scientists and experts: SYKE: Mr Seppo Knuuttila, Mr Jan-Erik Bruun, Dr Maiju Lehtiniemi, Mr Riku Varjopuro, Dr Juha-Markku Leppänen, Dr Kari Lehtonen, Dr Jaakko Mannio, Dr Tuomas Mattila, Prof. Markku Viitasalo, Dr Heikki Peltonen, Dr Harri Kaanpää, Ms Anna Toppari, Ms Aira Saloniemi, Dr Outi Setälä, TRAFI: Dr Anita Mäkinen, HELCOM: Dr Maria Laamanen, Ms Johanna Laurila, FMI: Mr Jouni Vainio, Prof. Kimmo Kahma, Dr Heidi Pettersson, Olarin Lukio: Ms. Maija Flinkman and FGFR: Mr Jukka Pönni and Dr Eero Aro.

We, the editors of this volume, want to express our warmest thanks to all these institutions and experts for their generous help and contributions.

This presentation package can be downloaded and used free of charge. The editorial group owns the copyright to the slide series. Petri Kuokka owns the copyright to the figures and layout. The package can either be downloaded or used directly from the Internet.

Eeva Furman, Mia Pihlajamäki,
Pentti Välipakka and Kai Myrberg
Helsinki, 31.12.2013



The Baltic Sea is a northern semi-enclosed sea and the largest brackish water body in the world. Its catchment area is 1,633,290 km², four times the area of the sea itself, which is 392,978 km². The maximum length of the catchment area in a N-S direction is over 1,700 km, while its maximum width (W-E) exceeds 1,000 km. The northernmost part of the sea lies within the Arctic Circle. The Baltic Sea encompasses nine coastal countries (Denmark, Germany, Poland, Lithuania, Latvia, Estonia, Russia, Finland and Sweden), but five more countries (the Czech Republic, the Slovak Republic, the Ukraine, Belarus and Norway) are in the catchment area.

The total population of the Baltic Sea region is about 85 million, of which 38 million live in the Polish catchment, 9.2 mil-

lion in the Russian catchment (St. Petersburg alone has a population of 5 million and is by far the largest city in the region) and 9.1 million in the Swedish catchment. Nearly 8 million people live in the catchments of the non-coastal countries.

Land use is influenced by soil type and the presence of bedrock. In the southern parts of the catchment, agriculture is the dominant form of land use, whilst the northern parts are largely forested, although agriculture is practised all around the coast of the Baltic Sea.

Hundreds of rivers discharge their waters into the Baltic Sea; of these, six have catchments greater than 25,000 km². The seven largest rivers are the Neva, the Vistula, the Daugava, the Nemunas, the Kemijoki, the Oder and the Göta Älv. The

Baltic Sea can be divided into the following sub-regions: the Kattegat, the Danish Straits, the Arkona Basin, the Bornholm Basin, the Gotland Sea^{1,2} the Gulf of Riga, the Gulf of Bothnia and the Gulf of Finland. The Gulf of Bothnia can be further divided into the Bothnian Sea and Bothnian Bay. The Archipelago Sea and the Åland Sea can also be distinguished as part of the Gulf of Bothnia.

¹ The Arkona Basin, Bornholm Basin and the Gotland Sea are together often known as the Baltic Proper.

² The Gotland Sea includes the western, eastern and northern Gotland Basins and the Gulf of Gdansk.

Unlike most other seas and oceans, the Baltic Sea is located entirely on one continental plate instead of lying on a continental divide, which explains why the sea is so shallow compared to the oceans. The average depth of the Baltic Sea is only 54 metres, whereas on average the mean depth of the oceans is 3,500 m. The deepest point of the Baltic, the Landsort Deep, which is situated in the western Gotland Basin off the Swedish coast northwest of the island of Gotland, is 459 metres deep.

During the last Holocene (Weichselian glaciation), which reached its greatest extent 20,000 years ago, the Baltic Sea area was depressed and modified by the ice. When the glacier finally receded approximately 8,500 years ago, the land started to rise at a relatively rapid rate. The still ongoing land uplift has gradually slowed down and, at the moment, land around the Baltic Sea is rising by 0–9 mm per year. The rate of land uplift is at its greatest around the Gulf of Bothnia (for more, see slide 8).

The bathymetric profile of the Baltic Sea can be divided into three zones. The coastal zone stretches from the mainland to the outer limit of the islands, where they are present. There is a transitional zone extending from the coastal zone to where the depth reaches 50 metres and the open sea zone begins. The Archipelago in the coastal zone can again be divided into zones, the number of which depends on the width and extent of the archipelago (see slide 8). The coasts of Sweden and especially those of Finland have rich archipelago areas (such as the Archipelago Sea).

The coastal zone is biologically diverse, comprising a continuum of varying habitat types from the mainland to the open sea. The coastal zone acts as a kind of filter between the mainland and the open sea, trapping nutrients and pollutants. The coastal zone is also well suited to recreational use and fisheries.

The transitional zone is a complex environment that has not been well studied and is poorly understood, making the effects of pollutants on the ecosystem in this zone difficult to predict. Environmental conditions in the transitional zone show large temporal and spatial variations. During strong storms, fine material settled on the bottom is re-suspended in the water column. In the deep-water areas of the open sea zone, however, all of the fine material, once settled on the seafloor, stays there as sediments. Only the occasional pulses of salt water from the North Sea and the slow land uplift return nutrients from the bottom layers into the productive part of the water column.

There are four mechanisms acting to induce currents in the Baltic Sea: wind stress at the sea surface, sea surface tilt, thermohaline horizontal gradients of density and tidal forces. Currents are furthermore steered by Coriolis-acceleration, topography and friction. As a result of these factors, the long-term mean surface circulation is anticlockwise in the main Baltic basins, and there is typically a two-layer flow system in which fresh water in the surface layer flows out of the Baltic and denser, more saline water enters near the bottom. There are no strong permanent current structures (like the Gulf Stream) in the Baltic Sea. However, in some areas the circulation is relatively stable. The amount of river discharge affects the strength of the surface currents near the coasts. In the open sea the currents are more irregular. The speed of the currents is on average 5–10 centimetres per second, but this can increase in extreme cases up to 50–100 cm/s, especially in narrow straits.

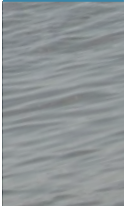
A single, wind-induced surface wave can grow up to 14 metres (a value recorded in the northern Gotland Sea in 2004) in the largest basin of the Baltic Sea. Wave heights are first and foremost controlled by the wind speed, the wind duration and

the fetch (i.e. the distance over which the wind blows). Due to its size, the Baltic Sea experiences wave heights larger than those in lakes but smaller than those in the oceans. The effects of wind speed and the wind duration (i.e. how long the wind blows) on the growth of waves are presented in the table below.

Wind speed/ duration	4 m/s	8 m/s	14 m/s	20 m/s
1h	<0.2 m	0.25 m	0.55 m	0.85 m
2h	0.25 m	0.45 m	0.90 m	1.50 m
3h	0.30 m	0.60 m	1.25 m	1.95 m
4h	0.40 m	0.80 m	1.60 m	2.45 m
5h	0.45 m	0.90 m	1.85 m	2.90 m
6h	0.45 m	1.05 m	2.15 m	3.30 m
Fully developed	0.45 m	1.75 m	5.30 m	(11 m)

Source: Laura Tuomi /Finnish Meteorological Institute

The interaction between ice cover and brackish water, which is typical of the Baltic Sea, is a rare phenomenon elsewhere in the world. The probability and duration of ice cover increases towards the northern and eastern parts of the sea. During normal winters the ice cover lasts 5–7 months in the Bothnian Bay, 3–5 months in the Bothnian Sea, 0–4 months in the Archipelago Sea, over 4 months in the Eastern Gulf of Finland and 1–3 months in the Western Gulf of Finland, whereas in the Gotland Sea it lasts less than a month and even then there are areas of open water present. Exceptionally cold winters can cause 70 %



of the Baltic Sea (c. 300,000 km²) to freeze over, but the probability of such an extensive ice coverage is 10 %.

The presence of ice reduces currents and waves, and affects sedimentation processes and the species inhabiting the shores, coastal waters and the open sea. The ice also causes difficulties for maritime traffic. In springtime, in coastal areas that are influenced by freshwater inflow from rivers, a layer of fresh water is formed between the ice and the brackish water. The fresh water originates partly from the inflowing river water and partly from the melting ice, and has a profound effect on the species living close to the surface.

Baltic Sea hydrography: a horizontal profile

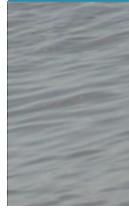
The upper figure illustrates the horizontal salinity and temperature profile from the Kattegat to the Gulf of Finland. The horizontal salinity, temperature and oxygen profiles from the Åland Sea to the Bay of Bothnia are presented in the lower figure. The oxygen profiles are from the Gotland Deep to the Gulf of Finland and to the Bay of Bothnia. The values for salinity and temperature are long-term averages for August, whereas the oxygen values are *in situ* observations from August 2012.

The average open ocean salinity is 35 ‰, but in the Baltic Sea it is less than 10 ‰, about 7 ‰, even though the variability is large. Because of its low salinity, the water in the Baltic Sea is termed brackish. The surface water salinity in the Kattegat is around 20 ‰ and decreases gradually towards the Gulf of Finland and the Bay of Bothnia, where the surface salinity is 0–3 ‰ and 2 ‰, respectively. This type of salinity gradient is typical of the estuaries of large rivers. In fact the Baltic Sea as a whole can be construed as a large estuarine sea. Several

hundred rivers bring fresh water into the Baltic Sea, whilst saline water flows in through the shallow sounds of the Danish Straits. As the inflowing salt water is denser than the brackish water, the Baltic Sea is stratified (i.e. its salinity increases from the surface to the bottom) with the most saline water in the deepest parts of the Gotland Sea.

Summer surface water temperatures are highest in the southern Baltic, the eastern Gulf of Finland and the Gulf of Riga. The highest temperatures are usually measured near the coast and in shallow areas. However, when the wind blows parallel to the coast (so that the coast is on the left-hand side) for at least a couple of days, a phenomenon known as wind-driven coastal upwelling occurs. The warm surface water is directed away from the coast towards the open sea and is replaced by cold water from the deeper water layers. The wind-driven coastal upwelling also brings new nutrients into the surface layer.

The deep areas below the halocline (a layer with a jump in salinity at a depth of 40–80 m) in the Gotland Sea often run out of oxygen, and hydrogen sulphide forms at the bottom of the deeps (see also slides 4 and 5). In the Gulf of Bothnia the oxygen concentration remains relatively high throughout the water column. This is mainly due to (1) the absence of a halocline, (2) the fact that the entire water column is well-mixed throughout the year and (3) the shallow straits south of Åland (60–70 m) and the shallow Archipelago Sea act to prevent the inflow of the deep-lying, dense low-oxygen water into the Gulf of Bothnia. The Gulf of Finland, on the other hand, does not have such a “protective sill” and thus the deep water of the Gotland Sea can have a marked influence on the Gulf of Finland hydrography.



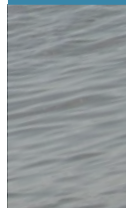
During the summer the Baltic Sea is usually stratified. These figures show the stratified structure of the water column. A thermocline, i.e., a layer in which the water temperature drops rapidly, normally forms at a depth of 10–20 metres. During the summer the depth of the mixed layer gradually increases. The thermocline prevents the exchange of water between the upper warm-water layer, where wind mixing takes place, and the lower cold-water layer where the mixing is intermittent in character. In the autumn, the surface water slowly cools down and eventually the thermocline disappears: the whole water column is then mixed by autumn storms and convection. In the Gulf of Bothnia the water column is mixed from top to bottom, but in the Gotland Sea only the water above the permanent halocline (the jump layer in salinity) is mixed (see the next slide).

