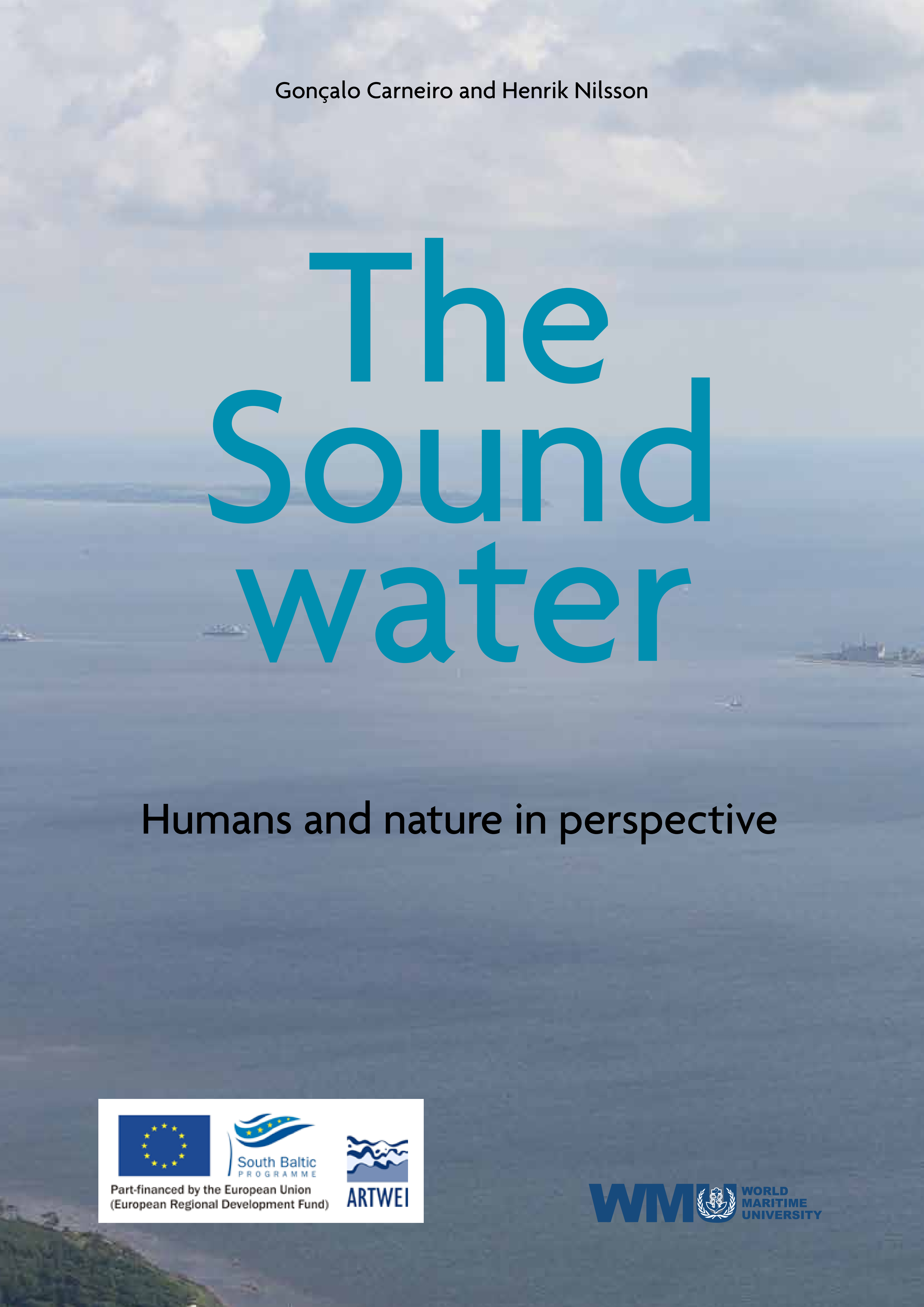
Gonçalo Carneiro and Henrik Nilsson

The Sound water

Humans and nature in perspective



South Baltic PROGRAMME
Part-financed by the European Union
(European Regional Development Fund)
ARTWEI
WMU WORLD MARITIME UNIVERSITY

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G. Carneiro
H. Nilsson
Malmö

The Falsterbo canal

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PREFACE

In most coastal regions of the globe, humans have historically relied on the ocean for the provision of a variety of goods and services. Settlements have been established along all coasts in the vicinity of fishing grounds and at maritime commerce points. The unprecedented growth in human population and the expansion in the global economy and trade of the last century have been accompanied by an ever increasing use and exploitation of the ocean. Technological advances, increasing levels of material wealth and growing concerns about the use of land-based resources have led to new claims for ocean space and resources. As a consequence, traditional maritime activities such as shipping, fishing and, in some parts of the world, aquaculture have to compete for limited space and resources with expanding offshore oil and gas exploitation, increasingly diverse maritime tourism activities, as well as emerging offshore renewable energy production and mineral resource exploration.

The Sound[1] constitutes no exception to this global trend. Historically a cornerstone in the political and economic development of Scandinavia and the Baltic, it is today one of the world´s most intensely used ocean areas. Not only does it sustain numerous local and regional activities, it is also a vital route linking the Baltic Sea to the global ocean.

Aiming to resolve increasingly diverse claims on ocean space, several countries have initiated processes for spatial ordering of maritime activities, generically known as marine (or maritime) spatial planning (MSP). With both Sweden and Denmark currently building the foundations of their respective MSP processes, a plan for the Sound is likely to emerge in the near future.

It is this development that the present report is intended to support. Its main aim is to provide an account of environmental values and status, as well as human uses of the Sound, considering not only present conditions, but also future trends. It compiles and summarises information from a variety of sources, thereby offering a uniquely comprehensive view of the importance of and threats to the Sound's marine environment. It is therefore expected to constitute not only a reference source for readers wanting to learn about the Sound, but also a valuable tool for those engaged in the management and planning of this marine area.

This book is the result of an analysis of existing literature related to the marine environment and maritime activities in the Sound, of interviews with key stakeholders in the region and of a workshop held in the spring of 2013. It is being produced as part of the ARTWEI project (Action for the Reinforcement of the Transitional Waters' Environmental Integrity), an initiative aimed at strengthening the transnational management of transitional waters funded by the EU South Baltic Programme.

1 *Öresund* in Swedish and *Øresund* in Danish. *Sundet* (the Sound) is also commonly used in both languages.

The northern part of the Sound, known as Øresundstragten or Öresundstrakten. In the foreground the Swedish town of Viken, in the distance Helsingør (right) and Helsingborg (left), and the island of Ven.

I INTRODUCTION – A BRIEF ENVIRONMENTAL HISTORY

The Sound is the strait that separates the eastern part of the Danish province of Sjælland from the western part of the Swedish province of Skåne. Together with the Little and Great Belts separating the Danish provinces of Jutland, Fyn and Sjælland, it is one of main connections between the Baltic Sea, to the east, and the North Sea, to the west, via the Kattegat and Skagerrak. Its location between these two starkly different large water bodies has given the Sound unique environmental characteristics. Its small size and narrowness, and the fact that it lies in one of the most developed regions of the world, result in it being one of its most intensely used marine areas. Its importance extends beyond the immediate neighbouring regions in Denmark and Sweden to encompass not only the whole of the Baltic Sea region, but also those other parts of the globe trading with Baltic Sea countries.

The contrasting landscapes on the north-eastern (Kullen, above) and south-eastern (Måkläppen, below) tips of the Sound.

The geological origins of the Sound date back approximately 18,000 years when the Baltic Ice Lake began to form as the result of the melting of the ice caps that covered Scandinavia. Some 3,500 years into this development a connection between this Ice Lake and the sea to the west was formed at the site of the Sound. Because of the height difference between the lake and the sea, it is believed that a large waterfall marked the site of this sill. A much larger opening to the west emerged less than 2,000 years later, leading Baltic waters to retreat along southern Scandinavia. The Sound dried out and a continuous land mass emerged stretching from northern Germany up to what is today Lake Vänern in Sweden. It was not until about 10,000 years ago – a period in the development of the Baltic Sea known as 'the Littorina Sea' – that a permanent outflow through the Belts and the Sound was established. The Littorina stage that lasted until 3,000 years ago was characterised by large fluctuations in sea level in southern Scandinavia, and it likely therefore that the Sound changed shape several times during that period. The last 2-3,000 years have been ones of relative stability, with crustal uplift in the region and fluctuations in sea level progressively ceasing. Today the Sound is limited to the north by the line stretching from Kullen in Skåne to Gilleleje in Sjælland, and to the south by the line between Stevns lighthouse in Sjælland and Falsterbo in Skåne

The earliest settlements around the Sound have been dated back to the early Littorina stage. Towards its end the region experienced important economic and cultural development that culminated during the later Bronze Age 3,800–3,000 years ago. Much of this development rested on the abundance of flint, used in local manufacture and for exports, making the Sound an important centre for trade. Exchanges with the Greek and Roman empires are believed to have occurred during the Iron Age, until about 1,500 years ago. The role of waterways as central elements in the consolidation of Scandinavian kingdoms was strengthened during the late Viking period, with the Svea kingdom centred around Lakes Vänern, Vättern and Mälaren, and the kingdom of the Danes encompassing the Belts and the Sound. The centrality of the Sound for Denmark was such that its centre was shared between the royal house in Roskilde, Sjælland and the archbishop in Lund, Skåne.

At that time, shortly after the turn of the first millennium, the Sound region entered a period of prosperity and importance that extended first across the Baltic and progressively to distant locations in Europe. At its basis lay an exceptionally rich herring fishery that every autumn attracted large numbers of people to the narrow and shallow grounds in the southern Sound. Cities such as Skanör in the south-westernmost tip of Sweden, and later Copenhagen and Malmö rose on the riches of the herring fish fairs. These soon expanded to become sites for a diversity of trades; around the year 1250 the so-called Skåne fairs ranked among the most important in medieval Europe, attracting merchants from all over the Continent. Denmark prospered commercially and culturally, not only on the fairs – which, along with the fishery, came to their demise in the 15th century – but increasingly on the control over the trade passing through the Sound. This control, in particular the Baltic toll established in Helsingør was so profitable to the Danish kingdom that Norwegian, Hanseatic and Swedish rulers repeatedly tried to expel the Danes and gain control over this entry to the Baltic. Indeed it was the control exerted by Denmark over exports from Sweden that prevented this country from fully benefitting from its large reserves of timber, iron and copper, which were in high demand elsewhere in Europe. This was a leading factor behind Sweden's campaigns to conquer Skåne from Denmark, which eventually occurred in 1658. Following the wars in Skåne, during which Denmark repeatedly tried to recover the region, the Swedish-Danish border was finally established at the Sound in 1720.

Despite the need to clearly demarcate Skåne from Denmark after the 1658 Treaty of Roskilde, the centuries that followed have been characterised by a continuous approximation, in part under the banner of Scandinavism. The recognition of the value of cross-border integration not only for intra- and inter-regional development, but also for enhanced integration with other regions in

The Kronborg castle in Helsingør, the site of the former Baltic toll.

Europe justified the construction in the late 1990s of a fixed link across the Sound. In operation since 2001, the Sound bridge and tunnel marks the beginning of yet another stage in the development of the Sound and the regions bordering it.

Industrial development around the Sound shares similarities with the evolution of the sociopolitical context. From a clear demarcation until the beginning of the 19th century, both sides have progressed along three main development phases, one of agricultural and industrial revolution in the 19th century, another of expansion of manufacturing during the first three quarters of the 20th century and finally one of economic transformation with origins in the 1970s and lasting until the present. These phases were accompanied by a succession of environmental and social crises that afflicted the region. Alongside other factors these have contributed to shaping the socioeconomic and environmental conditions in the Sound region in the last two centuries.

With its inclusion in the Swedish kingdom, Skåne went from being a central portion of a prosperous kingdom to becoming a peripheral

The Øresund Bridge seen from Limhamn in Sweden. Source: Michael Palmgren

The heavily industrialised Malmö waterfront in the early 1980s. The Kockums shipyard. Source: Sydsvenskans bildarkiv

region in an emerging one. By 1800 Skåne was markedly rural with only 8% of its population living in cities, the largest of which, Malmö, had less than 4,000 inhabitants, in marked contrast to the 100,000 then living in Copenhagen. This city was not only the key urban centre of Denmark, but also its principal industrial location. Small-scale industrial production had begun to emerge at several different locations in Skåne, and this diversification came to characterise industrial development in the region in the decades that followed. The marked intensification of industrial production in the second half of the 19th century was made possible by changes in land ownership that enabled agricultural investments and production to increase. This fostered the establishment of new trades and industries, many of them to satisfy the needs of an increasingly mechanised agriculture. Food industry was the first dominant branch on both sides of the Sound, with Skåne actually attaining an importance equal to that of Stockholm. In Denmark Copenhagen retained its dominant position; here, as well as in Malmö, metal and textile industries gained in importance alongside the food industry.

The progressive industrialisation of cities and the resulting growth of urban population resulted in a so-called hygiene crisis in the urban centres around the Sound by the turn of the 20th century. Sewage and industrial wastes had become an increasing problem in the expanding cities, leading to decisions to collect and discharge all wastewaters into the Sound. The first treatment plan opened in Copenhagen in 1920, but it was not until five decades later that other urban centres in the region acquired own plants. Air pollution in the crowded cities was also an issue of concern until after World Water II, when a conversion to energy fuels other than coal and coke began to take place.

The 20th century saw food industries lose their prominence in the rapid industrial development around the Sound, as textile and export-oriented

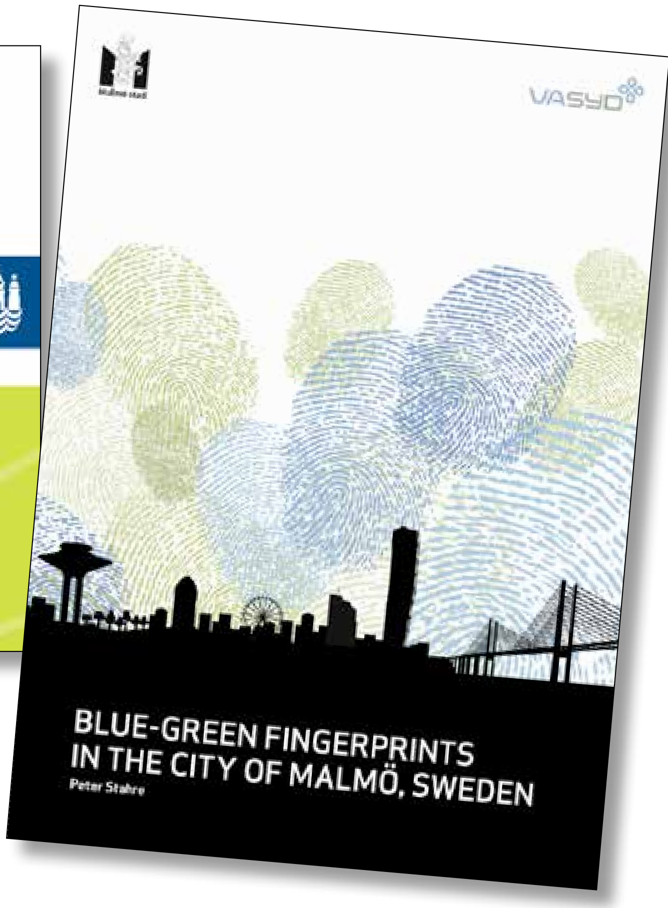
Demonstration in Lomma against the expansion of the Spillepeng waste disposal site, 1997. Source: Sydsvenskans bildarkiv

engineering industries progressively gained in importance. Among these, shipbuilding attained large proportions and was the largest employer in cities such as Copenhagen, Malmö, Landskrona and Helsingør. Cities in general increasingly became the industrial centres in this period, with urbanisation in the region rising from about 45% to 75% between 1900 and 1960. This rise was particularly notorious in the cities bordering the Sound.

The fast pace of urban and industrial growth was not without its difficulties. Air pollution problems were made worse by very high population densities in the inner cities, which resulted in these becoming increasingly degraded and less attractive. Large-scale housing projects emerged in the periphery of several cities, in some cases with accompanying social segregation. Environmental degradation also accelerated markedly with industrial expansion, as the effects of decades of accumulation of different types of contaminants became increasingly visible on land and at sea. In the 1960s and 1970s, rising concerns began to be voiced about the impacts on marine life of toxic organic compounds used in agriculture or in the paper industry, as well as of the accumulation of heavy metals from metal works. Eutrophication was another well-known recurrent problem throughout the whole Baltic. Urban sources of organic nutrients were largely dealt with through the construction of wastewater treatment plants from the 1970s and onwards. These had been built largely with the aim of improving bathing water in the vicinity of cities, a problem long recognised in the larger urban centres in the Sound. Various sources of nutrients from agriculture remained a problem though, which persists to this day.

The late 1980s mark a turning point in the awareness about the environmental status of the Sound. Evidence of large scale release of toxic chemicals into specific areas in the Sound had accumulated at least since the mid-1970s, but it was not until a decade later that concerns of more generalised impacts on marine life began to be voiced. Results from sample tests showing dramatic reductions in the number and diversity of marine species confirmed repeated accounts of reductions in fish abundance and widespread fish mortality. In 1987 the dire status of the marine environment in the north-eastern Sound was captured on film, and later narrated in a series of local newspaper articles. In the summer of 1988 a virosis caused mass mortality of seals all along the west coast of Sweden. Seal corpses were joined by blooms of toxic algae, prompting wide media coverage and debate over what was truly happening under the surface. Large protests were organised along the Sound coast to raise awareness of the need to protect its marine environment.

On land, the economies on both sides of the Sound have undergone dramatic transformations since the industrial crises that followed the oil shocks of the 1970s. The downturn was particularly severe in Skåne, which went from being one of Sweden's wealthiest regions in the 1960s to becoming one of its poorest at the beginning of the 1990s. The region lost many of its heavier industries and largest employers, namely the shipyards, and went through a period of stagnation, including population size. This period progressively gave way to the emergence of new forms of development based on the services industry, on education and research and in particular in the field of life sciences. Concerns with the status of the environment and later with sustainability and climate took an increasingly central role in societal organisation. Today, cities in the Sound region pride themselves of and openly display their environmental achievements as a means of boosting their attractiveness and competitiveness.



Examples of environmental profiling in the two largest cities in the Sound region; Copenhagen´s Eco-Metropolis strategy and Malmö´s work with a modern sewage treatment system.
Sources: http://www.kk.dk and http://www.vasyd.se

Integration across national borders is seen as the key to regional development in an increasingly globalised economy. It is being realised through a series of large-scale infrastructure projects linking Scandinavia, through the Sound, to the Continent. Waterways, however, are no longer seen as the decisive integrative element they were five centuries ago. Indeed, fast and efficient integration is achieved today by bridging land- and air-based modes of transport over bodies of water. Such has been the case in the Sound, where the opening of the fixed link between Copenhagen and Malmö initiated a new phase in the approximation of Skåne and Sjælland. Today, with the Fehmarn Belt link between Denmark and Germany being planned, attention has turned to wider regional integration between the Sound and Hamburg regions. Future economic and population growth is likely to dictate the need for yet another fixed transport infrastructure across the Sound between Helsingborg and Helsingør.

For the waters of the Sound, the renewed dynamism of the whole region implies ever increasing levels of utilisation. This remains one of the world's most trafficked straits, with over 30,000 ships passing annually. And even if fishing is of relatively modest proportions, recreational uses of the sea and coasts are clearly on the rise. Offshore wind parks are a recent addition to an already crowded Sound, and their number is expected to increase to match future renewable energy production targets. Land reclamation for city expansion and coastal engineering have dramatically altered stretches of the Sound's shoreline. Population growth, erosion problems and the threat of future sea level rise will likely justify continued interest for those types of interventions. All of this in a waterbody facing severe eutrophication and chemical contamination, the causes of which are often remote and difficult to address. It is the combination of these challenges that current and future management of the Sound has to contend with and which the remainder of this book is devoted to.

The Øresund Bridge

Plans for the construction of a fixed link across the Sound date back at least to the 1880s, then in the form of an underwater tunnel connecting Helsingborg to Helsingør. The large depth and strong currents in the area led interest to turn to a connection between Copenhagen and Malmö, with a two bridge solution over the island of Saltholm appearing in the 1930s. This interest grew with the intensification of cross-border traffic after World War II, but it was not until the 1980s that viable technical and financial options were found. For the Danish government, however, greater priority was assigned to fixed links across its three large internal straits. On 24 August 1991 representatives from the Swedish and Danish governments signed the agreement for the construction of the Øresund Bridge, which started in 1995. The bridge and tunnel were inaugurated on 12 July 2000, six months ahead of schedule.

The four-lane road and two-lane rail link includes an immersed 3.5km tunnel under the Drogden sill on the Danish side, a 4km long artificial island (Peberholm) and a 7.9km bridge over the Flint sill on the Swedish side. A project of this size has not been free from controversy, and from very early in the discussions concerns were voiced about its negative environmental impacts, especially in Denmark. At 12% of the total project cost, a comprehensive environmental management and impact minimisation programme was put in place. Its three main aims were 1) to implement the so-called 'zero solution', whereby no changes to the water and salt flow through the Sound had to be ensured; 2) to limit the reduction in eelgrass and mussel beds to 25% in the area extending 500m on either side of the link; and 3) to ensure that no negative impacts on marine flora and fauna were noticeable five years after construction. All of these targets were met, and the link is not considered to have any significant environmental impact on the Sound or the Baltic.

The Øresund Bridge under construction, November 1998. Source: Sydsvenskans bildarkiv

The Stevns lighthouse (Stevns fyr) at the south-western extreme of the Sound.

II INSTITUTIONAL FRAMEWORK FOR MARINE MANAGEMENT

In the previous chapter, there was a description of how the development of the societies in the Sound region was accompanied by degradation of their natural environments. The progressive realisation of the dire condition of the Sound's waters increasingly called for political action to reverse, or at least halt, the evident degradation of the marine environment. As political systems developed and environmental policies gained prominence, a large array of legal and policy instruments were developed. Their implementation required the creation of numerous new institutional functions tasked solely with overseeing the status of the marine environment. Today, the web of institutions and instruments for marine management in the Sound is vast and complex. This is the subject of this chapter.

The organisation of the chapter follows the functional and sectoral divisions created by the Swedish and Danish public administrations to deal with maritime activities and the marine environment. Although such a clear demarcation is a useful way of describing the multiple ways in which societies interact with the marine environment; it does not necessarily have a correspondence in reality at all times. Indeed, there are several instruments and organisations that pertain to or deal with more than one sector, the environmental codes and the Coastguard being two noteworthy examples.

The focus is on legal as opposed to policy and other non-legally binding instruments. The reasons for this being that the former are the primary instruments for managing human interactions with the marine environment, as well as for establishing the roles and responsibilities of organisations. Non-binding instruments are only discussed when referring to anticipated changes to the existing management structures.

Maritime sovereignty

The rights and responsibilities of states concerning the sea are regulated through the branch of public international law known as Law of the Sea. This is made up of bi- and multi-lateral customary and treaty law and numerous rules and regulations adopted there under. The most fundamental instrument is the Law of the Sea Convention (LOSC)[1], often termed the "Constitution for the Oceans" and which all other legal arrangements pertaining to the sea have to pay regard. A basal concern of the LOSC has been to balance the interest of states in their multiple capacities against

The island of Ven seen from the south-east. In the background, Nivå Bay.

1 The LOSC was adopted in at the Third United Nations Convention on the Law of the Sea, in Montego Bay, Jamaica, on 10 December 1982 and entered into force on 16 November 1994. As of February 2013, 165 states were parties to the Convention.

one another, and this has partly been achieved by means of a system for delineating and attributing state territory at sea. This system comprises six main territorial entities:[2]

1. the baseline: an idealised line that demarcates the seaward limit of the land territory and which by default corresponds to the official low-water mark (so-called "normal baselines"). In indented coastlines and in the presence of islands and embayments "straight baselines" might be defined that cut across coastal waters;
2. internal waters: all water bodies landward of the baseline, over which the coastal state enjoys full sovereign rights;
3. the territorial sea: the seawaters extending to a maximum of 12 nautical miles (nm) from the baseline, over which coastal states enjoy sovereign rights provided the right of innocent passage of ships is observed;
4. the exclusive economic zone (EEZ): the seawaters extending from the outer limits of the territorial sea and to a maximum of 200 nm from the baseline, over which coastal states enjoy jurisdictional rights pertaining to use and conservation of all marine resources;
5. the contiguous zone: the seawaters comprised between 12 and 24 nm from the baseline, where coastal states enjoy jurisdictional rights pertaining to the enforcement of regulations pertaining to customs, tax, immigration, health and underwater heritage; and
6. the continental shelf: the underwater natural prolongation of the land territory, comprising seabed and subsoil up to the outer limits of the continental margin or to 200 nm from the baseline.

Denmark and Sweden are both parties to the LOSC since 2004 and 1996 respectively. The Swedish national legislation on maritime boundaries antedates ratification of the LOSC, with the laws on maritime territory and continental shelf dating back to the mid-1960s, and that on the EEZ to the early 1990s.[3] A government commission of inquiry is currently investigating the conditions for declaring a contiguous zone, partly motivated by the prospect of extending the scope of state action at sea in preparation for the upcoming marine spatial planning legislation.[4] Denmark on the other hand, has claimed all maritime zones it is entitled to under the LOSC. The early continental shelf law dates back to the late 1970s, whereas the laws on the EEZ and the demarcation of the maritime territory were adopted in the second half of the 1990s and that on the contiguous zone shortly after LOSC ratification.[5] The maritime

The maritime boundary between Denmark and Sweden in the Sound.

boundary between these countries in the Sound has, however, been settled in a declaration signed by the two kingdoms on 30 January 1932; apart from a minor rectification in the system of coordinates in 1995, this declaration is still in force today.[6] Since the greatest distance between the baselines of the two countries in the Sound is of approximately 13 nm (at its southernmost limit, between Stevns Fyr and Falsterbo), this sea area falls entirely within the respective countries' territorial seas.

An important distinction between Sweden and Denmark concerns ownership of marine waters. Whereas in the latter case all marine waters seawards of the high-water mark are exclusively owned by the state, in Sweden the owners of land bordering on water bodies – including the sea – have ownership rights to the water column and seabed 300m from shore or down to a depth of 3m, whatever comes last.

2 So-called "extended continental shelf" extending to a maximum of 350 nm from the baseline may be established under specific circumstances.

3 Lag (1966:374); Lag (1966:314); Lag (1992:1140).

4 Government of Sweden (2011).

5 LBK nr.182 af 01/05/1979; Lov nr.411 af 22/07/1996; Lov nr.200 af 07/04/1999; Lov no.589 af

6 BKI nr.41 af 22/02/1932; BKI nr.117 af 05/10/1995. 24/06/2005.

Detecting and repelling violations of the national territory is the role of each country's defence forces, the navies playing a particularly prominent role in securing maritime borders. The primary task of the Danish and Swedish navies is therefore protection against foreign aggressions and their core operations concern warfare. Nevertheless both engage regularly in non-military operations such as emergency preparedness and response, maritime surveillance, data generation and information exchange, and education and training. In Denmark it is the Admiral Danish Fleet (*Søværnet*) that bears formal responsibility for several of these areas – including the waters of the Faroe Islands and Greenland, whereas in Sweden these are performed by different civil authorities that the navy collaborates with.

Both states have also established public authorities charged with coordinating emergency preparedness and response for society as a whole (BRS, *Beredskabsstyrelsen* in Denmark; MSB, *Myndigheten för samhälsskydd och beredskap* in Sweden). Despite working closely with the military, the main focus is on non-military hazards and emergencies such as those related to weather, climate and all types of accidents. As is the case with the defence forces, those authorities are entitled to claim parts of the national territory – including at sea – to be reserved for safety and security purposes. Moreover they enjoy the prerogative of opposing or requiring changes to other claims on the territory, with their preferences often prevailing.

Denmark has adopted a strongly centralised model of state maritime administration, with the navy performing a broad range of functions that are typically the responsibility of civil authorities. Such functions include maritime surveillance; search and rescue at sea, including hosting the national joint rescue coordination centre, environmental surveillance and pollution control, ice- breaking, and shipping support such as maritime assistance and vessel traffic services. In Sweden responsibility for most of these tasks falls to the Coastguard (*Kustbevakningen*), a civil agency of the Ministry of Defence with a very broad range of competencies pertaining to detection of, prevention of and response to emergencies at sea. It cooperates extensively with other state organisations that have comparable functions but lack the resources to operate at sea. Besides coordinating civil maritime surveillance and information gathering, the Coastguard therefore works jointly with the maritime administration in search and rescue at sea and oversight of maritime dangerous goods, with the customs authority in patrolling and crime prevention operations, with the police in the national task force, with the fisheries administration in controlling fishing activities at sea and with the military in maritime surveillance and rescue, and as an extraordinary resource in cases of war or heightened security risk. In the Sound there are Swedish Coastguard stations near its northern and southern boundaries, at Helsingborg and Höllviken, and a Danish naval base in Copenhagen.

A further state organ with responsibilities in the areas of safety and security is the police. The Swedish police have two small maritime units based in Stockholm and Gothenburg. Half of the maritime police corps is active during summer months only, as their responsibilities pertain primarily to security in coastal zones and the archipelagos, both typical summer destinations. As is the case with the Danish police, operations at sea include oversight of maritime traffic, in particular of smaller craft, control of fishing activities, criminal and accident investigation and support to emergency operations. The Swedish maritime police has its own sea-going equipment, whereas its Danish counterpart uses equipment provided by the Home Guard.

The Danish Home Guard is one of the non-state organisations in the two countries whose activities pertain to safeguarding safety and security at sea, the other being the Swedish and Danish sea rescue societies.[7] All are volunteer organisations established, in the case of the former as a civil force to monitor and report unlawful acts and to guard specific activities or places and, in the case of the last two, with the purpose of providing rescue and transport of people in distress, as well as responding to environmental emergencies at sea and in lakes.

Coastal and marine spatial planning

The spatial planning systems of Denmark and Sweden have evolved over the last half a century in response to the perceived impacts of human activities on the natural and built environments. Their fundamental purpose is to enable societies to control and steer developments towards agreed goals in a manner that is systematic and open to citizen involvement.

The Danish planning framework went through a series of important transformations following the

7 Danish Naval Home Guard, *Marinehjemmeværnet*; Danish Sea Rescue Society, *Søredningsselskabet*; Swedish Sea Rescue Society, *Sjöräddningssällskapet*.

2007 reform of local government structure. With the disappearance of regional planning instances and the strengthening of planning mandates at municipal and local levels, Denmark moved from a comprehensive model based on the integration of planning objectives and measures across different levels of government, to a strongly decentralised system where most spatial planning rights are vested at the local level and the role of government is limited to providing guidance and overseeing implementation. With this transformation the Danish system came to more closely resemble the one in Sweden, where spatial planning rights are concentrated in municipalities.

Spatial planning on both sides of the Sound has its foundation in the Swedish and Danish planning acts.[8] These spell out the responsibilities of different state organs, the generic procedures to be observed, the hierarchy of planning instruments and measures that can be adopted and, in the case of the Swedish act, the minimum technical requirements for new constructions. Both the planning process and the balance of responsibilities are similar in the two countries. At the national level central governments are responsible for elaborating and providing guidance to planning organs at lower levels on overarching policy objectives and measures that need to be observed in spatial planning. Such instructions are derived from both national and international agreements, an example of the latter being water management plans adopted under the EU Water Framework Directive. In Sweden these instructions are contained in different sector policy and regulatory documents – chief among which is the Environmental Code (*Miljöbalk*) chapters 3 and 4 – whereas in Denmark the government issues at the outset of each four-year legislature the so-called National Planning Report (*Landsplanredegørels)* and the Overview of State Interests in Municipal Planning (*Oversigt over statslige interesser i kommuneplanlægningen*) containing detailed and binding instructions for lower-level planning authorities. In both countries central government assesses compliance of spatial plans against those instructions, with control in Denmark exerted by delegations of the ministry of environment and in Sweden by the County Administrative Boards, which constitute the state oversight organs at regional level.

The earlier form of regional spatial planning in Denmark has all but disappeared with the local government reform, as noted above. Except for the case of the Copenhagen capital city region, for which a comprehensive spatial plan is required by law, all other regions have to elaborate so-called regional spatial development plans which, despite their name, have a weakly defined spatial character. Conceived as projects by associations of municipal councils, businesses, regional council and other interests, such plans serve to elaborate and communicate a shared vision of the future of the region – with a clear focus on socioeconomic and in particular business development – rather than as instruments for spatial ordering of societal functions. Most Swedish regional planning has a similar character and serves similar purposes. A specific form of regional spatial planning co-exists with this more strategic type of development planning and which the Swedish planning act provides for. Currently conducted in the metropolitan regions of Stockholm and Gothenburg only, it is a mechanism for inter-municipal coordination of all spatial matters that cuts across municipal boundaries and that ultimately affects and is affected by each individual municipal plan.

