Part 1: Considering the future of the Baltic Sea

Contents

Since the 1900s, the Baltic Sea has changed from an oligotrophic clear-water sea into a eutrophic marine

1 Shortly about the Baltic Sea

The Baltic Sea is one of the largest **brackish water** bodies in the world. The sea is very shallow with a mean depth of only 54 meters. More than one third of the Baltic Sea is shallower than 30 meters. Therefore, total water volume in comparison to its surface area is very small.

The only connection with Atlantic Ocean is via Danish Straits. The exchange with seawater is very slow, while inflow of freshwater is high. Therefore, mainly waters of inflowing rivers determine the salinity level of water. The average salinity of the Baltic Sea is only a fifth of that found in the Atlantic Ocean. The specific of the Baltic Sea is that brackish water formed from freshwater inflow is separated by **halocline** from more saline water located in deeper parts of sea. The depth and salinity conditions are different in marine waters of each of countries of the Baltic Sea coasts.

The Baltic Sea in figures

- Average depth – 52 m.
- Volume – 21 700 km^3.
- Surface area – 415 200 km^2.
- The catchment is more than 1 700 000 km^2.
- Population – approximately 85 million inhabitants.
- Population density from <1 person/km^2 in the northern and north-eastern parts to >100 persons/km^2 in the southern and western parts.

Brackish water contains between 0.5 and 30 grams of salt per litre – more often expressed as 0.5 to 30 parts per thousand (‰). Thus, brackish covers a range of salinity regimes and is not considered a precisely defined condition.

Halocline is a layer of water isolating the surface waters from the deep waters. Because of different salinity conditions, also density of seawater differs. Increase salinity by 1 kg/m^3 results in an increase of seawater density of around 0,7 kg/m^3.

CHARACTERISTICS OF COASTAL ENVIRONMENT OF FINLAND

The shoreline length of the Finnish mainland is approximately 5 000 km. This would increase to almost 40 000 km, if the fragmented archipelago is included (HELCOM, 1998). Coastline consists mainly of bedrock, although the inner parts of the archipelagos and bays are sheltered enough for the deposition of fine material. Forty two percent of the coast is bedrock, with the similar percentage of moraine. Approximately 5 % is sand and 10 % is mud. Hard bottoms are usually found in more exposed outer archipelago areas were currents and wave action prevent particles from settling. Besides major cities – Helsinki, Espoo, Turku, Oulu smaller towns and settlements are located within coastal zone. Holiday cottages located along coastal areas are common feature in Finland.

CHARACTERISTICS OF COASTAL ENVIRONMENT OF ESTONIA

Coastal waters belong to the Gulf of Finland, Gulf of Riga and the Baltic proper. The length of the Estonian coastline is 3 794 km, of which 1 242 km are on mainland and 2 552 km are divided among the islands (HELCOM, 1998). Marine environment substantially differs in different coastal areas. Hard bottoms are frequent in areas of the Gulf of Finland and the Baltic proper, Gulf of Riga is dominated with soft bottoms, West Estonian archipelago sea hydrological regime define a variety of bottom types. Salinity varies from 6,5–7,2 ‰ in the Gulf of Finland to 0,5–2,00 ‰ near bigger river discharge zones. Besides major towns (Tallinn, Parnu, Kuresaare), a number of smaller settlements and scattered dwellings is typical for Estonian coastal zone.

CHARACTERISTICS OF COASTAL ENVIRONMENT OF LATVIA

The shoreline length of the Latvian mainland is 491 km, of which 182 km are along the Baltic proper and 308 km belongs to the coast of the Gulf of Riga (HELCOM, 1998). Latvian marine coastal part is dominated by soft bottoms – sand, silt, sandy gravel and gravel with boulders. Mean salinity in the Gulf of Riga is 5,8 ‰, in the Baltic Proper – 7 to 12 ‰. Biggest cities – Riga, Liepāja, Ventspils, as well as small towns, villages and scattered settlements are located within coastal zone, totally accounting for about one third of Latvia population.

