Factors of potential importance for the location of wind-driven water pumps in the Bornholm Basin

Technical report no.2

Malin Ödalen &
Anders Stigebrandt

C97
Rapport
Gothenburg 2013

Department of Earth Sciences
University of Gothenburg

Naturvetenskapliga fakulteten

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Abstract

The project BOX-WIN aims to construct a full-scale wind-driven pump for combined deepwater oxygenation and production of electric power to the grid. The objective of this report is to prospect the Bornholm Basin for suitable locations for the anchoring of wind-driven pumps. The investigated features are water depth, sediment type, extreme wind, current, wave and sea ice conditions, proximity to munition dumpsites, warning zones and sea floor installations, distance to land, ship traffic intensity and important areas for birds and for cod reproduction.

By initial inspections of topography, six sites that may be of interest for a pump installation in the Bornholm Basin are further assessed. For safety reasons, no locations within the primary dumping zone for chemical munitions have been considered. However, some sites are located within the secondary dumping zone and a military warning zone. At the investigated sites, sediment types range from mud to sand. In areas with sandy sediments, extreme events may cause current speeds of up to 1 m s^{-1}. Maximum wind speed and wave height are estimated to about 45 m s^{-1} and 15 m respectively. Ice coverage only appears during severe or extremely severe ice winters and primarily in the western parts of the basin. All of the sites are far from sea floor installations such as submarine power cables and the Nord Stream pipeline. Most of the evaluated locations are far from land (>20 km), but two sites are in the vicinity of the small island Christiansø, north-east of Bornholm island. However, these two sites are located within important bird areas. The entire Bornholm Basin is also a crucial area for cod spawning. Thus, this is an example of an ecological factor that may be of importance, independent of which location is chosen for the anchoring of a wind-driven pump. Ship traffic is more intense in the northern part of the area, due to the presence of the main shipping lane. A minimum in ship traffic is found north-east of Bornholm, near Christiansø. A concluding table presenting the status of the investigated characteristics at each site is constructed to summarize the report.

Sammanfattning

Projektet BOX-WIN har till syfte att konstruera en fullskalig, vinddriven pump för kombinerad syresättning av djupvatten och produktion av ström till elnätet. Målet med denna rapport är att finna möjliga platser i Bornholmsbassängen för förankring av konstruktionen. De undersökta egenskaperna i bassängen är vattendjup, sedimenttyp, extrema förhållanden för vind, strömmar, vågor och is, placering av områden för dumpning av kemiska stridsmedel och militära varningsområden samt anläggningar på havsbottnen, avstånd till land, fartygstrafikens intensitet samt viktiga områden för fåglar och fortplantningsområden för torsk.

Genom inledande undersökningar av Bornholmsbassängens topografi har sex platser som skulle kunna vara av intresse för en pumpinstallation lokaliseras och dessa utvärderas sedan vidare. Av säkerhetsskäl har inga platser i det primära dumpningsområdet för kemiska stridsmedel beaktats. Dock ligger några av de undersökta platserna inom det sekundära dumpningsområdet och inom militära varnings- och övningsområden. Vid de undersökta platserna varierar sedimenttyperna från lera till sand. I områden med sandiga sediment är det möjligt att det förekommer strömhastigheter på upp till 1 m $s^{-1.}$ Maximal vindhastighet uppskattas till ca 45 m s^{-1}. Maximal våghöjd, den s.k. hundraårsvågen, förväntas vara ca 15 m. Istäcke förekommer endast under svåra isvintrar och då främst i den västra delen av Bornholmsbassängen. Istäcke i hela bassängen är ovanligt, men det förekommer. Alla de utvärderade platserna ligger långt från anläggningar på havsbottnen, så som elektriska undervattenskablar och Nord Streams gasledningar. De flesta av dessa platser ligger långt från land (>20 km), men två platser ligger i närheten av den lilla ön Christiansö i ögruppen Ertholmene, nordost om Bornholm. På grund av närheten till öarna ligger dessa två platser inom viktiga fågelområden. Hela Bornholmsbassängen är också ett viktigt område för torskens fortplantning. Torsklek är därmed en ekologisk faktor som kan vara av betydelse oavsett vilken plats som väljs för förankring av en vinddriven pump. Fartygstrafiken är mer intensiv i den norra delen av det studerade området där den allmänna farleden går. Ett minimum i fartygstrafik finns nordost om Bornholm, nära Christiansö. Statusen för de undersökta egenskaperna på var och en av de utvalda platserna sammanfattas i en avslutande tabell.

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Preface

Results from the BOX-WIN project will be presented in a series of reports from the Department of Earth Sciences at the University of Gothenburg. A wide range of subjects are covered by BOX-WIN. Technological, environmental, economical and legal facts and circumstances must be considered to develop and locate a full-scale Demonstrator composed of a self-supporting, floating wind turbine unit with a generator producing electric power for deepwater oxygenation by pumping and for delivery to the grid. The Demonstrator will be developed for the Bornholm Basin, which at times has anoxic water in its deepest parts. The BOX and PROPPEN projects have shown that phosphorus leakage from anoxic bottoms may be stopped by oxygenation. The Demonstrator developed by BOX-WIN will hopefully be built to conduct tests in the Bornholm Basin. This would be an important step towards installation of a regional system of full-scale floating wind turbine units with pumps in the Bornholm Basin. An updated list of BOX-WIN reports is included at the end of the report.

The present report "BOX-WIN Technical report no. 2 - Factors of potential importance for the location of wind-driven water pumps in the Bornholm Basin", is written by Malin Ödalen and Anders Stigebrandt. The work is funded by the Swedish Agency for Marine and Water Management and Baltic Sea Action Plan Fund via Nordic Investment bank.

Gothenburg 14 January 2013

Anders Stigebrandt

1. Introduction

The project BOX-WIN aims to construct a full-scale wind-driven pump for combined deepwater oxygenation and production of electric power to the grid. For this, suitable locations in the Bornholm Basin are prospected in this report, where we present characteristics that may be of importance for a location to be appropriate for the anchoring and operation of the pump and for the results of the pumping to be measurable. The considered characteristics are

- the water depth; locations that are as deep as possible will be sought.
- sediment type.
- wind conditions
- current conditions
- wave conditions
- ice conditions
- proximity to munition dumpsites and warning zones.
- distance to electric cables or other installations on the sea floor, such as the Nord Stream gas pipelines.
- distance to land for connection to the grid.
- ship traffic intensity.
- environmental factors.

Topographic maps, sea charts, sea ice statistics, wave statistics, information on current conditions, maritime traffic statistics and maps of sediment type and ecologically important areas from the Bornholm Basin area have been evaluated to find possible locations of interest and the results of these investigations are presented in this report. Positions of locations are described by degrees and decimal minutes of longitude and latitude.

2. Topography

An overview of water depths is provided by a topographic map with a longitude (latitude) grid resolution of 2 (1) minutes, based on the topographic database of Leibniz Institute for Baltic Sea Research (Leibniz-Institut für Ostseeforschung Warnemünde, IOW)[1], see Figure 1. Depths are mean depths of each grid cell.

After comparison with online sea chart images of the area (based on digital sea chart data from Kort & Matrikelstyrelsen, KMS, Denmark)[2], some sites with large depths or with interesting topographic features are found. These are located within three main areas which are further presented below. Additional assessment of these areas with respect to sediment

type, warning zones, installations on the sea floor, shipping lanes and ecology will be made in sections 3-9.