It is at the municipal level that most spatial planning takes place in both Sweden and Denmark. Municipalities own the exclusive right to plan for the use of land and water resources within their territories, provided national – and in some instances regional – interests are taken into consideration. Municipal spatial plans are of different types:

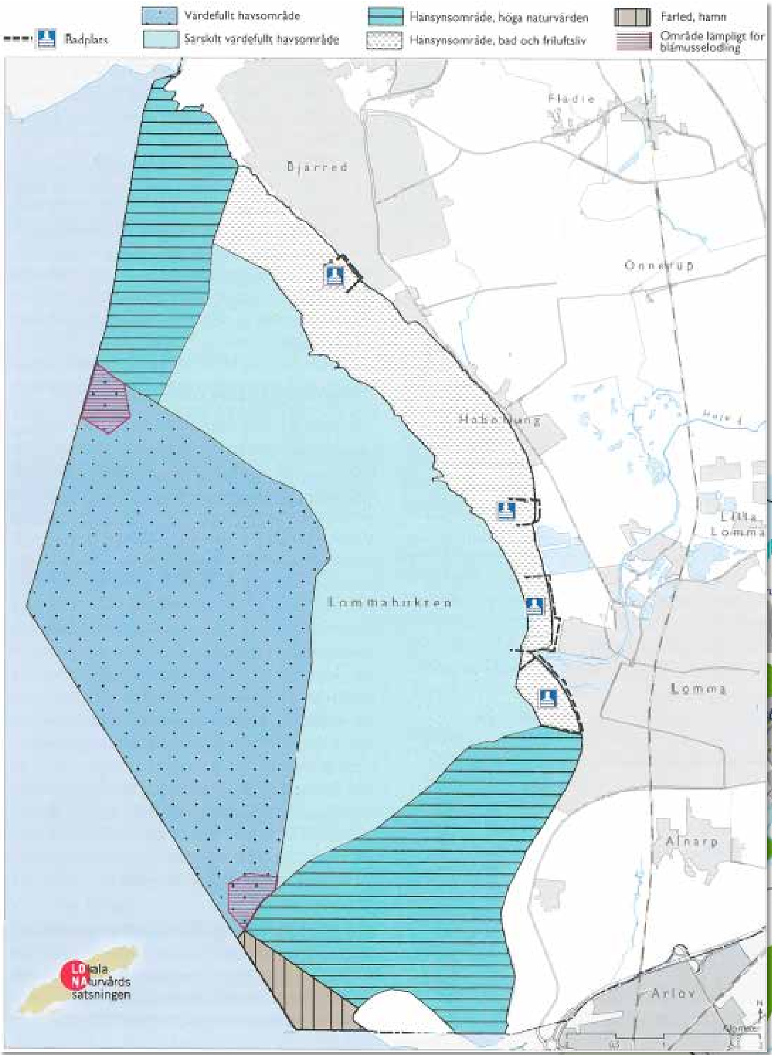
- Master plans, termed *Översiktsplaner* in Sweden and *Kommuneplaner* in Denmark, lay out the spatial development objectives and constraints, the guidelines for land use and the framework for detailed planning. These are non-binding instruments intended to guide the allocation of occupation and use licences to protect public and private interests;

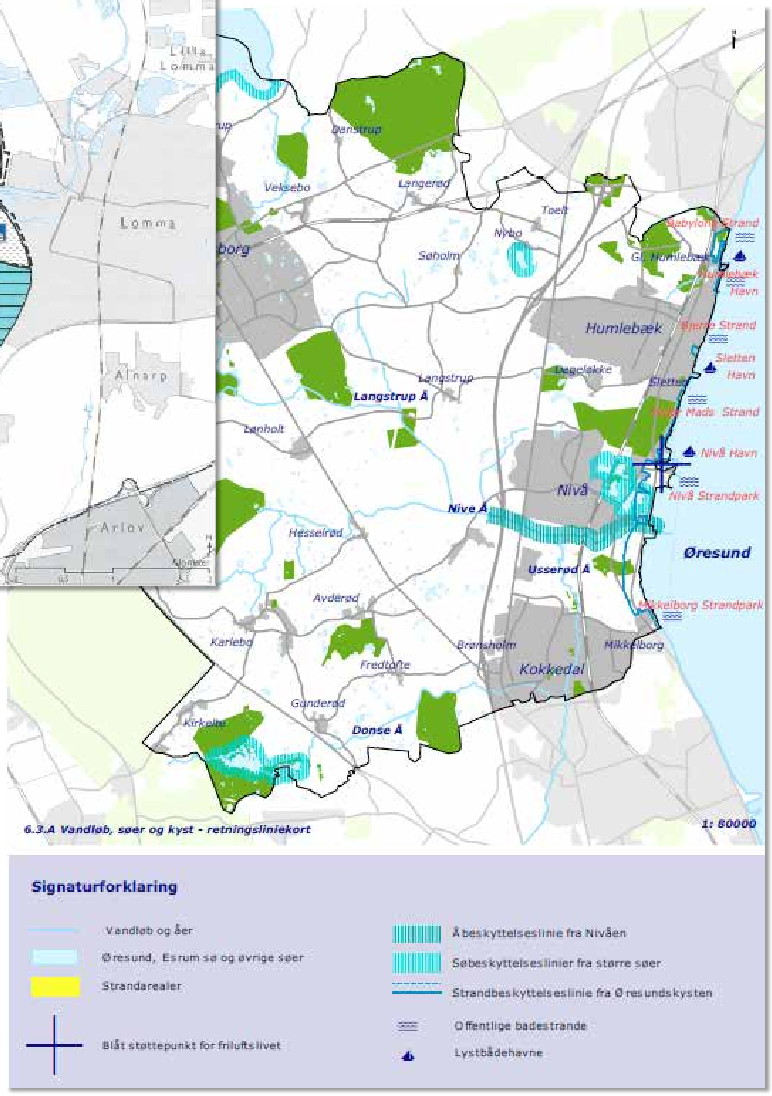
- Detailed plans in Sweden and Local plans in Denmark set out precise instructions regarding land use in specific locations usually subject to greater pressures. As binding instruments they enable a stricter control of occupation and use.

- Area regulations adopted under Swedish plans concern specific activities for which additional measures are required to attain specific protection or development goals. Often these goals are related to national or international commitments.

A very important distinction between the Danish and Swedish systems is that municipal territories in the latter case extend to the outermost limit of the

8 SFS 2010:900; LBK nr.937 af 24/09/2009.





Examples from the municipal master plans of Fredensborg, Denmark (right) and Lomma, Sweden (left), the latter encompassing the municipality's maritime territory in the Sound. Sources: Fredensborg Kommune (2013), Lomma kommun (2010)

territorial sea. Accordingly municipal authorities may – although very few actually do it – plan the territorial sea in exactly the same manner as they plan their land territory. In Denmark the planning rights of municipalities stop at the coastline (high-water mark), all entitlements to planning at sea belonging to the national state. National planning of Danish waters and of the Swedish EEZ are currently conducted on a sector-by-sector basis, both countries lacking a framework for cross-sector integrative marine spatial planning. In the Sound therefore two distinct systems co-exist for planning human use and occupation of the sea, municipal-level planning on the Swedish side and sector planning mostly by central government organs on the Danish one. With interest for marine spatial planning growing in both countries and across Europe, it is reasonable to expect that changes to this situation will occur in the near future.

The low-lying coast and shallow coastal waters of Lundåkra Bay, one of the two Ramsar sites in the Sound. Note the golf course of the Barsebäck Golf and Country Club.

Nature conservation

The overarching rights and obligations of states concerning the protection and preservation of the marine environment are contained in Part XII of the LOSC. Alongside the right to exploit resources within their jurisdictions, states are also obliged to ensure environmental conservation and restoration. Such obligations are in part to be carried out through the adoption of policies and legislation at national, regional and global levels to control the various causes of marine environmental degradation.[9] Like many other sea areas around the globe, the Sound is currently subject to a management regime involving global, regional and national – both Swedish and Danish – instruments.

At global level two conventions other than the LOSC deserve particular mention, namely the Convention on Biological Diversity and the Ramsar Convention on Wetlands, to which both Denmark and Sweden are parties. The former, signed in 1992 at the Rio Earth Summit establishes a global framework and lays down fundamental requirements for states to work with the preservation and sustainable use of biological diversity. In 1995 the Jakarta plan of action for marine and coastal biodiversity was adopted.

The 1971 Ramsar Convention in turn has as its main purpose the establishment of a framework for states to afford special protection to wetlands and their resources. It does so by designating so-called "Ramsar sites" and promoting the concept of "wise use", defined as "the maintenance of their ecological character, achieved through the implementation of ecosystem approaches, within the context of sustainable development".[10] Of the close to 2,100 Ramsar sites so far declared, two are located on the Swedish shores of the Sound, namely those of Lundåkrabukten and Falsterbo-Foteviken.

Important regional instruments include the 1992 Helsinki Convention on the Protection of the Marine Environment of the Baltic Sea Area, and a number of EU directives. The former commits all states bordering the Baltic Sea to different measures relative to human activities that have an impact on the status of the Baltic marine environment.[11] Such measures are contained in recommendations issued by the Helsinki Commission (HELCOM) – the governing body of the Convention – while broader policy guidance is also provided in the 2007 HELCOM Baltic Sea Action Plan and in numerous manuals and guidelines specific to the different pollution sources.

Relevant EU directives include the Water and the Marine Strategy Framework Directives (WFD and MSFD), as well as the Birds and the Habitats Directives. These last two, aimed respectively at protecting all naturally-occurring species of wild birds and at conserving natural habitats for the sake of preserving biological diversity, provide the framework for designating nature conservation areas that together form the EU-wide Natura 2000 network. A 2005 ruling of the European Court of Justice established that application of the Habitats Directive extends beyond the limits of the territorial sea to encompass all areas over which member states exercise sovereignty, this necessarily including the EEZ.[12]

The WFD and MSFD have a similar structure and implementation mechanism, key distinctions lying 1) in their domain of application – internal waters, including groundwater and coastal waters up to 1 nm from the coastline in the case of the former, and all marine waters from the coastline up to the outer limit of the EEZ in the case of the latter; and 2) in the fact that the WFD assesses ecological and chemical status separately, whereas the MSFD only considers an aggregate measure of environmental status. Within their respective domains of application both directives require states to adopt measures enabling good environmental status to be reached by 2015 and 2020 for the WFD and the MSFD, respectively. Implementation proceeds along six-year programming cycles involving environmental status assessment and definition of good-environmental status, establishment of monitoring programmes, elaboration of programmes of measures and its implementation and follow-up, reporting and review.

At the level of Danish and Swedish national legislation there are numerous instruments pertaining to the conservation of environmental values. In Sweden the environmental code constitutes the foundation of all environmental legislation, setting out the framework of state action and the generic rights and obligations of the different actors in society with respect to the state of the environment. Oversight of implementation of the code is carried out centrally by the Swedish Environmental Protection Agency (*Naturvårdsverket*). A large number of ordinances attached to the code contain provisions relative to specific environmental matters. Examples include the ordinances transposing the WFD and the MSFD, as well as those relative to the protection of habitats and of species of flora and fauna.[13] The

9 See Section 5, art.207-212. Sections 6, art.213-222 relative to enforcement of legislation, and 7, art.223-233 concerning judicial safeguards related to this enforcement are also relevant in this context.

10 <http://www.ramsar.org>

11 The present contracting parties to the Convention are Denmark, Estonia, the European Community, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden.

12 Judgement of the Court (2 Oct 2005), see art.117.

13 SFS 2004:660; SFS 2010:1341; SFS 1998:1341; SFS 2007:845.

Hunting and Fisheries Acts and related ordinances, which serve primarily to regulate these two activities, also contain provisions concerning the protection of species of fauna.[14] An overarching environmental code is absent from the Danish legislative framework for nature protection and regulations are thus found in a greater number of acts. The Act on Nature Protection is the primary piece of legislation providing for the designation of conservation areas and the protection of biodiversity. It also establishes the generic framework for state action in respect of environmental management and describes the rights and duties of organisations and individuals. Transposition of the WFD and MSFD has been done via the Environmental Objectives Act and the Act on Marine Strategy respectively, the former also providing for the designation and planning of conservation areas established under international law, namely Natura 2000 sites.[15]

Similar to the case in Sweden, both the Hunting and the Fisheries Acts include measures to protect species affected by these two activities, involving for example restrictions on areas important for species reproduction.[16] As in Sweden, responsibility for enforcement of environmental protection legislation is shared by state organs at all administrative levels, with national oversight currently resting with the Danish Nature Agency of the Ministry of Environment (*Naturstyrelsen*).

14 SFS 1987:259; SFS 1987:905; SFS 1993:787; SFS 1994:1716.

15 LBK nr.932 af 24/09/2009; Lov nr.522 af 26/05/2010.

16 LBK no.930 af 24/09/2009; LBK nr.978 af 26/09/2008.

17 Gold (1979), p.252.

18 With its entering into force on 20 August 2013, the 2006 ILO Maritime Labour Convention supersedes a total of 36 earlier conventions and one protocol, some extending as far back as 1920.

Ferry leaving Helsingborg for Helsingør.

Shipping and ports

A fundamental right of states originating from international customary law is the freedom of navigation, defined in the LOSC Art. 90 as every state's right "to sail ships flying its flag on the high seas." Rooted in the principle of freedom of the high seas, it resonated throughout much of the history of maritime transport with the notion of freedom from regulation. If for many centuries, or even millennia this remained largely an uncontested and virtually absolute premise – to the extent of exempting all but the shipowner of responsibilities for the fate of any maritime enterprise – the last two centuries have witnessed the progressive encroachment on this freedom by ever growing rights of appropriation over maritime territories by coastal states legitimised mainly by international treaty law. This "rise of the coastal state in the law of the sea"[17] has resulted in a current legal regime for maritime transportation that attempts to balance these two opposing rights, that of navigation by flag states and that of appropriation by coastal states.

Another distinctive feature of this regime is its extensive foundation in international law, a consequence of the borderless nature of shipping. Such foundation emerged from the need to set globally accepted operational standards to ensure a simplified, coherent and non-distorting framework for all operators regardless of origin and destination. The current body of international regulations and guidelines has been drawn primarily by two specialised agencies of the United Nations, the International Maritime Organisation (IMO) and the International Labour Organisation (ILO), with the UN Conference on Trade and Development also playing a role in the establishment of a harmonised regime for private shipping law. The former is the legislative organ for all operational matters concerning safety, security and environmental performance of international shipping, as well as for matters concerning training and certification of seafarers. The work of the ILO in turn has predominantly had to do with regulating labour conditions and standards of welfare for people working at sea.[18] Table 1 lists the key IMO and ILO regulatory instruments and indicates whether or not Denmark and Sweden are parties to each of these.

IMO conventions relating to maritime safety and security and ship/port interface	DK	SE
Convention on International Regulations for Preventing Collisions at Sea (COLREG), 1972	X	X
Convention on Facilitation of International Maritime Traffic (FAL), 1965	X	X
International Convention on Load Lines (LL), 1966	X	X
International Convention for the Safety of Life at Sea (SOLAS), 1974, as amended	X	X
International Convention on Maritime Search and Rescue (SAR), 1979	X	X
Convention for the Suppression of Unlawful Acts Against the Safety of Maritime Navigation (SUA), 1988 and Protocol for the Suppression of Unlawful Acts Against the Safety of Fixed Platforms located on the Continental Shelf (2005)	X [1]	X [1]
International Convention for Safe Containers (CSC), 1972	X	X
Convention on the International Maritime Satellite Organization (IMSO C), 1976	X	X
International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) as amended, including the 1995 and 2010 Manila Amendments	X	X [2]
Special Trade Passenger Ships Agreement (STP), 1971 and Protocol on Space Requirements for Special Trade Passenger Ships, 1973		X
IMO conventions relating to prevention of marine pollution	**DK**	**SE**
International Convention Relating to Intervention on the High Seas in Cases of Oil Pollution Casualties (INTERVENTION), 1969	X	X
Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (LC), 1972 (and the 1996 London Protocol)	X	X
International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto and by the Protocol of 1997(MARPOL)	X	X
International Convention on Oil Pollution Preparedness, Response and Co-operation (OPRC), 1990	X	X
Protocol on Preparedness, Response and Co-operation to Pollution Incidents by Hazardous and Noxious Substances, 2000 (OPRC-HNS Protocol)	X	X
International Convention on the Control of Harmful Anti-fouling Systems on Ships (AFS), 2001	X	X
International Convention for the Control and Management of Ships' Ballast Water and Sediments, 2004	X	X
The Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships, 2009		
Conventions covering liability and compensation	**DK**	**SE**
International Convention on Civil Liability for Oil Pollution Damage (CLC), 1969	X [3]	X [3]
1992 Protocol to the International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage (FUND 1992)	X	X
Convention relating to Civil Liability in the Field of Maritime Carriage of Nuclear Material (NUCLEAR), 1971	X	X
Athens Convention relating to the Carriage of Passengers and Their Luggage by Sea (PAL), 1974	X [4]	
Convention on Limitation of Liability for Maritime Claims (LLMC), 1976	X [5]	X [5]
International Convention on Liability and Compensation for Damage in Connection with the Carriage of Hazardous and Noxious Substances by Sea (HNS), 1996 (and its 2010 Protocol)		
International Convention on Civil Liability for Bunker Oil Pollution Damage, 2001	X	
Nairobi International Convention on the Removal of Wrecks, 2007		
Other subjects	**DK**	**SE**
International Convention on Tonnage Measurement of Ships (TONNAGE), 1969	X	X
International Convention on Salvage (SALVAGE), 1989	X	X
ILO convention relating to labour standards	**DK**	**SE**
Maritime Labour Convention, 2006	X	X

Table 1 List over the most important IMO and ILO maritime conventions and protocols, and status of ratification by Denmark and Sweden as of March 2013.

Notes: ([1])- Both Denmark and Sweden have ratified the 1998 but not the 2005 SUA Protocol; ([2])- Sweden has ratified the 1978 but not the 1995 STCW Convention; ([3]) Both Denmark and Sweden have ratified the 1976 and 1992 CLC Protocols, which in the case of the latter implies compulsory renunciation of the 1969 CLC Convention; ([4]) Denmark has ratified the 2002 PAL Protocol only; ([5]) Similar to the CLC Convention (see note 3), ratification of the 1996 LLMC Protocol by Denmark and Sweden carried compulsory denunciation of the 1976 LLMC Convention.

The narrowest point of the Sound between Helsingborg and Helsingør, where the Sound dues were collected. The Kronborg Castle is visible in the foreground.

The Sound dues and the regime of navigation in the Danish straits

In 1429 the Danish king established a transit duty on all ships passing through the Danish straits under the argument that these were part of the Danish territory. Passage through the Great and Little Belt not being permitted until later in the 15th century – and, after that, never accounting for more than 10-15% of traffic through the straits – the duty concerned primarily merchant ships passing through the Sound. Hence the designation 'Sound dues', which were collected at its northernmost entrance in Helsingør.

At their peak the dues amounted to about two thirds of the budget of the kingdom of Denmark, much to the discontent of traders sailing between the North and Baltic Seas. Ships from North German cities, Denmark and Sweden being exempted from payments, it was non-Baltic nations that contributed the most to that wealth, the Netherlands until the 19th century, and then England and later Russia. Because Swedish foreign trade was predominantly carried on board foreign vessels, this country was also severely affected by the dues, to the extent of justifying the construction of the Göta channel between 1810-1832 enabling grain exports to bypass the Sound. Note that despite Sweden owning part of the Sound since the 1658 Roskilde treaty, Denmark retained the right to levy transit charges on ships sailing this strait.

In the early 19th century Copenhagen merchants voiced their complaints against the dues, which were regarded as hampering trade in the very heart of the Danish kingdom. With income from the dues still representing around one eighth of the state budget, the Danish king remained loath to discontinue the dues until the USA – at the time an emergent maritime nation eager to remove obstacles to its maritime trade – unilaterally declared the cessation of payments with effect from 14 April 1856. Denmark reacted by calling all major trading nations using the Sound to a conference in Copenhagen, which resulted in a treaty, signed on 14 March and ratified on 31 March 1857 on redemption of the Sound dues. Denmark received "as indemnification and compensation for the sacrifices which [the treaty imposed] on His Majesty the Kind of Denmark"[19] signatory states paid the equivalent of one year passages, totalling close to 30.5 million rigsdalers. A separate convention was signed on 11 April in Washington perpetually exempting US vessels from the dues, against a compensation of 393 million US dollars.[20]

While their main purpose was the abolition of the dues, the agreements contain provisions that more generally pertain to navigation through the straits, namely:

1. (Art.I) that Denmark may not hinder or detain ships in passage;
2. (Art.II.1-2) that Denmark undertakes to maintain necessary aids to navigation and, more generically, to ensure the navigability of the straits and
3. (Art.II.3) that pilotage remains optional, under the supervision of Denmark.

Through the 1932 joint declaration by the kingdoms of Denmark and Sweden these provisions became applicable to the Swedish part of the Sound.[21]

The implications of the 1857 treaties for the regime of navigation through the Danish straits – including the Sound – have long been discussed in the light of the regime applicable to international straits most recently codified in part III of the LOSC. The contention has centred on whether the treaties award those straits a special regime or if, on the contrary the agreements do not provide a sufficient basis for claiming a special regime, the Danish straits thus falling under the international customary regime. The answer to this question is of legal relevance in two ways, firstly, it determines the regime of passage, that of non-suspendible innocent passage claimed under the special regime being more stringent than that of transit passage applicable under the customary regime. Secondly, if under a special regime, navigation rules in the Danish straits are not required to change with the customary regime, coastal states thereby retaining their decision-making rights.

Authors such as Brüell and Vitzthum have argued that the 1857 treaties do not offer a sufficient legal basis for claiming a special regime, the fundamental arguments being that they 1) were "negotiated in a purely commercial and fiscal context, and entered into for the purpose of removing a passage tax on merchant vessels", and hence had no aim of establishing a regime for navigations and 2) were meant to bring the Danish straits regime in line with the prevailing international customary regime of the time, by suppressing rights and dues regarded as "an anomaly in international relations and contrary to customary regulations of straits".[22] This being the case, the Danish straits should thenceforth be subject to the international customary regime prevailing at any time.

The counterargument, sustained among others by the Danish state, is that despite the explicit commercial purpose of the treaties, they undeniably contain provisions that explicitly pertain to navigation. Hence, as per the letter of the agreements, they effectively establish a regime for navigation, even if only partially. As for the second objection, it is maintained that the fact that the treaties aligned the Danish straits regime with customary international law does not necessarily imply that it has been made equal to this law. That alignment is thus merely circumstantial: should the customary regime change, the Danish straits regime would not be obliged to follow suit.

To substantiate this argument, the Danish government requested an exception to the international regime of straits to be inserted in the LOSC, concerning "straits in which passage is regulated in whole or in part by long-standing international conventions in force" (art.35(c)). The dominant view today on this matter is that this clause applies to navigation in the Sound and the remaining Danish straits, the 1857 treaty and convention constituting the basis of the respective regime for merchant navigation.

19 Treaty for the Redemption of the Sound Dues, art.IV.
20 Convention for the Discontinuance of the Sound Dues between Denmark and the United States of 11 April 1857.
21 BKI nr.41 af 22/02/1932.
22 Brüell (1947) in Vitzthum (1983), p.557.

The Danish-flagged oil-&-chemical tanker MV Saturnus passing Nordre Røse off Copenhagen on its northbound route through the Sound. In the background, the island of Saltholm.

At regional level the EU and HELCOM are two important standard-setting and regulatory organs. Both have generally refrained from creating new rules different from those of the IMO, and instead focused their efforts on ensuring regional compliance with the international regulatory regime. A salient exception in recent years was the EU's imposition of an accelerated regime – relative to IMO's proposed calendar – for phasing out single-hulled tanker vessels following the Erika and Prestige accidents. Within its transport policy the EU is also active in the areas of multi-modal integration and the regulation of competition and state-aid to the shipping and port sectors.

The Danish and Swedish states have a number of responsibilities towards vessels flying their respective flags, as well as foreign vessels calling at national ports. Flag state duties include ensuring that Danish and Swedish vessels comply with all applicable national and international legislation. The former comprises, besides the transposition of international agreements, laws and regulations concerning register of and jurisdiction over the ship and its crew, the exercise of that jurisdiction and related controls, generic contractual matters relative to the freight carriage and the investigation of incidents and accidents involving national vessels, and subsequent judicial measures. Such headings are found in the fundamental legislative texts of both countries, the Swedish *Sjölag* and the Danish *Sølov*.[23] Both are complemented by several ordinances. Port state duties include controlling the enforcement of applicable international legislation on board foreign flagged vessels once these enter a national port. Common control procedures have been established at regional level in different parts of the world, Denmark and Sweden being part of the so-called Paris Memorandum of Understanding on Port State Control, of which all EU coastal states, Canada, Croatia, Iceland, Norway and Russia are signatories.

Commercial fisheries and aquaculture

The fundamental rights of states concerning access to and management of fishery resources have been codified in the LOSC, namely in Article 2, which extends coastal state sovereignty to include the territorial sea, thereby granting these states the right to exploit resources therein[24], Article 56, which prolongs the exclusive sovereign rights and obligations of "exploring, exploiting, conserving and managing the natural resources, whether living or non-living" to the waters and seabed of the 200 nm EEZ and complemented by Article 193, where this sovereign right is reaffirmed and balanced against the imperative of ensuring adequate levels of environmental protection.

23 SFS 1994:1009; LBK nr.856 af 01/01/2010.

24 LOSC art.2 is equivalent to its predecessor, Art.1 of the 1958 Geneva Convention on the Territorial Sea and the Contiguous Zone.

With respect to commercial fisheries, Denmark and Sweden have as EU member states transferred most of these rights to the European instances. Through its Common Fisheries Policy (CFP) the EU has since the late 1970s taken over the responsibility for most matters concerning fisheries in the waters of, or conducted by vessels flying the flags of its member states. The current CFP regulation – EC 2371/2002 – comprises the following key domains of intervention – conservation and sustainability, adjustment of fleet capacity, control and enforcement systems, international fisheries agreements, markets for fishery products and research and data collection. In these domains the EU exercises the main legislative right, individual member states retaining the responsibility for implementation, enforcement and control.

This transfer of legislative authority to the EU is in principle complete with respect to fishing in the EEZ, member states solely holding the right to legislate on matters concerning fishing vessels flying the member state's own flag. With respect to the territorial sea, individual member states are only entitled to adopt special resources protection and management measures provided these are non-discriminatory towards other member states. The EU has not adopted any specific measures for the same area, the measures are in line with the objectives of the EU and are not less stringent than the applicable EU regulations and there are no specific agreements concerning fisheries in the area.

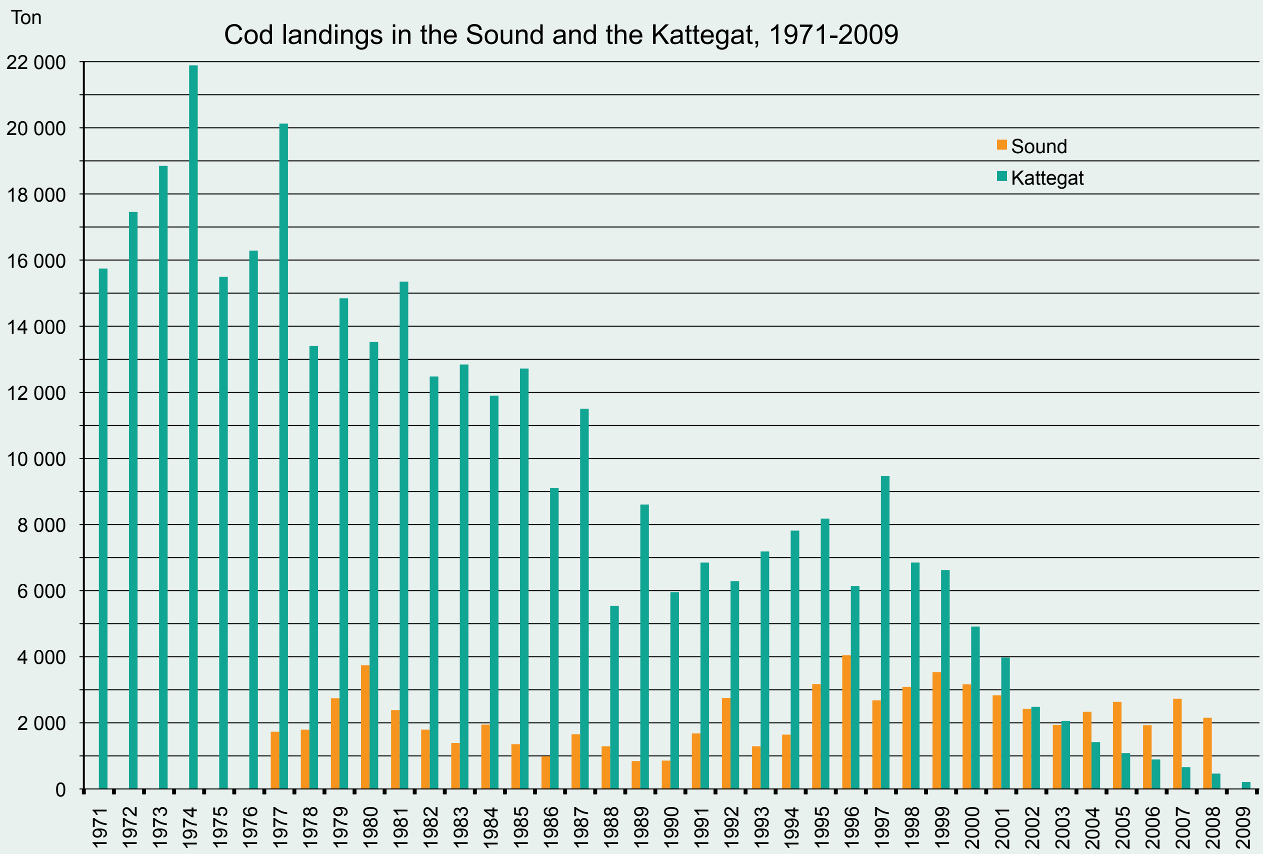
The Sound is an area covered by one such agreement, namely that entered into by the Danish and Swedish kingdoms on 31 December 1932 concerning fishing activities in shared marine waters in the Kattegat, Sound and Baltic Sea.[25] The two most salient provisions of this agreement concern a ban on trawl fishing and the sharing of fishing opportunities by fishermen of both countries. The ban, which applies to all towed gear including trawls and Danish and purse seines applies to the whole Sound with the exception of a triangular area north of the line between Ellekilde in Denmark and Lerberget in Sweden. Together with three other areas in the adjacent Kattegat, fishing in this northernmost portion of the Sound has since 1 January 2009 been regulated by another joint Danish-Swedish agreement for the protection and rehabilitation of Baltic and North Sea cod populations. Access restrictions apply to both recreational and professional fishermen and consist of a ban of fishing methods and gears for capturing cod enforced between 1 February and 31 March, the cod spawning period.

25 BKI nr.228 af 21/08/1933.

A small fishing vessel in the vicinity of the Middelgrund wind park off Copenhagen.

Shipping benefits Sound cod

Concerns over the safety of merchant shipping dictated the ban of trawl fishing from most of the Sound in 1932. In the northernmost portion of the Sound and in the adjacent Kattegat such ban has not been applied and towed fishing gears have been used up to the present day. Commercial demersal fish stocks have shown signs of degradation in both areas since the 19th century, and most are considered commercially extinct in the Kattegat. Landings surveys attest to decreasing stock biomass and the truncation of size and age distribution in this latter area, with a marked decline of larger, older fish. Such effects have not been detected in the Sound, where cod landings and catch per unit effort have remained largely stationary over the last three decades (see figure). Other environmental and anthropogenic stressor of marine ecosystems in general and demersal fish stocks in particular being largely the same in both the Sound and the Kattegat, the far superior performance of cod and other demersal species stocks in the Sound has been attributed to the incidental trawl ban of 1932. This relatively simple measure has shown to be far more effective at conserving these stocks than the numerous technical regulations applied in the Kattegat.



Values for cod landings in the Sound and the Kattegat in the period 1971-2009, in tons. Note the pronounced decrease in Kattegat and the relative stability in the Sound. Data sources: Svedäng (2010), Cardinale & Svedäng (2011)

With respect to the sharing of fishing opportunities, the 1932 agreement stipulates that the whole Sound remains open to fishermen of both countries, except for the areas along the coast landward of the 7m isobath, where foreign fishermen may only fish herring with gillnets and angle during the period of July to October. In addition to the 1932 Sound-wide agreement, both countries have established small resource access restriction zones in conformity with the provisions of the CFP. Most of these zones are found in coastal waters adjacent to river mouths.

