Overview of the Water Bodies in the Baltic Sea Countries

El-Sayed E. Omran and Abdelazim M. Negm

Abstract The chapter takes a look at the Baltic Sea from various aspects to develop a synthesis of the existing knowledge and add a new perspective on the water bodies in the Baltic Countries Sea using RS. The Baltic Sea, with a composition that is neither sea nor fresh water, is one of the largest brackish water bodies in the world. The Baltic Sea Drainage Basin (BSDB) is a large heterogeneous region. The drainage basin is occupied by 14 countries and covers an area of 1,739,000 km^2 and home to about 84 million. There are 14 larger international river basins within the BSDB, with an approximate area of 1,050,000 km^2. Such river basins vary in size, many basin sharing countries, witnessed environmental issues, and how they are handled. Over 200 rivers discharge into the Baltic Sea, creating an area of about 1,700,000 km^2 of catchment and drainage that is about four times larger than the sea itself. This catchment area is considered to be part of the Large Marine Ecosystem of the Baltic Sea (BSLME). As a result of global warming, the future rise in sea level will affect the coastal regions of the world. Although the speed of sea-level rise is not clear, it will have serious and global implications. So how could one judge whether the land went up or the water went down? Well, a solution might be to calculate the occurrence frequency for a long time over a larger area, in this case, across the entire Baltic Sea. One of the solutions to cope with the rapidly changing environment is renewable energy. Wind and wave turbines are becoming increasingly common, although ensuring that they do as little harm as possible to the environment is crucial.

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1 Introduction

A separate Sustainable Development Goal (SDG) has been allocated to marine ecosystems among the 17 global goals established by the United Nations (UN), which is SDG No. 14 [1]. It was argued that we need to consider the ecosystems of the past in order to understand current environmental disturbances [2]. Today's highly disturbed seas may act as time machines for certain marine areas on a slower anthropogenic disruption trajectory [3]. The Baltic Sea is one of the largest semi-enclosed brackish water bodies in the world, enclosed by nine developed and industrialized nations and five more belonging to the catchment area, almost entirely land-locked and distinguished by very restricted movement of water. Because of its unique geographical, oceanographic, and climatic characteristics, the Baltic Sea habitats are highly susceptible to the environmental impacts of human activities at sea and in their catchment area [4].

The Baltic Sea is severe for shelf seas, let alone the open ocean, due to its young age, average water depth of only 58 m, and a low exchange rate with North Atlantic water. Our chapter's main idea is that these unique aspects are also specifically the requirements that led to the current multi-stressor situation (eutrophication, warming, oxygen, and acidification status), make the Baltic Sea a large-scale, real-world counterpart only in the future for other coastal regions.

As other landlocked marine areas, the Baltic Sea has a favorable water balance in temperate latitudes in tropical regions. The average annual freshwater deficit of 481 km^3 is almost the same as the annual North Sea saltwater inflow [5]. Freshwater balance [river runoff (428 km^3) + precipitation (237 km^3)—evaporation (184 km^3)] is dominated by runoff because precipitation and evaporation are relatively well balanced.

The Baltic Sea Drainage Basin (BSDB) is a vast heterogeneous region. The drainage basin is occupied by 14 countries and covers an area of 1,739,000 km^2 (Belarus, Czech Republic, Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Norway, Poland, Russia, Slovakia, Sweden, and Ukraine) and home to about 84 million. There are 14 larger international river basins within the BSDB, with an approximate area of 1,050,000 km^2. These river basins have different sizes. Some of these basins sharing among several countries. Also, these river basins share witnessed environmental issues and how they are handled. But there is something they have in common. All of them are international and are based in the same geographical area, the Baltic Sea Area.

However, increased industrialization and natural resource exploitation have resulted in the Baltic Sea Large Marine Ecosystem (BSLME) declining and decaying since the 1940s. Today, the Baltic Sea drainage basin is populated by more than 85 million people and their actions can affect and change the Baltic Sea climate for good or worse.

Over 200 rivers discharge into the Baltic Sea, creating an area of about 1,700,000 km^2 of catchment and drainage that is about four times larger than the sea itself. This catchment area is considered to be part of the Large Marine Ecosystem of the Baltic Sea (BSLME). Management measures to protect and repair the BSLME must, therefore, be carried out on land as well as at sea. This situation becomes even more critical as the Baltic Sea is a semi-enclosed brackish water region, after the Black Sea, the second largest in the world. It is marked by an ongoing vertical stratification of its water layers and resident (turnover) period estimated at 25–30 years for a full exchange of its water volume. Such factors significantly increase the Baltic Sea's vulnerability to pollutant accumulation.

The goal of the chapter is to develop a synthesis of the existing knowledge and add a new perspective on the water bodies in the Baltic Countries Sea using remote sensing (RS).

2 Geography, Formation, and History of the Baltic Sea

The Baltic Sea, with a total area of about 415,000 km^2, is the second-largest brackish (low-salinity) water body in the world. The Baltic Sea's northern part comprises the Bothnian Sea, the Bothnian Bay with the Quark in between, and the Gulf of Finland. The main part is the Baltic Proper, separated by the Archipelago Sea and the Aland Sea from the northern part. The Baltic Proper can be split "into the Northern Baltic Proper, the Southern Baltic Proper, and the Eastern and Western Gotland Basins. In the East from the Baltic Proper, there is the Gulf of Riga and the Gulf of Gdansk in the South" (http://lifempa.balticseaportal.net/media/upload/File/Deliverables/Book/SEE%20THE%20SEA%20EN%20veb.pdf). The relatively narrow Danish belts (the Wave, the Great Belt, and the Little Belt) and the Kattegat form the link to the North Sea. It thus knows as a semi-closed sea (see Fig. 1).

The Baltic region is known for many people around the world because of its amber wealth. Amber is a resin material derived from the extensive subtropical pine forests that occupied the region from 35 to 50 million years ago. The resin, before being deposited in the soil, often encapsulated and embalmed pieces of plants and small animals. It is often seen, often picked up and transported by sea, washed up on the beaches today. From archeological discoveries of amber products in Mediterranean cultures such as ancient Greece, Egypt, and Rome, we know that a substantial part of this amber came through the amber trade route linking the Mediterranean sea with the Baltic Sea.

Geologically, biologically and as far as humans are concerned, the Baltic Sea is a young (about 10,000 years old), relatively shallow with an area of about 413,000 km^2. Nevertheless, about 100,000 years ago, a thick ice belt covered the whole of Scandinavia and what is today the Baltic Sea. In the last glacial phase, the Baltic region