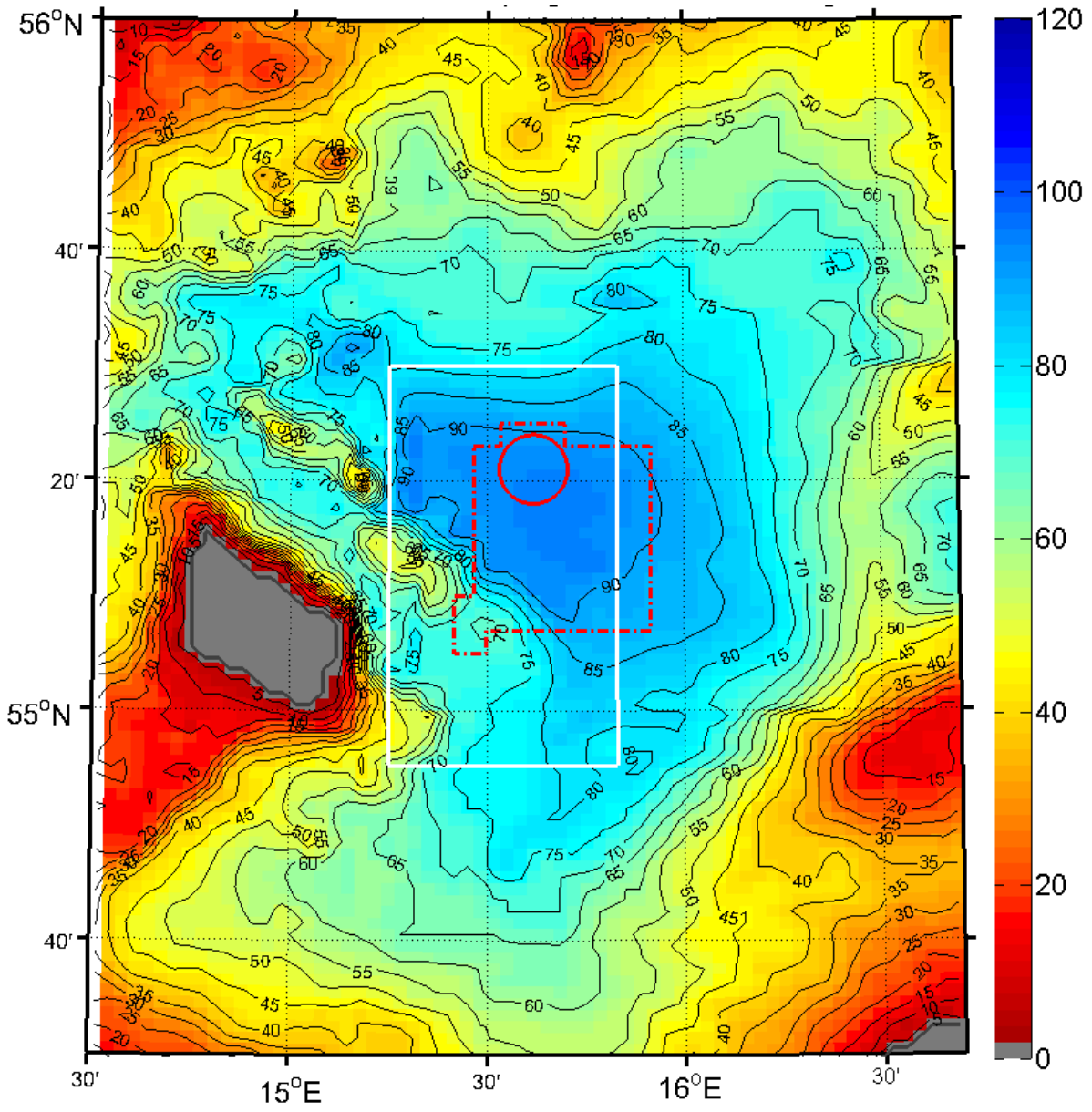


Figure 1. Topography of the Bornholm Basin area (longitude (latitude) grid resolution, 2 (1) minutes). Red lines mark known munition dumpsites (solid line – primary dumpsite, dashed line – secondary dumpsite). White line marks military warning zone. Bornholm island is marked in dark grey and the contour for zero depth. Maximum depths in the centre of the basin exceed 100 m.

2.1 North

An isolated deep basin is found north of Bornholm, at 55° 32’ N, 15° 9’ E, henceforth called site a). For a zoom on this area in the topographic map, see Figure 2. According to online sea chart images[2], anchoring and other seabed activities are not advised in the proximity of this area. However, the reason for this recommendation is not stated. The online sea chart images also show that the main shipping lane crosses the area where this basin is located.

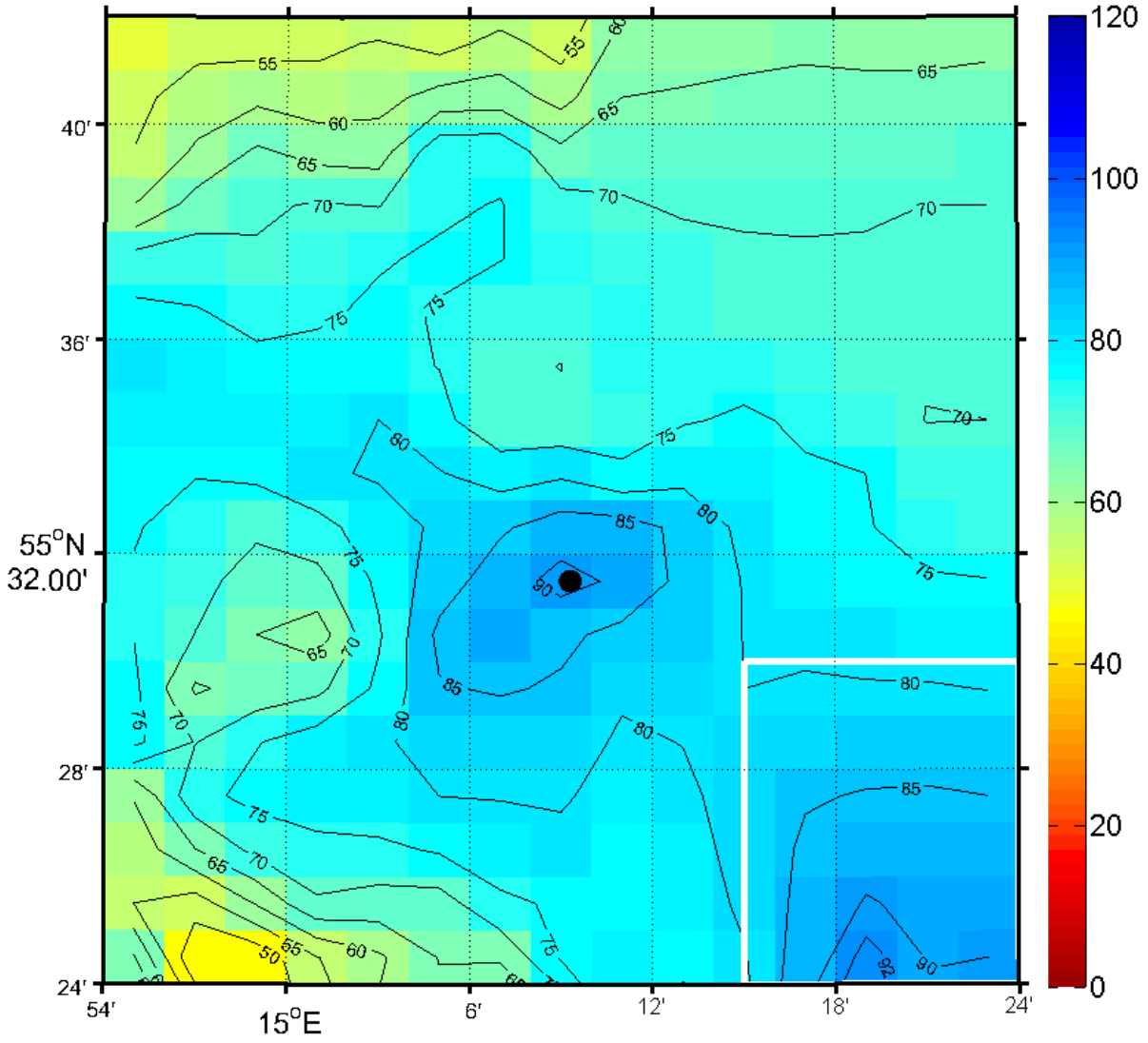


Figure 2. Area of interest north of Bornholm island, with a small deep basin of >90 m depth, outside of military warning zone and munition dumpsites. The deepest part of the basin is marked by a black dot. This location will be referred to as site a).

2.2 North-East

In the vicinity of the small island Christiansø (the biggest of the islands in the group called Ertholmene), two connected areas with mean depths >92 m can be found (see Figure 3). The northern will be further evaluated in this paper, and will be referred to as site b). According to online sea chart images[2], another deep area is located close to the island (see green dots in Figure 3 and Figure 4). Here, the local depth is indicated to exceed 100 m. The area is not visible in the topography in Figure 3 due to the coarse resolution of the topography database. This location will be called site c).

2.1 East

Near the eastern limit of the secondary dumping zone for munitions (see Figure 1) the water depths are large and may thus be of interest for the BOX-WIN project (Figure 5). Local depths of >95 m at some distance from the centre of the secondary dumping zone have been sought in online sea chart images[2] and possible suitable locations are marked in the map in Figure 5 (sites d-f). For safety and other reasons, it may be of interest to stay outside of the limits of the warning zones marked in the maps. This topic is further discussed in section 5.

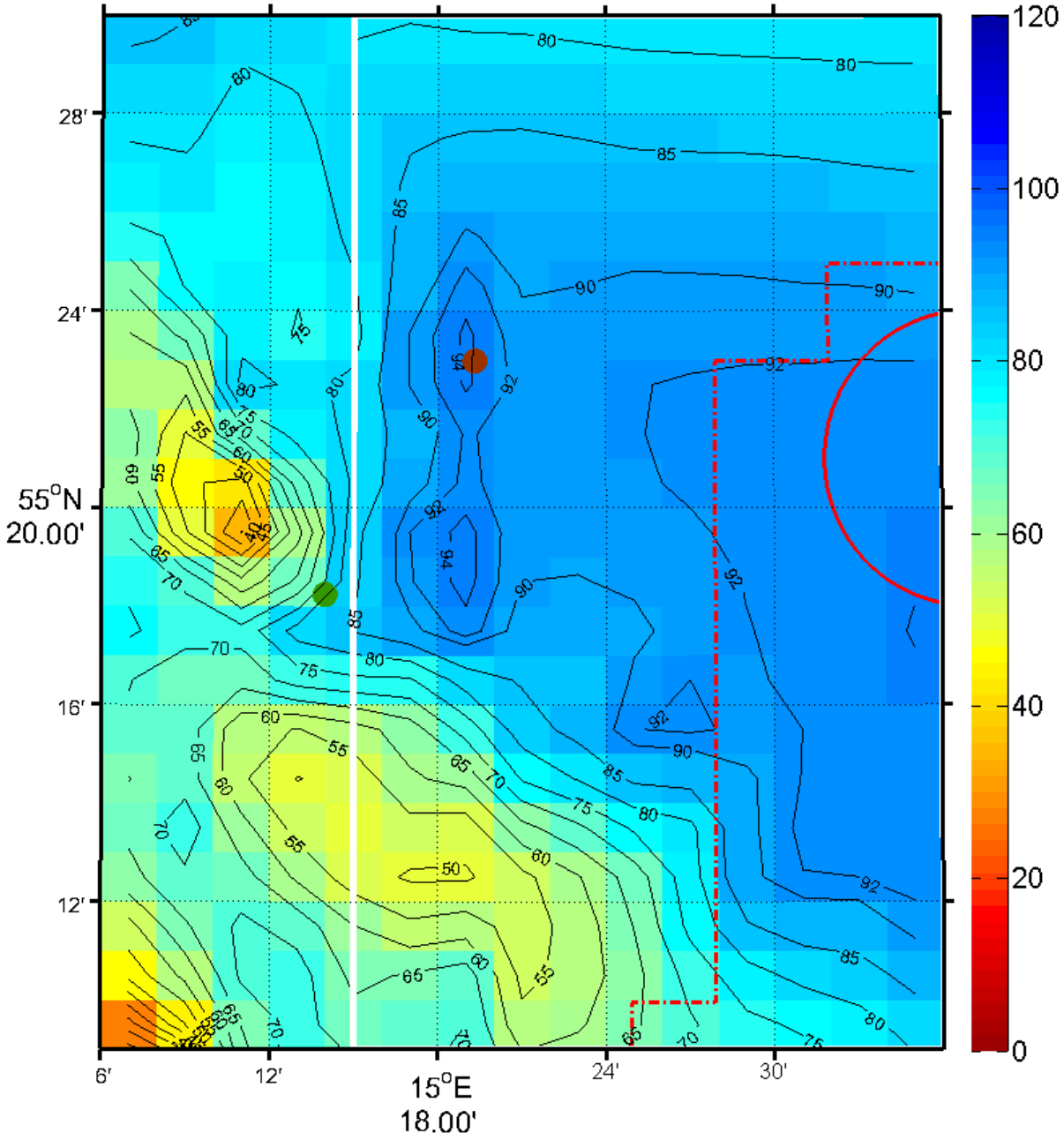


Figure 3. Area of interest north-east of Bornholm island. An area of mean depths >92 m is found just inside the military warning zone, but outside of the munition dumpsites. Here, the site marked by a brown dot will be further investigated (site b). According to online sea chart images (see Figure 4) a depth of >100 m is located closer to Christiansø (Ertholmene, orange area at 55° 19' N, 15° 11' E). This deep area is here marked with a green dot (site c) and will also be of interest for further examinations.

