NATUR VÅRDS VERKET
SWEDISH ENVIRONMENTAL PROTECTION AGENCY
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Oceanografi
Nr 88, 2007

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Prospects of designating BWE areas in the Skagerrak and the Norwegian Trench

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Author: Pia Andersson, SMHI	Clients: The Swedish National Environmental Protection Agency The Swedish Maritime Administration		Report No: Oceanography No 88
Reviewers: Philip Axe, SMHI Bertil Håkansson, SMHI	Review date: 2007-10-15	Diary no: Mo2007/1709/1933	Classification: Public

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Distribution By conditions from the Swedish National Environmental Protection Agency and the Swedish Maritime Administration	
Classification (x) Public	
Keywords Designated ballast water exchange areas, transport, currents, hydrography, biology, Skagerrak, Norwegian Trench	
Other	

BALLAST WATER EXCHANGE AREAS

Prospects of designating BWE areas in the Skagerrak and the northern Norwegian Trench

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FRAMSIDA	Photo from R/V Argos of the Baltic Proper. Photographer Bengt Yhlen
LAYOUT	Pia Andersson
PRODUCTION	Swedish Meteorological and Hydrological Institute
YEAR	2007
CITY	Gothenburg, Sweden
PAGES	68
CONTACTS	Pia Andersson, Bertil Håkansson, Swedish Meteorological and Hydrological Institute, Melanie Josefsson, Swedish National Environmental Protection Agency, Johan Fransson, Swedish Maritime Administration
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SUMMARY

Investigations were made to find out if there are areas with suitable environments for ballast water exchange (BWE) in the Skagerrak and the Norwegian Trench. Suitable conditions may be areas of certain depths (preferably >200 meters) or distance from the coast (preferably >200 nm or >50 nm). Certain oceanographical, biological and envitonmental issues should also be considered.

In the Skagerrak there is no area >50 nm from the coast, but there is a small area within the Swedish territorial waters with depth >200 m. There is an area >50 nm from the coast with depth >200 m in the northern Norwegian Trench.

Discharged ballst water in the BWE areas will be transported towards a coast or protected area. The main distance between the potential Skagerrak BWE area and the Natura 2000 areas are 10 to 15 nm.

There are strong currents in both BWE areas and discharges could be transported over large areas during the following month. The entire Skagerrak area would be reached. Most parts of the costal zone would be reached within a week. The probability that a BW discharge will reach the nearby Natura 2000 areas is high. The shortest drift time to the protected areas along the Swedish coast and to the Norwegian coast is only a few days.

A ship would have to stop or greatly reduce its speed to complete a BWE within the proposed Skagerrak area. In the northern Norwegian Trench, there is no major shipping lane nearby.

The wave climate in the Skagerrak may not cause major concern for the safety for large ships. In the northern Norwegian Trench BWE area of interest, wave heights are a significant hazard on board most ships.

Nutrient levels are not low enough to efficiently reduce the survival rate of the organisms introduced by BW.

Discharged pollutants could normally affect the protected areas if transported to the area.

There is no way to say what specific salinity level kill BW organisms since there are many different organisms in the BW. As a rule of thumb, there is always a risk that they may survive. If the organisms are harmful, they can or will affect vulnerable native organisms.

The environment at the BWE area or in nearby protected areas, possibly with important assets, can be affected by the BW, although it is dependant on the BW contents. There is a wide variety of what it can contain. If the organisms or pollutants are harmful to a single species or to entire ecosystems, there is a clear risk of affecting protected areas.

Important assets like fish and mussel farms can be affected. Competing or predatory species may cause harm, especially in spawning areas of fish or on benthic native species.

Circulation of the central Skagerrak surface waters and eddies in the northern Norwegian Coastal Current, increase the risk of ships taking up previously discharged BW. The waters in the BWE areas have strong stratification, which prevents mixing with deep water.

The risk of uptake is high, albeit with a reduced concentration. In many of the referenced texts however, the concentrations of the organisms are not of major importance. New organisms may survive and reproduce even at low starting numbers.

Most results indicate that the proposed BWE areas are not suitable for BWE with reference to the requirements in the Ballast Water Convention and G14.

CONTENTS

INTRODUCTION

The Swedish National Environmental Protection Agency and the Swedish Maritime Administration have commissioned and funded this report.

In the Ballast Water Convention (International Convention for the Control and Management of Ships' Ballast Water and Sediments, hereafter BWC) of the International Maritime Organization (IMO), ballast water exchange between ports is an alternative to ballast water treatment until acceptable treatment systems have been developed. This alternative treatment is only valid during a restricted time period. Ballast water exchange (BWE) is today the only chance to reduce the risks of introducing and/or survival of new, alien species in an area.

In the BWC, several requirements that should be complied in order to make a BWE area are listed. The main requirements are that the BWE area should be situated >200 nautical miles (nm) from the coast and with a depth of >200 meters (m). If there is no such zone along or near shipping lanes, BWE zones should be situated >50 nm from the coast with a depth of >200 m. In the "Guidelines on designation of areas for ballast water exchange" (G14) from the BWC, it is stated that areas of BWE can still be designated even if the stated requirements above do not comply. Though there are several other criteria listed in G14 that need to be considered when designating a BWE area (read further about G14 in appendix 8).

In the Skagerrak, there is no area >200 nm from the coast, or >50 nm from the coast with depths >200 m. There are areas less than 50 nm from the coast with depths >200 m. The Norwegian Trench extends from the Skagerrak, following the coast of Norway up to the latitude 63° N, in line with Trondheim. Only a very narrow region >50 nm and >200 m depth extends from Stavanger up to Bergen. North of Bergen, the area with the desired depth and distance from the coast, widens.

The aim with this report is to give an oceanographic description of the areas of interest and to scientifically investigate if it is possible and acceptable to designate BWE areas in these areas.

Recommendations from this report are based upon general oceanographic conditions of the areas of interest and the main parts of the descriptions are included in the appendices.

ASSIGNMENT

The main aim of this report is to describe the currents and circulation of the central Skagerrak and the northern Norwegian Trench. Investigations are made to assess if the areas of interest could provide a suitable environment that would reduce the risks of alien species introduction or spreading through ballast water exchange. Suitable conditions may be areas of certain depths or salinities or other conditions that effectively kill the organisms from ballast water and sutch that they do not spread beyond the BWE area. The ship (here meaning all ships/tankers/etc. containing ballast water) and crew safety demands from the BWC must be ensured and the areas need to have the capacity to be used by all ships identified as high risk traffic for alien species introduction and spreading.

Considering the requirements in the BWC and G14, the assessment includes the following issues:

- **Oceanographic conditions –** (1) Will the discharge of ballast water in the BWE area be transported towards or away from the coast? (2) Will the organisms, discharged with the ballast water, circulate horizontally in the surface waters and by that, be present for ballast water uptake when the next ship is passing? (3) What is the vertical circulation?

- **Biological conditions –** (4) Will the discharged organisms die in the BWE area or in further transport after ballast water uptake from the next passing ship? (5) Will the proposed BWE areas be affected by harmful aquatic organisms, including harmful algal blooms?

- **Environmental conditions –** (6) Are protected areas/environments affected by discharges of alien organisms in the proposed BWE areas? (7) Are protected areas/environments affected by discharges of pollutants or increased nutrient concentration in the proposed BWE areas?

- **Important assets –** (8) Are important assets, sutch as fisheries/spawning areas /nursery grounds affected by BWE in the proposed areas?

Following guidelines from the G14 (§ 7.2.4 and § 7.2.5) should also be taken under consideration:

- Proposed BWE areas should be situated along the main shipping lanes or as close as possible.
- The exchange procedure of the ballast water in the proposed areas may not jeopardise the safety of the ship or crew.
- The proposed BWE areas should be monitored regularly in accordance with G14 § 11.

METHODOLOGY

Information and data from the Swedish Meteorological and Hydrological Institute (SMHI) are processed and analysed in order to answer some of the questions above.

To assess the Norwegian Trench area, reports and articles were studied (see references).

For information of alien species introduction, Inger Wallentinus and Malin Werner involved in AquAliens were contacted and several reports were studied.

To create scenarios of discharged BW, the SMHI model Seatrack Web was used in the Skagerrak area. For simulations in the northern Norwwegian Trench, Det Norske Veritas was contacted.

RESULTS

The numbered questions are addressed one by one. Most of the results and general descriptions are further described in the appendices. Main methods and data used are also described in the appendices. The main part of the questions regarding important assets, biological and environmental conditions have been answered in Andersson 2007. In this report most answers are similar hence brief answers will be given here, with a recommendation to read further in Andersson 2007. Many of the questions with a biological or environmental angle, were answered by interviewing Inger Wallentinus and Malin Werner, active within the research programme AquAliens.

Maps displaying both of the proposed BWE areas, protected areas and major shipping lanes for the Skagerrak are displayed in figure 1 and the Norwegian Trench in figure 2. Larger maps are found at page 25 and 27.

OCEANOGRAPHIC CONDITIONS

1. Will the discharge of ballast water in the BWE area be transported towards or away from the coast?

BW will be transported towards a coast or protected area. The speed and direction of the surface water depends mainly on the wind and the general surface currents in the marked BWE areas in the Skagerrak and Norwegian Trench.

Map of the Skagerrak area

There is no area in the Skagerrak that is >50 nm from the coast. Within the Swedish economic zone there is an area with depth of >200 m (pink area to the left in figure 1). Based on the G14 recommendations, the area of investigation was set to depths >200 m within the Swedish economic zone.

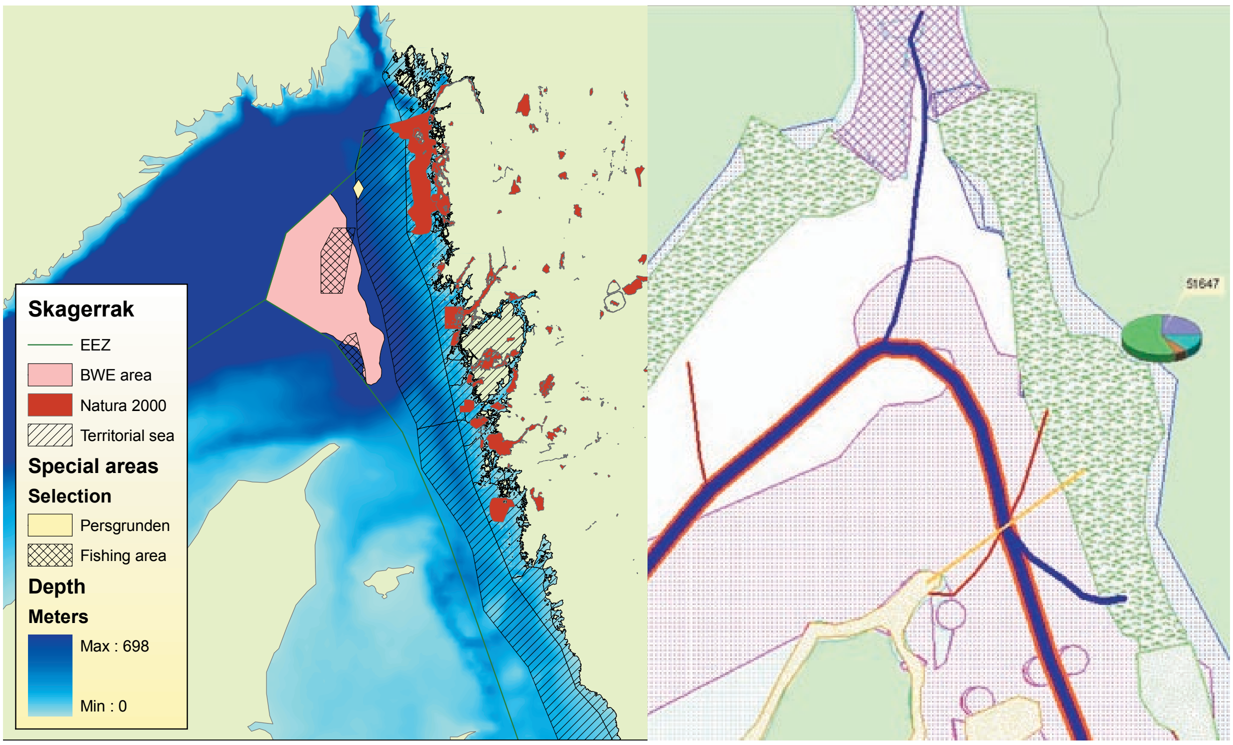


Figure 1. Map of the Skagerrak with BWE area of interest displayed to the left (pink area), together with protected areas along the Swedish coast and fishing areas within the BWE area. To the right is a map over the general shipping lanes (source: MARIS viewer).

The 200 m depth curve runs roughly rather parallel to the Swedish coastline and the distance to the coast is about 20 nm. Natura 2000 areas extend offshore 5 to 10 nm along most of the Swedish Skagerrak coast.

The distance between the 200 m depth curve and the Natura 2000 areas are 10 to 15 nm. There is also an area besides the Natura 2000 areas that is marked as a High Valued Area at Persgrunden. The distance to from the possible BWE area to Persgrunden is about 5 to 10 nm. There are additionalprotected areas along both the Norwegian and Danish coasts, although these are not marked on the maps. Two fishing areas are also marked on the map. There are several more fishing areas in the Swedish territorial sea. Information of the Natura 200 areas and other special areas come from the county administrative board in Västra Götaland.

Map of the Norwegian Trench area

The area of interest in the Norwegian Trench is shown in figure 2. Depth is displayed in different colours with the 200 m depth level marked in red. The hatched area marks areas within 50 nm distance of the coast. There are three orange dots in the northern Norwegian Trench, marking the chosen outlet areas.

South of the three orange dots is a very slim section of >200 m depth and >50 nm from the coast. Modelled figures of the currents in this area are included, although the area is too small to designate as a BWE area.

Main surface currents in the Skagerrak

A large amount, if not most of the water flowing into the North Sea, passes through the Skagerrak with a mean cyclonic (counter clockwise) circulation, before leaving along the Norwegian coast in the Norwegian Coastal Current.

The surface currents in the Skagerrak are complex compositions of current systems, wind, inertial oscillations and tides, though there is a general surface current pattern in the Skagerrak (figure 3). The main surface currents are the Jutland Coastal Current, the Baltic Current and the Norwegian Costal Current.

The Jutland Coastal Current is situated north and northwest of the Danish coast. In the Skagerrak, the main directions are easterly and westerly, with eastward dominating. As the eastward flowing Jutland Coastal Current passes the northern tip of Denmark, the current divides into a northward and a southward flowing current. The main part of the Jutland Coastal Current turns north along the Swedish coast where it eventually mixes with the Baltic and the Norwegian Coastal Currents.

The Baltic Current is the northward flowing surface water, mainly originating from the Baltic Proper. The northward Baltic Current is topographically steered by the Swedish coastline. As a result, the main part of the Baltic Current is situated along the Swedish coast. The phenomenon is obvious for the Jutlandic and Norwegian Coastal Currents.

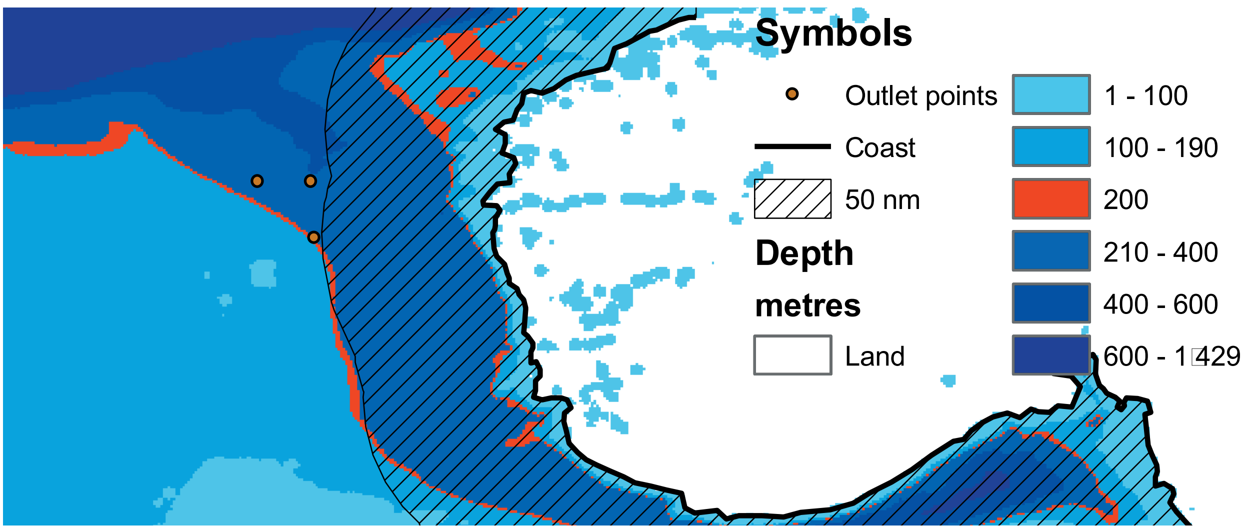


Figure 2. Map of the Norwegian Trench with BWE area of interest displayed as three orange dots in the northern Trench. The hatched area display the 50 nm distance from the coast.

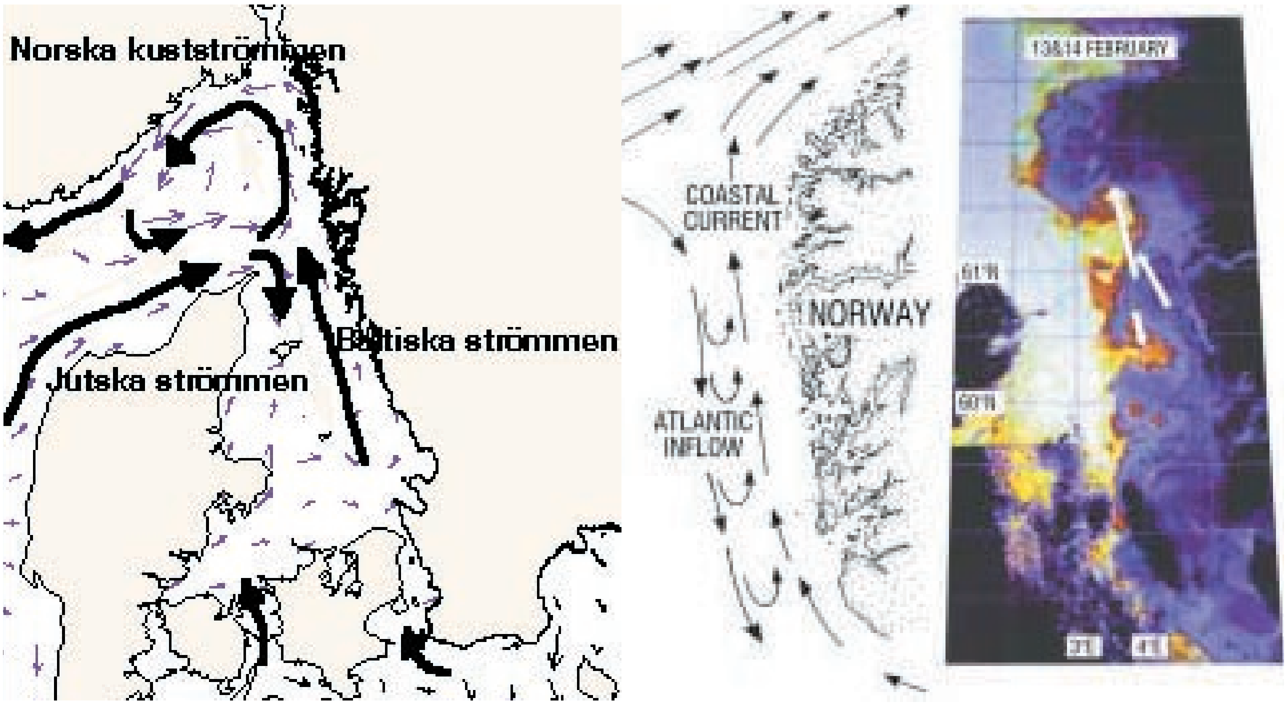


Figure 3. Left: General surface currents of the Skagerrak. Right: An infrared image of a part of the Norwegian Coastal Current. Yellow represents Atlantic water, dark blue represents coastal water. Clouds appear as black areas over the ocean. White arrows are current vectors. The meandering patterns are frequent features in the current. Middle: A sketch of the satellite image.

Both the Jutland and the Baltic Currents join the westward flowing Norwegian Coastal Current. This current flows from the north-eastern part of the Skagerrak, rounding the western most part of Norway before turning northeast, following the Norwegian coast.

The three main surface current systems in the Skagerrak area create an anticlockwise rotation in the central part of the Skagerrak. The circle is completed by southward flowing water, deflected from the Norwegian Coastal Current.

Main surface currents in the northern Norwegian Trench

The Norwegian Coastal Current flows in an eastward, northward and then northeastern direction along the western Norwegian cost. West of the coastal current is the Atlantic in flow, heading in the opposite direction (figure 3, middle). The main part of the inflowing Atlantic water is at great depth, but some inflowing water is situated closer to the surface.

Along the Norwegian Coastal Current, in the frontal zone between the different water masses, large meandering shapes (eddies) in the water are common features. The eddies are transient and very energetic (typically 50 km in diameter and 200 m in depth, with a maximum current speed of about 2 m/s).

Modelled transports in the Skagerrak

The flow field was taken from SMHIs operational oceanographic model for the Baltic Sea (HIROMB) with a horizontal resolution of three nautical miles. To simulate BW discharges, the oil drift forecast model Seatrack Web was used. The particles were released and transported by the currents at 6 meters depth. Since the Skagerrak is an area with several current systems with different densities, discharge simulations were also produced for at a depth of 20 metres.

During the simulation, particles representing the BW discharge were released every 24 hours at 11 locations in the proposed discharge area in the Skagerrak. Particles are only “active“ during 30 days and then disregarded. The following statistical data was calculated after each run:

1. the maximum relative frequency of arrival of the particles to different grid cells in the underlying HIROMB domain,
2. the mean drift time of the particles and
3. the shortest drift time.

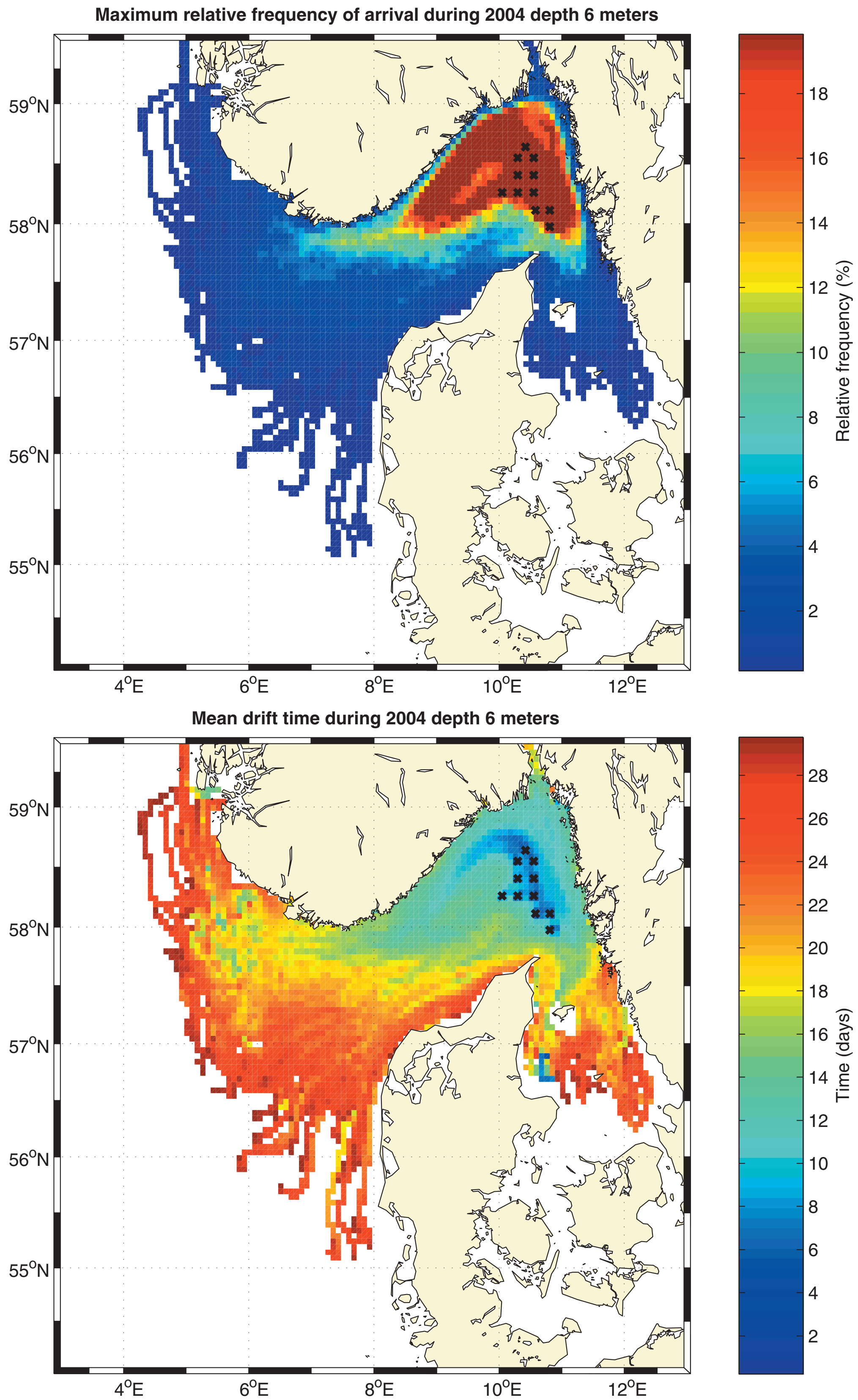
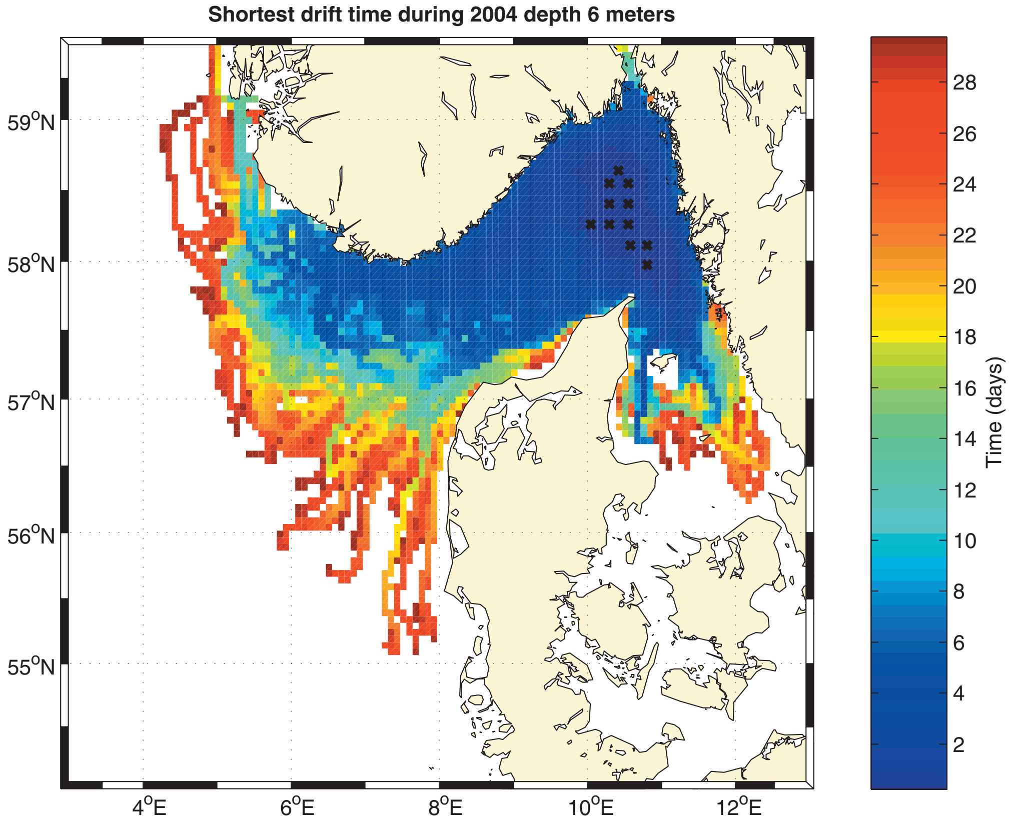


Figure 4a-c. Maximum relative frequency (a-top), mean (b-bottom) and shortest drift time (c-top at next page) at 6 m depth in 2004.