CHARACTERISTICS OF COASTAL ENVIRONMENT OF LITHUANIA

The shoreline length is 94 km. Located in south–eastern part of the Baltic Proper Marine Coastal area is characterized with diverse bottom types. Along Curonian Spit sandy bottoms prevails. The Marine coastal slope extending from the shore downwards to 25–30 m is characterized by the most diverse bottom types with alternating quartz sand, pebble–gravel deposits, stony bottoms alternate with patches of silty sand and mud in natural depressions. The salinity in upper layers of Baltic proper is about 7 ‰ (HELCOM, 1998).

Curonian Lagoon connected with the Baltic Sea through Klaipeda Straight is the main nutrient accumulation basin. Curonian Lagoon receives waters from the 937 km long R. Nemunas (catchment area – 97 928 km^2) and its left hand tributary R. Prieglius (15 500 km^2), The Nemunas River Basin drains the territories of Belarus, Lithuania, Russian Federation, and Poland. The Prieglius River Basin occupies the area of 15 500 km^2, of which only 88.4 km^2 belong to Lithuania. Besides major town Klaipeda, small towns and settlements (Palanga, Giruliai) are located within coastal zone and on Curonian Spit.

CHARACTERISTICS OF COASTAL ENVIRONMENT OF POLAND

The Polish Marine zone comprises the eastern and western part of the southern Baltic Proper together with Szczecin Lagoon and Vistula Lagoon. Marine coastal part is dominated by soft bottoms – sand, silt, sandy gravel. Some small areas of stony bottoms occur in Slupsk Bank and in the Gulf of Gdansk[2]. The salinity in upper layers is about 7 ‰, while beneath the halocline it varies between 10 ‰ and 18 ‰. Polish Baltic coast is approximately 528 kilometres long. Nearly all inland water of Poland is swirled northward into the Baltic Sea by the Vistula, the Oder, and the tributaries of these two major rivers. About half the country is drained by the Vistula. The Oder and its major tributary, the Warta, form a basin that drains the western third of Poland into the Bay of Szczecin. Besides major cities (Szczecin, Gdansk, Gdynia), a number smaller towns and settlements are located within coastal zone.

The Baltic Sea is divided in to several sub-basins – Bothnian Bay, Bothnian Sea, Archipelago Sea, Gulf of Finland, Gulf of Riga, Baltic Proper – and a transition zone to the North Sea – Belt Sea and the Kattegat. The catchment area of the Baltic Sea is more than 1 700 000 km^2.

Figure 1. Catchment area of the Baltic Sea, its sub-basins and depth (Source: HELCOM, 2006. Development of tools for assessment of eutrophication in the Baltic Sea Balt. Sea Environ. Proc. No. 104)

Eutrophication is major problem of the Baltic Sea. The main ecological objective is to reduce nutrients load to reach natural level of algal blooms in the Baltic Sea*

2 What is eutrophication?

Over the past century, a wide range of human activities – the intensification of agriculture, wastewater discharge and coastal development – has substantially increased the discharge of **nutrients** into the environment (Urtāne L., 2014). In the water environment nutrients stimulate the growth of algae, cyanobacteria and water plants. When the concentration of nutrients is too high, this growth becomes excessive, leading to a condition called **eutrophication**.

The term “eutrophication” originates from Greek language, in which “eu” means “well”, and “trophos” – “nourishment”. In water environment, “well nourished” means to have high concentrations of nutrients.

In natural conditions, nutrients are used for **primary production** and form the base of the marine food chain. It also provides most of the oxygen in the atmosphere (Solow A. R. 2004.). Without primary production, the Planet Earth would be a much different place.

When nutrients in water are in unnaturally high concentrations the growth of algae and cyanobacteria results with a **blooming**, which is recognized by the discoloration in the water from their pigments.

*defined by Baltic Sea Action Plan.

Nutrients are chemicals, specifically nitrogen (N) and phosphorus (P), that are essential for plant growth. Algae and water plants are using inorganic nitrogen in the form of nitrite (NO_2^-), nitrate (NO_3^-) or ammonia ions (NH_4^+), but inorganic phosphorus in the form of phosphate ions (PO_4^{3-}).

Eutrophication is the enrichment of water by nutrients, especially nitrogen and/or phosphorus, causing an accelerated growth of algae and water plants.