Marine aquaculture is not regulated by the EU CFP, but instead by numerous national and European regulations pertaining mainly to environmental aspects of production and food safety aspects of commercialisation and human consumption.

In Sweden the licensing of marine aquaculture installations is granted by the national fisheries agency, whereas in Denmark it is done by coastal municipalities in the case of facilities near the coast, and the Environment Ministry in the case of facilities further offshore. Environmental impact statements are generally required, and operations have to conform to each respective country's environmental code. Specific regulatory matters relative to aquaculture operation that have to be observed in both countries pertain to animal protection and health, and to the use of antibiotics and other medicines and their release into the environment. Aquaculture products for human consumption also have to observe applicable legislation relative to food products.

Transferable fishing concessions – The advent of privatised fisheries?

Commercial marine fisheries in Europe are currently managed by a combination of instruments of three main categories:

1. catch restrictions, where limits are placed on the fishing opportunities of each country and, within these, on the share of the national quota allocated to fishermen or vessels,
2. effort restrictions, with limits imposed on the intensity and duration of fishing activities and
3. technical measures, generally for protecting specific stocks or marine habitats, and including among others, gear restrictions, closed seasons, closed areas or minimum landing sizes.

Within the first category one option consists of attributing to individual fishermen, fishing cooperatives or vessels a predetermined share of the national quota. These quota shares may be transferable or not, in the former case by sale, lease or loan. Similar, but less common systems exist for the allocation of fishing effort shares.

The purpose of these share systems is to establish some form of private concession in marine fisheries. The private nature of such a concession – of the exploitation of the resource, rather than of the resource itself – is believed to be essential for countering the spiral of the overcapacity, resource overexploitation and falling profitability affecting most European fisheries. The main anticipated benefits with fishing concessions, in particular transferable ones, are related to four key characteristics of property rights:

- Security of title, with the concessions recognised and protected by national law and entrusted to withstand challenge by others, making them a secure reference for investments
- Exclusivity, with concession holders being granted access to the resources without unanticipated and unauthorised interference by others, within the frame of applicable fisheries regulations
- Permanence, where concessions extending over several years offer much improved investment prospects and management alternatives than the rations or shares traditionally allocated on seasonal or yearly basis and
- Transferability, where fishing possibilities can be adjusted directly by the fishermen according to their preferences, investment decisions or any unforeseen situation, and where sale of concession becomes a potentially interesting option for those wishing to exit a fishery, in the longer run favouring the most effective operations and adjusting effort and fleet to actual fishing possibilities.

The problem with transferable fishing concessions is that they lead to an excessive concentration of fishing possibilities in the hands of commercially powerful interests. This results in the marginalisation of less profitable fisheries and the disappearance of fisheries livelihoods and fishing communities that are socially and culturally important. Vessel concessions in particular have been suspected of compromising the employment possibilities of non-vessel owning fishermen.

Denmark introduced its first transferable concession scheme in 2003 for pelagic herring fisheries, and subsequently for all other industrial fisheries. On 1 January 2007 vessel quota shares were introduced for the majority of demersal fisheries, replaced in 2009 by a system of individual transferable quotas (ITQ), which were then extended to include the blue mussel fishery. All Danish commercial marine fisheries have since operated under an ITQ management system.

In Sweden non-transferable individual quotas (IQ) were first allocated for herring, mackerel and sprat pelagic fisheries in 2007, the system having been changed in 2009 to accommodate a share of transferable quotas. Allocations are for a period of ten years, and subject to provisions aimed at avoiding excessive quota concentration and protecting small-scale fisheries not covered by the quota system. By 2011 a 50% reduction in the capacity of the fleet operating under the IQ/ITQ system had been observed. With concessions-based fisheries management gaining prominence in the post-2014 CFP, it is likely that more Swedish fisheries will come under individual quota management systems in the future.

Offshore energy

Under international law, coastal states have exclusive sovereign rights to the commercial exploitation of all marine waters under their jurisdiction. With respect to the production of energy from offshore sources, article 56 of the Law of the Sea Convention, LOSC, explicitly mentions "the production of energy from the water, currents and winds." This exclusivity is embodied in the national legislation of the maritime territories of the two countries bordering the Sound. At the regional level, the EU has through the so-called "Renewable Energies Directive" regulated matters pertaining to the granting and administration of exploration and exploitation licenses.[26] Its main aim is to ensure harmonisation and non-discrimination in the access to energy production opportunities – in view of enhancing production from renewable sources – and has no actual bearing on the fundamental rights of states to identify, plan and regulate suitable production sites as granted by international law. Hence in both Danish and Swedish maritime territory and in the respective EEZ, offshore energy production can only be carried out upon the granting of a license by the respective states.

In both countries all forms of extraction of marine minerals must be accompanied by an environmental impact assessment.

This exclusive right of the coastal states is however bound by the obligation – also inscribed in the LOSC – that any artificial installations do not block or otherwise hinder international navigation. In the Sound, a strait used for international navigation, observing this obligation is of paramount importance not only in the planning of offshore energy production installations, but also of any other human activities.

The mapping of suitable production sites has been carried out by different entities in both countries, including the respective state energy agencies, local municipalities, commercial firms and citizen associations. In Chapter Four an overview is provided of both existing and planned offshore wind energy facilities in the Sound. So far no other forms of energy from marine sources have been tested in the Sound. Some of these planned sites – notably those identified by the national agencies – are included in the list of sites of national interest for spatial planning, whereby they gain hierarchical preponderance in planning at regional and local levels.

Licenses for building and operating offshore energy facilities – including the laying of underwater cables and pipes in the territorial sea – have to be requested by operators from the national governments in both Denmark and Sweden, the responsible ministries currently being that of climate, energy and building and that of enterprise, energy and communications, respectively. Technical assessment is carried out by the nominated state agencies, in Denmark the Energy Agency (*Energistyrelsen*) and in Sweden the Geological Survey (*Sveriges geologiska undersökning*). As focal points in the licensing process, these two agencies are charged with gathering the views of all other organisations with a stake in a particular site. These are most often other state organs, but may also include industry and civil society representatives. As per the provisions contained in the applicable national laws – primarily the Continental Shelf Act, but also the Act on Specific Pipelines in Sweden[27], and the Act on the Promotion of Renewable Energy, and the Acts on the Exclusive Economic Zone and on the Continental Shelf in Denmark[28] – licenses are granted for a limited number of years. In both countries, and for all kinds of installations, environmental impact assessments are required, which, in some instances and in accordance with the Espoo Convention, might need to take into account transboundary impacts. This is the case in the Sound, given the proximity of all installations to an international border, and both countries have so far had good cooperation in this domain.

Marine minerals

The regime for the extraction of marine minerals from the seabed shares a number of commonalities with that pertaining to the exploitation of offshore energy sources. Coastal states enjoy exclusive rights to any commercial exploitation of all materials on or under the seabed, both in the territorial sea and the EEZ.[1] This sovereign exclusivity is inscribed in the national laws of both Sweden and Denmark, namely the respective acts on the continental shelf and, in the case of the latter, also the Act on Raw Materials and the Subsoil Act, pertaining to sediments and hydrocarbons, respectively.[30] These acts declare that any intervention on the seabed must be authorised

26 Directive 2009/28/EC.

27 Lag 1966:314; SFS 1978:160.

28 Lov nr. 1392 af 27. december 2008; Lov nr.411 af 22/07/1996; LBK nr.182 af 01/05/1979.

29 In countries with extended continental shelves, this applies up to a maximum distance of 350nm from the coast. Neither Sweden nor Denmark has claimed an extended continental shelf.

30 Lov nr. 950 af 24. september 2009; Lov nr. 889 af 4. juli 2007.

The 48-turbine Lillgrund wind park located off Klagshamn. In the background, the Øresund Bridge and the city of Malmö.

by government, all extractive uses for commercial purposes requiring a license. In Sweden it is the Geological Survey that coordinates all licensing processes for activities affecting the continental shelf, holding the responsibility for consultations with all relevant stakeholders, notably other state organs. In Denmark there is an administrative division that follows from the two laws indicated above. Activities concerning the exploitation of non-hydrocarbon minerals – for example marine sand and gravel – are handled by the ministry of environment through the Nature Agency. Licenses are awarded on the basis of a public tendering process for a number of predetermined areas. As a rule the highest bid is awarded the concession for a given amount of time. Exploration and exploitation of hydrocarbons, as well as subsoil storage of CO^2 or gas are licensed by the Energy Agency. In both countries all forms of extraction of marine minerals must be accompanied by an environmental impact assessment. Exploitation of minerals in the Sound is limited to sediment extraction on a number of sites in Danish waters.

The laying of pipelines and cables comes under a different regime. In the EEZ and according to the LOSC, coastal states cannot hinder the laying of such structures. However they can require that the respective path be altered on account of the need to preserve specific values. Other rules may be inscribed in national legislation provided they do not interfere with the fundamental premises of the LOSC. In the territorial sea however, cables and pipelines placed on the seabed are treated in the same manner as any other fixed installation and hence wholly dependent on a formal warrant by the coastal state.

Finally it is worth alluding to regional legal instruments pertaining to offshore mineral extraction. The first is the so-called Hydrocarbons Directive of the EU, which in addition to

ascertaining the sovereign exclusive rights inscribed in the LOSC of member states to regulate access to exploration zones, provides for harmonised rules of non-discrimination as well as for obligations relative to the compilation and sharing of information. HELCOM has issued two recommendations: 1) Rec.18/2 of 12 March 1997 concerns specific measures to reduce the environmental impact of offshore activities, requesting *inter alia* that no such activities be conducted in designated Baltic Sea Protected Areas; and 2) Rec. 19/1 of 23 March 1998 requiring signatory states to follow a number of control and assessment procedures contained in the Guidelines for Marine Sediment Extraction that integrate the recommendation.

Maritime leisure & underwater heritage

The preservation of underwater cultural heritage is dealt with in international law in Article 303 of the Law of the Sea Convention, LOSC, and in the 2001 UNESCO Convention on the Protection of the Underwater Cultural Heritage. This latter treaty, which entered into force in January 2009, establishes basic principles of protection, lays out a framework for cooperation between states and provides a set of guidelines for preserving and researching this heritage. Neither Sweden nor Denmark has yet ratified the convention. As for Article 303 of the LOSC, it establishes the duty of states to protect and cooperate in the protection of underwater heritage at the same time that it acknowledges the possibility of private ownership of it. It further grants coastal states the prerogative of regulating access to and handling of finds through national legislation both in the territorial sea and the contiguous zone.

Both Denmark and Sweden have passed laws concerning cultural, historical and natural heritage found in the respective territories, the Museum Act and the Cultural Environment Act respectively.[31] With respect to underwater heritage, these laws apply in the territorial sea and contiguous zone in Denmark, but only in the territorial sea in Sweden, as this country has not yet declared a contiguous zone. However, the exception is created that if a heritage object found on the sea bottom outside the territorial sea is carried or towed into Swedish territory, then it belongs to the Swedish state. What counts as underwater heritage is also defined differently in the two countries; in Denmark it is objects lost more than 100 years ago, whereas in Sweden it is objects lost before 1851. Regarding ownership of such objects, both countries recognise the right of ownership if this can be proved. Where this is not the case, the Danish state claims ownership of all underwater heritage, whereas its Swedish counterpart only does so in those cases where a find is associated with a previously classified heritage object. Where this is not the case, ownership remains with the finder. Otherwise the two acts are fairly similar; they establish the duty of reporting finds to the authorities, set out the rights and obligations of these authorities, including, with respect to heritage, investigations and prohibit unlicensed tampering with heritage objects. A fundamental principle observed in both laws is that of *in situ* preservation.

The two main maritime recreational activities in the Sound are fishing and boating. A fundamental principle in both Denmark and Sweden is that any person is entitled to sail freely and fish for non-commercial purposes in any public water body, including the sea. To this generic freedom a number of conditions – including restrictions – have been added through specific legislation. So for example, although leisure sailors generally do not require any specific license, the boats themselves have to observe a number of construction, safety and environmental requirements inscribed in EU Directive 94/25/EC. Moreover, international rules and guidelines concerning navigation have to be observed by all, including leisure sailors and fishermen. The latter are, in accordance with the regulation on recreational fisheries,[32] obliged to carry a license in Denmark, but exempt from any such requirement in Sweden. However both states impose restrictions regarding fishing areas and seasons, types of fishing gear allowed as well as minimum sizes for certain species. In Denmark such regulations are determined centrally by the ministry in charge of fisheries, whereas in Sweden they are set both by central government and the county administrative boards. Hence, for the Sound, fishing regulations are set both by the Swedish Agency for Marine and Water Management and the County Administrative Board of Skåne.

The mouth of the Höje river in Lomma, with the recreational harbour in the far left corner. Note the large number of sailing boats lining the canal and the three fishing vessels parallel to the right-hand canal wall.

31 Lov nr. 473 af 7. juni 2001 and SFS 1988:950. With respect to this latter act, the analysis in these paragraphs pertains to its new redaction valid from 1 January 2014.

32 BEK nr.1199 af 11/12/2008.

Blue-fin tuna caught during a fishing competition in the Sound in 1949. The last specimen was caught in 1964. Source: Sydsvenskans bildarkiv

III THE BIO-PHYSICAL ENVIRONMENT

Climate in the Sound region

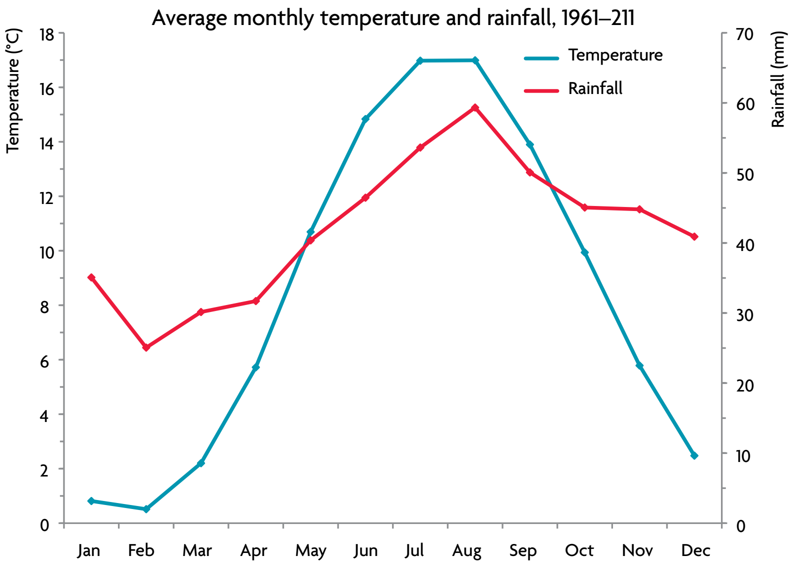
The Sound and most of the south Baltic region is located at the northern edge of the so-called warm temperate zone. In the northern hemisphere this zone finds itself predominantly under the influence of westerly winds that transport humid and relatively warm air masses from the North Atlantic. The northern and eastern parts of the Baltic basin however experience a significantly stronger influence of drier air masses of continental origin. The encounter of these two systems over the Baltic is one of the causes of the instability of weather states generally observed in this region.

In the course of a typical year, the westerly flow starts to intensify in the late summer, usually peaking in the mid-winter, around the months of January and February. During this period, the gradient between two dominant pressure systems over the North Atlantic – the Iceland Low and the Azores High – progressively gain in strength. Another high pressure system intensifies simultaneously over northern Russia, causing a south-westerly flow of cold, dry continental air that covers large areas of the northern and eastern Baltic during large parts of the cold season. In the south Baltic and the Sound this flow of polar air frequently encounters the eastward Atlantic flow, leading to the frequent alternations of frost and thaw periods even at the height of this season.

The end of winter in the Baltic generally coincides with the weakening of the pressure gradient over the Atlantic and the resulting decrease of the westerly air flow. Most of the region, in particular its south-western part, finds itself then mainly under the influence of an extension of the Azores High.

The gradient between the persistent Iceland Low and Atlantic High pressure systems – termed the North Atlantic Oscillation (NAO) – that dominates variability of weather and climate over the Sound is itself subject to considerable seasonal and inter-annual fluctuations. Although the mechanisms behind the NAO cycles are still poorly understood, it is known that positive NAO phases – that is with intense low and high pressures and thus a large pressure gradient – typically result in intensified westerly air flows and relatively warm and wet winters over northern Europe. On the other hand, negative NAO phases are associated with a greater continental influence and thus colder and drier winters.

The predominance of the Atlantic air flow over the Sound results in relative mild average temperatures year round. These vary between approximately 0ºC and 17ºC in winter and summer respectively. Yearly rainfall averages between 500 and 800mm and is evenly distributed throughout the year, with a slight increase during the summer and autumn months.

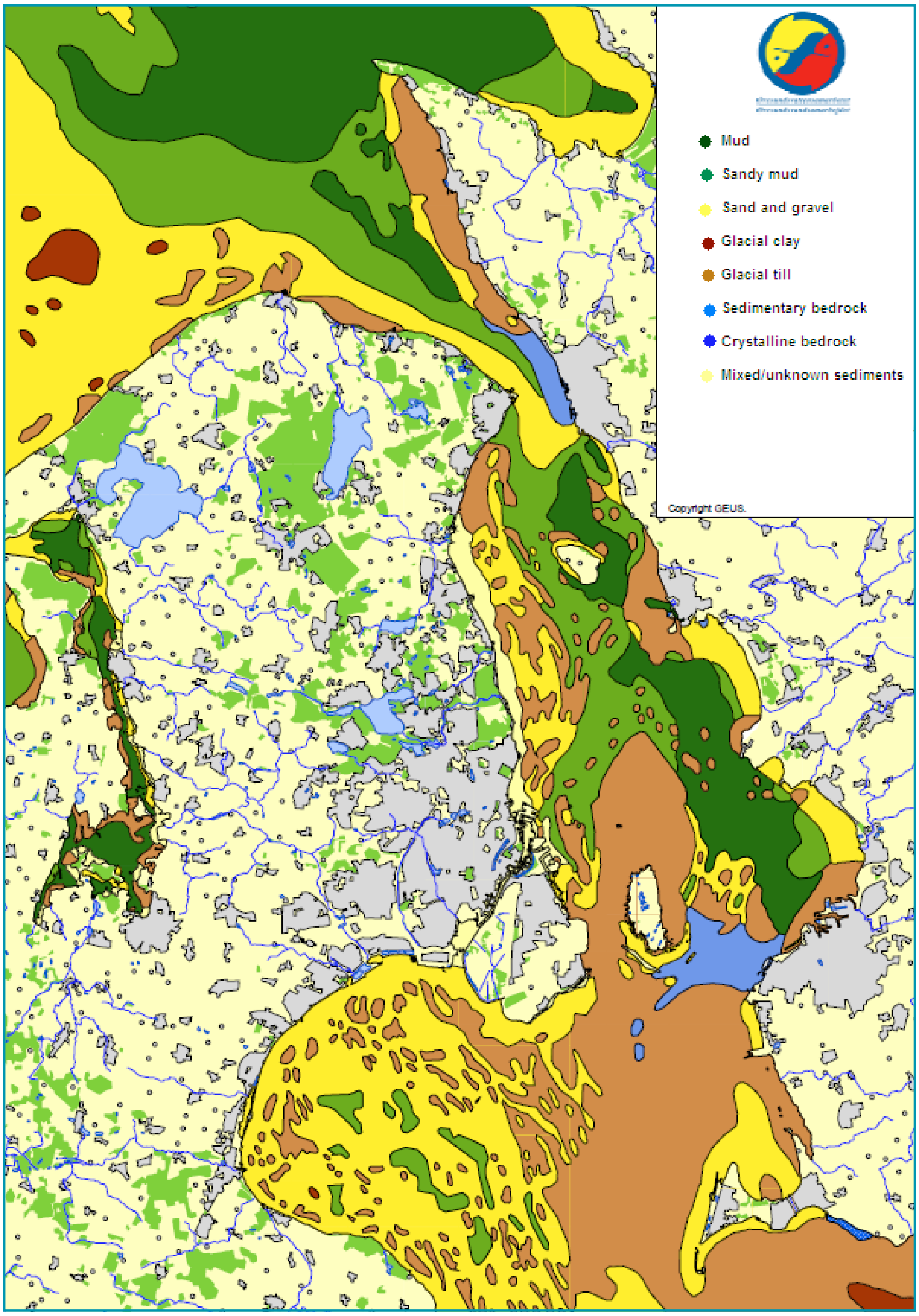


Average monthly temperature and rainfall at Falsterbo, based on data for the period Jan 1961-Dec 2011. Data source: SMHI

Sea bottom geology and sediments

There exist two main geological formations in the shelf beneath the Sound. South of a line stretching from Helsingør in Denmark to Landskrona in Sweden, one finds bedrock consisting predominantly of lime-, sand- and marlstone from the early to mid-Palaeogene period (approximately 65–35 million years ago). The shelf north of this line is of considerably older provenance – early to mid-Mesozoic, 230–150 million years ago – and composed of alternating deposits of clay, shale, sandstone and coal bearing strata.

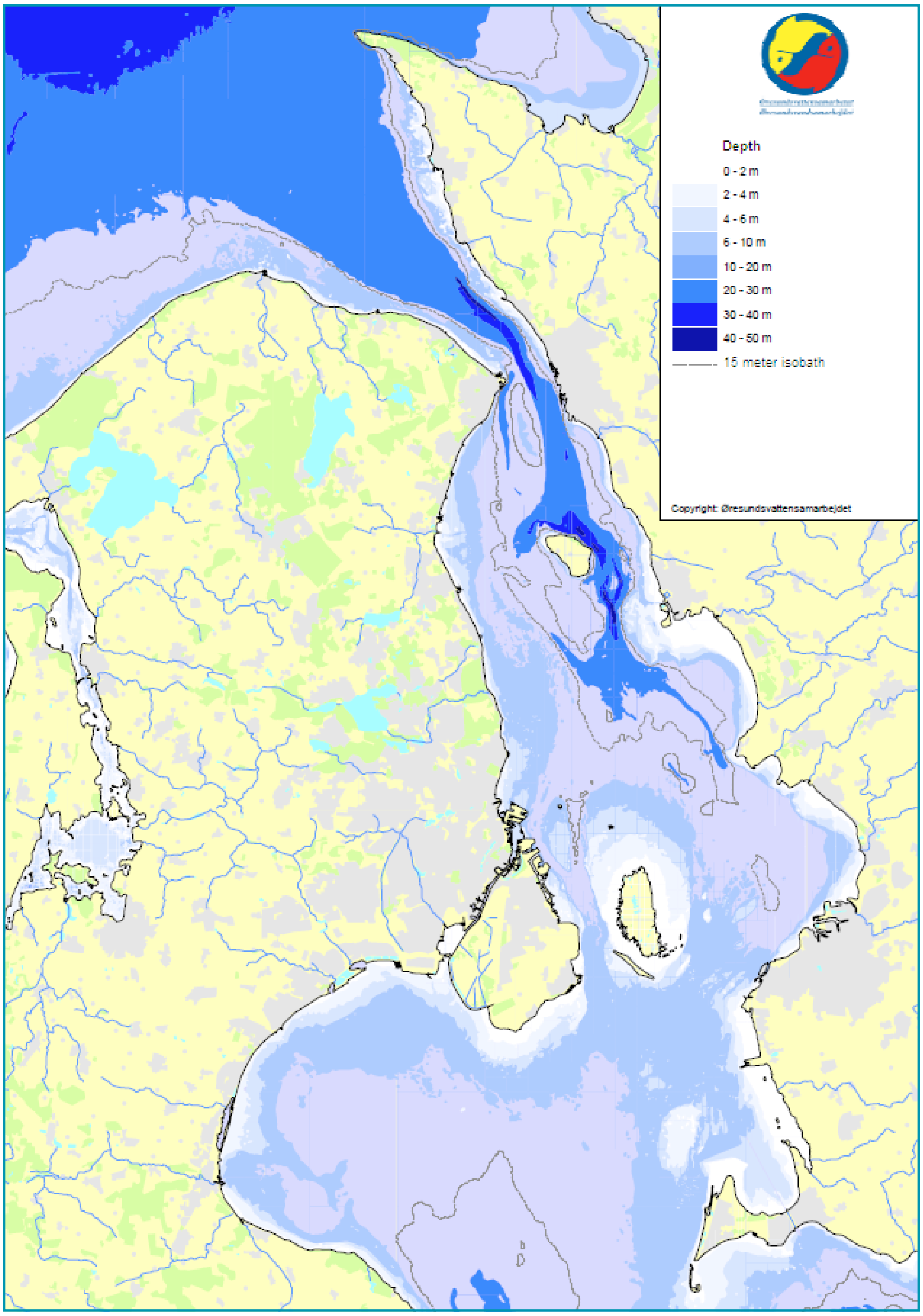
Map of the surface layer (0.5m) of bottom sediments in the Sound. Image courtesy of the Sound Water Cooperation, based on map by GEUS



Bottom sediments in the Sound exhibit greater diversity than the underlying bedrock. To the south of the Sound Bridge, one finds mainly soft bottoms of sand interspersed with mud and clay in most of Køge Bay, whereas glacial till makes up most of the coarser bottoms towards the Swedish shore. Around the Falsterbo peninsula soft bottoms of fine sand predominate.

In a radius of a couple nautical miles around Malmö one finds some of the few bottoms of sedimentary bedrock, other such outcrops existing only in the Helsingborg area and, to a minor extent, between Höganäs and Kullen near the Swedish shores of the northern Sound.

The middle parts of the central and northern Sound are mainly covered by postglacial muds, which originate from the deposition of clay during the later stages of the formation of the Baltic. Such accumulations are today more pronounced in the deeper areas. In shallower areas closer to the coasts of both Denmark and Sweden muddy bottoms are mostly replaced by those of sand and gravel, frequently interspersed with harder bottoms of glacial till.



The bathymetry of the Sound. Image courtesy of the Sound Water Cooperation.

Bathymetry and hydrology

The Sound is a relatively shallow body of water, with depths averaging less than 15m in over two thirds of its area. The greatest depths are found in its northern half, along an underwater channel in the middle of the Sound stretching from its northern inlet and southwards to Lundåkra Bay. Depths along this channel generally exceed 25m, attaining a maximum of 53m in the Landskrona Deep south of Ven Island, the Sound's deepest point. Except for the cliff-dominated coast south of Kullen in the north-eastern edge of the Sound, coastal waters are predominantly shallow.

One topographic feature in particular determines the biophysical characteristics of the Sound, namely the 7–8m deep sill extending over its whole breadth from Dragør in Denmark, over the southern tip of Saltholm island to Lernacken in Sweden. Together with the substantially deeper (18m) Darss sill at the Baltic entrance to the Belt Sea, the so-called Drogden-Limhamn sill in the Sound greatly influences water exchanges between the North Sea and the Baltic as a whole.

The main inflow of water into the Baltic is from rivers, the largest of which discharge into the Bay

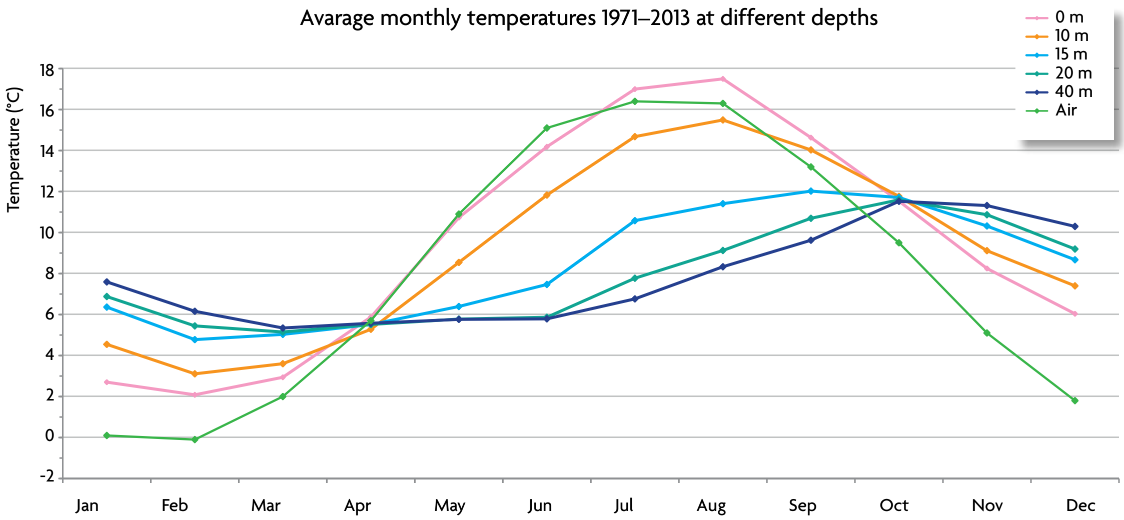
of Bothnian, the Bothnian Sea and the Gulf of Finland. The large *apport* of riverine freshwater causes the surface water of the Baltic to be brackish, salinity ranging from as low as 3ppt in the inner Bay of Bothnian and the Gulf of Finland to around 12ppt in the Arkona Basin. As freshwater flows into the northern Baltic a mass gradient is formed that forces surface water south-westwards towards the Baltic's only outlets in the Belt Sea and the Sound. The result is an almost continuous flow of brackish water northward through the Sound.

Underneath this layer of brackish water one finds a different water mass with origin in the Kattegat and North Sea. Because of its much higher salt content and density, this water tends to sink below the lighter brackish layer, the frontier between both occurring at a depth of approximately 10m. An abrupt change in salinity is observed where the two layers meet – the so-called halocline – and the resulting density difference renders the two water masses practically immiscible.

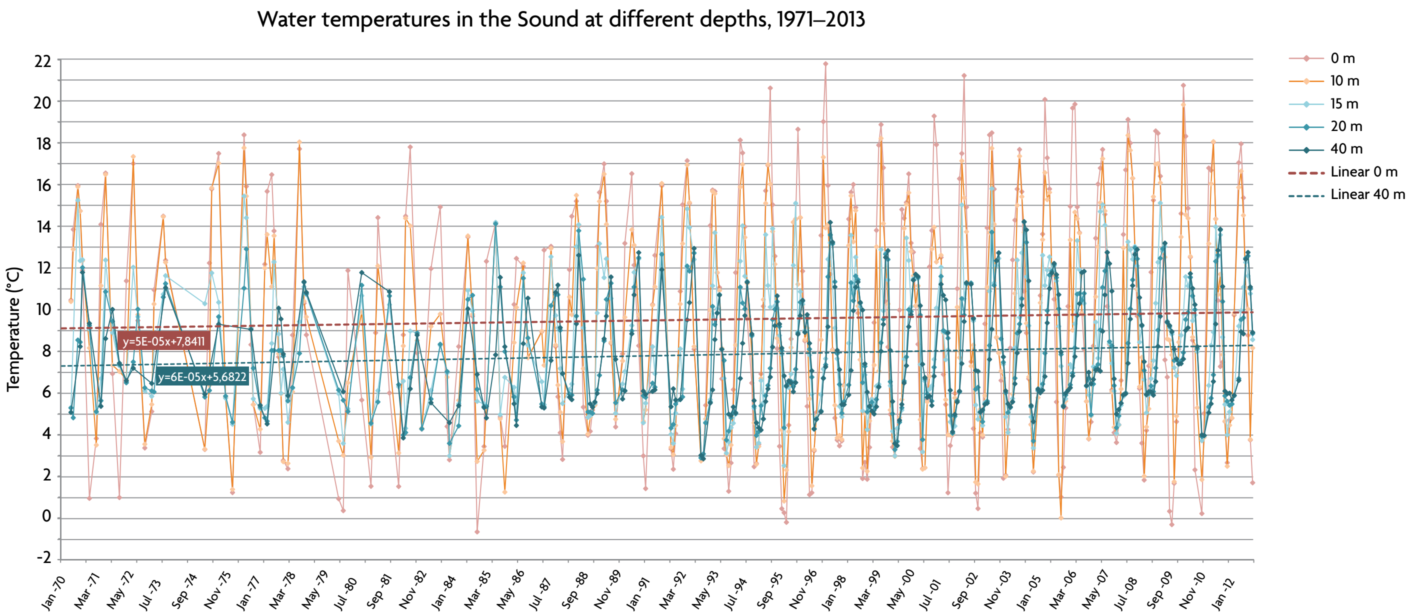
The denser saline water tends to move southward through the Sound. Since it often occupies depths greater than that of the Drogden-Limhamn sill, it only occasionally flows over it and into the Baltic. Such events typically coincide with intense westerly winds that force Kattegat and North Sea water through the Sound and the Belt Sea towards the Baltic. On such occasions a net southward current through the Sound is observed. Such pulse inflows of saline water are of crucial importance for renewing the water in the deeps of the Baltic.