The maximum relative frequency of arrival should be interpreted as the maximum probability that a BW discharge occurring somewhere in the proposed discharge area will arrive to a certain grid cell within 30 days.

Figure 4a-c show the maximum relative frequency of arrival, mean drift time and shortest drift time for 2004 at 6 m depth. The black crosses mark the 11 discharge points. Close to the discharge points the probability approaches 100 % since all discharged particles must arrive to those cells. However, the probability decreases rapidly with increasing distance from the discharge points.

The maximum relative frequency of arrival presented in the figures is calculated per grid cell and not per unit area. This implies that the absolute values of the frequencies depend on the size of the grid cells.

General remarks:

- Cyclonic current patterns are evident in the central Skagerrak.
- The Skagerrak is an area with strong currents. The particles cover a vast area within one month and can reach the Swedish coast within a few days.
- Some particles enter the Kattegat and some particles are directly transported towards the west, but the main part is transported in a cyclonic path and eventually ends up in the Norwegian Coastal Current.

Comparing the 6 metre depth to the 20 metre depth:

- Generally the 6 metre depth particles reach further.

Comparing 2002 to 2004:

- At the depth of 20 metres, there is no major difference in either the one point or 11 point discharges.
- At the depth of 6 metres, there are more particles caught in the Norwegian Coastal Current in 2002. In 2004 the particles extend further south, towards Denmark.

On the basis of the simulations it is concluded that the discharges could be transported over large areas during the time period of one month and would reach the entire Skagerrak area. Most parts of the Skagerrak coastal zone are reached within a week. The probability that a BW discharge will reach the nearby Natura 2000 areas is high. The shortest drift time to the protected areas along the Swedish coast can be reached in only a few days (figures 4a-c and table 1).

Table 1. Approximation of Maximum relative frequency of arrival, mean drift time and shortest drift time to the Natura 2000 areas along the Swedish coast.

	2002				2004			
	6 metres		20 metres		6 metres		20 metres	
	1 point	11 points	1 point	11 points	1 point	11 points	1 point	11 points
Maximum relative frequency	0-6 %	0-12 %	0-4 %	0-12 %	0-12 %	0-20 %	0-4 %	0-12 %
Mean drift time (days)	8-12	12	14	14	14-18	8-12	14-20	10-18
Shortest drift time (days)	0-6	0-6	8-14	0-6	0-8	0-6	8-14	0-6

Modelled transports in the Norwegian Trench

Det Norske Veritas (DNV) was contacted to perform similar simulations for the northern Norwegian Trench with the oil drift model OILTRAJ (DNV, 1994). Statistical drift simulations of passive tracers in 3 positions between Shetland and Norway has been performed:

Position 1	61 º 18,0' N	02 º 30,0' E
Position 2	61 º 18,0 N	03 º 01,0' E
Position 3	60 º 45,0 N	03 º 03,0' E

The model calculates statistical parameters such as hit probability and drift time (similar to the Seatrack Web maximum relative frequency, mean and shortest drift time).

The horizontal grid resolution is 10 x 10 km. 3600 different wind simulations are performed, with 1 tracer released every time step (=1 hour) through the release duration (24 hours). Each tracer is followed in 30 days or until the tracer hits the coast.

In figure 5 the hit probability, average and minimum drift time for the whole year is shown. The figures show the influence area where the hit probability is greater than or equal to 5%. Only discharges from position 3 is displayed here. Results from the ramaining two are found in appendix 4.

For position 3 the shortest drift time to land is 2,6 days (in January). The total stranding probability is 57,2 % i.e. 2060 of the 3600 simulations reach the coast of Norway (figure 5).

Seatrack Web

There is a slim area between the Skagerrak and the northern Norwegian Trench that is > 50 nm from the coast and > 200 metres of depth. Seatrack Web reaches this area hence there are a few extra simulations (figure 6). This "middle" area is small and very slim, but it is interesting to see the transport of particles in this area. Within 30 days, the particles do not reach the Skagerrak, but are quickly (less than a week) transported towards the Norwegian coast. The modelled results from Seatrack Web and DNV are in agreement.

Calculation of transports

The surface water is affected by wind as well as the main current systems. Since the direction of the wind is dominated by south-westerly to westerly winds, that transports the surface waters towards the Swedish coast in the Skagerrak and the Norwegian coast in the northern Norwegian Trench Transport due to wind has been calculated.

In Andersson 2007, the calculations of speed and direction of the surface current due to wind forcing, were described. Since the same physics applies in the Skagerrak and the North Sea, the reader is referred to Andersson 2007 for the methodology. Some of the results are repeted here.

To transport the upper 5 metres of water with a wind induced surface current a distance of 10 nm (minimum distance from the Skagerrak BWE area), it takes:

- 5.2 days with a 5 m/s wind speed and
- 1.8 days with a 15 m/s wind speed.

Comparing the calculations to the modelled shortest drift times, the results are similar.

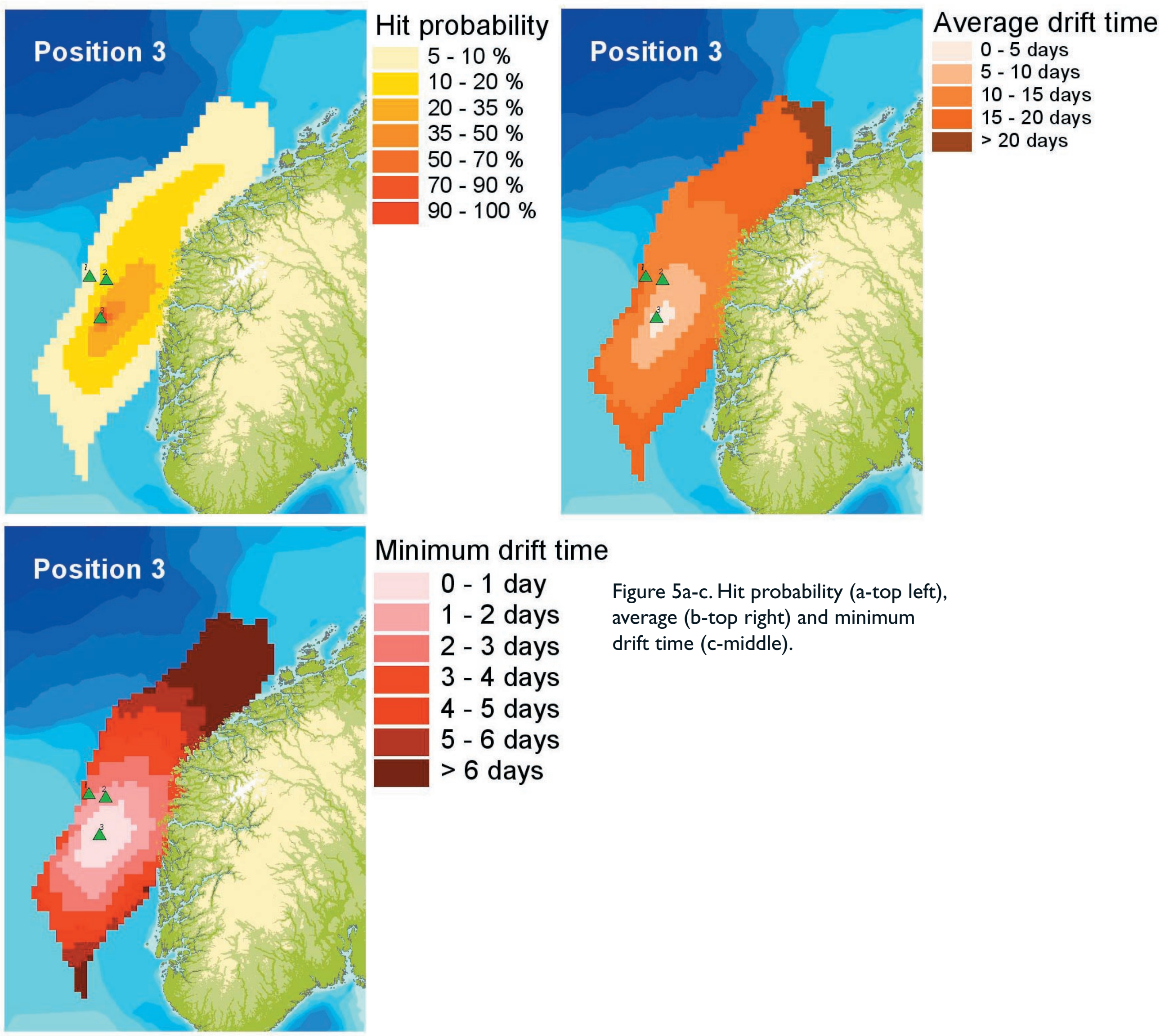


Figure 5a-c. Hit probability (a-top left), average (b-top right) and minimum drift time (c-middle).

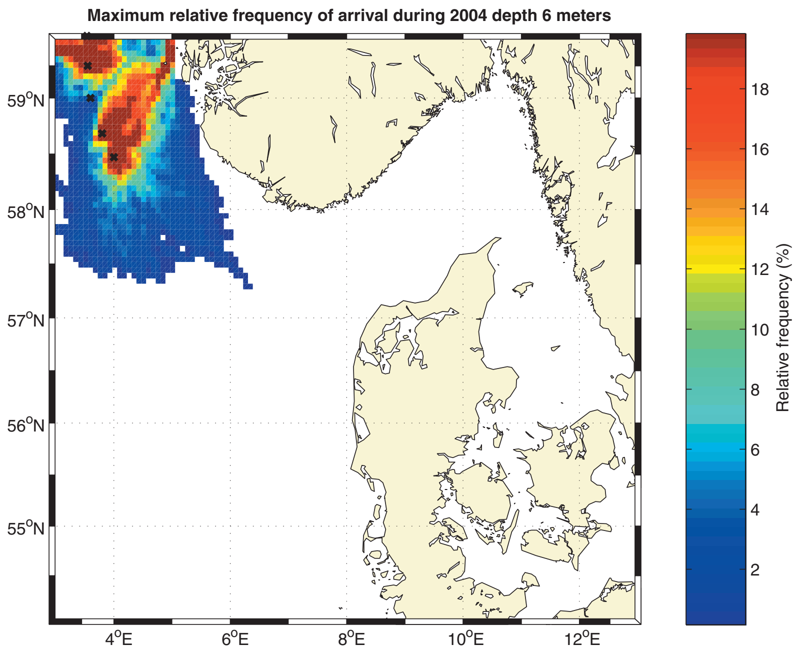


Figure 6. Maximum relative frequency of arrival for five outlet points in the middle of the Norweigan Trench, 2004 at 6 m depth.

2. Will the organisms discharged with the ballast water circulate horizontally in the surface waters and by that, be present for ballast water uptake when the next ship is passing?

Most probably, the uptake of BW in the BWE area will be comprised of previously discharged BW, but at a low concentration.

Figure 4a shows the maximum relative frequency of arrival for 2004 at 6 m depth. In the figure, the horizontal circulation of the surface water in the central Skagerrak, where the BWE area is located, is obvious.

Large meanders and eddies in the water along the Norwegian Coastal Current are common features. When present, the eddies horizontally recirculate discharged water to the BWE area. Otherwise, the Norwegian Coastal Current transports the water towards and along the Norwegian coast, not recirculating the water to the BWE area.

The general current systems and winds dominate the paths of the discharged water. In the Skagerrak, there are many ships passing during one day which means that the currents may not completely transport the BW away from the BWE area before other ships enter the area, to take up BW. Mixing of the discharged water means that the next ships uptake will consist of previously discharged BW, diluted with local water. When discharged water is transported out of the BWE area, the BW concentration will decrease day by day and when horizontally recirculated into the BWE area, the concentration is very low.

A rough estimate of the risk of possible uptake by the next ship in the southern Baltic Proper was made in Andersson 2007. An approximation for the areas in this report has not been made. The same approximations and assumptions can be used.

The general results were that the surface waters within the BWE area would consist of diluted discharged BW, at low concentrations.

A factor concerning the concentration is that normally in a major shipping lane, the ships tend to follow similar routes, markedly increasing the risk of BW uptake at higher concentrations.

However, the concentration of the organisms in the BW is not of major importance (Leppäkoski & Gollasch 2006, Dragsund et. al 2005), although sometimes the new organisms can survive and reproduce even at low starting numbers.

3. What is the vertical circulation?

The vertical circulation at the stations chosen to represent the BWE area is not deep.

Due to the large supply of brackish water from the Baltic and river outlets to the Skagerrak and the Kattegat, there is a strong salinity gradient high up in the water column.

The stronger the stratification, the harder it is for the mixing processes to mix the top layer with the water beneath. In the Skagerrak, there is also a seasonal thermocline during summer. During autumn, cooling of the surface and increased mixing due to wind results in more homogenous surface layer temperatures. There remains a stable perennial halocline at 10-20 metres depth (figure 7).

Observations from the Norwegian Trench BWE area are not presented here. However, the Norwegian Trench region is strongly influenced by fresh water input and, due to the low salinity in the upper layer, has a stable stratification all year round with a perennial halocline at about 50 meters (figure 8) (OSPAR Quality Status Report 2000).

Wind is the dominating factor mixing the surface layer to the lesser of either the Ekman length (the depth of unrestricted wind induced mixing) or the pycnocline depth (appendix 3). Waves and turbulence from general currents also mix the water.

Only with very low wind speeds is the Ekman length less than the pycnocline depth in the Skagerrak, hence the pycnocline depth is the main mixing depth.

In the Northern Norwegian Trench, the pycnocline is deeper, hence the wind regulates the mixing depth. At wind speeds of 20 m/s or more, the pycnocline restricts deeper mixing.

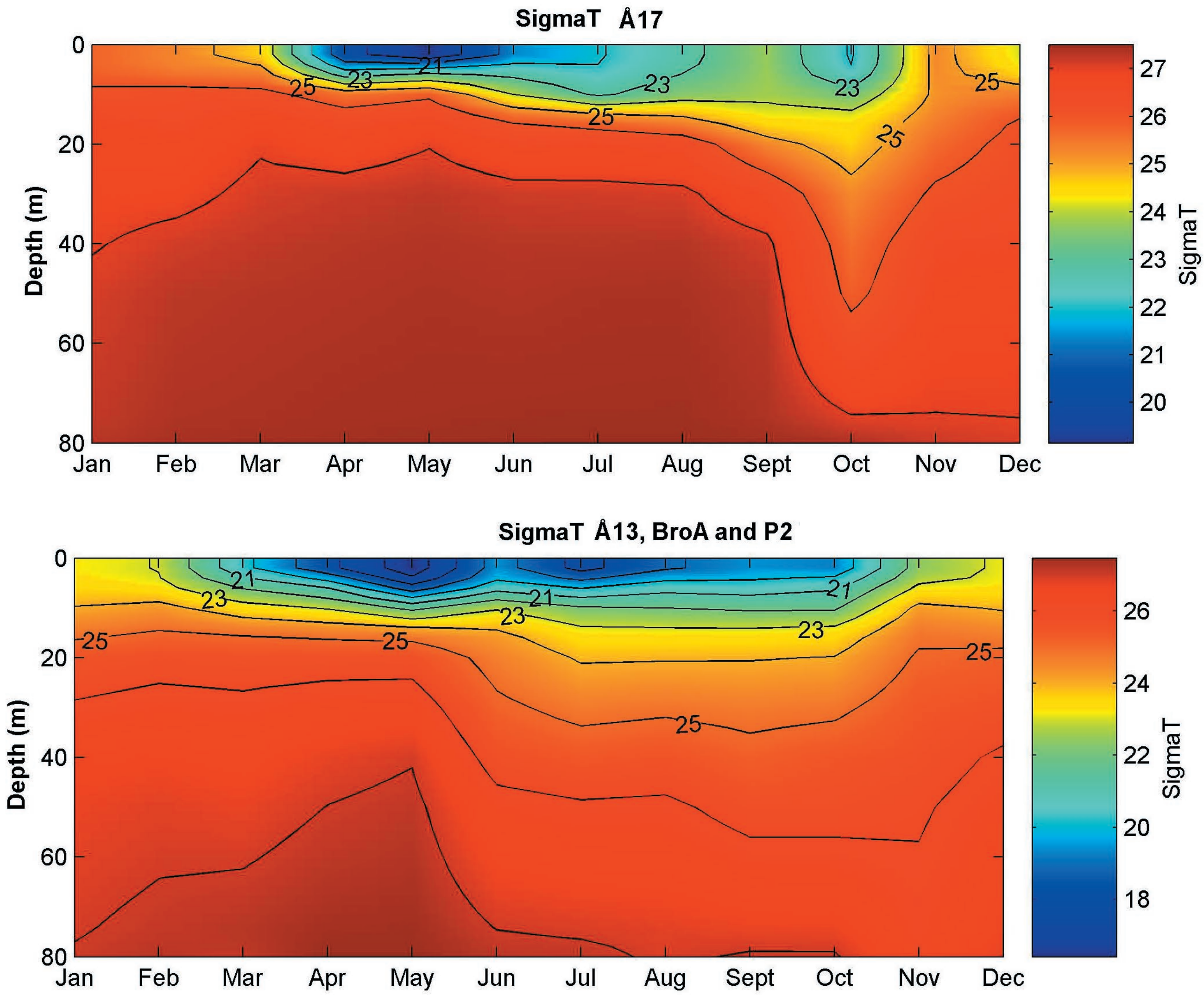


Figure 7. Monthly mean values 1994 to 2006 for density as isoplots for Å17 (top) and Å13, BroA and P2 (bottom).

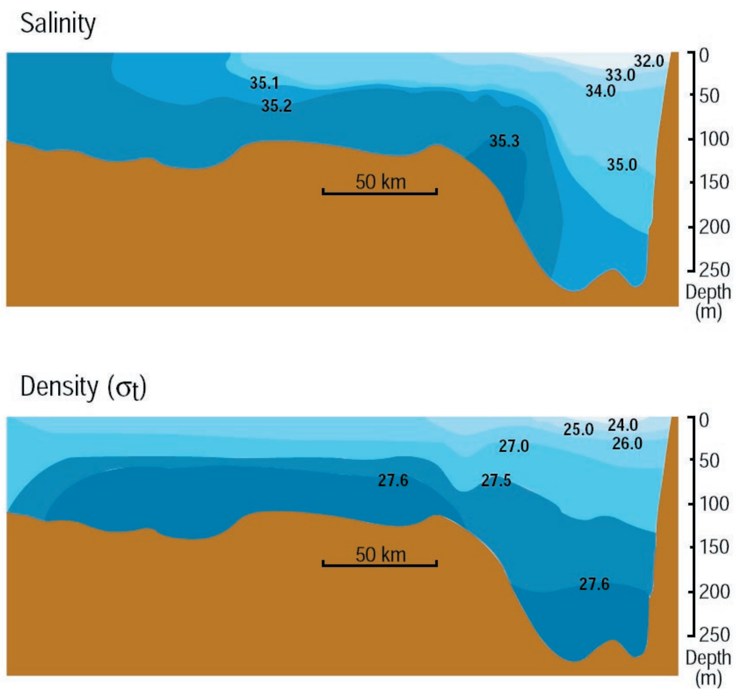


Figure 8. Mean summer vertical salinity and density sections between Norway and Scotland along the 57 17' N. Source: OSPAR Quality Status Report 2000.

BIOLOGICAL CONDITIONS

The remaining questions were addressed in Andersson (2007) and for most part, the answers are the same. A brief summary of the answers from the previous report is presented, with a recommendation to read further in Andersson 2007. Inger Wallentinus and Malin Werner (AquAliens) were then interviewed for information of species introductions and introduction through Ballast water.

4. Will the discharged organisms die in the BWE area or in further transport after ballast water uptake from the next passing ship?

As a rule of thumb, there is always a risk that they may survive. The nutrient level in the Skagerrak is high enough to support major algal blooms. Biological activity is high most of the year. Ergo the nutrient level is not low enough to efficiently reduce the survival rate of the organisms introduced by BW (see appendix 2 and 5).

The salinity ranges from brackish to almost marine in the Skagerrak, hence the BWE area does not provide with strictly marine environment.

There is a wide variety of the BW salinity range in the ballast tanks, ranging from fresh water to marine waters. There is no way to say what specific salinity level will kill the BW organisms since there are many different organisms in the BW. Some can survive in a wide variety of salinities, others cannot. Some organisms may survive a long time even though the new surroundings are not favourable. Other organisms may die very quickly.

5. Will the proposed BWE areas be affected by harmful aquatic organisms, including harmful algal blooms (HABs)?

Yes, if harmful aquatic organisms or HABs are present in the BW, they will affect the area in some way. The BWE area might not be the area that suffers, since the algae or other organisms may need to grow in numbers to constitute for example a harmful algal bloom. While they increase, currents may transport the bloom away from the original BWE area.

If the organisms are harmful, they will affect vulnerable species, through competition, predation or discease.

ENVIRONMENTAL CONDITIONS

6. Are protected areas/ environments affected by discharges of alien organisms in the proposed BWE areas?

What is discharged can be transported to protected areas by currents, if the organisms can live in the pelagic zone. If the organisms are harmful to a single species or to entire ecosystems, there is a clear risk of affecting protected areas.

There are a number of protected areas in the vicinity. The distance to the protected areas is 10 to 15 nm from the proposed BWE area. Surface water from the BWE area can be transported to the protected areas in less than two days, given the appropriate circumstances.

The problem with alien species is that there is no way to predict how well they will behave in a new area. One species can have a successful life in one area, causing major problems, while in a similar area with apparently similar conditions there is hardly any impact. However, there are many examples of negative impacts caused by an alien species in varyied environments, according to Wallentinus (personal communication).

Numerous alien species have been found in the Skagerrak area, BWE being one of the reasons for the introductions. For example *Gracilaria vermiculophylla, Ensis directus, Mnemiopsis leidyi, Verrucophora cf. fascima (Chattonella), Chrysochromulina* spp., *Chaetoceros concavicornis, Karenia Mikimotoi* and *Pfiesteria piscicida* may have been introduced by ships/BWE (http://frammandearter.se).

7. Are protected areas/ environments affected by discharges of pollutants or increased nutrient concentration in the proposed BWE areas?