Primary production is the synthesis of organic compounds during the process of photosynthesis. The organisms responsible for primary production are known as primary producers and form the base of the food chain. In water environment these are algae, cyanobacteria and vascular water plants.

Water blooming is status when density of algae or cyanobacyteria in water is very high and becomes visible as blue-green colour. The number of individuals per litre of water may range from 1000 to 60 million.

Figure 2. In nutrient rich water, the density of algae or cyanobacteria becomes so high, that water is discoloured in blue-green colour. Photo: A.V.Urtans.

Blooms are a natural phenomenon in the Baltic Sea ecosystem. During last decades, the Baltic Sea blooms two times per year – once in the spring and once in the late summer. In late summer, blooms dominate nitrogen-fixing organisms – cyanobacteria. According to HELCOM data the extensive surface blooms (HANSSON M., 2007; HANSSON M., ÖBERG J., 2008–2011; ÖBERG J., 2012–2016), especially cyanobacteria blooms, become more frequent and extensive due to eutrophication.

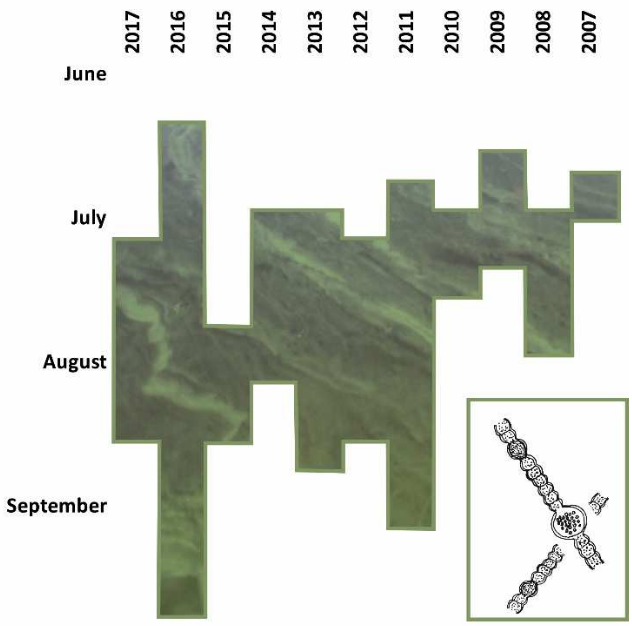

Figure 3. Periods of extensive cyanobacteria blooms of the Baltic Sea. Phoro: A.V.Urtāns, picture L.Urtāne (Source: HELCOM)

The algae and cyanobacteria blooming is detected with satellites based equipment MODIS[1] and VIIRS[2].