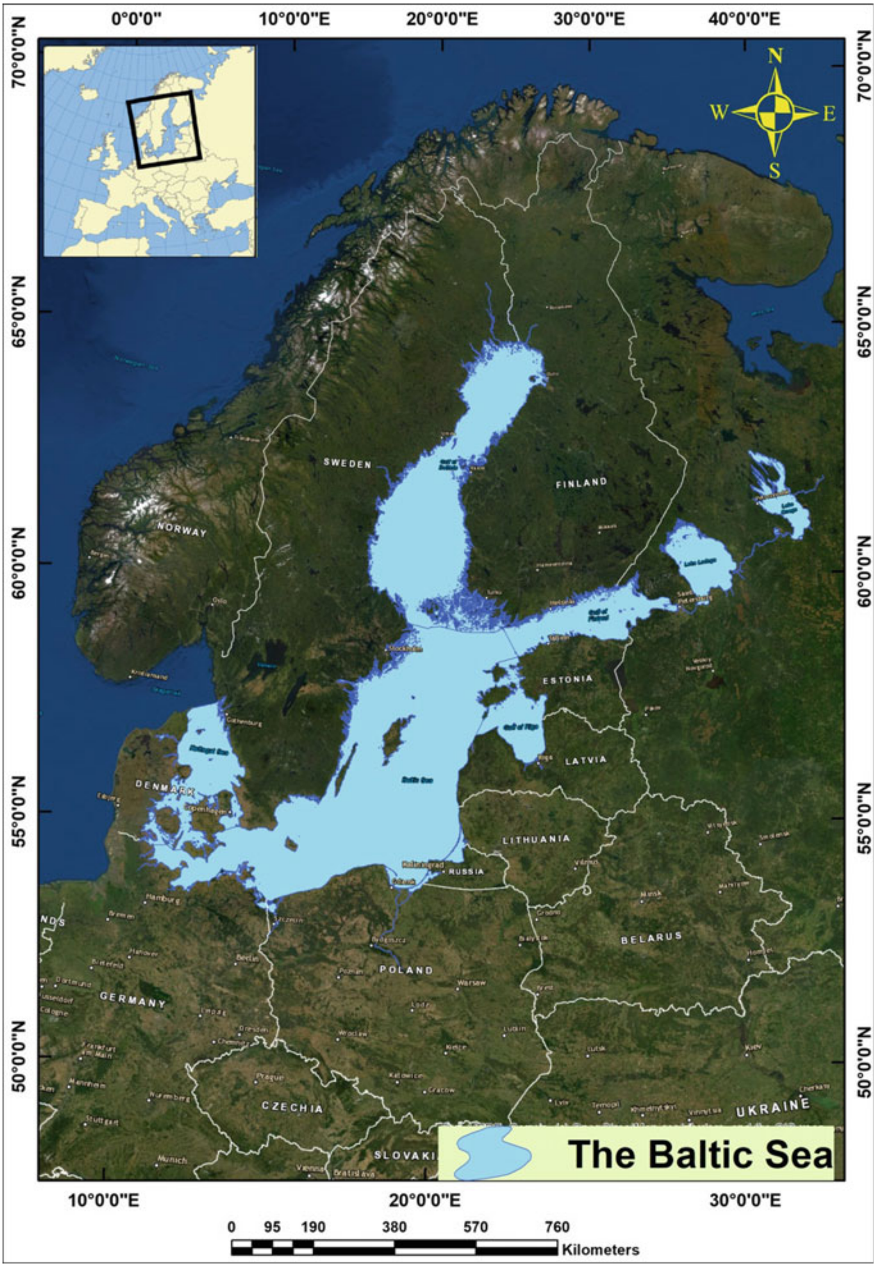

Fig. 1 The Baltic region map

was subject to glaciation over several ice ages. The last ice began to melt about 15,000–7000 years ago, and about 10,000 years ago, the ice was gone.

The ice began to melt between about 13,000 and 10,300 years before the present day (or BP) and a freshwater Baltic ice lake was formed. In the next phase, a largely marine area called the Yoldia Sea formed from 10,300 to 9500 years BP. Then a freshwater enclosed Ancyclus lake formed again from around 9500 to 8000 years BP before the establishment of the Littorina Sea between 8000 and 4000 years BP [6]. The marine life of the Baltic Sea is estimated to have less than about 4000 years old in its current state of development. but it was developed over a much more extended period [7].

In Öresund and the Great Belt, the Littorina Sea is distinguished by nearly marine environments, with saline water entering through broad straights. This, coupled with the warmer climate and increased availability of nutrients, resulted in significant ecological changes in the Baltic Sea environment, including higher primary production and a new species-rich fish population dominated by cod, flounder, plaice, mackerel, and herring. Since the "peak" Littorina time, salinity in the Baltic Sea has decreased by approximately 4 psu [8]. The Baltic Sea is a relatively young and complex formation in geological terms.

Many changes in the water body known today as the Baltic Sea have occurred since the end of the last Ice Age. Relieved from the heavy ice cover, the Earth's crust started to rise, resulting in its relation and disconnection to the North Sea and the Atlantic Ocean via the Danish Belts or what are today Sweden's large lakes, and the White Sea and the Arctic Ocean. It has also increased over the years and reduced in length. The following stages of the Baltic Sea can be distinguished [9] in the post–glacial period (see Fig. 2).

The area became a Barbarian Sea ruled by heathen Vikings, moving forward to around 1000 AD. The Vikings from the west of Denmark and Norway mainly migrated to the west while the Swedish Vikings traveled to the east, even to the Black Sea and the Mediterranean. According to some Scandinavian sagas, the Curonian tribes in the eastern Baltic stubbornly battled the Vikings and sometimes defeated them. Around 1400 AD, major unions formed around the Baltic, especially the Hanseatic League, which promoted trade between communities such as Lubeck, Rostock, Danzig, and Riga, as well as Novgorod in Russia and Bergen in Norway. The Hanseatic League was competing with Scandinavian traders and military forces, particularly the Gotland region.

An Iron Curtain isolated the socio-economically disadvantaged populations of the eastern Baltic, controlled by the Soviet Union to the east, from the richer countries to the west, until the early 1990s. A significant change began in the region in 1991, leading to the recognition of the following nine coastal Baltic countries: Russia, Poland, Estonia, Latvia, Lithuania, Germany, Denmark, Finland, and Sweden. The accession to the European Union (EU) in 2004 of Estonia, Latvia, Lithuania, and Poland leaves Russia as the sole coastal Baltic Sea country outside the European Union. The EU's enlargement will have significant impacts on the Baltic Sea States' land, coastal, and marine policies, particularly in the areas of agriculture, transport, environment, fisheries, water resources, and scientific research.

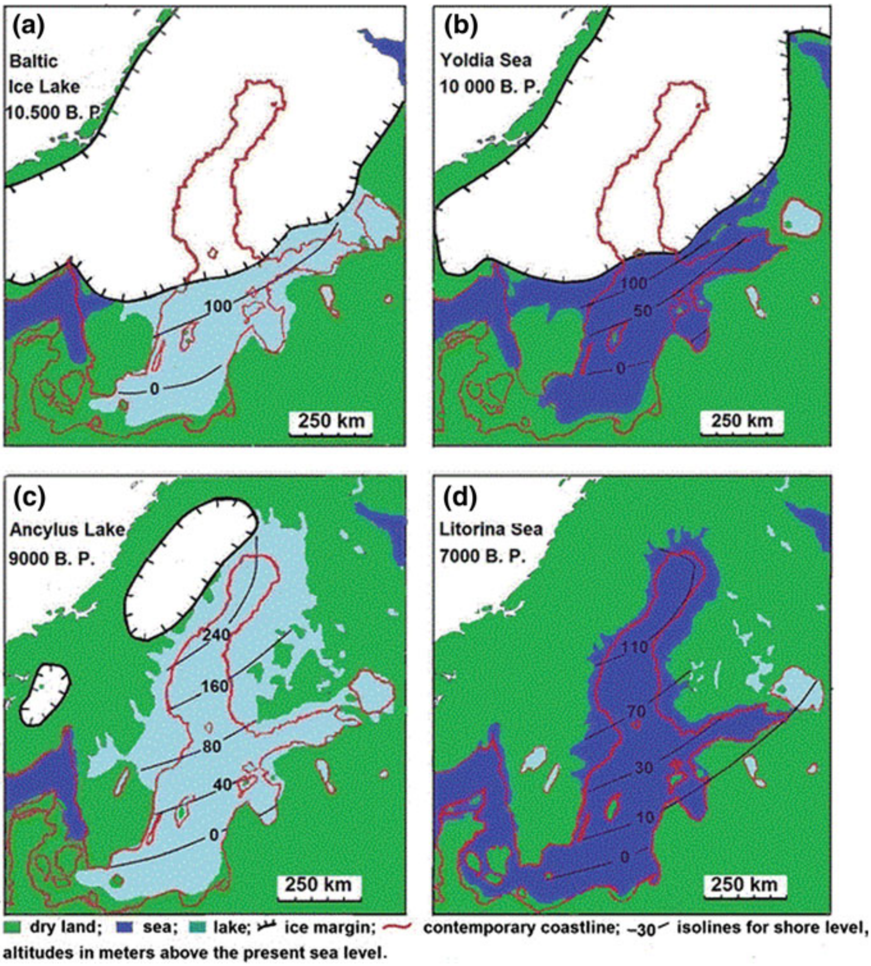

Fig. 2 Stages of early development of the Baltic Sea [10]

The Baltic is made up of three deep basins: the Arkona Deep inside the Baltic Sea entry, the Bornholm Deep, and the farthest inland Gotland Deep. Through the shallow, narrow entry, saltier, denser, and oxygen-rich water from the North Sea joins the Baltic Sea and propagates along the deeper areas, while a counter stream of freshwater flows outward to the surface. It results in two largely stratified sections of the water column, which seldom overlaps, throughout most of the ocean. Such stratification significantly prevents the flow of oxygen from the surface to the deeper water. North Sea oxygen-rich water inflow allows the deeper voluminous water masses to flush with their oxygen levels increasing. Such flushing activities often minimize the concentration of toxins in the water masses as a whole, including reducing the concentration of excessively high contaminants from land-based run-off. Therefore, oxygen-rich water inflow is vital to the biota's well-being and productivity as well as to the environmental quality of the Baltic Sea's aquatic ecosystems. However, these inflow causing Baltic Sea flushing are erratic and rare, with stagnant periods between flushing events lasting as long as several decades, such that oxygen levels decrease over time between each inflow due to the biological oxygen requirements of living organisms and the degradation of organic material. Although the influxes are essentially natural and related to weather change that is not due to human factors, these influxes tend to be diminishing in both frequency and intensity during the second half of the 20th century.