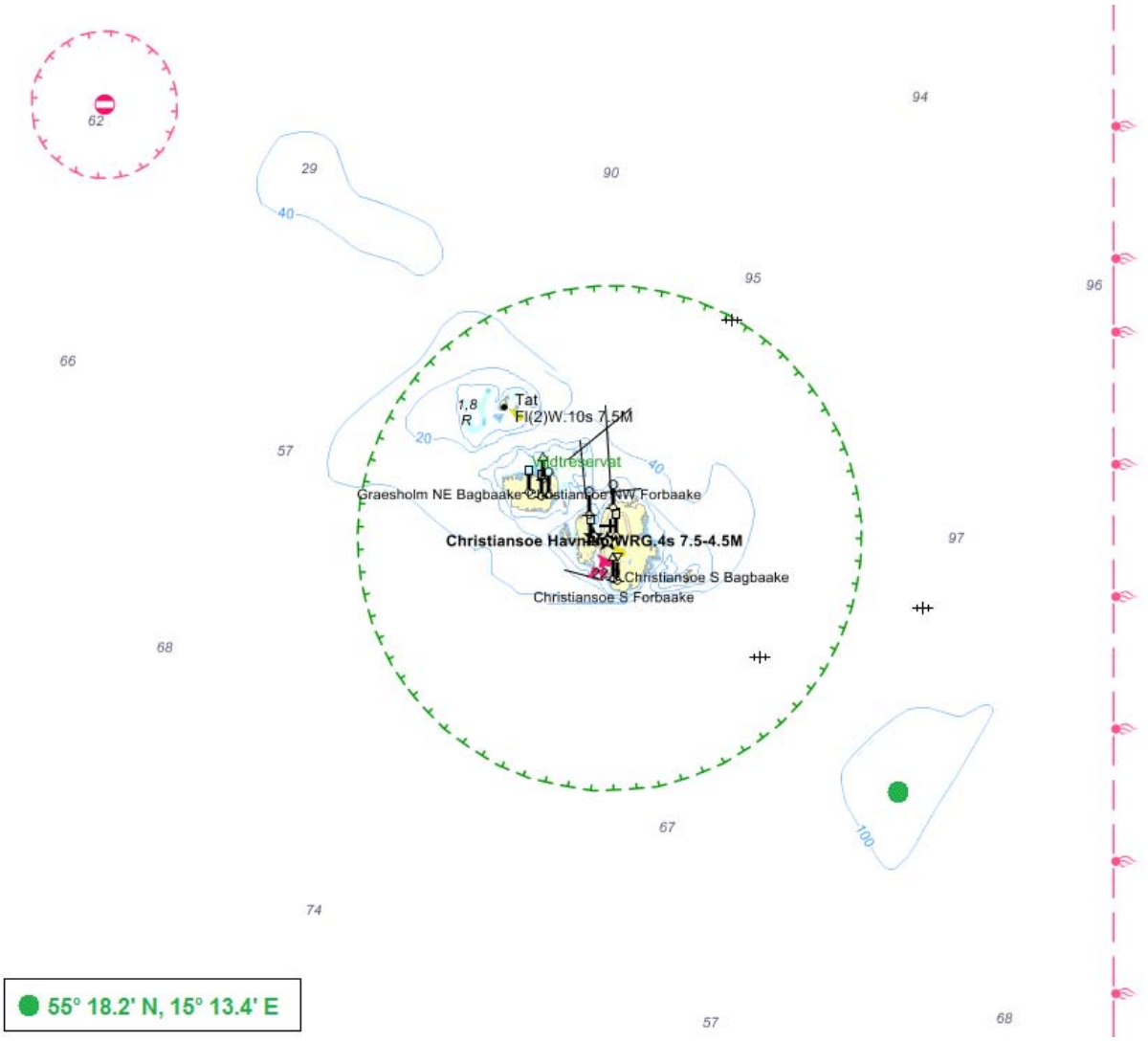


Figure 4. Screen shot of a chart of the waters surrounding Christiansø/Ertholmene (captured from http://kartor.eniro.se)[2]. The green dot marks the approximate centre of the >100 m depth area and has been added manually to the image (site c). Its position was however given by the GPS function of the above mentioned website. The red line with flames marks the limit of the military warning zone (see white line in Figure 3). © Copyright Eniro. Reproduced with the permission from Kort & Matrikelstyrelsen (KMS, Denmark) and Eniro.

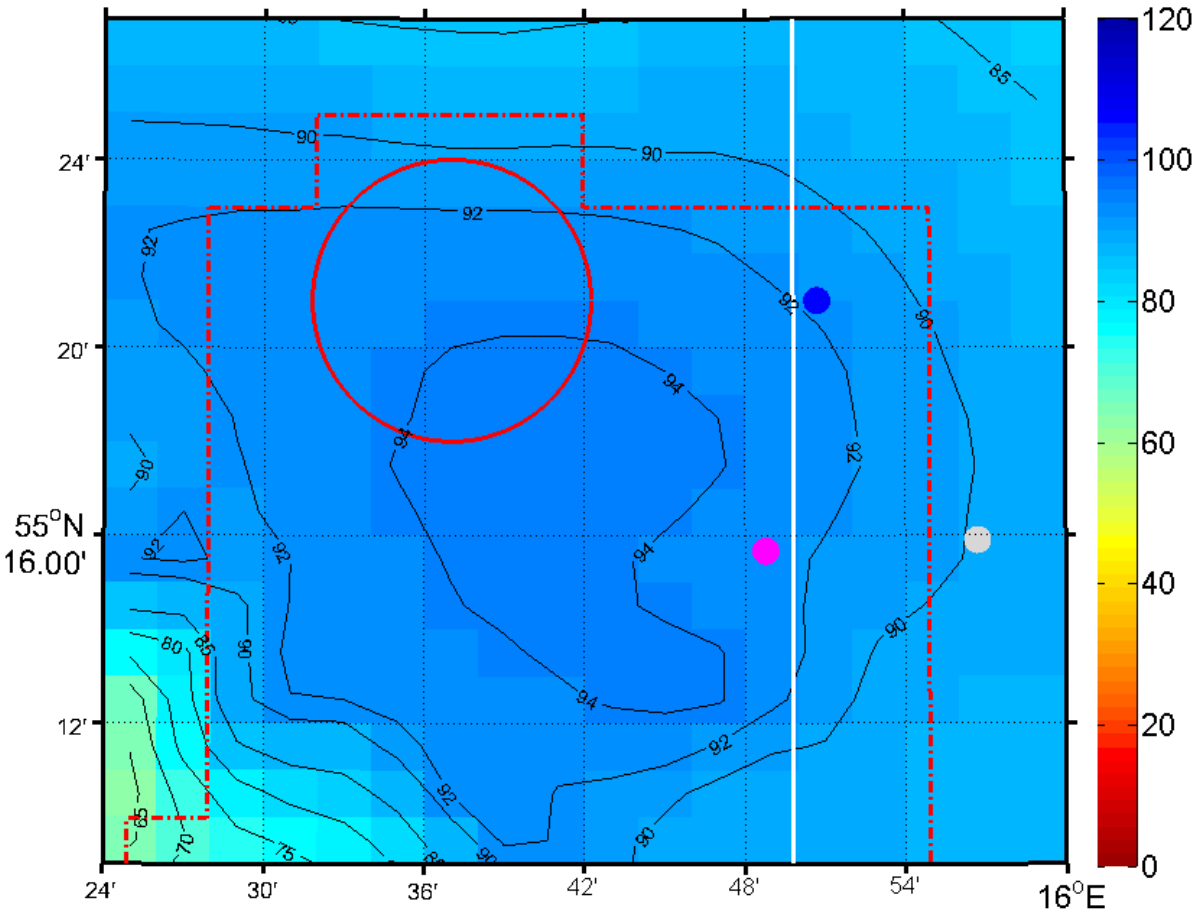


Figure 5. Area of interest east of Bornholm island. The coloured dots represent some locations where the local depth is >95m, according to online sea chart images[2]. The positions and depths of these locations can be found in Figure 12 in section 8 (sites d (blue), e (magenta) and f (grey)).

3. Sediment types

An overview of sediment types in the area was provided by the HELCOM Map and Data Service (Figure 6).[3] In this map, we see that the bottoms in the Bornholm Basin mainly consist of fine grained, muddy sediments. Coarser sediment types are found around the islands Bornholm and Christiansø (Ertholmene).