Discharged pollutants normally affect the protected areas. A possible increase of nutrients in the surface waters, due to BW discharge, may increase the bloom capacity of the next bloom event or change the content of a normal bloom situation. A larger bloom can in turn lead to larger amounts of detritus sinking to the bottom, consuming oxygen when decomposing, hence decreasing the oxygen level at the bottom. It is however unlikely that BW will markedly influence the surface nutrient level, according to Wallentinus (personal communication) more than other nutrient sources from upwelling, land runoff and atmospheric deposition.

The Skagerrak is a potential eutrophication problem area. The coastal areas are problem areas hence already suffer suffer ecological stress, making it easier for invading species to become established/HABs to occur (Håkansson 2007).

IMPORTANT ASSETS

8. Are important assets, sutch as fisheries/spawning areas/nursery grounds affected by BWE in the proposed areas?

This depends on the content of the BW. BW does not have to be harmful, but if the BW contains fish parasites or organisms harmful to for example mussels, important assets like fish and mussel farms can be severely affected. Also competing or predatory species may cause harm, especially in spawning areas of fish or on benthic native species.

The effect depends on many parameters, for example: where the BW comes from, what is the environment like there, what bio-region is it, the survival skills of the organisms in the new area and during the previous transport, the stress tolerance of the organism and what concentration of the organisms are there in the BW.

ADDITIONAL GUIDELINES FROM G14

Proposed BWE areas should be situated along or near main shipping lanes. In the Skagerrak this is the case, but the area is very small and the distance to the nearest coast from the centre of the Skagerrak is about 40 nm. In the northern Norwegian Trench, there is no major shipping lane nearby.

The exchange procedure of the BWE may not jeopardise the safety of the ship or crew. In the Skagerrak, there are frequent storms in November to January and March. At some occasions the significant wave height can exceed 7 metres, though for larger ships this may not cause major safety concerns. However, in the northern Norwegian Trench BWE area of interest, the wave heights of the estimated 50-year extreme maximum are more than 30 metres. That constitutes high risk in the terms of safety on board most ships (appendix 7).

The proposed BWE area should be monitored regularly. In the Skagerrak, SMHI monitors the area on a monthly basis. SMHI does not monitor the remaining Northern Trench area. However, it is likely that the area is monitored by Norway.

DISCUSSION & CONCLUSIONS

In this report, investigations were made to find out if there are areas with suitable environments for ballast water exchange in accordance to the IMO Ballast Water Convention. Suitable conditions may be areas of certain depths (preferably >200 metres), salinities or other conditions that can effectively kill organisms from the ballast water and circulation patterns such that they do not spread to the coast or to protected areas.

Oceanographic conditions

Discharged ballst water in the BWE areas will be transported towards a coast or protected area. The main distance between the BWE area and the Natura 2000 areas are 10 to 15 nm.

A large amount, if not most of the water flowing into the North Sea, passes through the Skagerrak with a mean cyclonic circulation, before leaving along the Norwegian coast in the Norwegian Coastal Current.

The instantanious surface currents in the Skagerrak are complex, but there is a general large scale circulation pattern. The main surface currents are the Jutland Coastal Current, the Baltic Current and the Norwegian Coastal Current.

The northward Baltic Current tends to turn slightly to the east, due to the Coriolis force, but the Swedish coastline prevents the deflection. As a result, the main part of the Baltic Current is situated along the Swedish coast. This topographic steering is obvious for the Jutland and Norwegian Coastal Currents. A southward deflection of the Norwegian Coastal Current in the Skagerrak, completes the cyclonic circle, which is the dominant feature in the Skagerrak.

On the basis of the simulations it is concluded that there are strong currents in both BWE areas and the discharges could be transported over large areas during one month. The entire Skagerrak area would be reached, most parts of the coastal zone within a week. The probability that a BW discharge will reach the nearby Natura 2000 areas is high. The shortest drift time to the protected areas along the Swedish coast can be reached in only a few days.

There is a very high risk that discharged BW in the northern Norwegian Trench will reach the coast and the shortest drift time for that is less than 3 days.

Comparing the calculations to the modelled shortest drift times, the results are similar hence the modelled results are reliable.

The proposed BWE area in the Skagerrak is close to the main shipping lane, but the area is very small and the distance to the nearest coast from the centre of the Skagerrak is about 40 nm. A ship would have to stop or greatly reduce its speed to complete a BWE within the area. In the northern Norwegian Trench, there is no major shipping lane nearby.

The wave climate in the Skagerrak may not cause major concern for the safety for large ships. However, in the northern Norwegian Trench BWE area of interest, the wave heights can definitely be of high risk in the terms of security on board most ships.

Biological conditions

There is always a risk that discharged organisms may survive. If the organisms are harmful, they can or will affect native organisms.

The nutrient level in the BWE areas is high enough to support major algal blooms. The biological activity is high most of the year. Ergo the nutrient level is not low enough to efficiently reduce the survival rate of the organisms introduced by BW.

According to Wallentinus and Leppäkoski & Gollasch, usually trans-Atlantic ships and those arriving from very far away have had the possibility to conduct a BWE in suitable areas. The high risk ships are mainly European ships, not having suitable areas along the route. Despite this, the most important donor area for invasive species is the east coast of North America.

If the organisms are planktonic, it does not matter if they are released far from land, since as long as there are nutrients and light or food available, they can survive. The idea of exchanging BW in the middle of the Atlantic is in the hope that the nutrient level is so low that discharged organisms will not survive due to the lack of food and that the organism from there are adapted to live far offshore hence will not thrive in coastal waters. In the proposed BWE areas, nutrients are available most of the year. During spring, the biovolume is at its highest, though there are biological activities (even HABs), mainly to the end of the year.

Another risk reducing measure is a large salinity difference between donor and recipient waters. However, there is also no way to say what specific salinity level will kill BW organisms since there are many different organisms in the BW. There is always a risk that they may survive.

In the risk evaluation (Leppäkoski & Gollasch), factors like temperature, salinity, time of the transport and route were analysed. In general there is a high risk when the area of origin and recipient is in the same bio-region and low risk when they are not even located next to a similar area (greater distances = lower risk). The greater the difference in salinity between two areas, the lower the risk. For the transport time; <3 days gives high risk and >10 days gives low risk. However, that also depends on the organisms, and in general resting stages will probably survive and constitute a high risk for a long time.

Environmental conditions and important assets

The environment at the BWE area or in nearby protected areas can be affected by the BW, but this is dependant on what the BW contains. If the organisms or pollutants are harmful to a single species or to entire ecosystems, there is a clear risk of affecting protected areas. The effect then depends on many parameters, for example: where the BW comes from, what the donor environment is like, from what donor bio-region, the survival skills of the organisms discharged in the new area and during the previous transport, the stress tolerance of the organism and the BW organism concentration.

Organisms discharged with the BW can be transported to protected areas by currents.

Important assets like fish and mussel farms can be gravely affected. Also competing or predatory species may cause harm, especially in spawning areas of fish or on native species on the sea bed. Discharged pollutants affect the protected areas if transported to the area.

Ballast water uptake

Normally in a major shipping lane, ships follow similar paths, markedly increasing the risk of the re-uptake of BW at higher concentrations. Currents cannot transport the discharged BW in the surface waters away quicklyenough from the BWE area before the arrival of the next ship.

Circulation of the central Skagerrak surface waters and eddies in the northern Norwegian Coastal Current increase the risk of ships taking up previously discharged BW. The waters in the BWE areas have strong stratification, which prevents mixing with deep water. In the Skagerrak, the depth of the pycnocline is shallow (10 to 20 meters), resulting in less dilution of the surface waters and hence higher concentration of the discharged BW.

The conclusion is that most probably, the uptake of BW in the BWE areas will be comprised of previously discharged BW, but to a low concentration. However, in many of the referenced texts, concentrations of the organisms are not of major importance. Sometimes the new organisms can survive and reproduce even from low starting numbers.

ACKNOWLEDGEMENTS

Colleagues from SMHI that have contributed to this report are Philip Axe and Bertil Håkansson, who reviewed the report and Ola Nordblom who contributed with the section of the Seatrack model for the Skagerrak area. Philp Axe also contributed with wave statistics.

Anders Rudberg from DNV contributed with the section of the OILTRAJ modelling of the northern Norwegian Trench.

In the previous SMHI Ballast Water report (Andersson, 2007) Inger Wallentinus and Malin Werner (AquAliens) were interviewed for information of species introductions and introduction through Ballast water and also of general effects the organisms in the ballast water can have on the surroundings. Since some of their comments are brought up again in this report, they are acknowledged here.

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Internet:

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http://www.aqualiens.tmbl.gu.se/

Främmande arter i Svenska Hav:
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HELCOM MARIS viewer:
http://62.236.121.189/website/MARIS1/viewer.htm

Länsstyrelsen Västra Götalands Län:
http://www.o.lst.se/o/amnen/Naturvard/Natura+2000/

OSPAR Comission, Quality Status Report 2000 for the North-East Atlantic:
http://www.ospar.org/eng/html/qsr2000/QSR2000welcome3.htm

Bathymetry image:
http://www.fettes.com/Shetland/Northern_Isles/nordic_bathymetry.gif

APPENDICES

APPENDIX I: DESCRIPTION OF BWE AREAS

In the assignment, two areas of interest were mentioned:

- the Skagerrak area, with depth >200 m, distance >50 nm from the coast and within the Swedish economic zone and
- the Norwegian Trench with depth >200 m and distance >50 nm from the coast.

There is no area in the Skagerrak that is >50 nm from the coast.

Within the Swedish economic zone there is an area with depth of >200 m. The 200 m depth curve is almost parallel to the Swedish coastline and the distance to the coast is about 20 nm.

The Swedish economic zone in the Skagerrak is shaped like a triangle, pointing to the middle of the Skagerrak. The distance from the tip of the triangle in the middle of the Skagerrak to the nearest Swedish coast is 40 nm. In the Guidelines on designation of areas for ballast water exchange (G14) from the BWC, it is stated that areas of BWE can still be designated even if the requirements of depth and distance to the coast do not comply.

Based on the G14 recommendations, the area of investigation was set to depths >200 m within the Swedish economic zone. In figure 9, the Skagerrak area of interest is displayed, together with protected areas along the Swedish coast.

There are protected areas along almost the entire Swedish coast of the Skagerrak. Natura 2000 areas are marked in red in the figure 9. The main distance between the 200 m depth curve and the Natura 200 areas are 10 to 15 nm. There is also an area besides the Natura 2000 areas that is marked as a High Valued Area at Persgrunden. The distance to from the possible BWE area to Persgrunden is 5 to 10 nm.

Two fishing areas are also marked on the map is als within the possible BWE area. There are several more fishing areas in the Swedish territorial waters. The territorial waters are displayed as the hatched area along the coast (here the hatched area does NOT mark any specific distance from the coast as in figure 11). The information about protected areas comes from the county administrative board in Västra Götaland and the Swedish National Environmental Protection agency.

There are protected areas along both the Norwegian and Danish coasts, but these are not marked on the maps.

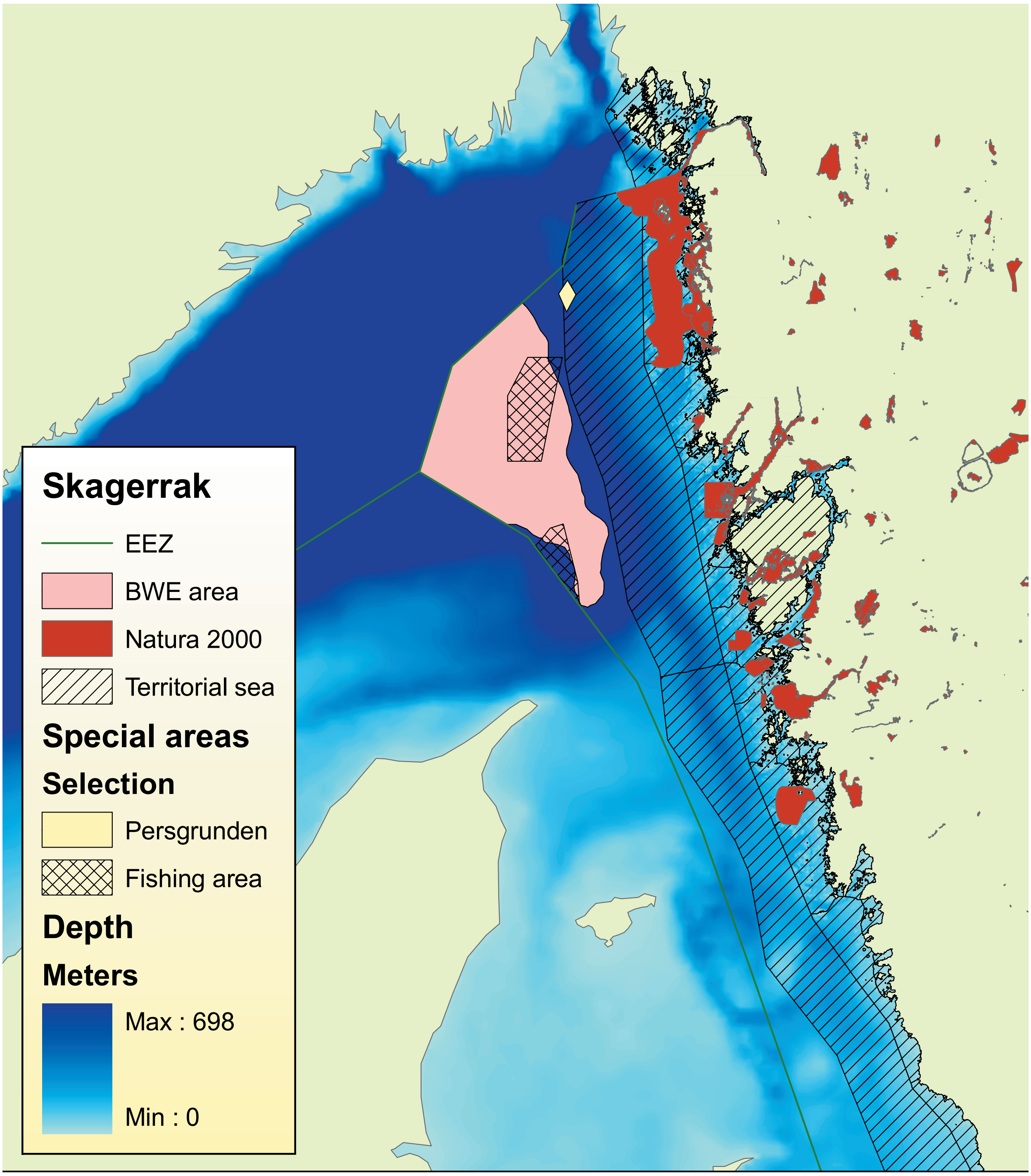


Figure 9. Map of the Skagerrak with BWE area of interest displayed (pink area), together with protected areas along the Swedish coast and fishing areas within the BWE area.

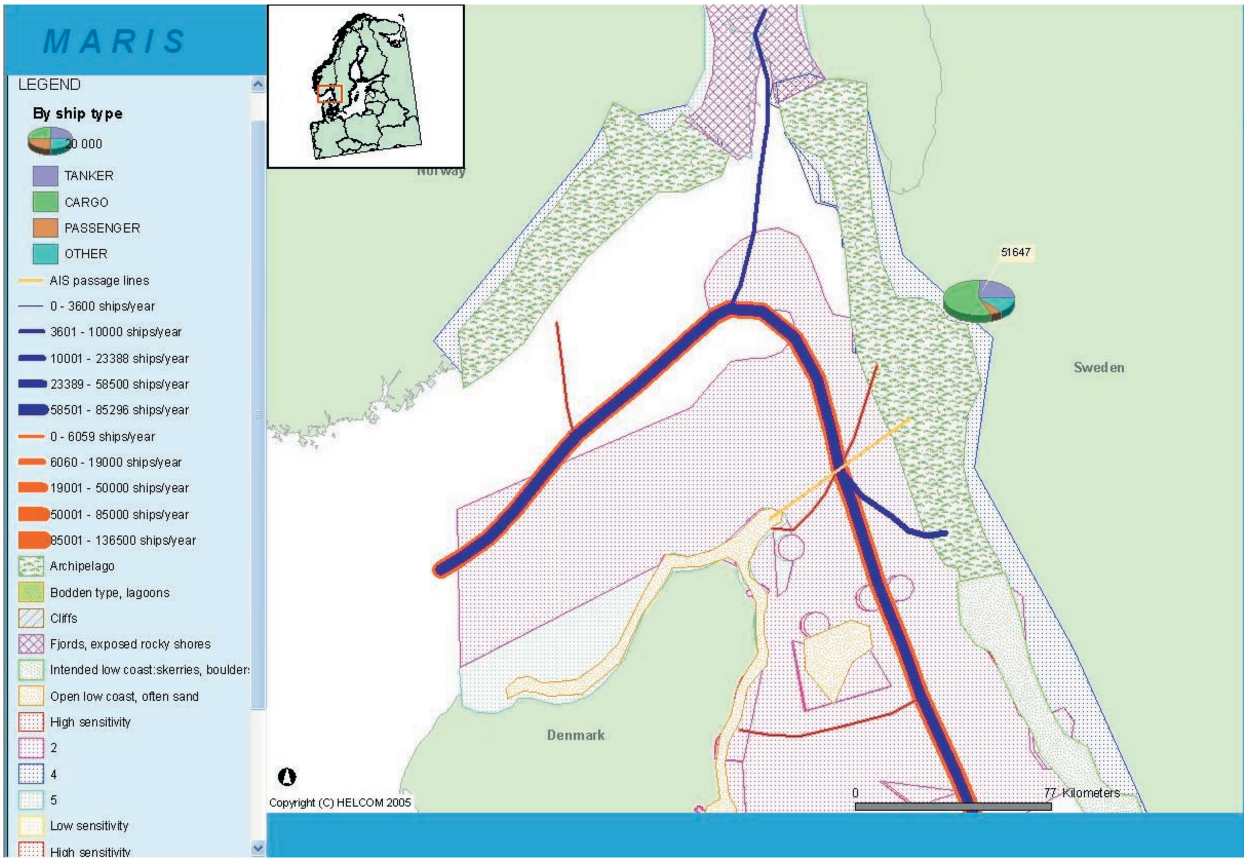


Figure 10. Shipping lanes viewed by the HELCOM MARIS web site viewer.

Shipping lanes in the Skagerrak area are displayed in figure 10 (source: web site MARIS viewer). There are about 140 ships passing between Skagen and the Swedish coast every day and according to the figure 10, the main shipping lane is through or close to the proposed BWE area. More than fifty percent of the ships are cargo ships and about twenty five percent of the ships are tankers (MARIS web site viewer).

The area of interest in the Norwegian Trench is displayed in figure 11. The depth is displayed with the 200 m depth level marked in red. Here, the hatched area marks the 50 nm distance from the coast. There are three orange dots in the northern Norwegian Trench, marking the chosen outlet areas. The easternmost dots are 50 nm from the Norwegian coast.

The main area is the northern Norwegian Trench, but further south is also a slim section of >200 m depth and >50 nm from the coast. It is a very narrow area, so is of no interest to this assignment as a possible BWE area. It is however of interest to display the surface currents in this area to get a general idea of the coupled current systems.

A station map is included (figure 12), where Å17, Å13, Kosterfjord, BroA, Släggö and P2 are shown. These are used for the description of the general hydrography and biology, Väderöarna is used for the wave climate description and Måseskär as the land based wind station.

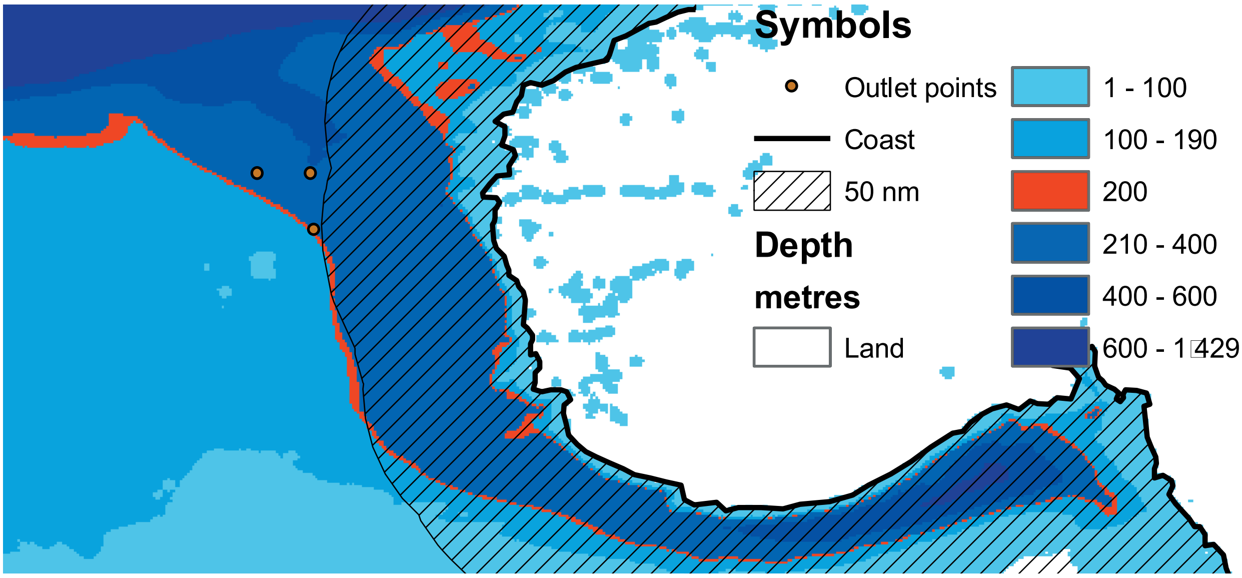


Figure 11. Map of the Norweigan Trench (dark blue area). The three orange dots in the northern Norweigan Trench mark the BWE area of interest. The line-marked area marks the 50 nm distance from the coast.

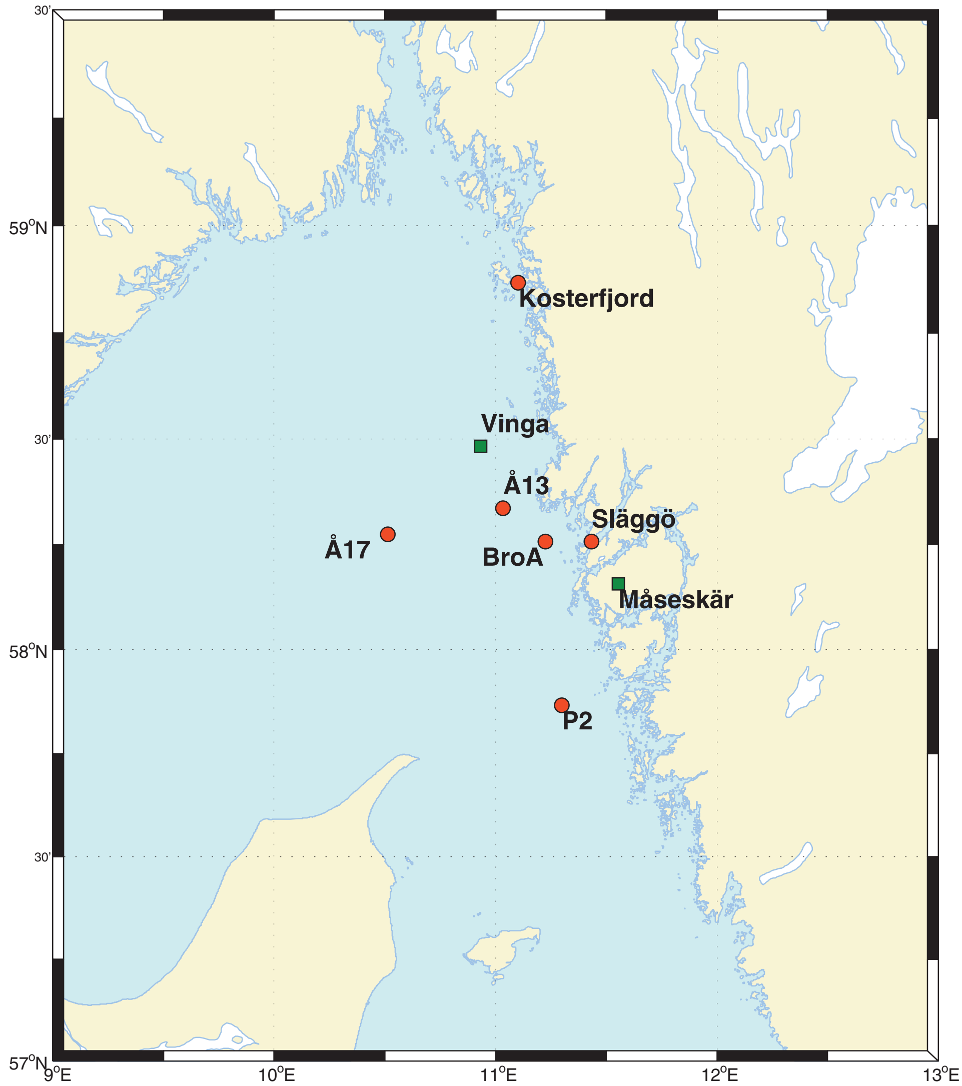


Figure 12. Map of the stations used. Å17, Å13, Kosterfjord, BroA, Släggö and P2 are used for the description of the general hydrography and biology. Väderöarna is used for the wave climate description and Måseskär as the land based wind station.

