Fish and Fisheries

Baseline Reports regarding Fehmarnbelt

Final report

Fish Ecology in Fehmarnbelt

Prepared for: Femern A/S

Fehmarn Belt Environment Consortium JV

In association with: IFM-GEOMAR

E4TR0038

Volume I

Responsible editor:
Orbicon A/S
Ringstedvej 20
4000 Roskilde
Denmark

FeBEC Project Director: Kristian Nehring Madsen, Orbicon
www.orbicon.dk

Please cite as:
FeBEC (2013). Fish Ecology in Fehmarnbelt. Baseline Report.
Report no. E4TR0038 – Volume I

Report: 306 pages
One appendix

May 2013

ISBN: 978-87-92416-45-2

Maps:
Unless otherwise stated:
DDO Orthofoto: DDO®, copyright COWI
Geodatastyrelsen (formerly Kort- og Matrikelstyrelsen), Kort10 and 25 Matrikelkort
GEUS (De Nationale Geologiske Undersøgelser for Danmark og Grønland)
HELCOM (Helsinki Commission – Baltic Marine Environment Protection Commission)
Landesamt für Vermessung und Geoinformation Schleswig-Holstein (formerly Landesvermessungsamt Schleswig-Holstein) GeoBasis-DE/LVermGeo SH

Photos:
Martin Kielland – livetunderoverfladen.dk (Cover page), www.kc-denmark.dk (26), Lotte Worsøe Clausen - DTU Aqua (36), Christian B. Hvidt (39), M. Bleil - vTI (2003) (86).

Co-financed by the European Union
Trans-European Transport Network (TEN-T)

PREFACE

The establishment of a Fehmarnbelt Fixed Link has been under consideration for several years and became more feasible during and after the planning and construction of the Øresund Fixed Link.

From 1995 to 1999, a series of investigations including environmental effects of a fixed link across the Fehmarnbelt were carried out. In 2005 and 2006, an environmental consultation process was carried out, in which government agencies, stakeholders and the public commented on the environmental aspects.

On 3rd September 2008, the Ministers of Transport of Denmark and Germany signed the state treaty on the Fehmarnbelt Fixed Link and the Danish Parliament approved a law for the planning of the fixed coast-to-coast section on 26th March 2009. In Germany, the law ratifying the state treaty was accepted by the Bundestag on 18th June 2009. On 10th July 2009, it passed the Bundesrat, and the law took effect on 24th July 2009.

The Danish planning law enables comprehensive preliminary investigations of, among others, the environment. As part of these environmental investigations FeBEC JV, lead by Orbicon A/S and partners Institute for Applied Ecology (Germany) and Fish Ecological Laboratry (Denmark), have carried out a number of baseline investigations and surveys on Fish and Fisheries for Femern A/S. Femern A/S is responsible for the 1) planning, 2) environmental investigations and assessments, and 3) designs of the 19-kilometre long coast-to-coast section (planned as a combined four-lane motorway and a double-track electrified railway), between Denmark and Germany across the Fehmarnbelt.

The present draft baseline report has been prepared in accordance with the scope of work described in the Scoping Report identifying key issues to be investigated on fish communities and fish ecology.

Table of content

1. Summary

Femern A/S is fully aware that construction and operation of infrastructural projects of the size of the Fehmarnbelt Fixed Link may have significant and severe impacts on the environment. To ensure that negative environmental effects can be avoided or minimized, key environmental issues have been identified and investigated. The present report presents the results from the baseline investigations comprising surveys on the fish communities and the migration and spawning pattern of key fish species in Fehmarnbelt. The baseline has been designed to provide information for a subsequent Environmental Impact Assessment and for the design of a monitoring programme to assess impacts on fish communities during and after the construction of the Fehmarnbelt Fixed Link.

Fehmarnbelt plays a key role in the water exchange system of the Baltic Sea and is an important passage way for migrating cod, herring and silver eel, as well as a spawning area for a number of fish species, including cod and flatfish in general. During the scoping process several environmental components were identified to be considered as key issues: Eastern and Western Baltic cod (*Gadus morhua*), Western Baltic herring (*Clupea harengus*), European eel (*Anguilla anguilla*), sprat (*Sprattus sprattus*), flatfish and shallow water species/minor species. For each environmental component the level of importance of spawning, nursery/feeding and migration have been assessed following the guidelines of the Fehmarnbelt Fixed Link EIA manual.

Beside these components the present baseline description has also addressed the mapping of fish communities of important habitats in the coastal and open areas of the Fehmarnbelt.

The objectives of the inventories can be summarized as:

- To describe the fish habitats and fish communities in Fehmarnbelt and adjasent waters.
- To describe the development of life stages from egg to larvae, and the dynamics and transport in time and space of eggs and larvae of commercially important fish stocks, to identify potential spawning grounds in Fehmarnbelt.
- To evaluate the significance of Fehmarnbelt as a migratory route and to investigate the behaviour and preferred migration routes for the important migrating species European eel, herring, cod and sprat.
- To describe the distribution of spring and autumn spawning herring in potential spawning grounds in Fehmarnbelt.
- To describe the importance of Fehmarnbelt for protected fish species.

The surveys included:

- A programme designed to catch fish eggs and larvae. This was performed with a bongonet along a 20 km coastline of Lolland including Rødsand and along the northern and eastern coastline of Fehmarn as far south as Mecklenburger Bight. The sampling was performed as 12 discrete campaigns in autumn 2008, spring, summer and autumn 2009, and late winter 2009-2010, to cover the spawning season of almost all fish species in the area. Gonad maturity of the commercial important species cod, herring, sprat and flatfish in Fehmarnbelt was estimated in order to to identify seasonal spawning patterns.
- Herring gill net surveys and video screenings of the sea bottom for herring eggs along the German and Danish coast in the autumn of 2008 and 2009, and spring 2009. The gill net surveys included registrations of herring gonad development, herring worm infection and genetic analysis.
- Investigations of fish communities in specific habitats based on monthly sampling from May 2009 to April 2010 with multi-mesh gill nets in Danish and German coastal waters, and trawl surveys in the deeper parts of Fehmarnbelt. The investigations of nursery areas in specific habitats were based on sampling by fyke nets and beach seine nets

in the coastal waters of Fehmarn and Lolland. Furthermore the YOY-trawl was used in the shallow sandy areas in Rødsand and west of Rødbyhavn.

- Hydro-acoustic surveys, which included monthly surveys along the planned alignment, were performed from September 2009 to July 2010, and three large scale surveys were performed in April-May 2009, September-October 2009 and in February-March 2010. The equipment consisted of two Simrad echo sounders, an EK60 mounted with a split beam echo sounder (120 kHz) and an ES60 system mounted with a single beam dual frequency transducer (38/200 kHz).
- Tagging experiments on migrating silver eel were performed with both intelligent tags (DST) (logging depth, temperature and time), and T-bar tags. The surveys included tagging and release of eel captured in pound nets from the coastal areas of Lolland and Fehmarn in late autumn 2009, and the release of eel in the Arkona Basin in October 2010.
- A small scale tagging experiment on spawning cod caught by local fishermen on the spawning grounds in the western part of Fehmarnbelt during spring 2010. The cods were tagged with T-bars or DST's.

Collection of relevant literature and Identification of information have been an ongoing process throughout the project, and collection of relevant literature has been a part of the services provided.

Existing legislation, guidelines and references on methodologies focusing on the Baltic Sea area has been reviewed, and existing knowledge on fish communities and fisheries on a regional and more general scale has supplemented the results obtained from the field investigations.

In summary the results from the baseline investigations of fish populations in Fehmarnbelt can be summarized as:

<u>Benthic fish communities.</u> In total 57 different fish species were registered during the mapping of fish communities in the area. The coast along Fehmarn had 43 species and was the most species-diverse area, compared to the 37 species registered along the coast of Lolland. The lowest number of species was found in the deeper areas of Fehmarnbelt where 35 species were registered. Ten of these species were only registered in the deeper parts of Fehmarnbelt.

The shallow water fish community in the surf zone (<2 m) was generally dominated by small fish such as sticklebacks, gobies and sand eel, but larval and juvenile stages of pelagic fish such as herring and sprat were also frequently registered. The fish community reflected a typical fish community of the Belt Sea, and subareas along the coasts of both Fehmarn and Lolland were shown to function as nursery areas for several fish species.

The western and north-western sandy habitats off the coast of Fehmarn were dominated by flatfish species such as dab (*Limanda limanda*) and flounder (*Platichthys flesus*). In addition, the highest abundance of hooknose (*Agonus cataphractus*) and whiting (*Merlangius merlangus*) were also found in these habitats. The highly structured habitats with vegetation, stones and boulders along the eastern and south-eastern coast of Fehmarn were dominated by cod, whereas almost no flatfish species, except flounder, were caught within these habitat types. Beside cod, species like sea stickleback (*Spinachia spinachia*), wrasses (mainly goldsinny wrasse (*Ctenolabrus rupestris*)) and gobies were characteristic for these habitats.

Cod was the dominant species along the coast of Lolland in habitats with vegetation, stones and mussels, while dab and whiting were most numerous in sandy habitats. In the lagoon of Rødsand, the extensive eelgrass habitat was dominated by small fish species like three- (*Gasterosteus aculeatus*) and nine-spined stickleback (*Pungitius pungitius*), eelpout (*Zoarces viviparus*) and several species of gobies.

The most dominating benthic species in the deeper areas of Fehmarnbelt was dab, but whiting, cod and plaice (*Pleuronectes platessa*) were also numerous.

The pelagic fish community of Fehmarnbelt includes at least 10 species with sprat, herring, whiting and cod as the most numerous. Considerable seasonal variability was present (abundance and species composition) and occasionally pelagic species like garfish (*Belone belone*) and Atlantic horse mackerel (*Trachurus trachurus*) were highly abundant. The density of pelagic fish in Fehmarnbelt was low compered to other observations made in other areas including the Øresund.

Cod. Two genetically different cod stocks are found in the Baltic Sea; the western cod stock occurring west of Bornholm including the Belt Sea and the Øresund, and the eastern stock occurring east of Bornholm. The eastern stock grows slower and their eggs are larger and have greater buoyancy due to a physiological adaption to the lower salinity. Both stocks are highly exploited by fisheries and their abundances have declined throughout the last century. The predicted spawning stock biomass for year 2010 of the western stock is 24,000 tonnes.

Although the western cod stock is significantly smaller than the eastern stock, drifting larvae of the western stock spawned in Fehmarnbelt and Mecklenburg Bight is believed to contribute significant to recruitment in the eastern stock. The field investigation showed that Fehmarnbelt is an important spawning ground for the western Baltic cod with the primary spawning period from February to March, although results in 2009 showed that spawning continued at a low level throughout the summer. In general, the primary spawning season of the western Baltic cod is earlier than the spawning season of the eastern Baltic cod.

Average cod egg density in Fehmarnbelt in March 2010 was 3 eggs per m^3, corresponding to approximately 25 eggs per m^2, which is only slightly lower than the density recorded during the peak of the spawning season in the Bornholm Basin from 1969-1996.

From the estimated annual egg production of the entire sampling area, it was calculated that approximately 800 tonnes of cod spawn inside the investigated area. Since the stock spawning biomass (SSB) of the entire western Baltic has been estimated to be 20,000 tonnes since 1995, it is assumed that at least 4% of the spawning biomass in the entire western Baltic Sea spawns in Fehmarnbelt.

When backtracking early-life-stages of cod eggs caught in Fehmarnbelt to their place of origin, it was found that they were primarily spawned in the deep central areas of Fehmarnbelt, the Belt Sea near Langeland, Mecklenburger Bight and the western part of the Arkona Bassin. Spawning areas in the deeper, central parts of Fehmarnbelt was supported by a peak in the catches of adult cod convergent with the main spawning period in February and March 2010. However, the hydro-acoustic surveys did not show any significant aggregations of cod during the spawning season.

Overall, these results correspond well with previously identified spawning grounds, and support the hypothesis that the Fehmarnbelt stock is important to the recruitment of the western Baltic cod stock, as well as possibly supplementing recruitment to the eastern stock in the Baltic Sea. Furthermore, tagging experiments have shown a tendency of homing towards spawning grounds in Fehmarnbelt.

The high density of juvenile cod present in the shallow coastal waters of Fehmarn and Lolland, indicate these areas as important nursery grounds.

Starvation by the cod larvae or heavy predation on egg and larvae by predatory gelatineous plankton did not appear likely during the investigated period.

Western Baltic Herring. The baseline has identified at least three components of the Western Baltic herring stock:

- A very small component of autumn spawning herring, most likely just passing Fehmarnbelt to and from spawning and feeding areas,
- A moderate sized spring spawning herring component (primarily Rügen herring), most likely passing Fehmarnbelt to and from spawning grounds,
- A small more local spring spawning component.

Moreover, genetic analysis haave identified components of North Sea herring and Eastern Baltic herring. The Fehmarnbelt most likely plays a minor role compared to the Øresund as a passage way or route between feeding areas in the Kattegat/Skagerrak and the North Sea and spawning grounds in the western Baltic.

Very low catches of herring and herring larvae in the autumn, as well as no observation of herring spawning activities, either by video screening or hydrodynamic back-tracking, indicates none or very little autumn herring spawning activity in Fehmarnbelt. Correspondingly, the density of herring larvae in the autumn of 2008 was less than 0.001 per m^3. Furthermore, when back-tracking their origin to spawning grounds, none of the larvae seemed to have been hatched from eggs spawned in Fehmarnbelt.

Although a significantly higher abundance of mature herring was present in the spring than the autumn, very few spent herring were caught. Furthermore, despite intensive screenings of the sea bottom no herring eggs were found. However, the density of herring larvae during the spring of 2009 was higher than in the autumn, albeit their density still did not exceed an average of 0.05 herring larvae per m^3. By back-tracking eggs, probable spring spawning sites could be identified along the southeastern and northeastern coast of Fehmarn. Larval densities indicated that there was a 10 fold lower abundance of larvae in Fehmarn Belt compared to spawning grounds in Greifswalder Bodden and Kiel Fjord. This suggests that the spring spawning activity in Fehmarn Belt most likely is limited.

There were no indications of starvation of herring larvae or that predatory gelatineous plankton constituted an important threat to eggs or larvae.

Sprat. During the past 20 years sprat has become more dominant in the Baltic Sea, while cod and herring stocks have declined. At present, sprat plays both an important role in the Baltic ecosystem as a prey species for cod and whiting, and as a predator on lower trophic levels as well as on pelagic eggs of other fish species.

The egg and larvae surveys revealed that sprat spawn in Fehmarnbelt from April to August. At the peak spawning period in May, the egg densities were similar to densities recorded during the main spawning period in the Gotland Deep 1976-1996 of the central Baltic Sea. Thus the deeper parts of Fehmarnbelt and adjacent areas are considered important spawning areas of sprat. A rough estimate of the spawning stock biomass, suggests that approximately 2,000 tonnes of sprat spawn in the investigated area. This would account for about 0.2% of the spawning biomass of the entire Baltic Sea.

Fehmarnbelt was found to function as both a nursery and feeding area for sprat. Sprat was recorded in the Belt from spring to autumn. In the winter period, sprat was mainly located in the deeper parts of the western Baltic Sea.

