Chapter 1
Introduction

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1.1 The Baltic Sea

The Baltic Sea (Fig. 1.1) stretches from the Gulf of Finland to the Kattegat over 1,200 km in the east–west direction and from Odra Bay to Bothnian Bay near the polar circle over 1,300 km in the north–south direction. It covers an area of 415,266 km^2 and has a water volume of approximately 21,000 km^3. Traditionally, it has been divided into five main regions (Table 1.1).

- Belt Sea–Kattegat (including Sound) in the Western Baltic Sea
- Baltic Proper, with the Arkona Sea, Bornholm Sea and Gotland Sea
- Gulf of Bothnia, with the Åland Sea, the Archipelago, the Bothnian Sea and the Bothnian Bay
- Gulf of Finland
- Gulf of Riga

The catchment area of 1,745,100 km^2 comprises the nine countries bordering the Baltic Sea and a further five countries not bordering the Baltic Sea. Around 48% of the catchment area is covered by forest, 20% is arable land, 17% is open, non-productive land and 8% is marshland. Approximately 85 million people inhabit the catchment area.

The influence of the shore side is basically determined by the amount of the river inflows. Major inflows come from the rivers Neva, Vistula, Neman, Odra and Daugawa, with the Neva accounting for 20% of the freshwater inflow of the whole Baltic Sea (average annual runoff 2,500 $m^3\ s^{-1}$).

Since Baltic water can, in turn, advance far into the interior, depending on the sea water level and seasonal changes in the water regime, a basic knowledge of the structure and function of the Baltic Sea is necessary to grasp the processes occurring in the estuaries.

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Fig. 1.1 The Baltic Sea. The main subareas of the Baltic Sea and their catchment areas (outlined in *white*) are indicated (HELCOM 2001)

Table 1.1 Characteristic data on the Baltic Sea and its five main sub-areas (HELCOM 2001)

Subarea	Sea area (km^2)	Sea volume (km^3)	Maximum depth (m)	Average depth (m)	Freshwater input ($km^3\ a^{-1}$)
Baltic Proper	211,069	13,045	459	62.1	100
Gulf of Bothnia	115,516	6,389	230	60.2	193
Gulf of Finland	29,600	1,100	123	38	100–125
Gulf of Riga	16,330	424	>60	26	18–56
Belt Sea-Kattegat	42,408	802	109	18.90	37
Baltic Sea area	415,266	459	52.3		

1.1.1 Geological Background

The geological subsoil in the north of the Baltic Sea is formed mainly by Precambrian and Palaeozoic crystalline bedrock. In the southern parts of the Baltic Sea, glacial and pre-glacial deposits predominate, overlying the old sedimentary layers of the Silure and the Tertiary (Winterhalter et al. 1981). In contrast to the crystalline bedrock, the glacial and pre-glacial deposits are very rich in calcium, which may contribute to the Calcium-anomaly in Baltic Sea water (see below).

Compared with the North Sea, which was part of the Zechsteiner shelf as early as 180 million years ago, the Baltic Sea is a very young water body. Its present shape developed only 12,000 years ago. Only the southern part of the Baltic Sea was ever a (temporary) part of the Zechsteiner Shelf Sea.

The postglacial history of the Baltic Sea began when the glacial ice crusts began to melt and a freshwater ice sea emerged. A first surface connection to the ocean appeared over central Sweden approximately 10,000 years ago. As a result of water exchange, the brackish "Yoldia Sea" was formed. Strong salinity variations were probably characteristic of that period, as there was also a second temporary connection to the White Sea. Upward movements of the earth's crust closed these early connections to the ocean at around 9,250 BC. A freshwater sea – the "Ancylus Sea" – developed, which existed from 9,250 to 7,100 BC.

As a brackish sea close to its present shape, the Baltic has existed since 7,100 BC. From 7,100 BC to 4,000 BC, the "Littorina Sea" developed, with *Littorina litorea* as the index species. During the next 4,000 years, the salinity again decreased. The freshwater mussel *Limnea ovata* (Limnea period) became the index species. This was followed by the "Mya period" (*Mya arenaria*) approximately 1,500 years ago; this index species remains characteristic of the current Baltic Sea.

A striking feature of the Baltic Sea is its topographical structure, with the Darß Sill and the adjacent large Baltic basin as characteristic features (Fig. 1.2). The Darß Sill represents the border between the Baltic Proper and the Western Baltic. With a maximum depth of 18 m the Darß Sill (and also the Drogen-Sill/Øresund with a depth of 7 m) makes the connection to the North Sea considerably more difficult. This explains why it is only through irregular bigger or smaller inflow events of North Sea water that larger amounts of water with considerably higher salinity can enter the Baltic. The deepest part of the Baltic (the Landsort Deep; 459 m) is located in the eastern Gotland Basin; its oxygen supply is completely dependent on the inflow of North Sea water.

According to the criteria formulated by Hakanson and Jansson (1983), bottom type classification differentiates between three basic area types:

- Accumulation areas prevail where fine materials can be deposited continuously
- Transportation zones appear where there is continuous deposition of fine particles/aggregates
- Erosion areas prevail where there is no deposition of fine material.