Temperature, oxygen and light

The stratification of the water column in the Sound is evidenced by its temperature profile, as illustrated in the figures. The first, depicting the monthly average temperature at depths down to 40m for the period 1971–2013 measured in the station south of Ven Island shows how the temperature of surface water varies together with air temperature, from a minimum of around 2°C in winter to maximum of close to 18°C in late summer. With a lower amplitude, a similar pattern of monthly variation is observed at depths down to 10m. Below this value – that is, below the depth of the halocline, the frontier between brackish Baltic and saline North Sea water – temperature variations are far less pronounced. Below 25m depth water temperature varies between approximately 5°C in early spring to just over 11°C in early autumn.



Water temperature in the Sound at different depths, monthly averages 1971-2013 for the measuring station south of Ven Island. Data sources: SMHI (water), DMI (air)



Water temperature at different depths in the measurement station south of Ven Island, Jan 1971-Jan 2013. Source: SMHI

Ice conditions in the Sound are often relatively mild, it generally remaining ice-free except for the shallower areas, ports and smaller embayments. Ice formation typically occurs around the months of January and February, and break-up usually during the month of March. In particularly severe ice winters – the latest of which were those of 1985, 1986 and 1987 – the whole Sound might be covered by a layer of pack ice a couple decimetres thick.[1]

This second picture depicts the temperatures measurements at different depths in the station south of Ven Island between January 1971 and January 2013. The more intense variation at shallower depths is once again visible, with temperatures at depths greater than 20m concentrating in a narrower band ranging roughly between 4ºC and 14ºC. The linear trend lines for temperatures at the surface and at 40m depth are also included in the figure. The positive coefficients in the respective equations indicate that, amidst significant yearly variation, there is a warming trend of the whole water column in the Sound.

Oxygen concentration in water is another parameter strongly influenced by the separation between surface and deep water masses in the Sound. This separation implies that the atmospheric oxygen dissolved in the upper layer only occasionally reaches the waters at the bottom. Here, biological processes continuously consume the available oxygen; with insufficient ventilation this may result in hypoxic or even anoxic conditions in deeper areas. Ventilation of

1 See Nilsson (1988) for a careful analysis of the ice conditions during this period.

the bottom layer in the Sound occurs either via vertical mixing with the top layer or via large inflows of well-aerated North Sea water from the Kattegat. Oxygen depletion in the Sound is thus a variable and largely unpredictable phenomenon. In some years, such as that of 2002, severe hypoxia may be extensive; in others, like 2007, mild hypoxia may be recorded only in the deepest areas or even in other cases, such as the year 2011, when sea bottom oxygen conditions were considered good in the whole Sound.

Situations of low oxygen concentration in the waters of the Sound generally occur when:
– winter and spring rainfall is intense and results in the discharge of large amounts of nutrients from land. These in turn support intense phytoplankton growth during the early spring months and
– there are prolonged periods of warm and calm weather during later spring and summer. Warmth increases the rate of degradation of biological matter and accentuates the density difference between the top and bottom water masses and calm prevents mixing and thereby ventilation of bottom waters where a large proportion of the biological degradation takes places.

Phytoplankton growth rates decrease in the course of the spring and summer as nutrients dissolved in seawater are consumed.

Plankton abundance is also one of the factors affecting how deep light penetrates the waters of the Sound. Underwater visibility is in general good, with average yearly Secchi depth values in the order of 7–8m in the central Sound.[2] Variations can be very pronounced though, ranging from less than one meter at times of intense runoff from land or during plankton blooms, particularly in shallower coastal waters, to more than 10m in oligotrophic deeper waters. The photic zone in the Sound extends normally down to 10-15m, a depth below which the amount of available light is insufficient to support vegetation growth.

Biological communities

Plankton

Plankton dynamics in the Sound are determined by light intensity, water temperature and nutrient availability. Biomass is normally very low during the winter months, mainly due to insufficient light and occasionally ice cover. The early spring usually witnesses a bloom of autotrophic microscopic plankton species, of which the largest groups are single-celled diatoms and in smaller amounts, dinoflagellate algae. A second, less intense bloom is typically observed in the autumn, around the month of October.

Phytoplankton species diversity is greatest in the northern parts of the Sound where the higher salinity sustains a larger number of purely marine species. This spring bloom, with duration of one to two weeks, has its peak during the months of March or April. Phytoplankton growth rates decrease in the course of the spring and summer as nutrients dissolved in seawater are consumed. Nitrogen is usually the limiting element for diatom and dinoflagellate growth, and its exhaustion often triggers the growth of autotrophic plankton capable of fixating atmospheric nitrogen. Cyanobacteria, also known as blue-green algae, constitute the dominant group of such organisms, which, provided weather conditions are calm and warm (>16ºC), may bloom extensively in the central and southern Baltic. Freed from competition from other phytoplankton species, cyanobacteria thrive on the largely untapped reserves of dissolved phosphorus. Microscopic cyanobacteria dominate the early phases of the blooms, but are soon replaced by larger filamentous species that cover large areas of the Baltic proper in late summer. Only very rarely do cyanobacteria blooms originate in the Sound, and most of the occurrences here are from blooms in the Baltic pushed westward by winds.

In all three phytoplankton groups – diatoms, dinoflagellates and cyanobacteria – one finds numerous species capable of producing toxins of varying toxicity to both other marine species and humans. Upper limits have been established for several of such species and episodes of excessive concentrations in different locations in the Sound are not uncommon.[3]

Most phytoplankton serves as food for heterotrophic zooplankton, also known as zooplankton, the biomass of which increases rapidly following the spring phytoplankton bloom. As with phytoplankton, zooplankton species diversity varies proportionally with salinity and hence decreases from north to south in the Sound. A diverse array of protozoans and animals with very distinct forms, life cycles and survival strategies, zooplankton may be divided according to size into nanozooplankton, comprising single-celled

2 For a complete record see the yearly reports issued by the Öresunds Vattenvårdsförbund, available online at http://www.oresunds-vvf.se/Dokument/rapporter.htm. Secchi depth corresponds approximately to the depth of water at which incident surface light is reduced to 10%. The photic zone, in turn, usually has its lower limit at the depth where incident light is reduced to 1%.

3 See, for example, the yearly reports on phytoplankton, chlorophyll and primary production issued by the Öresunds Vattenvårdsförbund, available at ‹http://www.oresunds-vvf.se/Dokument/rapporter.htm›.

The lion's mane jellyfish, also known as hair jelly (Cyanea capillata), a common inhabitant of the Sound. Source: Michael Palmgren

organisms smaller than 20µm, microzooplankton, with sizes 20-200µm, including ciliates, zoo-flagellates, rotiferans and copepods in their earliest development stages, among others and mesozooplankton, with sizes above 200µm, where one finds copepods, cladocerans and larvae of numerous marine species. Jellyfish are generally classed as gelatinous zooplankton – as opposed to crustacean zooplankton, for instance – and their importance in the Sound and the Baltic is believed to be on the increase. Because jellyfish prey on other zooplankton species and on fish eggs and larvae, and are not eaten by any other life forms in the Sound, the increase in their numbers has a negative impact on the marine ecosystem.

Pelagic species

There are relatively few purely pelagic macroscopic species in the Sound. In addition to jellyfish species – of which the moon jellyfish, Aurelia aurita, is the most common – the pelagic waters in the Sound are inhabited by a few species of medium-sized fish, some of which are of high commercial value. The most abundant pelagic species include:

– herring (*Clupea harengus*), a small pelagic fish that often swims in very large shoals. The western Baltic population, with its origin off the German island of Rügen, migrates every spring northward through the Sound on its way to feeding grounds in the Kattegat and Skagerrak. The southward migration takes place in the autumn when the Sound herring fisheries take place. A smaller population exists that spawns in the eelgrass meadows of the Sound;

– Atlantic mackerel (*Scomber scombrus)*, which also forms large shoals, is a seasonal inhabitant of the Sound waters. It spends most part of the cold season in deeper waters in the North Sea, approaching the coastal waters of the Skagerrak, Kattegat and Sound during the spring and summer to spawn;

– Garfish (*Belone belone)* have a similar migratory pattern, spending the autumn and winter in the Atlantic off the British Isles and arriving in the Sound in mid-spring to spawn. In shallow waters it aggregates into dense schools. It is believed that until the mid-20th century blue fin tuna followed garfish into the Sound in their yearly migration;

– Thicklip or lesser grey mullet (*Chelon labrosus)* is also present in the Sound during the spring and summer months, spending the rest of the year in the warmer waters of south-western Europe

and northern Africa. It has become increasingly frequent off the western Scandinavian shores in the last five decades;

– Salmon (*Salmo salar*), present in the Sound in relatively small numbers during its migrations from rivers to the North Sea and

– Sea trout (*Salmo trutta*), which, like salmon, spawns in inland waters, but, unlike salmon, migrates very little once it reaches the coast, and hence is more abundant in the Sound. As is the case with salmon, sea trout is not a purely pelagic species, sometimes feeding near the sea bottom.

Some demersal fish species are occasionally found in the pelagic zone of the Sound, two of the most important being cod (*Gadus morhua*) and saithe (*Pollachius virens*). The former, more common in the Sound than the latter, spends most of its time in the water column when preying on herring during its migration through the Sound. More abundant in the Skagerrak and Kattegat, saithe is to a lesser extent than cod a benthic species, especially in coastal waters, where it is found hunting in small shoals down to 40m depth. Like cod, it feeds extensively on herring, as well as on other fish and crustaceans.

Benthic communities

The very diverse sea bottom habitats and conditions in the Sound support a varied benthic fauna and flora. Among the latter one finds both flowering plants and macroscopic algae of which green, red and brown algae exist in the Sound. Faunal communities are typically named after the dominant animal species as described further below.

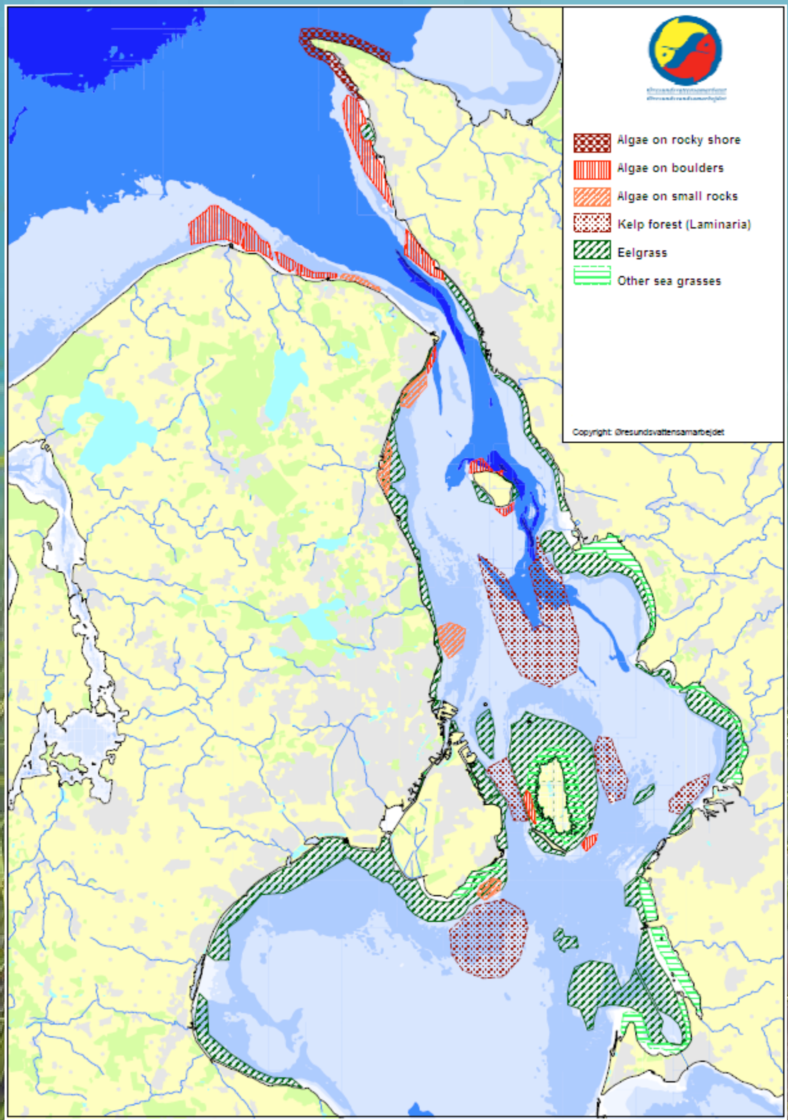
The distribution of **underwater vegetation** is determined by factors such as bottom substrate, light intensity, salinity, oxygen and levels of nutrients and pollutants. Pollution and high nutrient loads reduce floral diversity with naturally occurring species progressively replaced by opportunistic, pollution-tolerant ones. Oxygen depletion, on the other hand, leads to a generalised reduction in vegetation, which is entirely absent from hypoxic and anoxic zones. With respect to salinity, plant and algae diversity is greatest at salinities between 25 and 35ppt, that is, the salinity range of oceanic waters. Hence in the Sound, as is the case for all other marine species, vegetation diversity decreases from north to south.

Watercolour of cod (Gadus morhua) in the mixed substrate benthic environment of the northern Sound. Image courtesy of Sven-Bertil Johnson

Light intensity determines the vertical and also temporal distribution of vegetation. Green and brown algae, for example, require more light than red algae and hence dominate in shallower areas. The same applies to flowering plants of the *Ruppia* and *Potamogeton* species, which are only found at depths of less than one metre below which the eelgrass *Zostera marina* dominates. Seasonal variations in light availability are pronounced in the Sound. Insufficient light and low temperatures cause a significant reduction in vegetation biomass during the autumn and winter months. Many species do not last more than one vegetative season and perennial species retract during the cold season. The spring and summer typically see the appearance of numerous species of one-year filamentous algae. In conditions of high nutrient loads, the latter might grow to the extent of reducing light and oxygen in water and thereby impair the growth of other seasonal and perennial species.

The composition of the sea bottom substrate is the decisive factor separating the distribution of algae *vis-à-vis* flowering plants. The former need hard substrates on which to anchor via their holdfasts whereas the latter require soft substrates of sand or mud in which to plant their roots. Algae are thus more abundant in the rocky shores in the north-eastern part of the Sound, on the large boulders found on both sides of the northern half of the Sound, on submerged hard structures such as coastal piers, walls and bridges, and even on areas covered with gravel or small stones interspersed with sand or mud. Green algae are frequent at depths of less than five metres and usually in relatively low densities, although they might become abundant in the presence of high nutrient concentrations. In such cases it is the single-season sea lettuce (*Ulva sp.*) that is the most frequent.

Short-lived filamentous algae are also common in the top metres of the waters of the Sound. These grow often on hard substrate, on other algae and on marine grasses but in cases of extensive growth may become loose and drift with currents, frequently washing ashore where they accumulate as thick and sticky mats. Some of the most frequent species of single-season filamentous algae in the Sound include the brown algae (*Pilayella littoralis* and *Ectocarpus siliculosus*), as well as red algae of the genera *Polysiphonia* and *Ceramium*.



Map showing the distribution of underwater vegetation in the Sound. Image courtesy of the Sound Water Cooperation.

Eelgrass interspersed with filamentous algae on soft sediments in the southern South. Source: Michael Palmgren

Watercolour representing the succession of algae on a large boulder in Grollegrund, south of Höganäs. Image courtesy of Sven-Bertil Johnson.

With increasing depth green algae are progressively replaced by first red and then brown algae, both types colonising hard substrates down to the lower limit of the photic zone around 20 metres. Among the brown algae one finds some of the longest species in the Sound namely the sugar kelp (*Laminaria sacharina*), bladder wrack (*Fucus vesiculosus*) and toothed (or serrated) wrack (*F. serratus*). Red algae are on average smaller, some of the larger (>10cm) species including the edible dulse (*Palmaria palmate*), the red rags (*Dilsea carnosa*) and the sea beech (*Delesseria sanguinea*). One also finds species of filamentous algae among the brown and red algae. In the Sound, species diversity is largest amongst the brown and red, and smallest among the green algae, with an estimated 70 species for each of the former two and between 30 and 40 for the latter group (Carlsson et al., 2006).

Sugar kelp (L. sacharina) on rocky substrate. Source: Michael Palmgren

Eelgrass (*Z. marina*) is the most common flowering plant, covering large areas with sandy sea bottoms at depths between two and six metres. Eelgrass can also be found at depths above and below these values, but with reduced densities. The areas in the Sound with the largest eelgrass extensions are Nivå and Køge Bays, and the areas around Tårbæk, Copenhagen and Saltholm in Danish waters, and north of Helsingborg, between Landskrona and Ålabodarna and around Falsterbo on the Swedish side. Eelgrass can grow to one metre in length and form dense meadows. These provide the habitat for a large number of marine animals and the roots minimise sediment movements, thereby reducing coastal erosion.

Close-up of an eelgrass (Z. marina) meadow outside Malmö. Source: Michael Palmgren

Other groups of seagrasses exist in shallow (< 2m depth) waters of the Sound where sandy bottoms are protected from strong wave or current action. Such areas include a narrow belt along the Swedish coast from Foteviken in the south to Landskrona further north, and south of Copenhagen and around Saltholm on the Danish side. Thriving shoreward of the eelgrass belt one finds ditch grasses (*Ruppia sp.*), horned pondweed (*Zannichellia sp.*) and plants of the genus *Potamogeton.* Seagrass-resembling algae of the genus *Chara*, which attach to the substrate by means of root-like rhizoids, are found in decreasing numbers among the seagrasses.

Zoobenthos communities in the Sound are generally described according to a classification first established by the Danish marine biologist Carl Georg Petersen in the early 20th century.[4] Petersen's findings and descriptions have been complemented by later studies, notably those of Thorson and Muus,[5] and have served as the baseline for investigations of ecological status for the past century. The classification applies to faunal assemblages in and on soft sediments; in hard substrates it is algae that constitute the main habitat builders.

Five of Petersen's six biotope typologies are named after the animal genus that is most abundant. The exception are the so-called 'brackish water communities', which, despite the presence of a few characteristic species, vary widely in composition between different areas of the Sound. Although the communities are described in isolation and with an indication of preferential depths, there are often no clear boundaries between the different assemblages of fauna found in the six typologies. It is also worth highlighting that the classification pertains primarily to sessile fauna. Motile species, such as fish, are typically not confined to a given benthic community and are therefore not at the core of the classification. The sedentary nature of benthic species renders them particularly suitable for the assessment of the impacts of different kinds of natural and anthropogenic phenomena over time. For this reason, environmental status investigations in the Sound have often been conducted on the locations initially sampled by Petersen.[6]

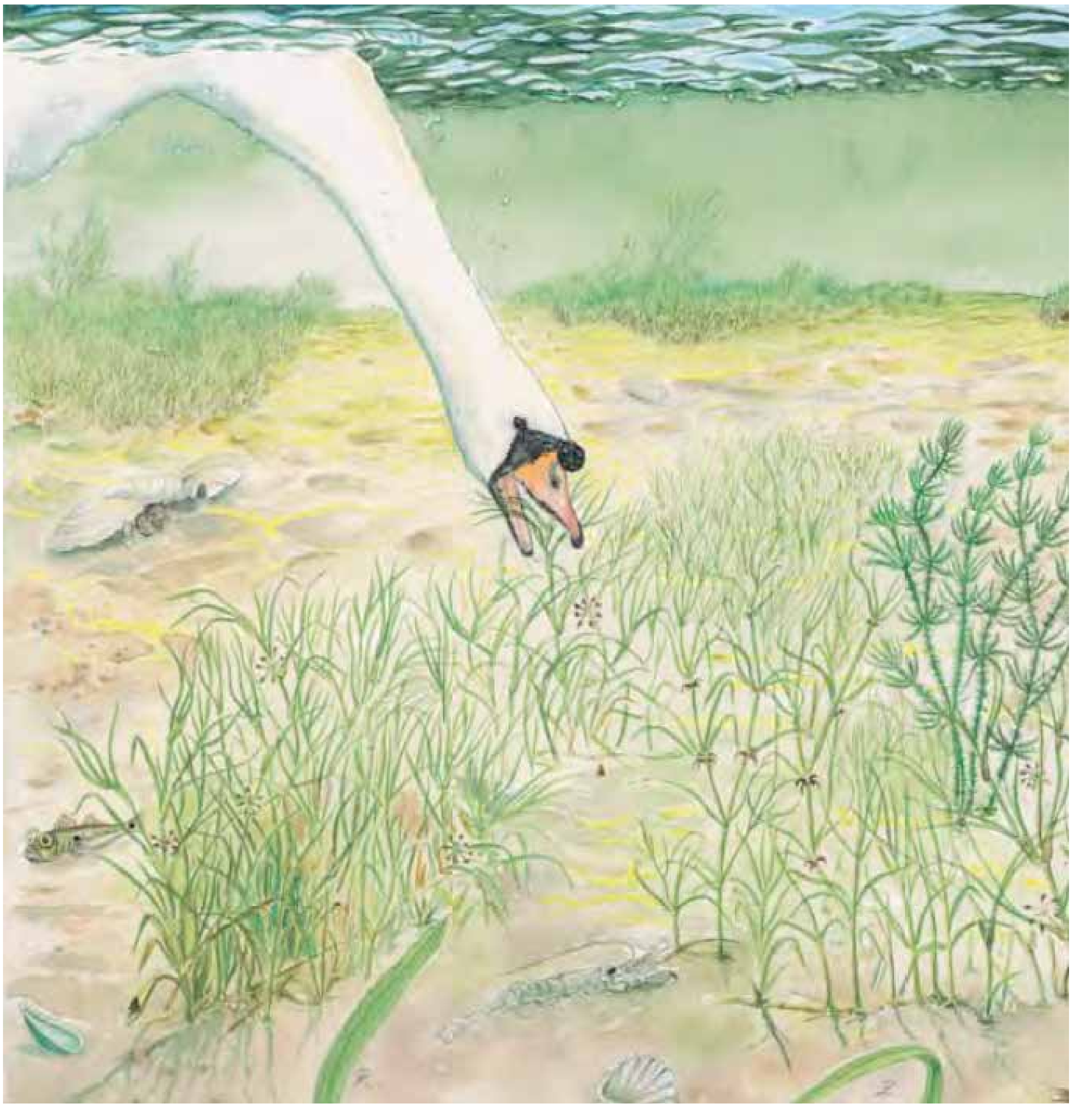
Brackish water communities is a generic name that refers to a variety of faunal assemblages in shallow waters (<2m depth) in the Sound. Because of their shallowness, marine ecosystems in these areas are subject to intense variations in

4 Petersen (1911, 1913).

5 Thorson (1957), Muus (1966).

6 For an overview see Göransson (2002).

Watercolour depicting an idealised vertical profile of the Sound with the different benthic communities. On the top right the Kronborg castle in Helsingør. Image courtesy of Sven-Bertil Johnson.



Watercolour of mute swan (C. olor) feeding on a meadow of Ruppia sp., Zannichellia sp. and Potamogeton sp. grasses. Algae of the Chara genus are visible on the right-hand side. Image courtesy of Sven-Bertil Johnson.

water movement, temperature and salinity as well as nutrients and other dissolved substances from land runoff. Hence sessile species found here must be particularly resilient and capable of tolerating large changes in all these parameters. In the top metres of the Sound, water salinity is relatively low, usually not exceeding 15ppt, which excludes many purely marine species that require higher salt concentrations. The base of the food chain is composed of bacteria in the sediment and diatoms in the water column on which a small number of animal species feed often attaining large densities. Shallow coastal waters are very productive and support a number of marine birds such as the pied avocet (*Recurvirostra avosetta*), the Eurasian oystercatcher (*Haematopus ostralegus*), the mute swan (*Cygnus olor*), the common eider (*Somateria mollissima*) or the herring gull (*Larus argentatus*). Despite the variety of brackish water biotopes, brackish water snails of the genus *Hydrobia* and the ragworm (*Hediste diversicolor*) – a polychaete worm of the Nereidae family – are frequently found amidst other species. In poorer, loose sand bottom areas one finds often faunal assemblages dominated by deposit-feeding amphipods of the genera *Haustorius* and *Bathyporeia*. Areas of finer sediment are usually richer in organic matter and hence support a richer faunal diversity, which is further accentuated in vegetated zones. Buried in the sand, one finds different species of gastropods, amphipods and worms. The blue or common mussel (*Mytilus edulis*) is found is small aggregations interspersed in the vegetation, or in larger accumulations in vegetation-free areas, such as in the mussel banks around the Limmhamn-Drogden sill.

At the depth interval of 2-16m, the most frequent benthic biotope is the so-called Macoma community, named after the Baltic clam – also

A black goby (Gobius niger) on a mussel bank in the southern Sound. Source: Michael Palmgren

known as Baltic tellin or macoma – *M. balthica*, a saltwater bivalve mollusc of the Tellinidae family. This community is the dominant one in most of the Baltic and lines much of the submerged coast on both sides of the Sound. North of the Limhamn-Drogden sill the Macoma community does not usually extend below depths of 12m, where it is replaced by the Abra community. Associated with the macoma, one typically finds the Laver spire shell (*Hydrobia ulvae*) – a gastropod mollusc - and the polychaete worm (*Pygospio elegans*). The latter attains particularly high densities in areas with fine sediment bottoms and high organic contents. Located above the halocline, the waters where the Macoma community is found are subject to important variations in salinity – which is generally low – and temperature. It shares a number of characteristics with brackish water communities, namely the predominance of short-lived small species and the relatively low species diversity, occasionally with high density of individuals of the same species. Mussels and clams predominate in sea areas with bottoms of sand, whereas vegetated zones house different species of snails and crustaceans living in and on the sediment.

In much of the Sound north of the Limhamn-Drogden sill at depths between 12m and 20m soft sea bottoms are dominated by the Abra community, named after another bivalve mollusc, the white furrow shell (*Abra alba*). This is often found in the company of the chalky macoma (*Macoma calcarea*) and the polychaete worm (*Terebellides stroemi*). Around the depth of the halocline between 12m and 15m one observes a transition between the Macoma and the Abra communities, the composition of which is more stable below the latter depth.

The basis of the food chain is made up of plankton that deposits down through the water column and is captured by the numerous filter feeders. Several of these are worms that live partly buried in the sediment with their feeding organs protruding from it, examples including the horseshoe worm (*Phoronis muelleri*) and the polychaete worms *Euchone papillosa* and *Galathowenia oculata*. The rate of energy conversion, in particular through predation, is high, and the Abra community generally sustains a large variety of fish species. Species richness is greater than in the communities in shallower waters due largely to the higher average salinity that enables the establishment of a greater number of marine species. Contrary to the above two communities, the Abra biotope is dominated by larger species that live for a few years. The granulometry and organic contents of the substrate partly determine species density and biomass. In organically rich sea bottoms of fine sediment the highest densities are attained by the cumacean *Diastylis rathkei*, the Laver spire shell (*H. ulvae*) and the polychaetes *T. stroemi* and *Nephtys ciliata*, whereas the greatest biomass values are achieved by an exceptionally long-lived edible clam, the ocean quahog *(Arctica islandica)*.

Nutrient poorer sea bottoms of more granular sediment exhibit a larger density of the polychaetes *Rhodine gracilior* and *Scoloplos armiger*, the white furrow shell (*A. alba*) and the cumacean *D. rathkei*. The chalky macoma (*M. calcarea*) often attains the greatest biomass values.

Below the halocline, salinity and temperature conditions are more constant and similar to those of purely marine environments in the Kattegat, Skagerrak and North Sea. For this reason, the muddy sea bottoms in the Sound north of the Limhamn-Drogden sill at depths greater than 20m are inhabited predominantly by species requiring higher salinity values. Individuals tend to attain larger sizes and live longer. Another consequence of the stronger oceanic influence is that values of biological diversity and biomass are generally higher than in the biotopes at shallower depths.

Below the halocline, light intensity is insufficient to sustain any primary production, even in summer. Hence the basis of the food chain is made up of plankton that sinks from the top and of bacteria growing in and on the sediment. Deep water currents, which are often strong in the Sound, carry additional nutrients from the Kattegat and beyond that help sustain the deep water biotopes.

Three common biotopes have been described at depths greater than 20m. The first is the Amphiura community, which is common in the central parts of the northern half of the Sound, as well as in the Kattegat, Skagerrak and North Sea. It gets its name from its most common habitat builder, the brittlestar (*Amphiura filiformis*). This is a suspension feeder that subsists on a diet of mixed plankton, re-suspended bottom nutrients and detritus, which it captures with arms protruding from the sediment where it burrows. Adult life forms of *A. filiformis* are slow growing, individuals occasionally having a life span of 20 years. Other frequent inhabitants of this biotope include another brittlestar (*Ophiura albida*), polychaete worms such as *Pholoe baltica*, *R. gracilior* and *Anobothrus gracilis*, molluscs such as the glistenworm (*Chaetoderma nitidulum*) and the clams ocean quahog (*A. islandica*) and Müller's nut clam (*Nuculana pernula*), as well as crustaceans such as *Diastylis lucifera* and *Ampelisca tenuicornis*. In a very limited number of locations around the island of Ven at depths below 25m one finds the Haploops community, named after the dominant genus of amphipod crustaceans. These animals encapsulate themselves in small mud tubules in the sediment, leaving only their tentacular feeding organs outside with which they avidly prey on the larvae of numerous other species. *Haploops* crustaceans themselves are preyed on by benthic fishes, namely cod. Another crustacean that is common in this community is *Philomedes globosus*, often in the company of the small brittlestar (*Ophiura robusta*) and the bivalve mollusc (*Pseudamussium septemradiatum*). Polychaetes are, as in most fine sediment benthic biotopes in the Sound and elsewhere, represented by numerous species, including *Anobothrus gracilis*, *Maldane sarsi*, *Prionospio fallax*, *Aurospio banyulensis* and *Glycera alba.*

The last benthic biotope and the one found at greatest depths receives its name from the genus of mussels that agglomerate into dense banks at around 30m depth. The so-called Modiolus communities have a limited distribution in the Sound, occupying but a few small areas off Helsingborg and possibly at greater depths around Landskrona and Ven, all on the Swedish side of the Sound. Contrary to all other five biotopes described above, *Modiolus* communities are not established on homogeneous soft substrate, instead the shells of both living and dead mussels forming a rugged tri-dimensional structure resembling an irregular rocky sea bottom. This provides habitat for numerous other species, including epifauna, that is, species that grow on the very mussel shells. This is the case of the acorn barnacle (*Balanus balanus*), the northern blind limpet (*Lepeta caeca*), anemones such as *Stomphia coccinea* and *Urticina feline*, and the soft coral *Alcyonium digitatum*, known as dead man's fingers. Red and brown algae occasionally also grow on mussel shells.

The large (up to 22cm long) northern horse-mussel (*Modiolus modiolus*) is the dominant species in this biotope. Horsemussels feed on sinking phytoplankton that they filter from the surrounding waters and, when young, are themselves preyed upon by starfish such as *Solaster endeca*, *Crossaster papposus*, *Leptasterias muelleri* and the bloody Henry (*Henricia sanguinolenta*) among others. Horsemussel banks harbour a wide diversity of marine fauna including, in addition to the species already mentioned, the crevice brittlestar (*Ophiopholis aculeate*) and the black brittlestar (*Ophiocomina nigra*), the sickle hydroid (*Hydrallmania falcate*), the polychaetes *Petaloproctus tenuis* and *Pherusa plumose*, the arthropod *Numphon grossipes* and the yellow excavating sponge (*Cliona celata*).

Watercolour representing a horsemussel (M. modiolus). Image courtesy of Sven-Bertil Johnson.

Watercolours depicting species assemblage and key species in the six main benthic community types. Images courtesy of Sven-Bertil Johnson.

a) Brackish water community at a few meters depth off Lernacken;

b) Macoma community at 7m depth in Nivå Bay;

c) Abra community at 15m depth in Lomma Bay;

d) Amphiura community at 25m depth off Höganäs;

e) Haploops community at 36m depth off the island of Ven;

f) Modiolus community at 30m depth outside Råå.