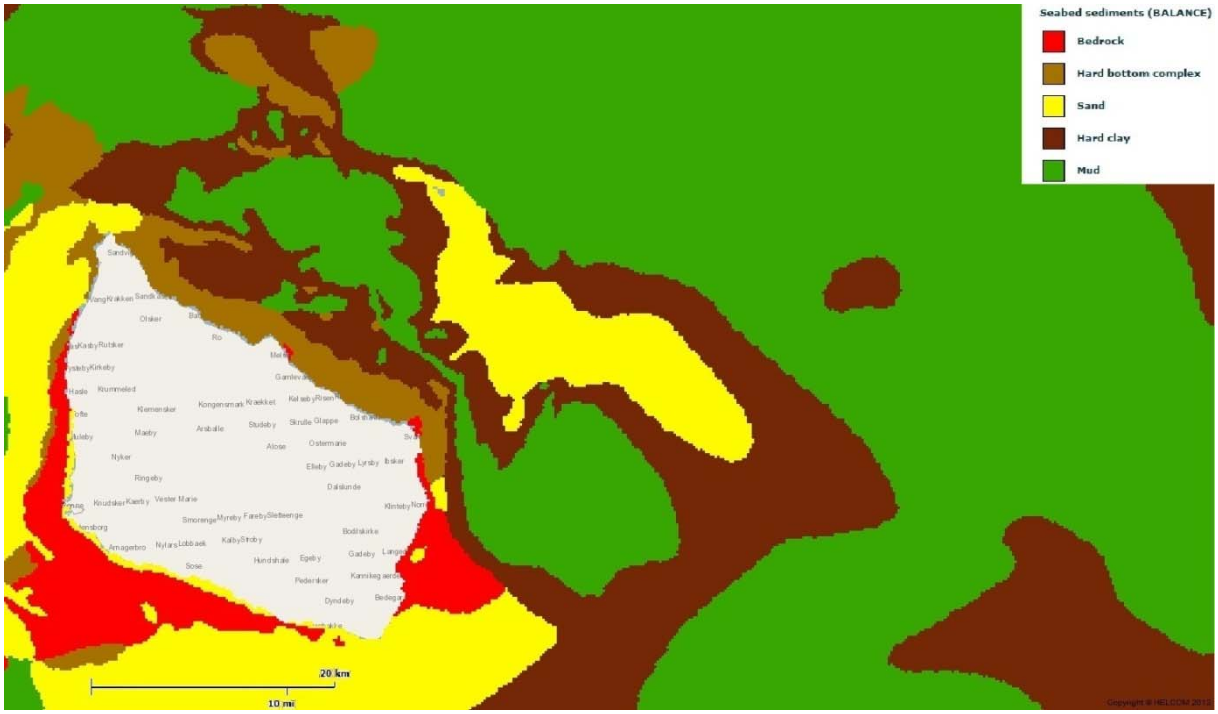


Figure 6. Sediment types in the Bornholm Basin and around Bornholm island. Fine grained, muddy sediments (green) are dominant in the deep basin, with some areas of more course hard clay (brown). Courser sediments are also found in and around the sand bank (yellow) extending from Christiansø towards the deep basin. (map from HELCOM Map and Data Service)[3]

4. Ice, wave, wind and current conditions

Anchored structures like a wind-driven pump must be constructed so that they can stand maximum forces exerted by winds, currents, surface waves and moving ice. It is thus necessary to know the strongest winds, the strongest currents, the highest waves and the largest forces associated to moving ice-structures in areas considered for anchoring wind-driven pumps. Below we describe briefly the wind conditions of the southern Baltic Sea area and the extreme conditions of currents, waves and ice that may be encountered in the Bornholm Sea.

4.1 Wind conditions

The most extreme mean wind measured by SMHI (the Swedish Meteorological and Hydrological Institute) in the southern Baltic Sea area was 40 m s^{-1} at Ölands södra grund (56° 04' N, 16° 41' E) in 1967.[4] This station is located to the north-east of the Bornholm Basin and gives an estimate of the most extreme conditions that may be expected in the area.

At nearby station Hanö, instantaneous wind speeds of 43 m s^{-1} have been registered in 1999.[4] Thus, during extreme events, winds up to 45 m s^{-1} may occur in this area.

General observed wind conditions from measurement stations in the Baltic Sea area are presented in Höglund et al. (2009).[5] Their wind distribution diagram from station Utklippan (55° 57' N, 15° 42'E), located off the coast of Blekinge, north-east of Bornholm, is shown as an example of the wind conditions in the investigated area (Figure 7). The distribution from Ölands södra udde (56° 12' N, 16° 24' E) in the same publication as well as other published distributions from the southern Baltic Sea[6,7] are similar to the distribution from Utklippan, which can therefore be considered to be representative for the area. The distribution is centred at wind speeds of about 5 – 8 m s^{-1} and shows that wind speeds higher than 15 m s^{-1} are rare.

In a report by Cappelen and Jørgensen (2009)[8] for the Danish Meteorological Institute (DMI) statistics of observed wind speeds and directions from Christiansø 1961 – 1990 are presented. The report shows that westerly winds are dominant in the area and the mean wind speed is 8.5 m s^{-1}.

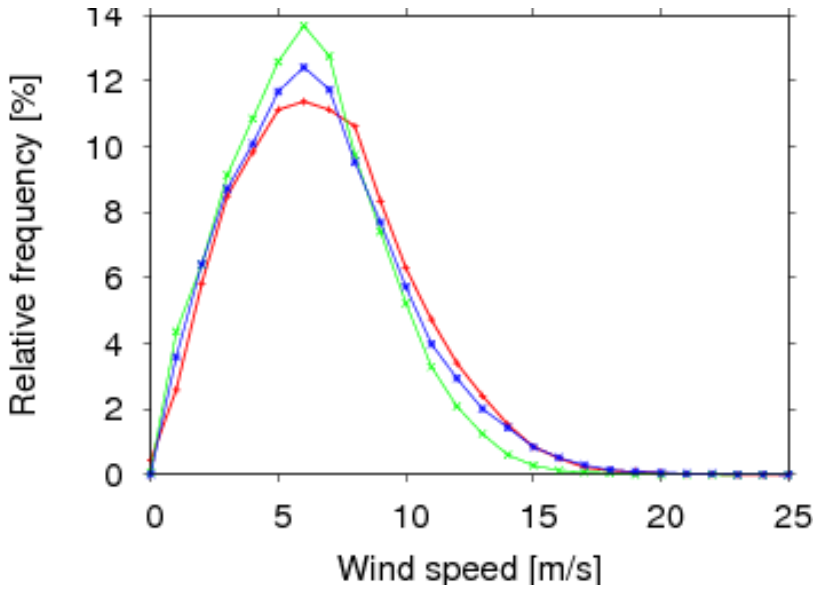


Figure 7. Observed and simulated winds at station Utklippan from Höglund et al., 2009 (reproduced with the permission of the authors).[5] In these figures the red graph corresponds to observations and the green and blue lines to unmodified model results and modified model results respectively. The model evaluated in the study is the regional model RCA (ver. 3.0), with lateral forcing from the global ERA-40 model.

4.2 Current conditions

According to SMHI there are no prevailing surface currents in the Baltic Sea,[9] and thus this is also the case for the Bornholm Sea. Temporary currents arise from wind forcing and changes in sea level. In the halocline, currents with speeds of 0.5 m s^{-1} have been observed.[10]

Average currents near the bottom are in general weak, with speeds of less than 0.1 m s^{-1}. [10] Strong currents in the deepwater of the Bornholm Basin only occur during inflow events, when dense bottom currents originating from the Kattegat penetrate to the deepest part of the basin.[11] Such events are rare and occur more seldom than once per year,[11] with the strongest occurring only about once per decade.[12]

During such an inflow current speeds of 0.75 cm s^{-1} have been registered. The event, described in Piechura and Beszczyńska-Möller (2003)[13] was labelled a medium-sized inflow. It is thus reasonable to expect that, for large inflows, current speeds should be able to reach at least 1 m s^{-1}. The thickness of the inflow layer observed in 2003 was about 20 – 30 m. Similar results are found for the inflow of 1993 described in Liljebladh and Stigebrandt (1996).[12]

Areas where high current speeds occasionally occur can be located by observation of sediment types in the area. High current speeds are generally associated with coarser sediment types,[14] and thus those of the investigated sites that are located in areas with sandy or hard clay sediments are likely to experience stronger bottom currents than those where sediments are muddy. When comparing the sediment distribution in Figure 6 to the paths of dense bottom currents, as described by Sivkov and Sviridov (1994)[11] (see Figure 8), it is clear that the sites a) – c) north of Bornholm will be subjected to stronger currents than the sites located further to the east (d – f), in the centre of the Bornholm Basin. Location c), where the sediments consist of sand, is likely to be the site most influenced by strong bottom currents.