Throughout Europe, the abundance of brackish water fauna and flora has been diminished by several Pleistocene glaciations. About 15,000 years ago, as the ice covering the Baltic basin started its retreat, a large freshwater lake formed on its outskirts. The lake became a sea arm and subsequently underwent another period of freshwater before re-establishing a connection with the sea. The climate has become less saline, and brackish water levels have characterized the Baltic Sea for about the last 4000 years after a long and more saline time. The Baltic is distinguished by a lower number of plant and animal species (biodiversity) than in more saline water due to this background and its brackish nature. For most aquatic species, the brackish water is too salty, and for most marine species, it is too fresh.

3 The Dynamic Coastline of the Eastern Baltic Sea

Baltic Sea's full coastline is about 8000 km wide, 1847 km of which stretches across Lithuania, Latvia, and Estonia. Due to the diverse processes shaping the coastline, it varies within the Baltic countries and consists of a remarkable diversity of shore forms—shifting dunes, sandy beaches, rocky shores, calcareous cliff shores. The coastline (coastal zone) is a region where two different environments intersect—coast and sea. It is a rapidly changing environment in a constant process of destruction and regeneration of existing formations simultaneously [11].

Wind waves and the flow of sediment washed into the sea by rivers and borne along the shore by waves and underwater currents are the main driving forces in this relationship. Other significant factors are the shoreline and sea bottom structure and orientation as well as the sediment type: the direction of the underwater currents and sediment flow depends on how the shoreline is exposed to the dominant wind direction. The combination of all these factors will decide which system will prevail at a particular stretch of the coastline.

The cycles of erosion and deposition are more or less in equilibrium on most of the coastline and the beach shape is reasonably stable. Observations, however, show that coastal erosion has increased dramatically over the past decades, due to factors such as the following:

– Increasing occasions of strong storms (when wind speed exceeds 30 m/s and the water level increases more than 1 m above average);

- Artificial structures such as piers at harbors obstructing the movement of sediments and causing sand accumulation in front of the pier and intensifying erosion behind it;
- Sediment deficit in the movement of sediments caused by river damage;
- Ice scarcity along the coast shielding the coast against erosion;
- The increase of the World Ocean's mean water level.

Another phenomenon that influences the character of the coastline is the slow fluctuation of the Earth's crust such as the ongoing land-lifting post-glacial process. The vast, thick ice sheet exerted varying pressure on the surface in different areas during the Ice Age and created depressions. The land gradually began to rise again after the ice melted. This cycle can still be found as far as the Estonian coastline in the areas around the Gulf of Bothnia. The land elevation is achieving ca in these regions. Annually 4–10 mm; it is estimated that it will continue for another 10,000 years. It is estimated that rising land will create a bridge between Finland and Sweden about 2000 years from now, turning the Gulf of Bothnia into a lake. Archipelagos consisting of thousands of islands and small islets slowly emerging from the ocean are typical ecosystems of land level areas [7].

As a result of the procedures described above, the Baltic coastline has acquired its diverse character and regional specifics. Lithuania has the shortest stretch of coastline—only about 90 km away—mainly marked by a system of erosion forming sandy beaches and dunes. The extraordinary aspect of the Lithuanian coast is the Curonian Spit—97 km long (51 km from Lithuania) and a rounded peninsula up to 3.8 km wide, where the highest drifting dunes in Europe can be found: the highest reaches 60 m, although most of the spit is covered by forest. The spit separates the sea from the Curonian Lagoon—the largest of the lagoons in the southeastern coast of the Baltics, shallow and an almost freshwater body connected to the Baltic Sea through a very narrow strait at Klaipeda. It is one of the most productive waters in the Northern and Eastern parts of Europe, hosting 50 fish species [9]. In 1991, and later, the Natura 2000 site was developed to preserve the unique ecosystem of the Curonian Spit and the Curonian Lagoon.

The remaining Lithuanian coastline is made up of sandy beaches up to 300 m wide, formed by accumulation processes. Accumulation has largely been replaced by erosion processes over the last decades, however, and the Lithuanian coastline is being continually washed away by the ocean. Oland cap is a distinctive feature of this coastal stretch—a moraine cliff of 25 m high, formed in a region of evident erosion. Coastal areas from Klaipeda to Palanga are included in Pajuris Regional Park.

The Latvian coastline is ca. 497 km long and rather smooth as the result of alternating erosion and accumulation processes. Most of the Latvian coastline, however, are suffering from erosion, mostly on the western coasts, which are more vulnerable to strong winds and waves. The highest erosion points are near Bernati, where up to 64 m of land has been washed away during the last 15 years, and the Cape of Kolka that has lost 50 m [12]. Behind the reservoirs lie intense erosion areas, for example, around Liepāja, Pāvilsosta, and Ventspils. Already suffering from erosion are several coastal areas in the Gulf of Riga. It not only destroys the land but also threatens the coastal settlements and houses that were situated some distance from the sea at the beginning of the last century. Erosion processes have succeeded in spectacular moraine and sandstone cliffs being formed at the same locations. Latvia's longest and tallest moraine cliff (up to 20 m) stretches along the coast near Jūrkalne, while the most impressive sandstone cliffs can be found in the "Stony Beach of Vidzeme" Nature Reserve.

However, the Latvian coastline also includes vast sandy beaches with different stages of dunes, including moving dunes. The longest and most extensive beaches (70–100 m) can be found on the southern coastline of the Baltic Sea near Liepāja, along the Irbe Strait and in the southern part of the Riga Gulf. The accumulative coastline has been overgrowing in a few areas of the Gulf of Riga with meadows or reed stands, e.g., near the Estonian border where the Nature Reserve "Randu Meadows" was established to protect the largest complex of coastal meadows and lagoons in Latvia. Estonia has the three Baltic States' longest coastline—1240 km along the mainland and 2540 km on the islands. It is also the most embayed and pointed with varying sizes and shapes of islands. There's a minimum of ca. 1500 Islands, about 80% of which are small islands. In the natural conditions and character of the coastal systems, the Estonian coastline is also the most extensive. The land-up-lift system plays a significant role, most specifically in North-West Estonia, and is responsible for the number of islands and islets. The rather flat and low-lying coastal area of Estonia, particularly in the south, could be severely affected by the effects of climate change such as rising sea level and increasing frequency of storms, which exacerbate erosion processes. The rising sea level, however, is somewhat balanced by the up-lift property. The Estonian coastline offers a wide variety of shore forms and marine ecosystems. There are vast sandy beaches near Pärnu Bay on the southern coast. Often characteristic of the northern coastline along the Finnish Gulf and in areas of Saaremaa and Hiiumaa islands are sandy beaches and dunes, although some island shores are lined with gravel or pebbles. Silty shores filled with reed beds are very popular in Western Estonia—on the islands as well as the coastline along the Väinameri Straits. The main marine wetlands in Estonia are the Kasari delta, Matsalu Bay and adjacent tidal lagoons, shallow inlets and bays, coastal meadows and reed beds. Stony till shores are scattered throughout Northern and Western Estonia with erratic boulders. The most impressive characteristic of the Estonian coastline is the cliffs located along the northern coastline and in Saaremaa (Fig. 3) [9].

The North-Estonian Klint is the cliff bordering the coastal plain created by the slope of the calcareous plateau. The most remarkable cliffs are in the Western part of the Harju plateau on Väike–Pakri Island (13 m high), on Pakri Cape (24 m), at Türisalu (30 m) and at Rannamõisa (35 m). Under the shore, the cliff continues with steep slopes or several terraces, reaching 100 m high. The overall cliff height is thus measured at approximately 150 m.