A

B

C

D

E

F

All benthic habitats support a large diversity of **demersal fish** species that feed on the varied flora and fauna found there. Some of these species were mentioned earlier, namely cod (*G. morhua*), saithe (*P. virens*), salmon (*S. salar*) and seatrout (*S. trutta*), all of which are considered benthopelagic, spending time in both pelagic and benthic environments. A vast variety of other demersal fish species exist in the Sound, some of the most representative including:

- Among the gadoids – that is, cod- and hake-like species – and besides cod and saithe, also European pollock (*Pollachius pollachius*), haddock (*Melanogrammus aeglefinus*), whiting (*Merlangius merlangus*), ling (*Molva molva*), European hake (*Merluccius merluccius*), and pout and Norway pout (*Trisopterus luscus* and *T. esmarkii*);
- Flatfish such as European plaice (*Pleuronectes platessa*), European flounder (*Platichthys flesus*), common dab (*Limanda limanda*), witch flounder (*Glyptocephalus cynoglossus*), turbot (*Psetta maxima*), as well as common and lemon sole (*Solea solea* and *Microstomus kitt*);
- Several species of elasmobranchs, which tend to remain in deeper waters due to reduced tolerance to low salinity, among which sharks such as the small-spotted catshark (*Scyliorhinus canicula*), the spiny dogfish (*Squalus acanthias*), and larger and less frequent species such as the porbeagle (*Lamna nasus*) and the basking shark (*Cetorhinus maximus*). Rays in the Sound are represented by the thornback, the thorny and the common or blue skate (*Raja clavata*, *R. radiata*, and *Dipturus batis*), the last of which a critically endangered species;
- In seagrass meadows, in particular among the eelgrass, a variety of fish with elongated bodies, such as the endangered European eel (*Anguilla Anguilla*), the rock gunnel (*Pholis gunnellus*), and in the pipefish family the great and the lesser or Nilsson's pipefish (*Syngnathus acus* and *S. rostellatus*), the broad- and the straight-nosed pipefish (*Siphonostoma typhle* and *Nerophis ophidion*) and the snake pipefish (*Entelurus aequoreus*). Other frequent inhabitants of seagrass habitats include the three-spine, nine-spine and sea sticklebacks (*Gasterosteus aculeatus*, *Pungitius pungitius* and *Spinachia spinachia*), the viviparous blenny (*Zoarces viviparous*) and the two-spotted goby (*Gobiusculus flavescens*).
- A large number of gobies, of which the most common species include, other than the two-spotted goby, the common, the painted and the sand gobies (*Pomatoschistus microps, M. pictus* and *P.*

Close-up view of the head of a common dab (L. limanda). Source: Michael Palmgren

minutus), as well as the transparent and the black gobies (*Aphia minuta* and *Gobius niger*).
- Inhabiting mainly hard substrate habitats, several species of often brightly coloured wrasses, such as the green, the cuckoo, the ballan and the corkwing wrasses (*Labrus viridis*, *L., ossifagus*, *L. bergylta* and *Symphodus melops*).
- In brackish waters towards the south of the Sound, a number of freshwater species are common, namely pike (*Esox lucius*), perch (*Perca fluviatilis*), ide (*Leuciscus idus*) and roach (*Rutilus rutilus*).
- And finally, a number of commercially valuable fish species not listed above such as anglerfish (*Lophius piscatorius*), striped red mullet (*Mullus surmuletus*), Atlantic wolffish (*Anarchias lupus*), rainbow trout (*Oncorhynchus mykiss*), and the greater weever (*Trachinus draco*).

A sea sickleback (S. spinachia), a common inhabitant of seagrass meadows. Source: Michael Palmgren

A shore (or green) crab (Carcinus maenas), adopting a defensive position on a sugar kelp (L. sacharina) leaf. Crabs are typically preyed upon by gobies and sculpins, as well as by marine birds. Source: Michael Palmgren

Marine mammals

Two species of seals are regularly observed in the Sound, namely the harbour seal (*Phoca vitulina*) and the grey seal (*Halichoerus grypus*), the former being three to four times more abundant than the latter. As elsewhere in the Baltic, Kattegat and Skagerrak, seal populations in the Sound have expanded since the late 1970s, after decades of intense hunting and exposure to an excess of marine pollutants. However, events of mass mortality of harbour seals have occurred at irregular intervals. The events of 1988 and 2002, motivated by the so-called phocine distemper virus, were particularly severe in the Kattegat and Skagerrak, having resulted in the death of about half of the seal population. Large mortality caused by other, as yet unknown agents, was again reported in the Kattegat, with around 3,000 seal deaths in 2006 and a few hundred in 2007.

Seal colonies in the Sound exist in the Måkläppen sandbar off Falsterbo in the south-easternmost tip of the Sound, on the island of Saltholm in front of Copenhagen and on the Gråen-Gipsön islet outside Landskrona. The first harbours by far the greatest concentration, being home to more than half the Sound populations of both harbour and grey seals. Grey seals found in the Sound belong to the Baltic Sea population, which is found in greatest numbers in the northern Baltic. Hence in the Sound their distribution is restricted to the southern half, with a total estimated population of 50-100 individuals.

Cetaceans are also present in the Sound, the harbour porpoise (*Phocoena phocoena*) being its most frequent representative, especially in the northern half of the Sound. In both the North Sea and the Baltic Sea their populations have been reduced significantly over the last decades, due primarily to exposure to marine pollutants and entanglement in fishing gear. In the Baltic proper, the species is considered critically endangered. The harbour porpoises observed in the Sound are part of a genetically differentiated population of close to 11,000 individuals that also inhabit the Kattegat, the Belt Sea and the western Baltic. The distribution of individuals in this area is not even, large concentrations existing in certain narrow areas, the Sound being one of these. The distribution changes with the seasons as porpoises follow their prey. In the Sound, greater densities are typically found during spring and summer, in particular in its northern half. Several other species of cetaceans are occasionally sighted in the Sound and neighbouring waters.

Harbour porpoises (P. phocoena) in the company of gulls off Hellebæk in the northern Sound. Image courtesy of Kristian Vedel.

Grey seal (H. grypus). Image courtesy of Kristian Vedel.

Human-induced changes in the marine environment

Chemical pollution

The levels of chemical pollution currently observed in the Sound may be said to result from a combination of the following three main points: 1) steadily growing human pressure, with the population in the region presently estimated at close to 3.8 million and expected to reach 4 million by 2021; 2) a close to two-century long industrial development, the phasing out of most heavily polluting industries and the fact that the 'greening' of the regional economies did not take place before the 1980s; and 3) the nature of the sea bottom sediments in the Sound, the fine particle size which typically binds contaminants in large concentrations and for long periods of time. All of these aspects have a bearing on the dynamics of all types of contaminants found in the Sound.

Three main categories of anthropogenic chemical pollutants pose the greatest environmental concerns in the Sound, namely organic nutrients containing large quantities of phosphorus and nitrogen, heavy metals and organic substances used in or produced by different industries. A fourth category may be considered, namely that of novel chemical substances, most of which are organic in nature. While it is recognised that these groups are of particular environmental relevance – not least because of the lack of methods for their detection and insufficient knowledge of their ecological effects – too little is known of their presence in the marine environment in the Sound to enable an elaborate description in this section. It is important to observe that knowledge of chemical pollution in the Sound is uneven across the former three categories. This is a consequence of differences in the ability to detect and measure pollutant levels at the source, differences in detection methods in terms of practicability, cost, sensitivity and reliability, inconsistencies in sampling procedures, affecting the completeness and reliability of time series and hence the identification of trends and of limitations in access to data. In the Sound the level of knowledge is highest for organic nutrients, followed by that of heavy metals and lastly that of organic chemicals. In the paragraphs that follow these three categories will be discussed in this order.

Organic **nutrients of phosphorus and nitrogen** – primarily phosphates and nitrates – enter the Sound via three main routes, watercourses carrying excess nutrients used in agriculture in the drainage area of the Sound, water-treatment facilities and other industrial installations releasing wastewater into the Sound and atmospheric deposition. The first and the last constitute so-called diffuse sources, that is, there are several unspecified nutrient emission sources, whereas installations in the second group are generically termed point sources. Organic nutrients are a precondition for all marine life as they constitute the feed for all autotrophic species and the presence of nutrients *per se* is not therefore a direct indication of pollution. However, excessive amounts of nutrients – a condition commonly termed eutrophication, but which more correctly should be designated hypertrophication – frequently results in excessive phytoplankton growth, the degradation of which requires large amounts of dissolved oxygen. In the Baltic this has led to chronic hypoxia and even anoxia in the poorly aerated depths, such conditions also being periodically observed in the Sound, as described above.

The evolution of nutrient emissions to the Sound in the last two decades is depicted in figures 1–6. Immediately apparent from the first graph is the much greater volume of nitrogen emitted to the Sound compared to that of phosphorus. Figure 1 also depicts a significant reduction in the emission of both types of nutrients, that of phosphorus being more pronounced – approximately 80% over that period – and sustained than that of nitrogen, where a 50-60% reduction is visible, but with marked variations. From Figure 2 one can read that the reduction of emissions from point sources has contributed most visibly to the overall reduction. Volumes from diffuse sources show not only a much less clear reduction, but are also subject to great variability, which largely follows that of rainfall – with more rain more nutrients are washed to sea.

The different dynamics exhibited by nitrogen and phosphorus can be explained by considering the evolution of the respective emission sources, aspects of which are illustrated in the last four figures. The key anthropogenic source of phosphorus has been sewage, and hence wastewater treatment plants. The important reduction in emissions to the Sound can therefore largely be attributed to improvements in these plants, in particular the introduction of techniques for phosphorus removal. By comparison, phosphorus from diffuse sources has remained relatively constant over the last two decades (Figure 5). Phosphorus removal was introduced in Swedish wastewater treatment in the 1970s and 1980s, whereas introduction in Denmark only took place from the late 1980s onwards. The marked reduction in phosphorus in the early 1990s is mainly the result of measures taken on the Danish side of the Sound, as illustrated in Figure 3.

Improvements in wastewater and industrial effluent treatment facilities have also led to a reduction in nitrogen emitted from point sources (Figure 6), and here again the main contribution appears to have come from Sjælland (Figure 4). However, most of the nitrogen emitted to the Sound has its origin in agriculture, where it is used much more extensively than phosphorus and where measures to curb utilisation have been much less successful. Nitrogen from agriculture has thus buffered the reduction from point sources and currently stands out as the main concern relative to eutrophication not only in the Sound, but in the wider Baltic. It should be noted in this respect, that Skåne is a significantly larger contributor of nitrogen to the Sound than Sjælland.

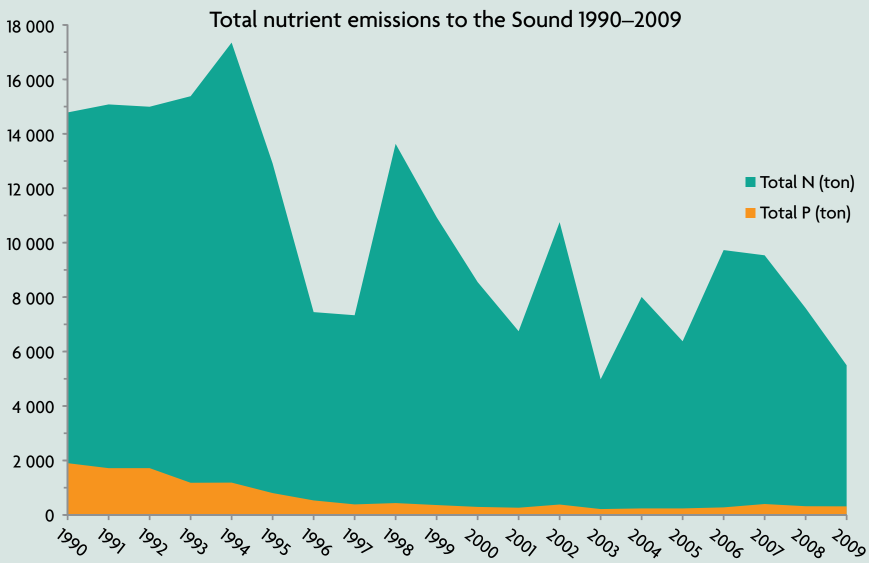


Figure 1 Emission of nitrogen and phosphorus to the Sound in the period 1990-2009. Data source: Øresundsvandsamarbejdet, 2010

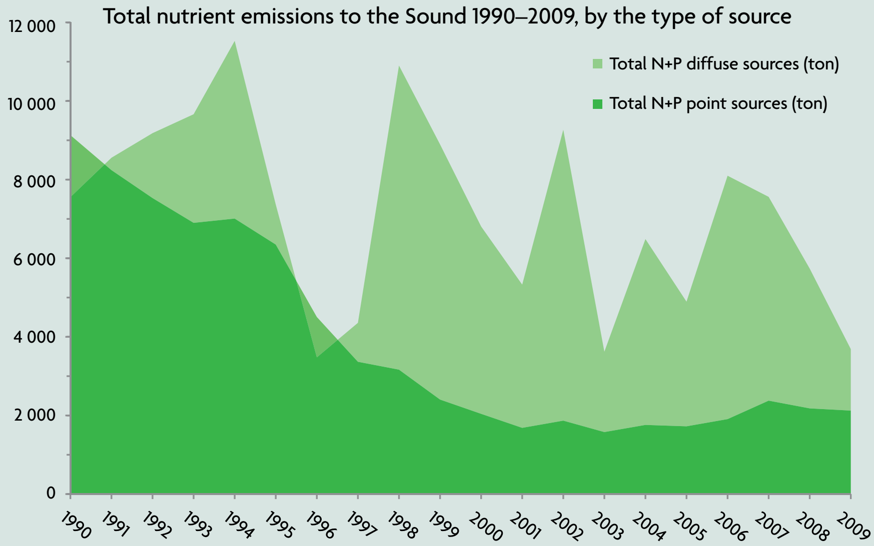


Figure 2 Emission of nitrogen and phosphorus to the Sound in the period 1990-2009, by type of emission source. Data source: Øresundsvandsamarbejdet, 2010

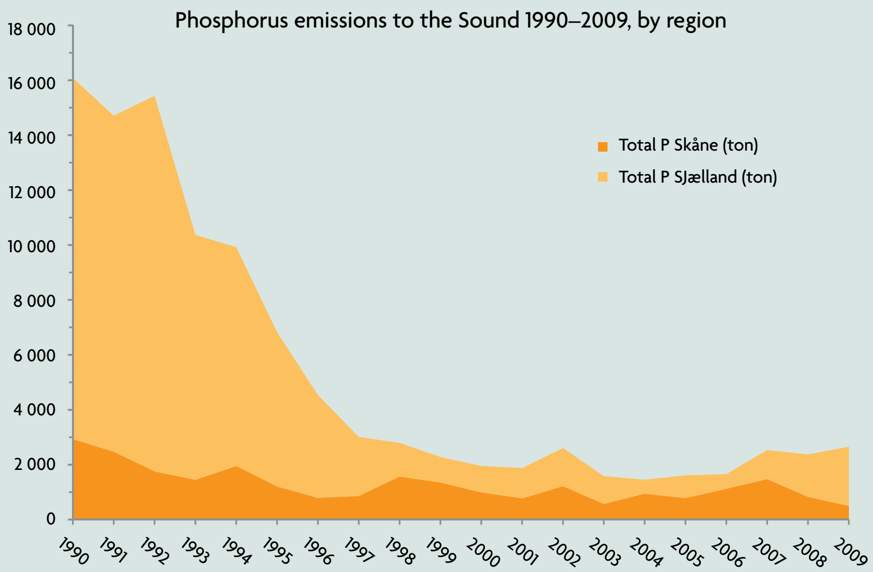


Figure 3 Emission of phosphorus to the Sound in the period 1990-2009, by region. Data source: Øresundsvandsamarbejdet, 2010

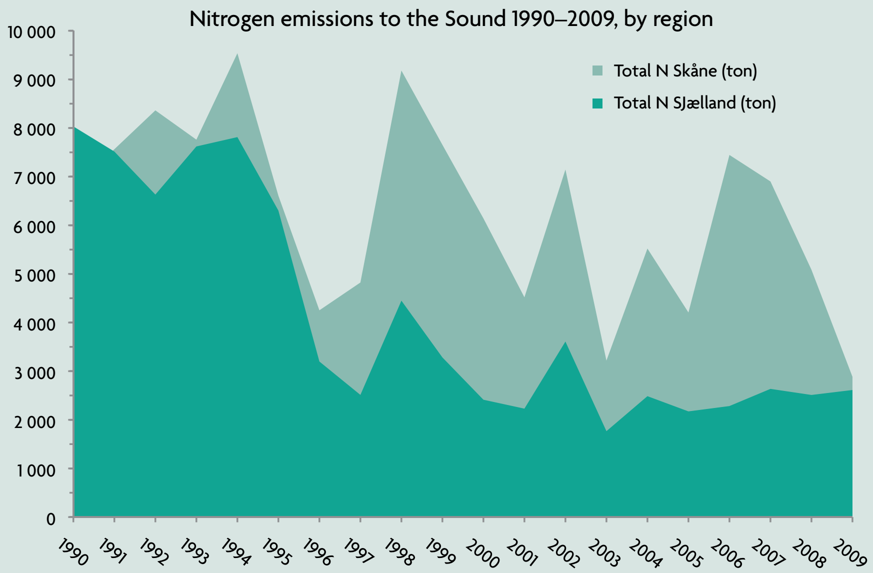


Figure 4 Emission of nitrogen to the Sound in the period 1990-2009, by region. Data source: Øresundsvandsamarbejdet, 2010

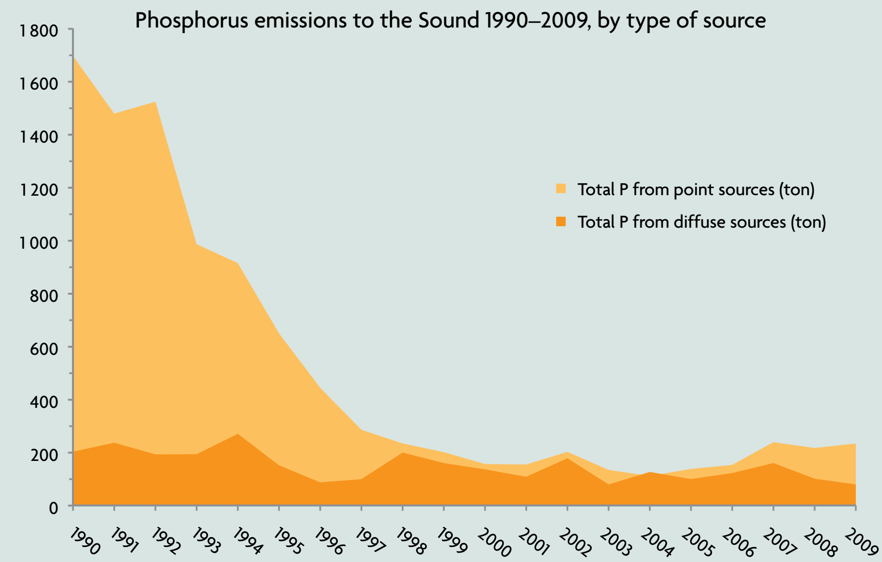


Figure 5 Emission of phosphorus to the Sound in the period 1990-2009, by type of emission source. Data source: Øresundsvandsamarbejdet, 2010.

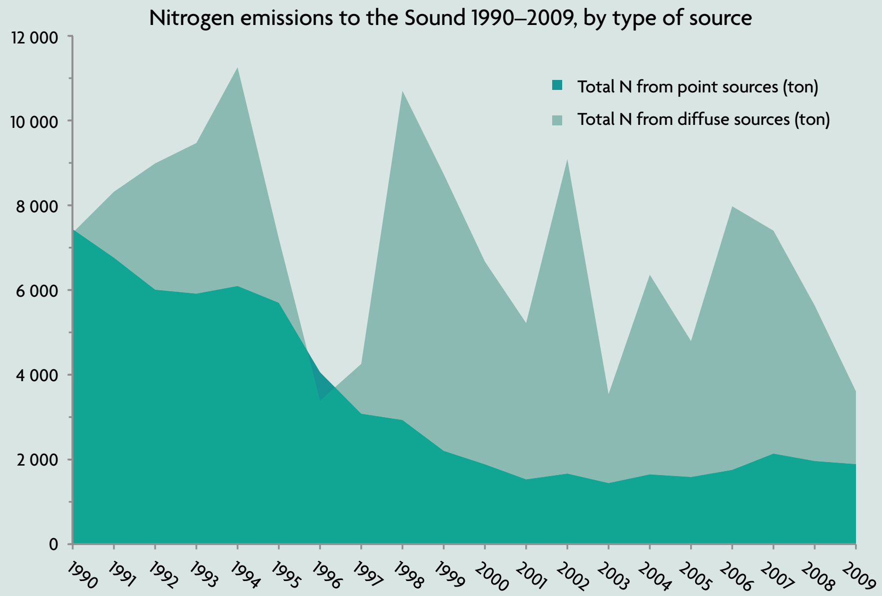


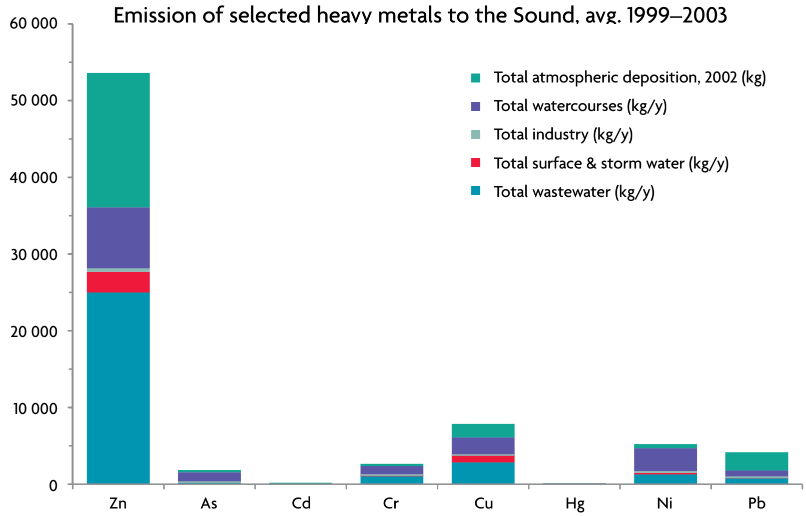
Figure 6 Emission of nitrogen to the Sound in the period 1990-2009, by type of emission source. Data source: Øresundsvandsamarbejdet, 2010.

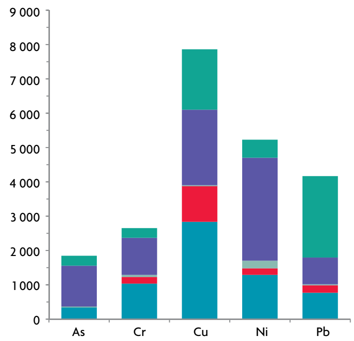
The industrial port of Helsingborg, a site of recurrent high levels of contaminants in sediments and biota.

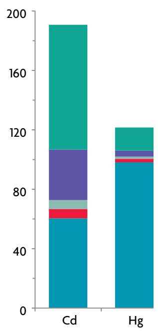
Contamination with **heavy metals** is an attribute of most, if not all water bodies, subject to intense human pressure. With an industrial history going back two centuries, the Sound constitutes no exception and heavy metal pollution has long been regarded as an issue of concern. Besides their natural occurrence, heavy metals originate from most human activities – they are present, often in minute quantities, in a large variety of appliances of daily use – and enter the marine environment primarily via atmospheric deposition, emissions from wastewater treatment facilities and runoff from rivers. Industries have historically been responsible for large emissions of certain metals that typically accumulated in considerable quantities near effluent outlets.

The situation in the Sound concerning industrial pollution in general and heavy metal emissions in particular has improved markedly in the course of the last three decades, as described in Chapter One. In the two decades running up to the turn of the millennium, for example, anthropogenic emission levels were cut by 50-80%. The average annual emissions for the period 1999-2003 for zinc (Zn), arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni) and lead (Pb) to the Sound are depicted in the graphs to the right. Worth highlighting are the important contributions of atmospheric deposition and river runoff, indicating that the Sound is the destination of pollutants originating elsewhere. With respect to point sources, it is water treatment plants and not industrial effluents that stand for most of the emitted volumes across all of the metals currently monitored.

Gaps in the follow-up of heavy metal emissions to the Sound result in there being large uncertainties as to the current emission levels. Even so, it is generally believed that these have been reduced further during the last decade. Regrettably, decreasing emissions have been slow to translate into reduced heavy metal concentration in sediments and, more importantly in the biota. In this respect, although the more open and historically less impacted areas of the Sound often have concentrations below detection or natural background levels, areas more exposed to human activities continue exhibiting excessive contamination levels. Typically these occur near harbours and other (especially older) industrial facilities, at the mouth of rivers, and near the larger settlements. From an ecological perspective it is essential to bear in mind that it is not only the absolute concentration, but also the relative







Above and below Emission of selected heavy metals to the Sound, average for years 1999-2003. Note the differences in scale.
Data source: Nerpin et al., 2005

toxicity, the solubility in biological tissues and the stability of the bonds with sediments, as well as the concentration relative to the known natural background level that determine the degree of contamination. Hence in the Sound it is mercury that has the most worrying combination of all these factors, despite the insignificant emission levels when compared to most other metals depicted in the accompanying figure. Mercury is estimated to have a concentration in sediment over 40 times the naturally occurring level, followed by copper and cadmium with a positive anomaly of five times. Nickel and chrome on the other hand are found in the sediments of the Sound at a concentration equivalent to the natural background level.

Knowledge about the use, emissions and occurrence of **organic contaminants** in the

Sound is very limited. Difficulties in estimating any of these volumes begin with fragmentary reporting of use and production of an immense variety of organic substances with a very wide range of applications. This is further compounded by a constantly growing number of novel substances – for the detection of which methods are often not available – and the fact that many organic pollutants arise as by-products of numerous human activities. Polycyclic aromatic hydrocarbons (PAH) for example originate primarily through the combustion of fossil fuels, notably oil and coal, whereas hexachlorobenzene, also a by-product of fuel combustion, was intentionally used as fungicide. The amount with which it enters the atmosphere and from there into the marine environment can thus never be known with exactitude. Emissions from point sources should be easier to quantify, one could reasonably expect, at least in those cases where production figures are known. However, reporting obligations are in the best cases only loosely adhered to, a limitation again compounded by difficulties in accurately measuring specific organic products in large effluent volumes. Concentrations in the environment, often measured in sediment and in selected biota can only be measured at a limited number of sampling sites. Moreover, concentrations in living tissues depend on the ability of organisms to metabolise a substance of interest, transforming it into metabolites that escape measurement. Hence even for the Sound, where a reasonably comprehensive monitoring programme has been in place for several decades, knowledge of organic contaminant levels is necessarily patchy, and conclusions about the status for the Sound's entire area must be drawn with much caution.

Despite these limitations, surveys carried out over the past three decades enable the following statements about organic pollution in the Sound to be made:

- Levels for most regulated and banned substances show a generally downward trend, the highest concentrations being registered today in areas particularly exposed to polluting activities. Such substances include biocides such as DDT (dichlorodiphenyltrichloroethane), HCH (hexachlorocyclohexane), and HCB (hexachlorobenzene). Estimates of total riverine input of pesticides to the Sound vary between 500 and 1,000kg per year.
- Polychlorinated biphenyls (PCB), a class of insulating and cooling substances, despite having been banned in the late 1970s show a more mixed trend in the Sound, with levels at some monitoring stations – for example Helsingborg harbour – registering persistently high values both in sediments and in biota. Surface and storm water systems appear to contribute large amounts of PCBs to the Sound, the amount of oil entering the Sound from these two sources having been estimated at 10-20 ton/year.
- Concentrations of highly fat-soluble PAHs also exhibit considerable spatial and temporal variability in the Sound, their occurrence being highest near large settlements and industrial sites;
- Tin-based organic (so-called organotin) compounds, of which tributyltin has been used extensively in self-polishing anti-fouling paints in sea-going vessels, continue to exhibit very high levels in both sediment and biota. Values are highest along the major shipping corridors and in port areas.

Climate change

Analyses of climate change and of the respective impacts on marine ecosystems specific to the Sound have not yet been produced. However, in what concerns the climate's key physical and chemical parameters, the Sound is expected to undergo similar changes to the rest of the Baltic

Non-motile marine species, among which sea grasses and algae face local density reductions and even extinction as a consequence of climate-induced environmental changes. Bladder wrack (F. vesiculosus) interspersed with eelgrass (Z. marina) in the southern Sound. Source: Michael Palmgren

Sea region. Indeed, all Baltic climate change assessments so far conducted encompass not only the Sound, but also the other Danish Straits and Kattegat. With respect to the impacts on and the response of marine ecosystems, it is not possible to extrapolate findings from elsewhere in the Baltic to the rather unique conditions in the Sound. In this regard, the lack of Sound-specific investigations poses considerable difficulties for detecting and predicting change. In this section, observed and predicted changes to selected atmospheric, hydrological and oceanographic parameters in the Baltic Sea region are reviewed, following which some possible impacts on the Sound's marine ecosystems are discussed.

Accompanying the global warming trend caused by increasing atmospheric greenhouse gas concentrations, mean **air temperatures** in the Baltic Sea region have increased in the last 150 years. The rate of warming has been substantially larger than the global average of 0.05°C/decade, amounting to 0.07°C/decade and 0.10°C/decade south and north of 60°N, respectively. This warming has not been linear, though, with alternating warming and cooling periods. Warming has manifested itself primarily through higher mean daily temperatures and has been more pronounced in the spring season. A reduction in the number of cold nights and an increase in that of warm days have also been registered, particularly in summer. As alluded to earlier, milder winters appear to correlate positively with an intensification of the westerly airflow over Scandinavia. It is anticipated that the region will continue to warm at a rate above the global average, with mean annual temperatures at the end of the 21st century of 3°C to 5°C higher than at the turn of the millennium. This warming is likely to result in an elongation of the growing season by 30 to 90 days in the southern Baltic over the same period.

The average long-term increase in air temperature in the Baltic Sea region has not yet found correspondence in a linear increase of **sea surface temperature** (SST) over the past 150 years. During the last three decades, however, the waters of the Baltic – as well as those of the North Sea – have warmed at an unprecedented rate, and in particularly in summer the warming has been close to three times as high as the global average, an observation that is partly due to the succession of extremely warm years. The warming trend is expected to continue into the 21st century, with the waters in the Sound and the other Danish Straits estimated to warm by 2°C-4°C during its course.

Warmer seas have manifested themselves in a reduction in the duration of the **sea ice** season and the thickness of the ice cover. Although the only major shift in ice extent so far observed pertains to the ending of the so-called little ice age in the second half of the 19th century, a steady shortening of the ice season has been measured over the last century. This negative trend is anticipated to continue into the next century, affecting primarily the northern and central parts of the Baltic where ice is more frequent today.

Despite no measureable changes in mean cloud cover and solar radiation, mean annual **precipitation** has increased over the whole region. Spatial and seasonal variations are very pronounced, with the largest increases measured over Sweden and the eastern coast of the Baltic, and in the winter and spring seasons. During summer, higher rainfall in the north has been accompanied by drying in the south. Snow depth has shown a similar pattern, with a positive trend in the north and a negative one in the southwest of the region. Despite particularly large uncertainties related to future precipitation projections, it is expected that these trends will continue and in some cases even accentuate during the coming century.

The observed changes in precipitation have not yet translated into statistically significant changes to **freshwater inflow** to the Baltic Sea. It is important to note that this parameter is subject to pronounced inter-annual variability, which makes small longer-term changes more difficult to discern. However, in tandem with the predicted changes in precipitation, annual river flow is expected to increase in the north and decrease in the south of the Baltic Sea basin. Here, reduced river flow particularly in summer will be the result of lower rainfall and greater evaporation due to warmer temperatures.

The **salinity** of the Baltic Sea is subject to multi-decadal variations, and no robust long-term trend has been observed during the 20th century. Nonetheless, the predicted increase in average rainfall is expected to lead to a reduction in salinity, in particular in the northern and central parts of the Baltic. In this latter area, average surface layer salinity might drop from today's 7ppt to around 4ppt within the next century. In the Sound, due to the greater oceanic influence, changes are not expected to be as pronounced.

One of the most visible consequences of global warming is the rise of mean **sea level**, motivated primarily by thermal expansion of the ocean and melting of land ice. The impacts of this rise for coastal areas around the Sound have been studied by the Sound Water Cooperation in 2010,[7] using emission scenarios developed by the IPCC and the European Commission.[8] The predicted rise in sea level varies markedly with the different scenarios, as depicted in the accompanying table, where the peak flood heights of periodic extreme events are also included.