The European eel. The Danish sounds and belts are vital for the migration of the European eel between the Baltic Sea and the North Sea. The European eel stock has continuously declined in most European waters since the 1950s and has reached historically low level,. Similarly, recruitment of glass eel is also at an historical low level and also continues to decline. In the Baltic Sea, the recruitment of yellow eel is now less than 10% of that observed in the 1950s and 1970s.

Numerous factors have been suggested to be responsible for the decline of eel; stress from overfishing, pollution, habitat loss and barriers to their migration are just some. Diseases and parasites, as well as oceanic and climatic factors have also been suggested to contribute to eel recruitment failure.

European eel is red listed in most European countries, including Germany and Denmark. As a consequence of the alarming declines in abundance, the European Commission has recently taken drastic measures for the protection of eel. The goal is to restore the stocks to historical levels, and EU countries have agreed to take measures that will allow 40% of the pristine level of the stock to escape from inland waters to the sea.

In Fehmarnbelt, the migration of silver eel occurs from August to December and peaks in October. Tagging experiments revealed that Fehmarnbelt has some importance as a passageway for migrating silver eel, although the majority of eel leaving the Proper Baltic presumably migrates through the Øresund. It is likely that not more than 30% of the Baltic silver eel used Fehmarnbelt as a migration route in 2008 and 2009.

Silver eel migrating along the Swedish coast appear to prefer the Øresund as their migration route, while silver eel migrating along the southern Baltic coast select the southern route through the Belt Sea to a greater extent. The preferred route does not appear to depend on an imprint during the juvenile stage, but rather on present water current and salinity conditions in the Arkona Basin.

Silver eel seem to prefer migrating in the deeper waters along their route. They swim near the surface during the dark hours while frequently undertaking dives from surface layers to either the bottom or thermocline. During the day they mostly rest at the bottom. Migration speed is highly variable, depending on the frequency of resting periods. During active migration, the speed is approximately 0.4 m/s amounting to approximately 17 km/day.

A fyke net survey in autumn 2009 revealed that the Fehmarnbelt area has only minor importance as a nursery and feeding area for yellow eel.

A very little genetic difference among eel in European waters points toward only one population. This either indicates that there is no geographical separation of spawning grounds in the Saragossa between Northern and Southern European eels, and/or that it is random where the offsprings end up at the European coasts. E.g. offsprings from spawning eel originating from Northern Europe just as well might end up in Southern Europe and vice versa.

Flatfish contribute significantly to the fish fauna of Fehmarnbelt, and both nursery areas, feeding areas and spawning areas are found.. Spawning of flatfish occur throughout most of the year, with plaice spawning in December-March, flounder in Februar-April, dab in March-July and turbot (*Psetta maxima*) and sole (*Solea solea*) in May–August.

Fehmarnbelt is an important spawning area for flatfish, especially plaice, flounder and dab as suggested by the high egg densities and back-tracking of their eggs to spawning grounds in Fehmarnbelt and nearby areas. All stages of plaice, flounder and dab eggs and larvae were found in Fehmarnbelt, while larvae of witch flounder (*Glyptocephalus cynoglossus*), sole, American plaice (*Hippoglossoides platessoides*) and eggs and larvae of turbot were only found sporadically.

The primary spawning sites of plaice were located in the deep parts of Fehmarnbelt and in an area between Lolland and Langeland. The female spawning biomass in the investigated area was estimated to be 338 tonnes. Spawning sites of flounder and dab were located in areas along the northern and eastern coastline of Fehmarn, and to a larger area between Langeland and Fehmarn.

Mesozooplankton densities and RNA/DNA levels did not indicate starvation of flatfish larvae, and predatory gelatineous plankton did not appear to constitute any important threat to eggs and larvae.

The Fehmarnbelt area is used as nursery- and feeding grounds by the three dominating flatfish species (plaice, dab and flounder) during their different life stages. Juvenile plaice and flounder primarily use the shallow and protected areas of Fehmarn and Lolland as nursery grounds, while dab prefer deeper waters. The exposed coastline of Lolland does not appear to have significant nursery grounds compared to Fehmarn. Feeding grounds of flounder and plaice are found on sandy areas along the coast, while the deeper part of Fehmarnbelt is mainly used as a transit area by adult flounder and plaice migrating from coastal feeding grounds at Fehmarn and Lolland and back to their spawning grounds. Feeding grounds of dab are located in the deeper areas of Fehmarnbelt.

Other juvenile and adult flatfish species, such as turbot, brill (*Scophthalmus rhombus*) and sole were also registered at the investigated areas of Fehmarnbelt, but their abundances were considerably lower compared to the three most abundant species. It is, however, assumed that these species also use Fehmarnbelt as nursery- and feeding grounds.

<u>Red listed species.</u> In total, nine red listed species (according to the German and Danish Red lists) were recorded during the investigations. These were, snakeblenny (*Lumpenus lampretaeformis*), sea stickleback, corkwing wrasse, ballan wrasse (*Labrus bergylta*), sea trout (*Salmo trutta*), Atlantic salmon (*Salmo salar*), greater weever (*Trachinus draco*), European eel and painted goby (*Pomatoschistus pictus*). In addition, autumn spawning herring is also listed as critically endangered on the German red list. The majority of the listed species occurred at very low numbers. However, the seastickleback in particular, was frequently abundant in the autumn. Other species like corkwing wrasse, ballan wrasse and greater weever showed a significant seasonal distribution. The river lamprey (*Lampetra fluviatilis*) is listed in the EU habitats directive Annex II and small number of this species was caught in Fehmarnbelt by local fishermen during the baseline study period. Detailed considerations to the red listed species are addressed in the NATURA 2000 assessment.

2. Introduction

Large marine infra-structure projects, like the Fehmarnbelt Fixed Link, will affect the environment during construction and operation phases. To minimize these effects and to have a reference for future impact assessments, key environmental issues have been identified and investigated.

The baseline study has been designed to provide the essential information on fish communities, fish migration and spawning of key fish species in the Fehmarnbelt. This information is a pre-requisite for the subsequent environmental impact assessment and will furthermore be used as a point of reference in a future monitoring programme.

The present baseline report presents the results of the baseline inventories and surveys on the fish communities, fish migration and spawning of key fish species in Fehmarnbelt.

In the Environmental Impact Statement (EIS) framework, the environmental factors concerning fish can be divided into several components as illustrated in Table 2.1. For each environmental component, the importance will be evaluated based upon inventory and survey results.

Table 2.1: List of environmental factors, sub-factors and components concerning fish communities.

Environmental factor	Environmental sub-factor	Environmental component
Flora, fauna and biodiversity	Fish communities	Western Baltic cod
		Western Baltic herring
		European eel
		Sprat
		Flatfish
		Shallow water species
		Protected species

2.1 Background and objectives

Between 1995 and 1999 several preliminary environmental investigations were carried out to obtain data for the feasibility studies for the Fehmarnbelt Fixed Link. Further investigations followed in 2005 and 2006, aiming at identifying the importance of spawning and fish nursery in Fehmarnbelt and to gather information on the distribution of commercially important fish species (Riber and Raschke, 1999; Dynesen and Zilling, 2006).

The aim of the present baseline study is to combine historical data, data from the feasibility study and empirical data collected during 2008-2010 to describe the baseline conditions for the fish communities in Fehmarnbelt.

The objectives are:

- To identify and describe fish habitats and fish communities in Fehmarnbelt
- To identify possible spawning grounds in Fehmarnbelt
- To describe the temporal and spatial dynamics of fish eggs and larvae in Fehmarnbelt
- To evaluate the importance of Fehmarnbelt as a migratory route
- To investigate the behaviour and preferred migration routes of the important migrating species European eel, herring and cod
- To describe the distribution of spring and autumn spawning herring in Fehmarnbelt and to identify potential spawning grounds for herring.

2.2 The Baltic Sea and Fehmarnbelt

The Baltic Sea is one of the largest brackish water areas of the world. It covers 415,000 km^2 and has a volume of approximately 20,000 km^3. The ten largest rivers deliver roughly 60% of the water flowing into the Baltic Sea.

The Baltic Sea area is located in the northern temperate zone, embedded in the Northern atmospheric circulation system, with predominantly westerly winds. However, the region is not homogenous as two distinct climate types may be distinguished. The largest part of the central and the northern area belongs to the continental temperate climatic zone, characterised by long and cold winters. The southern area belongs to the oceanic climatic zone, characterised by persistent westerly winds and relatively mild, wet winters.

The bathymetry of the Baltic Sea is characterised by broad, shallow coastal areas and an array of deep basins. The connection between the Baltic Sea and the North Sea is by several shallow and narrow straits with Fehmarnbelt being the southernmost of them. Fehmarnbelt connects the Kieler Bight and the Great Belt with the Mecklenburg Bight in the southern Baltic Sea.

Fehmarnbelt has a key role in the water exchange system of the Baltic Sea. It is characterized by a high variability of the hydrodynamic parameters, especially salinity. Salinity levels change on a horizontal and vertical scale, and therefore different levels can be found in coastal and offshore areas. These salinity gradients are of great importance for fish communities and especially for the spawning success of cod.

Salinity in the surface layers of Fehmarnbelt typically ranges from 11 to 15 psu while water layers below 20 m typically range between 18 and 28 psu. Occasionally, the Baltic Sea is subject to major salt water intrusions from the North Sea and during these events the water column in Fehmarnbelt turns more or less homogeneous. During these events, salinity levels can reach up to 28-30 psu and the salinity increase is often accompanied by an increase in dissolved oxygen.

The outflow of freshwater at the surface and the inflow of saline water in the deep also lead to a distinct vertical layering of water masses and a permanent halocline in the basins. In summer, additionally a thermocline develops, which dissolves in autumn with wind driven mixing of the surface layer. This wind induced mixing is however not strong enough to ventilate the water body under the permanent halocline. Biogeochemical processes in the deep basins consume the dissolved oxygen and result in zones of oxygen deficiency, sometimes leading to the formation of hydrogen sulphide.

2.3 Fehmarnbelt and the fish community

Several fish species and fish communities in the Fehmarnbelt area are of ecological and economic importance. Fish-eating birds and marine mammals are dependent on the availability of food resources in Fehmarnbelt. Furthermore, the commercially important fisheries of cod, herring, sprat, European eel and various flatfish species are important for local economies.

The ecosystem of the Baltic Sea has undergone large changes in fish communities during the last two decades, which among others is expressed by a dramatic decrease in cod and herring stocks (ICES, 2007a). Parallel to this development, a large increase in the sprat stock and the landings of sprat has been registered (Cassini et al., 2006; ICES, 2007b; Cassini et al., 2008).

Cod is one of the economically most important fish species in the Baltic Sea. Two overlapping cod stocks are found around Bornholm; the eastern Baltic cod stock and the western Baltic cod stock. Cod which are caught in Fehmarnbelt most likely belongs to the western cod stock

(WWF, 2006). As a result of the decline in stock size of the Baltic cod, it is now included in HELCOM´s Red List of threatened and declining species of the Baltic Sea (HELCOM, 2005).

The European eel has also declined dramatically in the Baltic Sea, as elsewhere in Europe, since the end of the 1980s (Hilge, 2004) and the European Commission has recently taken drastic measures to protect the eel population. The European eel is red listed in Germany and Denmark.

Two major herring stocks, the spring spawning and the autumn spawning herrings, are normally distinguished in the western Baltic. Especially the autumn spawning herring has decreased in abundance since 1980 and the autumn spawning stock is now red listed in Germany.

The Fehmarnbelt area is an important spawning site for a number of fish species, including flatfish and cod as indicated in the feasibility study (Riber and Raschke, 1999). In addition, the influx of cod larvae to the Baltic Sea is believed to be of importance for the entire Baltic cod stock (Neuenfeldt et al., 2007).

Sprat is known to spawn in the deep basins in the Baltic (Bauman et al., 2006; Voss et al., 2007) and larvae of sprat are transported by currents to shallow water nursery grounds all over the Baltic Sea, including Fehmarnbelt.

The availability of high quality nursery grounds is an essential and limiting factor in recruitment of many fish species. The shallow waters of Fehmarnbelt provide nursery and feeding grounds for a number of economically and ecologically important species. Vegetated areas along the coasts of Lolland and Fehmarn are suitable for fish nursery, and non-vegetated sandy or silty substrates are important feeding grounds for demersal fish species like flatfish.

Migration of fish is primarily related to a change in life stage, to feeding behaviour or to spawning activities. Most migrations take place between spawning grounds, nursery grounds and/or feeding grounds. The ability to perform migrations may well be crucial for survival, growth and recruitment of many fish populations.

Small scale migrations can occur frequently, e.g. in relation to predation on moving prey. Migrations covering substantial distances often occur on an annual basis, as in the adult Rügen herring and Baltic cod, which both migrate every year between spawning and feeding grounds. Finally, some species perform huge migrations once in a lifetime. This is seen for the European eel, where juvenile stages migrate from the Atlantic Ocean into freshwater systems and adult silver eels migrate back to the sea.

Cod are known to migrate annually over large distances to feed and spawn. The offspring drift and swim to nursery areas, where they settle. When reaching the adult stage, the young cod migrate from the nursery grounds to the feeding grounds.

Most herring stocks in the western Baltic are migrating between feeding grounds in Skagerrak and spawning grounds in the Fehmarnbelt area and adjacent areas.

The European eel migrates from the Baltic Sea into Skagerrak, but the specific routes taken from the Baltic Sea are not well known. Information on silver eel migration from the Baltic Sea is mainly available from studies performed along the Swedish east coast. Little information exists on the migration of eel in Fehmarnbelt.

2.4 Natura 2000 areas

The Natura 2000 areas in or near Fehmarnbelt include SCIs (Sites of Community Interest, under Council Directive 92/43/EEC, Habitats Directive) and SPAs (Special Protected Areas, under Council Directive 79/409/EEC, Birds Directive) (Figure 2.1 and Figure 2.2). The proposed alignment crosses the German SCI Fehmarnbelt (DE 1332-301). This Natura 2000 site has a size of approximately 280 km^2 and is located north of Fehmarn within the Fehmarnbelt trench. This 35 m deep trench accounts for approximately 70% of the water exchange between the North Sea and the Baltic Sea.