A further aspect is coastal change as a late inheritance of the ice age. Having been freed of the ice crust, which was at that time several kilometres thick, Norway,

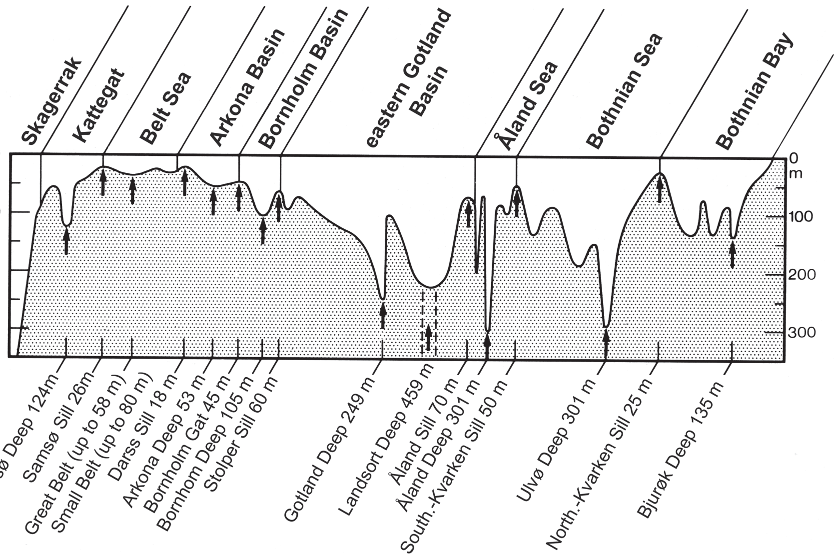

Fig. 1.2 Depth profile in longitudinal axis. Depth of basins and sills in metres (Rheinheimer 1995)

Sweden and Finland are still rising at a rate of up to 9 mm year^{-1}. As a countermove, the Southern Baltic coast sinks by 1–2 mm year^{-1} (Fig. 1.3). Over long periods this leads to clear changes in the coastlines.

1.1.2 Climate, Hydrology and Chemistry

The theoretical residence time of water in the Baltic is approximately 32 years. This is calculated from the total volume of 21×10^3 km^3 and the average value of the total inflow (approximately 16,000 m^3 s^{-1} fresh water + approximately 4,000 m^3 s^{-1} salt water at 35 psu).

Predominantly physical processes control water exchange in the Baltic Sea. In the southern part, such processes are directed mainly towards the east or north-east, with a counter current in the northern part of the Baltic. Correspondingly, we find run-off of less salty surface water along the northwest coast into the North Sea.

In the course of a year, clear differences in the surface water can be observed. During spring and summer, new fresh water coming from rivers and less salty lakes is kept on the surface by the low salinity and the developing thermal stratification. This leads to a salinity minimum at the end of the summer. Normal conditions are restored in late autumn and winter by mixing with water from the region of permanent haloclines. Mixing is guaranteed by the usual surface activities, with a shift of surface water into deeper zones via Ekman transportation.

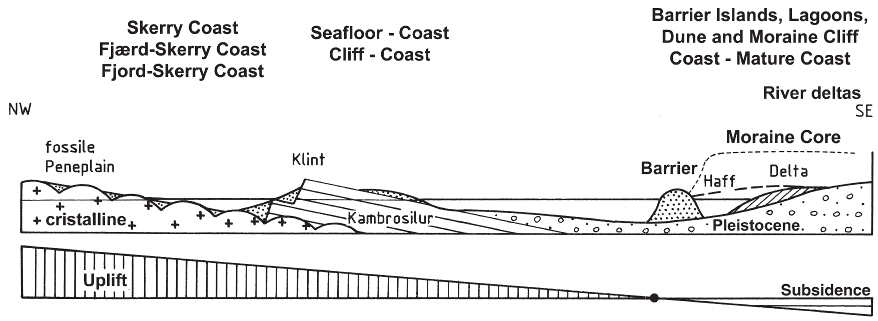

Fig. 1.3 Principal spatial arrangement and correlations of coastal types of the Baltic Sea. Structure of subsoil and isostatic compensation movements (Lampe 1996)

The Baltic Sea represents a "microtidal" system, with an average daily tidal component of 15 cm. Only the Kattegat, being under the influence of the North Sea, shows higher tide amplitudes. Changes in the sea level therefore emerge due to air pressure differences and the influence of the wind, and can reach values up to over 3 m above and 2.5 m below sea level. In the innermost Gulf of Finland, seiches can lead to changes in sea level of up to 4 m above sea level (Fonselius 1996). Tiesel (1995) describes a seasonal behaviour with high air pressure over the whole Baltic Sea in the winter (October–February, partly also in May). In the summer months it is mainly the southwest Baltic that is influenced by strong air pressure gradients.

Connected with water exchange is the transportation of sediments. Sediment transport is characterised by the shifting of sedimentary material from the shallower western or north-eastern basins into the deeper Gotland Basin. During such transport, transformation processes change the structure of the sediment considerably.

The total amounts of carbon, nitrogen and phosphorus (in tons, for the whole Baltic Sea deposition bottom area in 1–5 cm sediment) are 48.3×10^6, 5.6×10^6 and $1{,}295 \times 10^3$, respectively (Carman and Cederwall 2001). The high amount of organic carbon in the deep offshore sediments of the Baltic Proper (36.7×10^6 t) is due most likely to high primary production (Jonsson and Carman 1994) and altered decomposition efficiency.

The north-south extension of the Baltic Sea of more than 1,200 km and its integration into the North European continent results in a strong temperature gradient from south to north. Thus, the mean annual temperature near Warnemünde in the southern Baltic amounts to +8.4°C, whereas near Helsinki it is only +4.5°C. There is also an increasingly continental climatic influence on eastern and northern parts of the Baltic, explaining why regular ice coating in the winter is characteristic of the eastern and northern Baltic Sea. In severe winters it can cover almost the entire Baltic.

Also connected with the north–south extension, from the southernmost point at 54°N to the northernmost at approximately 65°N, is a clear gradient of solar irradiation. Such differences, however, are minimised during the summer due to thicker cloud coverage in the south (6/8 compared to 4/8) and longer hours of sunshine (maximum 4 h) in the north. The biggest differences are therefore found in winter.

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