The water column also has a vertical salinity gradient as well as a temperature gradient. Water becomes denser and thus heavier with increasing salinity and decreasing temperature until the temperature of maximum density (about 2–3 degrees °C in the Baltic Sea). The heavier, more saline water sinks to the bottom of the water column leading to a gradient of increasing salinity with depth. A halocline, that is, a layer

of water where the salinity increases rapidly, forms at a depth of 40–80 metres in the Gotland Sea. Autumnal mixing of the water column is restricted to the layers above the halocline. In the Gulf of Bothnia there is practically no halocline, as salinity is low throughout the water column. In the Gulf of Finland a halocline occasionally forms in the near-bottom water layers at depths exceeding 60 metres, because of the more saline deep water flowing in from the Gotland Sea and settling at the bottom of the deeps.

The oxygen content of the water below the halocline is very low for two reasons. Firstly, the water has not been mixed, and thus oxygenated, since it arrived during a pulse of saline water through the Danish Straits and settled below the outflowing less saline water. Secondly, oxygen is consumed in the bacterial decomposition of the organic material that has settled on the bottom. In 2012, in the Gotland Sea, the water at depths below the halocline was stagnant; it had run out of oxygen and hydrogen sulphide had formed in the water as a result of anoxic decomposition. This deep water is replaced on average only every 10 years, when a new large pulse (the so-called Major Baltic Inflow) of dense saline water flows into the Baltic through the Danish Straits (see next slide).

In the Bothnian Bay the oxygen concentration stays fairly constant throughout the water column, with only a minor decrease towards the bottom. The reason is that there is no halocline in the Bothnian Bay, so the entire water column is mixed from top to bottom each year and the oxygen stores in the deep waters are replenished. In the Gulf of Finland occasional oxygen depletion is seen in the deeps of both the open sea and the archipelagos. In the open sea the oxygen depletion is due to the formation of a halocline in the near bottom waters of the deeps. In the archipelago, on the other hand, it is caused by a strong thermocline that forms during the summer, preventing the mixing of the lower cold-water layer. The water below the halocline or thermocline becomes anoxic, because bacteria consume all of the available oxygen when breaking down dead organic matter that has settled on the bottom. Unlike the halocline, however, the thermocline breaks down in the autumn, and the autumnal mixing re-oxygenates the water in the deeps.



There is a permanent halocline in the Gotland Sea at a depth of 40–80 metres. The water below the halocline is much heavier than the water above it and the convective autumnal mixing caused by the cooling of the surface water layers cannot penetrate through the halocline. Even the effects of strong storms do not reach deep enough to break down the permanent halocline. Consequently, the water below the halocline does not get re-oxygenated.

The deeps are sinks for dead organic material, and oxygen is used up there in the bacterial decomposition of this material. When the water below the halocline is not re-oxygenated over a long period, the oxygen content steadily decreases until it reaches zero. This is called as stagnation. After all of the oxygen has been consumed, anaerobic bacteria continue the decomposition of the organic material and, as a result, poisonous hydrogen sulphide forms at the bottom.

The lack of oxygen and the presence of hydrogen sulphide kill or drive away all fish and benthic macro fauna, and turn the benthos and near-bottom water layer into a dead zone. The oxygen depletion also accelerates the flux of nutrients from the sediments back into the water column, increasing the nutrient concentration of the near-bottom water layer. This process is called internal loading; the sea is polluting itself by releasing nutrients that have been stored in the sediments over time.

Only a sufficiently large pulse – the Major Baltic Inflow – of saline water coming through the Danish Straits can break down the stagnation, by replacing the stagnant water with new oxygen-rich, dense saline water. Figure A illustrates the effect of the regular annual inflow of saline water. Such a small

amount of saline water cannot ventilate the deeps of the Baltic Proper. Figure B shows how the occasional larger inflows of saline water replace the deep water in the Bornholm Deep, but have no effect on the stagnation existing in the Gotland Deep.

The intrusion of a sufficiently large amount of saline water to replace the stagnant water in the Gotland Deep happens only sporadically (Figure C). When this does happen, the saline, low-oxygen, nutrient-rich water in the deeps is displaced, making its way towards the shallow coastal areas, where it is brought into the surface layer.

Following a Major Baltic Inflow, a temporary rise in salinity occurs almost throughout the whole of the Baltic Sea and, consequently, the distributions of several plant and animal species change in response to the change in salinity. At these times, many of the marine planktonic species spread further northwards and eastwards. Furthermore, the improved oxygen situation in the deep-water areas enables new benthic communities to form in the previously dead areas of the seafloor. Additionally, cod is able to spawn further north, even reaching the Gotland Deep, which, when oxygenated, is an important spawning area for cod.

Major Baltic Inflows, however, also have negative consequences. Eutrophication increases as the nutrient-enriched deep waters are brought into the photic, productive surface layer. The displaced saline low-oxygen water may settle in the deeps of the Gulf of Finland all the way to its eastern end, forming a halocline at the bottom of the deeps, which prevents the re-oxygenation of the deep water; this may thus lead to anoxia and internal loading in this area.

Anoxia is a natural phenomenon in the Baltic Sea. However, in recent decades the saline pulses have become fewer and fewer, possibly due to climate change. The saline water pulses are mainly associated with winter storms. Since 1953 major inflows have occurred in 1973 and during December 1975–January 1976, after which the stagnation lasted until 1993, when a large inflow entered the Baltic. The latest Major Baltic Inflow took place in 2003, after which stagnation has continued and the oxygen conditions worsened in the Baltic Proper and also in the Gulf of Finland where the natural variability is large.

The number of species in the Baltic Sea is much lower than in other seas, such as the North Sea. This lower diversity is mainly due to three factors: the difficult salinity conditions, the short history of the sea in its current form and the lack of intertidal shores and great depths.

The brackish water and large temperature range create a challenging environment. Both marine and freshwater species experience difficulties when faced with the brackish water of the Baltic Sea. The salinity is either too low or too high. The low water temperatures, especially in the winter, also present a problem. The salinity and temperature stress is manifested not only in the distribution of different species but also in their size. The adult size of many species in the Baltic Sea is much smaller than elsewhere. Marine examples of species of smaller adult size are the Pacific blue mussel (*Mytilus trossulus*) and the sea lace (*Chorda filum*); freshwater examples are the greater pond snail (*Lymnaea stagnalis*) and many fish such as perch (*Perca fluviatilis*), pike (*Esox lucius*) and vendace (*Coregonus albula*).

Historically, the Baltic Sea is a very young sea. Only 12,000 years ago large parts of the Baltic Sea were still covered by the continental ice sheet of the last glaciation. Since the ice age the Baltic Sea basin has gone through several phases of changing shape and salinity. The current morphological and physico-chemical conditions have developed during the last 8,000 years.

There have been phases of higher salinity, when there has been a more open connection to the North Sea than at present; thus only a few true brackish water species have had the chance to evolve. Likewise, marine species have not had time

to adapt to the lower salinities. On the other hand, the glacial history of the Baltic Sea has left behind relict species that originate in the Arctic Ocean and have lived in glacial lakes formed during the ice age. Examples of typical glacial relict species in the Baltic Sea are the amphipods *Monoporeia* and *Pontoporeia*, the isopod *Saduria entomon* and the opossum shrimp *Mysis relicta*. Some of the species that are now common in the Baltic Sea, such as the barnacle *Amphibalanus improvisus* and the sand gaper (*Mya arenaria*), were introduced into the Baltic Sea as a result of human activities (for more information about alien species, see slide 20).

The lack of tides, and thus intertidal shores, and the limited depth of the sea reduce the availability of possible habitats and hence limit the number of species compared to other seas.

The number of species gradually drops from the west coast of Sweden (Kattegat) through the Baltic Proper towards the northern reaches of the Gulf of Bothnia and the eastern end of the Gulf of Finland. There are approximately 1,500 macroscopic marine species living on the west coast of Sweden compared to the 150 marine species found in the southern Baltic Proper, 52 in the Åland archipelago and a mere 2–3 in the Bothnian Bay. Certain freshwater species, particularly some fish and aquatic plants, are distributed throughout the Baltic Sea. However, none of the 21 bivalve species present in Finnish lakes are found in those parts of the Baltic Sea where salinity exceeds 3‰, and only 7 out of the 35 freshwater gastropod species occur in salinities exceeding 3‰. The figure shows the extent of the distribution of some common marine (blue line) and freshwater (red line) species in the Baltic Sea.

Zoobenthic biomass decreases gradually from the North Sea to the Bothnian Bay. The high biomass values are largely due to the abundance of the large clams and mussels. The biomass of the microscopic zoobenthos (the meiofauna) does not change parallel to the macrofauna; rather, the abundance of the meiofauna actually increases towards the northern and eastern parts of the Baltic Sea.

	Macrofauna: Meiofauna ratio	Zoobenthic biomass (g/m ²)
Bothnian Bay	1:2.5	1–2
Bothnian Sea	10:1	10–25
Northern Baltic Proper	20:1	50–150
Danish Straits	30:1	200–700

An ecosystem consists of living organisms and their physical and chemical environment. The Baltic Sea is a large brackish water ecosystem, where the saline water of the Atlantic Ocean mixes with the fresh water from 250 rivers; it can also be divided into separate coastal, open sea and deep benthic ecosystems.

Energy flows through the ecosystem from the producers to the consumers and decomposers through a multitude of food chains, which together, through complex interactions, form a food web. The organisms that convert inorganic material into organic matter are called autotrophs. Autotrophs are also called producers, and are responsible for the primary production in the marine environment. Heterotrophs require ready-made organic material and are also called consumers. Organisms that can live as either autotrophs or heterotrophs are called mixotrophs.

Plants are primary producers that use light energy, water, carbon dioxide and inorganic nutrients to produce organic material. This makes them phototrophs, or photosynthesising autotrophs. Macrophytes, including aquatic vascular plants, aquatic bryophytes and macroalgae, are the most important primary producers in the coastal zone, whereas the free-floating phytoplankton, consisting of single-celled or colony-forming microscopic algae, are responsible for primary production in the open water.

Herbivores are consumers that feed directly on the primary producers, that is, on phytoplankton or macrophytes. Typical herbivores include zooplankton in the open water and snails in the coastal zone. Higher-level consumers, which feed on other animals, are called predators. Predators are meat-eaters or carnivores. In the *grazing food chain*, energy produced by the

primary producers is passed on through the herbivores to the higher-level consumers.

Bacteria and other consumers, such as worms, bivalves and amphipods that feed on the remains of dead plants and animals (detritus) are called detritivores or decomposers. These are mainly benthic, but detritivorous bacteria can also occur in the pelagic zone. The detritivores, through their actions, return organic material into an inorganic form ready for use by primary producers. Other consumers also release inorganic material back into the system. The detritivorous bacteria are in turn fed on by heterotrophic and mixotrophic flagellates and protozoans, such as amoebas and ciliates. This is called the *detritus food chain*.

Bacteria can utilize the dissolved organic matter (DOM) excreted by other living organisms or released as organisms die, thus transforming it into particulate organic matter (as a part of the bacterium), making it available to consumers and returning it into the food web. Heterotrophic and mixotrophic flagellates and protozoans feed on bacteria, and are, in turn, fed on by larger zooplankton. This mainly happens in open water, but also in the bottom sediments. This is known as the *microbial loop*.