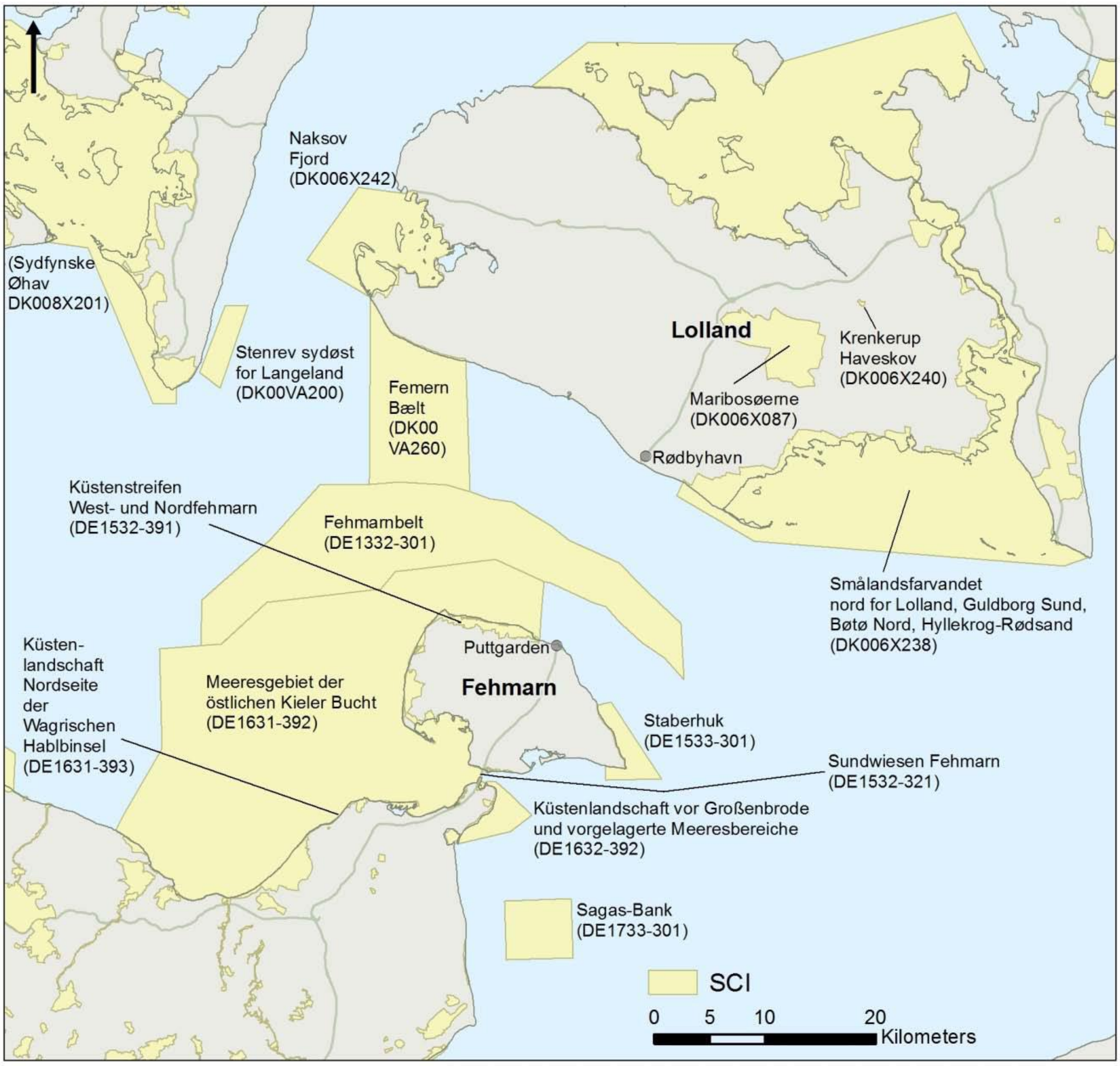


Figure 2.1: German and Danish SCIs in the region around the planned Fehmarnbelt Fixed Link.

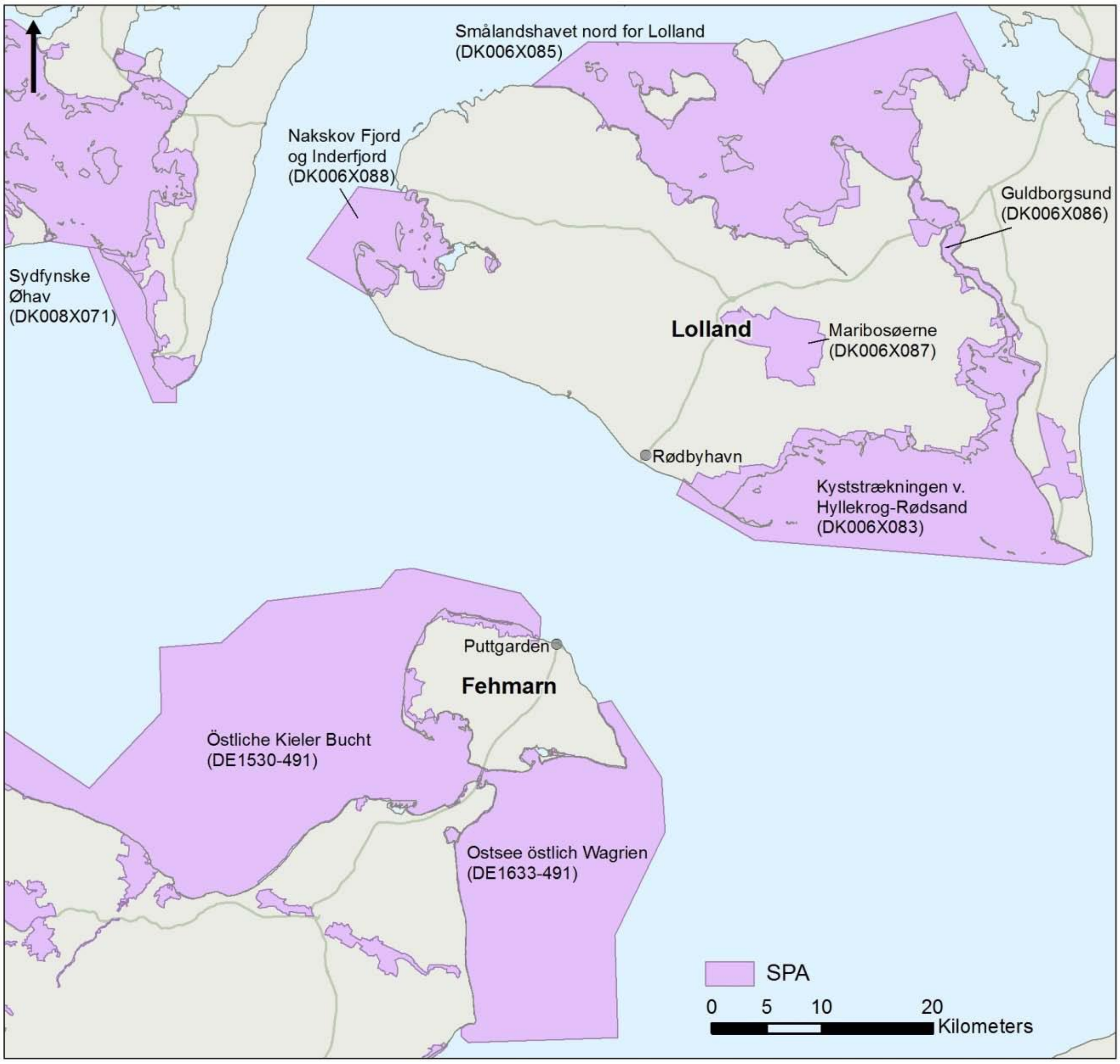


Figure 2.2: German and Danish SPAs in the region around the planned Fehmarnbelt Fixed Link.

Neither the SCI Fehmarnbelt nor any other Natura 2000 area near the proposed route has been designated because of the presence of fish species of community interest (Annex II species). Therefore no Annex II fish species are specifically protected within these areas. However, no functional impairments on structural habitat elements within or outside these areas is allowed to significantly affect fish communities, which are specifically associated with the structural elements (habitats) that are characterising the Natura 2000 sites.

3. Baseline methodology

The primary objective of this baseline study was to collect temporal and spatial data on communities of ecological and commercially important fish species present in Fehmarnbelt.

To achieve this goal, several methodological approaches were applied. These included field studies, tagging studies, biochemical analyses and genetic analyses.

Field studies and tagging studies were performed to identify and elucidate:

- The composition and habitat relationships of important fish communities in Fehmarnbelt
- Possible spawning grounds and habitats for pelagic spawners such as cod, sprat and flatfish
- Possible spawning grounds and habitats for benthic spawners such as herring
- The presence of fish eggs and larvae in Fehmarnbelt
- Maturation of adult fish in order to determine the spawning season of each species
- Migration of pelagic fish communities through Fehmarnbelt
- Migration of the European eel through Fehmarnbelt
- Migration of cod

Biochemical and genetic analyses were performed to:

- Verify species identification of collected eggs
- Identify stock affiliations of adult herring and selected fish larvae in Fehmarnbelt.
- Verifying condition indeces of fish larvae by means of biochemical analyses (RNA/DNA).

Along with the field and laboratory inventories gathering information and literature studies has been an ongoing process. Existing legislation, guidelines and references on methodologies focusing on the Baltic area has been reviewed, and existing knowledge on fish communities and fisheries on a regional and more general scale has supplemented the results obtained from the field inventories.

Finally, the overall objective of the baseline was to evaluate the importance of Fehmarnbelt for fish species and fish communities in the region. For each environmental component the level of importance of spawning, egg- and larvae drift, nursery, feeding and migration have been assessed and criterias for the rating have been defined. In general the assessment of importance follows the overall guidelines of the Fehmarnbelt Fixed Link EIA manual.

3.1 Fish community and habitat mapping surveys

3.1.1 Sampling strategy and locations

With the objective of identifying the spatial and temporal distribution, including the association with specific habitats, of different fish communities, rare species and important nursery areas in the Fehmarnbelt area, a number of field surveys and investigations were carried out in 2009 and 2010 using an array of methods.

More specifically, the purposes of these inventories were to:

1. Investigate the fish communities in specific habitats based on sampling with gill nets in Danish and German coastal waters of Lolland and Fehmarn.
2. Investigate nursery grounds in specific habitats based on fyke nets and beach seine nets in coastal waters of Lolland and Fehmarn and on young-of-the-year (YOY) trawl in the shallow sandy areas of Rødsand and west of Rødbyhavn.

3. Investigate the fish communities in the deep areas of Fehmarnbelt based on bottom trawl (WPT).
4. Investigate the habitat structure at the sampling stations based on video surveys (regarding gill net and fyke net stations in Danish and German coastal waters).

(1) The investigation of fish communities by sampling with gill net was initiated on the 16th of May 2009 and was finalized on the 30th of April 2010. A total of 35 stations on the German side and 24 stations on the Danish side were sampled on a monthly basis (Figure 3.1). In September an additional 40 stations (including fyke nets) were sampled on the Danish site (not included in Figure 3.1).

(2) During the sampling period, 748 gill net samples were collected from the 99 stations. The samples were collected at depths between 0.6 m and 18.5 m.

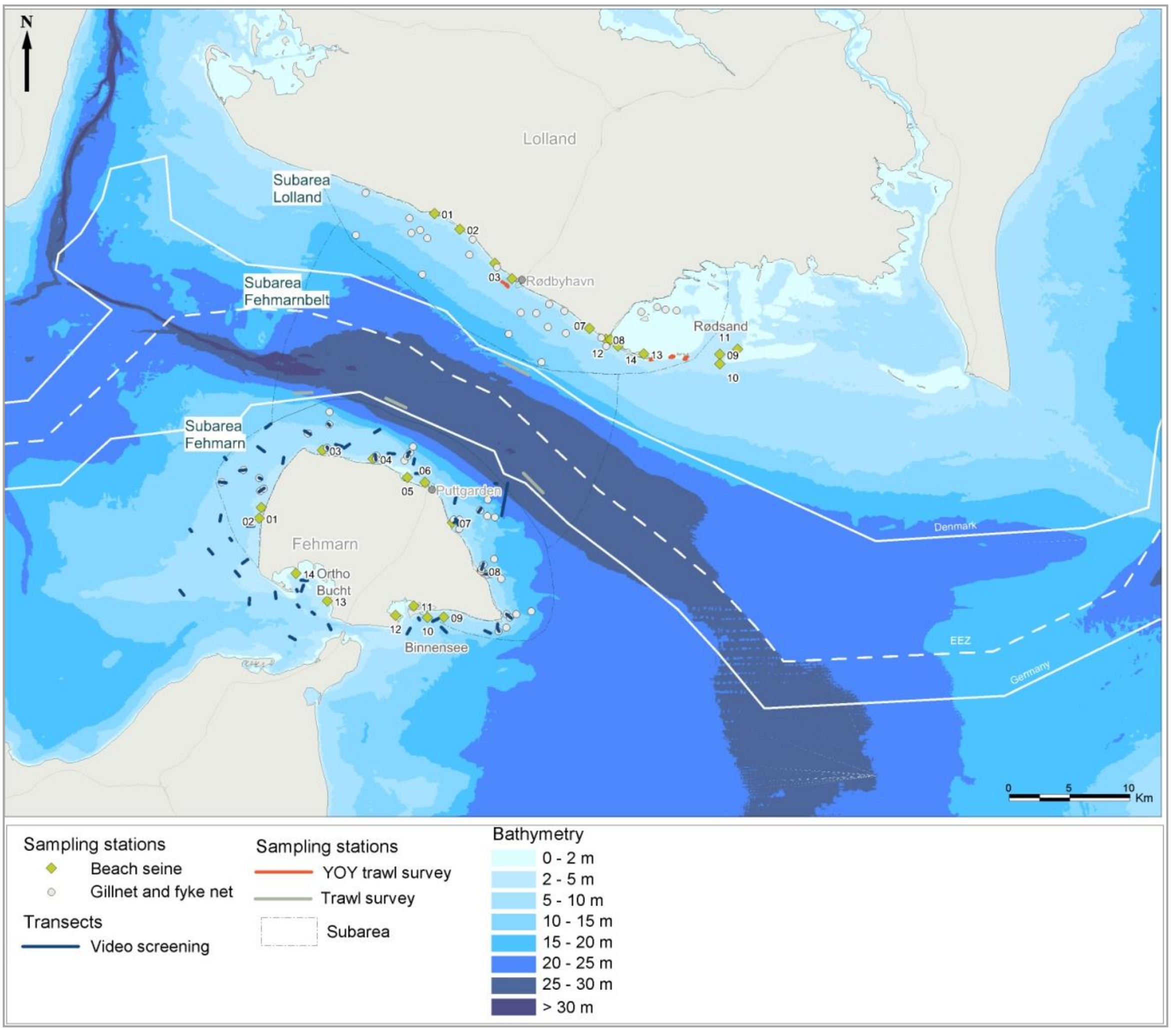


Figure 3.1: Sampling stations of gill net (fish community), fyke net (nursery ground) (not all stations were sampled with fyke nets), "young of the year" trawl surveys and beach seine net stations in coastal waters of Lolland and Fehmarn. Furthermore, sampling stations used at the trawl surveys in the deep part of Fehmarnbelt and transects used in the video screening of habitats during spring and autumn 2009.

(3) The fyke net surveys for nursery grounds in coastal waters of Lolland and around Fehmarn were performed between the 8th of September 2009 and the 30th of April 2010. A total of 292 samples were collected at depths between 0.6 m and 10 m during monthly surveys at 21 gill net stations on the German coast and 4 stations on the Danish side. Heavily exposed gill net stations were not sampled with fyke nets.

In addition to the fyke net surveys, a YOY-trawl survey, with a total of 10 hauls covering 2.1 km, was carried out on the 14th of July 2009 in the shallow sandy areas at Rødsand and west of Rødbyhavn (Figure 3.1).

A supplementary sampling of juvenile fish at their potential nursery grounds in shallow water areas, i.e. at water depths less than 2 m, was conducted in May and June 2010 along the south coast of Lolland and Fehmarn using beach seine nets. The station grid (Figure 3.1) mainly covered the stations used in the gill net and fyke net sampling. In addition to the areas which were also surveyed with gill and fyke nets, six stations along the south coast of Fehmarn were sampled. Stations 11 and 12 were located in the bay "Binnensee", which is a very shallow area sheltered from wind and waves by two barrier spits. Likewise stations 13 and 14 were located in the shallow and sheltered bay Orther Bucht in the southern part of Fehmarn. By contrast, stations 9 and 10 represented a more exposed area. A total of 52 beach seine nets samples were collected from the 26 stations.