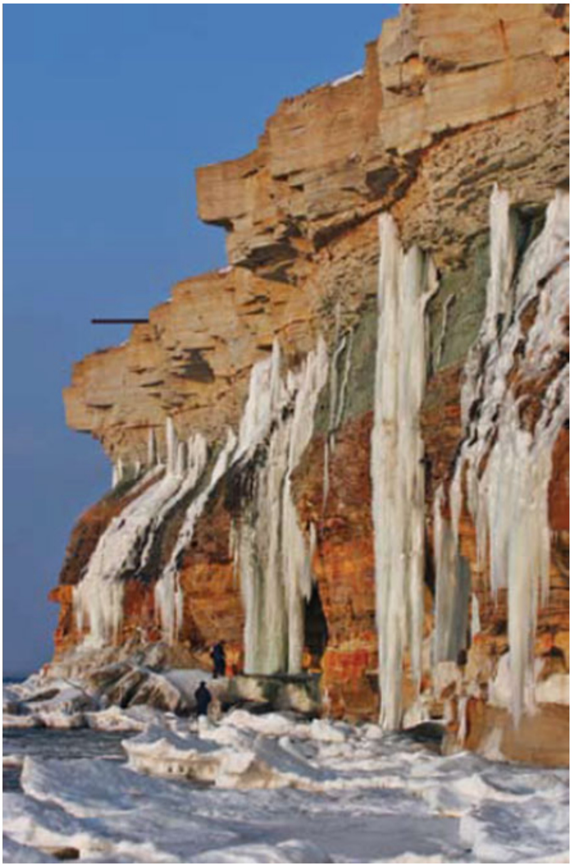

Fig. 3 The North–Estonian Klint is the cliff formed by the slope of the limestone plateau bordering the coastal plain [9]

4 Drainage Basin of the Baltic Sea

This section deals with large transboundary rivers and some of their transboundary tributaries discharging into the Baltic Sea. It also contains reservoirs in the Baltic Sea system.

The Baltic Sea, with a composition that is neither sea nor fresh water, is one of the most massive brackish water bodies in the world. Approximately 200 rivers in the basin flow into the sea, leading to the generally low salinity of the ocean [13]. Nearly half of the flow comes from the seven main rivers in the catchment area [14]. Salinity varies widely across the sea, but it is about one-fifth that of the world's oceans, which are too low to support most marine species and too salty for most aquatic animals [15]. The result is a unique, highly sensitive marine ecosystem.

Nine countries directly border the Baltic Sea ("littoral states"): Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Sweden, and Russia. The catchment area covers 1.7 million km^2 and includes five more riparian countries: Belarus, Czech

Republic, Norway, Slovakia, and Ukraine. In the Baltic Sea zone, about 85 million people live. Around 20 million of those live within 10 kilometer (km) of the coastline of the ocean and about 50 million live within 150 km of the sea. Land cover and population density vary widely within the region. The region's southern part contains highly populated urban areas and extensive agricultural land. Vast expanses of trees, rivers, and wetlands cover the landscape in the north and include some very sparsely populated areas. The population density in Poland, Germany, and Denmark ranges from over 500 inhabitants/km^2 to less than 10 inhabitants/km^2 in the northern parts of Finland and Sweden [16].

Traditionally, the sea zone has been divided into the following sub-catchment areas: Bothnian Bay, Bothnian Sea, Archipelago Sea, Finnish Gulf, Riga Gulf, Baltic Proper, Belt Sea, and Kattegat [7]. Geography of the Baltic makes it particularly vulnerable to damage to the environment. The sea is relatively shallow, with an average depth of about 55 m and a one-fourth surface area of its catchment area. Therefore, relatively large sources of land-based pollutants are provided by a limited volume of water. In contrast, the Baltic Sea is semi-enclosed, with only a small outlet south of the Danish Strait allowing for limited water exchange with the North Sea and finally with the Atlantic Ocean [17]. Just 3% of the water is shared every year. The replenishment of the sea takes approximately 25–30 years, which ensures that any harm to the ecosystem can be maintained for a long time [18]. Table 1 shows the transboundary waters in the basin of the Baltic Sea.

5 Fragile Ecosystem

The Baltic Sea's unique ecological character is caused primarily by slow water exchange with the rest of the World Ocean. Through the Danish Belts, which are quite narrow and deep, the Baltic Sea is related to the North Sea—the depth at the shallowest areas of the Belt Sea is only 18 m, while in the Sound is only 8 m. Consequently, saline water inflows are typically minimal—ca. 475 km^3 per year relative to the brackish water outflow—approx. 940 km^3 into the North Sea. At the same time, the Baltic Sea is continuously provided with freshwater (approx. 660 km^3 per year) from over 250 rivers, including the Oder, the Vistula, the Nemunas, the Daugava and the Neva rivers, as well as precipitation.

This produces brackish water conditions with an average salinity of about 6–8‰, which is very low compared to the salinity in the ocean (ca. 35‰). The salinity in the semi-enclosed bays with large freshwater inflow is even lower, such as the mouth of the Finnish Gulf with the Neva River and the mouth of the Daugava River in the Gulf of Riga.

Saltwater intake and brackish water outflow are natural processes that take place simultaneously. Discharge of the brackish water occurs at the surface layer, while at the sub-surface layer more saltwater flows in the opposite direction. The effect is water column stratification and a boundary forming between the more saline bottom water and less saline surface water called halocline. Stratification can be noticed

Table 1 Transboundary waters in the basin of the Baltic Sea (recipient)

Basin/sub-basin(s)	Total area (km^2)	Riparian countries	Hydrology of the basin
Torne	40,157	FI, NO, SE	The river starts at Torneträsk Lake (Norway), which is the river basin's largest lake. The river's length is around 470 km. On the Torne tributaries, there are two dams: one on the Tengeliönjoki River (Finland) and the other on the Puostijoki River (Sweden). At the Karunki site, the discharge in the period 1961–1990 was 387 m^3/s, with the following minimum and maximum values: MNQ = 81 m^3/s and MHQ = 2197 m^3/s. Spring floods may occasionally cause damage in the downstream part of the river basin
Kemijoki	51,127	FI, NO, RU	The river originates near the border with Russia and usually flows southwest to the Gulf of Bothnia at Kemi for about 483 km. The river system is used for the development of hydroelectric power and is vital for salmon fishing and log transport. For 1971–2000, the mean annual discharge at the Isohaara site was 566 m^3/s with a minimum discharge of 67 m^3/s and a maximum discharge of 4824 m^3/s. Spring floods cause erosion damage on the bank of the Kemijoki
Oulujoki	22,841	FI, RU	The basin of Oulujoki is complex, with heavily modified bodies of water and natural waters. The Oulujoki basin's coastal area contains special brackish waters. At the Merikoski monitoring site (Finland), the mean annual discharge for the period 1970–2006 was 259 m^3/s (8.2 km^3/a)
Juustilanjoki	296	FI, RU	The Juustilanjoki basin on the Finnish side comprises the Mustajoki River, the Kärkjärvi River catchment and part of the Saimaa Canal, including the Soskuanjoki River. Average discharge was shown by random current meter measurements at the Mustajoki site to be 0.8 m^3/s, and at the Kärkisillanoja site of 0.2 m^3/s. Lake Nuijamaanjärvi (total lake surface 7.65 km^2) is part of the Juustilanjoki river basin. The lake is situated south of the Salpausselk ridge at the border of Finland and the Russian Federation. From the total lake area, 4.92 km^2 are in Finland and 2.73 km^2 in the Russian Federation

(continued)

Table 1 (continued)