Nutrients are continuously circulated through the ecosystem. Some matter is lost from circulation when it settles on the seafloor and is stored in sediments. Nutrients enter the system via runoff from the land and through atmospheric deposition. A part of the nutrients stored in sediments are returned into circulation through resuspension and leaching of the bottom sediment (i.e. the *internal cycle*). Blue-green algae are also able to fix atmospheric nitrogen.

The Baltic coastal zone is an area of high primary production, which is partly due to the riverine input of nutrients from

the catchment areas and partly due to the shallowness of the coastal area. Large parts of the coastal zone belong to the phytal zone, i.e., that part of a water body that is sufficiently shallow for enough light to reach the bottom to enable the growth of rooted green plants and attached macroalgae. Macrophytes play a major role in the phytal parts of the coastal zone. The species composition of an area is dependent on its bottom substrate. The bottom may either be hard, consisting of bedrock or other rocky substrates, or soft, consisting of sand, clay or organic-based mud, also called gyttja. The coastal ecosystem also functions as a breeding and nursery ground for many pelagic fish (e.g. the Baltic herring, *Clupea harengus membras*) and several invertebrates. Some invertebrates, such as the Moon jellyfish (*Aurelia aurita*) have a life cycle that is partly dependent on the coastal zone.

The pelagic open-sea ecosystem has an important role in Baltic Sea primary production. There are two routes through the pelagic food web from primary producers (microscopic phytoplankton) to the highest-level predators (such as salmon and seals). Energy and matter can be transported either directly from the phytoplankton through the zooplankton and pelagic fish (e.g. herring and sprat), or alternatively may travel via the microbial loop. Plankton blooms are a typical feature of the pelagic ecosystem. Most of the fish living in the Baltic Sea are dependent on the pelagic ecosystem.

The deep soft-bottom ecosystem, the profundal, covers most of the Baltic Sea bottom area. Dead organic matter from the pelagic and coastal ecosystems settles on the deep soft bottoms, where it is utilized by the decomposers. Baltic soft-bot-

tom benthic communities mainly consist of a few key species. The Baltic tellin (*Macoma balthica*) is the most common benthic species in most parts of the Baltic Sea, apart from the Bothnian Bay and the easternmost Gulf of Finland, where bivalves are absent and meiofauna (microscopic fauna) plays the most important role in the benthic community. Most soft bottoms are located at a depth of 50–150 metres. There are large areas of seafloor lying below 80 metres that are entirely void of benthic fauna, because of the anoxic conditions below the halocline.

The archipelagos, the zonation of shores and land uplift

The **archipelagos** found in the Baltic Sea are diverse and varied. The Åland archipelago, the Stockholm archipelago and the archipelago off the southwestern coast of Finland (the Archipelago Sea) are especially well developed and are dominated by rocky shores.

Archipelagos are also found along the shores of the Gulf of Bothnia and to the south of Stockholm. The Gulf of Bothnia is rich in till (moraine), which is an important element in the development of archipelagos in that area. In the Bothnian Bay and in the more southern parts of the Baltic Sea the coast is mainly open and flat, consisting largely of sandy shores, and islands are scarce.

Land uplift makes the archipelagos a unique environment. The rate of land uplift varies from 0 to 9 millimetres per year, being at its highest around the Bay of Bothnia (8–9 mm per year). In the southern parts of the Baltic Sea region (i.e. Denmark, Germany and Poland), the land uplift is zero. Earlier, the land uplift has been faster than the rise in sea level, but in recent decades the rate of sea level rise has accelerated (in i.e. 1961–2003, the sea level rose 1.8 mm/year while 1993–2003 the rise was 3.1 mm/year).

The archipelago can be divided into 4–5 different zones. The number and extent of zones vary between areas, along with the terminology used to describe the zones, but the basic structure remains the same. The zone that is located furthest out toward the open sea, called the *open sea zone*, consists mainly of open water apart from a few small bare islets. The next zone towards the coast, namely the *outer archipelago zone*, is scattered with somewhat larger forested islands. The border between the outer archipelago zone and the open sea zone also represents the archipelago forest line. Further in, between the outer archi-

pelago and the mainland, lies the *inner archipelago zone*, where the islands are larger and more numerous and the land area is greater than the water area. In the innermost *mainland zone*, land becomes ever more dominant, and some islands are connected to the mainland.

Conditions in the archipelagos change along the gradient from the coast to the open sea, with increasing depth, lower summer surface-water temperatures and increasing salinity. The decrease in salinity towards the coast is most noticeable around the mouths of rivers or estuaries.

The nature of shallow phytal bottoms changes towards the inner parts of the archipelago. The rocky bottoms common in the outer archipelago are replaced first with sandy bottoms and then, further in towards the coast, with clay and mud (gyttja) bottoms. The more sheltered the area, the finer the bottom sediment. Water changes from the clear water of the open sea to the less saline, more productive water of the inner archipelagos, which is rich in nutrients and humic substances. The Secchi depth in the archipelago varies from 5 metres to a metre, and may be well below a metre in the more eutrophicated parts. The average Secchi depth in the archipelago is 2–4 metres.

There is a visible, both spatial and temporal, transformation of seafloor to land in the archipelagos. Following land uplift, soft bottoms first become beach, then forest, shallow basins become lakes, swamps, marshes and woods, and the islands themselves become rocky outcrops and hills. The species composition slowly changes from marine species at the outer edges of the archipelago to the more freshwater species in the inner parts of the archipelago and finally to terrestrial species.

The absence of tides, and thus the absence of intertidal shores, makes the shores of the Baltic Sea very different from

those of the oceans. The tidal range in the Baltic Sea is at its largest only a few centimetres. However, there are longer-term fluctuations in water level of up to 3 metres in the Gulf of Bothnia and 2 metres in the inner parts of the Gulf of Finland, caused by wind forcing, barometric changes and rocking of the water mass, also known as a seiche.

The profile of the seashore can be divided into four sections. The *littoral zone* exists between high and low water; this is further divided into *geolittoral*, which is above the waterline, and *hydrolittoral*, which is below the waterline. Below the low water line there are the *sublittoral* and *profundal* zones. The hydrolittoral zone and sublittoral zone together form the *phytal* zone, in other words the zone where primary production by photosynthesis is possible. Photosynthesis can still occur even where only 1 % of the light at the surface penetrates. The profundal zone is the zone where there is not enough light for plants to photosynthesise. The depth of light penetration is determined by the amount of particulate matter, such as plankton, in the water column, and can vary widely both on a large and a small spatial scale (between and within areas). In the southern parts of the Baltic Sea the profundal zone starts at a depth of some 30 metres, whereas in the northern parts it starts at 18–25 metres, and in some parts, such as the archipelagos, the Bothnian Bay and the eastern Gulf of Finland, it can start from as little as 10 metres.

The different zones have their own typical ecological communities. In the northern parts, the rocky surfaces in the hydrolittoral zone are commonly covered in filamentous algae, whilst the perennial algae and mussels are confined to the sublittoral zone. The profundal zone is characterized by settled dead organic matter (detritus). Benthic invertebrates and microbes are the main species in the profundal zone.

The most diverse biological communities in the Baltic Sea are found along the coast, but these are, however, much less diverse than those found on the intertidal shores of the oceans.

Different types of shores have characteristic assemblages of flora and fauna. The various plant and animal species are, however, not restricted to just one type of habitat, and are commonly found on different kinds of shores. Many pelagic species, such as herring and whitefish, use the coastal waters as breeding and nursery areas.

Coastal ecosystems are much more unstable than pelagic or deep benthic ecosystems, due to factors such as a large temperature range, wave exposure and the abrasive action of ice. Coastal communities are characterised by seasonal cycles.

The seaward side of islands, especially in the outer archipelago, is often characterised by rocky shores, while the sheltered side of the islands (especially towards the inner parts of the archipelago and coast) are characterised by finer bottom sediments. The shores can be steep and exposed to the winds and wave action (A) or gently sloping (B), and sheltered. The steep and exposed rocky shores are characterised by macroalgal and blue mussel communities whereas the sheltered soft sediment shores and bottoms are characterised by communities of aquatic plants and benthic invertebrates.

The main species in the part of the macroalgal community characterised by filamentous algae (1) are the green alga *Cladophora glomerata* and the brown alga *Pilayella littoralis*. These algae are opportunistic, annual species and their growth form and abundance vary seasonally. The filamentous algae are important as food sources and a habitat for many invertebrates and their juvenile stages. Typical invertebrate species to be found in the filamentous algal zone include isopods of the

genus *Idotea* (2) and amphipods of the genus *Gammarus* (3). During winter the abrasive action of the ice scours the annual filamentous algae off the rock surface. In spring a new generation of filamentous algae colonises these bare surfaces.

The macroalgal community below the filamentous algal zone is dominated by the perennial bladder wrack (*Fucus vesiculosus*) (4). The bladder wrack zone plays a very important role in the Baltic Sea coastal ecosystem, providing shelter and a source of food to many of the invertebrates and fish of the coastal zone, such as barnacles (*Amphibalanus improvatus*) (5), mysids (*Praunus* spp.) (6), pike (*Esox lucius*) (7), and perch (*Perca fluviatilis*) (8). Many of the invertebrates (such as isopods and amphipods) that spend their early lives in the filamentous algal zone migrate into the bladder wrack zone as they mature. Below the bladder wrack zone is a zone characterised by red algae (9). Red algae utilise the deep penetrating green light, and are thus able to live and photosynthesise in lower light conditions and at greater depths than other algae. The faunal community in the red algal zone is similar to that of the bladder wrack zone, although the Pacific blue mussel (*Mytilus trossulus*) (10) are more abundant in the lower red algal zone. The Pacific blue mussel aggregates into large beds on hard substrates and supports a habitat of circa 40 macrofaunal species.

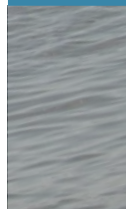
The only algae living on soft bottoms habitats (B) are microalgae. Macroalgae are usually unable to attach to soft substrates, as they have no root systems. However, certain macroalgal species such as the free-floating filamentous algae (11) or attached stoneworts, e.g. the coral stonewort (*Chara tomentosa*), are occasionally found living on soft bottoms. Eelgrass (*Zostera marina*) (12) is the only marine angiosperm found in the Baltic Sea. It grows on sandy bottoms, forming large underwater

meadows. The shallow sandy bottoms are commonly inhabited by gobies and the common shrimp (*Crangon crangon*) (13). Turbot and flounder (14) are found on slightly deeper sandy bottoms. The lagoon cockle (*Cerastoderma glaucum*) (15) and the sand gaper (*Mya arenaria*) (16) burrow into the soft sediments and acquire their food and oxygen from the surface through a siphon. Close to the waterline, snails (17) graze on microalgae and are in turn fed on by wading birds (18).

The mud-burrowing amphipod *Corophium volutator* is a typical crustacean found in the shallow muddy sediment habitats of the Baltic Sea, whilst the larger isopod *Saduria entomon* (19) is common on the deeper soft bottoms. The Baltic telling (*Macoma baltica*) (20), which lives burrowed into the sediments, inhabits both shallow and deep muddy bottoms, whereas the amphipod *Monoporeia affinis* (21) and the alien polychaete species *Marenzelleria* spp (22) are typical of the deep muddy bottoms.

The shores of soft sediment bottoms are occasionally lined by stands of the common reed (*Phragmites australis*) (23), which provide a suitable habitat for many fish, insects and their juvenile stages as well as many other invertebrates both above and below the surface. The reed stands are the preferred habitat of species such as the water louse (*Asellus aquaticus*) and dragonfly larvae.

Perch (8), sticklebacks and gobies are fish commonly found in the shallow waters of the Baltic shores, whereas the deeper waters are inhabited by various sculpins (24). Cod (25) visits the coastal zone occasionally, but mainly lives in deeper water.