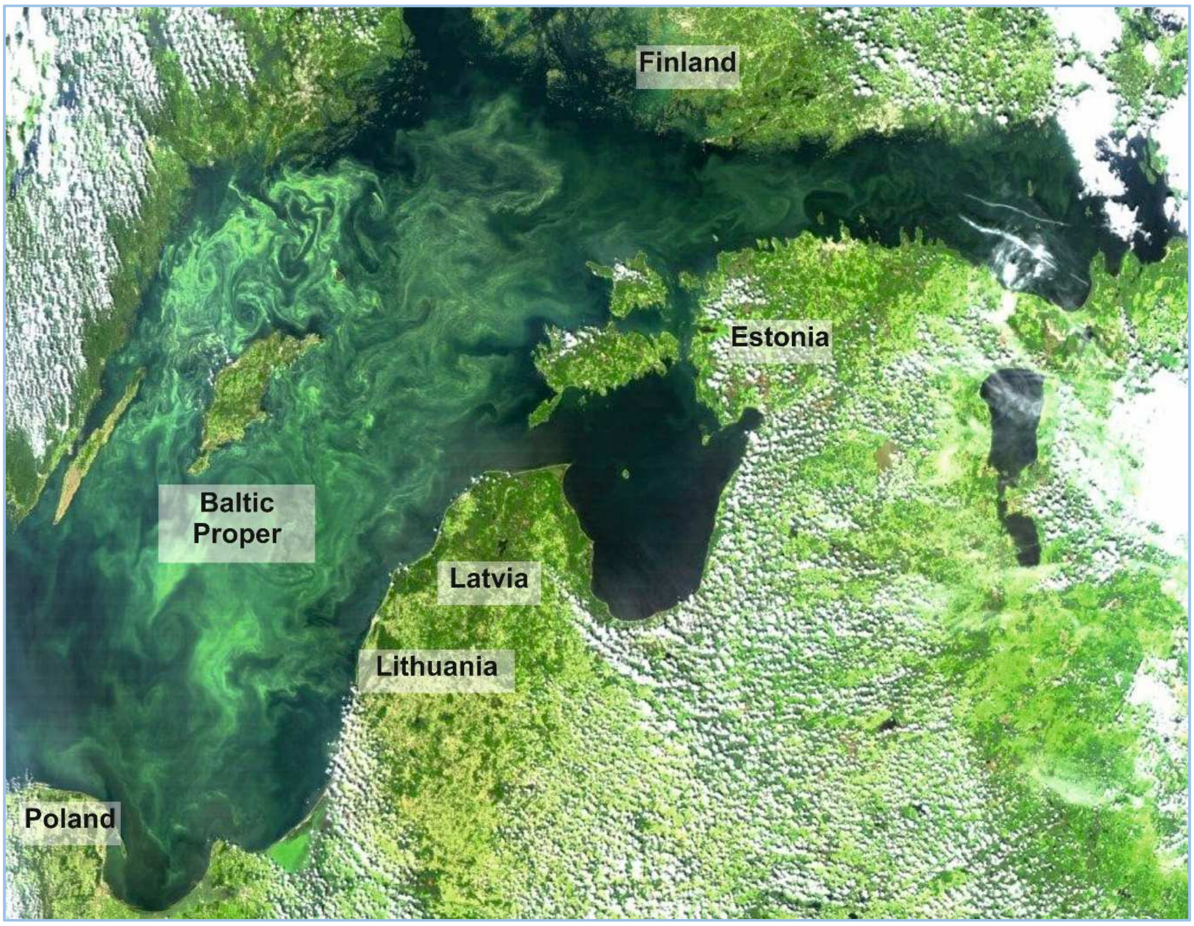

Figure 4. Observation of cyanobacteria blooming from space Photo: NASA.

[1] MODIS – Moderate Resolution Imaging Spectroradiometer, which is a key instrument aboard the Terra (originally known as EOS AM-1) and Aqua (originally known as EOS PM-1) satellites.

[2] VIIRS – Visible Infrared Imaging Radiometer Suite is a sensor designed and manufactured by the Raytheon Company on board the Suomi National Polar-orbiting Partnership (Suomi NPP) weather satellite.

Due to natural conditions – slow renewal of water masses, strong stratification, small water volume and large river runoffs – and high human impact, the Baltic Sea is very sensitive to nutrient enrichment and

3 What is consequences of eutrophication?

Algae is the bases for marine food chain. They support the growth of species at higher trophic levels – zooplankton, fishes, mammals – and also provide food resources for mi-croorganisms. Higher production of planktonic algae may initiate food chain changes and distribution of water both in shallow and deep parts of the Baltic Sea (Cloern, 2001).

A **food chain** shows how the organisms are related with each other by the food they eat. It is a linear network of links in a food web starting from primary producers and ending at predator species, detritivores or decomposer species.

An increased intensity and frequency of algae and cyanobacteria blooms typically leads to decreased water clarity and increased sedimentation, which in turn increase oxygen con-sumption at the bottom areas of sea and may lead even to oxygen depletion. These con-ditions further limit the distribution of water vegetation – macroalgae and water plants, and reduce the quality of the sea bottom.