APPENDIX 2: GENERAL HYDROGRAPHY

The appendix is a general description of the hydrography, bathymetry, circulation, front systems and stratification in the Skagerrak and Norwegian Trench (waves and currents excluded). A mean salinity map for the Baltic Sea has been produced by calculating the mean of the top layer from the HIROMB model data for the year 2003 (figure 19). The surface waters for a number of parameters are displayed by month for the Skagerrak area.

To analyse the general hydrography, the Å17, Å13, BroA and P2 stations were used (figure 12). The monthly mean values between 1994 and 2006 for temperature, salinity and sigmaT in the Skagerrak were compiled to present the change and depth of the pycnocline over the year.

North of the North Sea is the deep Norwegian Sea. The Northn Sea is generally shallow, but there is a deep trench along the Norwegian coast, ending in the even deeper Skagerrak (figure 13).

Due to this topography, large amounts of Atlantic water flow into the area. This, together with the general anticlockwise circulation of the North Sea, causes most of the water in the North Sea to pass through the Skagerrak. Moreover all the water from the Baltic Sea also passes through it and it receives major riverine inputs from both Norway and Sweden.

Increased oxygen consumption in the water and large amounts of contaminants in the sediments are issues of concern. The residence time of the Skagerrak surface water is typically about a month, while the deepest water (500 – 700 m) may be stationary for several years (OSPAR report 2000).

The water of the shallow North Sea consists of a varying mixture of North Atlantic water and freshwater run-off. The salinity and temperature characteristics of different areas are strongly influenced by heat exchange with the atmosphere and local freshwater supply. The deeper waters of the North Sea consist of relatively pure water of Atlantic origin (OSPAR report 2000).

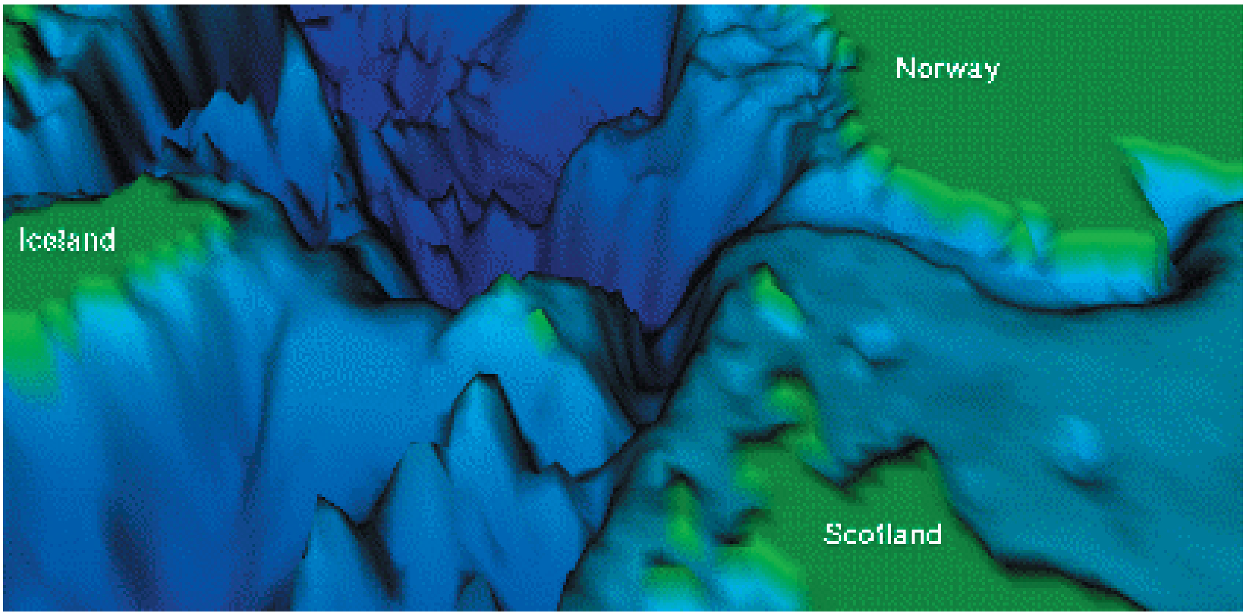


Figure 13. Bathymetry of the deep northern Atlantic and shallower Northern Sea. The Norwegian trench is a deeper trench along the Norwegian coast. Source: http://www.fettes.com/Shetland/Northern_Isles/nordic_bathymetry.gif.

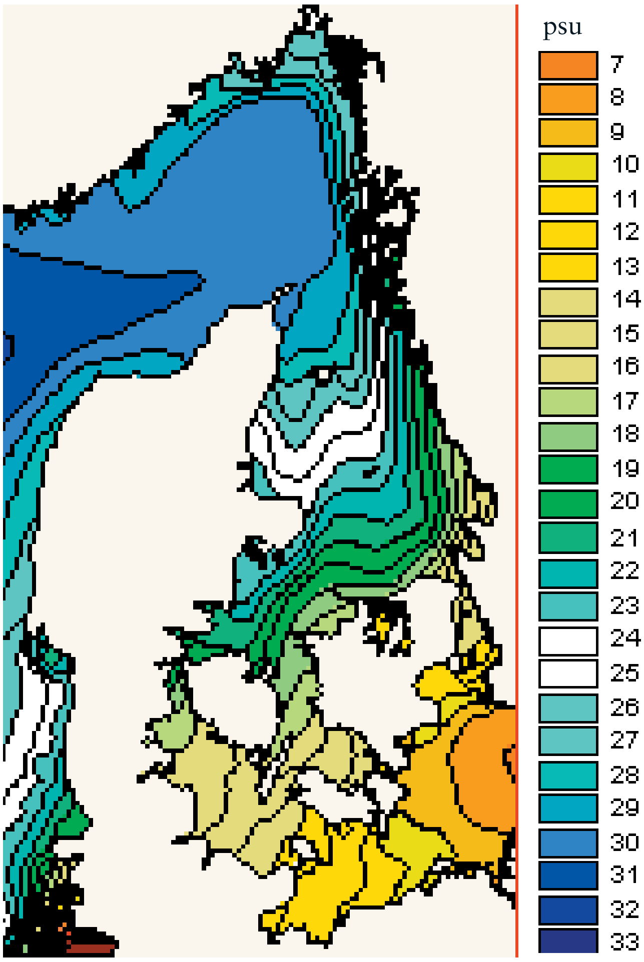


Figure 14. Salinity gradients in the Kattegat and the Skagerrak.

Fronts

Fronts or frontal zones mark the boundaries between water masses. For example, salinity fronts form where low salinity water meets water of a higher salinity. Prominent salinity fronts are the Belt front which separates the outflowing Baltic surface water from the Kattegat surface water, the Skagerrak front separating the Kattegat surface water from the Skagerrak surface water and the front on the offshore side of the Norwegian coastal current. Fronts often have currents, meanders and eddies associated with them. Fronts are important because they may restrict horizontal dispersion and because there is enhanced biological activity in these regions (OSPAR report 2000).

Stratification

The Skagerrak and Norwegian Trench region of the North Sea are strongly influenced by fresh water input, and due to the low salinity in their upper layer, have a stable stratification all year round, though runoff, currents and wind can influence the properties at a station. The deep water in these areas is not mixed with the surface water.

In coastal waters beyond estuaries and fjords, typical salinity ranges are 32 to 34.5, except in the Kattegat and parts of Skagerrak where the influence from the Baltic results in salinities in the ranges 10 – 25 and 25 – 34, respectively (OSPAR Quality Status Report 2000).

Due to the relatively large freshwater supply from the Baltic, there is a horizontal salinity gradient from the southern Kattegat to the northern Skagerrak (figure 14). Every now and then, water from the Kattegat flows into the Baltic Proper, but most of the time there is an outflow from the Baltic. There is also a vertical salinity gradient (pycnocline) that is deeper and sharper in the southern Kattegat than in the Skagerrak.

To estimate the depth of the mixing layers, monthly mean values for temperature, salinity and sigmaT are compiled to present the change and depth of the seasonal and permanent pycnocline over the year. In figure 15, isoplots from Å17 are plotted and in figure 16, Å13, BroA and P2 are plotted. The annual cycles are apparent, as well as the structure of the water with depth. Seasonal thermoclines are developed during summer. During autumn, the surface and deeper water temperatures are evened out.

The features in figure 15 and 16 are quite similar. The permanent halocline at Å17 is sharper and closer to the surface (about 10 metres) than at the coastal stations. There, the permanent halocline extends to slightly deeper waters (about 15-20 metres).

Above the halocline, salinity may vary for several reasons. Coastal stations are more influenced by the Baltic Current so have more consistently low surface salinities. The temperature increase at depth in the summer is more delayed at Å17 than at the coastal stations due to larger interactions with North Sea water. The resulting density structure is a combination of the temperature and salinity, giving the seasonal/permanent pycnocline.

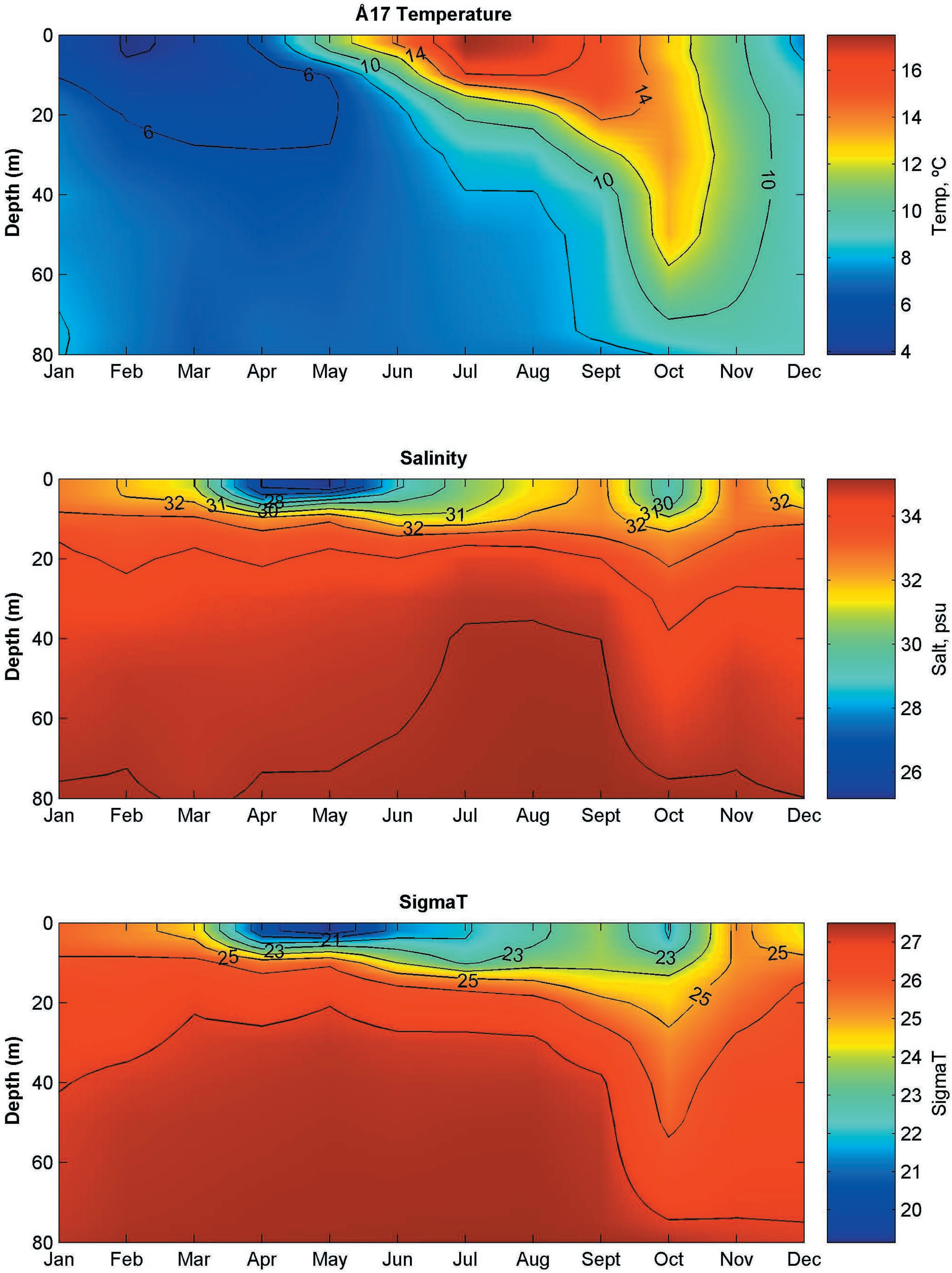


Figure 15. Monthly mean values 1994 to 2006 for temperature, salinity and sigmaT as isoplots for Å17.

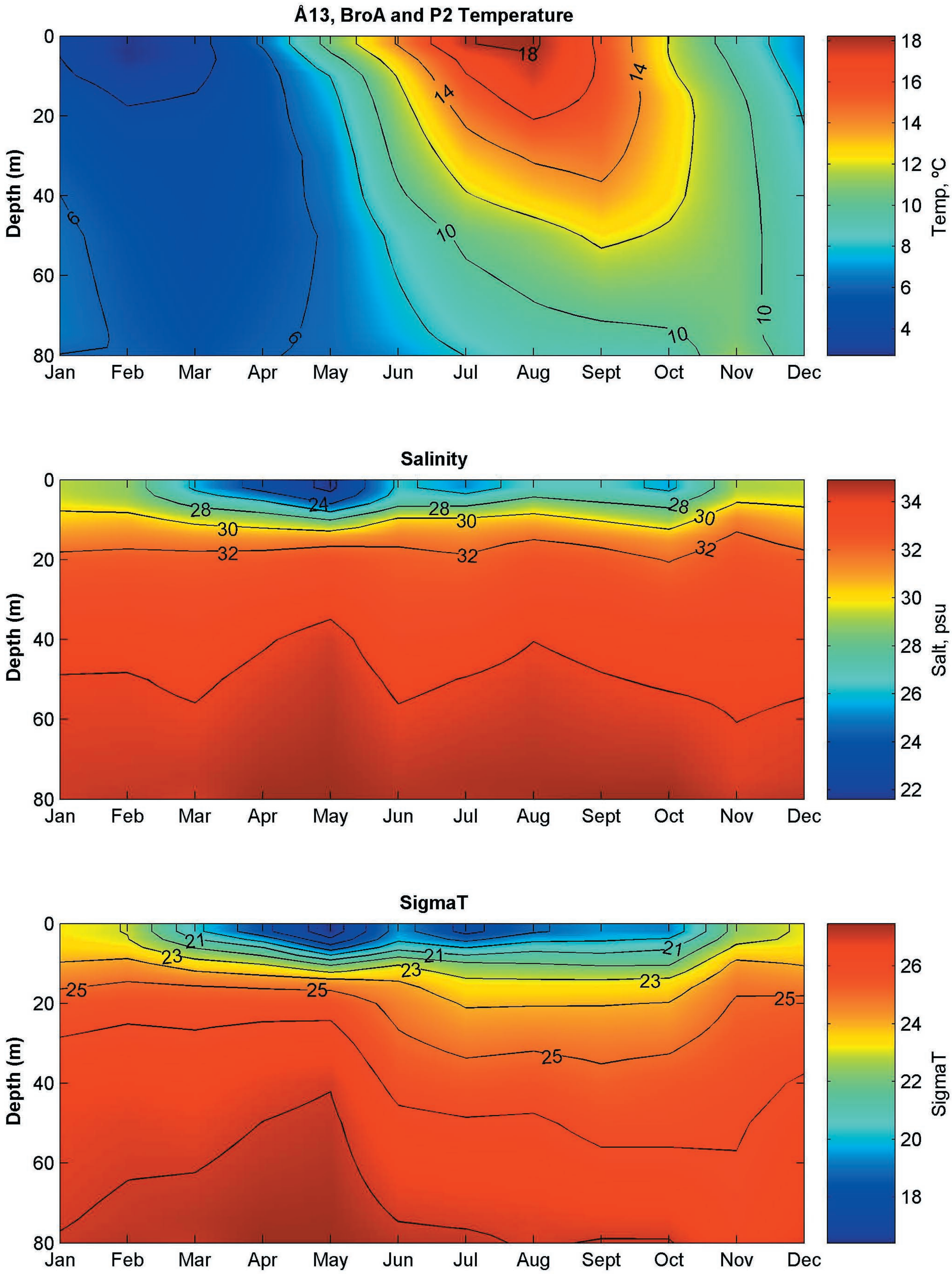


Figure 16. Monthly mean values 1994 to 2006 for temperature, salinity and sigmaT as isoplots for Å13, BroA and P2.

Wind and/or negative buoyancy (increase of surface water density relative to the surrounding water) mixes the surface water with deeper waters, increasing the nutrient level in the surface. How deep the mixing reaches depends on a few factors, but mainly the mixing depth is to the permanent halocline reaching only 10 to 20 metres. During strong winds in late autumn and winter, the pycnocline weakens allowing the mixing can reach further (about 70 metres at Å17 and about 50 metres at the coastal stations). Due to the freshwater supply in the area, there is still a weak pycnocline during winter.

Nutrients and physical parameters in the Skagerrak

In the scatter plots (figure 17), surface values between 1990 and 2006 were used. In the isoplots with monthly values, data between 1994 and 2006 was used. The scatter plots show conditions in the surface waters for a number of parameters, displayed on a monthly basis. The Å17 station is plotted in a different colour to highlight the station in the middle of the Skagerrak compared to the stations closer to the coast.

The stations correlate well with each other, suggesting that they represent the area well. There are distinct seasonal changes in all but a few parameters. The salinity at Å17 is generally higher than the other stations. There are large fluctuations of the surface salinity due to runoff, fresh melting water, wind speed and direction, distance to the coast and thermoclines preventing salinity entrainment from deeper layers. There is no evident seasonal change in Secchi depth and only minor seasonal changes in the TotN and NH_4.

Sea surface temperatures (SST) show a strong yearly cycle. The surface temperature varies from -1.8 degrees in February to above 20 degrees in August.

There is clear evidence of biological activity in O2Sat (oxygen saturation), chlorophyll-a concentration and most of the nutrients, mainly during spring, summer and early autumn (see Appendix 5 for a general biological description). In February to March, there is a peak in the surface chl-a, which leads to an almost complete consumption of NO_3 and reduction of PO_4, TotP and NO_2. Though there are still nutrients enough for the summer and autumn blooms. These waters are clearly rich in nutrients to feed spring, summer and autumn blooms. Further nutrient enrichment may lead to larger blooms.

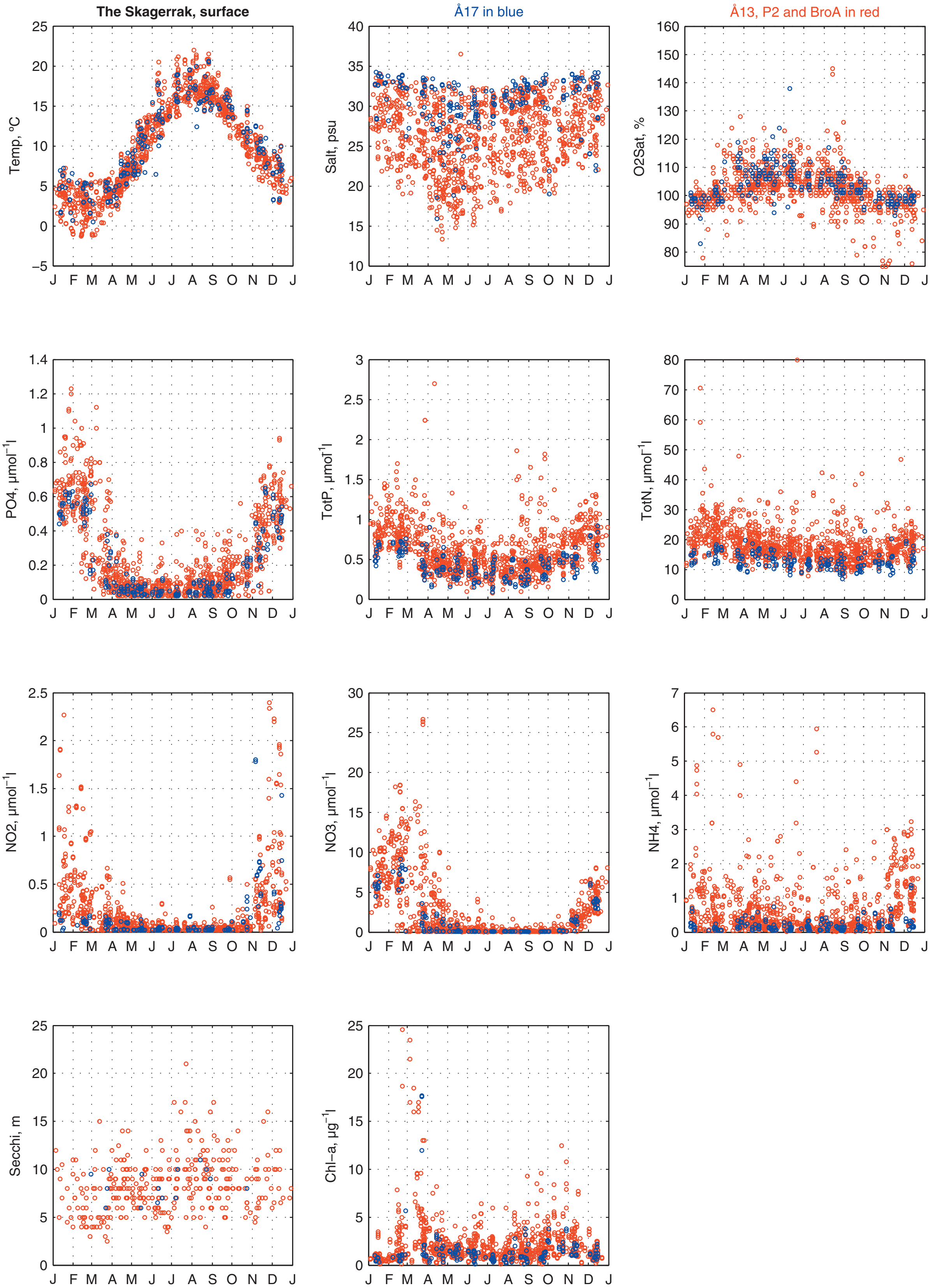


Figure 17. All values between 1990 to 2006 displayed over one year for nutrients, physical parameters and chl-a for Å17, Å13, BroA and P2.

APPENDIX 3: GENERAL SURFACE CURRENTS

This appendix is a general description of the currents in the North Sea, Norwegian Trench and the Skagerrak. A general surface current map for the Baltic Sea has been produced by calculating the mean of the top layer from the HIROMB based on data from the whole of 2003. Surface currents due to wind and tides are described as well as vertical circulation.

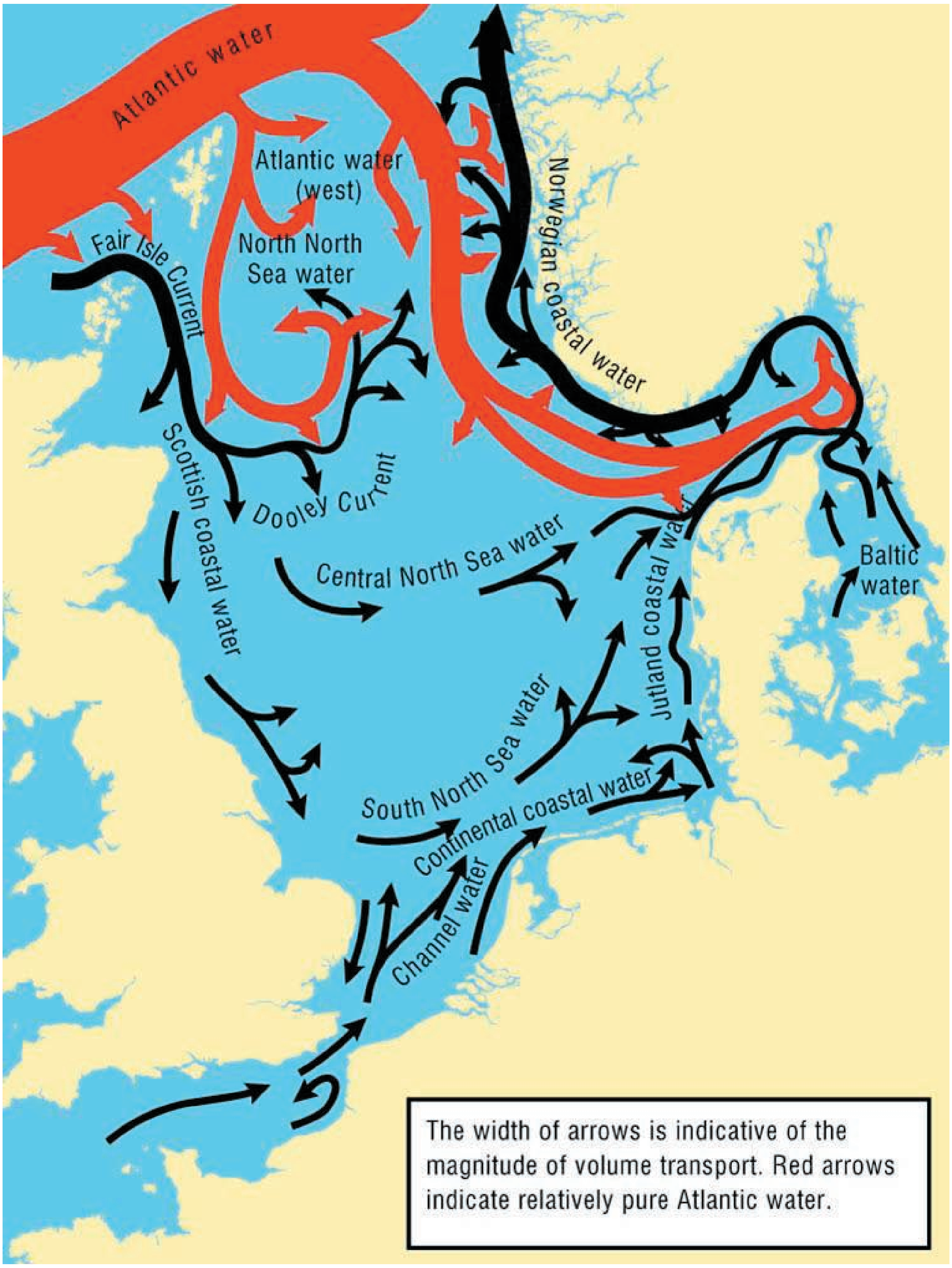


Figure 18. Map of the general currents in the North Sea. Source: OSPAR Quality Status Report 2000.