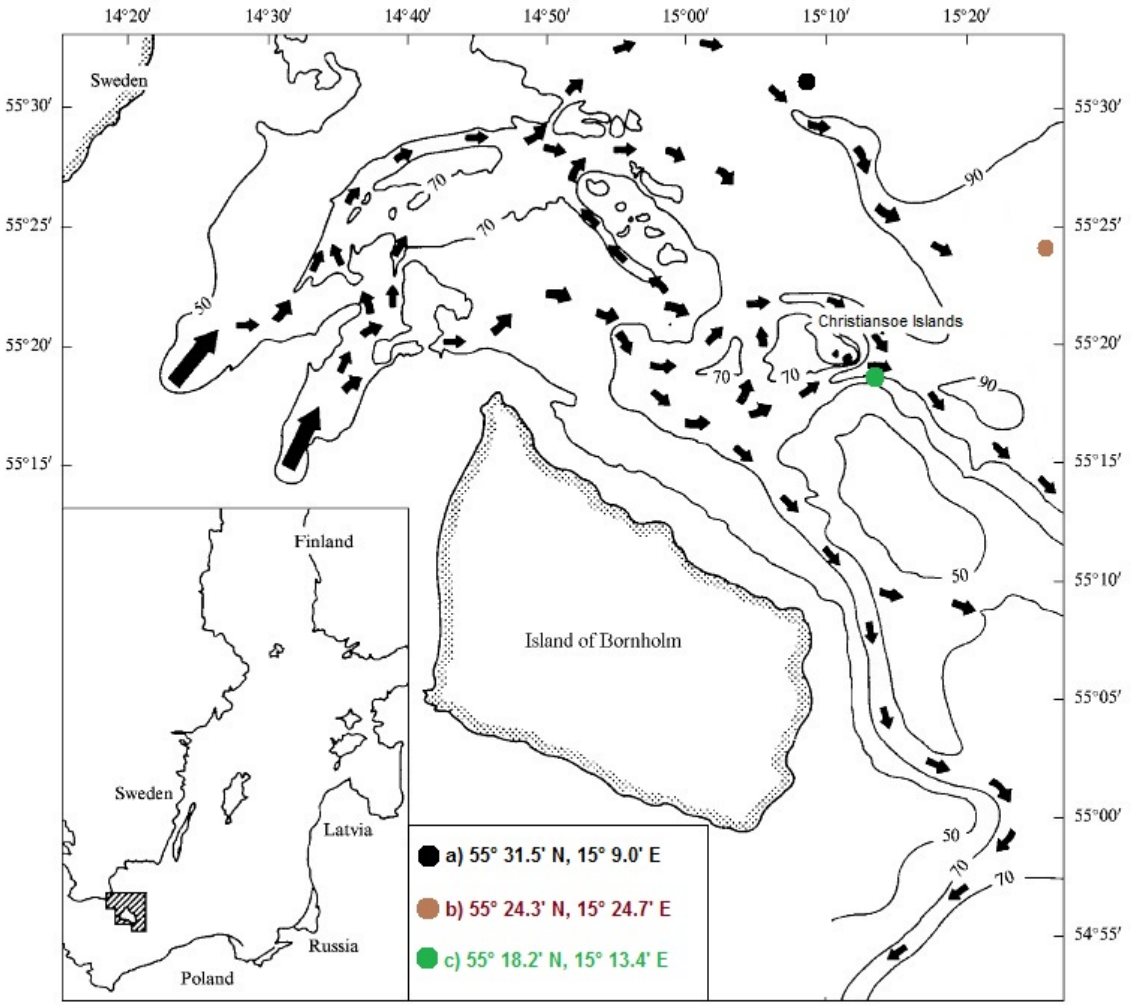


Figure 8. Paths of dense bottom currents after entering the Bornholm Basin through the Bornholm Strait and positions of investigated sites north and north-east of Bornholm Island. (map adapted from Sivkov and Sviridov (1994))[11]

4.3 Wave conditions

The potential impact of wave action may be estimated through the maximum significant wave height that should be expected in the area and the maximum height of single waves that may occur in connection with such events. Significant wave height is commonly referred to as the average of the highest one-third of waves and the maximum wave height that should be expected in association with this wave action is approximately twice the significant wave height.[15] The maximum significant wave height that should be expected in the southern Baltic Sea is about 7 m,[16,17] and thus the maximum height of single waves should be roughly 15 m. The reoccurrence period of such extreme events is around 100 years.[17]

Distributions of measured significant wave heights from two measurement stations in the southern parts of the Baltic Sea are presented in Carstens (2008).[18] Both distributions are similar (see example in Figure 9) and they show that significant wave heights of more than 2 - 3 m are rare.

We have not tried to estimate local differences in extreme wave conditions between the investigated sites.

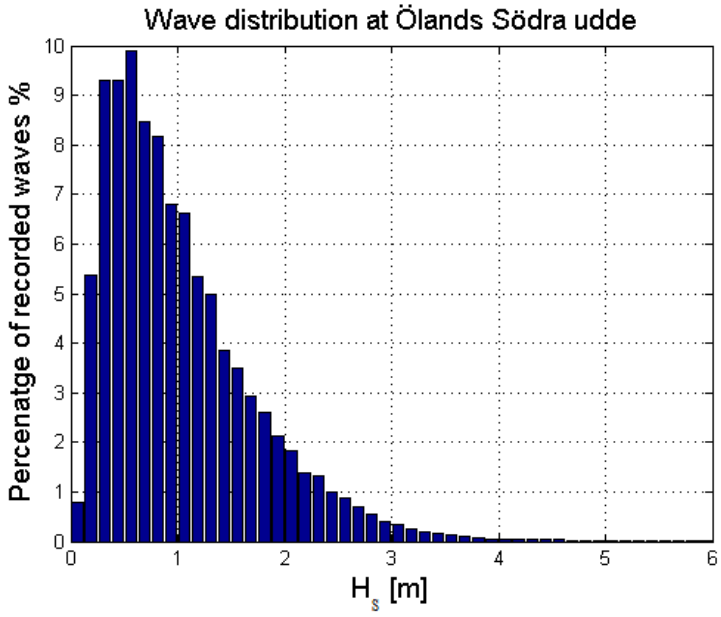


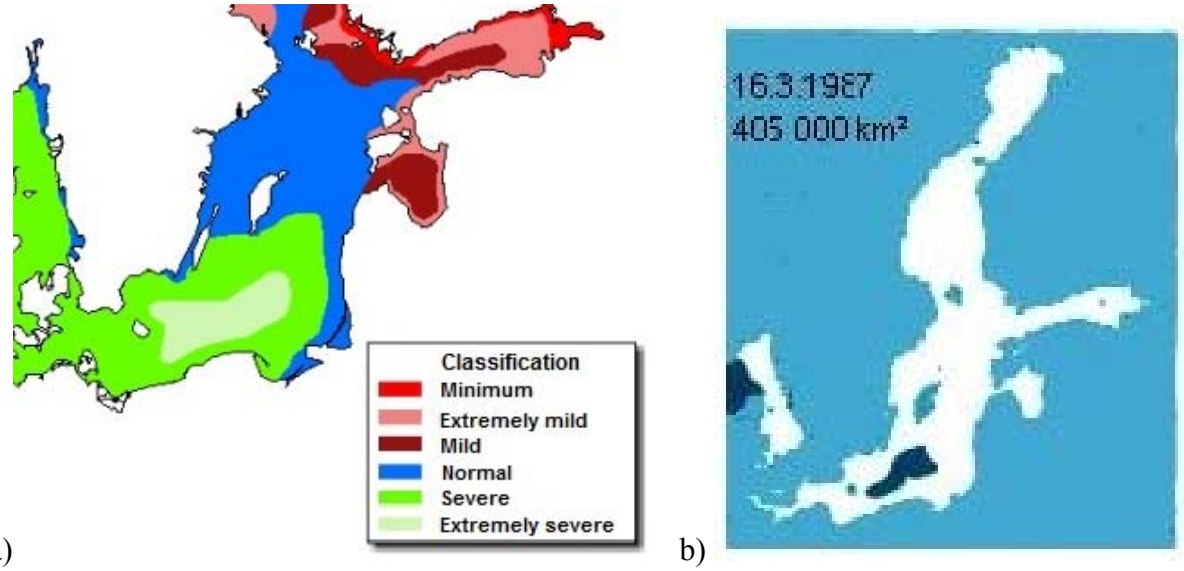
Figure 9. Distribution of significant wave heights, H_S, based on SMHI measurements (1978 – 2004) from Ölands södra grund (56° 04' N, 16° 41' E). (After Carstens (2008)[18], reproduced with the consent of the author.)

4.4 Ice conditions

In the southern Baltic Sea, ice coverage does not occur every winter. In the Climatological Ice Atlas, which presents statistics for 1963 – 1979 for the area, the probability of ice occurrence around the investigated sites is between 10 and 25% with lower probabilities in the eastern part of the area (sites d – f). During a winter with ice coverage, the average number of days with ice is 10 – 20. Freezing usually begins in February and the ice breaks up again, at the latest, by the end of March.[19] According to SMHI,[20] 1963 – 1979 was on average a period with more events of severe ice conditions than the past 10 years, so the statistics in the Climatological Ice Atlas may represent more difficult conditions than the present average.

Figure 10a shows the different classifications of ice winters and the areas that are covered with ice during a winter of the corresponding classification. According to this image, the area east and north-east of Bornholm, is the area in the Baltic Sea where ice is formed only during

extremely severe ice winters, thus when the total area of the ice is more than 380 000 km^2.[21] Such extreme conditions are rare and according to SMHI this has only occurred once since 1957, when reliable records of ice coverage in the Baltic Sea begin.[20] This happened in 1987 and the maximum extent of the ice for this year is seen in Figure 10b.[22] However, it is reasonable to expect variability within the system and thus, the entire area may experience ice coverage also during severe ice winters.[23] Severe ice winters occur at least a couple of times per decade.[21]



a) b)

Figure 10. a) Classification of ice winters from minimum to extremely severe and the extent of the typical areas that become ice covered during the corresponding type of ice winter. Areas covered with ice during milder winters are also covered during more severe winters. (after Havsmiljöinstitutet – the Swedish Institute for the Marine Environment)[21] b) Maximum extent of sea ice coverage in 1987 (from the Finnish Meteorological Institute, published on The Baltic Sea Portal)[22]. 1987 is the only extremely severe ice winter that has occurred since 1957 when reliable records of ice coverage in the Baltic Sea begin.[20,21]

According to Haapala and Leppäranta (1996)[24], ice thickness north of Bornholm at the peak of the extent of the ice cover in 1987 reached 10-20 cm. The ice was mostly level (non-deformed) drift ice and, between Bornholm and Christiansø, pack ice (90-100% coverage) with some ridging near Christiansø. At the same time waters in the eastern part of the Bornholm Basin were open or semi open (maximum 30% ice). Generally, the frequency of high ice concentration in this area is less than 10% and the most common ice type in the area is open pack ice. According to the Climatological Ice Atlas statistics, level ice thickness in the area is on average below 10 cm and rarely exceeds 20 cm. On average, the amount of ridged ice stays below 10%.[19]

5. Warning zones

To further narrow the selection of locations that may be suitable for pumping, limits of known munition dumpsites and military warning zones were added to the topographic map in Figure 1.[2] Since anchoring and work on the sea floor within these limits are not prohibited, though not recommended, some sites in these areas will still be further evaluated (sites b, d and e). However, sites close to the primary dumping zone or near the centre of the secondary dumping zone have been avoided in the search for locations of interest. This decision was made due to the results of studies of the abundance of munitions in the sediments of these areas[25] and on the findings of the HELCOM report on chemical munitions dumped in the Baltic Sea[26]. If a site inside of these limits should, for other reasons, be considered the most appropriate for the anchoring of the pump, the presence of these warning zones in the area are likely to be an important issue in further investigations of the location. Site f) is not located within these warning zones, but in an overlapping military submarine exercise area. This exercise area extends east and south from the edge of the primary munition dumping zone. [27] Consequently, site e) will also be affected by these exercises.