Shallow coastal waters consist of a mosaic of dynamic habitats going through a gradual change following land uplift. The shallow water areas can be seen as a more or less separate ecosystem, and are therefore ecologically important in terms of primary production. The type of shallow water habitat found in a particular location is dependent on many factors. The part of the archipelago or mainland coast where it is located has an important influence, as do, for example, salinity, bottom substrate, degree of exposure and depth. The degree of isolation of a shallow water body from the surrounding sea also influences the habitat type.

Some water bodies slowly become separated from the sea due to land uplift, forming enclosed basins and lagoons with a restricted exchange of water with the surrounding sea because of underwater sills. Shallow lagoons are called flads. The development of a flad can be divided into four stages, beginning with a juvenile flad, which still has quite an open connection to the surrounding sea, and ending in a glo, which is almost entirely separated from the sea and receives only occasional flows of sea water (e.g. during exceptionally high water or storms).

A glo-lake is a glo that has lost its hydrological contact with the sea. The intermediate stages are called flads and glo-flads, but all stages are commonly referred to as flads. Flads in dif-

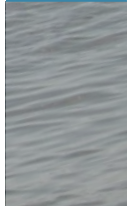
ferent stages are typical of the inner and outer archipelagos, with their mosaic of bays, shallow straits and stretches of open water.

Water temperatures in the shallow and enclosed flads rise quickly in the spring, and biological processes start ahead of the surrounding more open waters. The shallow bays and flads offer an ideal habitat for macrophytes, with nutrient-rich bottom sediments and excellent light conditions. Consequently, flads usually have abundant and diverse macrophyte communities. Primary production is high, which in turn leads to increased sedimentation, promoting the process of shallowing. A succession of floral and faunal communities forms that mirrors the changing conditions in a flad as it slowly becomes shallower and more isolated.

The shallow waters, sheltered bays and different stages of flads are all productive environments. The dense vegetation keeps the water clear, which is beneficial to fauna, for example, by making it easier for them to orientate themselves. The vegetation provides a habitat for many animals, including snails, worms, crustaceans, insects and fish. Several species of fish and birds, such as osprey, the Caspian tern and various waterfowl, come to the shallow waters to feed. The diversity of macrophytes and waterfowl are interlinked.

The flads, gloes and glo-flads are ideal breeding sites for many species. Freshwater fish that have adapted to life in the brackish coastal waters, such as perch (*Perca fluviatilis*), pike (*Esox lucius*), common bream (*Abramis brama*), ide (*Leuciscus idus*) and roach (*Rutilus rutilus*) return to the less saline waters of the flads to spawn. Gloes and glo-flads are also used as nursery areas by many fish. The water warms up quickly in the spring, promoting the growth of the juvenile fish, to which the abundant vegetation offers much needed shelter.

Water in the isolated flads stays clear even when the surrounding sea becomes eutrophicated. Flads act as refuges for many aquatic plants and algae, such as the stoneworts, that are sensitive to eutrophication and are disappearing from the surrounding eutrophicated water areas.



During the winter there is an abundance of nutrients in the water column, but the growth of phytoplankton is limited by the insufficient availability of light, due to short days and an ice cover. Planktonic organisms overwinter as resting stages on the seafloor. In the spring, as the ice melts and the light levels increase, the plankton rapidly become more abundant, the spring bloom forms and the water turns brown. During the spring bloom, the phytoplankton community is dominated by diatoms and dinoflagellates. The numbers of herbivorous zooplankton also increase rapidly at the beginning of the spring bloom, in response to the increased food supply. This is followed, with a short lag, by the predatory zooplankton.

The fast-growing bloom quickly uses up all of the dissolved inorganic nutrients available in the water column. As the nutrients become scarce, the bloom comes to an end and the dead phytoplankton settles on the bottom (sedimentation). Zooplankton numbers also fall following the virtual disappearance of phytoplankton. At the beginning of the summer, phytoplankton

production is low and the water becomes relatively clear again.

In the spring and summer the surface layer of the water column warms up and a thermocline forms separating the warm surface water from the colder water below. The thermocline prevents the circulation of water between the warm-water and cold-water layers, and consequently the phytoplankton only circulates in the warm surface layer, depleting it of nutrients by the beginning of the summer. Occasionally, for example due to rough weather, the thermocline is temporarily broken down and nutrient-rich water is brought into the surface layer. If the nutrient enrichment is followed by a period of calm and warm weather in late summer, blue-green algae may bloom, forming large aggregations floating near the surface (scums).

As with the spring bloom, zooplankton also become more abundant following the blue-green algae bloom; sedimentation also increases then, although not to the extent that it does after the spring bloom, as most of the blue-green algae are broken down in the water column before ever reaching the bottom.

In the autumn the surface-water layer cools down and convective mixing breaks down the thermocline, allowing strong autumn storms to mix the water column all the way down to the bottom (or to the permanent halocline, where this exists). Nutrient-rich water is then distributed evenly throughout the whole water column (above the halocline), but the temperature and light conditions are now too low for the phytoplankton to utilise the nutrients and bloom. The phytoplankton is already preparing to overwinter and is producing resting stages. However, small diatom blooms may still occur in the autumn during exceptionally warm and calm periods.

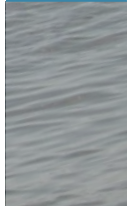
The **pelagic ecosystem** is a complex web of interactions between chemical, physical and biological factors. Not until the 1980s did scientists begin to understand the functioning of this ecosystem. Research revealed that the organic matter and energy produced in primary production are transported up the food web via two routes, namely the grazing food chain and the microbial loop.

In the grazing food chain, products of the primary production are passed on to the higher-level consumers through herbivorous zooplankton. The length of the chain from the primary producers to the top predators varies. The shortest chains may consist of top predators such as fish feeding directly on the herbivorous zooplankton or even on the plant matter itself.

The chain may also be very long, with several consecutive steps of larger consumers feeding on smaller ones, transferring the energy up the chain. Bacterial decomposition of dead plant and animal matter returns nutrients into the water column, making them available for use by phytoplankton in primary production.

For a long time the microbial loop was poorly understood, and received less attention than the grazing food chain. However, research into pelagic food webs has revealed its importance in the recycling of nutrients. The microbial loop starts with dissolved organic matter (DOM). DOM consists of organic molecules such as proteins that are released into the water as metabolic by-products and faeces, or as a result of several pro-

cesses such as leaching from plants and sloppy feeding by zooplankton. DOM is useless to primary producers and consumers. Bacteria, however, can utilise DOM as a source of energy. Bacteria, together with blue-green algae and picoplankton, form the diet of small flagellates that are in turn consumed by larger flagellates, ciliates and rotifers (mesoplankton), and so on through the larger zooplankton all the way to the top predators. The microbial loop returns matter lost as DOM back into the food web and thus, through decomposition, into an inorganic form that can be utilised in primary production. The microbial loop is most efficient in the warm waters above the summer thermocline.



It is difficult for us to understand the scales and proportions of organisms, especially as some of the organisms are not visible to the naked eye. It is much easier to put the size and scale of organisms into proportion if we compare them to distances that make sense on the scale of people. If the length of a bacterium were comparable to the distance to the nearest shop, then the length of a seal would equal the distance from the earth to the moon.

Scale is not only important relative to size, but also to the spatial requirements of organisms. Although a droplet of water contains millions of bacteria, they are not squeezed in, but there is ample space between individuals. It is as well to remember, however, that the space requirement of a bacterium or a fish is not directly in proportion to its size. A fish needs much more space in relation to its body size to move and forage than a bacterium does. The range of different life spans among aquatic organisms is also huge. The life span of a planktonic alga may be only a few hours, whereas a grey seal reaches maturity at three years and may live to be over 40 years old.

The unique characteristics of the Baltic Sea make it especially susceptible to the environmental impacts of human activities, both on land and at the sea. The main pressures on the marine environment include i) nutrient and organic matter enrichment, ii) contamination by hazardous substances, iii) biological disturbance, iv) interference with hydrological processes, v) physical loss of the seabed, vi) physical damage to the seabed, and vii) other physical disturbance.

Nutrient and organic matter enrichment. Eutrophication of the Baltic Sea is caused by the excessive input of nutrients, namely nitrogen and phosphorus. Nutrients originate from point and diffuse sources, including waste-water treatment plants, agriculture, aquaculture, industry, dispersed settlement, forestry and atmospheric deposition. The raised concentrations of organic matter may lead to increased oxygen consumption and hypoxia. For more information on eutrophication, see slides 17–19.

Contamination by hazardous substances. Hazardous substances are often persistent, toxic and able to accumulate in organisms. Land-based contaminants enter the Baltic Sea from both point and diffuse sources. Point sources include waste water treatment plants, waste disposal sites and industries. Diffuse sources comprise the load of pollutants carried in by rivers and (long-range) atmospheric transport. These sources originate from the use of household chemicals and pesticides as well as from energy production. In addition to land-based sources, there are contaminant sources in the sea itself, such as shipping, construction (harbours, marinas and

oil platforms), dredging and disposal of dredged material, and fishing. For more information on hazardous substances, see slides 21 and 22.

Biological disturbance. Biological disturbance is caused by the selective extraction of species and the introduction of alien species and microbial pathogens. Fishing affects the structure of the Baltic Sea food web, as mainly predatory species such as cod, pikeperch, pike and salmon are removed and, in the worst case, overexploited (e.g. cod, see slide 23). Invasive alien species are mainly introduced into the Baltic Sea accidentally via shipping (i.e., in ballast tanks or as hull fouling), but some species have been deliberately introduced by stocking. Invasive species pose a threat to the Baltic Sea ecosystem (see slide 20). Animal husbandry (livestock manure), passenger ships, waste-water treatment plants and fish farms are potential sources of microbial pathogens to the Baltic Sea. Pathogenic micro-organisms such as *salmonella* and *listeria*, for example, can cause serious illness in humans.

Interference with hydrological processes. Coastal structures, such as defence structures, power plants, dams, waste-water treatment plants, bridges and wind farms, can cause changes in the thermal or salinity regimes. For example, coastal power plants are locally a significant source of warm and/or fresh water, which can change local productivity and species composition.

Physical loss of the seabed. Smothering or sealing of the sea bed occurs as a result of construction (harbours, wind farms,

cables, piers, bridges, or pipelines), dredging and the disposal of dredged material. Physical loss of the sea bed affects biodiversity and the abundance of species by destroying natural habitats.

Physical damage to the seabed. Siltation of hard bottoms, abrasion of the sea bed and targeted extraction of minerals from specific seabed types cause physical damage to the seabed, which can lead to the disappearance of biotopes and changes in the physical and biological characteristics of the seabed, and may correspondingly affect threatened biotope types and their habitats. Physical damage is mainly caused by exploitation of mineral resources, constructions on the sea bed, dredging, disposal of dredged material, coastal shipping, anchoring and fishing (bottom trawling).

Other physical disturbance. Marine litter may pose a threat to marine life. Macroscopic litter originates from fishing, shipping, dumping of armaments and toxic chemicals, leisure boating, tourism, and coastal settlements, while microscopic litter is produced by e.g. the degradation of plastic waste. Underwater noise is mainly due to construction activities, shipping, fishing, leisure boating, wind farms and military activities. The impact of underwater noise in the Baltic Sea is relatively unknown. In other sea areas it has hampered the communication of mammals and caused stranding of whales.

The food choices people make in the Baltic Sea region affect the state of the Baltic Sea: plant cultivation, animal husbandry and related food production activities are known to enhance environmental problems such as eutrophication and climate change. The state of the Baltic Sea, on the other hand, may affect human health due to the hazardous substances present in the marine environment and food products from it.