The North Sea

The information in this subchapter is from the OSPAR Quality Status Report 2000.

The mean currents of the North Sea form a cyclonic circulation (figure 18). The main Atlantic deep water inflow occurs along the western slope of the Norwegian Trench. Considerable inflows also occur east of the Shetland Islands and between Shetland and the Orkney Islands. Less than 10% enters through the Channel. All of these inflows are compensated by an outflow mainly along the Norwegian coast. The circulation can occasionally reverse into an anti cyclonic direction.

Most water in the different inflows from the north-west are steered eastwards to the Norwegian trench. Only a small part flows southward along the coast of Scotland and England.

Most of the inflowing water probably passes through the Skagerrak – with an average cyclonic (counter clockwise) circulation – before leaving along the Norwegian coast. The water in the deepest part of the Skagerrak is renewed by cascades of dense water formed during cold winters over the more shallow parts west of the trench in the northern North Sea.

The Skagerrak

The surface currents in the Skagerrak are complex compositions of general current systems, wind, inertial ocsillation and tides. Though there are many fluctuating components that influence the currents, there is a general surface current pattern in the Skagerrak (figure 19).

The main surface currents are the Jutland Coastal Current, the Baltic Current and the Norwegian Coastal Current.

The Jutland Coastal Current flows along the north-west Danish coast. The current can flow towards any direction, but the main direction is towards the east. As the eastward flowing Jutland Coastal Current passes the northern tip of Denmark, heading towards the Swedish coast, the current divides into a northward and a southward flowing current. The southward part flows into the central Kattegat. The main part of the Jutland Coastal Current turns north along the Swedish coast where it eventually mixes with the Baltic outflow to form the Norwegian Costal Currents.

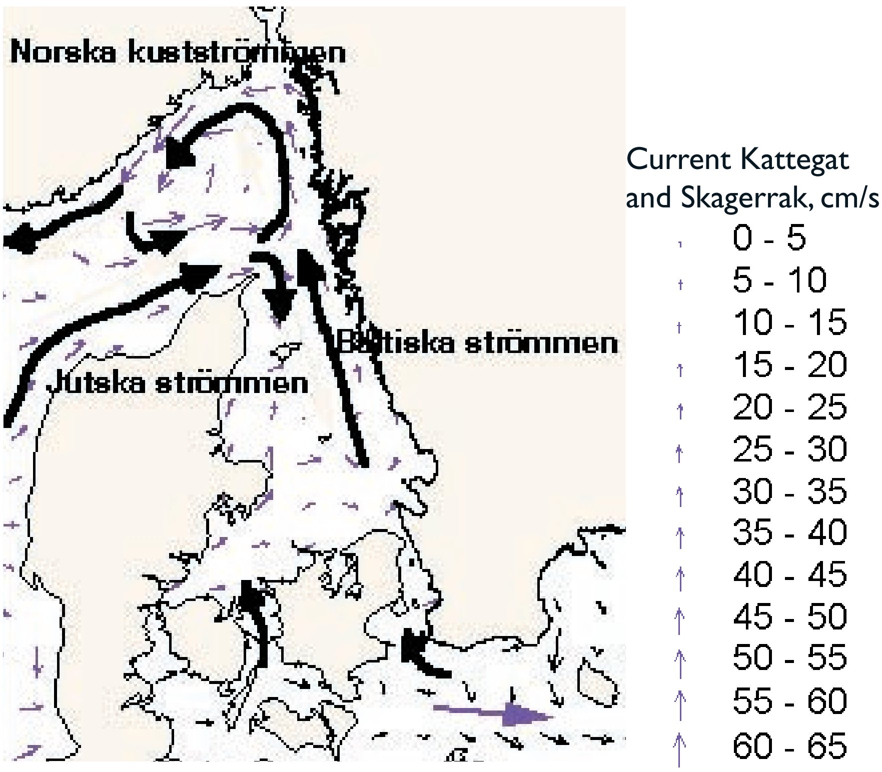


Figure 19. Map of the general currents in the Kattegat and Skagerrak.

The Baltic Current is northward flowing surface water, mainly originating from the Baltic Proper, with water less salty than in the remaining Kattegat and Skagerrak. Water from river discharge along the Swedish coast also joins the Baltic Current.

Due to the freshwater excess in the Baltic, there is a general outflow of water from the Baltic to the Kattegat. The yearly mean volume (1977-2005) of the accumulated flow through the Sound between Sweden and Denmark is about 350 km^3. Occationally, the flow through the Sound reverses towards the south. Then there is no distinct northerly flowing Baltic Current.

The Baltic Current is mainly present as a northward current along the Swedish coast.

If the Baltic Current is weak, there can be a southerly current in the Kattegat and the Jutland Coastal Current then has a larger influence on the Kattegat water. When the Baltic Current is strong, fresh water extends from the Sound up to the Norwegian border. The current is light due to the low salinity of the Baltic outflow, so the heavier Jutland Coastal Current tends to dive beneath the Baltic Current.

Along the Swedish coast, the Baltic Current mixes with the surrounding water. However, there is still a clear salinity signal close to the Swedish coast when the current reaches the Skagerrak. The depth of the fresher layer is about 10-25 meters in the south-eastern open Skagerrak.

Both the Jutland Coastal Current and the Baltic Current join the westward flowing Norwegian Coastal Current. This current flows from the north-eastern part of the Skagerrak, rounding the western most part of Norway to then turn north-east, following the Norwegian coast.

The three main surface current systems in the Skagerrak area create an anticlockwise circulation in the central part of the Skagerrak. The circle is completed by southward flowing water, deflected from the Norwegian Costal Current.

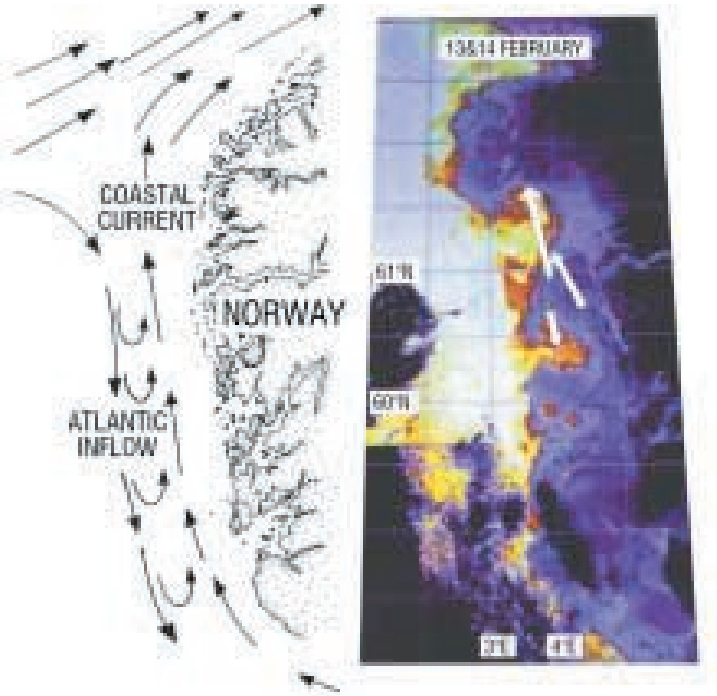


Figure 20. To the right is an infrared image of a part of the Norwegian Costal Current. Yellow represents Atlantic water, dark blue represents coastal water. Clouds appear as black areas over the ocean. White arrows are current vectors. To the left is a sketch of the same area.

The Norwegian Trench

The Norwegian Trench is visible in the bottom topography (figure 11) as the area deeper than 200 metres extending along the west coast of Norway into the Skagerrak.

The Norwegian Coastal Current flows in a northward direction along the western Norwegian cost, as seen in figure 18. West of the coastal current is the Atlantic inflowing water, heading in the opposite direction. The main part of the inflowing Atlantic water is at larger depths, but some of the inflowing water is situated at more shallow levels. The surface water west of the Norwegian Coastal Current can be composed by North Sea water, flowing in any direction.

Along the Norwegian Coastal Current, in the frontal zone between the different water masses, large meanders and eddies are common features (figure 20). The eddies are considered an important cause of the generally observed patchiness of biota and biological processes. The eddies are transient but very energetic (typically 50 km in diameter and 200 m in depth, with a maximum current speed of about 2 m/s). Their origin is uncertain, but they may be generated partly by topography and partly by the pulsating outflow from the Skagerrak (OSPAR Quality Status Report 2000).

Wind induced surface current

The surface water gets affected by the wind and the speed of the wind induced surface current is dependant on the wind speed. Depending on the strength of the wind, the direction of the surface current varies, but is slightly to the right of the direction of the wind. The direction of the wind is dominated by south-westerly to westerly winds.

In Andersson 2007, the calculations of speed and direction of the surface current due to wind forcing, was described. Since the same physics applies in the Skagerrak and the North Sea, the results from the previous report can be applied.

The mean speed and direction of the surface water depends on the wind and the thickness of the surface layer of interest. To transport the upper 5 meters of wind induced surface current a distance of 50 nm, it takes:

- 26 days with a 5 m/s wind speed and
- 9 days with a 15 m/s wind speed.

Inertial oscillations

Due to the rotation of the earth, the Coriolis force deflects water in motion to the right (in the northern hemisphere). If a strong persistent wind sets the surface water in motion, the current will be deflected to the right compared to the wind direction. The direction of the current will be persistent. When the wind relaxes, there is no longer a force that restricts the surface current to further deflect to the right. The result is water slowly spinning in a circular motion, deflecting to the right, until the energy of the motion dies out. The pattern of a tracer in the water is similar to a somewhat stretched spiral.

Tides

Tides also affect the currents in the Skagerrak. The following text, with some additions, originates from the OSPAR Quality Status Report 2000.

Tides in the North Sea result from the gravitational forces of the moon and sun acting on the Atlantic Ocean. The resulting oscillations propagate across the shelf edge, entering the North Sea both across the northern boundary and through the Channel. Semi diurnal tides (two per day) predominate at the latitudes concerned and are further amplified in the North Sea by a degree of resonance with the configuration of the coasts and depth of the sea bed.

Tidal currents are the most energetic feature in the North Sea, mainly in the southern and the western parts, stirring the entire water column. In addition to its predominant oscillatory nature, this cyclonic propagation of tidal energy from the ocean also forces a net residual circulation in the same direction. The mean spring tidal range can be more than 8 metres with associated current speeds of over 5 knots in the southern North Sea. In the Skagerrak, the range is not more than 0.2-0.4 metres and the speed of the tidal current is not more than 0.25 knots.

Along the coasts, tidal currents are oriented parallel to the coast and the exchanges between coastal and offshore waters are limited. In stratified waters, the tides can generate internal waves that propagate along the interface between the two layers. These waves can have important biological effects, as a result of enhanced vertical mixing where such waves break as well as the oscillatory movement of biota into the euphotic zone via the vertical displacements involved.

The western coast of Norway is more influenced by the tide than the Swedish Skagerrak coast, but the effects are also here much smaller than the southern and western parts of the North Sea. For example the tidal range in Trondheim harbour can be up to 3.2 metres (between the lowest low water and the highest high water).

Vertical circulation

The thickness of the mixed layer is a function of the surface buoyancy flux, the wind stress and the stratification.

Fresh water is lighter than salty water and warm water is lighter than cold. Adding heat or fresher water to the surface, the surface water gets more buoyant, or there is a positive buoyancy flux. Cooling or evaporation leads to higher surface density, which in turn can make the surface water sink (negative buoyancy flux, or convection). This procedure of vertical mixing can happen on a daily basis with heating during the day and cooling at night (Nerheim, 2006).

The stratification in the water is the density structure over depth. If the water is strongly stratified, there is a strong gradient of either temperature or salinity at some depth. The stronger the stratification, the harder it is for the mixing processes to mix the top layer with the water beneath. In the Skagerrak, there is a seasonal thermocline developed during summer. During autumn, cooling of the surface (negative buoyancy flux) and increased mixing due to wind results in more homogenous temperatures. There is a rather stable perennial halocline at 10-20 meters depth.

Wind mixes the surface water with deeper waters. If the buoyancy flux vanishes or is positive but small, the mixing depth due to the wind is set by the wind speed and the local Coriolis parameter (latitude dependency). This is called the Ekman length.

The seasonal thermocline usually prevents mixing below the thermocline, even though there might be stronger winds able to mix water at greater depths. Mainly the mixing depth in the summer is to the seasonal thermocline, if the thermocline is above the perennial halocline. During autumn the thermocline deepens and weakens, hence the mixing can reach further. During strong winds in late autumn and winter, the seasonal thermocline is too weak to prevail and the mixing can, with strong wind and negative buoyancy, reach further down.

There is another mixing depth aspect not mentioned above: If there is a positive buoyancy flux, the water becomes more stable and the turbulence is needed to mix the lighter water into the deeper water. The result is a new pycnocline above the older one. The new depth to the new pycnocline is called the Monin-Obukhov length.

During positive buoyancy, the depth of the wind induced mixing, is the shallowest of the mentioned length scales. Since there has been no investigation within this report of the buoyancy fluxes, the approximation is that the wind is the dominating factor mixing the surface layer to the lesser of the Ekman length and the pycnocline depth.

In table 2, the Ekman length has been calculated for different wind speeds at the latitude of 57°. Only with very low wind speeds, the Ekman length is less than the pycnocline depth, hence the pycnocline depth is the main mixing depth.

Table 2. Ekman lengths at the 57th latitude for different wind speeds.

Wind speed	Ekman length
5 m/s	10 m
10 m/s	20 m
15 m/s	35 m
20 m/s	51 m
25 m/s	69 m

APPENDIX 4: MODELLED TRANSPORT SCENARIOS

The Skagerrak

This section shows examples from model simulations of the transport of the water from a BW discharge in the Skagerrak. The purpose of the simulations is to demonstrate how an area in the Skagerrak could be exposed to a BW discharge and how fast a discharge could be transported by the currents to different areas of interest, e.g. protected areas and coastal areas. The simulations were carried out using Seatrack Web, which is a particle transport model for oil drift forecasts in the North Sea – Baltic Sea area. In this study, however, all processes related to oil drift were excluded and the model calculated only the advection of particles, i.e. transport by the currents. Hence, a BW discharge is represented in the model by a particle, which is moving with the ambient flow.

The flow field was taken from SMHIs operational oceanographic model for the Baltic Sea (HIROMB). The HIROMB model calculates current velocities in a regular grid with a horizontal resolution of three nautical miles and a vertical resolution ranging from 4 m at the surface to 60 m at the deepest parts. To simplify the simulations, the particle transport was limited to a horizontal plane near the water surface and no turbulent dispersion was included. The particles were released and transported by the currents at 6 metres depth. This corresponds to the centre of the next uppermost grid cell, which means that the currents are strongly affected by the wind at the water surface.

Since the Skagerrak is an area with several current systems with different densities, figures of the 20 metre depth were also produced. This mostly to display the paths of water parcels pressed beneath the Baltic Current.

To capture different seasonal current conditions, the simulations covered a time period of one year. In Andersson 2007 two different years, 2002 and 2004, were selected for the runs. Similar settings were requested for this report so the same time periods was used. Both years contain periods with strong wind conditions, but the directional characteristics are different. During the simulation, particles representing the BW discharge were released every 24 hours at 11 different locations distributed over the proposed discharge area in the Swedish Economic Zone in the Skagerrak. By keeping track of the particle trajectories and the release time of each particle, the following statistical data was calculated after each run:

1 the maximum relative frequency of arrival of the particles to different grid cells in the underlying HIROMB domain,
2 the mean drift time of the particles and
3 the shortest drift time

To limit the time a discharge is affecting the surroundings, the maximum lifetime of the BW discharge was assumed to be 30 days. This means that particles that had been drifting around for more than 30 days were not considered.

The maximum relative frequency of arrival was calculated in two steps. In the first step, the relative frequency of arrival was computed separately for each of the 11 different discharge points. This was accomplished by calculating the sum of the particles that had arrived in each grid cell and dividing by the total number of discharged particles (= 365). No particle was counted more than once in each cell. Thereafter, the largest frequency of arrival from the 11 discharges was calculated. The resulting maximum relative frequency of arrival should be interpreted as the maximum probability that a BW discharge occurring somewhere in the proposed discharge area will arrive to a certain grid cell within 30 days.

The mean drift time is the average time it takes for particles originating from all discharge points to reach a certain grid cell. The shortest drift time, on the other hand, is the least time it takes to reach a certain grid cell from any of the discharge points. Hence, if there is a BW discharge somewhere in the proposed discharge area, the shortest drift time tells us how fast the species in the water could reach different areas of the Skagerrak.

Figure 21 shows the maximum relative frequency of arrival for 2002 and 2004 at 6 m depth. The black crosses mark the 11 discharge points. Close to the discharge points the probability approaches 100 % since all discharged particles must arrive to those cells. However, the probability decreases fast with increasing distance to the discharge points.

Note that the maximum relative frequency of arrival presented in the figures is calculated per grid cell and not per unit area. This implies that the

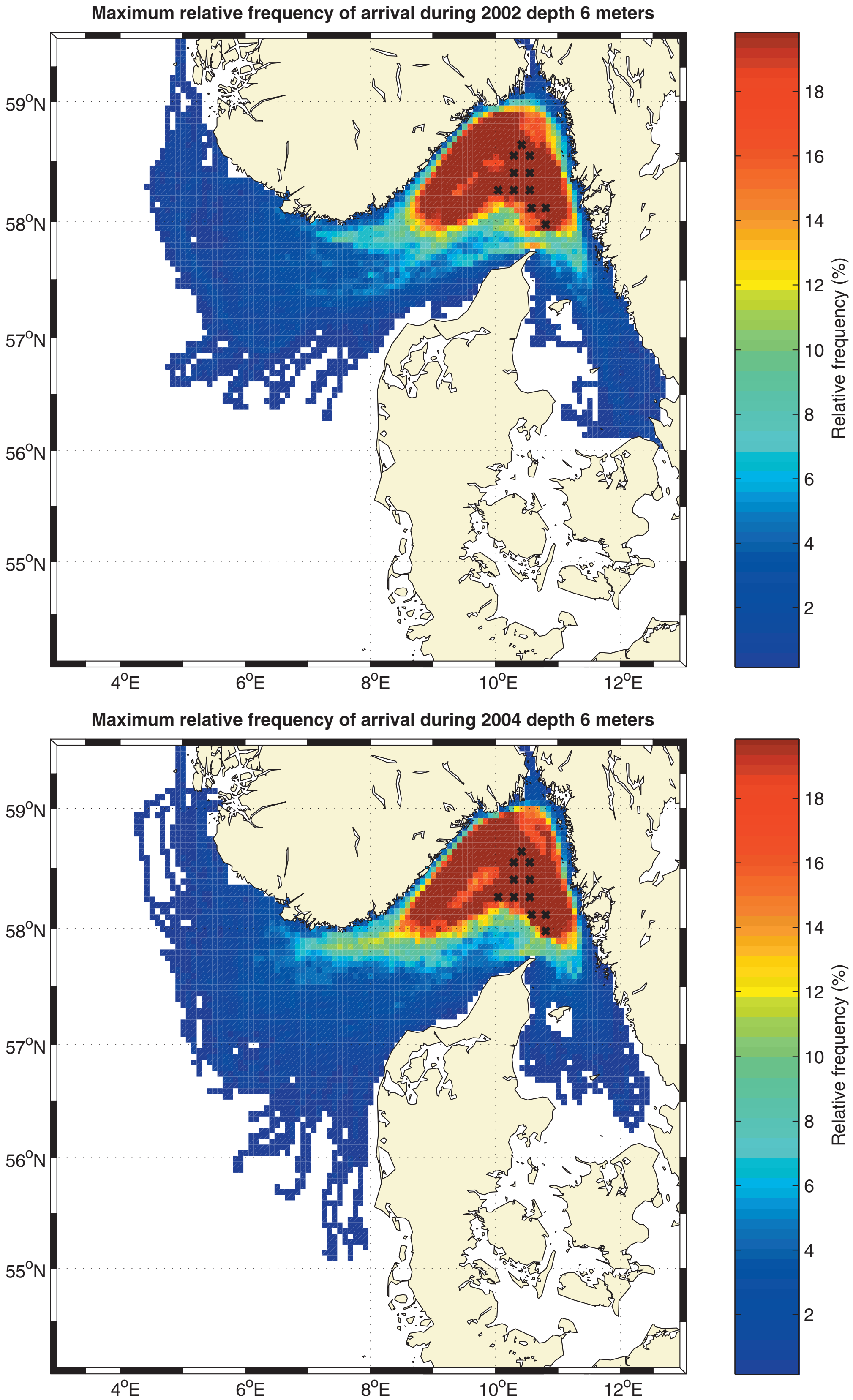


Figure 21. Maximum relative frequency of arrival at 6 m depth and 11 outlet points.

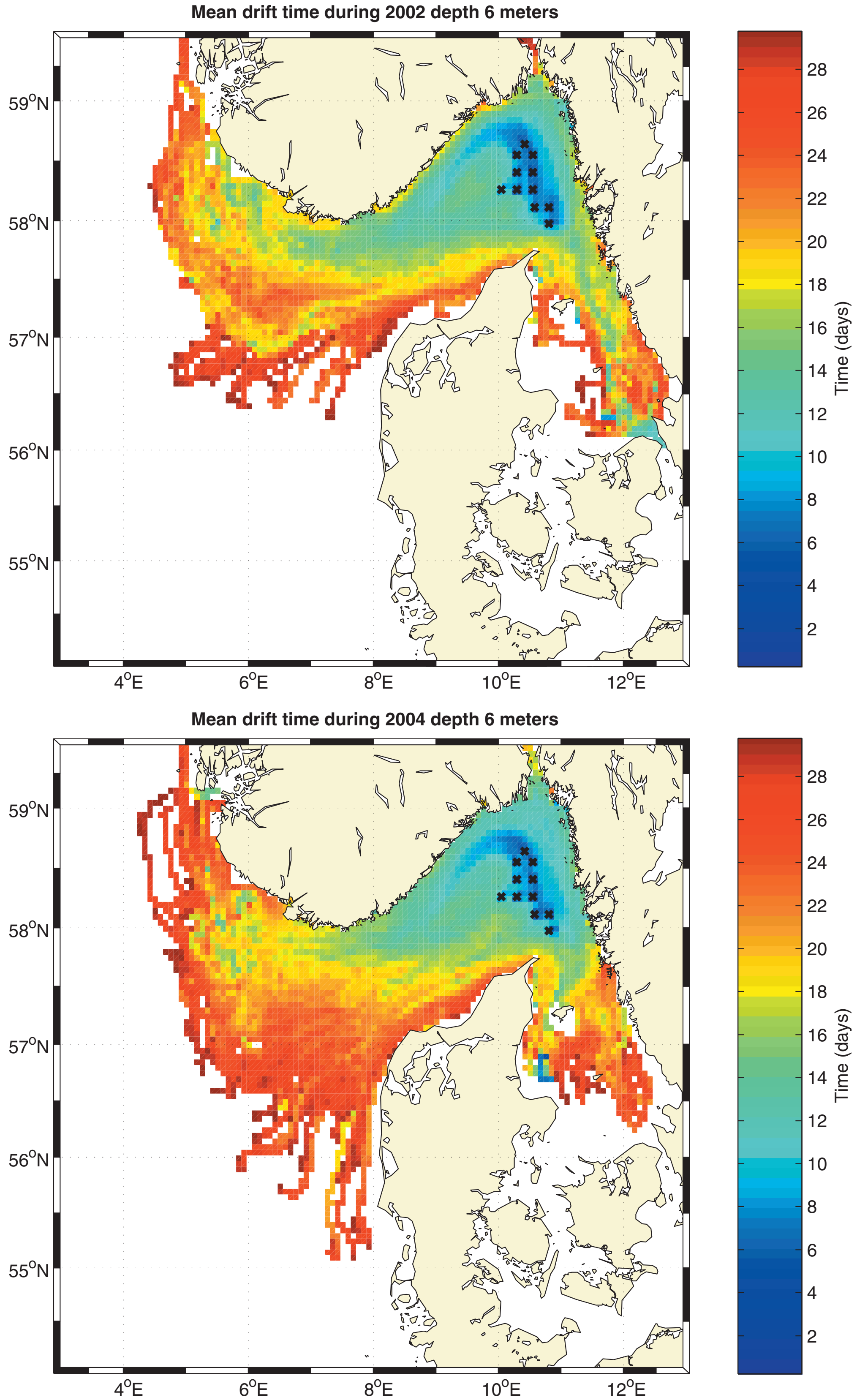


Figure 22. Mean time of arrival at 6 m depth and 11 outlet points.