6. Installations on the sea floor and other sea floor activities

The examined sea chart images[2] do not show any submarine power cables or any other fixed installations in this area. However, for the chosen location this matter should be further investigated. This conclusion is made from the fact that the Nord Stream gas pipelines are known to be present west of the munition dumpsites[3,27,28] (see Figure 11), but are not marked in the sea chart images. None of the sites of interest are affected by the position of the pipeline (see Figure 12 in section 8). The HELCOM Map and Data Service[3] has also been used to check for cables and other sea floor activities that may cause concerns in the choice of a suitable location for a full-scale, wind driven pump. The investigated sites are found to be far away from such activities. According to the administration at Christiansø[29], there are no telecommunications or power cables connecting the island to Bornholm, thus no submarine cables should be present on the sea floor between the two islands. As seen in Figure 11, the investigated area will not be affected by present plans for cable and pipeline routes or wind park locations.

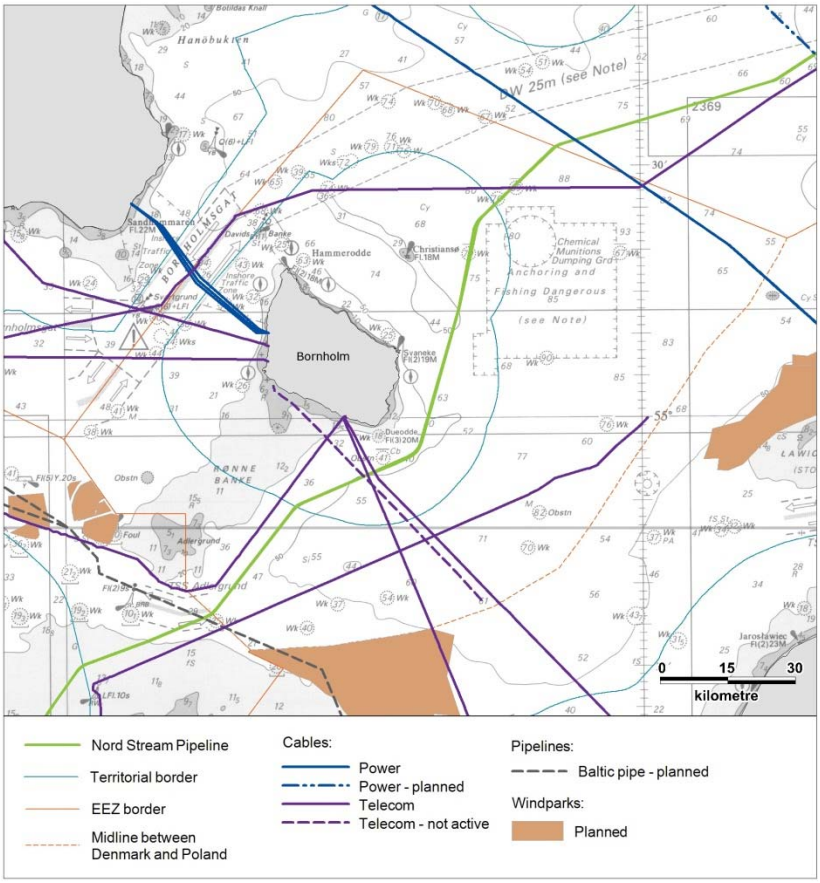


Figure 11. Cable positions, pipeline route (Nord Stream) and munition dumpsites in the Bornholm Basin area. (from Nord Stream AG, 2012)[28]

7. Distance to shore

If the wind-driven pump (the Demonstrator) is located close to land, excess electricity from the wind turbine can easily be transported to shore and connected to the local grid. If a site close to inhabited areas is chosen for the Demonstrator, local regulations for e.g. visual and aural disturbance need to be considered.[30] Because of their proximity to Christiansø, the locations in the north-eastern area of interest (section 2.2) are closest to a local grid compared to the sites in the other investigated areas. Currently Christiansø is powered by diesel generators and there is no power cable connecting the island to Bornholm or the mainland.[29,31]

Table 1. Distance (km) from the investigated sites a) – f) to the nearest shores, which in these cases are the shores of the islands Bornholm and Christiansø (Ertholmene).

Location	Distance to Bornholm (km)	Distance to Christiansø (km)
a)	35	23
b)	34	17
c)	19	2.5
d)	50	41
e)	45	40
f)	53	48

8. Maritime traffic data

Statistics of AIS-data (Automatic Identification Systems) published on the website of the EfficienSea-project[32] can be used as a basis for finding areas where ship traffic is too intense and also for finding locations particularly suitable due to low traffic. These data are shown graphically in Figure 12 together with the positions of the sites of interest for the BOX-WIN project that were presented in section 2.

AIS-data show that the area north of Bornholm (described in section 2.1) is very high in traffic, due to the fact that the main shipping lane is located here (Figure 12). On the eastern side of Christiansø island, where the locations described in section 2.2 are found, traffic is more limited and for the area closest to Christiansø it is very sparse. The eastern area of interest (section 2.3) is also generally low in traffic.

Closures for cod fishing during the spawning season occur every year since the mid-1990s from 1 July until 31 August in the deep parts of the Bornholm Basin[33] (see Figure 13). For some specific areas within the closure zone, the closure has since 2006 been extended to 1 May to 31 October. Due to these closures, ship traffic is expected to temporarily decrease when no fishing vessels are operating in the area. This specifically affects the eastern area of interest.

South and north-east of Bornholm, long-term increases in traffic are expected to occur until 2015 (Figure 13).[3] The largest increase (19 000 – 50 000 ships/year) is expected south of Bornholm and will thus not affect any of the sites investigated in this report. Two of the points of interest are located in the area north-east of Bornholm island, one close to Christiansø island and one further north-east. An increase in ship traffic in this area may influence the point of interest located further to the north-east (Figure 12, brown dot), where traffic is already in the higher range.

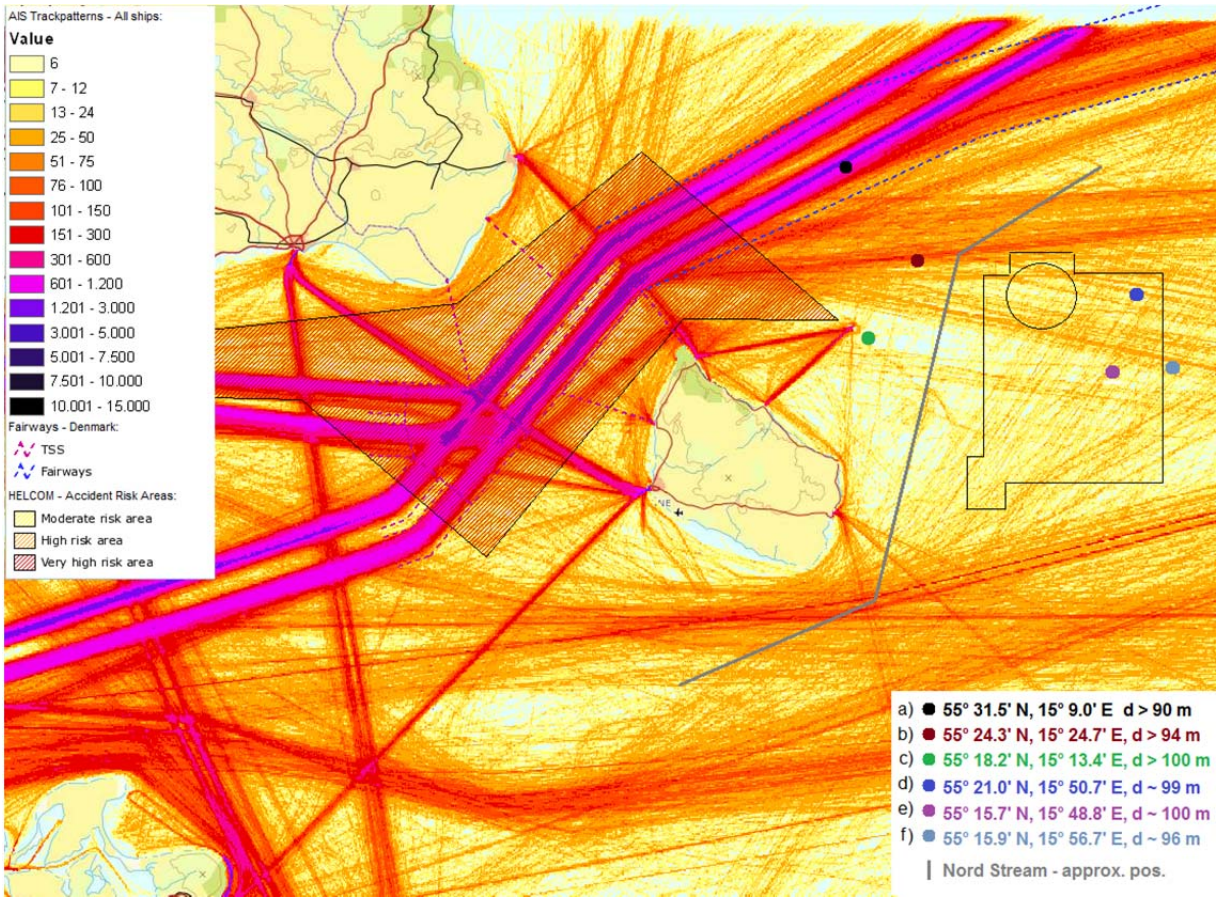


Figure 12. Map of AIS maritime traffic data completed with munition dumpsites, Nord Stream gas pipeline position and sites of potential interest for the BOX-WIN project, denoted a) – f) and marked in the map by coloured dots (see legend). (adapted from the EfficienSea GIS Internet Application)[32]