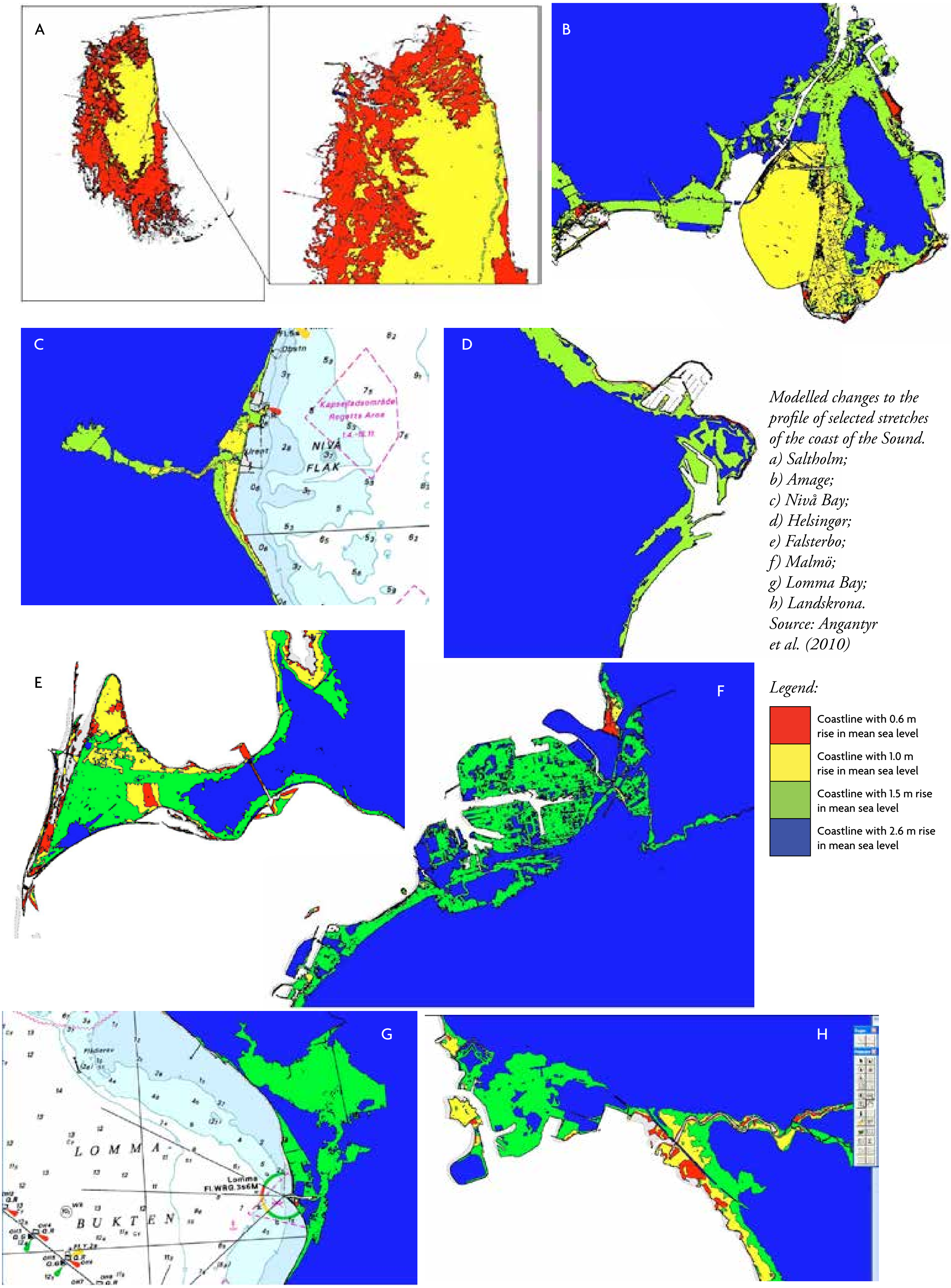
The same authors modelled the change in the profile of selected stretches of the Sound coast that would result from a rise in average sea level of 0.6, 1.0m, 1.5m and 2.6m. The results are illustrated in the accompanying figures.

7 Angantyr et al. (2010)
8 Nakićenović & Swart (2000); Commission of the European Communities (2007).

Scenario	Mean	1-year storm	10-year storm	20-year storm	50-year storm	100-year storm	Historical data
Present (2010)	4 cm	92 cm	122 cm	131 cm	143 cm	152 cm	152 cm (a) 190 cm (b) 206 cm (c) 210 cm (d) 280 cm (e) 370 cm (f)
2050 (A1B)	10 cm	102 cm	132 cm	141 cm	153 cm	162 cm	
2100 (EU2C)	20 cm	112 cm	142 cm	151 cm	163 cm	172cm	
2100 (A2)	60 cm	152 cm	182 cm	191 cm	203 cm	212 cm	

Estimated sea level height in the Sound for selected time frames, emission scenarios and periodic extreme events. All values are deviations from the 1990 reference value at Copenhagen harbour. Adapted from Angantyr et al. (2010)

Historical data: (a) Highest measurement by the Danish Coastal Directorate in the period 1888-2007, taken in 1921; (b) Dec 1862 floods in Copenhagen; (c) Christmas 1902 storm in Lomma harbour; (d) Jan 1825 floods in Copenhagen; (e) Nov 1872 storm flood in Avedøre Holme, DK; (f) Oct 1760 storm flood in Avedøre Holme, DK.



Modelled changes to the profile of selected stretches of the coast of the Sound. a) Saltholm; b) Amage; c) Nivå Bay; d) Helsingør; e) Falsterbo; f) Malmö; g) Lomma Bay; h) Landskrona. Source: Angantyr et al. (2010)

Legend:

- Coastline with 0.6 m rise in mean sea level
- Coastline with 1.0 m rise in mean sea level
- Coastline with 1.5 m rise in mean sea level
- Coastline with 2.6 m rise in mean sea level

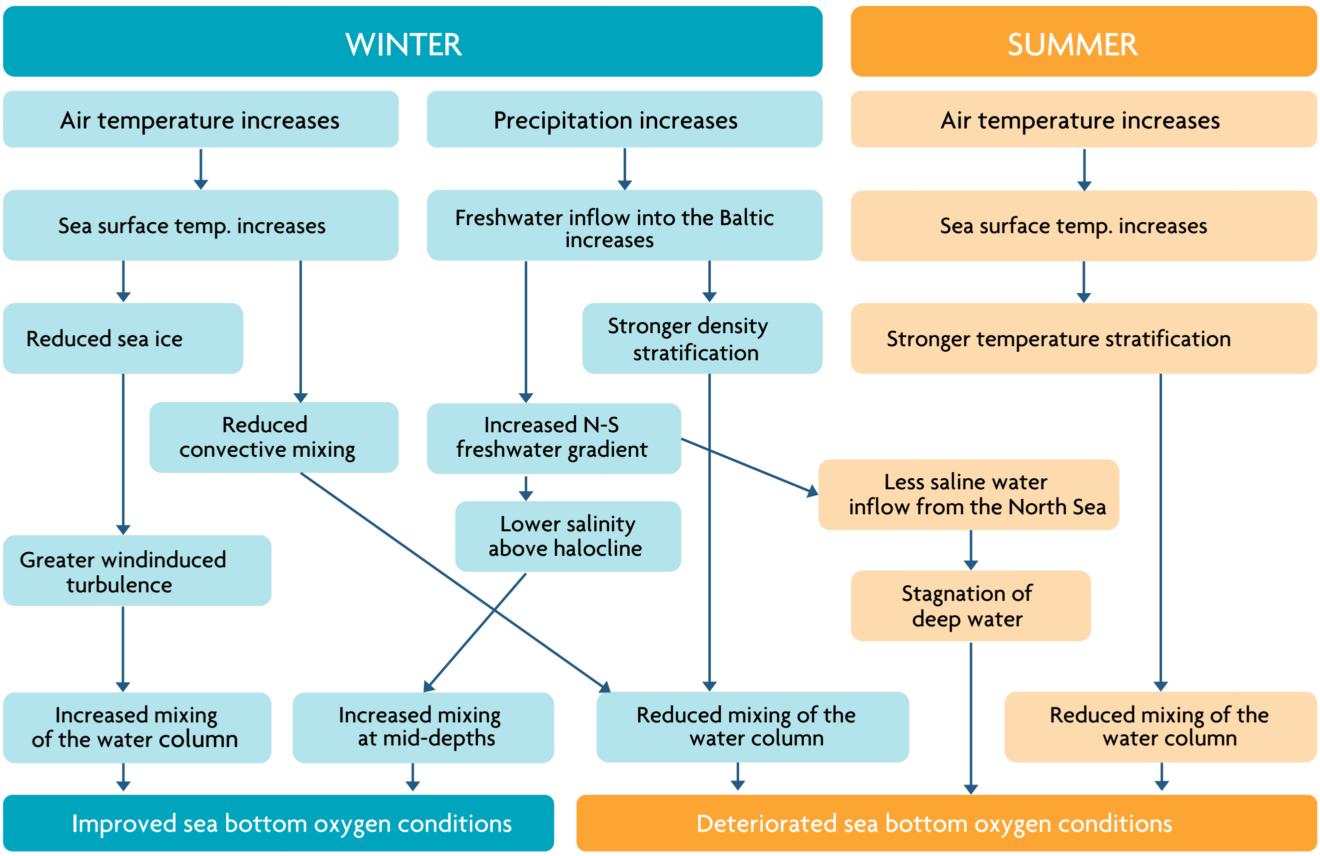
Anticipating climate-induced changes to marine ecosystems is made difficult by the large variety of natural and anthropogenic factors acting on them. This is particularly true in the Sound where the marine environment is subject to large temporal and spatial variability. Even so, observations of past and present ecosystem changes and predictions of future climate enable certain changes to marine ecosystems in the Sound to be anticipated.

The rising trend in **sea surface temperature** is expected to lead to changes in the abundance and distribution of marine species. Motile species are likely to shift their geographical ranges towards the pole, the success of this movement depending among other things on the ability to outcompete or otherwise coexist with species already present at the new sites. For sessile species, among which most non-planktonic primary producers such as macroalgae and marine grasses, warmer waters may result in local reductions in density and, in extreme cases, in local extinction. Changes in abundance and distribution of primary producers are expected to have wider implications for marine trophic webs, but it is as yet impossible to predict how such cascading effects will manifest themselves in the Sound. For marine birds, food availability at sea and on land – in the latter case strongly dependent on the length of the vegetative season, which, as described above is expected to become longer in a warmer climate – has been shown to influence mortality, migration patterns and range.

Salinity is also known to affect the distribution of both zoo- and phytoplankton, and in the Baltic proper the expected overall reduction in surface salinity is anticipated to lead to the southward shift of the distribution boundaries of many species inhabiting waters above the halocline. Salinity changes in the Sound are more difficult to predict; the increase in precipitation and river runoff affecting primarily the northern Baltic might lead to a greater volume of freshwater leaving the Baltic through the Danish Straits thereby reducing average surface layer salinity in the Sound. However, it is as yet uncertain how the heightened evaporation rates expected for the southern Baltic will affect that volume of water, and hence salinity profiles in the Sound.

Should longer-term sea surface warming and salinity reduction in the Baltic in general and the Sound in particular materialise, a more pronounced **stratification** is to be expected between surface and deeper water layers. Vertical mixing will be further impaired, particularly in the warmer season, thereby aggravating the aeration of the deeper areas in the Baltic, many of which are already subject to chronic oxygen depletion. In the colder season the chain of climate change-

Representation of the impacts of anticipated temperature and precipitation changes in the bottom oxygen conditions in the Baltic Sea. Adapted from Viitasalo (2012)



induced events is likely to be more complex, as depicted in the accompanying diagram. It should be highlighted that these impacts will vary between different areas of the Baltic, site-specific effects being difficult to predict at present.

Absent from this representation is the contribution of intensified phytoplankton growth to **oxygen depletion** in the depths of the Baltic, something that, with lesser intensity, might also occur in the Sound. Recent studies of sediment records have shown periods of higher sea surface temperature to correlate positively with intensified cyanobacteria growth and bottom anoxia. Because cyanobacteria growth is not usually limited by nutrient availability, it is reasonable to expect that blooms will become more frequent as the ocean becomes warmer, leading to further oxygen depletion in the depths. A different biological pathway through which higher sea surface temperatures worsen oxygen conditions involves bacteria. As is the case with most other marine organisms, bacterial metabolism increases with temperature, which, among other effects, results in greater rates of mineralisation of organic matter, including nutrients. This will worsen the already severe eutrophication status of the Baltic and the Sound, accelerating the respective internal circles of nutrient loading. It is important to note in this regard that increased precipitation in the northern Baltic will result in higher nutrient loading from river runoff to the Baltic as a whole, including the Danish Straits. On the whole the anticipated temperature and hydrology changes in the wider Baltic Sea region are expected to aggravate eutrophication and the oxygen condition of Baltic waters.

Reproduction of certain marine species will equally be affected negatively by climate-induced changes in salinity profiles of Baltic waters. Cod eggs, for example, sink to depths where they achieve neutral buoyancy, typically with salinity values of around 11 ppt. Should the halocline deepen in connection with a decrease in surface layer salinity, then cod eggs risk sinking to depths where their survival is impaired by too severe oxygen depletion.

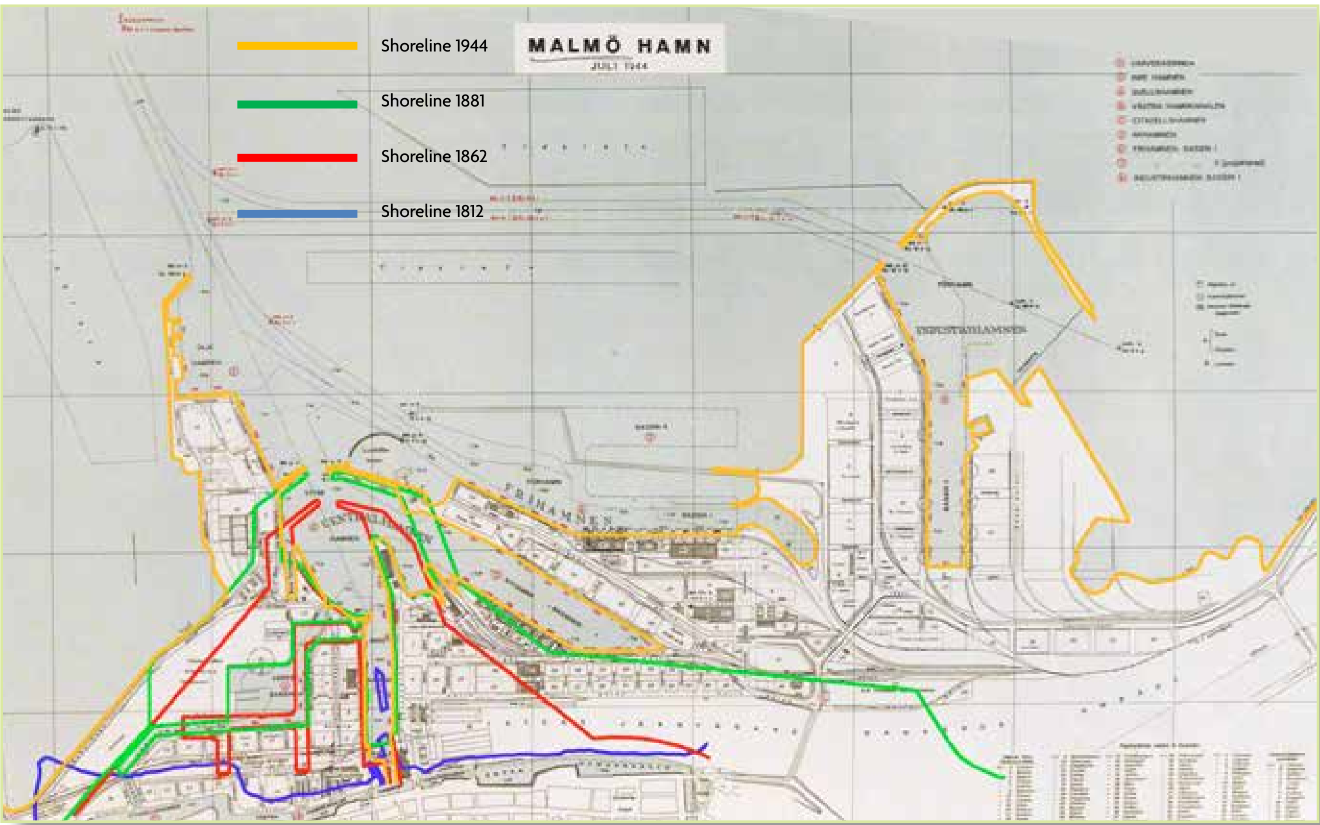
Reproductive success of not only fish, but also a number of other marine species has been shown to correlate negatively with sea water **acidity**, which has been estimated to have increased by 30% over the last century as a result of the dissolution of an ever greater amount of atmospheric CO_2. Despite most studies on impacts of acidification having been conducted in experimental settings and uncertainties remaining about the magnitude of impacts in the wild, concerns are mounting that ocean acidification will constitute a major issue not only for the structural integrity of calcifying marine invertebrates, but also for the reproductive capacity of a much broader range of species, including fish.

A male lump fish (Cyclopterus lumpus) guarding eggs. These are a much appreciated delicacy in both Sweden and Denmark. Source: Michael Palmgren

IV ACTORS, INTERESTS AND HUMAN USAGE

A relatively small marine area surrounded by one of the most densely populated Nordic regions it is not surprising that the Sound and its shores have been progressively and profoundly altered in the course of the last few centuries. Some of the earliest and more severe physical alterations have occurred along the coastline, motivated by the need to protect human settlements from the waters of the Sound or by the desire to create more space for different human activities in areas previously occupied by these waters. Consequently numerous protection barriers have been erected on the waterfront of most of the larger towns and along erosion-prone stretches of the coast, and the few large land reclamations for some of the largest infrastructure on the shores of the Sound. The wish to integrate the growing societies on the two sides of the Sound might also be said to lie behind the construction of what can be considered the region's signature infrastructure, the Øresund Bridge.

Maritime activities have justified numerous installations along both sides of the Sound such as shipyards and large merchant ports for shipping, harbours and landing sites for fishing and marinas and smaller infrastructure on land for coastal and marine recreation. Fixed aids to navigation have been installed throughout the history of human development in the Sound and are today numerous. The movement of large vessels also causes physical disturbances to marine ecosystems along traffic routes both in the form of underwater noise and stirring of bottom sediment. Sea bottoms are also impacted in a small number of locations by cables lying on them or buried under their surface although the impact of such structures is often small and transitory, and confined to periods of construction and maintenance. Larger, but also largely transitory physical impacts to underwater environments are those caused by offshore wind parks. On the surface, however, their presence is detrimental and their impact on other maritime uses is permanent.



The gradual expansion of Malmö into the Sound from 1812 – 1944. Source: Malmö museum/Malmö city

Shipping

Serving as one of the major entry points to the Baltic Sea, the Sound has a long history as a navigation route for merchant ships bound for different destinations around the Baltic. In the middle of the 13th century when the herring fisheries were well established, a large number of fishing boats and merchant ships trafficked the Sound, particularly in the southern parts where herring fishing was intense. During the middle of the 19th century the first ferry connections started to operate between Sweden and Denmark establishing a regular east-west transport route across the Sound that had not previously been seen. Later, more ferry connections also started to operate between different cities including inter alia Malmö-Copenhagen and Helsingborg-Copenhagen. More recently cruise ships have started to traffic the Sound stopping in Malmö, Copenhagen, Helsingborg or Helsingør before continuing to other destinations around the Baltic Sea. Ultimately the Sound is also trafficked by a large number of leisure boats which increase in numbers particularly during the summer months.

Development of number of passages through the Sound

Today the Sound is trafficked by a variety of ship types and is also one of the most trafficked waters in the world, with approximately 36,000 ships passing through in 2012. This can be compared with other heavily trafficked straights in the world such as the Bosporus straits in Turkey where approx. 48,000 ships passed through in 2012, and the straits of Gibraltar where approx. 109,000 ships passed by in 2012.

The development of number of ships passing through the Sound over the years has varied but seen in a historical perspective increased substantially. In the 1990s the increase was particularly noticeable as the number of passages went from 23 000 in 1990 to 40 000 in 1997, an increase of 42% in just seven years according to figures from the Danish Maritime Authority. During the second half of the 2000s the number of ships passing through the Sound decreased to approx. 32,000 ships (2008) as a consequence of the worldwide financial crises but during the last three years the numbers have started to go up again. In 2012 the Sound VTS in Malmö registered approx. 36,000 ships passing through the Sound.

The increase in the number of ships in recent years is dramatic but becomes even more dramatic when seen in a more historical perspective. In the mid-16th century the number of ships passing through the Sound was only 3,100 annually.

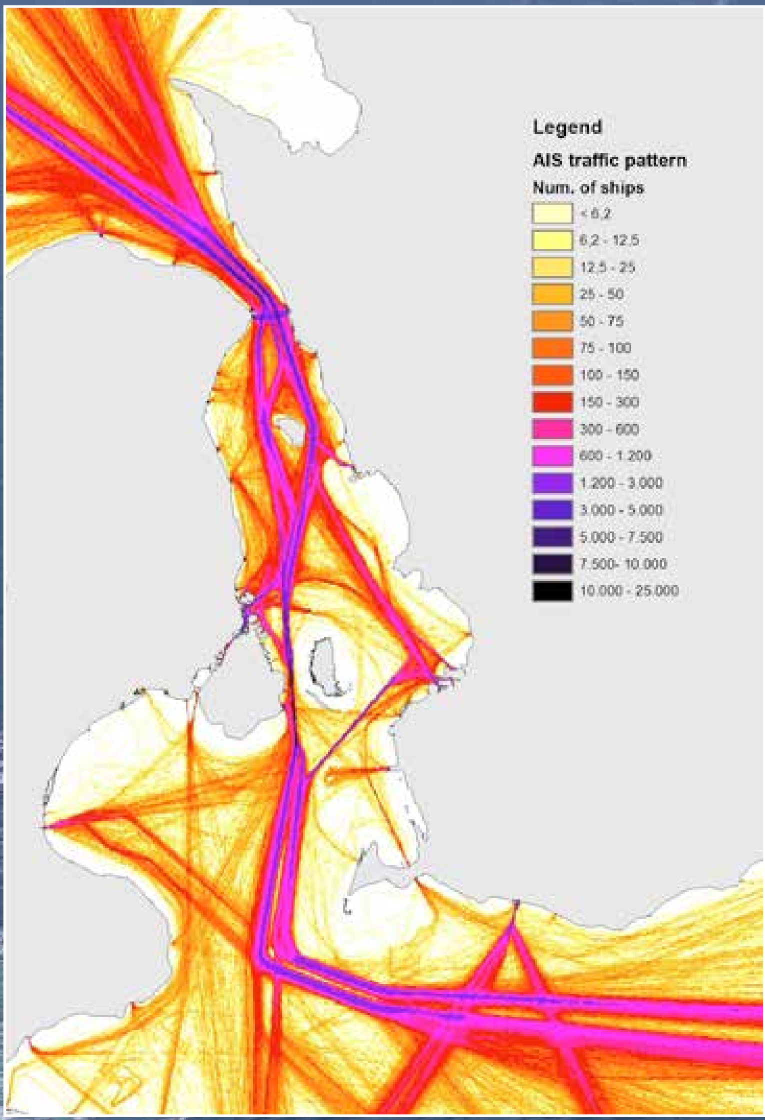
For ships coming from the North Sea and Kattegat the Sound is one of four different entry points to the Baltic Sea together with the Great and Little Belt in Denmark and the Kiel Canal in Germany. The Sound and the Kiel Canal had approximately the same number of ships passing through in 2012, approx. 36,000 in the former and approx. 34,000 in the latter, whereas the Great belt had somewhat less, approx. 23,000 ships.

For ships bound for ports in the central Baltic proper and northwards the route through the Sound is shorter than through the Great Belt allowing ships to save both time and fuel by choosing this route. The Sound is however not as deep as the Great Belt and is thus not an option for ships with a draft > approx. 7, 2 metres. The two navigational routes crossing the fixed link between Malmö and Copenhagen – Drogden and Flintrännan – are approx. 8 and 7.5 metres deep respectively whereas the Great Belt has an average depth of 17 metres. Some ships therefore choose to go through the Great Belt when sailing loaded and through the Sound when sailing ballast.

Accidents and Risks

The Sound is at its narrowest point only 4 km wide and 28 km at its widest. In addition there are several shoals, strong current, heavy traffic and relatively narrow navigation routes which makes navigation challenging and requires good skills and awareness of the navigator. The opening of the Øresund Bridge between Malmö and Copenhagen in 2000 has changed the risk patterns in the Sound slightly. Ferries that previously crossed the sound in an east-west direction between Limhamn and Dragör have ceased to operate and the risk for collision with merchant ships going in north-south directions eliminated. Also, during the construction of the Bridge, the navigation routes through Flintrännan and Drogden were deepened and straightened which is likely to have improved the navigational safety too.

AIS vessels traffic pattern for all vessels carrying AIS in 2010 in Danish and adjacent waters. Colored by number of vessels per cell. Cell width is 100 m. Data is collected for the months of February and August and then mutiplied by 6,2 to represent a full year.



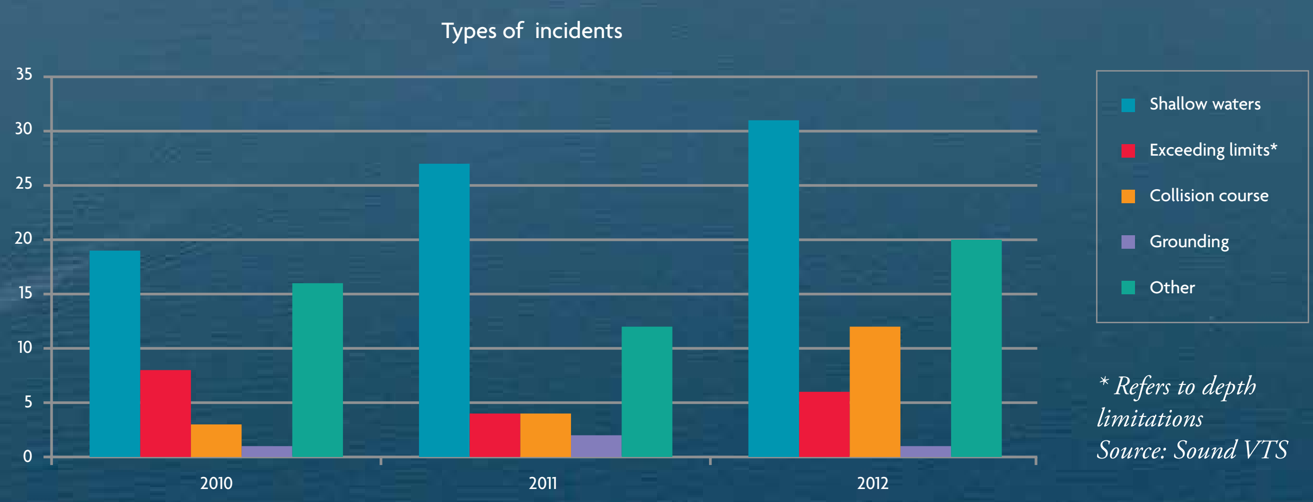
In a report carried out in 2006 ("Navigational Safety in the Sound between Sweden and Denmark") on behalf of the Royal Danish Administration of Navigation and Hydrography, The Danish Maritime Authority and The Swedish Maritime Administration ship accidents are divided into three different categories:

- Ship-ship collisions
- Groundings
- Ship-obstacle collisions

Data on where in the Sound registered accidents occurred over the period 1988-2005 has been collected and illustrated on a map. The map shows that the most frequent type of accident is groundings and that the majority of these occurred in or near the area of the navigational routes Drogden and Flintrännan. Other areas, where the concentration of groundings was also higher than in other parts of the Sound, were west/southwest of Landskrona and just north of Helsingborg.

In more recent years data from the Vessel Traffic Service centre in Malmö shows that the most

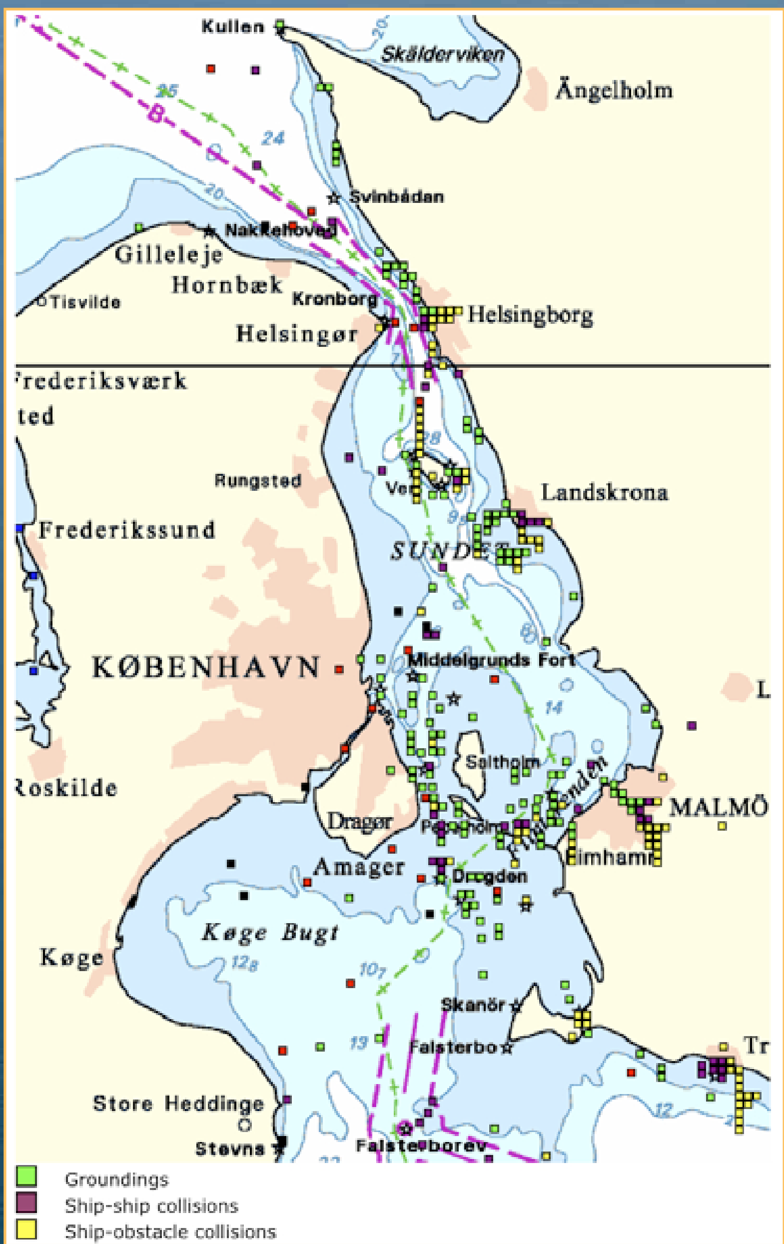
The Sound at its narrowest point is only 4 km wide. Helsingør is seen to the left and Helsingborg to the right.



** Refers to depth limitations*
Source: Sound VTS

frequent type of accident in the Sound is still groundings. In 2010, 2011 and 2012 there were 1, 2 and 1 groundings respectively.

In order to improve the navigational safety and protect the marine environment in the Sound, the Danish Maritime Safety Administration (abolished in 2011) and the Swedish Maritime Administration entered into a joint venture in 2007. In a pilot project a voluntary ship reporting system for the navigational routes Drogden and Flintrännan was established encouraging all ships with a dead weight of 300 tonnes or more to participate. The system called SOUNDREP was, and still is, operated by a Vessel Traffic Service centre (VTS) located in Malmö with staff from both the Swedish and Danish administrations. In 2011 the operational area of the VTS was extended and now covers the area from a northern borderline between Rågeleje in Denmark and Kullen in Sweden to a southern border line extending from Stevns lighthouse in Denmark to Falsterbo in Sweden. In the same year, reporting also became mandatory for all ships with a dead weight of >300



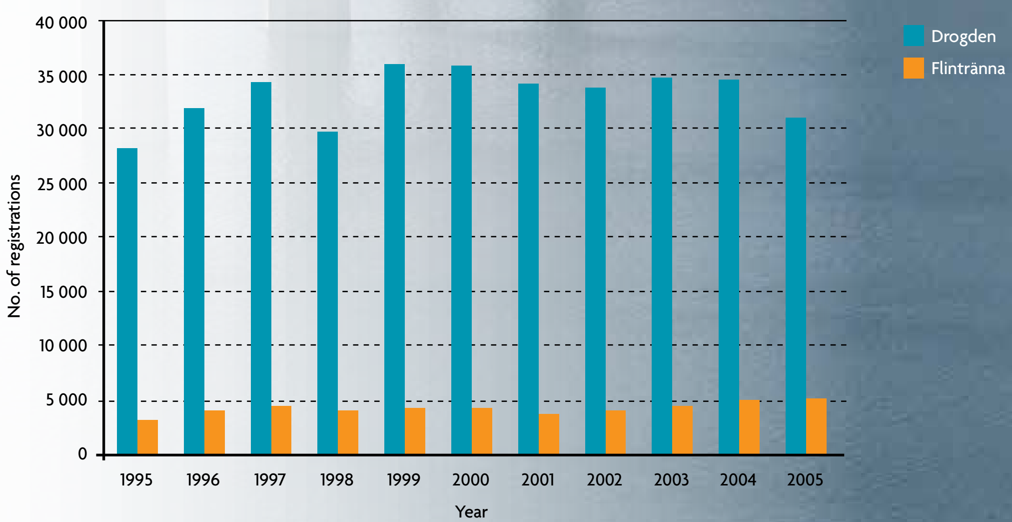
Accidents in the Sound between 1988-2005 Source: Ramboll, 2006.

gross tonnage. Ships entering this area must report a number of details to the VTS including inter alia ship's route, destination, cargo and number of staff on-board. Much of this information is transmitted via AIS (automatic identification system) but ships are nonetheless also required to report by radio, email or telephone in order for the VTS operator to confirm the information. In turn, the VTS provides information to the ships about other vessels in the area, conditions of fairways and navigational aids, meteorological and hydrological information to mention just a few.