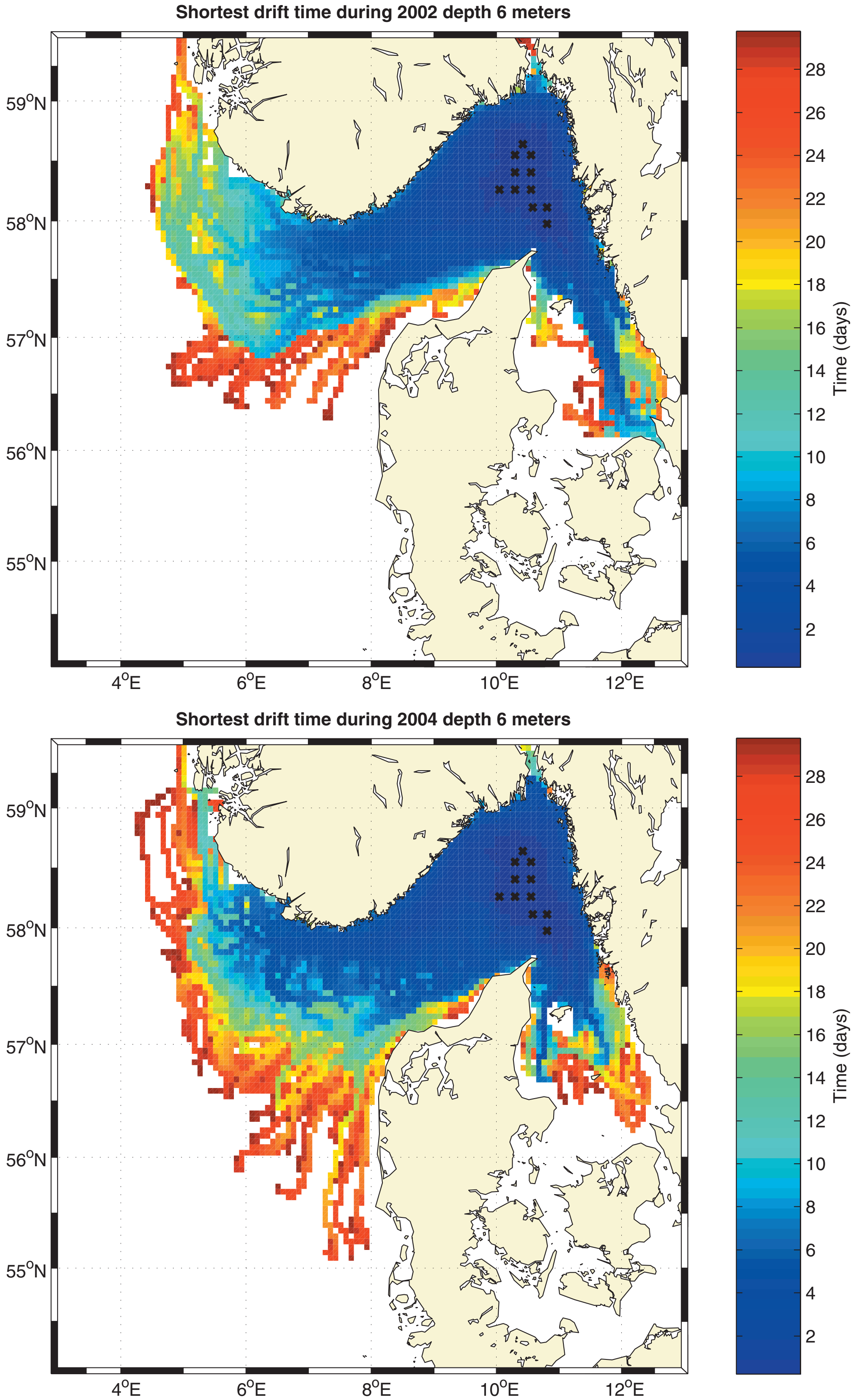


Figure 23. Shortest time of arrival at 6 m depth and 11 outlet points.

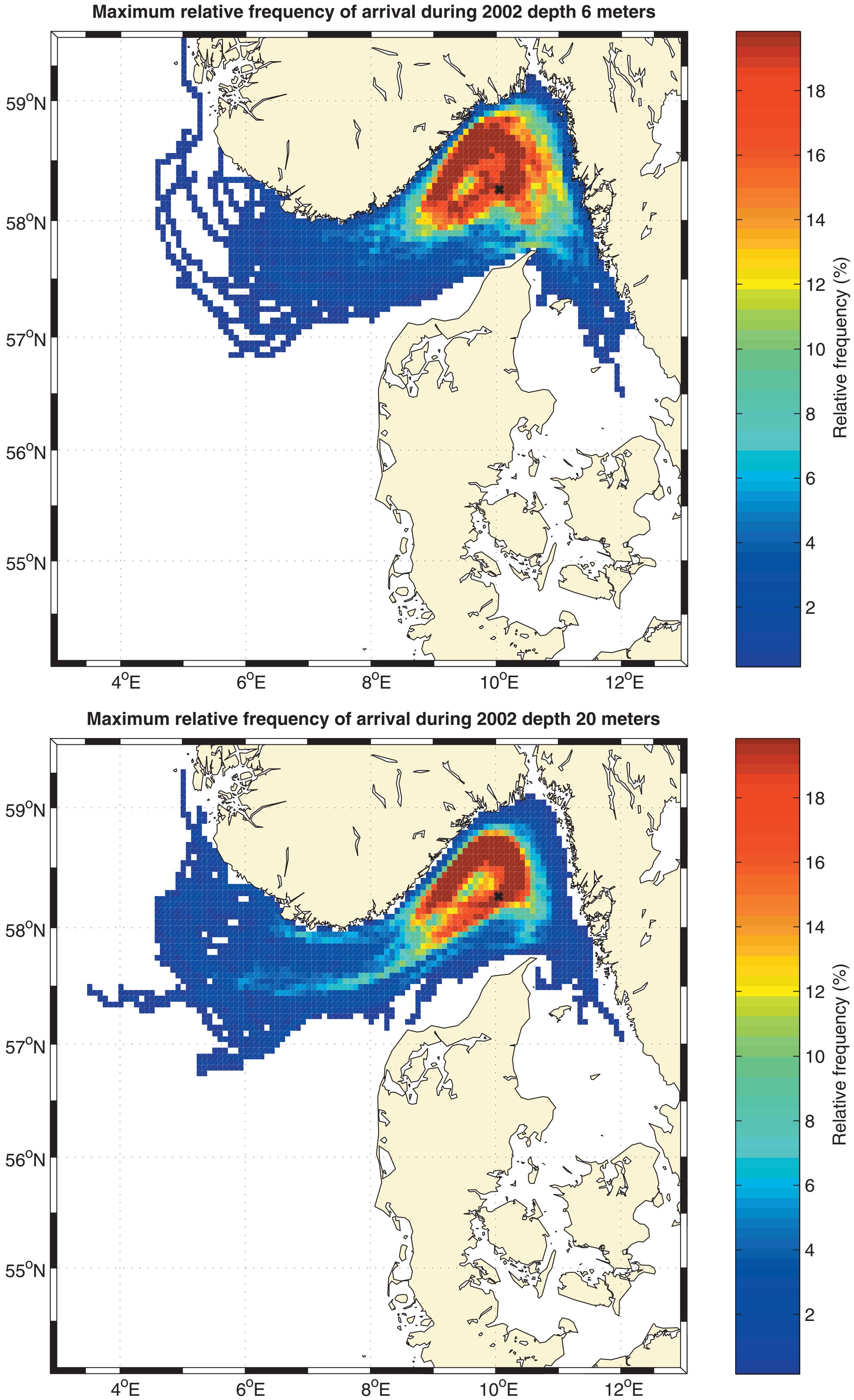


Figure 24. Maximum relative frequency of arrival at 6 (top) and 20 (bottom) m depth and one outlet point (2002).

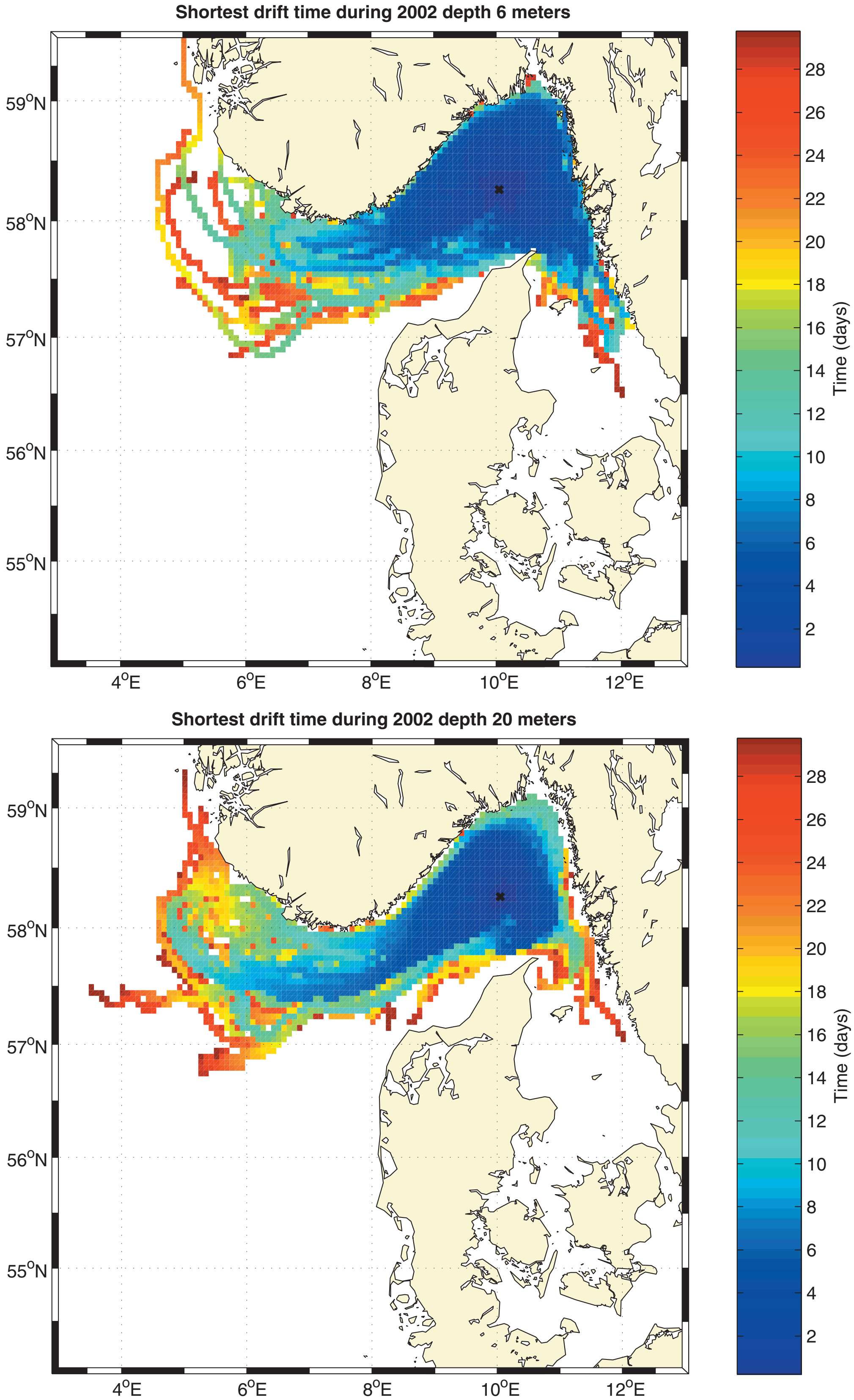


Figure 25. Shortest time of arrival at 6 (top) and 20 (bottom) m depth and one outlet point (2002).

absolute values of the frequencies depend on the size of the grid cells. The smaller the grid cells in which particle arrivals are counted, the smaller the relative frequency of arrival to each cell will be.

Figures 22 to 23 show the corresponding mean drift time and shortest drift time.

The distance to the nearest coast from the eastern part of the proposed BWE area is very short (<20 nm). The distance from the westernmost tip of the proposed BWE area is 40 nm. It is interesting to display the difference (if any) between including all 11 outlet points and only one outlet point, in the centre of the Skagerrak (figures 24 to 25).

General remarks:

- Cyclonic current patterns are evident in the central Skagerrak.
- The Skagerrak is an area with strong currents. The particles cover a vast area within one month and can reach the Swedish coast within a few days.
- Some particles enter the Kattegat and some particles are directly transported towards the west, but the main part is transported in a cyclonal path and eventually ends up in the Norwegian Coastal Current.

Comparing the 6 metre depth to the 20 metre depth:

- Generally the 6 metre depth particles reach further.

Comparing 2002 to 2004:

- At the depth of 20 metres, there is no major difference in either the one point or 11 point outlets.
- At the depth of 6 metres, there are more particles caught in the Norwegian Costal Current in 2002 while in 2004 the particles reach further south, towards Denmark.

Comparing 1 outlet point to 11 outlet points:

- With 1 outlet point, the coverage area is slightly smaller.
- With 1 outlet point, it takes a slightly longer time to reach the Natura 2000 areas.

On the basis of the simulations it is concluded that the discharges could be transported over large areas during the time period of one month and would reach the entire Skagerrak area. Most parts of the Skagerrak costal zone are reached within a week. The probability that a BW discharge will reach the nearby Natura 2000 areas is high. The shortest drift time to the protected areas along the Swedish coast can be reached in only a few days (figures 21 to 25 and table 3).

Table 3 (the same as table 1). Approximation of Maximum relative frequency of arrival, mean drift time and shortest drift time to the Natura 2000 areas along the Swedish coast.

	2002				2004			
	6 metres		20 metres		6 metres		20 metres	
	1 point	11 points	1 point	11 points	1 point	11 points	1 point	11 points
Maximum relative frequency	0-6 %	0-12 %	0-4 %	0-12 %	0-12 %	0-20 %	0-4 %	0-12 %
Mean drift time (days)	8-12	12	14	14	14-18	8-12	14-20	10-18
Shortest drift time (days)	0-6	0-6	8-14	0-6	0-8	0-6	8-14	0-6

The Norwegian Trench

The model used to make transport simulations in the Skagerrak did not cover the entire area of interest for the Norwegian Trench. For this reason, Det Norske Veritas (DNV) was contacted to perform similar simulations for the northern Norwegian Trench.

Det Norske Veritas (DNV) has performed statistical drift simulations of passive tracers in 3 positions between Shetland and Norway (see Figure XX):

Position 1	61^{O} 18.0' N	02 ^{O} 30.0' E
Position 2	61 ^{O} 18.0' N	03 ^{O} 01.0' E
Position 3	60 ^{O} 45.0' N	03 ^{O} 03.0' E

The oil drift simulations are carried out with the (oil) drift model OILTRAJ (DNV, 1994). The model calculates statistical parameters such as hit probability and drift time.

Input parameters for the statistical oil drift simulation

The statistical oil drift model OILTRAJ uses current and wind data from the hind-cast database from DNMI. This includes monthly climatological current fields (DNMI, 1992) and time series for wind in selected positions for the period 1955-1994 (DNMI, 1994).

The horizontal grid resolution is 10 x 10 km. It is performed 3600 different wind simulations, and 1 tracer is released every time step (=1 hour) through the release duration (24 hours). Each tracer is followed in 30 days or until the tracer is stranding.

Statistical oil drift simulation results

Statistics are generated for drift in a 10 × 10 km grid in UTM 33 co-ordinates. In figure 26, 27 and 28 the hit probability, minimum drift time and average drift time for the whole year as a season is shown. The figures show the influence area where the hit probability is greater than or equal to 5%.

For position 1 the shortest drift time to land is 3.8 days (in January). The total stranding probability is 45.8 % i.e. 1650 of the 3600 simulations reach the coast of Norway.

For position 2 the shortest drift time to land is 2.8 days (in January). The total stranding probability is 48.9 % i.e. 1762 of the 3600 simulations reach the coast of Norway.

For position 3 the shortest drift time to land is 2.6 days (in January). The total stranding probability is 57.2 % i.e. 2060 of the 3600 simulations reach the coast of Norway.

As an example figures showing the spreading in different time intervals for the single scenarios representing the shortest drift time to land are presented in Figure 29a-c.

Seatrack Web

There is a slim area between the Skagerrak and the northern Norwegian Trench that is > 50 nm from the coast and > 200 metres of depth. Seatrack Web reaches this area hence there are a few extra simulations (figures 30a-c). This "middle" area is very narrow and small, but it is interesting to see the transport of particles in this area. Within 30 days, the particles do not reach the Skagerrak, but can quickly be transported towards the Norwegian coast.

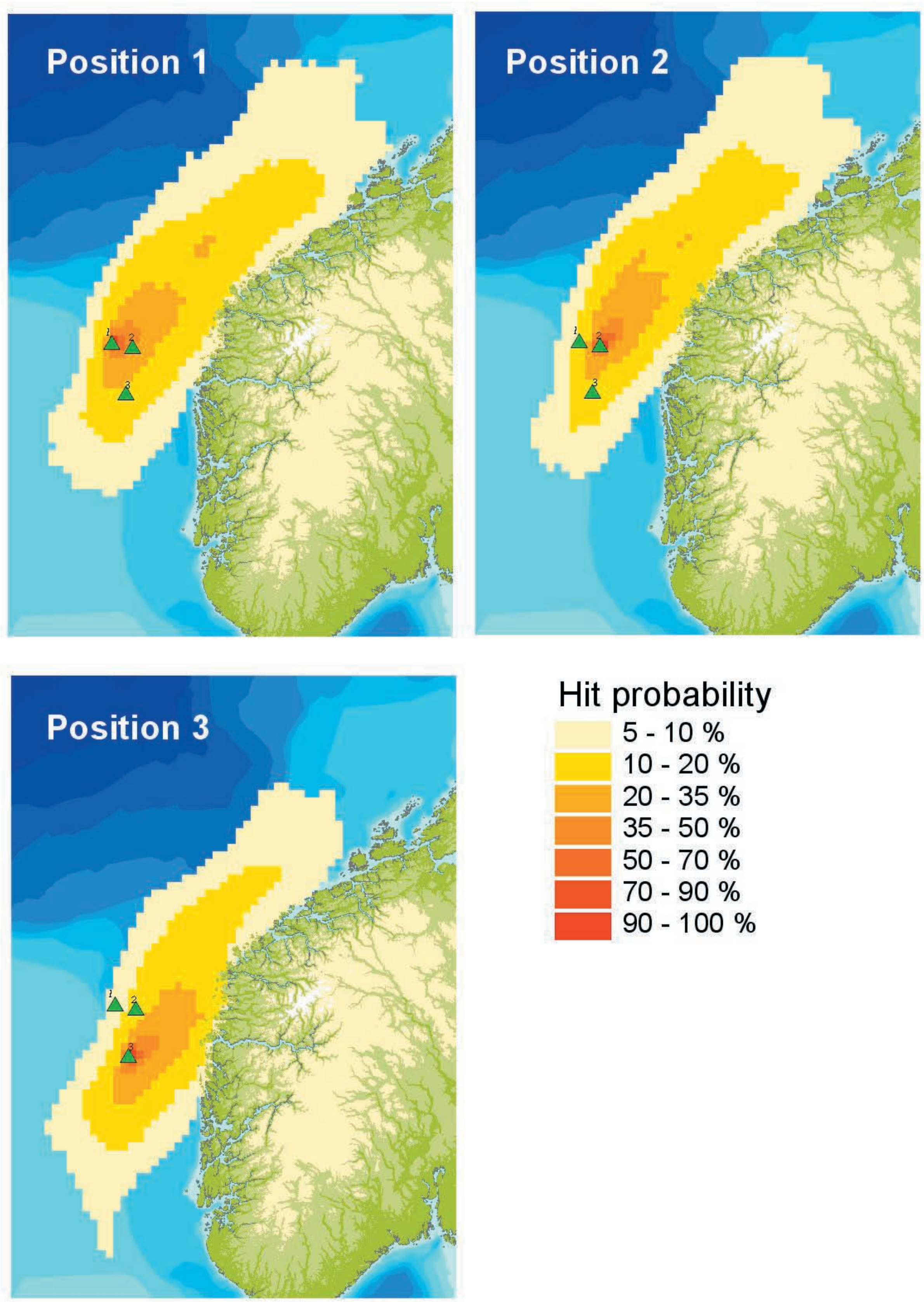


Figure 26. The influence area for the three positions within 5 % hit probability. The figures show hit probability in 10 x 10 km grid cells after 3600 different wind simulations. The release positions are marked with green triangles.

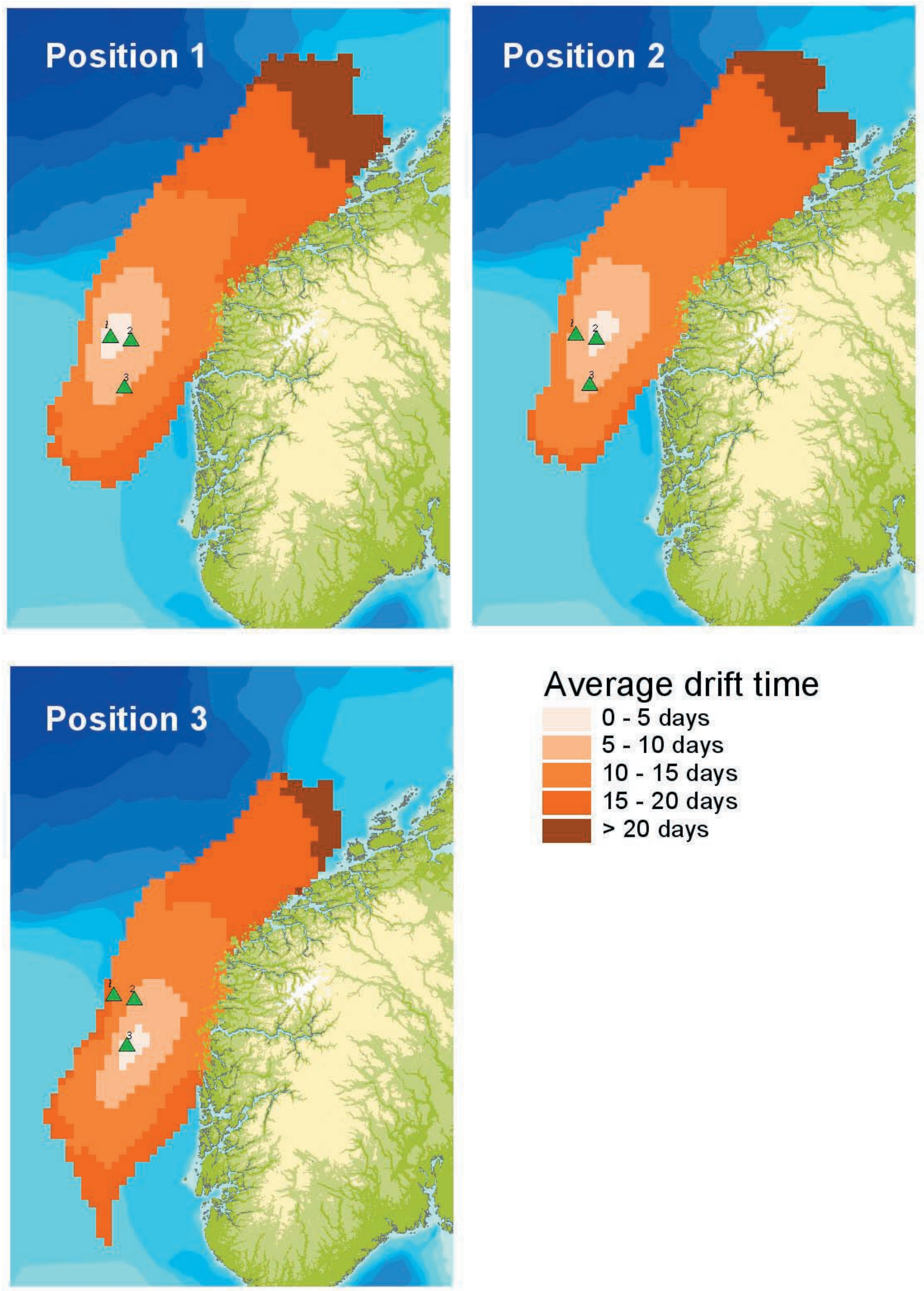


Figure 27. Average drift time in 10 x 10 km grid cells after 3600 different wind simulations within 5 % hit probability.