(4) The trawl surveys of the fish community in the deep parts of Fehmarnbelt were performed between the 7th of May 2009 and the 30th April 2010. A total of 48 samples were collected during the monthly surveys at 4 stations (Figure 3.1).

(5) To investigate the habitats at the stations, a total of 57 transects around Fehmarn were video screened during spring and autumn 2009 (Figure 3.1). Data from the video screening of possible spawning grounds for herring were also used in the description of the habitats (Figure 3.11).

3.1.2 Sampling equipment

A Nordic coastal multi-mesh gillnet, which is also used for HELCOM monitoring, was used for sampling of fish communities in coastal waters (FeBEC, 2010c). Three mesh panels were added to optimize the catch for smaller and larger species. The catches from the extra panels were registered separately so that the catches from the standardized nets could be compared with HELCOM monitoring data.

Fyke nets were used for sampling at nursery grounds. Fyke nets are also used in the Danish national monitoring program of coastal waters. The nets were equipped with double fyke nets with 8 m leader between the fykes and three throats and hearts in each fyke net (FeBEC, 2010c).

A young of the year trawl (YOY) was used to assess the presence of young flatfish and gobies at Rødsand and west of Rødbyhavn. This type of trawl is standard in the Danish national monitoring program.

A small (8 m) and a large (20 m) beach seine net (mesh size 5 mm) were used to collect young fish species in shallow waters (≤ 2 m) along the coast of Fehmarn and Lolland.

In the deep parts of Fehmarnbelt the "Windparktrawl" (WPT-TV300/60-20a) was used. This trawl has previously been used for investigations at offshore wind farms according to the StUK3 standards (BSH, 2007). The speed of the trawling was 3 to 4 knots per hour and the duration was 15 min. The time was reduced because of the high amount of fish caught. The mesh size of the cod-end was 20 mm (side length).

3.1.3 Data analysis

In the analysis and interpretation of data, the Fehmarnbelt area was divided into three subareas; subarea Lolland, subarea Fehmarnbelt and subarea Fehmarn (Figure 3.1).

Based mainly upon the video screenings, the habitats at the sampling stations were classified into six types (see section 4.1.1).
The collected data on, e.g., number of species and individuals, length and weight of caught fish were analysed by simple descriptive statistics and univariate analysis (see FeBEC, 2010c for further details). The diversity in the catches was described using the diversity index of Shannon and Wiener (1949) and the index of evenness based upon Pielou (1966). The diversity indices are indicators of species richness (biodiversity) as well of the evenness of the allotment of individuals among species.

The majority of the data were not normally distributed. Therefore, the median values were generally used, and non-parametric tests were used to test for significant differences. The Kruskal-Wallis one-way analysis of variance, the Nemenyi test, the median test and the Mann-Whitney U-test were all computed using the software StatEasy XP (Lozan and Kausch, 2007).
The descriptive parameters were illustrated as Box and Whisker Plots, created by the software StatEasy XP (Figure 3.2). The 1st and 3rd quartiles are illustrated as boxes on each side of the median. The indentations of the box mark the standard deviation of the median. The maximum and minimum values of the sample are shown as lines ("whiskers").

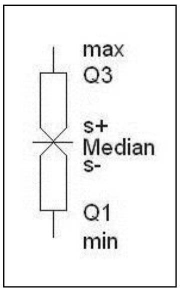


Figure 3.2: Layout of Box and Whisker Plot with maximum and minimum value, 1st and 3rd quartiles, standard deviation (s) and median.

In addition to the simple univariate analyses, a multivariate analysis of species composition and species-habitat relationships was carried out. Differences between stations were calculated with the statistical software PRIMER 6 (Version 6.1.11) and the results were illustrated in cluster analysis dendrograms and multi dimensional scaling (MDS) plots.

The quality of the separations was defined by a stress value (stress < 0.05: very good ordination with very little risk of error in the interpretation; 0.05 < stress < 0.1: good ordination; 0.1 < stress < 0.2: potentially good ordination, which can only be used with reservation; 0.2 < stress < 0.3: stations are almost randomly distributed).

Differences between fish communities were also tested with an analysis of similarities (ANOSIM). For this test the global R-value was calculated. The R-value indicates the differences between fish communities in different habitat types (R > 0.75: habitat types were clearly separated; R ≈ 0.5: habitat types were still separable but some similarities occurred; R < 0.25: habitat types were almost similar). The significance level (p value) was calculated to support the global R-value in case of converse correlation (Clarke and Warwick, 2001). The species which caused the similarity/dissimilarity between fish communities were identified with the SIMPER analysis (Clarke and Warwick, 2001).

Habitat modeling was completed for a number of fish species in the coastal zone. The modeling was carried out using a presence-only method, as the various fishing methods used, could not provide valid absence data.

The method used in the habitat modeling is called Ecological-Niche Factor Analysis (ENFA) and is a multifactorial analysis that compares the distribution of fish species to environmental variables described by so called Eco-Geographical Variables (EGVs) (Hirzel et al., 2002; Hir-

zel et al., 2006). The method uses data from the catches in the shallow water communities together with information of the habitat the fish were caught in.
The result is a spatial representation of the probabilities (scaled 0-100% probability) of a habitat being suitable for a given fish species. The prevailing map has a spatial resolution of 50 x 50 meters.

3.2 Hydro-acoustic surveys

3.2.1 Sampling strategy and locations

Hydro-acoustic surveys were used in the mapping of pelagic and semi-pelagic fish communities in Fehmarnbelt. Hydro-acoustics is one of the most powerful and commonly used tools worldwide for estimation of the abundance of pelagic fish, especially in marine environments.

The objectives of the hydro-acoustic inventories in Fehmarnbelt were:

- To map the spatial and temporal distribution patterns of pelagic and semi-pelagic fish communities, particularly herring, sprat and cod, in the Fehmarnbelt.
- To map the possible foraging and spawning areas in Fehmarnbelt and adjacent waters according to a variety of oceanographic and hydrographical parameters.

Two survey designs, called “continuous” and “periodic” surveys, were used in the hydro-acoustic investigations. The layout of both survey types followed a standard zig-zag transect pattern, as also used by Nielsen et al. (2001), with focus areas at depths greater than 10-12 m. The continuous surveys aimed to describe the spatial and temporal variation in the pelagic fish community within a relatively small area along the proposed alignment (Figure 3.3). Continuous surveys were performed 12 times between September 2009 and July 2010 (Table 3.1). From the periodic surveys, the distribution patterns and abundance of pelagic and semi-pelagic species were described on a larger scale in the Fehmarnbelt area (Figure 3.3). Three periodic surveys were carried out, each of them being timed to cover a biological key event in the marine environment of Fehmarnbelt (Table 3.1).

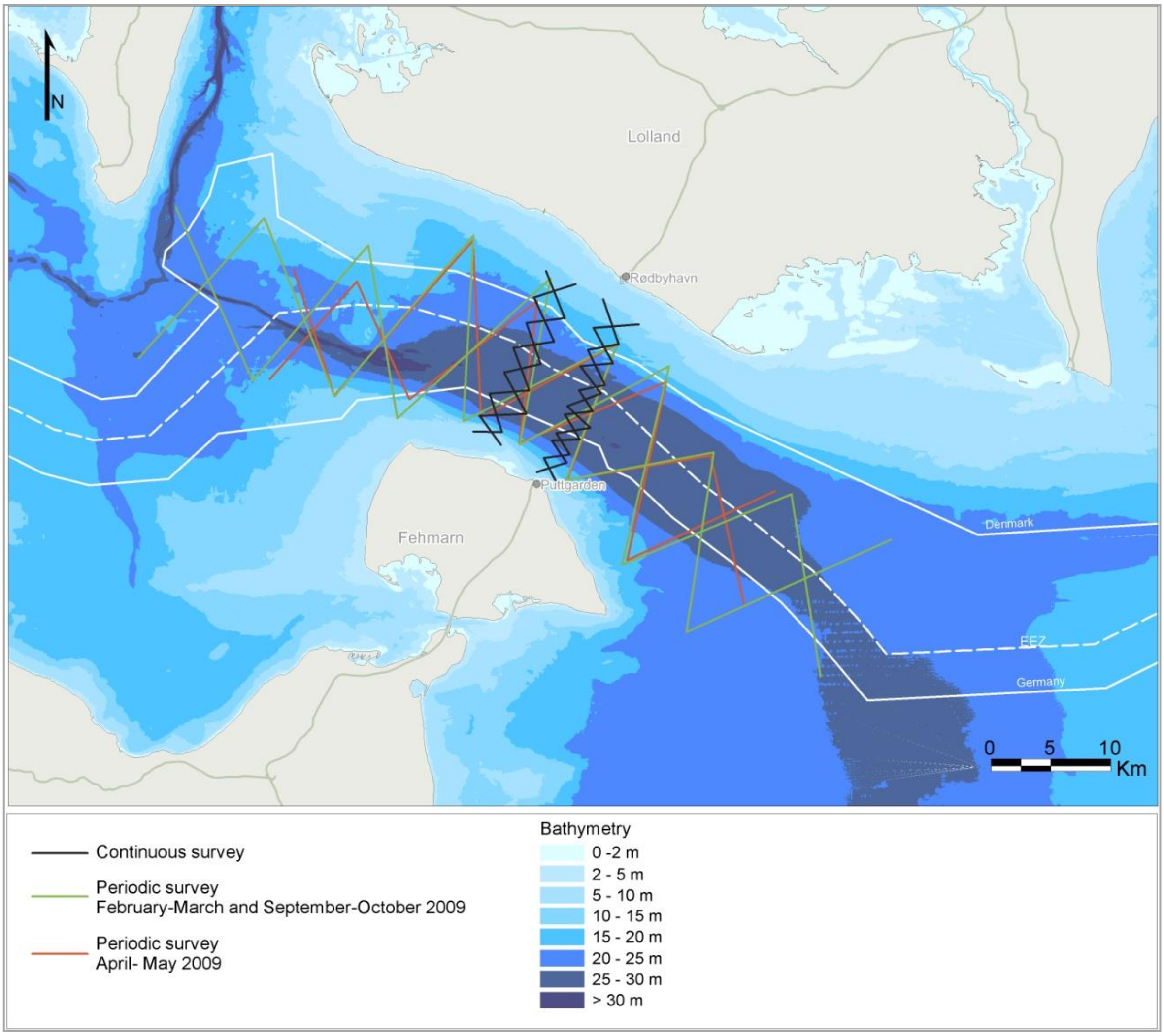


Figure 3.3: Survey routes used at the continuous and periodic surveys.

Table 3.1: Survey type, period and biological key events covered.

Survey name	Period	Date(s)	Expected biological key event(s)
Periodic 1	April-May, 2009	27/4 - 1/5 2009	Spring spawning herring (and sprat)
Periodic 2	September-October, 2009	5, 9, 10, 19, 27-30/10 2009	Feeding of gadoids and clupeids; autumn migrating species
Periodic 3	February-March, 2010	22-26/2, 8-12/3 2010	Spawning of cod
Continuous 1	September	8-9/9 2009	Feeding, cod/whiting and herring/sprat
Continuous 2	October 1	5-6/10 2009	Feeding, cod/whiting and herring/sprat
Continuous 3	October 2	27-29/10 2009	Feeding, cod/whiting and herring/sprat
Continuous 4	December	6-7/12 2009	Spawning cod
Continuous 5	January	18-19/1 2010	Spawning cod
Continuous 6	February 1	7-8/2 2010	Spawning cod
Continuous 7	February 2	23-24/2 2010	Spawning cod
Continuous 8	March	29-30/3 2010	Spawning sprat
Continuous 9	April	25-26/4 2010	Spawning herring
Continuous 10	May	10-11/5 2010	Spawning herring/sprat
Continuous 11	June	9-10/6 2010	Spawning sprat
Continuous 12	July	8-9/7 2010	Spawning sprat

3.2.2 Sampling equipment

The echo sounder sends out high frequency sound waves and receives echoes from all objects in the water and from the bottom. Typically, 2-5 sound impulses are sent out per second and the following sound impulse is not sent out until the echo from the previous sound impulse is received. The echo sounder is searching the whole water column within a conic column from the transducer, mounted on the vessel, down to the seabed.

The hydro-acoustic equipment consisted of two Simrad echo sounders, an EK60 system and an ES60 system (FeBEC, 2011a). The Simrad EK60 was mounted with a split-beam transducer (120 kHz) with an opening angle of 4° x 10° (4° along ship and 10° athwart ship). The second echo sounder, a Simrad ES60, was mounted with a single beam dual frequency (38/200 kHz) transducer with an opening angle of 31° x 31°.

A double set-up design has several advantages. The EK60 split-beam echo sounder gives highly precise data on length, density, biomass, vertical and horizontal distribution, but scans only a limited water volume due to the 4 x 10 opening angle. The length estimates are derived from the experimentally determined relationship between TS (target strength) and length, which is species specific and also varies with several other factors (depth, season a. o.). In the dual beam system, the 38 kHz frequency is very good for monitoring fish in water with high levels of suspended material. Furthermore, the dual frequency system expands the scanned volume considerably due to the 31° opening angle. The quality of the fish signals from this system is lower than the EK60 system but still adequate to identify single fish, school biomass and structures.

The hydro-acoustic method is not capable of discriminating between species. Information about the species composition was provided by trawl hauls. During each continuous survey, one day and one night calibrating trawl was performed. During the 1st periodic survey, eight calibration trawls were performed, whereas the number of hauls was reduced to four at the 2nd and 3rd periodic survey. All hauls, except for the eight trawls during the 1st periodic survey, were performed with a demersal TV3 (520/80) Baltic survey trawl, according to the specifications given in the ICES manual for the Baltic International Trawl Surveys (BITS) (ICES, 2007c). A pelagic trawl, similar to the sprat trawl used by the fishermen in the area, was used during the 1st periodic survey.

Following the first survey, it was decided to change method from pelagic trawl to bottom trawl. This was done in order to supplement present and future investigations of the pelagic fish communities. The TV3 trawl was used because of the need for trawl investigations in the fish community study (demersal fish communities in the deeper parts of Fehmarnbelt). The acoustic data was calibrated to the catch-data from the day-time hauls to create a correlation between acoustic signals and trawl data.

The trawl catches also provided information about the length distribution of the different fish species present in the surveyed area. This information is required for the conversion of data on acoustic energy to fish biomass (see below).

3.2.3 Data analysis

The analysis of the hydro-acoustic data was performed using a Sonar5 PRO post-processing software program developed by the Institute of Physics, University of Oslo, in cooperation with Simrad (www.fys.uio.no). The program has been developed specifically for the estimation of biomass and size distribution of fish. It follows the internationally accepted standards for analysis of biomass and size distribution of fish (MacLennan and Simmonds, 1992), with the final definitions and terms being defined by ICES (MacLennan and Fernandes, 2000).