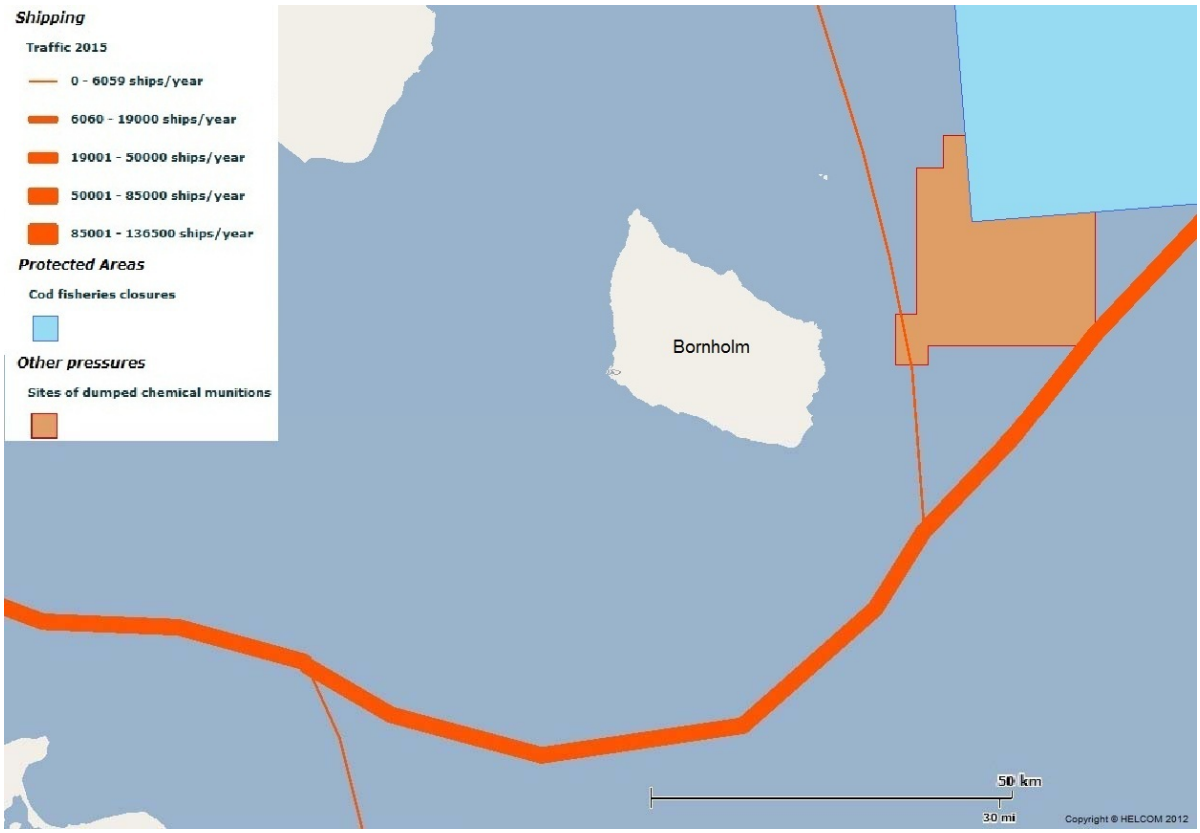


Figure 13. Areas of long-term or periodic changes in ship traffic intensity. Orange lines mark expected increases in traffic until 2015. Cod spawning protection areas are shown in light blue. The area of dumped munitions is marked for reference in comparison with maps in previous figures. (map from HELCOM Map and Data Service)[3]

9. Ecology

9.1 Cod

The Bornholm Basin is known as an important area for cod reproduction[3,34,35] (see Figure 14). As seen in Figure 13, cod spawning is protected through fishing closures in certain areas. However, the location of these protection areas has been questioned by studies of reproduction success for cod, which imply that reproduction is more successful outside of the protection zones.[35,36] Figure 15 shows that the waters between Bornholm and Christiansø islands may be equally important for cod reproduction as the central parts of the Bornholm Basin. These results suggest that effects on cod reproduction need to be considered regardless of which location is chosen for further investigations.

Hinrichsen et al. (2007)[36] studied the reproductive volume for Baltic cod (*Gadus morhua*) in the Bornholm Basin. They defined the reproductive volume as the volume where salinity is

above 11, oxygen concentration exceeds 2 mL L^{-1} and the temperature exceeds 1.5 °C. Waters with sufficiently high salinity are found below 60 m depth.[36,37] They base the definition of these criteria on several previous studies, i.e. Wieland et al. (1994)[38] and Nissling et al. (1994)[39]. According to their results, the thickness of the reproductive volume varies and is significantly larger during inflow years, when the deep water is replaced by new water from the Kattegat. During these years larger volumes of the water with sufficiently high salinity are also sufficiently high in oxygen. The most favourable conditions for spawning occur in the central area of the basin at depths > 80 m. In general, deeper areas were preferred for spawning over well oxygenated water masses and thus the highest concentrations of cod eggs were not always found in the areas with the thickest reproductive volumes and most favourable for survival of the offspring.

According to Nissling and Westin (1991)[40], the Bornholm Basin has become the only area in the Baltic Sea where successful cod spawning can occur. This is due to salinities being too low in other areas to allow cod eggs to float above the hypoxic bottom volume.

9.2 Other ecologically important areas

Around Bornholm island we find several marine protection areas as well as essential areas for moulting birds. Christiansø island and its surroundings is an important area for birds[3]. The entire island has been appointed a nature reserve.

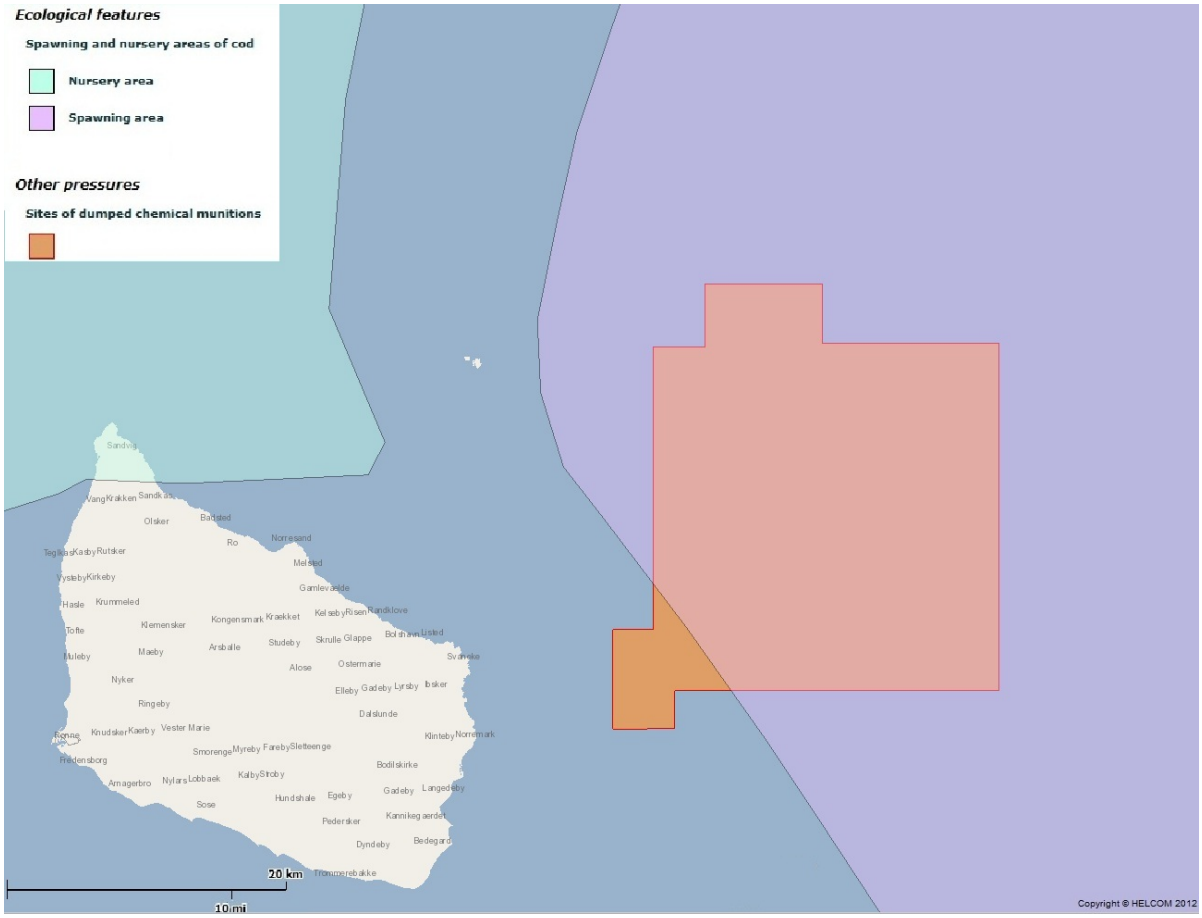


Figure 14. Areas of importance for cod reproduction in the Bornholm basin and around Bornholm island. The main area of dumped chemical munitions is marked for reference in comparison to other maps in this report. (map from HELCOM Map and Data Service)[3]