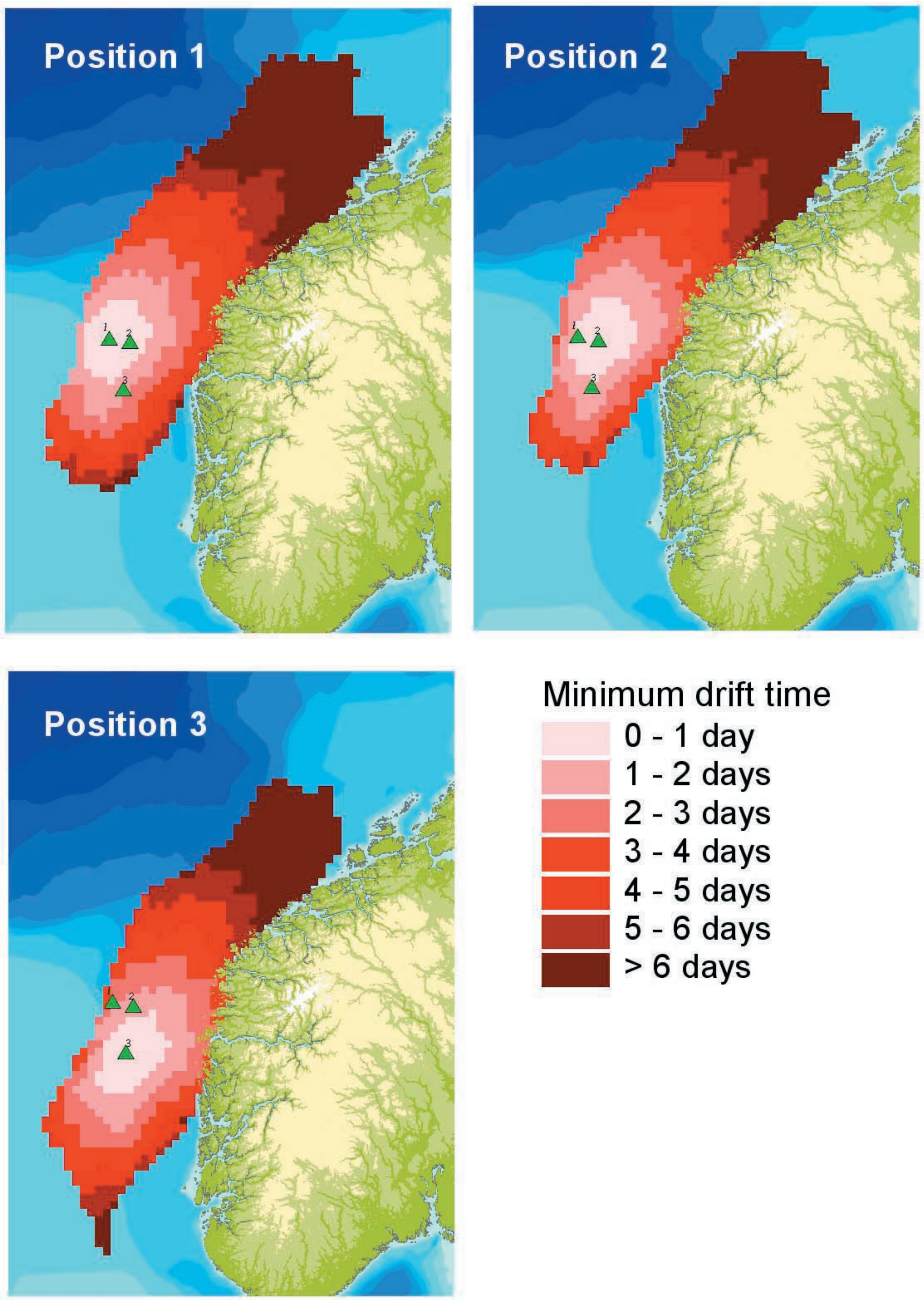


Figure 28. Minimum drift time in 10 x 10 km grid cells after 3600 different wind simulations within 5 % hit probability.

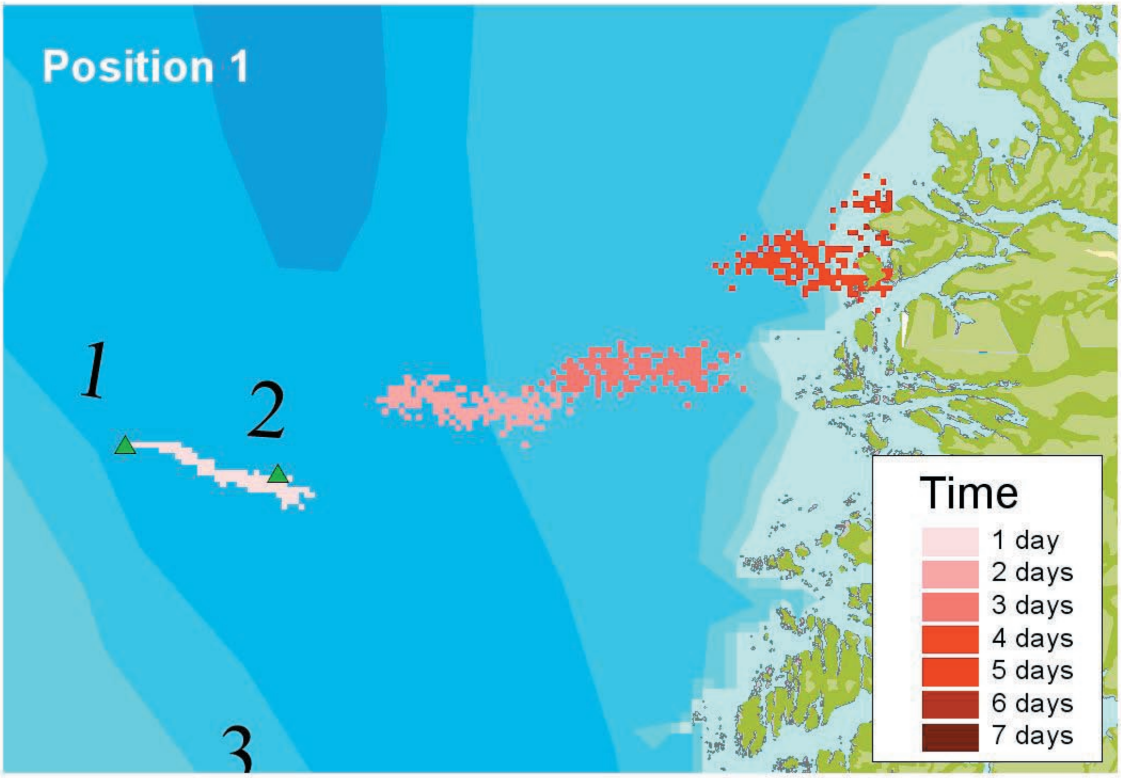


Figure 29a. Position 1 – surface spreading for the shortest drift time to land scenario from January. These results are presented in a 1 x 1 km grid.

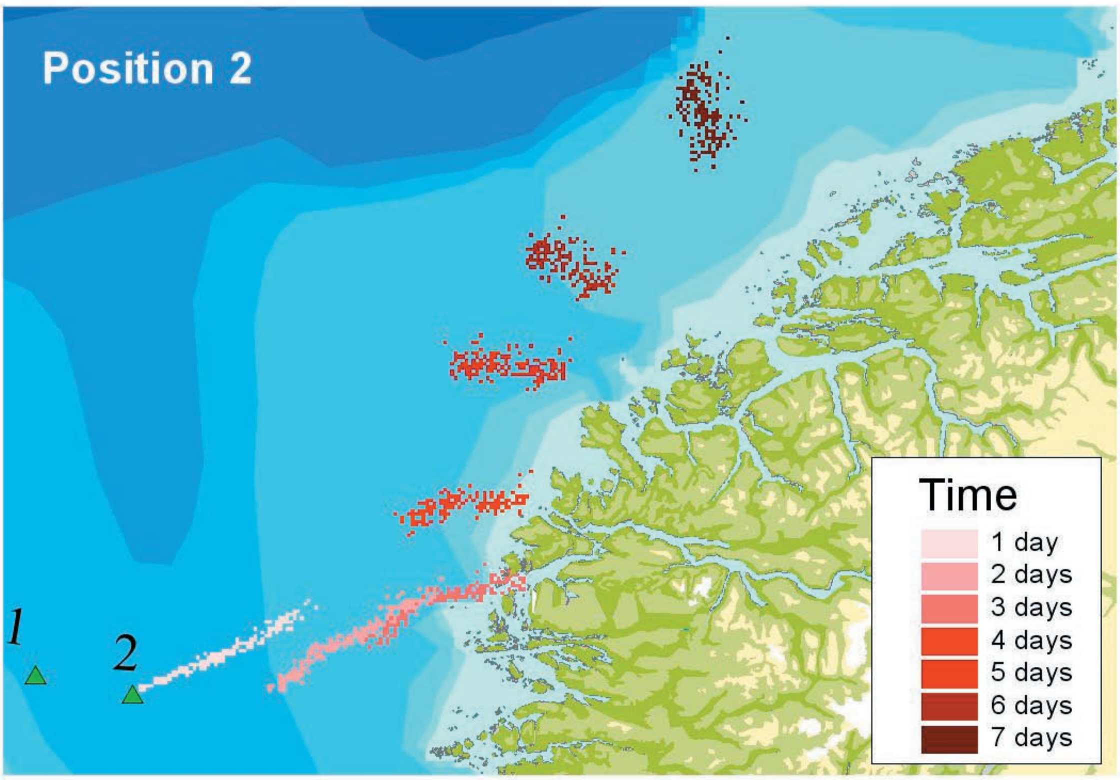


Figure 29b. Position 2 - surface spreading for the shortest drift time to land scenario from January. These results are presented in a 1 x 1 km grid.

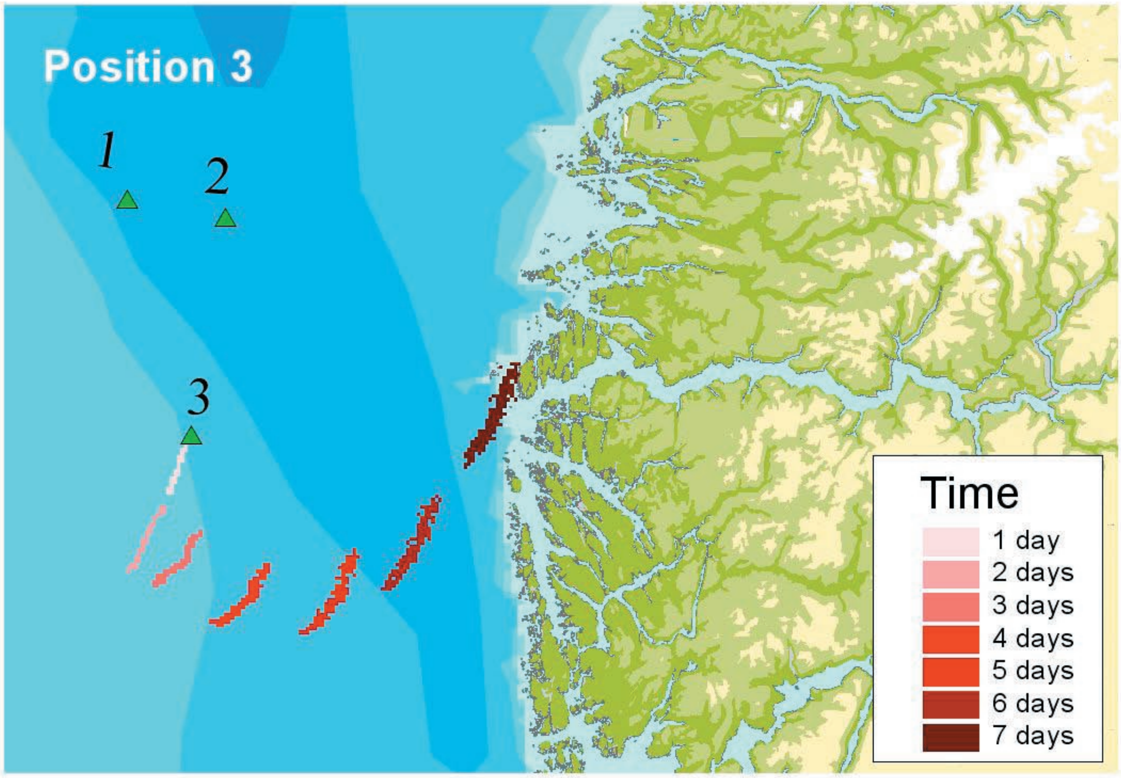


Figure 29c. Position 3 - surface spreading for the shortest drift time to land scenario from January. These results are presented in a 1 x 1 km grid.

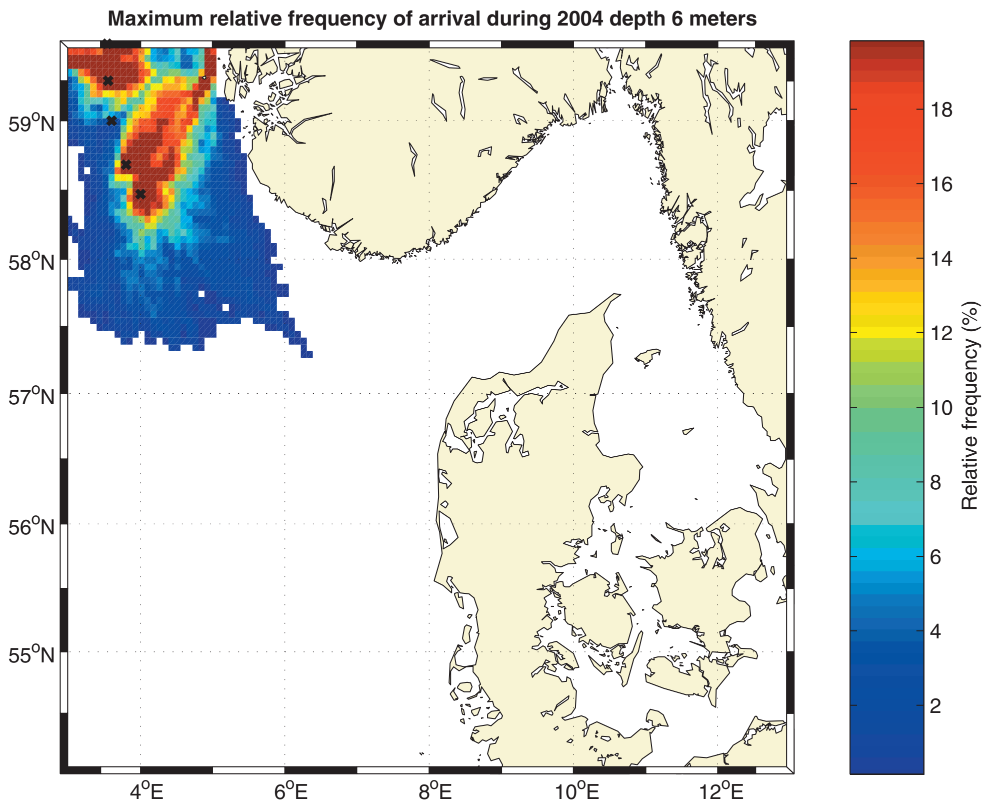


Figure 30a. Maximum relative frequency of arrival for five outlet points in the middle of the Norweigan Trench, 2004 at 6 m depth.

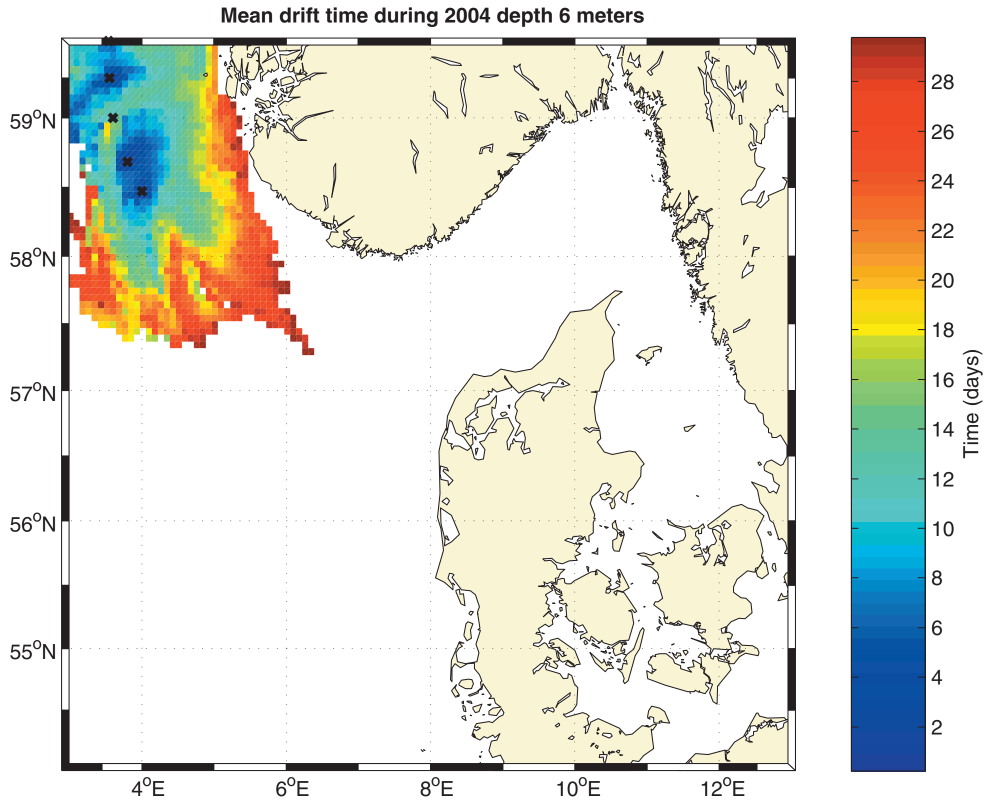


Figure 30b. Mean drift time for five outlet points in the middle of the Norweigan Trench, 2004 at 6 m depth.

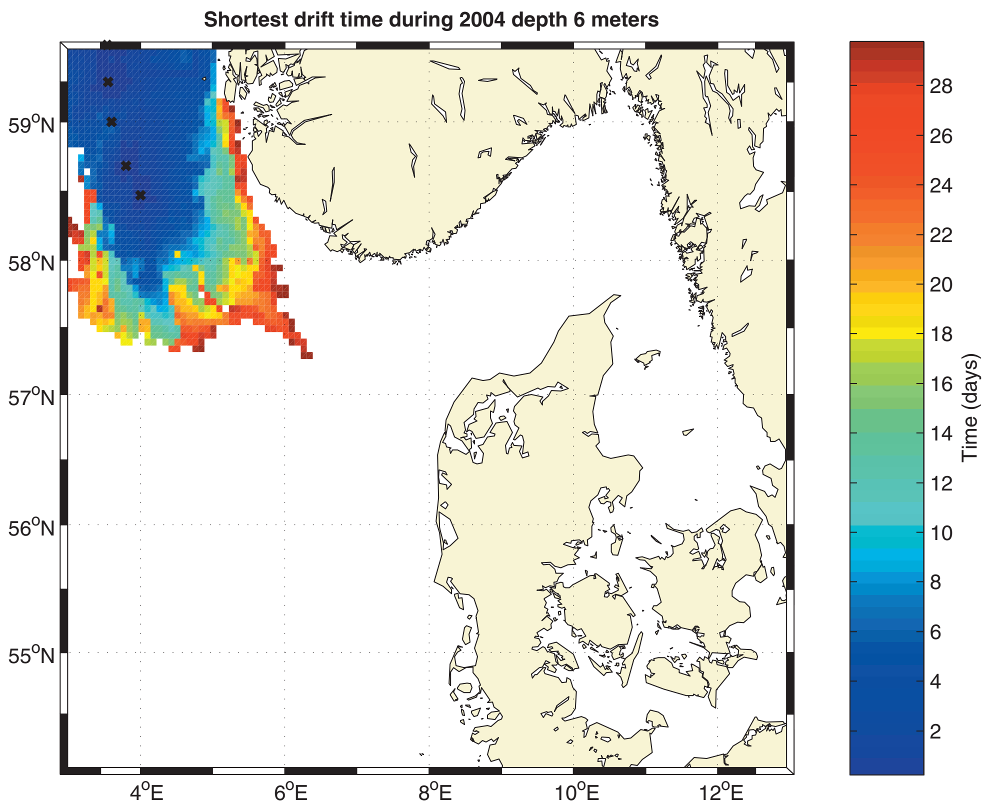


Figure 30c. Shortest drift time for five outlet points in the middle of the Norweigan Trench, 2004 at 6 m depth.

APPENDIX 5: GENERAL BIOLOGY

The Skagerrak

The general biological description is very brief, presenting total phytoplankton biovolume plots only for the Skagerrak. There is also a satellite image with blooms of *Emiliania huxleyi*, giving an idea of the biological activity even seen from space.

The Skagerrak is strongly influenced by fresh water input, and due to the low salinity in the upper layer, has a stable stratification all year round. The salinity stratification in these regions has large implications for primary productivity. The spring bloom starts earlier here than in other areas where stratification due to warming must precede the bloom.

In the figure 31, the total biovolume is calculated over the top 20 metres. The data cover all measurements made at a few selected stations during 1990 to 2005. The first sub figure is the sum of all biovolumes for the species at Å17 in the central Skagerrak. The next sub figure is the sum of all biovolumes for the species at the stations Kosterfjord, BroA and Släggö, which are closer to the coast. The next two sub figures are as above, but only for selected harmful algae.

In the Skagerrak, the two top sub figures indicate that there is biological activity (phytoplankton) in the water most of the time, if not all year around. There is a peak during the spring bloom, mainly consisting of diatoms. During spring, summer, autumn and early winter, there is biological activity in the photic zone.

What organisms that would act as harmful organisms when transported into another area than the Skagerrak, is hard to predict. The few genera selected in figure 31 are harmful algae in the Skagerrak and they are *Chattonella cf. verruculosa, Karenia mikimotoi, Chrysochromulina spp.*, and *Akashiwo sanguinea* that are harmful for fish and *Dinophysis spp., Pseudo-nitzschia spp., Alexandrium spp.* and *Protoceratium reticulatum* that are harmful for humans. *Pseudo-nitzschia spp.* can cause Amnesic Shellfish Poisoning (ASP), *Alexandrium spp.* can cause Paralytic Shellfish Poisoning (PSP) and *Dinophysis spp.* can cause Diarrhetic Shellfish Poisoning (DSP).

The few genera selected are presented to give an idea of the blooming periods of some possibly harmful events.

From February to October, it is evident that there is high biological activity, indicated in the biovolume figure. There are many harmful species present in the Swedish waters, but usually with low abundances. The timing of the HABs coincides with the general figure of the biovolumes. Hence there is a higher risk of BW uptake of harmful organisms between February to October, leaving November to January with lower risk of organism uptake.

Complementary information regarding chlorophyll-a, Secchi and oxygen saturation can be found in the general hydrography appendix.

The scale of biological activity in the Skagerrak is illustrated by blooms of the harmless coccolithophoride *Emiliania huxleyi,* which can cover the entire area. The water turns turquoise in the bloom and the view from space is spectacular (figure 32).

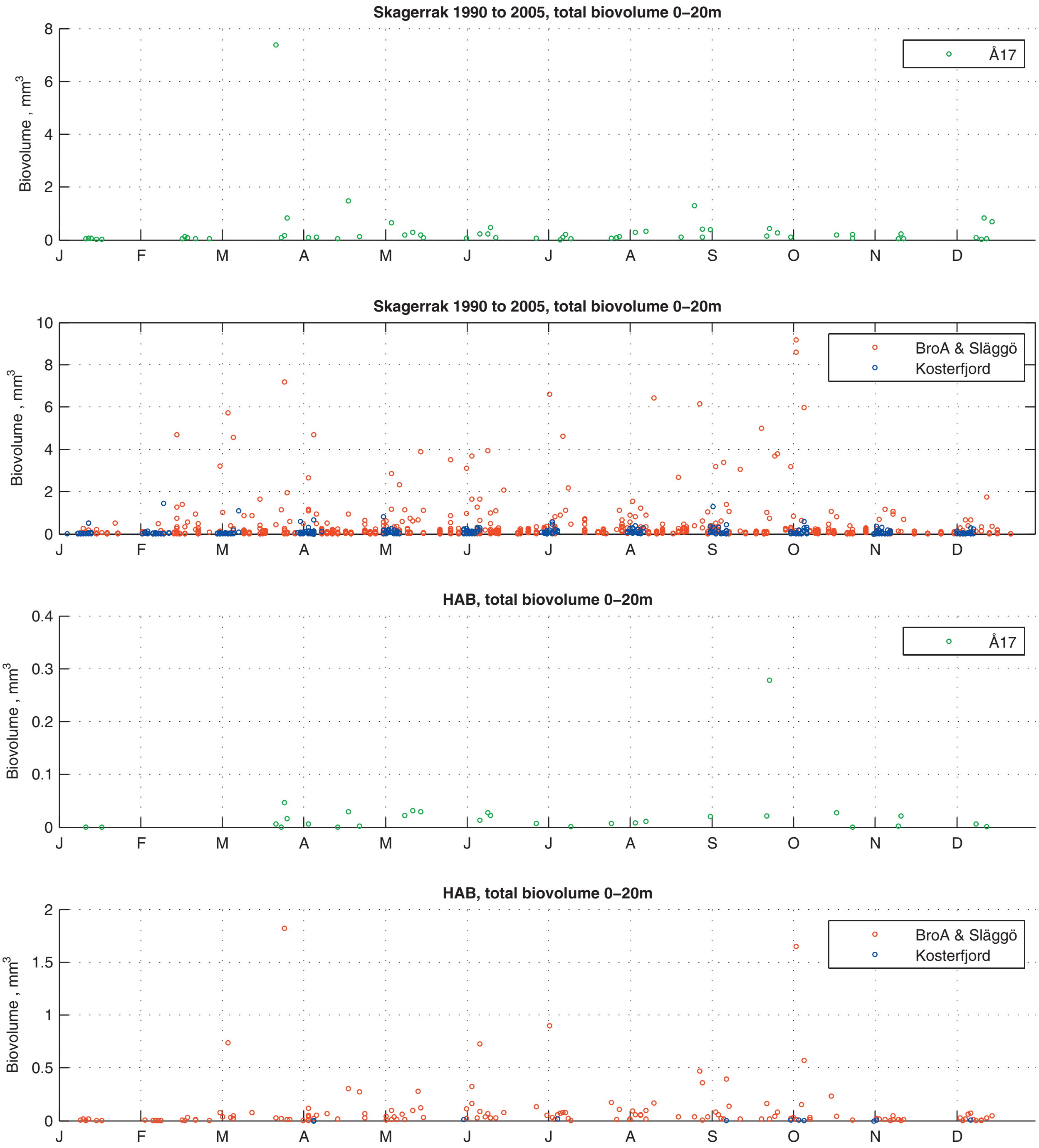


Figure 31. The top figure is the sum of all the biovolumes for all the species at the Å17 station in the central Skagerrak. The next figure is the sum of all the biovolumes for all the species at the stations Kosterfjord, BroA and Släggö, closer to the coast. The next two figures are a repetition of the above mentioned, but only the biovolumes of a few selected harmful algae are included. (1990 to 2005.)