Basin/sub-basin(s)	Total area (km^2)	Riparian countries	Hydrology of the basin
Rakkonlanjoki	215	FI, RU	The Rakkolanjoki River, a Finnish and Russian Federation transboundary river, is a Hounijoki tributary. The Hounijoki's final recipient is the Finnish Gulf (Baltic Sea). The mean annual discharge at the border with the Russian Federation is very small (1.3 m^3/s) and varies between 0.2 and 7.4 m^3/s (1989–2001)
Urpanlanjoki	557	FI, RU	The Urpalanjoki River flows to the Russian Federation from Lake Suuri-Urpalo (Finland) and ends up in the Finnish Sea. Its mean annual discharge at the gauging station in Muurikkala is 3.6 m^3/s (0.11 km^3/a). In the river basin, the Joutsenkoski and the Urpalonjärvi dams regulate the water flow. Altogether there are also 11 drowned weirs
Narva	53,200	EE, LV, RU	The Narva River is only 77 km long, but its flow is very high, ranging between 100 and 700 m^3/s. Its source is Lake Peipsi. The Narva reservoir was constructed in 1955–1956. Its surface area at normal headwater level (25.0 m) is 191 km^2 and the catchment area is 55,848 km^2. Only 40 km^2 (21%) of the reservoir fall within the territory of Estonia
Gauja/Koiva	8,900	EE, LV	The Koiva River's length is 452 km, 26 km of which is in Estonia. Run-off data is not available in Estonia. The Koiva basin's largest rivers are the Koiva itself and the rivers Mustjõgi, Vaidava, Peetri and Pedetsi
Daugava	58,700	BY, LT, LV, RU	The Daugava rises in the Valdai Hills and flows into the Riga Gulf through the Russian Federation, Belarus, and Latvia. The total length of the river is 1020 km
Lielupe	17,600	LT, LV	At the confluence of two transboundary rivers, the Lielupe River originates in Latvia: the Musa River and the Nemunelis River, also known as the Memele. The Musa has its source in the Tyrelis bog (Lithuania) and the Memele River in the Aukstaitija heights west of the city of Daugavpils (Latvia). The Lielupe River ends in the Baltic Sea. It has a pronounced lowland character. Besides the Musa and Nemunelis, there are numerous small tributaries of the Lielupe River, whose sources are also in Lithuania

(continued)

Table 1 (continued)

Basin/sub-basin(s)	Total area (km^2)	Riparian countries	Hydrology of the basin
Venta	14,2922	LT, LV	The source of the Venta River is Lake Parsezeris in Lithuania's Zemaiciu Highland; the Baltic Sea is its final receiver. The Barta /Bartuva River has its source in Lithuania's Zemaitija highlands and discharges into the Liepoja Lake (Latvia), which has a Baltic Sea connection. The Sventoji River's source is in the West Zemaitija plain in Lithuania; its final recipient is the Baltic Sea. All three rivers—the Venta, Barta/Bartuva and Sventoji—are typical lowland rivers
Barta	…	LT, LV	The Barta /Bartuva River has its source in Lithuania's Zemaitija highlands and discharges into the Liepoja Lake (Latvia), which has a Baltic Sea connection. The source of the Sventoji River is in the plain of West Zemaitija in Lithuania; the Baltic Sea is its final receiver. All three rivers—the Venta, Barta/Bartuva and Sventoji—are typical lowland rivers
Sventoji	…	LT, LV	The source of the Venta River is Lake Parsezeris in Lithuania's Zemaiciu Highland; the Baltic Sea is its final receiver
Neman	97,864	BY, LT, LV, PL, RU	The river Neman has its source in Belarus (Verkhnij Nemanec settlement) and ends up in the Baltic Sea. The basin's character is pronounced lowland. Large transboundary tributaries (shared by Lithuania) to the Neman River include the Merkys, Neris/Vilija and Sesupe rivers. In Lithuania, there are 48 reservoirs (>1.5 km length and >0.5 km^2 area) and 224 lakes (>0.5 km^2 area) in the RBD
Pregel	15,500	LT, RU, PL	There are two transboundary tributaries on the Pregel River: the Lava River (also known as the Lyna River) and the Wegorapa River (or Angerapp). The confluence of the Wegorapa and Pisa rivers in the Kaliningrad Oblast (Russian Federation) is generally regarded as the origin of the Pregel River. The major tributaries of the Pregel have their sources in Poland (the Wegorapa and Lava). Poland also shares the Russian Federation with a very small part of the Pisa. On Polish territory, there are 133 lakes in the Pregel basin with a total area of 301.2 km^2. There are also six NATURA 2000 sites, including the Lake of Seven Islands, a combined NATURA 2000 and Ramsar site of 10 km^2 situated very close to the Polish-Russian border

(continued)

Table 1 (continued)

Basin/sub-basin(s)	Total area (km^2)	Riparian countries	Hydrology of the basin
Vistula	194,424	BY, PL, SK, UA	The Bug River has its source in the northern edge of the Podolia uplands in the L'viv region (Ukraine) at an altitude of 310 m, also called the Western Bug to differentiate it from the Southern Bug in Ukraine. The river forms part of the Ukrainian-Polish frontier, crosses the Polish-Belarusian border, flows through Poland and empties into the Narew River near Serock (actually the man-made Zegrzynskie Lake, a dam built as the main source of drinking water in Warsaw). The most important transboundary river in the Vistula basin is the Bug River, shared by Belarus, Poland, and Ukraine
Oder	118,861	CZ, DE, PL	The 855 km long Oder River has its source at an altitude of 632 m in Góry Odrzańskie (Czech Republic), the southeastern portion of the Central Sudety mountain range. In the recorded period 1921–2003 (without 1945), the annual mean discharge at the Hohensaaten-Finow station (Germany, upstream basin area 109,564 km^2) has varied between 234 and 1,395 m^3/s. The mean average discharge was 527 m^3/s with an absolute maximum of 2580 m^3/s (in 1930) and an absolute minimum of 111 m^3/s (in 1921)

FI Finland, *NO* Norway, *SE* Sweden, *RU* Russia, *EE* Estonia, *LV* Latvia, *BY* Belarus, *LT* Lithuania, *PL* Poland, *SK* Slovakia, *UA* Ukraine, and *SE* Sweden between colder bottom water and warmer surface water forming a barrier called a thermocline, particularly noticeable during summer and early autumn, but disappearing during winter when the surface water cools. Such barriers separate the deep water from interacting with oxygen-rich surface water and create deeper layers of anoxic conditions. Also, at the same time, toxins and nutrients are accumulated in the lower layers leading to the formation of "dead zones," covering up to 100,000 km^2 of the bottom of the Baltic Sea.

Living under such severe conditions is highly stressful for most marine organisms. Only a small number of species have advanced in colonizing this particular area, as salinity is too low for most species of the Atlantic and the North Sea, but still too high for the species of freshwater. Nonetheless, a mixture of species of marine and freshwater has adapted to these brackish waters. That species plays a specific role in preserving the stability and dynamics of the entire system in such a young and fragile ecosystem as the Baltic Sea, with minimal biodiversity. When one species falls out, it can cause irreversible network harm, as no other species can replace it [7]. Such factors clarify the Baltic Sea's unique character and fragility as an ecosystem. It is highly vulnerable to change and contamination and is one of the most polluted oceans.

6 Surface Topography in the Baltic Sea and Its Transition Area to the North Sea

A map of the Baltic Sea's mean topography of the sea surface and its transition area to the North Sea is drawn (Fig. 4). Two primary features of the topography of the sea surface are found here. First, there is a steady increase in sea surface height from the North Sea to the Baltic Sea, with a height difference of 35–40 cm between the inner part of the Gulf of Bothnia and the Skagerrak. The main reason behind this is the significant salinity disparity, close to the maximum possible. Second, in the border zone between the Kattegat and the Skagerrak, a steep gradient of sea-level exceeds 2 cm per 10 km. It represents the salinity front that divides the brackish Baltic Seawater from the saline water of the North Sea and the associated Baltic Sea. In the Oslo Fiord, a regional peak can be seen on the sea surface, indicating an accumulation of low-salinity water.

7 General Types of Waters Considered in the Coastal Seas Around Europe

For coastal seas across Europe, there are two general types of water considered: marine and transitional waters. Coastal waters are bodies of surface ocean water up to one nautical mile from the baseline on the seaward side from which the width of