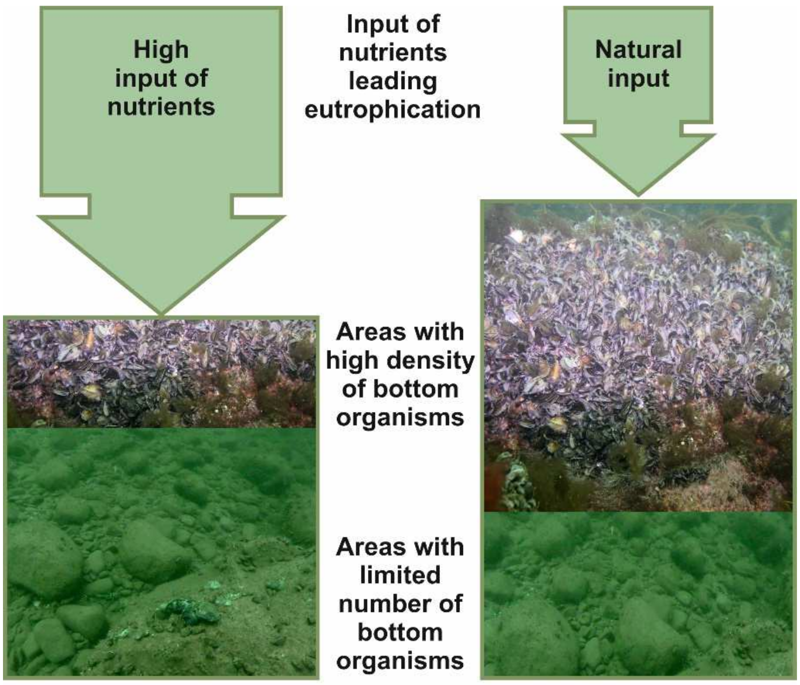

Figure 5. Impact of high input of nutrients leading eutrophication to quality of bottom habitats. Picture: L. Urtāne. Photo: J. Aigars.

The density of benthic animals is about 2000 in every m^2 in the shallow part of the Baltic Sea.

Benthic animals are a fundamental food source for fish and birds.

Benthic animals decompose organic matter that sinks to the sea bottom.

Benthic animals, during its digging and burrowing activities, promote sediment decomposition.

Mussels are natural water treatment plants, for example the water masses filtered by blue mussels is equal water volume of whole sea.

Benthic organisms form breeding areas for other species, for example, seaweeds and plants in the coastal area provide important environments for many fish species, which depend on these habitats for their reproduction.

Many species of the Baltic Sea are affected by nutrient enrichment. For example, the effects of eutrophication on oxygen deficiency at the sea bottom, affect benthic fauna and extend via the Baltic Sea food web to zooplankton, and may ultimately influence also food availability for fish, water birds and marine mammals.

Figure 6. The role and status of water organisms inhabit the bottom of the Baltic Sea. Photo: J. Aigars.

Both primary production and oxygen consumption have doubled in the period from 1970 to 2009 and is still increasing (Stigebrandt et al., 2013). In recent years, the intensification of algae blooms in the Baltic Sea has led to the regular appearance of "dead zones" in the deepest areas of the sea bottom. **Dead zones** form when aquatic organisms consume dissolved oxygen faster than it can be supplied and **hydrogen sulfide** (H_2S) is produced.

Eutrophication generates production of algae, which consequently consume oxygen when decomposed, implying that the supply of oxygen has been drastically overused. The sea bottom areas without any biological life due to oxygen depletion have increased drastically from approximately 5 000 km^2 in around 1 900 to the extension of 70 000 km^2 in summer of 2018[1] and this is 16,9 % of whole area of the Baltic Sea.

Dead zones are low-oxygen (oxygen concentration < 2 mg/l) areas in the sea, caused by excessive nutrient pollution from human activities that lead to the decrease of oxygen required to support most marine life in bottom and near–bottom water.

Hydrogen sulfide is the chemical compound with the formula H_2S. It is a colorless chalcogen hydride gas with the characteristic foul odor of rotten eggs. Hydrogen sulfide is often produced from the microbial breakdown of organic matter in the absence of oxygen.

The special concern in the protection of the Baltic Sea is the large area with low oxygen content, or no oxygen at all, in deep water area, which limits the distribution of plants and animals inhabiting sea bottom.