In order to estimate the total fish volume (or biomass) within the scanned area, all echo energy received from the sent impulses was integrated (Sv). The total echo energy was divided by the number of sound impulses sent to give the average value, which is representative for the amount of fish within the examined area. However, knowledge about the species composition and length distribution of the species within the area is a precondition for the conversion from acoustic energy (Sv) to biomass (tonnes) of fish. To exemplify the importance of this knowledge, a cod of 8 cm has an acoustic energy corresponding to that of a mackerel of 80 cm. This is because most of the reflected echo is due to the presence of a swimbladder, which means that fish species with swimbladders will have a greater reflection than those that do not have one. Please refer to FeBEC (2011a) for further details about the conversion of data on acoustic energy to fish biomass.

Based on spatial analysis, the results of the hydro-acoustic analyses were used to produce maps showing the distribution of pelagic and semi-pelagic fish (measured as tonnes per square nautical miles) within the surveyed area of Fehmarnbelt. The data on fish distribution were coupled to abiotic variables in a spatial analysis, in order to investigate if fish abundance was related to one or more abiotic parameters.

3.3 Studies of gonadal development

With the objective of describing the temporal patterns of maturing and spawning of the most important fish species in Fehmarnbelt, gonads of cod, herring, sprat, flatfish and other commercially interesting fish species were examined.

Fish for analysis were caught in trawls during the monthly hydro-acoustic surveys (September 2009 to June 2010, cf. section 3.2). In addition, fish were collected from landings by local fishermen during April - August 2009 and during January - February 2010, using only fish from pre-defined net settings.

The gonad maturity index of cod was determined macroscopically according to Tomkiewicz et al. (2002), who describe 10 maturity stages within the annual reproductive cycle. The gonadal development stages of herring and sprat were determined according to Bucholtz et al. (2008), describing 8 maturity stages. The gonad maturity index of all other species was determined according to Strand (2006). In addition to the gonad maturity index, the gonado-somatic index (GSI), describing the ratio between gonad weight and total weight, was measured. Gonad staging and GSI determination were performed on both male and female specimens.

Supplementary information on gonad development in cod came from local fishermen, who on a routing basis recorded the quality and weight of the roe together with the weight of rinsed cod in the landings. Cod roe is divided into two qualities; quality A roe without hydrated oocytes and quality B with hydrated oocytes; the latter corresponds to the main spawning stage and is sold at a reduced price.

3.4 Egg and larvae surveys

3.4.1 Sampling strategy and locations

The objectives of these investigations were to identify fish species spawning in the Fehmarnbelt area and to identify possible spawning grounds.

A total of 12 separate campaigns were conducted during autumn 2008 (2 campaigns), spring and summer 2009 (6), autumn 2009 (2) and late winter 2010 (2) (Table 3.2). The campaigns were planned to cover the spawning seasons of the most important species present in the Fehmarnbelt area. Different sampling grids were used for the campaigns performed during autumn and during winter, spring and summer (Figure 3.4).

Table 3.2: Overview of campaigns performed.

Survey	Period
2008-1	October 28 until November 7, 2008
2008-2	November 24 until December 4, 2008
A	March 3 until March 20, 2009
B	March 24 until April 4, 2009
C	April 21 until April 30, 2009
D	May 11 until May 20, 2009
E	June 15 until June 24, 2009
F	July 28 until August 6, 2009
G	October 3 until October 28, 2009
H	November 25 until December 9, 2009
I	January19 until February 14, 2010
J	March 7 until March 18, 2010

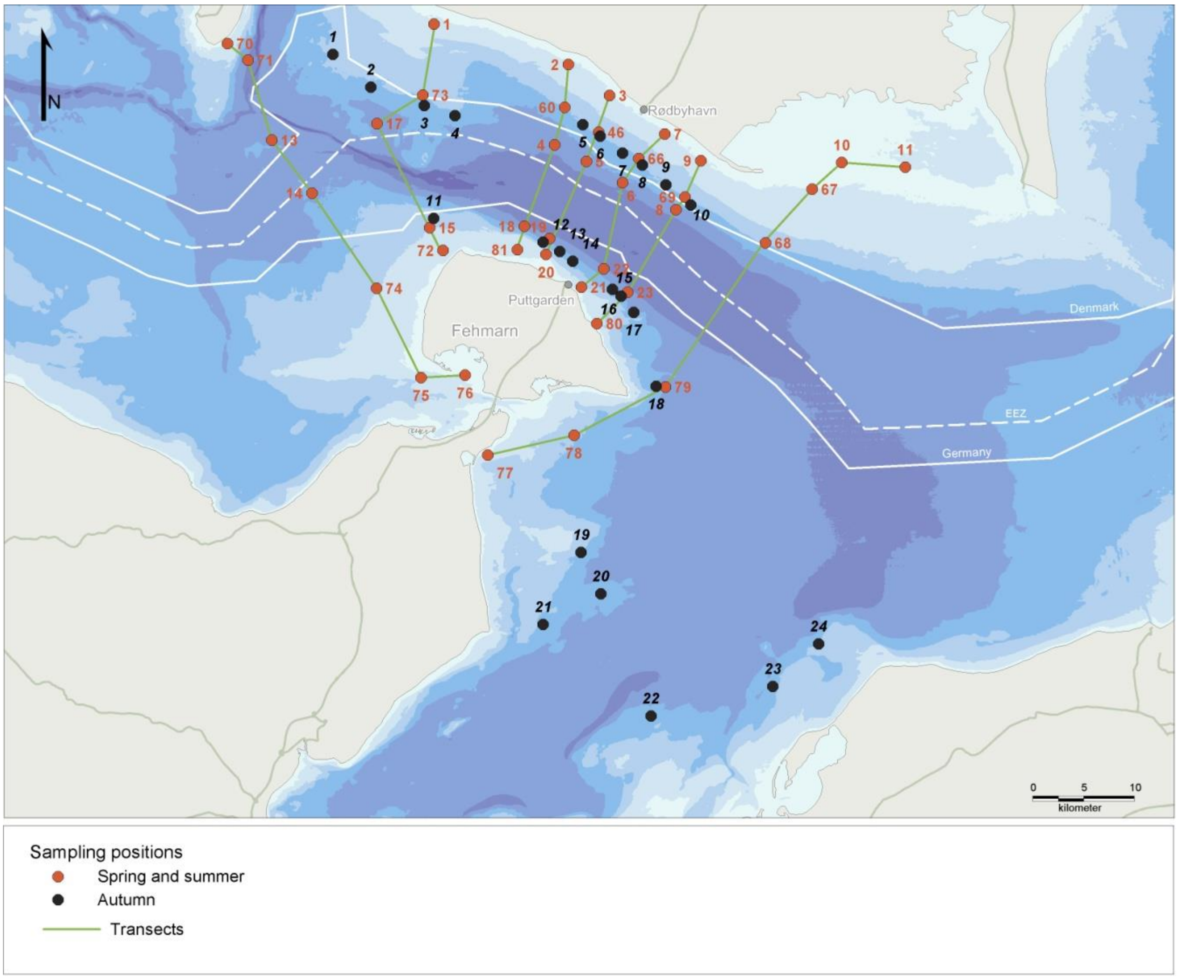


Figure 3.4: Sampling locations for egg and larvae surveys. Red dots indicate the sampling grid used in spring, summer and late winter. Black dots indicate the sampling grid used in autumn (October-December).

At the winter, spring and summer campaigns, samples for egg and larvae investigations were collected along a 20 km section of the Lolland coastline and along the northern and eastern coastline of Fehmarn as far south as Mecklenburger Bight (red dots in Figure 3.4). Riber and Raschke (1999) states that cod and flatfish spawn in the deeper waters of Fehmarnbelt and that spring spawning herring utilize the shallow waters for spawning. These findings were consistent with information obtained from local fishermen.

Samples were collected at 39 stations along 7 transects within Fehmarnbelt:

- 14 deep water stations covering supposed suitable spawning areas for the pelagic spawners cod, sprat and flatfish
- 8 mid water stations at approximately 15 m depth covering supposed suitable spawning areas for flatfish and sprat.
- 17 shallow stations at 3-7 m depth placed in areas rich in gravel, stones and vegetation that were supposed to be particularly suited for spring spawning herring, which is a benthic spawner.

The sampling programme was adjusted after the first spring survey (A) in March 2009, when 28 stations were used. A map showing the location of these stations is presented in FeBEC (2011a).

The autumn campaigns were specifically designed to investigate the distribution and abundance of larvae from autumn spawning herring. Samples were collected at 24 stations along the coastline at the 12 meter depth curve in Fehmarnbelt (black dots in Figure 3.4). According to Riber and Raschke (1999), Klinkhardt (1996) and local fishermen, the autumn spawning herring spawn in deeper waters (8-20 m) than the spring spawning herring. The distance between sampling stations were 2-5 km, with the smallest distance within the central part of Fehmarnbelt.

As a supplement, monthly samples of fish eggs and larvae, collected during the plankton campaigns (FEMA, 2010), were analyzed and data were included in the results.

3.4.2 Sampling equipment and handling of samples

Sampling of fish eggs and larvae was performed according to principles recommended by FAO (Smith and Richardson, 1977) and was in compliance with the method used in the Danish national environmental monitoring programme (Strand, 2006). A BONGO net equipped with a 500 µm nets and Hydrobios flowmeters was used (Figure 3.5). Towing speed was 1-3 knots, equivalent to approximately 0.5-1.5 m/s, thus allowing fish eggs and larvae to be caught undamaged. A DST tag (Data Storage Tag) continuously recording conductivity (mS/cm), temperature (°C) and depth (m) was mounted directly on the frame of the BONGO net.

Figure 3.5: A BONGO-net was used to collect fish egg and larvae. Source: www.kc-denmark.dk

Vertical profiles of depth, current, temperature and salinity were measured to identify possible pycnoclines (stratification of water bodies) that may affect concentrations of egg and larvae. During periods of stratification, separate tows were performed to cover the water masses above, in, and below the pycnocline. In autumn no stratification was expected and separate horizontal tows were performed at 4-5 m depth and at 9-10 m depth. Two replicates were collected from each tow. One replicate was fixed in 1.5% acidic Lugol's solution and one replicate in 5% acidic formalin solution. Lugol's solution has proved to be an effective fixation media both for fish eggs and larvae (Engell-Sørensen et al., 2012).

Prior to fixation of eggs and fish larvae, selections of fresh eggs were collected and preserved in 40% glucose and frozen (-20°C) for gel electrophoresis analysis. When the number of fish larvae was sufficient, a minimum of 5 larvae were preserved in RNA*later* (Höök et al., 2008) for determination of the RNA/DNA ratio to elucidate the nutritional and growth condition of the larvae.

Samples of predatory medusae, including the introduced ctenophore *Mnemiopsis leydii*, which potentially can impact the abundance of fish egg and larvae (Hansson, 2006; Kube et al., 2007), were collected from the Lugol preserved samples (Engell-Sørensen et al, 2009). Samples of potential prey for fish larvae, e.g. mesozooplankton (mainly calanoid copepods), were collected at each station.

3.4.3 Identification of eggs and larvae

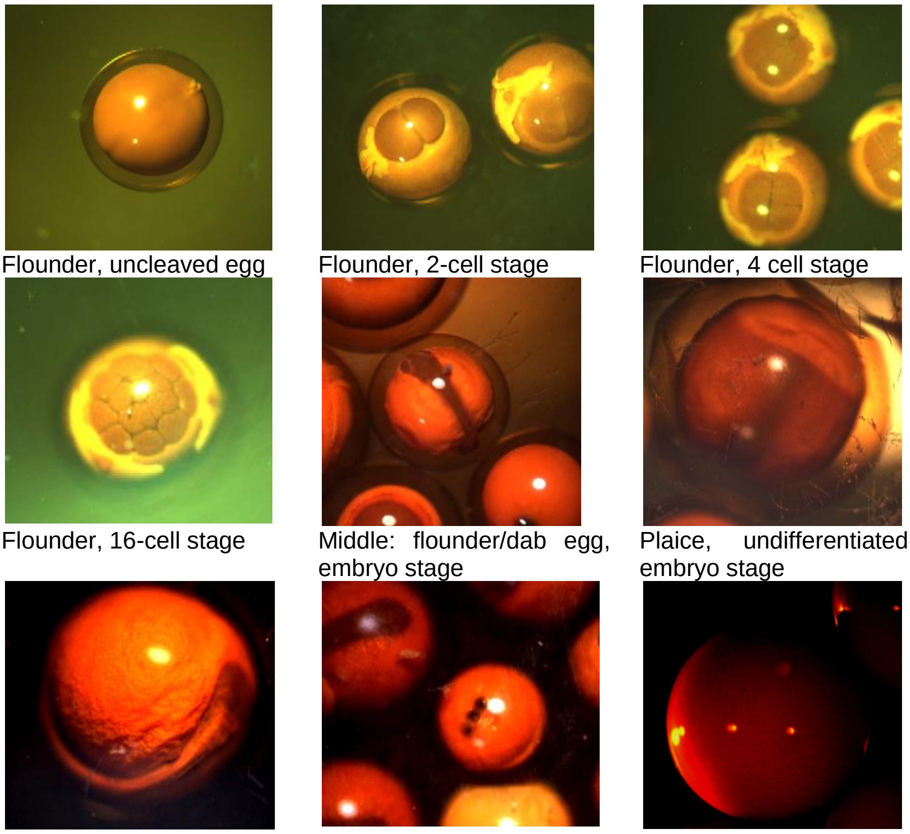
Eggs and larvae were identified using stereo microscopy, phase contrast microscopy and inverted microscopy of fresh and preserved material. Digital photo equipment was used to document key characteristics. Fish eggs, fish larvae and medusae were identified to species level (Ehrenbaum, 1905-1909, Heinen, 1910/11; Russell, 1976; Munk and Nielsen, 2008), and the biomass was calculated from simple measurements and formulas.

Visual separation of species was not always possible; in particular, eggs of flounder, dab and goldsinny wrasse are morphologically similar, and eggs of cod and whiting are morphologically similar (Russell, 1976). Species identification of these eggs was performed by means of gel-electrophoretic analysis (Paaver, 1991), with tissues from adult fish being used as standards. As a spot check, gelelectrophoretic analysis was also used to verify the species identification in cases where visual separation of species was used.

Developmental stages of eggs and larvae were identified and grouped into the following stages according to Westerhagen (1970) (Table 3.3 and Figure 3.6). Larvae were divided into yolk sac larvae and post larvae (in which the yolk sac is absorbed).

Table 3.3: Characteristics of different stages of eggs

Stage	Characteristics of stage
0	Unfertilized or undivided egg
1a	2 cell stage
1b	4 cell stage
1c	8 cell stage
1x	16 cell stage
1y	32 cell stage
1d	blastoderm stage
2a	undifferentiated embryo
3	embryo encircling between 180 and 270 degrees of the yolk
4	embryo encircling more than 270 degrees of the yolk
5	dead egg



Flounder, uncleaved egg | Flounder, 2-cell stage | Flounder, 4 cell stage

Flounder, 16-cell stage | Middle: flounder/dab egg, embryo stage | Plaice, undifferentiated embryo stage

Plaice egg, embryo stage | Middle: rockling egg with oildrops | Dead egg

Figure 3.6: Various stages of Lugol fixated fish eggs.