The food plate model is used to guide people to eat healthy meals, which usually correspond with less environmental effects. The recommended plate is divided into three parts: one half of the plate is filled with vegetables, one quarter with a serving of protein (e.g. meat, fish, beans), and one quarter with a serving of a carbohydrate source (e.g. potato, rice, pasta). An increase in the share of vegetables decreases the negative environmental effects (e.g. greenhouse gas emissions, nutrient discharges and pesticide pollution) and increases positive health effects.

The majority of the nutrient input from agriculture comes from the meat production sector. Of the meat products, beef has the highest eutrophication potential. The amount of nutrient discharges from animal husbandry depends on the feed the animals are given (e.g. grain has the highest eutrophication potential of the plant-based foodstuffs). 80 % of the crop production in the Baltic Sea region is used as animal feed. Nutrient leaching from plant cultivation is the main source of nutrient

emissions in the food chain. The amount of nutrient leaching depends on e.g. the soil conditions and the slope of the field parcel.

The eutrophication potential of e.g. pork and eggs is respectively three and eight times lower than that of beef. The difference is mainly due to land use requirements (how much land is used for the production of fodder and grazing) and the amount of manure produced. In other words, cows require more fodder and land for grazing, and produce more manure than pigs and chickens. In general, plant-based foodstuffs have a five times lower eutrophication potential than animal-based ones, and thus reducing meat consumption in the Baltic Sea region is one way of mitigating eutrophication.

Of the Baltic Sea fish species, rainbow trout, a popular species of farmed food fish in e.g. Finland, Estonia and Sweden, has a noteworthy eutrophication potential. Fish farms in general are significant sources of nutrients, and enhance eutrophication locally. Wild fish, such as the Baltic herring, have an adverse effect on eutrophication. Instead of adding to the total waterborne phosphorus load, the fishing of Baltic herring removes phosphorus from the Baltic Sea, and thus eating Baltic herring is another way of mitigating eutrophication.

Unfortunately, some Baltic Sea food products may be harmful for humans due to the hazardous substances present in the marine environment. Many of the larger Baltic Sea fish

species contain high concentrations of hazardous substances (e.g. dioxins, furans, PCBs), which are *potential* toxic and therefore harmful for human health. Although fish is generally recommended as food, risk groups are advised either to avoid or restrict the consumption of certain Baltic Sea species, such as herring, salmon and trout. The dioxins, furans and PCBs found in these species are known to cause cancer, developmental disorder and immunological disorder in humans. The PCB levels in farmed rainbow trout are significantly less than in wild fish.

Sometimes hazardous substances are formed during food production and preparation processes. For example, acrylamide, which increases cancer risk in humans, is formed in starchy foods (e.g. french fries and potato chips) when the food is heated at temperatures over 120 °C.

During the next 100 years the sea surface temperature is predicted to increase by several degrees. In the southern parts of the Baltic Sea the summer sea-surface temperature may increase by 2 °C and in the northern parts by ca. 4 °C. Also, precipitation will increase, especially during wintertime, whereas summers will probably get hotter and drier, especially in the southern Baltic Sea.

If the amount of rainfall and river discharge increases, Baltic Sea water will become less saline. This may induce a decrease in the abundance of marine species. The northern distribution limits of dominant marine species like bladder wrack and blue mussel are expected to move southwards. These species are important as habitats and food for many invertebrate, fish and bird species. In addition, the living conditions of certain marine fish species, such as the flounder and Baltic cod, will probably deteriorate in the Northern Baltic Sea. The eelgrass that now occurs only in the southwestern archipelagos may disappear altogether from Finnish waters. Meanwhile the abundance and distribution of freshwater species, such as roach and certain freshwater plants, will increase.

The warming-up of sea water will also lead to changes in species and communities. Species thriving in warmer water will probably increase and spread northwards. Non-indigenous species originating in more southerly sea areas may gain a foothold in the warmer Baltic Sea more easily. Also species that are dependent on the annual sea ice, such as the Baltic ringed seal, as well as sea ice microbial communities, will suffer from a diminishing of the sea ice.

An increase in the freshwater runoff to the sea could lead in some areas to an increase of nutrient discharge into the sea, especially if the water runs through thawed soils for most of the wintertime. The increased availability of nutrients leads to the enhanced primary production of algae, to increased sedimentation and degradation of organic matter and, hence, to increased oxygen consumption in deep water. When the sediment becomes anoxic, phosphorus starts leaching from the sediment through a chemical process called 'internal loading'. This additional phosphorus loading favours the occurrence of cyanobacteria blooms, which in turn leads to the binding of atmospheric nitrogen into the sea, which again enhances the production and sedimentation of organic matter. This "vicious cycle" of eutrophication may worsen, at least in the southern and central Baltic proper and the Gulf of Finland.

The consequences of the climate change will probably vary from one sea area to another. It has been suggested that, in the Gulf of Bothnia, the increase in freshwater runoff will not lead to enhanced eutrophication, because the river water in the region contains a lot of dissolved organic carbon (DOC). This DOC will enhance the growth of bacteria, which compete with algae for nutrients, thus slowing down the eutrophication effects of the higher nutrient availability.

Climate change is predicted to increase the sea level of the oceans by at least 18–59 cm by the year 2100. In the northernmost Baltic Sea this increase is counteracted by the crustal rebound, and in the Gulf of Bothnia the water is estimated to decrease. In the region between the Åland Sea and the Archipelago Sea the

crustal rebound and the sea level rise probably counteract each other, while over the rest of the Baltic Sea the sea level may rise. Such changes will strongly affect the structure and dynamics of the shallow water and littoral communities.

The increase in atmospheric carbon dioxide, associated with the climate change, will also induce an acidification of the world's oceans, including the Baltic Sea. A lowering of the pH hampers the calcification process of mussels and other shelled organisms. The consequences of such a change to the Baltic Sea ecosystem remain unknown.

The climate change proceeds slowly, and the climatological, oceanographic and ecosystem models include several uncertainties. Many of the consequences of the climate change on the Baltic Sea ecosystem therefore still remain uncertain.

The availability of nutrients is one of the primary factors limiting the growth of aquatic plants and algae. When large quantities of nutrients end up in the water, the abundance and species composition of algae and aquatic plants are significantly altered and the water body is said to be suffering from eutrophication. In the case of the Baltic Sea, the eutrophying nutrients are nitrogen and phosphorus in their various forms. The unique characteristics of the Baltic Sea (i.e., limited water exchange with the North Sea, stratification of the water column, and the long residence time of the water) make it particularly vulnerable to extensive inputs of nutrient.

The main driver behind eutrophication is the anthropogenic nutrient input, but natural processes such as the internal loading of phosphorus (release of phosphorus from sediments under anoxic conditions) and the fixation of atmospheric nitrogen (N_2) by blue-green algae (for more information, see slide 18) also enhance the phenomenon.

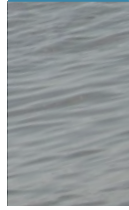
Eutrophication has both positive and negative effects. Initially the effects are often positive, with higher primary production followed by an increasing abundance of zooplankton, benthic fauna and plankton-eating fish, resulting in corresponding increases in certain fish catches. But, as eutrophica-

tion progresses, the negative effects start to become overriding and the ecosystem becomes disturbed. Bladder wrack, which forms an important habitat for juvenile fish and many invertebrates, suffers from the shading caused by the greater turbidity and higher amounts of epiphytes. The filamentous algae, which thrive in high nutrient conditions, support large populations of juvenile invertebrates, which move down to feed on the bladder wrack as they mature. This increased grazing pressure causes further damage to the bladder wrack communities. As bladder wrack disappears, so does the diverse faunal community it supports.

As a result of the excessive growth of planktonic algae, algal blooms are formed. The algal blooms, some of which are toxic, are a frequent phenomenon in the Baltic Sea. Massive blooms may harm recreational and economic use of the sea and its resources. Annually-occurring toxic blooms of blue-green algae (cyanobacteria) are also a health risk for humans and animals.

Eutrophication leads to greater turbidity and thus decreased light penetration (i.e. a decrease in water transparency), which restricts the habitat available for the macrophytes. Drifting algal mats, formed of living and dead algal material, settle on

the seafloor in sheltered places. Decomposition of the algal mats depletes the oxygen in the near-bottom water layer, and the resulting poor oxygen conditions have an adverse effect on the benthic faunal community. The increased primary production also leads to higher rates of sedimentation, and more and more organic material is deposited on the bottom, especially in the deeps which act as sinks for organic material. The bacterial decomposition of these masses of organic material consumes oxygen, and oxygen conditions in the deeps deteriorate. When the conditions become anoxic (i.e. completely depleted of oxygen), the bacteria producing the decomposition now release hydrogen sulphide (SO_x), which is extremely toxic. Gradually the living conditions for fish and the benthic fauna deteriorate. As conditions become anoxic, fish move away from the area, and mass mortality of benthic fauna results in large areas of the seafloor becoming devoid of life.



Eutrophication can be due both to the anthropogenic input of nitrogen and phosphorus as well as to the naturally-occurring process called internal loading. In the Baltic Sea the latter is significantly enhanced by the former, as the cycles of nitrogen, phosphorus and oxygen are interconnected. This interconnected, potentially self-sustaining, process is referred to as the vicious cycle of the Baltic Sea.

Nitrogen input from the land and from atmospheric deposition fosters an excessive production of planktonic algae, such as dinoflagellates, whereas a phosphorus load especially favours the growth of cyanobacteria, i.e. blue-green algae.

Following eutrophication, an increased amount of algae is decomposed and the sedimentation of organic material increases, which causes oxygen depletion in the bottom waters and eventually anoxia (a condition in which no oxygen is present). Under anoxic conditions, phosphorus is released from the

sediment into the water column (i.e., the internal cycle), which further enhances the blooms of blue-green algae.

Large amounts of nutrients are deposited in the sediments and returned into the water below the halocline suffering from anoxic conditions are largely of an anthropogenic origin. Although nutrients have been deposited in the bottom sediments over thousands of years, the rate of sedimentation and thus the amount of nutrients being stored in the sediments has increased greatly due to the anthropogenic inputs of nutrients in recent decades: during the 20th century, the sedimentation rate in the Baltic Sea has increased by 60 %.

Unlike other planktonic algae, blue-green algae are able to fix atmospheric nitrogen (N_2), and so the blooms of blue-green algae are not dependent on the anthropogenic input of nitrogen from the land and deposition from the atmosphere. Furthermore, nitrogen fixation by the blue-green algae increases the

availability of nitrogen in the water. Decomposition of blue-green algae in the surface layer also releases nitrogen into the water column. The nitrogen is then utilised by other planktonic algae.

This so-called vicious cycle is hard to break without reducing both anthropogenic nitrogen and the phosphorus load. Eventually, the reduction of the anthropogenic nutrient load also decreases the internal loading.

Most of the Baltic Sea is affected by eutrophication, but the severity and extent vary between different basins. Currently, the Gulf of Finland, the northern Baltic Proper and the Danish Straits suffer the most, while most of the Bay of Bothnia, some coastal areas in the Sea of Bothnia and Kattegat are relatively unaffected by eutrophication.

Nutrients end up in the Baltic Sea via waterborne (i.e. rivers and direct discharge from point sources) and airborne (i.e. atmospheric deposition directly into the sea) inputs. Most of the waterborne nutrients originate from diffuse sources, of which agriculture constitutes the largest share (over 70 % of riverine nitrogen and over 60 % of riverine phosphorus). Other important diffuse sources include dispersed settlement, forestry and atmospheric deposition on inland waters. The second largest waterborne source of nutrients originates from point sources such as municipal waste water, industry and fish farming. In addition to the anthropogenic sources, natural background sources (e.g. erosion and leakages from pristine areas) contribute to the total waterborne nutrient load and are the third largest nutrient source. Waterborne transboundary loads, originating from other than the coastal countries in the catchment area, constitute less than 10 % of the total waterborne phosphorus and nitrogen sources. The majority of transboundary loads originate from diffuse sources.