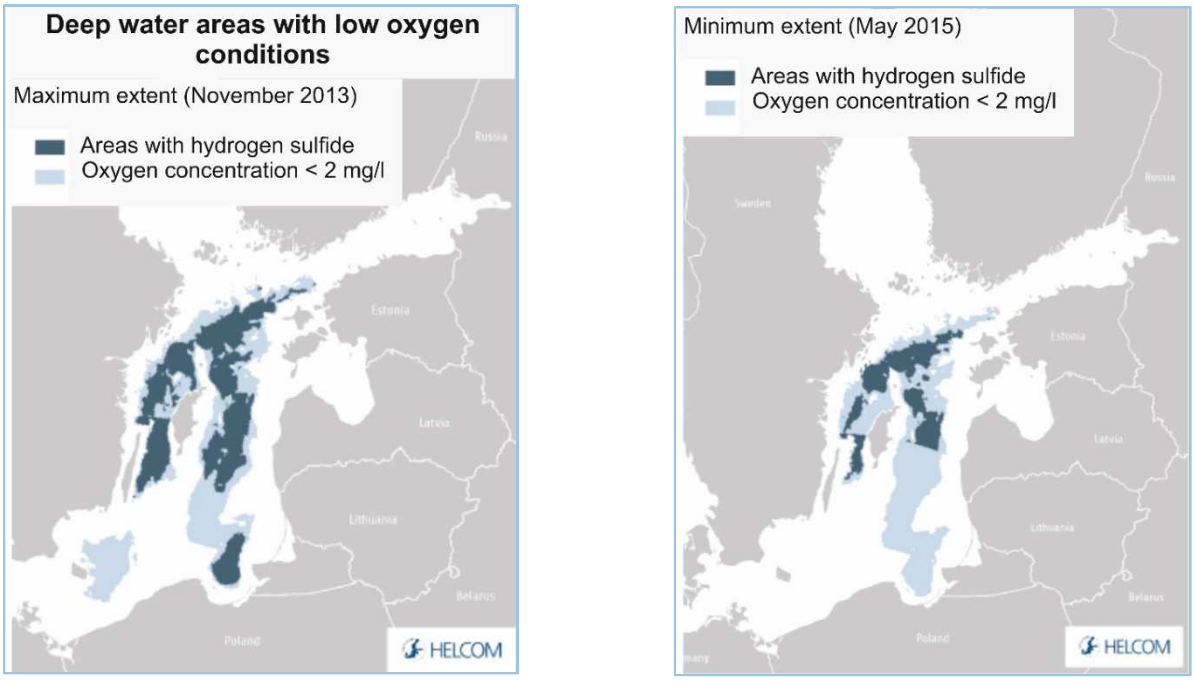

Figure 7. Deep water part of the Baltic Sea recognized as "dead areas" (Source: HELCOM (2018): State of the Baltic Sea – Second HELCOM holistic assessment 2011-2016. Baltic Sea Environment Proceedings 155.).