Additionally the buoyancy of the pelagic eggs of cod, flounder and plaice eggs were investigated under laboratory conditions. Spawning fish were caught and striped from January to March 2011. Fertilization of eggs was conducted in artificial seawater (FeBEC, 2010b). Eggs were brought to the temperature controlled laboratory facilities at IFM-GEOMAR, Kiel and neutral egg buoyancy of early egg development stages was determined in salinity gradient columns following the methodological approach presented by Coombs (1981).

3.4.4 Nutritional stage and growth of fish larvae

Growth and nutritional stage of selected herring and sprat larvae were determined by otolith microstructure analysis (Panella, 1971; Stevenson and Campana, 1992) and by analysis of the RNA/DNA ratio (Höök et al., 2008).

The age of larvae with a depleted yolk sac may be estimated using the otolith structure. At this stage the larvae are actively searching for prey, and different feeding and activity levels during day and night coupled to an endogenous rhythm lead to the formation of structures in the otolith which display the daily pattern. These increment structures make age determination possible in larval and juvenile fish, and the width of the increments gives a daily growth history.

Analyses of larval fish RNA/DNA ratios provide a powerful tool to analyze and assess larval condition (Clemmesen, 1994; Buckley et al., 1999; Pepin et al., 1999; Chicharo et al., 2003; Caldarone et al., 2006; Chicharo and Chicharo, 2008). The applicability of the nucleic acid ratio is based on the fact that DNA concentrations within individual cells remain fairly constant while RNA concentrations increase as protein synthesis increases (Buckley et al., 1999).

In the present study, more than 1,040 RNA/DNA ratio measurements were conducted on individual larvae. About 370 of these were used to develop, adjust and inter-calibrate methodological issues concerning the applied fixation medium (RNA*later)*. RNA/DNA ratios were measured for 670 larvae of 7 different species (herring, sprat, cod, gobies (not identifiable to species level), small sandeel (*Ammodytes tobianus*), longspined bullhead (*Taurulus bubalis*), and dab (*Limanda limanda*). The larvae were collected at 5 to 9 stations, ranging from shallow (0-6 m) to deep (>20 m) waters, during four campaigns between April and July 2009 (Figure 3.7). The analyses of RNA and DNA concentrations were performed using a modification of the method of Clemmesen (1993) and Belchier et al. (2004) described in FeBEC (2009c).

RNA/DNA ratios from herring in the Kiel Channel and Kiel Fjord, from laboratory studies, or from herring larvae originating from other hydrographical areas (Clemmesen, 1994; Donner, 2006; Peschutter, 2008; Höök et al., 2008), were used for comparison (Peschutter, 2008).

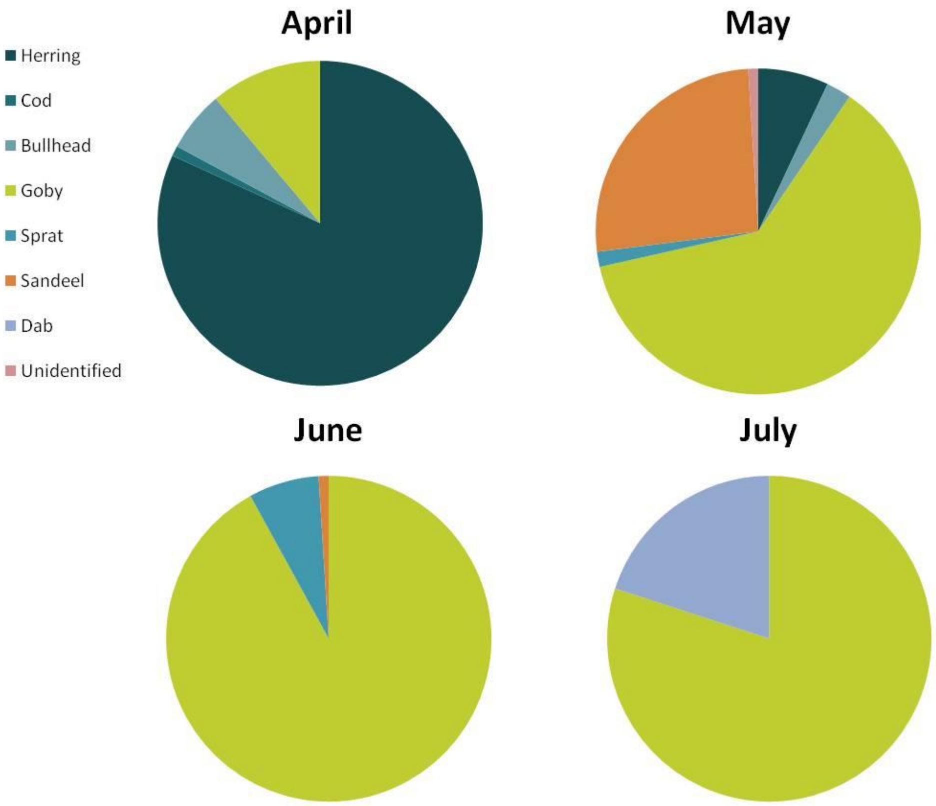


Figure 3.7: Proportion of frequency of all biochemically analyzed species separated by monthly campaign. April – 5 stations, May – 5 stations, June – 9 stations and July – 6 stations.

3.4.5 Data analysis

3.4.5.1 Estimation of development rates

Hatching time and the duration of each developmental stage of fish eggs are species specific and were used in the estimation of development rates according to data from the literature (Cunningham, 1880 and 1886 in Russell, 1976; Dannevig, 1895; Ehrenbaum, 1905-1909 in Russell, 1976; Bonnet, 1939; Breder and Rosen, 1966; von Westerhagen, 1970; Thompson and Riley,1981; Kjørsvik et al., 1984; Pauli and Pullin, 1988; Pepin et al., 1997; Engell-Sørensen, 1999; Fox et al., 2003; Fox et al., 2008). For dab, no temperature related development rates for eggs were found in the literature, thus temperature related development rates of flounder eggs were used.

The individual based model used includes the temperature dependent development rate of eggs from spawned to hatched, expressed as the daily fractional development (DFD). The DFD model is expressed on a scale from 0 to 1, where 0 is spawned and 1 is hatch. Besides two species specific constants, the DFD model includes only temperature as an independent variable. This implies that the age (in days/hours) of an egg may be estimated from the developmental stage of the egg and data on the temperature since spawning.

Fish larvae undergo development and gradual depletion of their yolk sacs at different larval stages. The developmental stage of the larvae reflects the number of day degrees (a function of time and temperature) since hatch. For herring, the utilization of yolk depends not only on the temperature but also on the origin of the larvae, so values for western Baltic herring were used to calculate the most likely time from hatch to post larvae (Rannak, 1958; Blaxter and Hempel, 1963).

3.4.5.2 Estimation of egg mortality

Egg mortality may be estimated from the relative frequency of different egg stages in a sample (Bunn et al., 2000). Assuming a) that the eggs from one species in a survey belongs to the same population, b) that the rate of development from spawned until hatched depends only on the temperature, and c) that the mortality decreases in an exponential pattern, it is possible to estimate the instantaneous daily egg mortality rate (Z) from the abundance of the different stages of eggs and the temperature (see Figure 3.8 as an example). The density of eggs at the time of spawning (N_0) may then be estimated from the equation $N_t = N_o{*}e^{-zt}$.

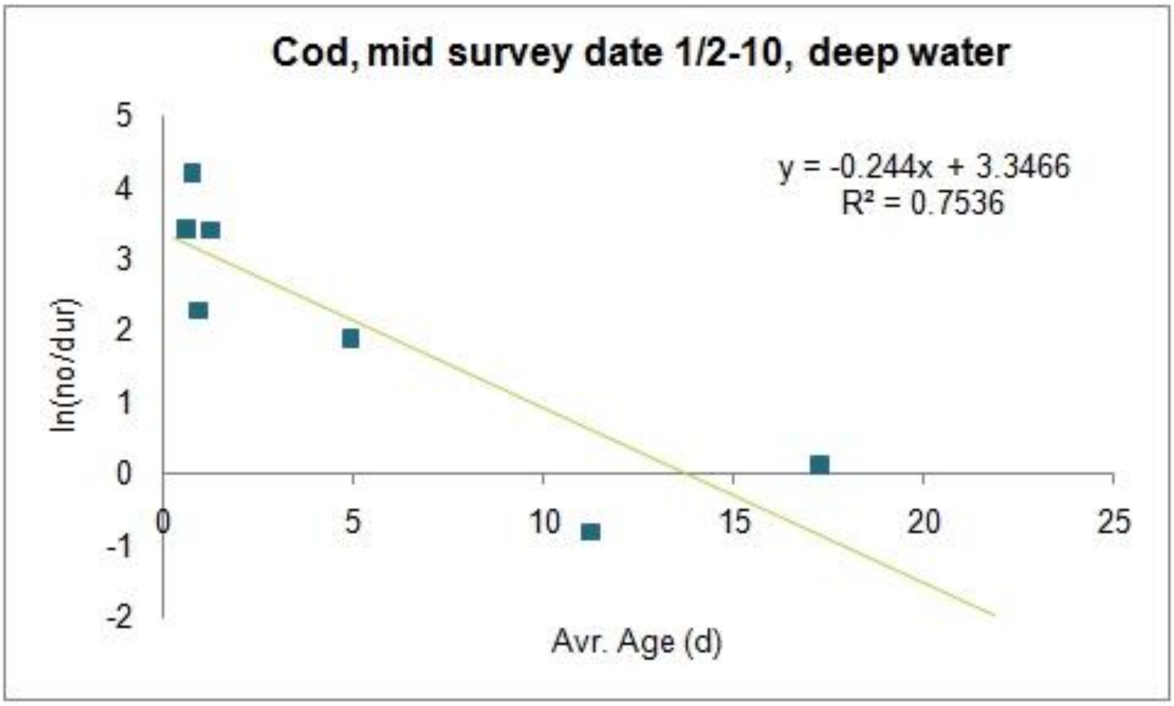


Figure 3.8: Estimation of instantaneous daily egg mortality rate (Z) from the age and abundance of various stages of eggs in a sample (survey). $N_t = N_o{*}e^{-zt}$. N_t = density at time t (days). N_0 = density at t_0 corresponding to the egg production, Z = instantaneous daily egg mortality. Since the various egg stages do not last equally long, the number of eggs in each stage was normalized by diving the number of eggs in a stage with the duration (days) of the stage in question. The data is collected in deep water during survey I (Jan-Feb 2010).

3.4.5.3 Estimation of egg production and spawning biomass

Based upon the calculations described above, the total egg production of a certain species at a certain time (t_0) within the surveyed area may be estimated by multiplying the estimated density of eggs (N_0) by the total water volume, assuming that the sampled water column is representative of the whole area (Figure 3.9). This is of course only possible for pelagic spawners.

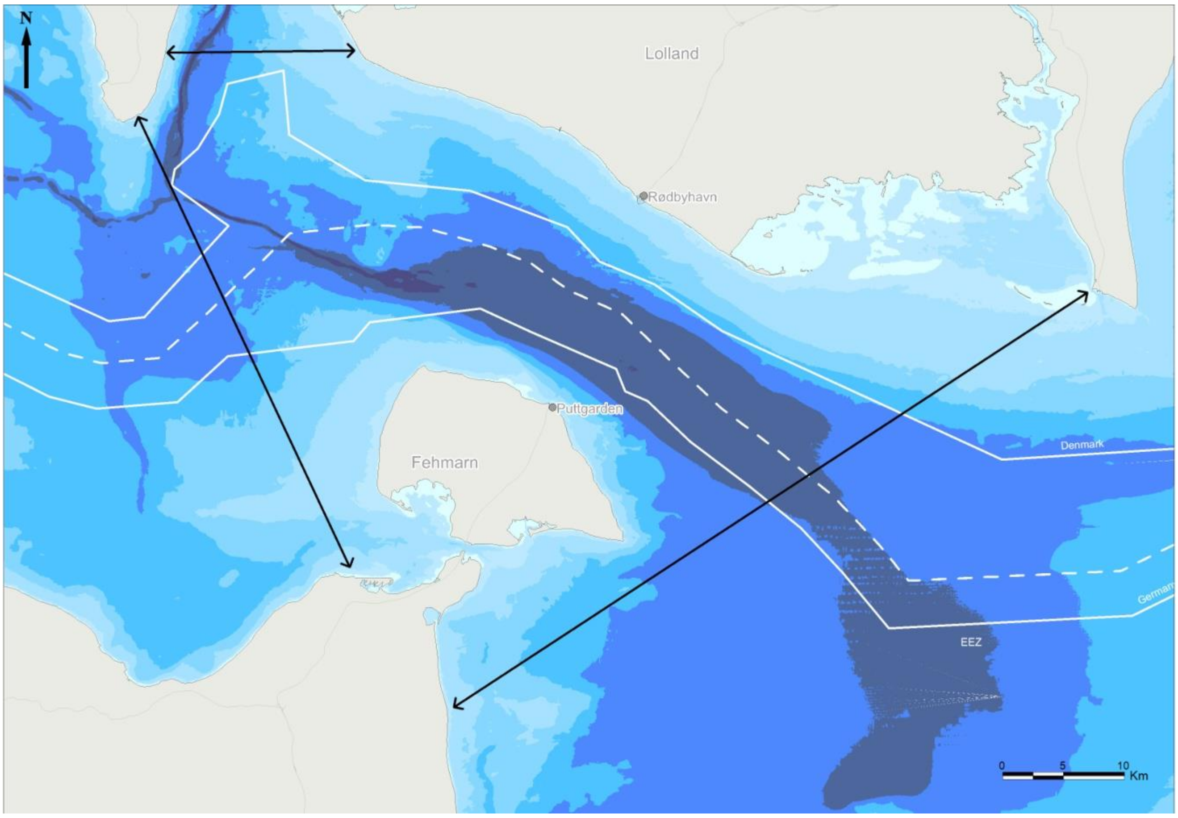


Figure 3.9: Map of Fehmarnbelt showing the delimitation of the area surveyed for eggs and larvae. The sampling area is within the arrows. The estimated total water volume within this area is $36*10^9$ m^3.

Data from deep water samples and shallow water samples were dealt with separately. The estimated density of eggs in each compartment was multiplied by the estimated volume of water below and above 10 m depth within the surveyed area. The annual egg production within each compartment was estimated by integrating the estimated egg production at each survey over the year (area under curve approach). Finally, the total annual egg production within the entire surveyed area was estimated by adding the estimates for deep and shallow waters combined with the calculated mortality (FeBEC, 2011b).

In those species where the fecundity of females was known from the literature, the total biomass of females spawning within the area could be estimated.

3.4.5.4 Backtracking of eggs and larvae

Back-tracking of eggs and larvae to possible spawning grounds was performed by combining a hydrodynamic model of drifting patterns with data on the temperature-dependent developmental rates of fish eggs and larvae.The relative developmental rates used in the back-tracking model are shown in Table 3.4.

Table 3.4: Percentage of development until hatch during the different development stages, for different species, used in the back-tracking model. 2-cell to 32 cell = the eggs remain from 2 to 32 cells, blastula/gastrula = the egg is in the blastula or gastrula stage, : <180°, 180-270°, >270° = the embryo encircles less than 180°, 180-270°, or >270°, respectively, of the yolk.