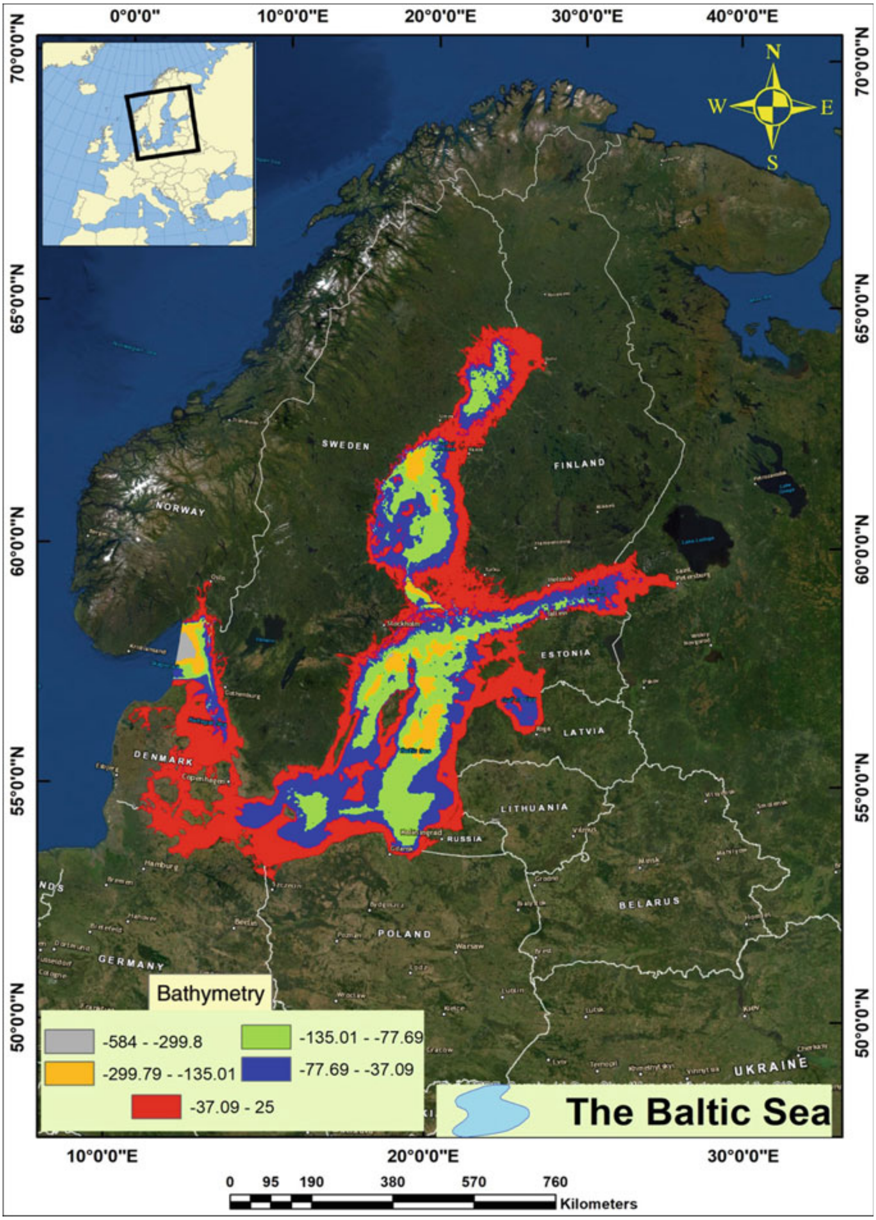

Fig. 4 The Baltic Sea's mean topography of the sea surface and its transition area to the North Sea

territorial waters is determined (Fig. 5). Transitional waters are surface water bodies in the vicinity of river mouths that are significantly influenced by freshwater flows.

Salinity is always the first variable in every water body to determine the environmental composition and classifies water bodies into salinity categories. Figure 6 displays the resultant surface salinity for the whole Baltic Sea. Salinity thresholds used to differentiate between types were chosen: Freshwater <0.5 PSU, Oligohaline waters 0.5–6 PSU, Mezohaline waters >6–18 PSU, Polyhaline waters >18–30 PSU [19].

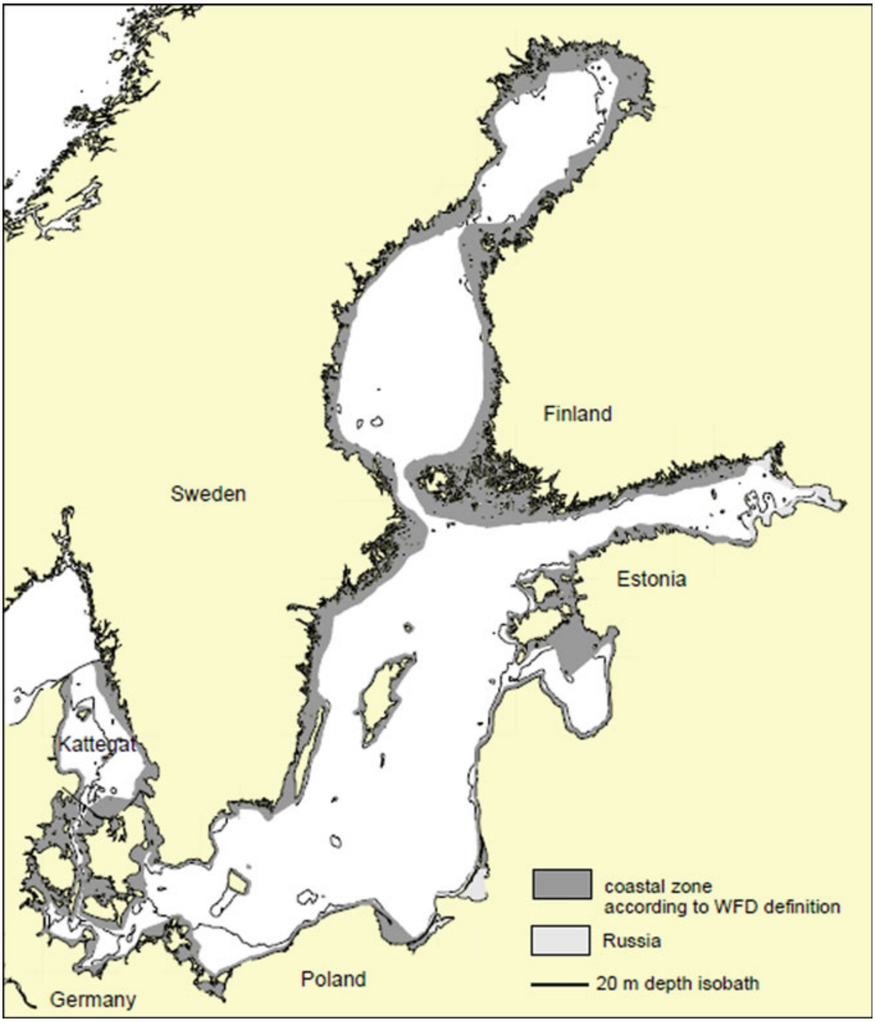

Fig. 5 The coastal waters of the Baltic Sea Ecoregion [19]

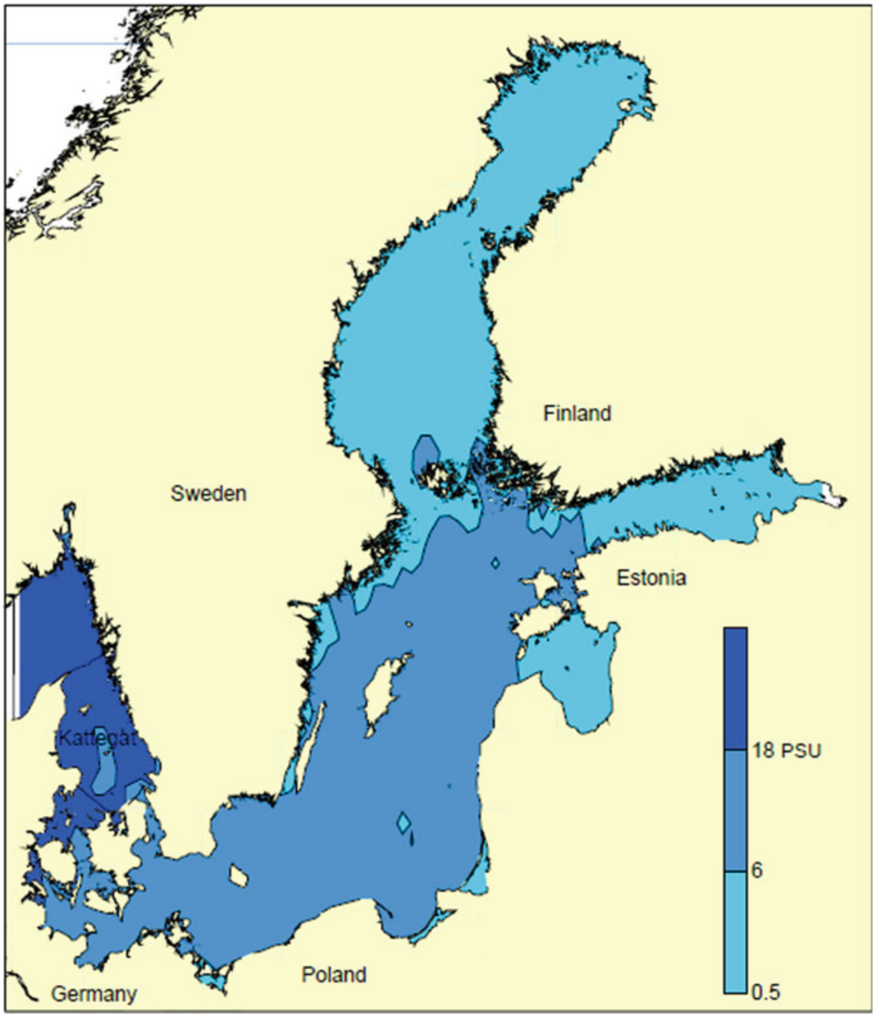

Fig. 6 Distribution of salinity in surface Baltic Sea waters up to 5 m depth [19]

Therefore, the typology of the Baltic Sea comprises three salinity classes, from oligohaline to polyhalite waters.