About 25 % of the nitrogen and 1–5 % of the phosphorus entering the Baltic Sea are airborne. The deposited atmospheric nitrogen (N_2) originates from e.g. transport (maritime, air and

road traffic), energy production, combustion in industries and animal manure and husbandry. Over half of the atmospheric deposition originates from the coastal countries, a third from distant sources (i.e. countries outside of the region) and less than 10 % from shipping.

In addition to the abovementioned, the total phosphorus load in the Baltic Sea is affected by the internal load. Large amounts of phosphorus are stored in the sediment, but under anoxic conditions, phosphorus is released back into the water column and utilised, especially by blue-green algae (see slide 16). The internal load is a significant source of phosphorus. However, the only way to reduce the internal load is to reduce the input of anthropogenic nutrient, both phosphorus and nitrogen, from the land.

In 2010, the total waterborne input of nitrogen was 894,000 tonnes and that of phosphorus 36,200 tonnes. The largest loads of waterborne nitrogen originate from Poland (34 %), Sweden (13 %), Russia (12 %) and Latvia (10 %). For phosphorus, the main waterborne sources are the same: Poland (41 %), Russia (17 %), Sweden (10 %) and Latvia (9 %). It should be noted, however, that the total waterborne nutrient loads in the figure for Latvia, Lithuania, Poland and Sweden also include transboundary loads.

The reduction of nutrient input from point sources is generally easier and cheaper than the reduction from diffuse sources. Consequently, a reduction in the nutrient input from many of the biggest point sources, i.e., municipal waste water, has been

achieved during the last few decades, and further reductions are expected as the new EU member states implement the Urban Waste Water Treatment Directive. Unfortunately, however, the reduction requirements set forth by the directive are too lax for the Baltic Sea (see slide 23). In Russia, the completion of the reconstructed South-West Wastewater Treatment Plant in St. Petersburg in 2005 and the application of more effective phosphorus removal have reduced the nutrient load from the most significant source of nutrient input in the region (i.e. a hot spot) considerably. Nutrient reductions from the diffuse sources, particularly from agriculture, are currently (and in the future) the most challenging task.

Alien species refers to those species that have been introduced into an area through human activities, either deliberately or accidentally. The number of alien species in the Baltic Sea has been constantly increasing, and to date around 120 alien species have been recorded, approximately 90 of which have remained permanently in some parts of the Baltic. The distribution and abundance of alien species are illustrated in the map on the left. The picture shows that alien species have invaded all parts of the Baltic Sea. The invasive alien species can cause significant changes in the marine ecosystem by modifying biodiversity and biogeography, but they also have adverse socio-economic impacts.

Over half of the alien species originate from the fresh- or brackish waters of the Ponto-Caspian region or North America. About one-third of the alien species have been introduced into the Baltic Sea region deliberately for stocking purposes. However, the great majority of alien species have been accidentally introduced via shipping (i.e., in ballast tanks or as hull fouling). These accidentally-introduced species, such as the Bay barnacle *Amphibalanus improvisus*, are of great concern, as they in particular have been observed to pose a significant threat to the marine ecosystem. “Associated” means association with aquaculture or other intentionally/unintentionally introduced species while “other” includes all other pathways, including canals, fisheries, escapes from captivity, etc.

Examples of alien species in the Baltic Sea:

The first observations of the Bay barnacle *Amphibalanus improvisus* were made in the Baltic Proper before the mid-1850s. *Amphibalanus* was transported to the Baltic on ship's hulls and in ballast water. Currently, the species occurs in the

coastal areas throughout the Baltic Sea (apart from the Bothnian Bay). The impacts of the *Amphibalanus* can be ecological and socio-economical, as the species can dominate the community, alter habitats, cause human injuries and fouling of underwater equipment (e.g. water intake pipes, heat exchangers) and ships' hulls.

The Prussian carp *Carassius gibelio* was deliberately introduced into small lakes and ponds in Latvia and Estonia around the 1950s. In 1985, the species was found in the Gulf of Riga, and has since spread to the coasts of the Baltic States. In 2005, the species was first observed on the coast of Helsinki, and by 2009 it had spread to the southwest coast of Finland. *Carassius* grows rapidly, reproduces efficiently, and competes (successfully) with native fish for food and space; it may therefore represent a threat to the marine ecosystem.

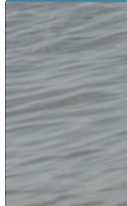
The Harris mud crab *Rhithropanopeus harrisii* was first found on the coast of Germany before the 1950s. Since then it has spread to the coasts of most Baltic Sea countries, apart from Sweden. It was found for the first time in Finland in 2009 in the Archipelago Sea. The negative impacts of *Rhithropanopeus* are still mostly unknown, but it may alter ecosystem functions by, for example, competing with native fauna.

The zebra mussel (*Dreissena polymorpha*) has spread into the low salinity, eutrophic eastern parts of the Gulf of Finland during the 1990's. Previously it has been present in the Haffs of the southern Baltic, where it arrived from the Black Sea and the Caspian Sea in the 19th century. Demersal fish and mussel-feeding birds prey on *Dreissena*. The negative impacts are rooted in its tendency to form aggregations, which alter the structure of benthic habitats and cause economic loss by clogging man-made underwater structures, such as water intake pipes.

The fish-hook water flea (*Cercopagis pengoi*) arrived from the more freshwater parts of the Black Sea in the early 1990s. The species is abundant in the eastern Gulf of Finland, but has also been found in the Gulf of Riga and the Gulf of Bothnia. *Cercopagis* competes with native fish for zooplankton and causes problems and economical losses for fishermen by attaching to and clogging fishing gear.

One of the most studied invasions in the Baltic Sea is that of the three species of *Marenzelleria* polychaete worms. The first *Marenzelleria* individuals were recorded in 1984 off the German coast. By the mid-1990s it had spread to the eastern Gulf of Finland and by the end of the 1990s to the Bothnian Bay. To date, the *Marenzelleria* is not only common in many soft-bottom habitats throughout the Baltic Sea region; in some bottom communities it has become the dominant species. The establishment of *Marenzelleria* impacts fluid exchange between water and sediment, and changes the structure of a native benthic community, but they can also improve the oxygen circulation in the sediment and thus help the native communities to recover from hypoxic conditions.

Another example of a more recent invader is the American comb jelly *Mnemiopsis leidyi*. The species was first observed in the southern Baltic Sea in the late autumn of 2006. *Mnemiopsis* can deplete populations of fish species and alter the food web structure of the sea. It consumes zooplankton, fish eggs and larvae, and therefore competes with fish for food. As a result, the species has had significant environmental and economic impacts in the Black Sea due to the depletion of commercially-important fish stocks and changes in the food web structure.



In the Baltic Sea the observed adverse effects of the species have been minor.

The Round Goby *Neogobius melanostomus* was first observed in the Gulf of Gdansk in 1990. In 2005 it was also found in the Archipelago Sea. The species competes with other fish (e.g. flounder) for food and shelter, and can thereby cause changes in the food web. The *Neogobius* has become a valuable catch for recreational fishermen in the Gulf of Gdansk.

All of the above-mentioned invasive species have spread into the Baltic as the result of man's actions, either deliberate or unintentional; nevertheless, they are good examples of the on-going biological changes in the Baltic Sea ecosystem.

The term “hazardous substances” refers to contaminants that are i) toxic, persistent and liable to bio-accumulation; ii) carcinogenic, mutagenic or toxic to reproduction, or iii) have an equivalent level of concern. In the Baltic Sea, hazardous substances can cause adverse effects on the marine ecosystem by accumulating in the marine food web. High concentrations are toxic to marine organisms, especially to predators, and can also present a health risk for people. Most of the Baltic Sea is contaminated by hazardous substances, as shown in the slide.

Hazardous substances are released into the environment during the entire lifecycle of a product: from the acquisition of raw materials, through energy production and use to the transport, use and disposal of the products. Land-based contaminants enter the Baltic Sea from both point and diffuse sources. Point sources include waste water treatment plants, waste disposal sites and industries. For example, the WWTPs are a major source of pharmaceutical substances such as antibiotics, anti-depressants, anti-psychotics and sedatives. Contaminants from the industrial sector originate from, e.g. the mineral, textile and chemical industries, power production, oil refineries, wood preservation and the pulp and paper industry. Diffuse sources comprise the load of pollutants carried in by rivers and (long-range) atmospheric transport. These sources originate from the use of household chemicals (e.g. detergents, pharmaceuticals, cosmetics) and pesticides, as well as from energy production. In addition to land-based sources, there are also marine contaminant sources, such as shipping, harbours, marinas and oil platforms³. Contaminants from shipping enter the Baltic Sea through atmospheric emissions from fuel combustion, the use of anti-fouling paints and intentional or accidental discharges of oil and hazardous substances.

Chlorinated organic compounds such as DDT (a pesticide), PCBs (a diverse family of chemicals used in industry) and dioxins (formed as by-products of other chemicals) make up the majority of halogenated organic compounds. These pollutants are persistent, fat-soluble (which means they are stored in tissues) and very toxic even at low concentrations, making them extremely dangerous to the Baltic Sea ecosystem. The other chlorinated organic compounds entering the Baltic Sea mainly originate from the pulp and paper industries. Recent developments in technology and the increased use of unbleached paper have led to a marked reduction in the emissions of halogenated organic pollutants. However, although emissions have been greatly reduced, the halogenated organic compounds stored in bottom sediments over a long period still pose a threat to the Baltic Sea marine environment.

Other important substances include flame retardants (such as polybrominated diphenylethers PBDEs and hexabromocyclododecane HBCDDs), which are widely used in plastics, textiles, furniture and electronics to restrict the spread of fire, and perfluorinated compounds (PFCs) used, for example in clothes and shoes (Goretex), carpets, furniture, non-stick frying pans (Teflon), cosmetics, cleaning products and fire-fighting foams, the compounds functioning to make these materials stain, oil and water-resistant. HBCDDs are known to leach easily into the environment during the entire lifecycle of a product, in addition to which they are toxic to marine organisms and may cause, for example, liver damage and cancer in mammals. PFCs are persistent in the environment; due to the observed temporal trends, high concentrations and negative environmental effects of many PFCs, these substances are currently of great concern.

The last few decades have also seen reductions in the heavy metal emissions from industry. However, the concentrations of cadmium (Cd), nickel (Ni), lead (Pb) and copper (Cu) in the shallow Baltic Sea still exceed those found in the North Sea. Mercury (Hg) concentrations are at the same level as in the North Sea. The Cd and Hg concentrations in the Baltic Sea are still increasing due to diffuse pollution entering the Baltic via rivers and through atmospheric transport, often from distant sources. Heavy metals are toxic to marine organisms at high concentrations.

The cold water and long duration of ice cover in winter make the Baltic Sea extremely sensitive to oil pollution. The main sources of oil in the Baltic Sea are constant small leaks from the land and local accidental oil spills as well as intentional discharges by ships at sea due to e.g. the illegal dumping of bilge water. The risk of a large oil spill is growing following the marked increase in oil transport through the Baltic Sea. A large oil spill would have dire consequences on the avian fauna and coastal communities; the smaller, but continual, releases, on the other hand, are a constant threat to the entire Baltic Sea ecosystem.

³ There are two oil platforms in the Baltic Sea: LOTOS Petrobaltic's "Baltic Beta" (B-3) is located in the eastern part of the Polish Exclusive Economic Zone and Lukoil's platform on the Kravtsovskoye (D-6) oil field is located 22.5km from the coast of the Kaliningrad region.