[1] According to researchers from Finland's University of Turku

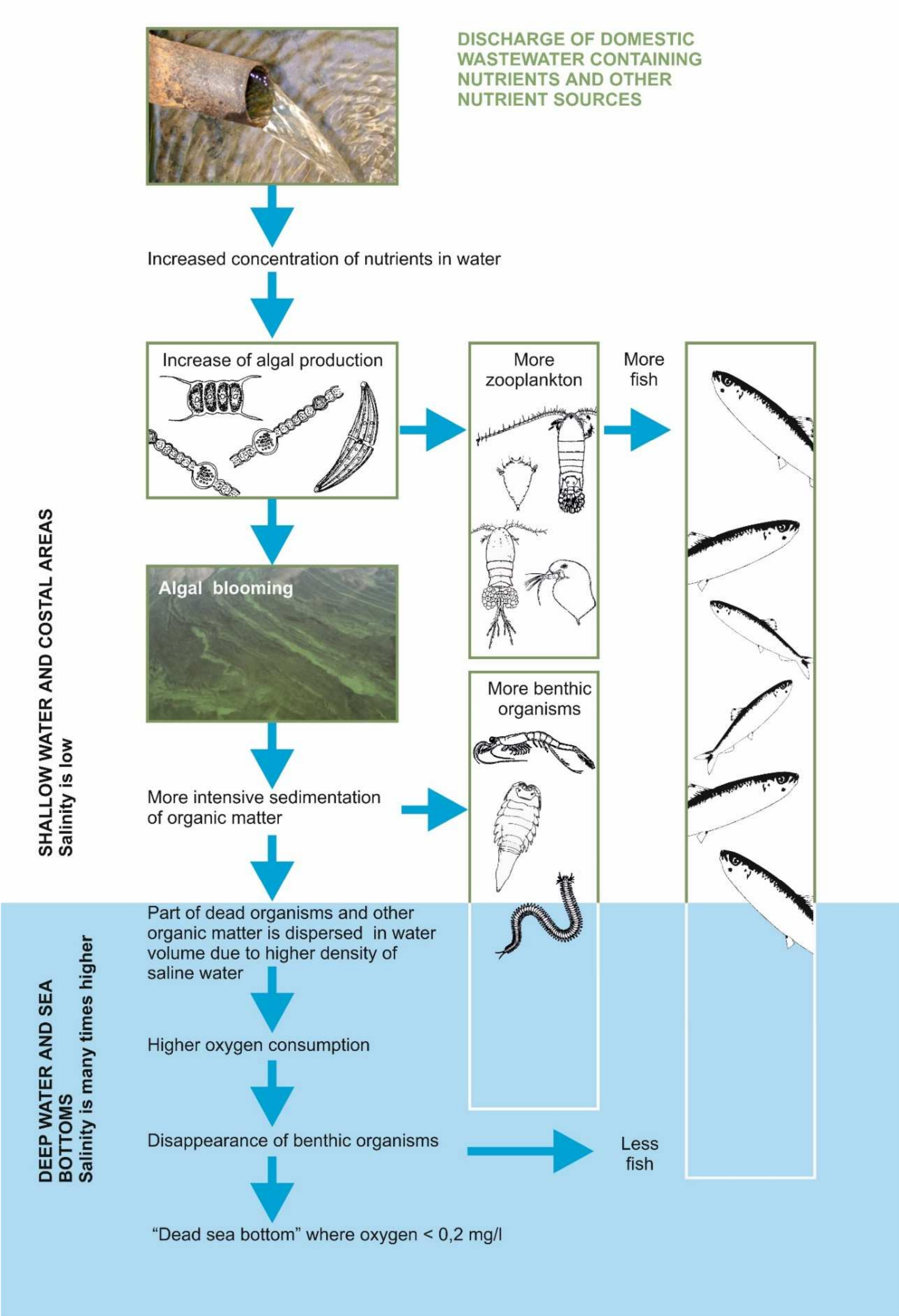

Figure 8. Eutrophication and its consequences in the Baltic Sea. Picture: L.Urtāne. Photo: L. Urtāne, A.V. Urtāns.(Source: Monitor 1988. Sweden's marine environment – ecosystems under pressure)

4 What is main pollution sources of the Baltic Sea?

Inputs of nitrogen and phosphorus have been increasing for a long time in the Baltic Sea, mainly between the 1950s and the late 1980s (Gustafsson et al., 2012), causing eutrophication and deterioration of water quality (Larsson et al. 1985; Bonsdorf et al. 1997; Andersen et al. 2017). The integrated eutrophication status assessment for 2011–2016 shows that the Baltic Sea is still affected by eutrophication (HELCOM, 2018). At least 97 % of the open sea area is still eutrophied and about 12 % is assessed as being in the category of poorest eutrophication status.

It is estimated that about 5% of the nitrogen load originated from point sources discharging directly into the Baltic Sea, while the rest entered via rivers (HELCOM, 2011). For phosphorus the contribution from point sources was higher, about 8%. Atmospheric deposition additionally supplied the Baltic Sea with 196 000 tonnes of nitrogen in 2006 (Bartnicki J., Fagerli H., 2008), while the atmospheric deposition of phosphorus directly to the Baltic Sea is considered as low.