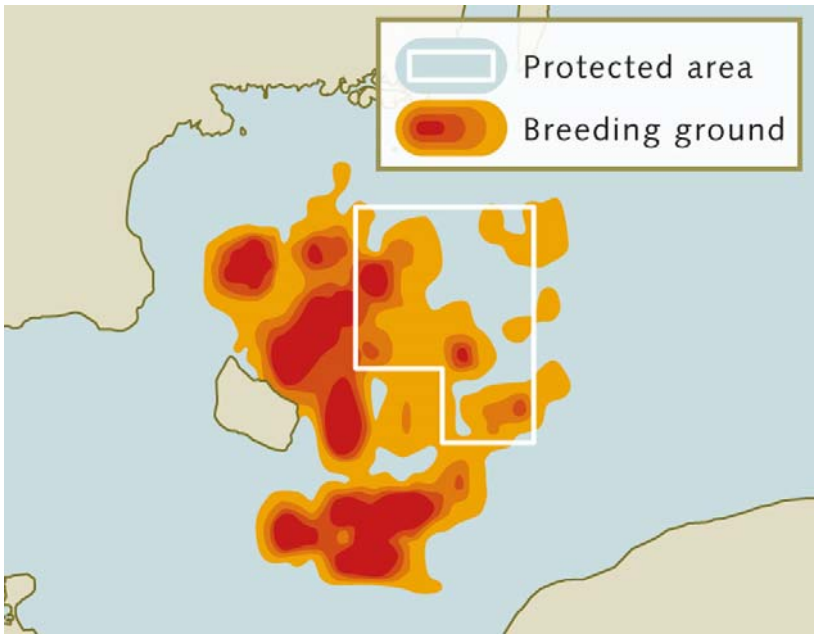


Figure 15. Area protected through fishing closures and the rate of successful breeding for cod in the Bornholm Basin area (from World Ocean Review, maribus gGmbH, Hamburg 2010).[35]

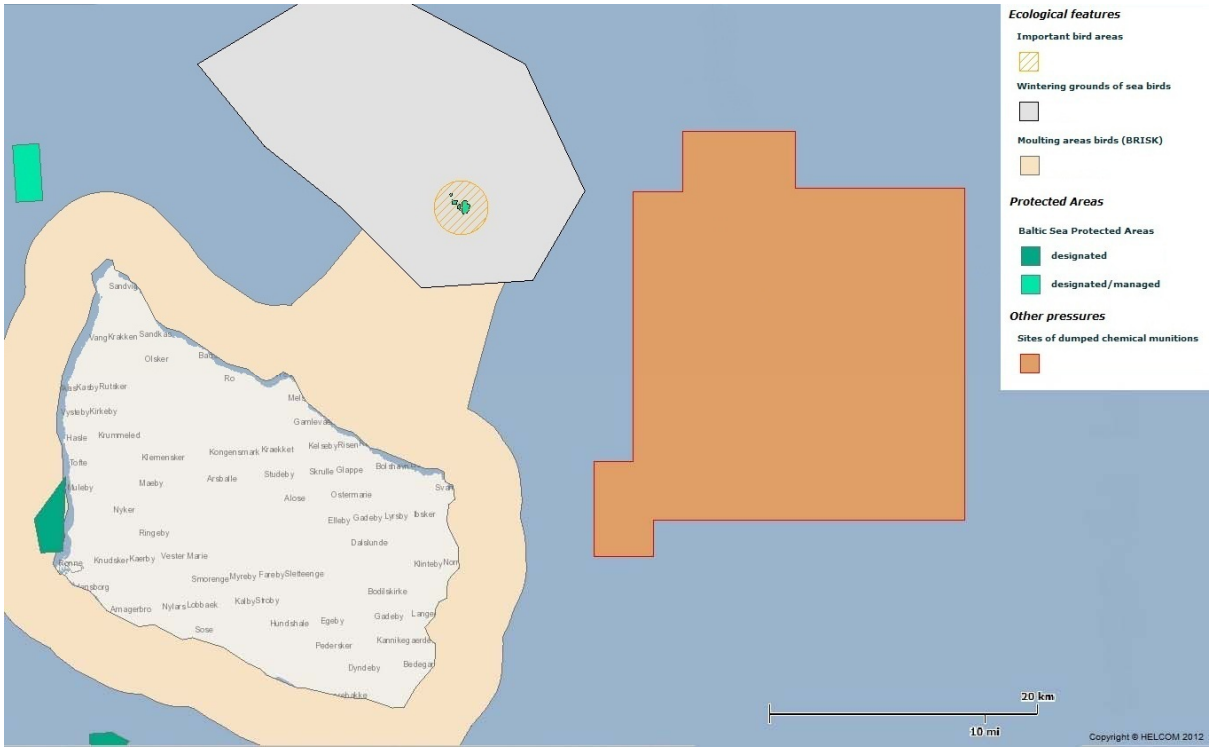


Figure 16. Important areas for birds (general (striped), wintering grounds (grey) and moulting (beige)) and marine protected areas (green). The main area of dumped chemical munitions is marked for reference in comparison to other maps in this report. (map from HELCOM Map and Data Service)[3]

10. Overall assessment of location suitability - summary

An initial assessment of location suitability is made in Table 2 where the aspects of topography, sediment quality, sea floor installations, ship traffic intensity, munition dumpsites and military warning zones are all accounted for (see Figure 12) together with potentially important ecological issues.

Since the entire Bornholm Basin is a crucially important area for cod reproduction, and all the investigated sites are within this area, this feature does not differ between the sites and is thus excluded from the table. The effects caused by ice coverage and extreme wind and wave events are also expected to be similar in all parts of the basin and possibly small differences are difficult to evaluate. Therefore, these factors are also excluded from the table. However, it is likely that the westernmost sites, a) – c), are the first in the area to be subjected to ice coverage during severe ice winters.

Water depths at the investigated locations exceed 90 m in all cases and some reach 100 m, i.e. locations c) and e). The sediment types at these sites are mostly mud or hard clay, except at site c) where we find sandy sediments.

Temporary strong currents may occur during exchange of the deepwater, when dense water from Arkona Basin penetrates to the deepest parts of the Bornholm Sea. The strongest currents occur in areas with coarse bottom sediments. From this point of view, site c) is expected to experience the strongest bottom currents.

The northernmost site, a) (described in section 2.1), is located well outside of munition dumpsites, the military warning zone and important bird areas and is at a safe distance from sea floor installations. It is, however, located within the main shipping lane, and therefore traffic intensity is higher here than in all the other investigated areas.

Within the north-eastern area (section 2.2), two sites of interest have been studied, b) and c). The site b) is located outside of the main munition dumpsites, but within the military warning zone and the important bird areas. It is in the vicinity of Christiansø island and is thus within 20 km from land. Ship traffic is however in the higher range compared to the sites c) – f) and within the prognosis for 2015 traffic is also expected to increase (Figure 13).

At the location just east of Christiansø island, site c), marked by a green dot in Figure 12, all restriction zones are avoided, ship traffic is limited and the location is close to an inhabited area (approximately 2.5 km), thus excess electricity from the wind turbine can easily be brought to shore. However, this site is located within an area that is ecologically important and where events with strong bottom currents are expected.

The three easternmost positions d), e) and f) (section 2.3), are further from land than the other sites and closer to munition dumpsites and military warning and exercise zones. In this area,

ship traffic is generally within a lower range, especially at site e), and is likely to be especially low during cod fishing closures (see section 8). Since this area is far offshore, it is not as important for the bird population as the areas near Christiansø and Bornholm.

The examination of the Bornholm Basin area made in this report may be helpful in finding suitable locations for anchoring a wind-driven pump. However, for a complete assessment of a site of interest the analysis may need to be completed with for example examination of detailed sea charts, sea floor monitoring, sediment scans and more thorough investigations of planned future ship traffic routes.

From the ecological perspective, birds and cod are examples of wild life that may be affected by the BOX-WIN project. However, before a full-scale prototype is built, the chosen location needs to be fully evaluated with respect to ecological features. The overall ecological effects of pumping are at present further investigated.[41]

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Table 2. Overview of the conditions of potential importance examined in this report and the state of those conditions at the studied locations of interest in the Bornholm Basin. The locations of interest are found in the areas a) north (section 2.1) b) north-east (section 2.2) c) north-east d) east (section 2.3) e) east f) east. Their coordinates and positions on the map are marked in Figure 10. Each condition has been given a colour coding, where green (red) generally indicates that the condition does not (does) influence the location. For current speed, a relative classification according to sediment type has been defined, where muddy sediments correspond to relatively weak currents (green), hard clay to moderate currents (yellow) and sandy sediments to strong currents (red). For distance to shore, green (red) indicates that the site is closer (further off) than 20 km to (from) shore. For ship traffic intensity the scale has been widened to four shades, in order to distinguish the differences between the locations. On this scale, high and medium corresponds to >300 ships per month and >100 to 300 ships per month respectively. Low corresponds to 25 to 100 ships per month and very low is <25 ships per month. The specific amounts of ship traffic at each site are presented in the legend in Figure 10.

Location	Max. depth	Sediment type	Current speed	Munition dumpsites	Military warning and exercise zone	Sea floor installations	Approx. distance to Bornholm (km)	Approx. distance to Christiansø (km)	Ship traffic intensity	Important bird area
a)	> 90 m	Mud	Weak	Outside	Outside	> 5 km from site	35	23	High	No
b)	> 94 m	Mud	Weak	Outside	Inside	> 5 km from site	34	17	Medium	Yes
c)	> 100 m	Sand	Strong	Outside	Outside	> 5 km from site	19	2.5	Very low	Yes
d)	~ 99 m	Mud	Weak	Inside	Outside	> 5 km from site	50	41	Low	No
e)	~100 m	Hard clay / Mud	Moderate / Weak	Inside	Inside	> 5 km from site	45	40	Very low	No
f)	~96 m	Hard clay / Mud	Moderate / Weak	Outside	Inside	> 5 km from site	53	48	Low	No

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