The effects of hazardous substances on biota can be investigated at various biological levels, including the molecular, cellular, organ, individual, population, community and ecosystem levels. A number of environmental factors, such as temperature, salinity and oxygen level, affect the toxicity of chemicals to organisms. The sensitivity of species to pollutants also varies markedly, with early life-stages often being more susceptible to chemical exposure. The brackish-water environment of the Baltic Sea is physiologically stressful to species originating both from the saline ocean and freshwater realms, and this can make them more vulnerable to exposure to hazardous substances.

At the individual level, hazardous substances may have physiological, morphological or behavioural effects that interfere directly with the functioning of organisms. In the 1970s, deformities found in the fins and skeletons of fish living in the vicinity of pulp mills were a classic example of the direct morphological effects of toxic pollutants, caused by the onset of teratogenesis and developmental disorders. A variety of chemicals is also known to interfere with sex determination in fish and other organisms; substances having this impact are collectively called endocrine disruptors. Population, community and ecosystem-level impacts can occur when exposure to hazardous substances causes shifts in the abundance of populations of organisms due to the differential sensitivity of species. It is also important to understand that, under natural conditions, organisms are usually exposed to mixtures of various toxic substances, which may have additive, synergistic or antagonistic effects when occurring together, and these may be further modified by environmental factors. Thus, a laboratory-based toxicity evaluation performed for a single toxicant is unlikely

to give a realistic picture of its ecological risk in the real environment.

In the 1970s the populations of Baltic grey seal (*Halichoerus grypus*) and white-tailed eagle (*Haliaeetus albicilla*) collapsed in the Baltic Sea region due to high concentrations of organochlorine pesticides (DDT and related compounds) and polychlorinated biphenyls (PCBs). The recovery in the productivity of the white-tailed sea eagle has been shown to correlate with the observed reductions in environmental concentrations of DDE and PCBs after the banning of these substances (Fig. 22, right).

The use of biological effects methods in environmental monitoring gives information on the effects of hazardous substances and their mixtures. Fish species such as perch (*Perca fluviatilis*), flounder (*Platichthys flesus*) and eelpout (*Zoarces viviparus*) have been widely employed in biological effects monitoring in the Baltic Sea. Of local invertebrates, the blue mussel (*Mytilus* spp.), the Baltic clam (*Macoma balthica*) and the benthic amphipod *Monoporeia affinis* have also been used for this purpose. These species have been found especially useful when monitoring the “early-warning” biological effects of contaminants, the so-called biomarkers. These include, e.g., changes in activity levels of the enzymes related to the detoxification of hazardous substances, oxidative stress or energy metabolism, damage observed at DNA or chromosomal levels, and cellular membrane damage. These kinds of indicators give rapid information on disturbances that may lead to serious effects on the growth, reproduction and general health status of organisms and that may further manifest at higher biological levels as pathologies and diseases, reduced offspring and declines in population size. The use of biomarkers in environ-

mental monitoring is therefore important to detect the possible effects of hazardous substances at an early stage so that protective actions can be taken before detrimental effects at the population, community and ecosystem levels take place.

As an example of the application of biomarkers in the monitoring of the effects of hazardous substances, the activity of ethoxyresorufin-O-deethylase (EROD) in perch has been followed on the Swedish Baltic Sea coast since 1988. EROD is a biotransformation enzyme and the most common biomarker used to indicate exposure to substances such as dioxins, PCBs and PAHs. A rising time trend in EROD activity measured in the liver of the fishes has been associated with a decrease in their gonadosomatic index (GSI), an indicator of reduced reproductive capacity (Fig 22., left). Thus, the elevated biomarker response is connected with more serious disturbances potentially manifesting at higher biological levels.

Overfishing, which which means that fishing pressure exceeds recruitment and growth, is recognised as one of the main threats to the Baltic Sea fish stocks and the ecosystem. Overcapacity of the fishing fleet (i.e. the potential catch of a fleet compared to the sustainable catch), insufficient management measures, high levels of by-catch and unreported fishing maintain the fishing pressure above the sustainable level. Excessive exploitation together with human-induced deterioration of the environment has led to the dramatic decline of many fish stocks, for example cod (*Gadus morhua*) and the wild stocks of salmon (*Salmo salar*).

The Baltic Sea fisheries catch consists of both marine and freshwater fish, although the marine species are commercially more important. Over 150 species (fish, molluscs, bivalves and crustaceans) are landed by fisheries in the Baltic Sea, but the most important commercially-caught species are the Baltic herring (*Clupea harengus*), sprat (*Sprattus sprattus*) and cod, which constitute about 95 % of the total catch. Of the marine species, flounder (*Platichthys flesus*), plaice (*Pleuronectes platessa*) and turbot (*Psetta maxina* or *Scophthalmus maximus*) are locally important catch species.

The most important freshwater species include whitefish (*Coregonus lavaretus*), zander (*Sander lucioperca*), perch (*Perca fluviatilis*), pike (*Esox lucius*) and the common bream (*Abramis brama*). The freshwater species are mainly caught near the coast and play an important role in the Gulf of Bothnia and Gulf of Finland fish stocks. Recreational fishing also impacts the coastal fish stocks. The main catch species in recreational fishing in Finland, for example, are perch, pike and roach (*Rutilus rutilus*).

The fish stocks are also affected by hydrographic factors. Salinity has an impact on the distributions of both marine and

freshwater fish living in the Baltic Sea. Many of the marine species have planktonic eggs that sink if the salinity is too low, in which case they may settle on the bottom or end up below the halocline, where they die as a result of the low oxygen conditions.

An example of this was the dramatic decline in cod stocks in the mid-1980s, when their northern spawning areas became unusable due to the widespread anoxia at that time. During the long periods of stagnation, cod has successfully bred only in the southern parts of the Baltic.

Catches of Baltic cod were at their peak in 1984 at 441,000 tonnes and at their lowest in 2008 at 62,000 tonnes. In years 2000–2008, the eastern Baltic Sea cod stock has been considered to be outside safe biological limits (i.e. overfished). Since 2008 the spawning stock biomass has been increasing and fishing mortality decreasing and the stock is now estimated to be inside safe biological limits according to ICES (2013). Yet the cod in the Baltic is still categorized as a vulnerable species, as determined in a recent HELCOM Red List assessment (2013).

Unlike cod, herring is distributed over the whole Baltic Sea. Catches of herring were largest in the 1970s and 1980s (over 400,000 tonnes), after which they have been steadily declining. In the 21st century, catches have varied between 230,000 and 270,000 tonnes. At the moment, herring stocks are utilised at their maximum sustainable yield.

The total quota of sprat in 1990 was 85,000 tonnes, rising to 529,000 tonnes by 1997. At this time, the fishing industries producing fishmeal and fish oils were developing. Herring and sprat stocks have survived the high catches so far, as the numbers of their natural predator, cod, have been so low as not to have had an effect on the stocks. The stocks of herring and

sprat are also dependent on each other through competition.

The fisheries of the EU member states are regulated by the Common Fisheries Policy (CFP). Russia, the only non-EU member state of the Baltic Sea coastal countries has a bilateral agreement with the EU on fishery in the Baltic Sea. Within the CFP framework, annual total allowable catches (TACs) are determined and allocated to the member states according to the “principle of relative stability”. The International Council for the Exploration of the Sea (ICES), which is an umbrella organisation for national research institutes, provides policy recommendations on the TACs to the EU in order to achieve and maintain sustainable exploitation of the Baltic Sea fisheries. However, in practice, the allocated TACs for all the stocks have been systematically higher than those recommended by scientists. Throughout the EU waters, the CFP has failed to achieve sustainable fisheries, as 88 % of European fish stocks are fished beyond their maximum sustainable yield and 30 % of these stocks are overfished, beyond safe biological limits.

Maritime transportation has always been particularly important in the Baltic Sea region for the transportation of people and goods. Regional development and trade are both highly dependent on maritime transportation. Over recent decades, maritime transportation has been increasing and nowadays the Baltic Sea, and especially the Gulf of Finland and the Danish Straits, is one of the busiest shipping routes in the world.

Currently, over 2000 vessels are at sea at any time in the Baltic, and the trend is increasing. It has been estimated that the number of vessels will be doubled over the next 20 years; maritime oil transportation, in particular, is expected to increase due to the persistent demand for oil products and the construction and expansion of Russian oil terminals. Consequently, the environmental effects of maritime transportation, such as the risk of oil and chemical accidents, air pollution, discharges of hazardous substances and sewage, together with the introduction of alien species, are also expected to grow.

Due to its unique characteristics, the Baltic Sea is particularly susceptible to the effects of accidental or illegal oil and chemical spills. Oil pollution can directly harm biodiversity and pollute vast areas if the spilled oil reaches the shoreline and the archipelago, from where the recovery of oil is very difficult and expensive compared to the open sea. The Baltic Sea states have improved their preparedness to tackle oil spills, but their readiness to tackle chemical spills is low.

The introduction of alien species is another significant threat to the marine ecosystem posed by maritime transportation, as the majority of invasive alien species are introduced into the region by shipping via ballast water and hull fouling. Invasive alien species may prey on native species or compete with them for food and space, and therefore affect ecosystem structure and functions.

Maritime transportation also enhances eutrophication by nutrient input from emissions of nitrogen oxides and discharges of sewage. The role of the maritime transportation sector as a source of nutrient input to the Baltic Sea is marginal compared to agriculture. However, the nutrient input is heaviest over the summer months, coinciding with the algal blooms, and the nutrients are readily available for consumption. In the summer months the nitrogen oxide emissions from ships constitute about 35–40 % of the total airborne nitrogen load entering the Baltic Sea.

Other harmful discharges and emissions from maritime transportation include emissions of sulphur dioxide (SO_x) and greenhouse gases (mainly CO₂), ozone-depleting substances such as halon, chlorofluorocarbons (CFCs), volatile organic compounds (VOC), and the leaching of anti-fouling paints.

On account of these factors, the Baltic Sea is exceptionally vulnerable to the environmental effects of shipping. Consequently, in 2005, the International Maritime Organization (IMO) designated the Baltic Sea (apart from Russian waters) a Particularly Sensitive Sea Area (PSSA), which means that

special protective measures are required from all vessels operating in the Baltic Sea. Subsequently, the Baltic Sea was also designated as a special area under the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78 Convention, Annex I and V), which means stricter regulations in the Baltic Sea than in other areas. In addition, Annex VI of the MARPOL 73/78 makes the Baltic an “SO_x emission control area” and requires significant decreases in the sulphur content of any fuel oil used on-board vessels. Even further restrictions for Finland are expected through Annex IV in the near future. Significant investments are required from the regional maritime transportation sector in order to meet the stricter requirements in the Baltic Sea.

The worrying state of the Baltic Sea reached wide publicity in the 1960s. In 1974, regional cooperation on the protection of the Baltic Sea was initiated, and the Convention on the Protection of the Marine Environment of the Baltic Sea (known as the Helsinki Convention) was signed. The main goal of the Convention was to control the pollution of the Baltic Sea from both land-based sources and ships. The Helsinki Commission (HELCOM) is the governing body of the Convention. A new revised version of the Convention was signed in 1992.

The Helsinki Convention was first of its kind in the world, and has been used as a model in other areas for regional environmental cooperation. All nine coastal countries and the EU are contracting parties to HELCOM. In addition, the governments of Belarus and the Ukraine, both located in the Baltic Sea catchment area but not bordering the Baltic Sea, have an observer status in HELCOM. Other intergovernmental organisations and international non-governmental organisations can also apply for observer status.