Navigational routes through the Sound

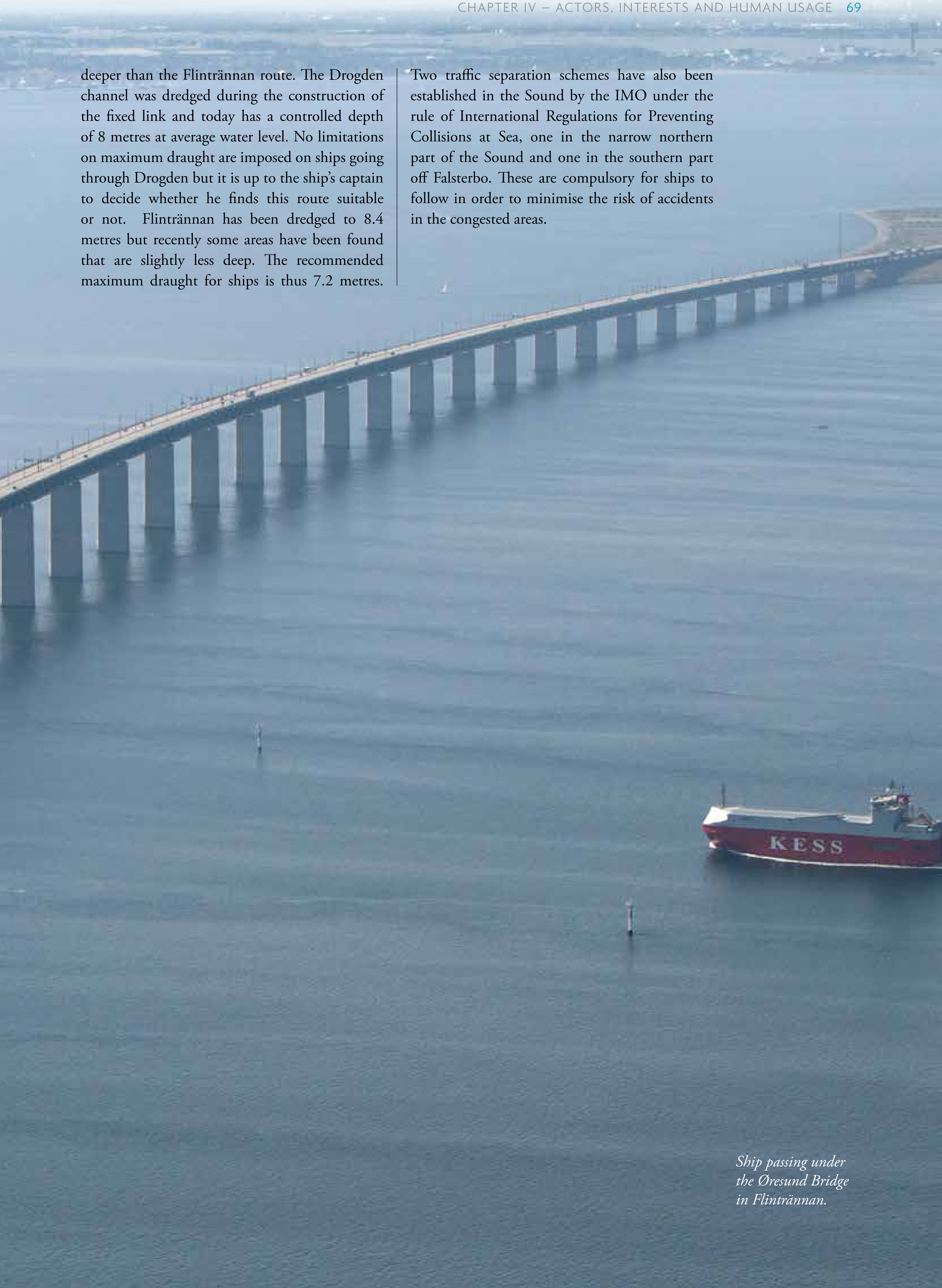
When navigating through the Sound ships may choose different routes depending on inter alia current weather conditions and the ship's draught. According to Article 3 in the UN convention on the law of the sea ships of all states enjoy the right of innocent passage through the territorial sea as long as the passage is not prejudicial to the peace, good order or security of the coastal state. Given the conditions in the Sound the majority of the ships choose however one of the two following navigation routes. Coming from the north, one route goes west of the island of Ven on the Danish side and one to the east of the island on the Swedish side. Ships can then either choose to go along the Danish coast to Kongedybet and Hollænderdybet, the former going west of the shoal Middelgrund where an offshore wind farm is located, and the latter east of the shoal. The route then continues west of the island of Saltholm and crosses the fixed link between Malmö and Copenhagen through the Drogden channel. Kongedybet is mainly used by ships coming from the south to the port of Copenhagen or leaving the port going south. The route along the Swedish side goes, after the island Ven, towards Malmö and then crosses the fixed link under the elevated bridge in the Flintrännan channel. Both ships that sail through the Drogden and Flintrännan channels merge south of the bridge in a traffic separation scheme off Falsterbo before continuing into the south Baltic Sea.

The majority of the merchant ships go through the Drogden channel mainly due to the fact that it is

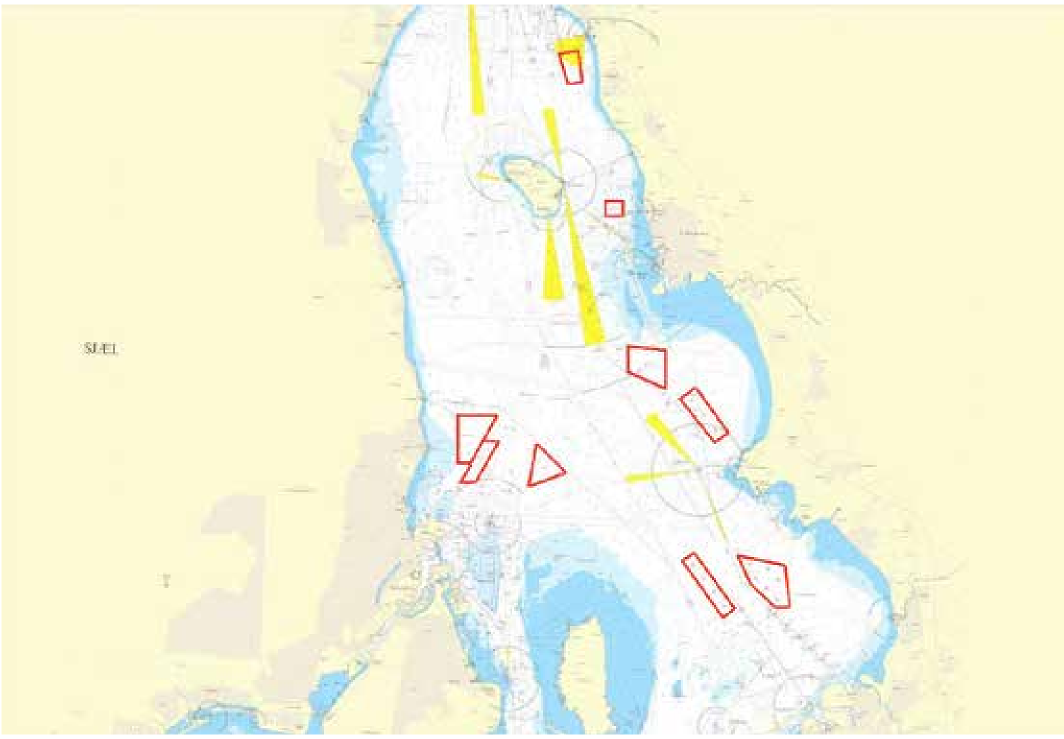


Ships per year passing through Drogden and Flintrännan. Source: Danish Maritime Authority deeper than the Flintrännan route. The Drogden channel was dredged during the construction of the fixed link and today has a controlled depth of 8 metres at average water level. No limitations on maximum draught are imposed on ships going through Drogden but it is up to the ship's captain to decide whether he finds this route suitable or not. Flintrännan has been dredged to 8.4 metres but recently some areas have been found that are slightly less deep. The recommended maximum draught for ships is thus 7.2 metres.

Two traffic separation schemes have also been established in the Sound by the IMO under the rule of International Regulations for Preventing Collisions at Sea, one in the narrow northern part of the Sound and one in the southern part off Falsterbo. These are compulsory for ships to follow in order to minimise the risk of accidents in the congested areas.



Ship passing under the Øresund Bridge in Flinträнnan.



Recommended anchorage sites marked in red. Yellow areas refer to coverage areas of lighthouses. Source: Sound VTS

Sites for anchorage are found throughout the Sound and are also marked on sea charts. These are however only recommended sites and ships are still allowed to anchor outside these areas as long as they are not within the borders of a non-anchorage area. Such areas include e.g areas where gas pipelines have been put out and within and around a wind farm park.

Cruise ships

Cruise ship tourism is increasingly popular, particularly in Europe and North America, with the Caribbean region being the number one destination visited in the world followed by the Mediterranean region in a second place and Northern Europe, including the Baltic Sea and the Norwegian fjords, in the third place. According to a study by the Danish Centre for Coastal Tourism *Cruise Feasability Report with Sande as a special case* there are however signs that the Mediterranean region may be somewhat saturated which is likely to motivate companies to expand deployments into other regions instead such as the Black Sea and Northern regions, during summer season.

Cruise ships visiting ports around the Sound are usually part of a Baltic Sea itinerary that also visits other large ports in the region such as St Petersburg, Stockholm and Tallin. Copenhagen is by far the port that accommodates most cruise ships in the Sound and is also one of the main calls for cruise ships on the Baltic Sea itinerary. Copenhagen has already seen a 100% increase of cruise ships since 2004 and with the current expansion of the port the capacity to receive more and larger ships will increase. The other cruise ports in the Sound, Helsingør, Helsingborg and Malmö, show relatively small numbers of visiting cruise ships and have not been able to increase their number of visiting ships significantly in the last 7 years.

Mariculture

Few initiatives of mariculture currently exist in the Sound. One ongoing example is a mussel farm set up in the waters of Malmö and Lomma by the two municipalities, Region Skåne and SEA-U Marine Science Centre. The initiative started out as a pilot project in 2010 with the purpose of analysing the possibilities of reducing nutrients in the sea and producing biogas.

Two farms, 50 x 12 metres, were initially put into the water, two in the waters of Lomma and two in the waters of Malmö. The technique used was the so called long-line type where a 50 m long wire is held up by one floating device in each end. Perpendicular to the long line, several strings were attached going from the surface down to approx. 6–7 m depth. The entire installation was then connected to the sea floor with heavy anchors.

Heavy storms and strong ice severely damaged the installations during the autumn and winter 2010 and a choice was made to exchange the original installations with a new technique. Instead of

Cruise ship in Copenhagen port.

using the long-line with perpendicular strings a net was being introduced which was directly attached to a floating device at the surface and anchorages at the seafloor. However this technique did not prove to be fully adequate for the conditions in the Sound and a third alternative was developed. The floating device to which the net is connected was now sunk approximately 2 m below the sea surface instead of keeping it at the surface as with the previous technique. In this way the risk of having ice cutting off the net from the floating device was eliminated and also the negative effects from heavy storms on the floating device were substantially reduced.

So far no mussels have as yet been harvested in any of the installations in Malmö and Lomma due to the problems caused by weather conditions that have damaged the installations. At the time of writing, current installations have been in the water approx. one year and the first harvesting is scheduled for autumn 2013. The mussels will be taken to Knislinge and used in a pilot plant for the production of biogas.

Blue mussels (Mytilus edulis) in the mussel farm outside Malmö. Source: Michael Palmgren

Lillgrund wind farm with its 48 turbines was at the time of inauguration in 2008 the third largest offshore wind farm in the world.

Offshore wind farms

Currently there are two offshore wind farms in the Sound, Lillgrund located 7 km from the Swedish coast south of the Øresund Bridge and Middelgrunden located outside Copenhagen, north of the Øresund Bridge. Lillgrund is the largest offshore wind farm in Sweden with its 48 turbines that annually generate 330 GWh. This provides sufficient electricity for 60,000 households. Lillgrund was also at the time of inauguration in June 2008 the world's third largest offshore wind farm. Middelgrunden has 20 turbines that annually generate 89 GWh. This represents approx. 3% of the total electricity consumption of the Municipality of Copenhagen.

Middelgrunden windfarm outside Copenhagen.

A prospectus for the Lillgrund offshore wind farm was issued in 1997 by Eurowind AB but was taken over by Swedish state-owned Vattenfall in 2004. The construction phase of the wind farm went on from March 2006-December 2007. By then all turbines were connected and delivered electricity to the network. Like the majority of all offshore wind farms Lillgrund is built in a shallow water area to facilitate the construction and minimise costs. Average depth in the area is 4-10 metres. Lillgrund is located off the ships' navigation route and calculations made by Vattenfall estimate the risk for collision between a ship and the wind farm to one in 6000 years. Also due to the shallow areas, particularly south and west of Lillgrund, a ship off its course will hit the shoal before it reaches the turbines according to estimates made by Vattenfall.

The shallow areas where the wind farm stands are considered as archaeologically valuable areas due to the chances of finding historical remains or shipwrecks. Archaeological investigations were made in addition to the environmental assessment and found one shipwreck within the area. According to marine archaeologists it is from the

17th century or even earlier and parts of the ship are spread out within a radius of 150 m from the main wreck. The location of the electricity cable connecting the wind farm with the power station on land therefore had to be changed slightly, making a bend around the wreck, instead of going straight through the area as initially planned.

The foundations of the wind farms have an expected lifetime of approx. 50 years. The actual turbines however have an expected lifetime of approx. 20 years meaning the turbines can be replaced twice before the foundations need to be replaced.

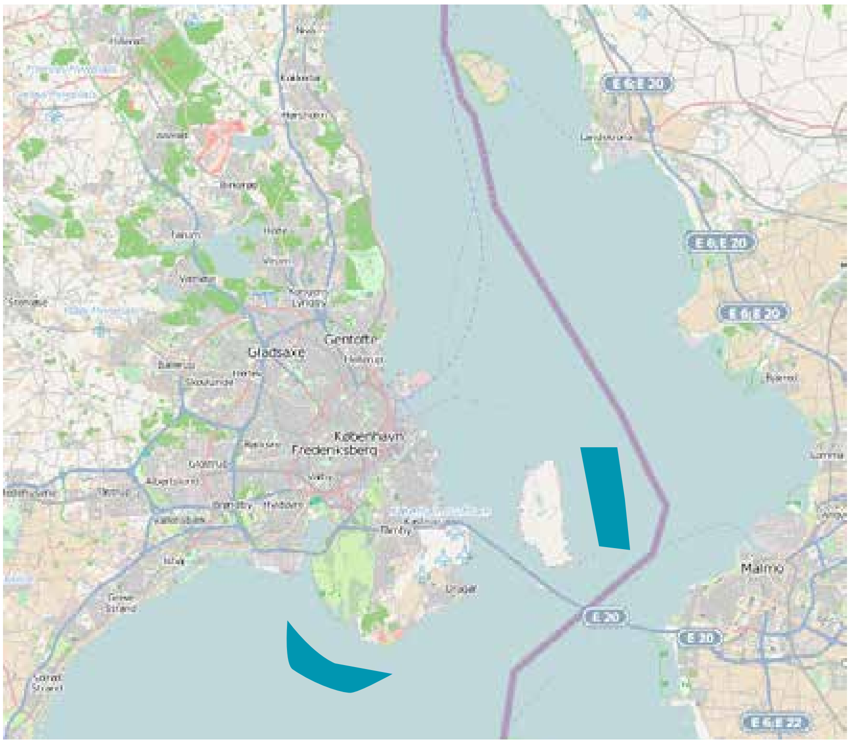
The Middelgrunden wind farm was developed jointly by Middelgrunden Wind Turbine Cooperative and Copenhagen Energy Wind, the latter being part of Copenhagen Energy which is owned by the Municipality of Copenhagen. The Middelgrund Wind Cooperative has 10.000 members consisting primarily of local citizens who have invested relatively small amounts of money (500–3000 euro) in the wind farm. The 10 most northern turbines are owned by Copenhagen Energy Wind and the 10 most southern by the Middelgrunden Wind Turbine Cooperative. Establishment of the wind farm was approved by the Danish government in 1999 and the construction was finalised in December 2000.

The location of Middelgrunden wind farm is on an earlier dumpsite, which was used for deposition of harbour sludge and construction material until 1980. Environmental impact assessments carried out prior to the start of construction showed that 3-4 intended turbine sites were contaminated by heavy metals such as mercury and copper.

The average depth on Middelgrunden is 3-6 metres. Along the sides of the shoal run two deeper channels – Kongedybet and Hollanderdybet. Maritime traffic is heavy here as it leads to the Drogden channel in which the majority of the ships pass by when crossing the fixed link between Malmö and Copenhagen.

Given the favourable wind conditions in the Sound more offshore wind farms are being planned. The Municipality of Copenhagen is planning to construct two new parks in the Sound in a not too distant future. Before the end of 2015 one park is planned to be erected on Aflandshage 3km south of Amager/Copenhagen. In addition, another park is being planned for the area east of the island of Saltholm close to the Swedish border.

The turbines at Lillgrund wind farm have an expected lifetime of approx. 20 years.



Areas for planned off shore wind farms on the Danish side of the Sound.

Fisheries

Historically the Sound was renowned for its rich herring resources which attracted merchants from both the Baltic and North Sea regions. At the end of the fifteenth century the fish markets around the Sound started to decline but several fishing villages continued with their fisheries and up until the end of the nineteenth century; the fishing village of Limhamn south of Malmö itself had more than 150 fishing boats. Today the fish abundance has decreased and subsequently also the number of fishing boats. Fish abundance is however still much larger in the Sound than in the adjacent Kattegatt due to an international agreement on a trawling ban between Sweden and Denmark.

The number of fishing boats landing fish from the Sound has decreased substantially in the last twenty years. Source: Sydsvenskans bildarkiv

Differences in fisheries regulations in Swedish and Danish waters

The national fisheries policies of the member states in EU are subordinate to the common fisheries policy of the EU (CFP) and the member states are thereby obliged to follow the CFP. Member states may however adopt national regulations to complement and implement the CFP as long as they do not conflict with the CFP. In the Sound both the Swedish and Danish national fisheries policies apply besides the CFP. Swedish and Danish national policies are however not harmonised and sometimes create contradictory measures in the Sound. Minimum landing size and closed seasons for fishing, for example, vary between the Swedish and Danish sides. Minimum size for sea trout (*salmo trutta*) is 40 cm on the Danish side and 50 cm on the Swedish side and for pike (*esox lucius*), minimum size on the Danish side is 60 cm whereas on the Swedish side it is 40 cm. It is prohibited to catch eel (*anguilla anguilla*), since 1 May 2007, on the Swedish side (exceptions are given for some professional fishermen who are economically dependent on eel fishery) but not on the Danish side. Minimum size on the Danish side is 35.5 cm. For cod (*gadus morhua*) the same minimum size applies on both the Danish and Swedish sides of the Sound i.e. 38 cm. Noteworthy is that in the adjacent Kattegat minimum size for cod is only 30 cm, both in Danish and Swedish waters.

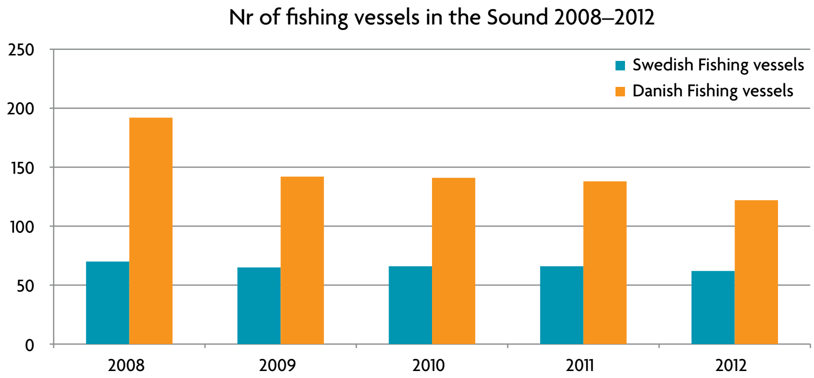
Closed seasons for fishing also differ between the Swedish and Danish side of the Sound, for the same species. Salmon and sea trout (*salmo salar* and *salmo trutta)* for example are not allowed to be caught on the Swedish side from 15 September to 31 December whereas on the Danish side the same restriction applies but for the period from 16 November to 15 January. In both Sweden and Denmark, areas adjacent to river mouths have special regulations for fishing in order to protect and allow migrating fish to move freely to and from their spawning grounds. On the Swedish side of the Sound it is prohibited to fish in these areas during the period 15 September to 30 April. In Denmark, if the river mouth is less than 2 metres wide, it is prohibited to fish there from 16 September to 15 March. If the river mouth is wider than 2 metres it is not permitted to fish within the sea area that stretches 500 metres from the river mouth, at any time of the year.

Minimum landing sizes in Sweden and Denmark

Species	Denmark	Sweden
Trout	40 cm	50 cm
Pike	60 cm	40 cm
Cod	38 cm	38 cm
Eel	35,5 cm	Prohibited to catch since 2007 (exemptions given to some fishermen)

Number of fishing boats in the Sound

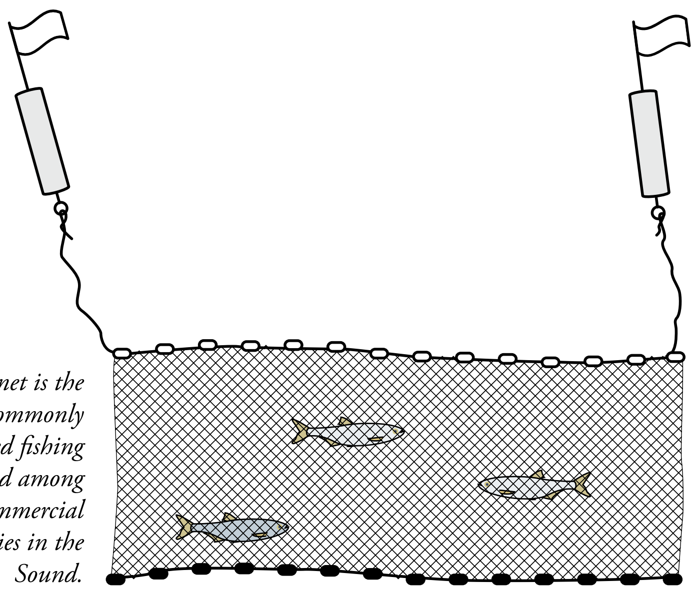
The number of registered commercial fishing boats in Sweden has decreased in the last 40 years. Today approximately 30% of the total fishing fleet that existed 1970 is left. In the beginning of 2002 there were 2,231 licensed fishing boats in Sweden. In 2012 the number had decreased to1,380. The Danish fishing fleet follows a similar pattern and has been reduced by 46% since 1995. In 2011 the fleet consisted of 2,787 fishing boats compared to 3,265 in 2005.



Figures refer to number of vessels that landed fish from the Sound during the given period. Source: Swedish Agency for Marine and Water Management and the Danish AgriFish Agency.

The decreasing number of commercial fishing boats in Sweden and Denmark is also visible in the Sound. The number of Swedish fishing boats that landed fish from the Sound in 2012 was 62. Four years earlier the number was 70. On the Danish side, 122 Danish vessels landed fish from the Sound in 2012. Four years earlier the number was 192.

Commercial fisheries are not limited to any particular location of the Sound but are carried out in the entire area. Certain locations, such as the deep areas around Ven, do however attract large number of fishing boats during the winter months, including tour boats and private recreational fishing boats due to the accumulation of large cod in the area.



Gill net is the most commonly used fishing method among commercial fisheries in the Sound.

The Swedish and Danish commercial fisheries in the Sound are to a large extent based on gill nets. Fyke nets are also used in some places mainly to catch eel. Gill nets consist of a netted wall that is kept more or less vertically by a floating line and a weighted ground line. The net can be set at the sea bottom or at a certain distance from the bottom depending on if demersal, benthic or pelagic species are to be captured.

Recreational fishing and organised fishing tours

As a consequence of the larger abundance of cod in the Sound compared to the adjacent Kattegat, tour fishing boats and recreational fisheries has become increasingly popular in the Sound. Swedish championships in recreational sea fishing have traditionally been held in the Kattegat but have now moved to the Sound since the variety of fish, cod size and abundance of fish is considered larger there.

In 2011 an investigation was done on cod catches on board Swedish tour boats and, at that time, the 10 Swedish tour fishing boats operating in the Sound by the Swedish Institute of Marine Research (IMR). The tour boat operators agreed to report their landings on a quarterly basis to the IMR which was carried out by visual estimates by the operators. In addition, the IMR also carried out control weightings on seven different occasions onboard the boats. The total landings of the ten tour boats during 2011 were 85,136 kg. This can be compared with the total landings of the Swedish commercial fleet operating in the Sound during the same year which landed 413,556 kg cod. Thus approx. 20% of all the cod that was landed in the Sound in 2011 was caught by tour boats.

The economic and social value of recreational fishing is significant according to several studies. According to a report from the IMR (Fiske 2005) approximately 3 million Swedes are involved in recreational fishing and were, in 2004, estimated to spend around three billion Swedish crowns on their fishing. A similar study carried out by the Danish Ministry of Food, Agriculture and Fisheries (Lystfiskeri i Denmark. Hvem? Hvor

Meget? Hvordan?) shows that approximately 17%–18% of all Danes between the ages of 18 and 65 have at least once in recent years been on a fishing trip. That corresponds to 616,000 people. In an international context this puts Denmark in a middle position when it comes to the percentage of the population who sometimes fish recreationally, somewhat less than in Sweden where the estimates are 33% and somewhat more than in the USA where estimates are approx. 16%. The study estimates that the total spending on recreational fishing in Denmark amounts to 2.85 billion Danish crowns. Of this 1.31 billion Danish crowns are considered to be so-called "activity creating consumption" i.e. consumption that directly influences the production and employment in Danish businesses. The remaining consumption is from VAT and fees.

In a marine spatial planning context these numbers are interesting as they show that there is a large interest for recreational fishing which is yet another actor among several who operate in the Sound. Small-scale commercial fisheries on the other hand have declined in both Sweden and Denmark in the last few years which is also reflected in the number of commercial fishing boats operating in the Sound.

Varvsudden in Landskrona port and Gipsön, 2013.

Varvsudden and Gipsön 1986
Source: Sydsvenskans bildarkiv.

Port expansion and marinas

There are six main commercial ports in the Sound and a number of small marinas for leisure boats. The commercial ports are partly or entirely built on land reclaimed from the sea and have continuously expanded in size since the beginning of their activities.

Commercial ports

Landskrona

The port of Landskrona has a long documented history and was mentioned in Danish history archives as early as the 13th century. The shipyard in Landskrona served for many years as an important employer in the city and up to 46% of the city's industrial workers were employed there in the 70s.

The southernmost area of the harbour, called Varvsudden (i.e. shipyard peninsula) is a land-filled area as well as the island of Gipsön in front of the shipyard. Gipsön is a 43 hectare artificial island built in the 70s with the residues from the fertiliser industry, AB SUPRA, then located in the harbour. The residues are contaminated with heavy metals and the leakage of cadmium and mercury is still observed in the water and in blue mussels around the island.

During a storm in the winter of 2011 a floating dock placed in Landskrona shipyard cut loose and drifted out of the port area. Heavy winds and a high water level at the time allowed it to enter the shallow waters of Lundåkra bay where it eventually ran aground. In the beginning of 2012 efforts were made to remove the dock from the bay, which is a Natura 2000 protected area. The dock was framed in by sand walls creating a pool into which water later was pumped. In addition a 2 km long canal was dug out on the sea bottom through which the dock was later towed out of the bay. Actions were taken to fill the canal after the salvage operations but the urge to finalize the work before the onset of spring led the work to stop before the canal was completely restored. Additional attempts have been made to fill the canal but the soft sea bottom in the area has impeded machines to fulfil the work.

Lundåkra bay with Landskrona in the background and the trace of the floating dock in the foreground.

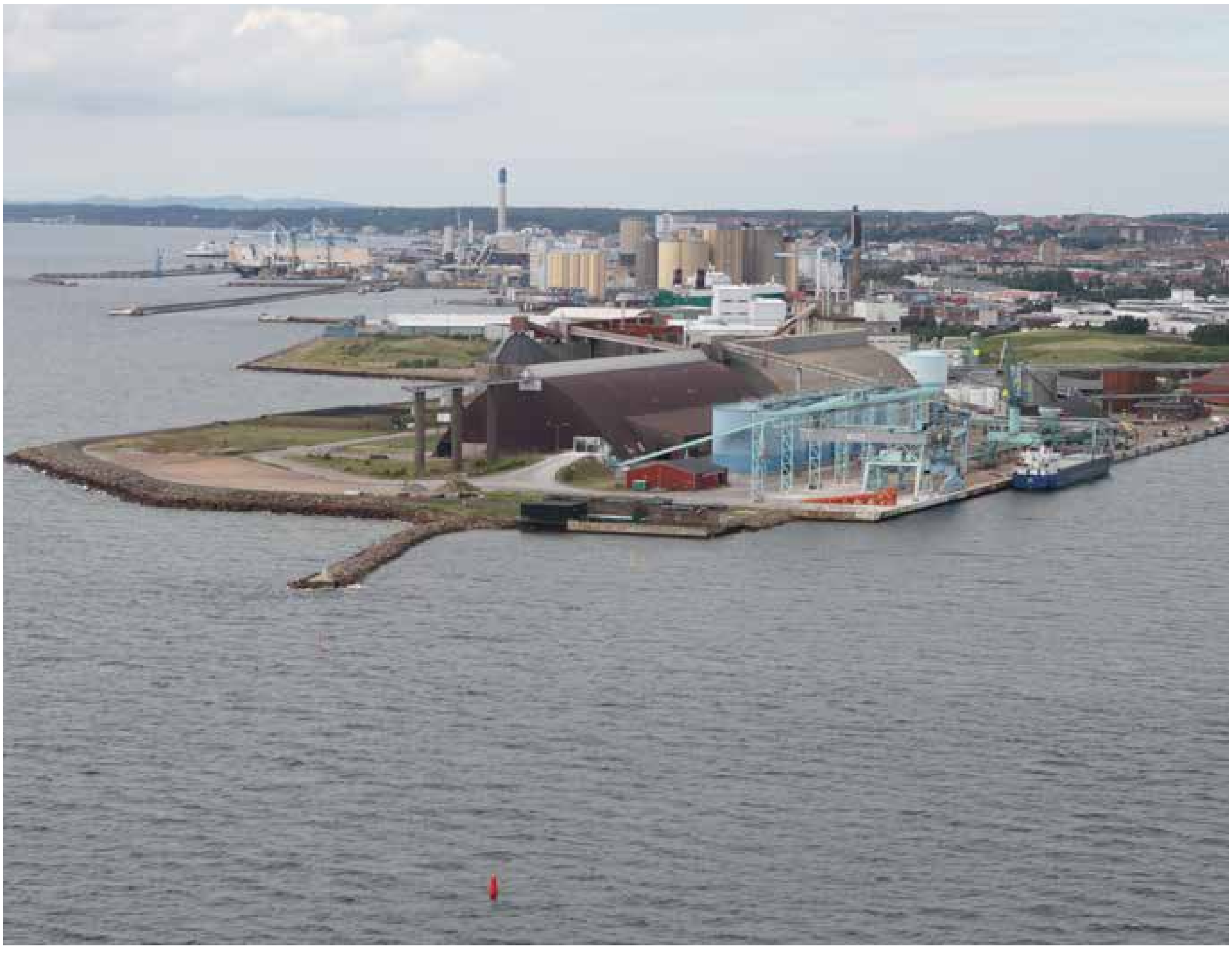
Trace of the canal where the floating dock was towed out of the bay.