Fish species	Zy-gote	2-cell	4-cell	8-cell	16-cell	32-cell	Blastula /gastrula	<180°	180-270°	>270°	Total
Cod	1.9	0.6	0.6	0.6	0.6	0.6	26.8	20.3	24.4	23.3	100
Flounder	2.7	0.9	0.9	0.9	0.9	0.9	23.8	16.8	15.4	36.8	100
Plaice	2.5	0.8	0.8	0.8	0.8	0.8	21.8	17.3	28.4	25.8	100
Dab, turbot, sprat, four-beard rockling	2.4	0.8	0.8	0.8	0.8	0.8	24.2	18.1	22.7	28.6	100

A total of 8,884 individual eggs and 91 herring larvae were back-tracked (Table 3.5).

Table 3.5: The number of back-tracked eggs and larvae per survey.

	NUMBER OF SAMPLINGS* (weighted according to the number of cells per sampling**)									
SPECIES	A	B	C	D	E	F	∑ A-F	I	J	∑ I-J
Fourbeard rock-ling	108	279	472	180	75	27	1,141	6	215	221
Cod	130	514	136	82	55	22	939	52	709	761
Flounder/dab	274	848	524	669	479	83	2,877	12	764	776
Plaice	102	167	55	6	12	0	342	44	435	479
Sprat	1	19	446	590	241	51	1,348	-	-	-
Herring (larvae)	-	-	55	34	2	-	91	-	-	-
	* With DFD < 0.35, except for herring where all ages were tracked									
	** Number of cells was not provided for surveys I and J.									

The location and relative importance of pelagic spawning grounds in Fehmarnbelt and adjacent areas were then estimated by combining:

1. The back-tracked position of where each egg was originally spawned (cf. the description above).
2. The estimated mortality of eggs during the period from spawning to catch (cf. section 3.4.5.2).
3. The density (no/m^3) of each particular egg stage at the catch site.

The location and relative importance of spawning grounds for benthic spawners (herring) was estimated by combining:

1. The back-tracked position of where each herring larva was originally hatched.
2. The natural mortality of larvae during the period from hatch to catch.
3. The density of each particular larval stage at the catch site.

3.4.5.5 Estimation of predation rates

For estimation of potential predation rates from gelatinous zooplankton (jellyfish, ctenophores) on fish eggs and larvae, clearance rates were calculated according to Purcell and Arai (2001).

3.5 Spawning herring surveys

3.5.1 Sampling strategy and locations

The aims of the baseline studies of herring spawning in the Fehmarnbelt area were:

- To estimate the time of spawning of autumn spawning and spring spawning herring
- To map the relative abundance of autumn spawning and spring spawning herring
- To map the location and habitat of spawning grounds
- To determine genetic affiliations of potentially spawning herring.

The studies included:

- Registrations of gonad development of herring caught in pound nets at the Danish coast
- Gill net surveys at the Danish and German coastlines
- Video screening of the sea bottom at the German and Danish coast during the autumns of 2008 and 2009 and in spring 2009
- Genetic analysis of species affiliation among a subsample of the caught herring.

An overview of the surveys is presented in Table 3.6.

Table 3.6: Timing of the surveys, number of sampling stations and number of examined herring.

	Autumn 2008		Spring 2009		Autumn 2009	
	GE	DK	GE	DK	GE	DK
Pound nets	27th Sep-9th Dec				14th Sep-29th Nov	
Sample occasions		21				15
Herrings examined		361				324
Gill net surveys	22th Oct - 12th Dec		15th Mar - 29th Apr		15th Sep - 12th Dec	
No. bottom set nets	45	55	40	35	55	56
No. surface set nets	45	55	60	63	55	56
Herrings examined	74	72	626	432	120	198
Video survey	22th Oct -12th Dec		15th Mar - 29th Apr		15th Sep - 12th Dec	
Remote video transects	45	55	56	101	24	2
Transects videoed by divers			35	91		

At two locations on the Danish coast, gonad maturity of herring caught by local fishermen in pound nets was continuously monitored during the autumns of 2008 and 2009. From each herring, length, total weight, gonad weight, gonad index (Bucholtz, 2008), sex, and number of herring worm were recorded. The findings from these investigations were used to plan the gill net surveys in autumn.

Extensive and intensive gill net surveys were performed along the coasts of Fehmarn and Lolland at depths between 7-20 m in autumn 2008 and 2009, and between 0.5-11 m in spring 2009. The shallow water areas Rødsand Lagoon and Orther Bight were included in the spring survey. The number of nets used at each survey is listed in Table 3.6 and the location of the nets is shown in Figure 3.10.

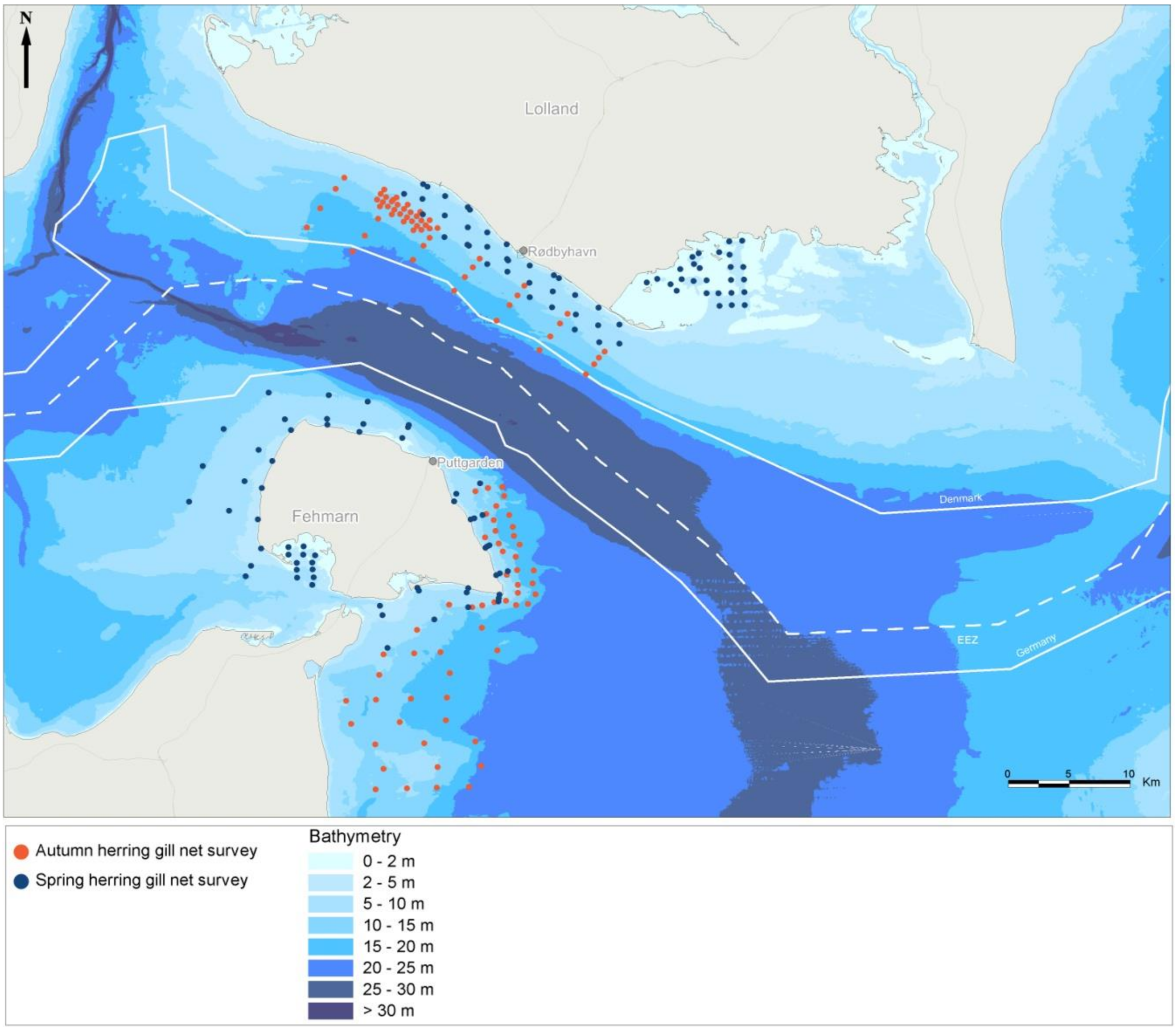


Figure 3.10: Location of gill net settings at the herring gill net surveys in the autumn of 2008 and 2009 (red circles) and in spring 2009 (blue circles) in Fehmarnbelt.

Screenings of the sea bottom for herring spawning grounds were carried out by remote video recording (autumn and spring) and by hand-held camera by divers (spring). The videoed transects were either 100-200 m tracks parallel to the settings of the gill nets or randomly chosen tracks of 500 m length along the coasts. In the autumn 2008 all gill net sampling locations were video recorded. The locations of the video recorded transects in spring 2009 are shown in Figure 3.11.

From subsamples of the catch, fecundity (number of eggs) was determined and otoliths and tissue samples were taken for analysis of age and genetic affiliation (a, 2010). Furthermore, total length and total weight of other fish species were recorded from each gill net.

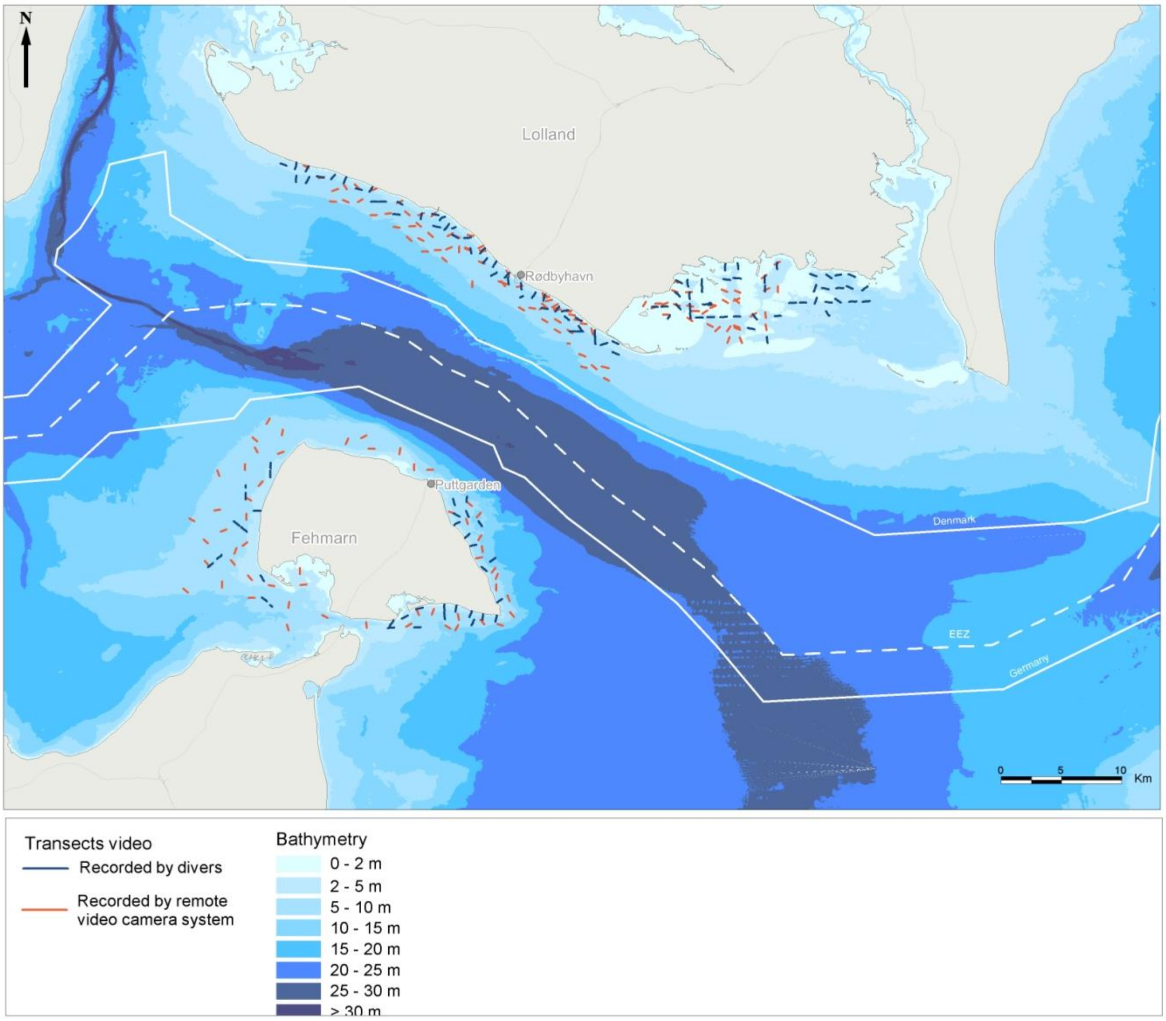


Figure 3.11: Locations of transects video recorded by divers (red lines) and by remote cameras systems (blue lines) at the herring spawning bed video survey in Fehmarnbelt in spring 2009.

3.5.2 Sampling equipment

The standard herring nets were composed of two net panels with mesh sizes of 27 mm and 30 mm, each with a length of 24 m and a height of 2 m. The nets were either floating or stationary on the bottom. They were either linked together in a 100 m link or were placed very close in two links of 50 m each (Figure 3.12). The soak time was approximately 22 hours for each gill net.

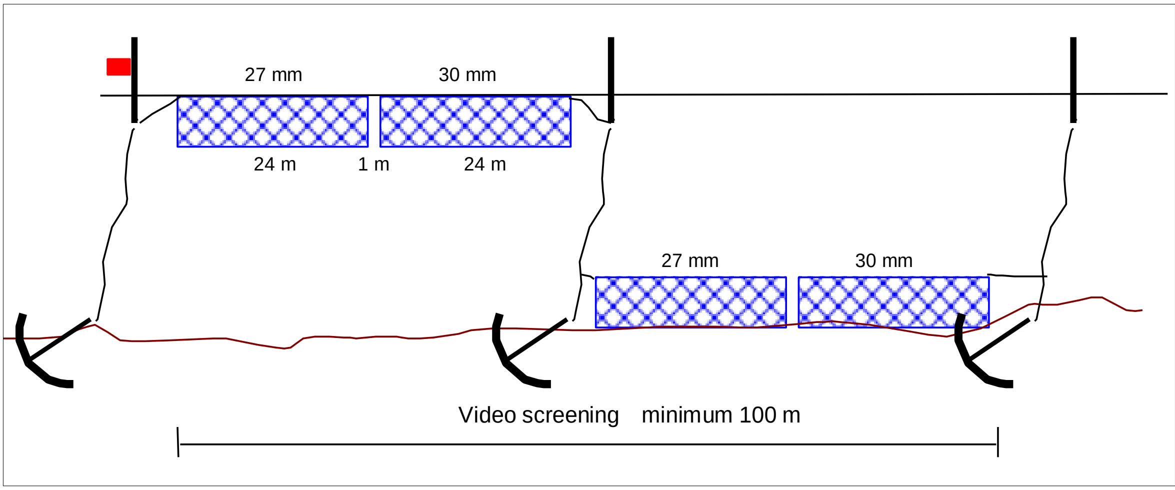


Figure 3.12: The dimensions and settings of the floating and bottom standing herring gill nets used in the spawning herring surveys in Fehmarnbelt in the autumns of 2008 and 2009 and in spring 2009.