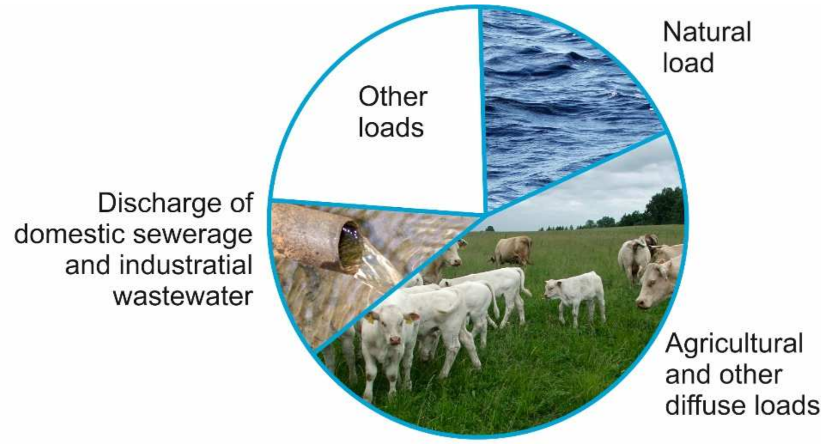

Figure 9. Proportion of different sources (in %) contributing to the total nitrogen load inputs into the Baltic Sea in 2006. Photo: L. Urtāne (Source: PLC-5).

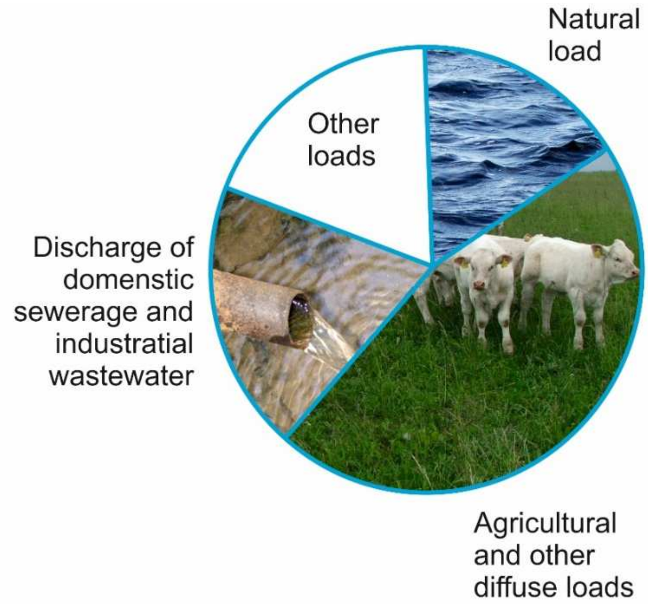

Figure 10. Proportion of different sources (in %) contributing to the total phosphorus load inputs into the Baltic Sea in 2006. Photo: L. Urtāne (Source: HELCOM, 2011).

Due to active transnational cooperation under **HELCOM** Convention, implementing **Baltic Sea Action Plan**, the total inputs of nutrients to the Baltic Sea have decreased since the late 1980s. The current nutrients load is equal those in the early 1960s. This indicates that treatment of centralised wastewater, reduction of air emissions as well as diffuse pollution from agriculture and forestry have led to a significant decrease in nutrient inputs to the Baltic Sea.

Nevertheless, phosphorus and nitrogen load in the Baltic Sea still exceeds natural sea ability for ecosystem self-stabilisation. Due to the long residence time of water in the open Baltic Sea, feedback mechanisms such as release of phosphorus from anoxic sediments, the prevalence of nitrogen-fixing cyanobacteria blooms in the sub-basins of the Baltic Sea, the recovery from the eutrophied state is slow (HELCOM, 2015).

Good results of treatment efficiency for municipal sewerage collected in the centralised order were reached with introduction of secondary, so-called biological and advanced treatment. **Nevertheless, the third biggest pollution load from scattered dwellings still is rather high** (HELCOM, 2011).

HELCOM – the Baltic Marine Environment Protection Commission, is an intergovernmental organization. HELCOM works on protection of the marine environment of the Baltic Sea.

Baltic Sea Action Plan is an ambitious programme of HELCOM to restore the good ecological status of the Baltic marine environment by 2021.

The percentage of population not connected to urban wastewater collection and treatment systems in VillageWaters Project countries is:

- 19 % (252 000 inhabitants) for Estonia,
- 19 % (900 000 inhabitants) for Finland,
- 29 % (645 000 inhabitants) for Latvia,
- 38 % (975 000 inhabitants) for Lithuania;
- 38 % (14.7 million inhabitants) for Poland, and
- 13 % (1 million inhabitants) for Sweden.

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