Figure 32. Satellite image of an *Emiliania huxleyi* coccolithophoride bloom that cover the entire Skagerrak area. The water turns turquoise in the bloom.

APPENDIX 6: GENERAL WIND

The wind climate is analysed by processing observed data from Måseskär. Actual wind measurements at sea are scarce and the wind measurements from Måseskär are assumed to be representative for the entire Skagerrak.

The Skagerrak

In figure 33, the wind speed from Måseskär is displayed in box plots for each month from 1997 to 2006 (measurements every 3rd hour). The median value is the red line in the blue box. The blue box encapsulate 50% of the data (25th percentile above and below the median), the black line is 1.5 times the inter quartile range. The red plus signs above are outliers.

The median wind speed is highest in October to February, about 8 m/s, and lowest in July, with about 5 m/s. The median values are quite low, but the many red plus signs indicate that even during summer, there can be winds up to 19 m/s and more than 26 m/s during winter.

In figure 34, wind roses for each quarter of the year are plotted giving information on both main wind speed and direction. The first figure is Jan - Mar, the next is Apr - Jun, Jul - Sep and the final one is Oct - Dec. In the figure, many stars are plotted on top of each other when the same speed and direction in the same month appear. The next figure gives complementary information of the amount of measurements each month in certain directions (a histogram).

The wind speed is marked as circles in the rose measuring 5 to 25 m/s. The 360 degrees scale outside the circles are the directions, 0 being wind from the north (N), 90 wind from the east (E) and so on. There is a dominance of SW to W winds, mainly during winter, when also the stronger winds are more common, but also during the rest of the year. Though, there are many occasions with wind from all other directions.

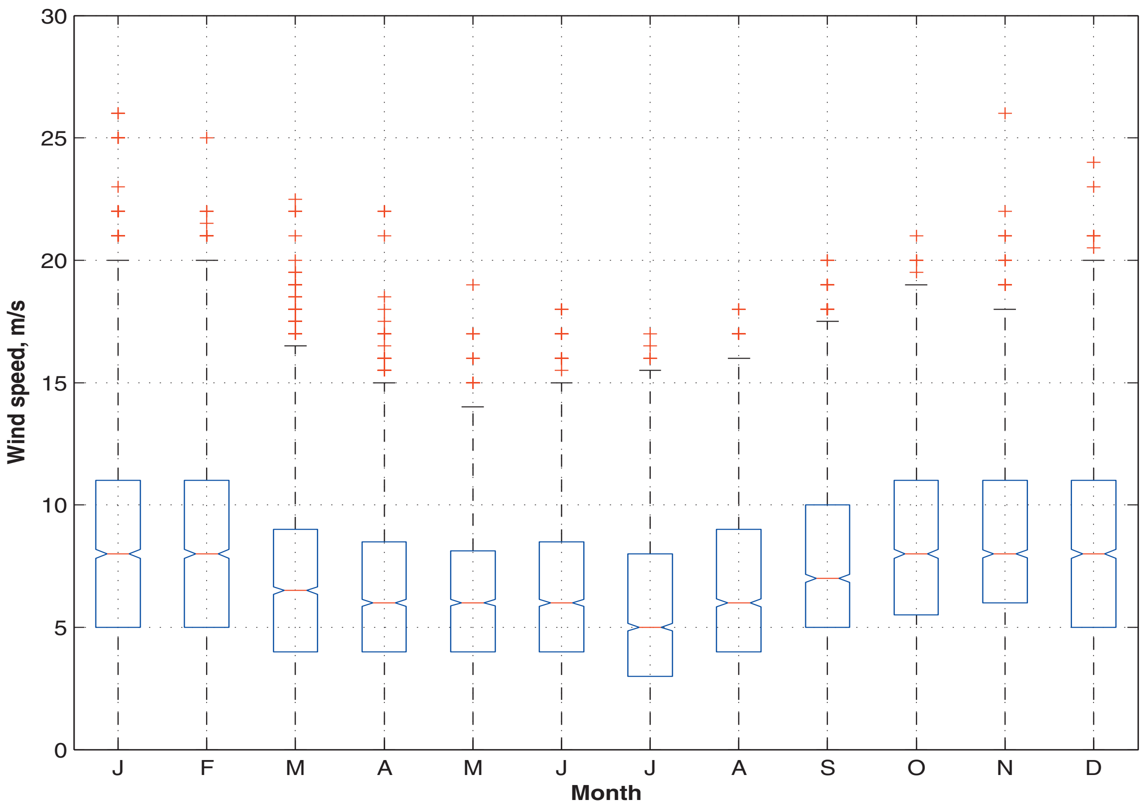


Figure 33. Box plots of mean wind speed each month at Måseskär 1997 to 2006. The median value is the red line in the blue box. The blue box encapsulate 50% of the data (25th percentile above and below the median), the black line is 1.5 times the inter quartile range. The red plus signs above are outliers.

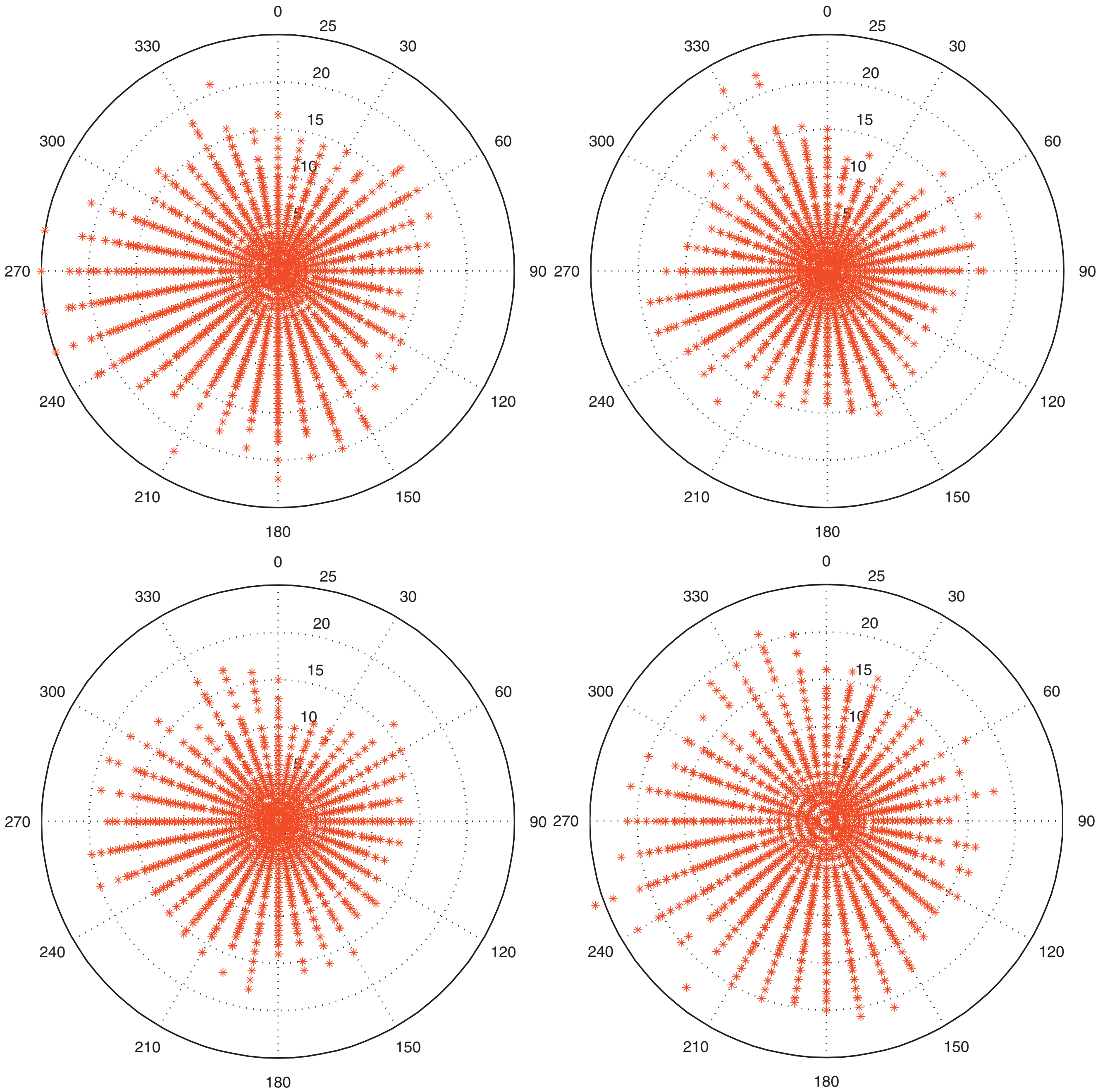


Figure 34. Wind roses for each quarter of the year presents both main wind speed and direction, though many markers are on top of eachother. The first figure is Jan - Mar, the next is Apr - Jun, Jul - Sep and the final one is Oct - Dec.

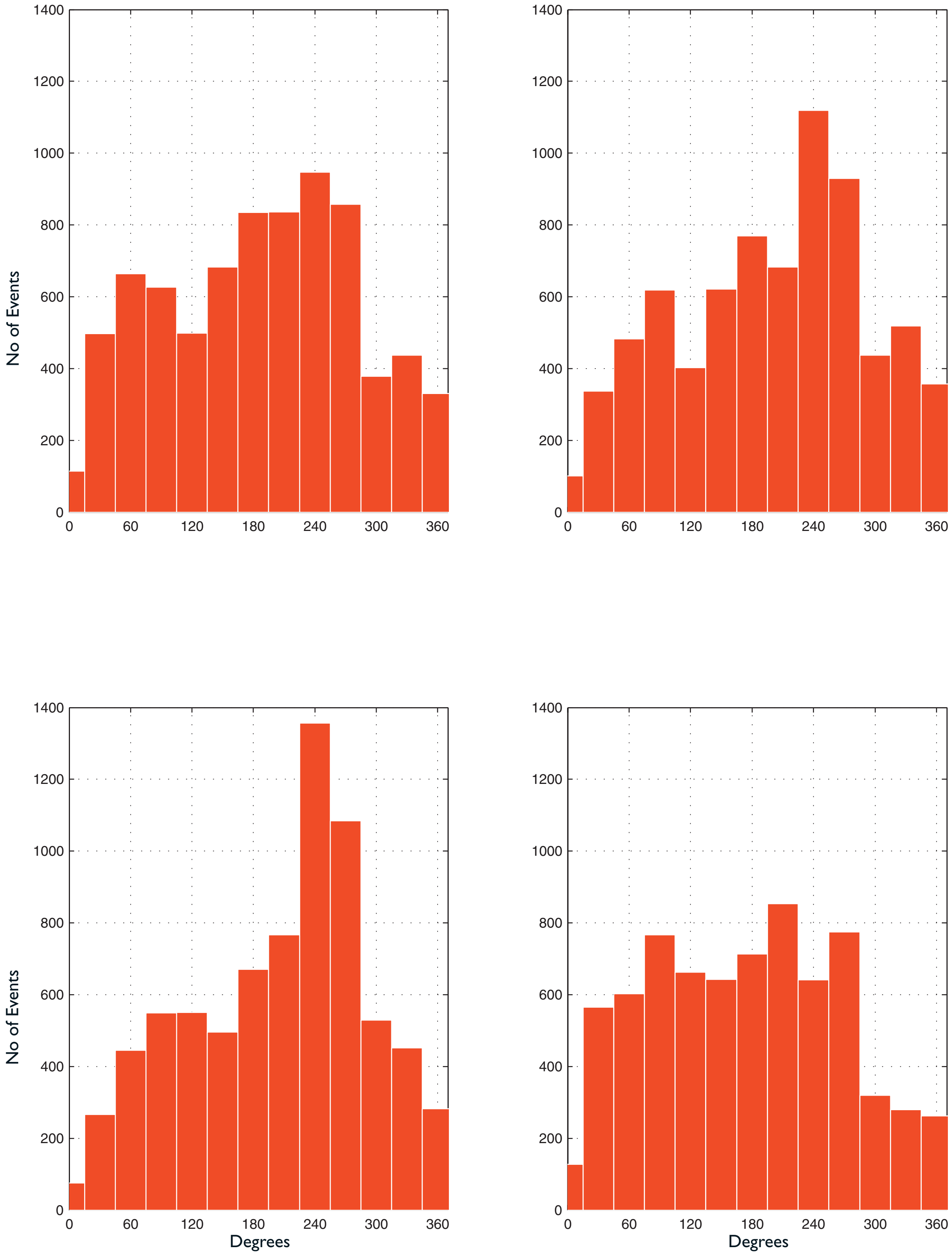


Figure 35. The number of measurements in each 20 degree direction bin displayed in histograms for each quarter of the year. The first figure is Jan - Mar, the next is Apr - Jun, Jul - Sep and the final one is Oct - Dec.

APPENDIX 7: GENERAL WAVES

The Skagerrak

There is only one SMHI operated wave buoy in operation today in the Skagerrak. The wave buoy at Väderö has measured waves at slightly different locations and time periods. The time series used is the most continuous and it covers March 2005 to October 2007 (figure 37).

Significant wave heights and wave periods are displayed by month and in a scatter plot where significant wave height is plotted against the wave period. The top image displays box plots, with highest mean and median wave heights and periods during winter and lower during the summer. The median wave height in November to January is under 2 metres, but there are significant wave heights over 7 metres, although those occur rarely, as can be noted by the scatter plot. Mainly the wave heights during summer are normally below 2 metres.

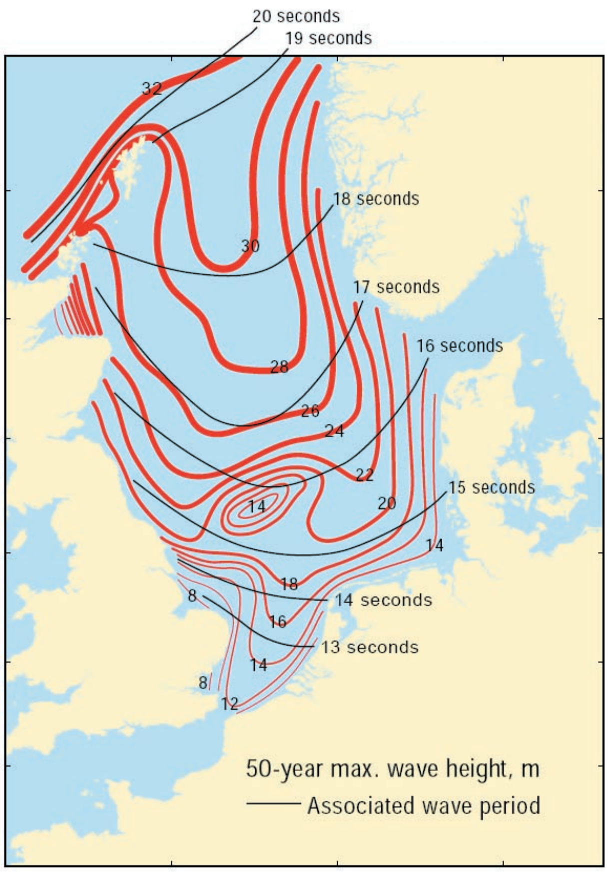


Figure 36. Estimated 50-year extreme maxima in the North Sea: wave height: distribution and associated wave period. Source of data: UK Department of Energy (1989).

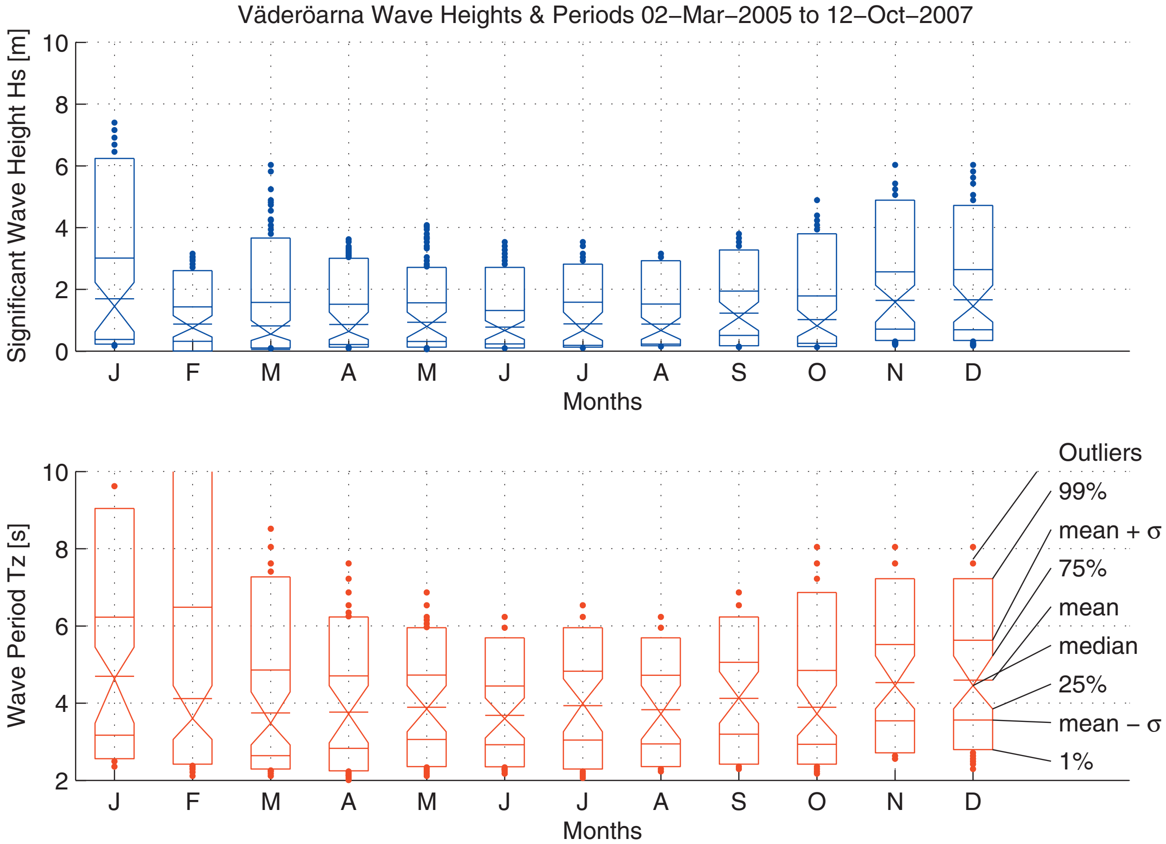
In the scatter plot, all data are used to create the sum of occasions of a specified wave height/period combination. The numbers in the scatter plot represent the number of times that the measurements have recorded that specific combination of period and wave height.

Focusing on the wave height, the very high values in the scatter plot are at lower wave heights. Mainly, the significant wave height is below 3 metres. In January 2007, the significant wave height reached over 7 metres at the Väderö station.

The Norwegian Trench

From the OSPAR Quality Status Report 2000: During storms, the re-suspension and vertical dispersion of bottom sediments due to waves and currents is a process that affects most of the North Sea, except for the deepest areas of the Skagerrak and the Norwegian Trench.

It is important to understand the processes of wave-current interactions that can produce abnormal waves, which are potentially dangerous for example, to shipping and offshore structures. In recent years, extreme-wave analysis for specific locations has also been relevant to site selection for fish farms. Extensive measurements have been made to estimate the wave climate of the North Sea (figure 36). In the area of interest for BWE, the wave heights of the estimated 50-year extreme maxima are more than 30 metres. That constitutes high risk in the terms of security on board most ships.



Scatter plot for Väderöarna, All observations from 02–Mar–2005 to 12–Oct–2007

Significant wave height [m] \ Wave period Tz [s]	1–1.9	2–2.9	3–3.9	4–4.9	5–5.9	6–6.9	7–7.9	8–8.9	9–9.9	10–10.9	11–11.9	12–12.9	13–13.9	14–14.9	15–15.9	16–16.9	17–17.9	18–18.9	19–19.9	> 20	Total
Total	0	3731	7798	5498	2943	492	150	57	22	0	0	0	0	0	0	15	2	3	2	4	41434
> 10																					0
9.50–9.99																					0
9.00–9.49																					0
8.50–8.99																					0
8.00–8.49																					0
7.50–7.99																					0
7.00–7.49									7												7
6.50–6.99									5												5
6.00–6.49							1	9	2												12
5.50–5.99							3	6	4												13
5.00–5.49							28	7	1												36
4.50–4.99						18	36	8													62
4.00–4.49						42	26	4	3												75
3.50–3.99					23	102	21	13													159
3.00–3.49					184	112	12	8											1		317
2.50–2.99				14	647	79	10	2												2	754
2.00–2.49				318	792	46	6														1162
1.50–1.99			74	1768	578	40	6										1			1	2468
1.00–1.49			1339	1765	304	27	1											1			3437
0.50–0.99		1078	3826	1118	328	22												1			6373
0.00–0.49		2653	2559	515	87	4										15	1	1	1	1	5837

Figure 37. Box plots and scatter plot of significant wave heights and periods at Väderöarna between 2005 to 2007.

APPENDIX 8: G14 GUIDELINES

In the assignment, references are made to the BWCs Guidelines on designation of areas for ballast water exchange (G14). G14 consists of 11 sections and few sections are included below to present some of the governing principles and recommendations relevant to this report. The numbering of the chapters are taken from the guidelines.

(Comment: The report describe the recommendations of the parameters distance from the nearest coast and the depth. The BWE, according to the BWC, can be conducted in an area >200 nm from the nearest coast and with a depth of >200 m. If a ship is unable to follow these recommendations then the BWE can be conducted in an area >50 nm from the nearest coast and with a depth of >200 m. A ship is not obligated to follow these recommendations if it means that by following the recommendations it has to make a detour or be delayed.)

7 IDENTIFICATION OF POTENTIAL SEA AREAS FOR BALLAST WATER EXCHANGE

Important resources and protected areas 7.2.3
In the designation of BWE area, Parties should consider and avoid, to the extent practicable, potential adverse impact in aquatic areas protected under national or international law, as well as other important aquatic resources including those of economic and ecological importance.

Navigational constraints:

7.2.4 Any designation of ballast water exchange areas should take into account navigation impacts, including the desirability of minimizing delays, as appropriate, taking into consideration the following:
.1 the area should be on existing routes if possible,
.2 if the area cannot be on existing routes, it should be as close as possible to them.

7.2.5 Constraints to safe navigation must be considered when selecting the location and size of the ballast water exchange area.

8 ASSESSMENT OF IDENTIFIED SEA AREAS

8.2 The identified ballast water exchange area(s) should be assessed in order to ensure that its designation will minimize any threat of harm to the environment, human health, property or resources taking into account but not limited to the following criteria:

8.2.1 Oceanographic (e.g., currents, depths)
- Currents, upwellings or eddies should be identified and considered in the evaluation process. Sea areas where currents disperse discharged ballast water away from land should be selected where possible.
- Areas where tidal flushing is poor or where a tidal stream is known to be turbid, should be avoided where possible.
- The maximum water depth available should be selected where possible.

8.2.2 Physico-chemical (e.g., salinity, nutrients, dissolved oxygen, chlorophyll ‘a’)
- High nutrient areas should be avoided where possible.

8.2.3 Biological (e.g., presence of Harmful Aquatic Organisms and Pathogens, including cysts; organisms density)
- Areas known to contain outbreaks, infestations, or populations of Harmful Aquatic Organisms and Pathogens (e.g. harmful algal blooms) which are likely to be taken up in Ballast Water, should be identified and avoided where possible.

8.2.4 Environmental (e.g., pollution from human activities)
- Sea area(s) that may be impacted by pollution from human activities (e.g., areas nearby sewage outfalls) where there may be increased nutrients or where there may be human health issues, should be avoided where possible.
- Sensitive aquatic areas should be avoided to the extent practicable.

8.2.5 Important resources (e.g., fisheries areas, aquaculture farms)
- Location of important resources, such as key fisheries areas and aquaculture farms should be avoided.

8.2.6 Ballast water operations (e.g., quantities, source, frequency)

- A foreseen estimation of the quantities, sources and frequencies of ballast water discharges from vessels that will use the designated sea area should be considered in the assessment of such area.

8.3 An assessment of the most appropriate size of the designated ballast water exchange area needs to take into account the above considerations.

9 DESIGNATION OF SEA AREAS FOR BALLAST WATER EXCHANGE

9.1 The location and size that provide the least risk to the aquatic environment, human health, property or resources should be selected for designation. It may also be possible for the designation of a ballast water exchange area to apply over specified timeframes.

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ISSN 0283-7714