Water exchange in the coastal sea zone is considered to be an essential factor. The water exchange has a significant impact on the water column's concentration of substances and the system's sediment/water movement. It is understood that enclosed systems vary from open coastal waters, as many chemical and biological parameters depend on the time of absorption of water in both freshwater and marine systems [19]. Water exchange was also one of the main factors used in the typology of Sweden for which three water classes according to the water exchange time were used [19]: 0–10 days, 10–40 days and >40 days. This approach in differentiating open

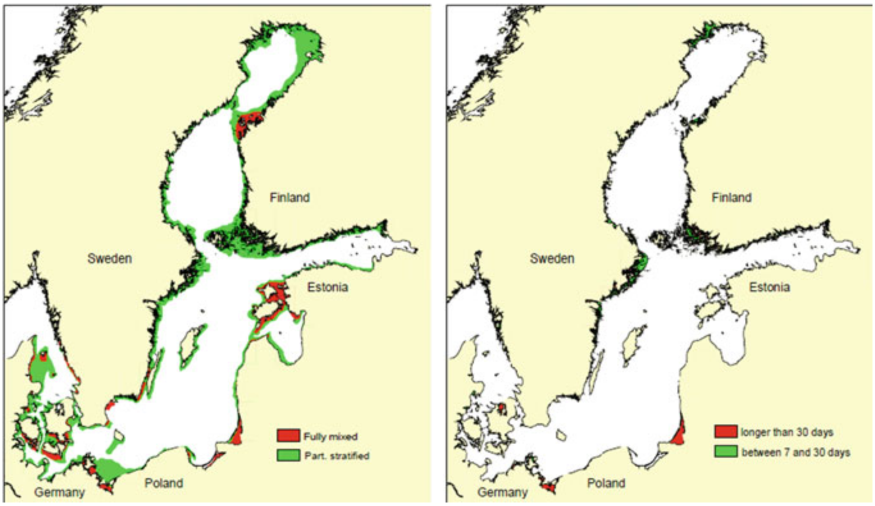

Fig. 7 Stratification (left) and water residence time (right) in selected inshore areas of the Baltic Sea [19]

coastal waters from enclosed areas and inner archipelagos was used. Using mathematical models, water residence time and stratification measurement are performed. Residence time is not an acceptable criterion for open waters because it depends on the size of the area considered. A very general first partition of the coastal zone was made based on residence time estimates based on the open sea exchange (>30 days, 10–30 days) and salinity stratification (Fig. 7).

Depth affects many other aspects of ecosystem features such as water column mixing and stratification, light penetration and distinctive sediment influences. Accordingly, in the Baltic Sea Ecoregion typology, it was presumed that the 20 m is a depth limit for most of the coastal WFD area. Only within a few baselines, delimited coastal waters are deeper than 20 m and in such locations, this typology leaves areas that, if possible, should be further categorized as different forms based on additional depth categories (e.g. under national typologies).

The typology method of the Baltic Sea makes the expansion to the whole Baltic Sea. It allows for a more comprehensive view of reference conditions, schemes for classification of water quality and monitoring (Fig. 8).

8 Is the Land Going up or the Water Going Down? Future Baltic Sea Level Rise

The first written document on raising the Baltic Sea level dates back to 1491. That year four townspeople from Östhammar, a town on the Baltic Sea coast somewhat north of Sweden, went to Uppsala to protest this their harbor could no longer be

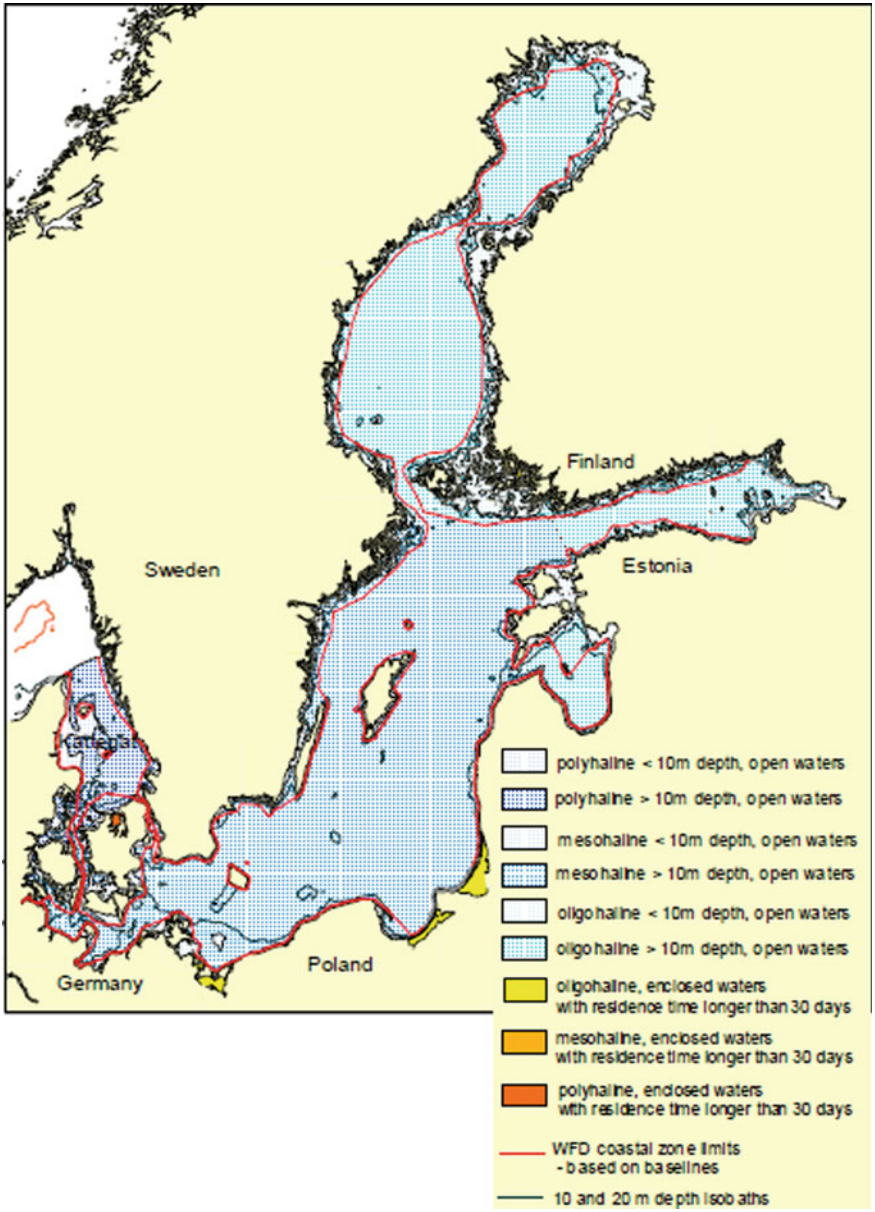

Fig. 8 Distribution of types for the entire Baltic Sea typology [19]

reached by ship [20]. During recent years, the land has grown outside the town at sea, so that where some years ago a cargo boat of five or six Swedish läster [about 15 tons] could come from the sea into the town of Östhammar not even a fishing-boat can go nowadays. And the land continues to grow and grow every year. Sweden was in union with Denmark and Norway at this time, their common king residing in Denmark.