HELCOM meets annually, in addition to which ministerial-level meetings are held occasionally. The working structure of HELCOM, supported by the Secretariat, consists of the plenaries of the Helsinki Commission, the Heads of Delegation, six main expert groups (i.e. Maritime, Response, Land, Monas, Habitat and Gear) and three cross-sectoral platforms (i.e. the fish and environment forum, the agriculture and environment forum, and the joint HELCOM-VASAB maritime spatial planning working group). Observers are able to raise issues and take part in discussions, but do not take part in decision-making. Decisions are made on a “one country, one vote” principle and must be unanimous, which implies that each country agrees to transform the decisions into national legislation and regula-

tions. However, countries do not face any sanctions if they fail to implement the agreed recommendations.

Currently, the main tool of HELCOM to restore the Baltic Sea ecosystem is the Baltic Sea Action Plan (BSAP), which was adopted in 2007. The BSAP implements the ecosystem approach to the management of human activities. This means that issues are not dealt with without considering linkages to the entire ecosystem. The overall aim of the BSAP is to reach a good ecological status of the Baltic marine environment by 2021. The BSAP has four main goals, which are: having a Baltic Sea 1) unaffected by eutrophication, 2) undisturbed by hazardous substances, 3) with a favourable conservation status of biodiversity and 4) with environmentally-friendly maritime activities. Under each of these segments, more specific objectives describe the Baltic Sea with a good ecological status. To reach the goals, the contracting parties have also identified and agreed on a set of actions. For example, in order to combat eutrophication, the plan sets maximum allowable nutrient input limits and proposes provisional country-wise annual nutrient input reduction targets for both nitrogen and phosphorus⁴.

During the 21st century, integration and harmonization of HELCOM work with the preparation, implementation and monitoring of EU marine policies has been an added-value benefit of HELCOM for the member states in the region. HELCOM has acted as a discussion platform for the Baltic Sea countries during the preparation and implementation of the EU Marine Strategy Framework Directive (MSFD), the EU Strategy for the Baltic Sea Region and the proposed directive on maritime spatial planning, but also as a source of regionally harmonised assessments, data and monitoring. For example,

HELCOM assessment and monitoring activities have been planned so that they benefit the implementation of both the BSAP and the MSFD. Preparation of the national marine strategies of the MSFD and the Strategy for the Baltic Sea Region also benefited from the regionally-agreed environmental goals and objectives.

Although the role and relevance of HELCOM in the protection of the Baltic Sea has been questioned after the enlargement eastwards of the EU, HELCOM's biggest asset remains: the participation of all nine coastal countries and the possibility of addressing the whole catchment area. In addition, the implementation of EU marine policies and regulations leans strongly on the past and current work of HELCOM.

⁴ The review of progress towards a good ecological status took place in the Ministerial meeting in the autumn of 2013. Subsequently, the nutrient load reduction scheme with reductions targets set for each Baltic Sea country was revised.

Since the EU's enlargement eastwards in 2004 (i.e. the accession of Estonia, Latvia, Lithuania and Poland), Russia has been the only non-EU member state out of the nine coastal countries. Therefore, from an EU perspective, the Baltic Sea is almost an internal sea of the Union and more important than ever before. At the same time, in the 21st century, marine protection has, for the first time, become an independent policy goal within the EU. The strength of the EU in Baltic Sea protection lies in its enforcement power, as member states are legally bound to implement all the adopted policies and directives.

The EU Integrated Maritime Policy (IMP) is intended to apply a more coherent approach to maritime issues, which is comprised of different policy sectors such as blue growth, marine data and knowledge, maritime spatial planning, integrated maritime surveillance and sea basin strategies. The EU Marine Strategy Framework Directive (MSFD), adopted in 2008, is considered as the environmental pillar of the IMP. The MSFD aims to achieve a good environmental status of the EU's marine waters by 2020. Each member state is required to prepare a national strategy for their respective marine waters. In the Baltic Sea region, the preparation of the national strategies leans heavily on the assessments and monitoring activities of HELCOM as well as on the goals and targets established in the HELCOM BSAP.

The European Union Strategy for the Baltic Sea Region, adopted in 2009, was the first comprehensive EU strategy to target a macro-region, and has served as a model for other sea basin strategies. The strategy aims to achieve a sustainable environment and optimal economic and social development through three overall objectives, which are: to save the sea, connect the region and increase prosperity. The environmental

segment of the strategy is based on the HELCOM BSAP and thereby supports its implementation.

In March 2013, the Commission proposed a directive on maritime spatial planning (MSP) and integrated coastal management. Maritime spatial planning is a public process for analysing and planning the spatial and temporal distribution of human activities in a sea area to achieve economic, environmental and social objectives. In the Baltic Sea region, the HELCOM-VASAB Maritime Spatial Planning Working Group was established to facilitate cooperation among the Baltic Sea Region countries for coherent regional MSP processes in the Baltic Sea. Integrated coastal management is a tool for the integrated management of all policy processes affecting the coastal zone, addressing land-sea interactions of coastal activities in a coordinated way with a view to ensuring the sustainable development of coastal and marine areas. In the beginning of 2014 negotiations concerning the directive are still in progress.

A great number of other EU policies and directives also have implications for the protection of the Baltic Sea. Water protection policies, such as the Urban Waste Water Treatment Directive (UWWTD), the Water Framework Directive (WFD) and the Nitrates Directive (ND) control pollution from land-based sources. However, many of the EU directives are often criticised for being too lax for the vulnerable Baltic Sea. For example, the UWWTD requires that 80 % of phosphorus and 70 % of nitrogen are removed from waste water during the treatment process, while the HELCOM BSAP recommends that the removal efficiency is 90 % and 80 %, respectively. Stemming from the ineffectiveness of region-wide protection policies, there is a call for spatial and temporal specification

of EU policies and measures. Consequently, many of the more recent directives, such as the WFD, try to respond to this call by introducing a regionalised approach to water pollution governance, as this invites Member States to draw up separate management plans for different river basins. The overall aim of the WFD is to reduce the pollution load to the Baltic Sea from land-based sources in order to reach a good ecological status of European surface waters and groundwater by 2015. The Nitrates Directive controls nutrient loading from agriculture, although the most important instrument for the reduction of nutrient input from agriculture is the agri-environmental programme of the Common Agricultural Policy. This programme has been criticised for lacking cost-effectiveness; despite the substantial amount of subsidies paid to farmers for carrying out environmental measures, the programme has not met the nutrient reduction targets. In fact, the CAP directs the sector towards bigger and more efficient practices, which increase the land area under cultivation as well as the farm size and the intensity of production. This in turn may actually undermine the nutrient reduction achievements at the farm level using environmental measures.

Other important EU policies include Habitats and Birds Directive, that protect certain Baltic Sea species and habitats, and the Common Fisheries Policy (CFP), which regulates fish catches and environmental impacts of fishing. The CFP (2002 reform), however, has not been a success story from the environmental point of view, as it has failed to achieve sustainable fisheries. Instead, 88 % of the European fish stocks are fished beyond maximum sustainable yield and 30 % of these stocks



are overfished (i.e. fishing pressure exceeds recruitment and growth). The latest reform approved a new, potentially more environmental friendly CFP that will take effect at the beginning of 2014. The new CFP will be more restrictive on overfishing and will, for instance, ban discarding of caught fish.

In addition to the above-mentioned policies, a number of other policies and regulations from different policy sectors affect either directly or indirectly the state of the sea. It is therefore important that protection of the Baltic Sea is integrated into the different policy sectors, e.g. agricultural, fisheries, industrial, energy and transport.

The deteriorating state of the Baltic Sea reached wide public awareness in Finland and Sweden in the late 1960s and early 1970s. At the same time, the first environmental non-governmental organisations (NGOs) were founded. For example, WWF Finland has worked to protect the Baltic Sea since it was founded in 1972. Traditionally, these NGOs have concentrated on nature conservation by raising public awareness on pressing environmental issues and participating in and contributing to the national and international environmental governance decision-making. In Russia, the Baltic States and Poland, the history of environmental NGOs is shorter and their role much weaker than in the rest of the coastal countries. Since the collapse of the Soviet Union (in 1991), however, a number of voluntary multi-lateral partnerships, organisations and projects around the Baltic Sea region have worked to promote more effective environmental governance in the region.

Despite the various governmental and non-governmental protection efforts at national and regional level over the past four decades, the Baltic Sea remains one of the most polluted seas in the world. Stemming partly from the frustration of individual citizens regarding the apparent ineffectiveness of traditional environmental governance, new modes of environmental governance have therefore emerged during the 21st century. For example, new independent foundations (e.g. the John Nurminen Foundation, the Baltic Sea Action Group and BalticSea2020) are engaging private donors and actors in environmental protection work by suggesting new approaches, such as public-private-partnership. These foundations can bypass the formal procedures of e.g. HELCOM and state diplomacy and instead build new forms of cooperation in the environmental governance of the Baltic Sea.

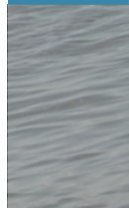
The John Nurminen Foundation was founded in 1992 to preserve the maritime history collection of the John Nurminen family company. In 2004, the foundation, on the initiative of Juha Nurminen (Chairman of Board), launched the Clean Baltic Sea project, which aims to combat eutrophication and increase tanker safety in the Baltic Sea region. Following the operational principle, the projects carry out concrete actions where the largest positive impact on the environment is achieved at the lowest cost (i.e. cost-efficiency). In practice, the foundation can be seen as a catalyst between various sectors of society and the coastal countries.

The first Clean Sea project of the John Nurminen Foundation, enhancing chemical phosphorus removal from the St. Petersburg water utility's (Vodokanal) three largest wastewater treatment plants, was completed in 2011. As a result, annual phosphorus discharges to the Gulf of Finland have been decreased by circa 20 %. The majority of the project was co-financed by the Foundation and Vodokanal. The project's success is largely due to direct communication between the project personnel and the CEO of Vodokanal as well as the mobilization of high-level decision-makers (i.e. the President of Finland and the Governor of St. Petersburg) to support the project.

The Baltic Sea Action Group is an independent foundation established in Finland in 2008. The operational principle of the BSAG is based on direct constructive dialogue between and among the private sector, civil authorities (including the heads of states), scientific organisations and NGOs as well as their mobilization to take concrete actions that are expected to benefit both the actors involved and the Baltic Sea. The BSAG organises events called Baltic Sea Action Summits (in Helsinki

in 2010 and in St. Petersburg in 2013), which have gained a lot of attention in the media. The Summit in Helsinki, for example, brought together the heads of states and over 140 companies and organisations around the Baltic Sea to make concrete commitments for the protection of the Baltic Sea.

BalticSea2020 was founded in Sweden by Mr Björn Carlson (in 2006) through his private donation. Similarly to the above-mentioned foundations, Mr Carlson's overall idea was to use his donation to create an organization that is able to act quickly and make sure that the necessary measures and initiatives are duly implemented in order to save the Baltic Sea. The foundation has contributed to the reform of the Common Fisheries Policy (CFP), initiated more than thirty projects for a cleaner and healthier Baltic Sea, and supported the execution and publication of more than twenty scientific studies. BalticSea2020 has also produced two price-winning TV documentaries (For Cod's Sake and Dirty Waters) that have been broadcasted in 12 countries so far.



What could be your own contribution to the conservation and sustainability of the Baltic Sea?

The behavioural patterns of people around the world, in the drainage area, and in particular along the coastline of the Baltic Sea have an impact on its ecological state. What we eat, how we organise our style of living and how we move between places are key decisions! It is also important how we vote, show an example to others, teach our children, and do practical things like the collection and disposal of rubbish and leaving living-room for wild animals. What else do you see as important for us to consider and act upon?



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