Helsingborg

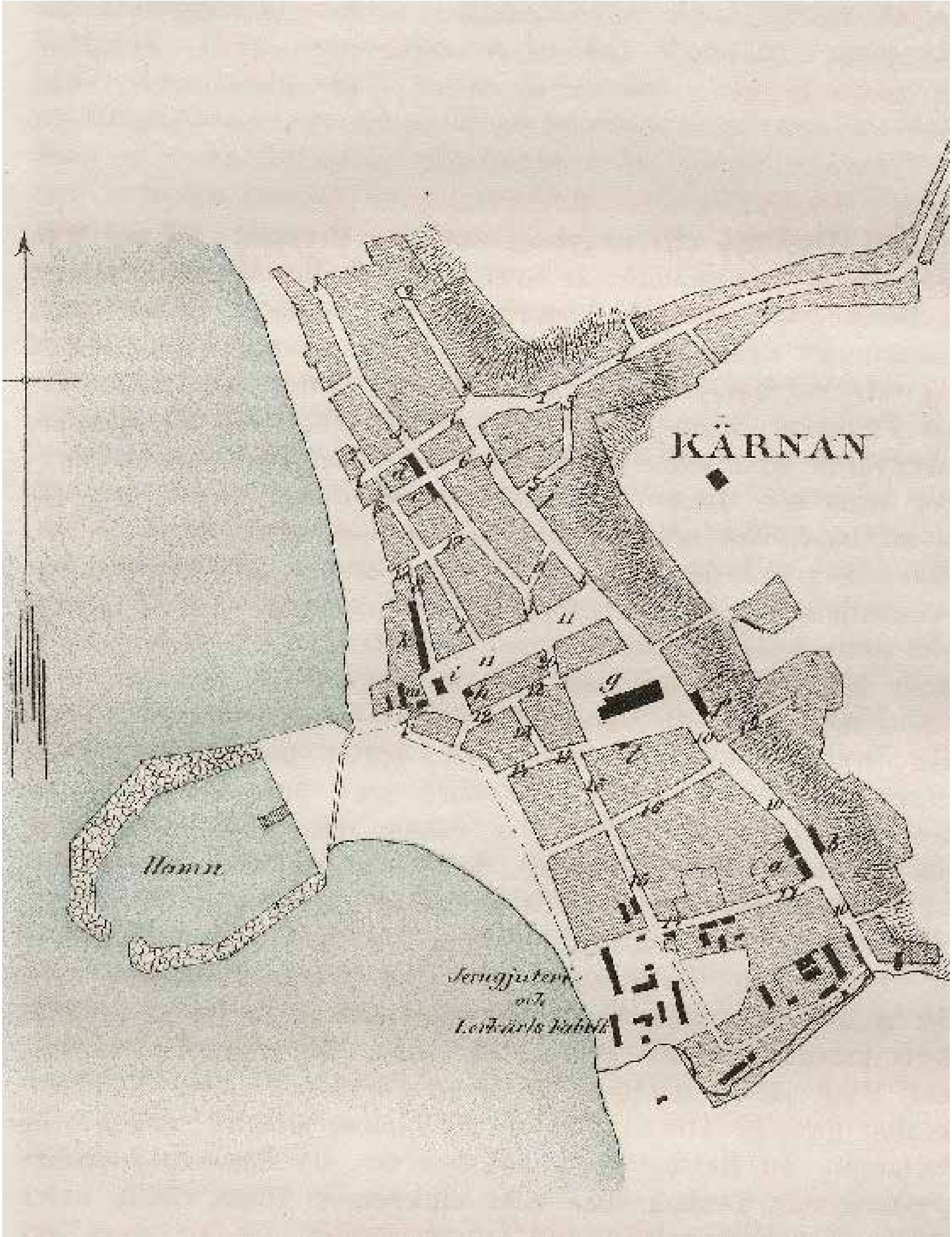
The port of Helsingborg also has a long history and although it is not a natural harbour the location of the city has always been an important trading point. Until the 18th century the port of Helsingborg was merely a wooden bridge stretching a few hundred metres into the sea. The first real port in Helsingborg was inaugurated in 1832 and by then two piers had been constructed giving improved shelter to the harbour. An important step in the development of the port was the construction of a railway extending into the port area. This infrastructural improvement provided Sweden with its first train-ferry connection with a foreign country when in 1892 a Danish paddle steamer started its operations between Helsingborg and Helsingør. During the nineteen twenties and thirties the port further expanded with the construction of the oil terminal and the so-called ocean harbour. Previously a stone pier, *parapeten*, had been constructed with rocks and dredging material from the construction of the ocean harbour, which further expanded the port into the sea. As a consequence of the agreement among the Nordic countries in 1952 passport requirements when crossing the international borders were abolished. This contributed to the increase in passenger traffic between Helsingborg and Helsingør which subsequently also gave rise to a new ferry dock in the port.

Today the port occupies large parts of Helsingborg's central and southern coastline along the Sound. It stretches from the central parts of the city and southwards approx. 4 km. The entire port area is located on reclaimed land. The most recent expansion of the port is the west harbour that was inaugurated in 1985.

As in several port cities along the Sound, parts of the city that once were used as port facilities have now been rebuilt and transformed into residential areas. Helsingborg is no exception. Parts of the northern harbour were rebuilt for the housing expo in 1999 and are now a residential area. The ocean harbour is also to be transformed into a residential area with commercial services and new workplaces. This area is currently being planning by the municipality.



The port of Helsingborg stretches approx. 4 km south of the city



Map of Helsingborg 1850. The two stone piers forming the original port is visible on the map in front of the central parts of the city.

Where the shipyard once was is today a cultural centre in the port of Helsingør.

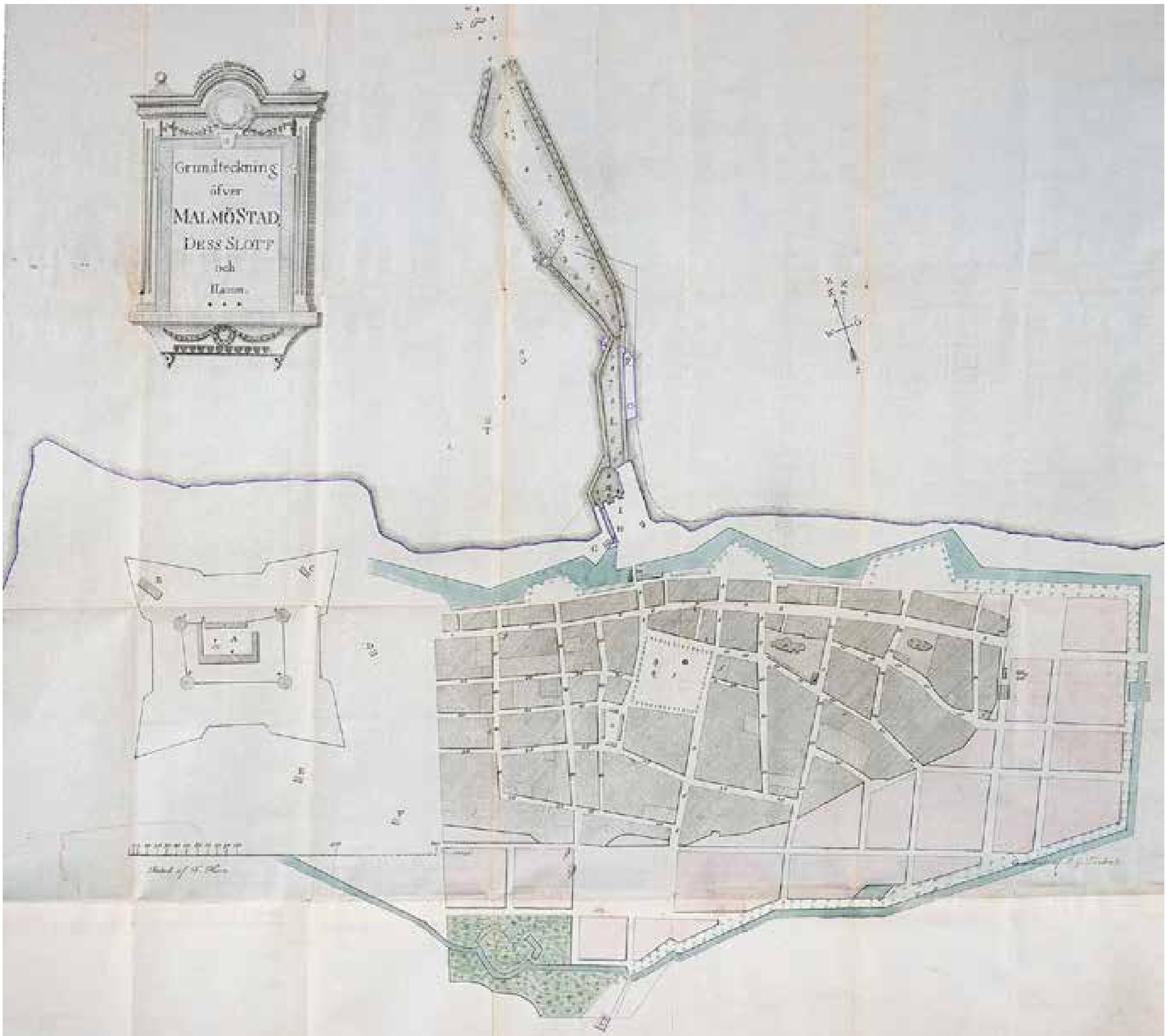
Helsingør shipyard in 1938. Source: Sydsvenskans bildarkiv

Helsingør

The port of Helsingør consists of two ports – Helsingør northern port and Helsingør port. The northern port was built for fisheries and leisure boats in 1932–1934. There was at first great reluctance among the public to the building of a new port with stone piers and wave breakers as it was thought to blur the impression of Kronborg's peculiar location. Some years later arguments in favour of a new port were however raised. A flood storm in 1902 had destroyed large parts of a green park area located close to the shore and new stone piers and wave breakers could serve as a combined form of coastal protection and port, it was argued. In addition, flourishing tourism, sailing, outdoor activities and improved facilities for the, at that time, 54 fishermen operating in the area also raised the need for a new leisure boat and fishing port. The construction of the new port was therefore started 1932 and finalised in 1934. A drawing of the area from 1936 shows the new port with its areas for leisure boats, fishing boats and swimming.

The next phase of port expansion came in the early 70s when the current port was extended with two new stone piers creating a new outer port for leisure boats outside the original port. The port of Helsingør is not connected to the Helsingør northern port by any waterways despite the short distance (approximately 400 metres) between them. For one hundred years large parts of the port of Helsingør were occupied by a shipyard that was eventually shut down in 1983. The shipyard extended from the old parts of the city out to Kronborg castle. Whereas Helsingør northern port was intended for fishing and leisure boats Helsingør port was, and still is, used for ferry traffic, cargo vessels and cruise ships. Railway and car ferries are still operating between Helsingborg and Helsingør and the southern part of the port, located on reclaimed land from the sea, is taken up by facilities for train and car transport.

The northern port of Helsingør was first built in 1932–1934 but has since then expanded substantially to its present size. The drawing is from 1936. Source: Municipality of Helsingør



Map of Malmö city and port 1812. Source: Malmö city museum

CMP - Copenhagen Malmö Port

The ports of Malmö and Copenhagen merged their activities in 2001 and now operate as one port under the name Copenhagen Malmö Port – CMP. A description of the physical expansion and reclamation of land from the sea in each of the two ports is given separately.

Malmö

The port of Malmö does not have any natural deep harbour and the commerce with ship borne goods was until the end of the 18th century carried out on a long wooden bridge extending 150 metres from the shore into the water. This bridge, called Fergebron, was mentioned in historical documents as early as 1390. The shallow waters around Malmö only allowed ships with a limited draft to enter the harbour which called for the development of a dredged port with embankments. In 1775 the initial steps were taken and the port of Malmö was founded after an initiative taken by the businessman Frans Suell. The first phase of the expansion included two parallel piers creating an inner harbour between them with a maximum depth of approximately 4 metres.

The next phase was the establishment of the western harbour where the shipyard Kockums established their activities in the late 19th century. The western harbour was built in different phases from the 18th century until 1987 when the last land was reclaimed. The material used for land filling consisted of sand, limestone, excavation material, construction rubble and residues from production industries. The port Malmö continued to expand its size by reclamation of land in the Sound

The western harbour in Malmö where Kockums industries were located has now been transformed into a residential area. At the same time new areas, north of the city, are being reclaimed from the sea and used as port facilities. This shift is observed in several of the commercial ports around the Sound.

Western harbour in 1989. Source: Sydsvenskans bildarkiv

The dock where the Kockums crane once stood is today a small harbour for leisure boats.

during the first half of the 20th century with the New harbour, the Industrial harbour and the Free harbour. Similar in size to the western harbour, approximately 25 hectare, is the most recent part of the port of Malmö i.e. the Northern harbour. The area of the Northern harbour had already been framed with piers the 80s. In connection with the construction of the new city tunnel in Malmö excavation material was taken to construct the Northern harbour. Arguments were raised that the construction of the Northern harbour would hinder the flow of water from the north to the southwest causing an accumulation of sediment in the sea north of the area and in the bay of Lomma. In 2008, after a decision by the Swedish environmental court, permission was however given to continue and finalise the reclamation of land needed to construct the Northern port.

Today the port of Malmö occupies the central and northern parts of the coastline of Malmö. The western harbour has been rebuilt and turned into a residential area with only minor parts left for industrial activities. In planning documents from the Municipality of Malmö a vision for the New harbour is also expressed stating that the area should be more integrated with the city and the Western harbour and that the space will be used for residential areas, businesses, culture and recreation.

Kockums industries in Malmö in the beginning of the 1980ies. The Kockums crane was for many years a landmark of Malmö but eventually dismantled in 2002. Source: Sydsvenskans bildarkiv

Land reclamation in the north harbour in Copenhagen. Middelgrunden wind farm in the background.

Copenhagen

The location of what today is the inner parts of Copenhagen port served historically as a natural harbour, particularly favourable for ships as it was protected from harsh weather conditions by the adjacent island of Amager. From there the port has expanded substantially in size and stretches today along the coast of Zealand from Kalveboderna in the south to the bay of Svanemøllen in the north, a distance of approximately 12 km in total.

From its original location, the port of Copenhagen expanded by reclaiming land from the sea in the waterway connecting the inner parts of the harbour with the Sound. A number of small islands, together known as Holmen, were constructed with dredging material from the port and served until 1990 as a base for the Danish navy. During the 19th century the capacity of the port had become too small in comparison with its activities and the limited water depth in the harbour also hindered large ships from entering. This gave rise to an extensive deepening of the waterway between the Sound and the harbour and of the harbour itself. The dredged material from this deepening was used to create the South harbour, Refshaleøen and the Free harbour thus expanding the port so it then reached the open waters of the Sound. Furthermore the most northern part of the port started to be constructed in the late 19th century and has in different phases gradually grown to its present extent. The Northern harbour continues to grow also today and a new large scale land reclamation is planned and initiated on its northeast end. Over the next 20 years that part of the port will grow with another 100 hectares allowing for more cruise ships to enter the port at the same time. Excavation material from the construction of the Copenhagen metro and the construction of the new road leading to the Northern harbour will be used for the new land filling. It is estimated that 18 million tonnes of excavation material will be needed to establish the new part of the harbour.

Køge

The port of Køge is one of the oldest in Denmark located in the southwest part of Køge bay in the south of the Sound. It has recently expanded its activities and size and is about to expand even more in the coming years by increasing the water depth to 8.5 m, construct another 1200-metre wharf and increase the port area with an additional 40 hectares. This will allow the port to receive ships that are up to 200 metres long and 30metres wide which is almost twice the size compared to today's capacity.

The port of Køge, at its present location, goes back to the 15th century where a small port was established at the location where the river Køge meets the sea. During the following centuries the port developed gradually but the infrastructure suffered some damage in heavy storms. In the 1930s Køge was established as a commercial port and expanded substantially with a wider waterway for entering the port and a 250 m long concrete wharf. In more recent years the port has continued to expand and in 2004-2005 the ferry terminal with ferries to inter alia Bornholm was established.

The current phase of expansion from 2007 to 2017 is the biggest in the history of the port. The new port area will be located between the present commercial port and the marina for leisure boats and an estimated 4 million m^3 of excavation material will be needed for land reclamation of the new site. Approximately 2 million m^3 of

The port of Køge is currently going through the largest expansion in the port's history contaminated and lightly contaminated soil will be used for the landfill. The material will come partly from road and construction sites in Copenhagen and partly from dredging during the construction of the new harbour. The soil is divided into four different categories depending on its level of contamination; category 1 is the cleanest, non-contaminated soil, and category 4 is the most contaminated. Oil and heavy metals are common substances in the contaminated soil from road and construction sites. In the construction of the new port it is planned to use soil from classes 1, 2 and 3. The site in the sea where the soil will be deposited will have double walls towards the south and east and a single wall towards the north. The filled area will be secured gradually as the construction proceeds and a final layer of non-contaminated soil, 0.75 m thick, will be placed on top.

A common aspect of the development of the commercial ports around the Sound is that the parts of the ports that are located parallel to the central parts of the city's centre, often the oldest parts of the ports, are today being transformed into residential and commercial areas, thereby losing their function as a port. At the same time new areas, away from the central parts of the city, are being reclaimed from the sea for port purposes. Given the increasing demand for goods produced in other parts of the world it is reasonable to believe that shipping and port expansion will continue to increase in the future.

The port of Køge 1934 at its original location where the Køge river flows out into the Sound. Source: Køge Byhistoriske Arkiv.

Shoreline protection in Sweden and Denmark

Provisions regulating shoreline protection in Sweden were established in 1950. The main purpose of the new regulations was to safeguard public access to coastal areas but also to conserve healthy environmental living conditions for animals and plants on land as well as in the water. The geographical coverage of shoreline protection extends 100 metres from the shoreline into the water as well as on land. The County Administrative Board can however extend this general coverage to include 300 metres in both directions. The protection includes all shorelines along the sea, lakes and streams and also the underwater environment. Within these areas it is not allowed to carry out certain types of activities such as the construction of buildings or excavate in preparation for construction. This general rule is however connected with a range of exceptions for which one can apply for exemption. Until July 2009 it was the responsibility of the County Administrative Boards to evaluate and decide on approval of exemptions. This then changed and it is now the responsibility of the municipalities. In certain cases, when the area within which the exemption is applied for in addition to the shoreline protection also is protected by other regulations e.g. Natura 2000, then it is still the responsibility of the County Administrative Board to decide on approval for exemptions. It is worth noting that even if exemption is given for construction within an area of shoreline protection, a free passage route of at least some ten metres must always be kept open for the public between the shoreline and the construction site. The route should be wide enough for the public to walk unhindered along the shore.

The Danish provisions for shoreline protection date back to 1937 and were established to protect the landscape scenery and public access to the coast. At that time the shoreline protection only included restrictions on construction and therefore also carried the name "strandbyggelinjen" (shore construction line). It extended from the shoreline and 100 metres inland.

In 1969 the shoreline protection area was extended to not only include restrictions on construction but to any kind of alteration in the terrain. At the same time the provision also changed its name to "shore protection line" (strandbeskyttelseslinjen) which also is the case today. In 1994 the geographical coverage of the shoreline protection area was extended to 300 metres from the coast instead of 100 metres, excluding summerhouse areas where the 100 metres limit still remains. In connection with this, it was also decided that a more specific description would be made illustrating the exact location of the shore protection line. A committee was appointed to carry out the task and in 2004 the work was finalised. The distance, in metres, describing the geographical area of the shoreline protection area was then removed from the provision and today the shore protection line is instead marked on a map available at the Ministry of Environment. The shore protection line today usually extends 300 metres from the shoreline in open landscapes and 100 metres or less in populated areas.

The shoreline protection is administered by the Danish environmental protection agency (Naturstyrelsen) which is also the body that approves application for exemptions.

The provisions regulating shoreline protection in both Denmark and Sweden are based on the principle that the public should have access to the coast and be able to move along the coast unhindered. On the Danish side of the Sound settlements are however in general constructed closer to the waterfront than on the Swedish side and occasionally private properties impede public access to the coast. These may be houses that were constructed before 1937 when the regulations on shoreline protection came into force or summer houses that constitute an exception from the general rule. On the whole the Danish coast in the Sound has been strengthened to a greater extent than the Swedish one. This reflects the more intense societal development and human occupation in Sjælland in general and the Copenhagen capital region in particular in comparison to Skåne.

The near shore constructions have in some places also increased the need for protection against coastal erosion. Measures have been taken in the form of construction of stone piers along the shoreline in these areas. A major difference in the Swedish and Danish regulations is that the Swedish shoreline protection extends both on land and into the sea whereas the Danish only extends on land.

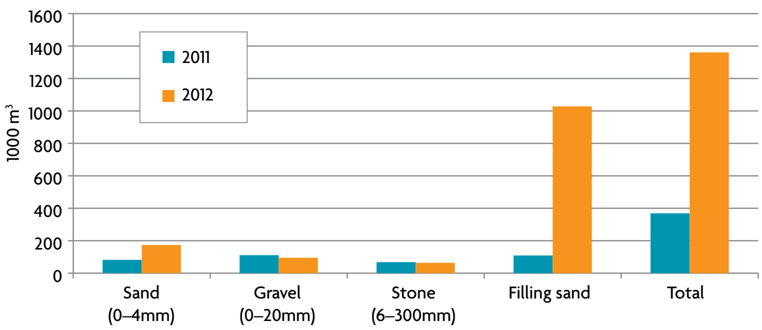
Coastal protection along the Danish coast north of Helsingør.

Extraction of sand and gravel

Extraction of sand and gravel from the seafloor is done for a variety of purposes including beach nourishment, construction and land reclamation. Although more expensive per tonne, sand extracted from the sea bottom has a rounder and smoother shape than sand extracted from land. Due to this, less cement and water is needed when producing concrete, which in turn, helps keeping the price of the concrete at a similar level to that produced with sand extracted from the land.

Denmark has increased its extraction of natural resources (not including oil and gas) substantially in recent years, from approx.7,500 m^3 in 2011 to 10,500 m^3 in 2012. Most of the material is extracted from the North Sea but large amounts are also coming from the Sound. Between 2011 and 2012 the increase in extracted sand and gravel in the Sound went up from 0.4 million m^3 to 1.4 million m^3. The principal reason for the steep increase was the expansion of the port in Copenhagen where large amounts of material were needed. The extraction is taking place in scattered places along the Danish part of the Sound including in Køge bay as well as in the central and northern parts.

Extraction of sand and gravel in the Danish part of the Sound



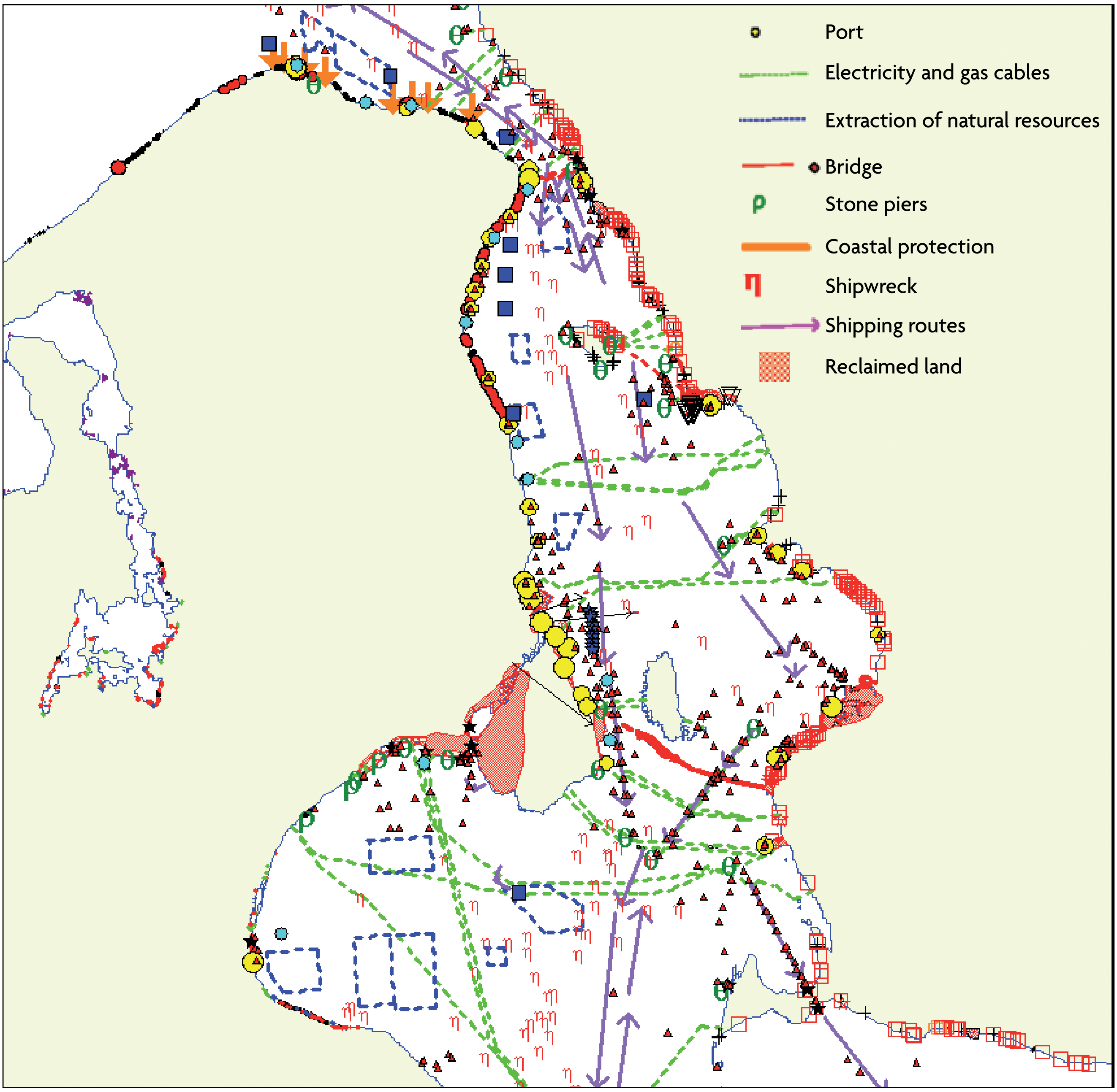
In Sweden extraction of sand and gravel from the sea has been done to very limited extent during the past 20 years. It is the national authority Geological Survey of Sweden that is responsible for administration and licensing of the extraction of marine aggregates in the territorial water. They must however, according to the Act of the Continental Shelf consult several authorities that may be affected before granting any licences. It includes inter alia the Swedish Agency for Marine and Water Management and the Environmental Protection Agency. Beyond the territorial waters, in the exclusive economic zone, it is the responsibility of the government to grant licencing for sand and gravel extraction. Since 1992 the Swedish Act of the Continental Shelf requires an environmental impact assessment to be done in connection with any application for extraction of marine aggregates.

One on-going example of sand and gravel extraction is currently taking place close to the Sound, on the south coast of Skåne, in the waters of municipality of Ystad. The municipality has been granted a licence from the Geological Survey of Sweden to extract 340 000 m3 sand and gravel from the sea floor over a period of ten years. The material will be used for beach nourishment in the areas of Löderups strandbad and Ystad Sandskog.

To conclude, the northern portion of the Sound down to Helsingør-Helsingborg is the less affected by fixed structures, both at sea and along the Swedish coast, where one still finds a couple of lighthouses and other navigational aids close to shore, as well as groynes in a few smaller harbours. On the Danish side there are harbours in Gilleleje and Hornbæk and the coast is lined with breakwaters along all settlements. There are also large sediment extraction sites offshore between Gilleleje and Villingebæk and just south of Helsingør in Danish waters. Ship traffic is intense in this part of the Sound, including the ferry link Helsingør-Helsingborg with its 36,000-plus east-west crossings annually. Those two cities have large ports and extended artificial seafronts.

The central Sound is clearly the most impacted part of the Sound in terms of physical alterations. Hard coastal protection structures are found in an almost continuous succession along the Danish coast between Helsingør in the north and the island of Amager in the south. Also along the Swedish coast one finds a profusion of breakwaters between Helsingborg and Landskrona, and further south in the Lomma Bay and around Malmö. The seafronts of these last three cities, as well as that of Copenhagen are largely, if not entirely artificial. With the exception of Lomma, merchant port facilities take up large parts of these seafronts, significant portions of which are built on reclaimed land

The impact on the coastline on both sides of the Sound south of the bridge is comparatively less than in the central portion of the Sound. There exists a large and expanding port at Køge, and coastal breakwaters and piers are found between Amager and Karlslunde Strand and again at Strøby in Denmark, but these are largely absent from the



Source: Sound Water Cooperation

Swedish coast south of Limhamn. On this stretch, the largest infrastructure is the artificial canal in Skanör separating the Falsterbo peninsula from the Swedish mainland. Finally, the whole southern Sound is rich in sunken ship wrecks but given that these are found mainly at greater depths they do not actually constitute a danger to navigation. Underwater cables exist with approximately the same density as in the central Sound.

An inventory of physical alterations of human origin in the Sound was conducted in 2007 by the Sound Water Cooperation (Angantyr & Nordell, 2007). It was found that despite no single site having been spared human intervention, there are still some areas where structural changes are relatively minor. These include:

- The northern part of the Sound, the steep rocky shore around Kullen in Sweden, the boulder reefs off Gilleleje in Denmark and, in the middle of the Sound, the Grollegrund site;
- The central part of the Sound, on the Danish side the portion of the coastal strip off Nivå – despite the small town harbour and a few groynes – and most of Saltholm and the surrounding waters, and on the Swedish side, the coastal strip between Råå and Landskrona and the Lundåkra Bay south of this city; and
- The southern Sound, the southern tip of Amager Island off Copenhagen, stretches of the coastal strip in Køge Bay, especially towards its southern edge, and most of the coastal and marine areas around Falsterbo in Sweden.

V SUMMARY AND FUTURE OUTLOOK

This book set out to provide an account of environmental values and status, human uses and structures for marine governance in the Sound. Past and present conditions, as well as foreseeable trends for the future are discussed in an attempt to give broader historical and social perspectives of the evolution of this unique body of water. Such perspectives have enabled a more comprehensive understanding of the marks left on the marine environment in the Sound at various levels by societal changes.

On the whole, the ecological status of the Sound has improved substantially compared to three or four decades ago. Land-based pollution from large industrial facilities along the coast, much criticised by the public in the1980s, has decreased markedly as societies on both sides of the Sound progressed from an industry- to a service-based economy. The enhanced environmental awareness led not only to the progressive curbing of pollutant emissions, but also to the establishment of a marine environmental status monitoring system. For use by those involved in the management of the Sound in both Denmark and Sweden and for the benefit of all using it, this system has allowed a remarkable expansion of knowledge about the Sound's marine environment and its status. Regular sampling and analysis of physical, chemical and biological parameters has been a fundamental ingredient for enhancing the control over human activities affecting the waters in the Sound.

This control has been exerted from an early stage by a multiplicity of policy processes and associated regulatory instruments, the most important of which are reviewed in this book. Those relating to fisheries have frequently been praised as exemplary for enabling the maintenance of stable populations of most commercial fish stocks, something that is not observed in adjoining maritime areas. With respect to maritime transport, the Sound has benefitted not only from the continuous improvement of global safety, security and environmental standards, but also from specific measures adopted locally. The most visible of these is arguably the introduction of the joint Swedish-Danish Vessel Traffic Service, which has undoubtedly contributed to this heavily trafficked strait maintaining high levels of maritime safety.

Increasing volumes of recreational activities at sea and on the coast, as well as non-traditional offshore activities – notably wind energy and mariculture – and the construction of large fixed installations – the Øresund bridge as well as numerous land reclamation areas – are however presenting a number of challenges for the management of the Sound, including that of its environmental condition. One particular aspect shedding new light on the long-recognised need for integrated planning and management is the complex web of interactions between these different activities. Developments on this front are likely to be framed in the years to come by a maritime spatial planning process gradually emerging on both sides of the Sound. These will add a new layer to the existing system of marine governance and hopefully strengthen efforts at harmonising maritime activities with one another and with the natural environment.

This book has been produced with an explicit focus on the waters of the Sound and with the overarching aim of compiling in one single source as much available information about the status and uses of this body of water as possible. By doing so, it fills a gap in the literature about the Sound in a work that combines academic rigour and graphical attractiveness and which will hopefully appeal to a wider readership. Hence this book targets both readers who have a professional connection to the Sound – for example through organisations involved in its use and management – as well as all non-specialists who wish to learn about it. With respect to this latter group of intended readers, it is instructive to recall that the book was produced within the ARTWEI project – Action for the Reinforcement of the Transitional Waters' Environmental Integrity – and accordingly should itself be regarded as an action to support and raise awareness about the environmental management of the Sound. This action includes the production of a Geographic Information System database with information about the spatial distribution of selected features and uses in the Sound, accessible via the World Maritime University's website, wmu.se.

The information presented in this book originates from an extensive literature review complemented by a number of meetings with representatives from organisations that either operate in the Sound or have interests in and responsibilities for parts of it. To all who voluntarily or otherwise contributed to this work, the authors once again express their sincere gratitude.

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Lomma bay

Agricultural landscape along the Swedish coast

Northern tip of Falsterbo peninsula

North coast of Sjælland

North of Helsingør

Danish coast south of Helsingør

The Øresund bridge and Pepparholm island


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