The above-mentioned text is the earliest explanation of the phenomenon we know today as the postglacial rebound or postglacial land elevation. The location of the Östhammar harbour probably stemmed from the 1100s. By the end of the 1400s, the people then must have been subject to a land uplift of nearly 2 m, entirely sufficient to destroy their shallow harbour. Where their harbor is today is dry land. One of the original buildings from 1491, thus erected due to the land elevation, is still to be seen in the new town of Öregrund, namely the church. The same problem appeared one and a half centuries later, but now farther north, in the northern part of the Bothnian Gulf. It was appropriate to move the harbor town of Luleå here. The townspeople and their mayor have also requested permission to evacuate the town [20]. The Luleå harbor site dates back to the 1300s. By the middle of the 1600s, this shallow area had to be exposed to nearly 3 m of land elevation, making it distinctly necessary to move the town and its harbor. The new city kept the old name, while the old city still remains as an old market place called Gammelstaden, "the old town."

Many rivers flowing into Bothnia and Finland's Gulfs, as well as the Baltic itself, caused the seawater to be much lower earlier than it is now. Such water must have continued to flow to the North Sea, eroding and widening the outlet in the long run. As a result, the Baltic Sea level should have been much lower. We may recognize here that while Östhammar/Öregrund's townspeople in 1491 identified the phenomenon as rising ground, it was defined two centuries later as a falling sea level. The townspeople probably considered their harbor dilemma to be entirely local, giving them the illusion of a land elevation [20].

So how could one judge whether the land went up or the water went down? Well, a solution might be to calculate the occurrence frequency for a long time over a larger area, in this case, across the entire Baltic Sea. This would basically give three possibilities [20]:

1. In the Baltic Sea, the same rate of change would suggest a general decline in water.
2. A higher rate of change in the north than in the south may suggest a decline in latitude-dependent water.
3. Different exchange rates in various parts of the Baltic Sea may suggest local land elevation.

As a result of global warming, a future rise in sea level will affect the coastal regions of the world. Although the speed of sea-level rise is not apparent, it will have severe and global implications. For relatively vulnerable developing countries, the effects of future sea-level rises are commonly investigated; however, a whole range of varying regions need to be considered in order to understand global consequences better.

The rate of rising in sea level is continuing to increase, according to IPCC [21]. A global mean rise in sea level of 0.63 m is likely to occur before 2100, with a practically assured continuous rise in sea level after this point [21]. On a millennium scale, the Greenland Ice Sheet's near-complete loss would cause an annual sea-level rise of 7 m with high confidence [21]. Consequently, the precise frequency and amount of future rise in sea level is highly uncertain [22]. In any scenario, the projected future increase in the sea level would flood areas along the coasts of the country, where we consider most of our communities and infrastructure (e.g. [23]). We are going to have to adapt. A first step in the adaptation process is to examine the impact on nature, human beings, and culture, including infrastructure, of sea-level rise, reversible, or irreversible.

Seawater intrusion into coastal aquifer systems would be a regular and potentially extreme consequence of the sea-level rise in coastal regions. For the Baltic Sea and elsewhere, several researches concentrated on the effects of climate change on the discharge of rivers [24]. Sherif and Singh [25] introduce one of the first studies on the effects of climate change on the accumulation of seawater in two coastal aquifers. Just relatively modest changes in mean sea level will be relatively far in the inland direction shift the toe position of the freshwater-saltwater interface of coastal aquifers. More specifically, studies indicate that the thickness and size of the Baltic Sea's coastal freshwater dams can be significantly reduced under increasing environmental conditions [26].

9 Adapting to Climate Change

The climate is changing throughout the world. Regardless of mitigation measures, i.e., greenhouse gas reduction initiatives, it will be essential to adapt to the changes already triggered by greenhouse gas emissions in order to meet the ecological, economic, and social implications anticipated by experts. Therefore, current climate policy is based on two pillars: reducing greenhouse gas emissions and responding to the already foreseeable effects of climate change.

Climate change mitigation was recognized at the national level in the Baltic States as an essential issue, and the first set of measures was adopted. In Estonia, Latvia, and Lithuania, however, the portfolio of adaptation steps is much more limited. This becomes particularly evident when comparing the Baltic States' already taken action on adaptation with other Baltic Sea area countries, such as Germany and Finland, which have established national adaptation plans and are already actively implementing climate change adaptation measures.

Addressing adaptation to climate change is essential, not only in order to be consistent with EU goals and priorities but also because some Baltic States regions are already experiencing first changes in the natural environment. In coastal areas, for example, climate-related changes such as rapid sea-level rise, more rise in sea-level temperatures and more extreme weather events can be expected to have a variety of impacts [27]. For example, the storm of January 2005 had a major impact on all three

Baltic States [28] and Latvia, Lithuania and Estonia will become more vulnerable to coastal erosion and flooding as climate change increases the frequency and intensity of storms in the Eastern Baltic Sea region [27].

10 Problems Meet Solutions

It remains a challenging task to solve the current environmental issues as the scale of economic activity in the Baltic Sea rises from year to year. Strengthened maritime regulations that lead to fewer incidents in the future. However, it seems issues such as eutrophication or off-shore oil and gas industries are will stay and in some cases and places are growing. Smart solutions are needed to overcome the trade-related problems of fish resource exploitation and, at the same time, meet fish demand. Continuing the small-scale coastal fishing industry as an essential part of the coastal communities' lifestyle and identity is also important. Fisher–folk are looking for new ways of managing their resources as traditional fishing methods are no longer enough.

Climate change is a complex issue concerning problems such as rising sea level, changing weather and water temperatures, shifting patterns of distribution of species, intensifying bad weather, etc. It is a global challenge to address these issues, but each country has to do its part. They will significantly increase the likelihood of a successful outcome by working together, educating and encouraging each other, sharing good practices on how to reduce the effects of climate change.

One of the solutions to coping with the rapidly changing environment is renewable energy. Wind and wave turbines are becoming increasingly common, although ensuring that they do as little harm as possible to the environment is crucial.

Nevertheless, the adoption of new resource management strategies and marine environmental protection initiatives alone will likely not produce the desired result if the people of the Baltic Sea countries, who are the end-users of the many services that the sea offers, do not change their minds towards more sustainable ways of living and consuming resources.

11 Conclusions and Meeting Future Challenges

The Baltic Sea is a shallow semi-enclosed sea with an area of 415,000 km^2 and a maximum depth of 460 m. A heterogeneous wide area is the Baltic Sea Drainage Basin (BSDB). The drainage basin is shared by 14 nations, covering an area of 1,739,000 km^2 and nearly 84 million inhabitants. There are 14 larger international river basins within the BSDB, with an approximate area of 1,050,000 km^2. These river basins vary in size, a number of countries sharing basins, environmental issues encountered and how they are treated. More than 200 rivers flow into the Baltic Sea, producing a catchment and drainage area of nearly 1,700,000 km^2 that is about four times larger than the sea itself. This catchment area is considered to be part of the Large Marine Ecosystem of the Baltic Sea (BSLME).

As a result of global warming, potential sea-level rise would impact the world's coastal regions. Although it is not known how high the sea level rises, it will have significant and international consequences. So how could one judge if the land was going up or the water was going down? A solution could be to measure the rate of incidence over a broader area for a long time, in this case, throughout the Baltic Sea. Renewable energy is one of the ways to cope with the rapidly changing environment. Wind and wave turbines are becoming increasingly common, although it is vital to ensure that they harm the environment as little as possible. Nonetheless, the adoption of new resource management approaches and marine environmental protection programs alone will probably not yield the desired result if the citizens of the Baltic Sea countries, who are the end-users of the many services offered by the sea, do not change their minds towards more sustainable ways of living and consuming resources.

Resolving the current environmental issues as the level of economic activity in the Baltic Sea rises from year to year remains a challenging task. The improved maritime legislation is leading to fewer incidents in the future, but problems like eutrophication and offshore oil and gas industries are here to stay and develop in some cases and areas. Smart solutions are needed to overcome the trade-related problems of fish resource exploitation and, at the same time, meet fish demand. Continuing the small-scale coastal fishing industry as an essential part of the coastal communities' lifestyle and identity is also important. Fisher–folk are looking for new ways of managing their resources as traditional fishing methods are no longer enough.

Successful spatial planning for the Baltic Sea in the future relies on the following:

1. Sustainability. Spatial planning addresses economic prosperity, social well-being, and environmental targets at the same time and balances their respective needs.
2. Pan-Baltic thinking. Considers the whole Baltic Sea ecosystem and the whole Baltic Sea as one planning space.
3. Pan-Baltic topics that need to be addressed jointly include a healthy marine environment, a coherent pan-Baltic energy policy, safe, clean and efficient maritime transport, and sustainable fisheries and aquaculture.

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