The remote cameras used for video recording were connected by cable to a digital recorder coupled with an echo sounder and a GPS receiver. The video signals were monitored on deck while videoing, and the morphology of the sea bottom was recorded following a modified method in the guidelines of the Danish NOVANA coastal fish survey program (Strand, 2006; FeBEC, 2010a).

3.5.3 Data analysis

Catch per unit effort (CPUE) of herring was calculated as mean catches of herring from both surface and bottom standing nets. Gonad somatic index (GSI) was calculated as (gonad weight/total weight)*100. The prevalence of herring worm was calculated as the percentage of infected herring out of the total number of herring caught (Chenoweth et al., 1986).

All distributions were tested for normality, and multiple regressions as well as two-sample tests were performed on catch data from gill nets, and on infection with herring worm, GSI and GI for male and females. The two-sample tests included Mann-Whitney U, Wilcoxon Rank-Sum and Kolmogorov-Smirnov tests in case of non normal distributions. The statistical data analysis was based on the NCSS 2007 statistical analysis system (NCSS systems, Utah, USA).

3.5.4 Otolith microstructure analysis

Analysis of otolith microstructure is a powerful tool for determination of life history trajectories, where determination of hatch season and larval ambient environment are the key proxies for individual population affiliation (Clausen, 2007). Differences in otolith growth trajectories between herring larvae experiencing different temperature and feeding regimes have been identified in both field and laboratory studies (Moksness, 1992, Stenevik et al., 1996, Folkvord et al., 1997 (Figure 3.13).

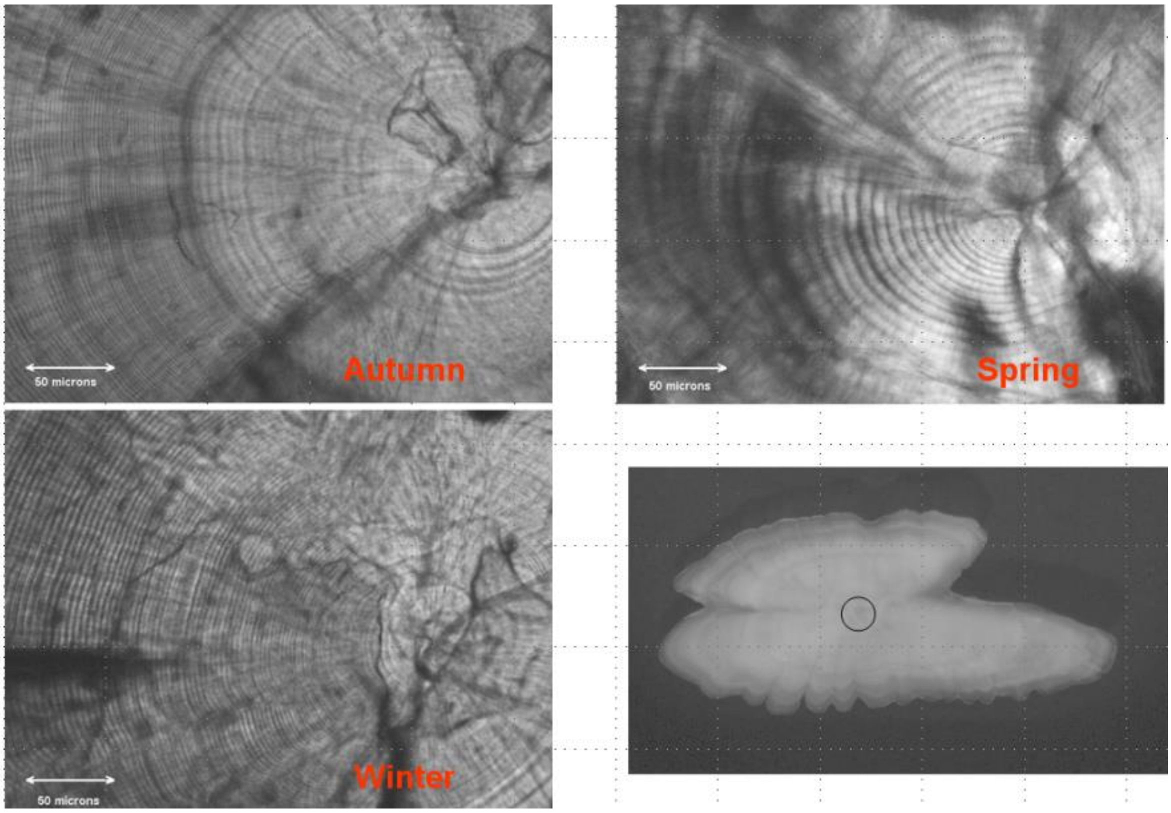


Figure 3.13: Herring otolith microstructure in the larval centre of the otolith (circle in lower right panel) enlarged after preparation showing the daily micro-increment pattern. These primary increments are found to be diurnal and increment width is assumed to indicate environmental conditions, primarily temperature. This microstructure is temperature dependent and reflects the life-conditions during the larval life and hence spawning time. © Lotte Worsøe Clausen, DTU Aqua.

Based on sampling month, GSI and parasite infection a subsample of 58 herring was selected for otolith microstructure analysis and among these tissues from 43 individuals were further genetically analysis (see section 3.5.5). The otoliths were digitised, aged and mounted on a glass slide for preparation. The spawning type was analysed by DTU Aqua (Clausen, 2010) applying the 'Otolith microstructure method' (Clausen et al., 2007).

3.5.5 Genetic analysis

The 43 tissue samples were processed by DTU Aqua (Bekkevold, 2010). Samples represented 26 herring collected in spring and 17 collected in autumn/winter. Genomic DNA was extracted from individual tissue samples and each individual was screened for a total of 30 single nucleotide polymorphisms (snps) using the SNaPshot® multiplex system from Applied Biosystems. For separating different western Baltic populations, the applied snp screening panel was developed specifically by selecting snps with high statistical power, from a 300 snp panel available from the EU Framework 7 project FishPopTrace. To examine the statistical power for genetically assigning individuals to population of origin using the 30 snp panel, simulations were carried out using genetic data from the FishPopTrace database for samples of spawning herring collected across the North Sea-Baltic Sea region. These samples were also subsequently used as a baseline, against which the 43 Fehmarnbelt herring were matched to determine their genetic origin.

3.6 Tagging of cod

The objective of the baseline studies on migration of the western Baltic cod was to collect information on the migration and migration behavior of cod in Fehmarnbelt. To comply with the overall objective, the purposes of the inventories of cod migration were:

- To identify migration between spawning and feeding grounds.
- To map the migration patterns of the spawning cod in Fehmarnbelt.
- To map the migration routes in Fehmarnbelt and adjacent waters according to a variety of oceanographic, hydrographical and meteorological parameters etc.
- To obtain baseline information on the migration pattern of individual cod (i.e. depth, temperature and route of migration).

In order to map the migration patterns of the spawning cod in Fehmarnbelt, a tagging experiment was initiated in February 2010. Cod were caught during the spawning period on a known spawning site in the area “Øjet” in the western part of Fehmarnbelt and tagged.

Two different fish tagging techniques were used; a simple sequentially numbered external fish tag (T-bar) and an intelligent Data Storage Tag (DST). The DST’s were programmed to log data on depth and temperature at 2 min. intervals. In all, 288 T-bar tagged cod and 40 DST-tagged cod were released in the period 4th of February to 10th of March. Numbers and dates of the tagging experiment are shown in Table 3.7.

Table 3.7: Number of tagged cod at each release date.

	Release date		
Tagged cod	4th February	5th March	10th March
T-bar tag	162	7	119
DST-tag	0	40	0

The fish for tagging where caught by a local fisherman in trammel nets. The nets were set from 20 to 48 hours before fetching and tagging. The nets were hauled on board the vessel using a net hauler, and the fish were gently removed from the mesh and immediately transferred to the tagging table. The length of the cod were registered, and T-bar tags were inserted just below the basis of the anterior dorsal fin by using a standard T-bar tagging gun, while the DST’s where installed using a costume-made tagging tool. Every tag was inspected for secure anchoring, and the cod were quickly transferred to a tank containing 200 l of continuously replaced seawater. Less than 30 individuals were kept in the tank at a time and at the most 40 minutes before release.

The tagged cod were released at a distance of approximately 0.25 nm from the catch site, where they were gently released into the sea by hand, one at a time. Individuals who did not swim to the bottom almost immediately were recaptured, and tags were removed. The weight of the individual cod was estimated from a general length-weight relation estimated from a sub-sample of 98 cod randomly chosen from the landings of cod in the tagging period. The length of the cod varied from 39 cm to 110 cm (Figure 3.14) with the majority of the cod in the length interval 60-80 cm and the mean weight was 4.58 kg.

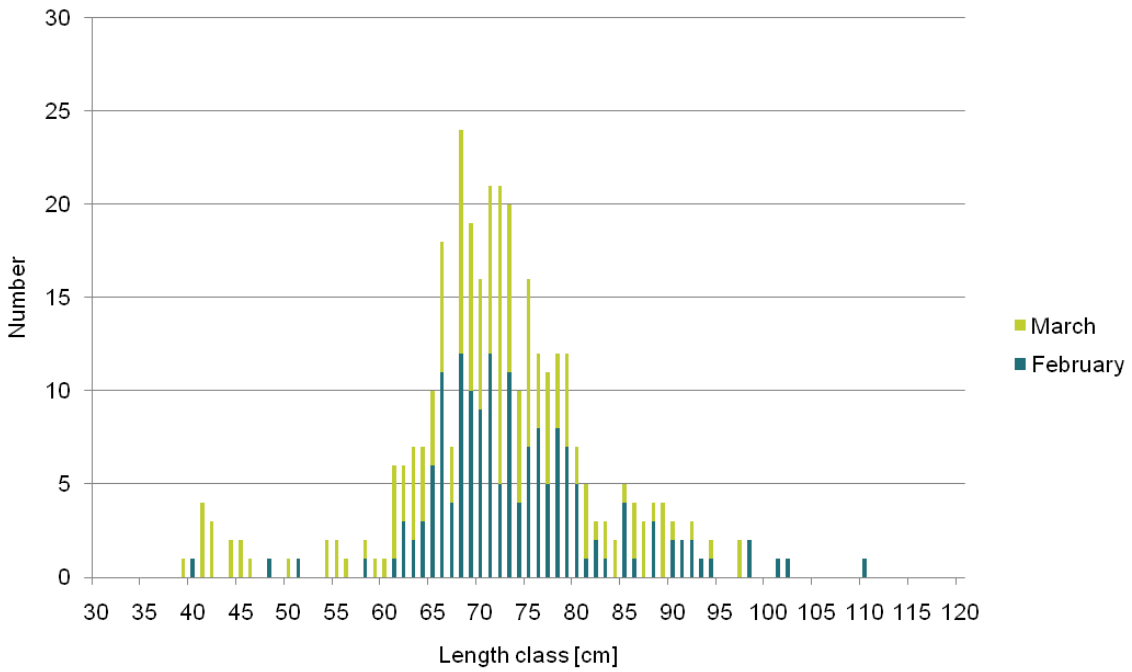


Figure 3.14: Length distribution of tagged cod, Fehmarnbelt 2010.

For further details on cod tagging method see FeBEC (2011g).

3.7 Tagging of eel

3.7.1 Sampling strategy, locations and equipment

The objective of the baseline studies on migration of the European silver eel was to collect information on the migration and migratory behaviour of silver eel in Fehmarnbelt. To comply with the overall objective, the purposes of the inventories of silver eel autumn migration were:

- To establish a baseline knowledge on the extent of the autumn silver eel migration through Fehmarnbelt
- To map the migration routes in Fehmarnbelt and adjacent waters according to a variety of oceanographic, hydrographical and meteorological parameters etc.
- To obtain baseline information on the migration pattern of individual silver eel (i.e. speed, depth and route of migration).

The studies focused on mapping the routes and possible migratory preferences of silver eel in Danish waters by means of a mark-recapture programme. The studies included tagging experiments in the autumns of 2008 and 2009.

Two different fish tagging techniques were used; a simple sequentially numbered external fish tag (T-bar) and an intelligent Data Storage Tag (DST) (Figure 3.15). The DST's were programmed to log data on depth and temperature at 2 min. intervals. The tags were mounted externally on the silver eel, just beneath the foremost part of the dorsal fin. For each eel, the total body weight was registered in addition to the unique ID number of the tag and the position and date/time of capture and release.

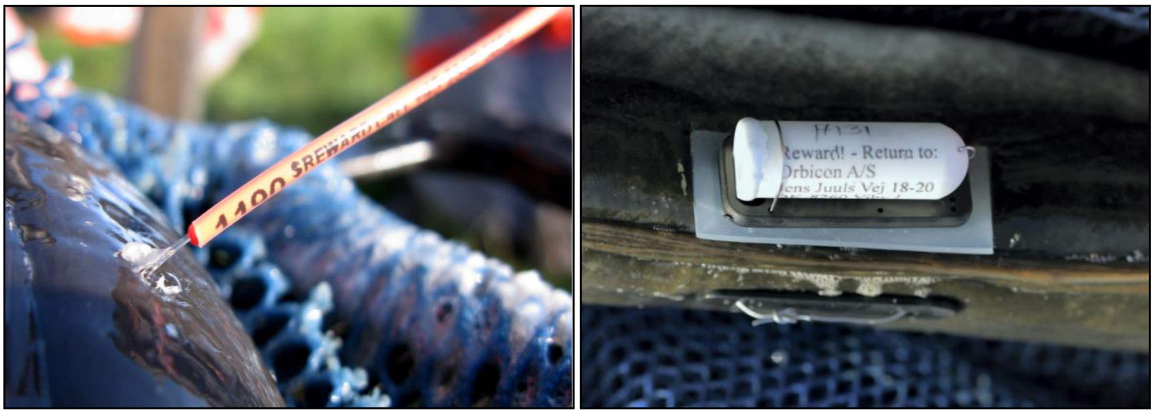


Figure 3.15: Left: A Hallprint T-bar tag with contact information text. Right: The DST (Data Storage Tag) with return Information text. The sensors of the DST store information on temperature and depth at user-defined time intervals. © Christian B. Hvidt.

The two tagging programmes were run in parallel at two campaigns in 2008 and 2009 (Table 3.8).

Table 3.8: Time and location of release of the tagged eel during the 2008 and 2009 campaigns.

	Autumn 2008		**Autumn 2009**	
Release Date	13thOct - 16thNov		9thOct - 30thOct	
Release location	North of Fehmarn	South of Lolland	North of Rügen	South of Sweden
T-bar tags	1156	699	771	914
DST-tags	30	74	101	99

The silver eel marked in 2008 were caught by local pound net fishermen along the coasts of Lolland and Fehmarn and were released in the vicinity of the capture site (Figure 3.16).

In 2009, eel were delivered exclusively by pound net fishermen along the coast of Lolland. The eels in this campaign were kept in tanks and were transported by a fishing vessel approximately 150 km eastwards where they were released south of the Swedish coast at Trelleborg and north of the island of Rügen (Figure 3.17).

Tag return was enhanced by a publicity campaign, contacts to commercial fisheries associations and a reward scheme.

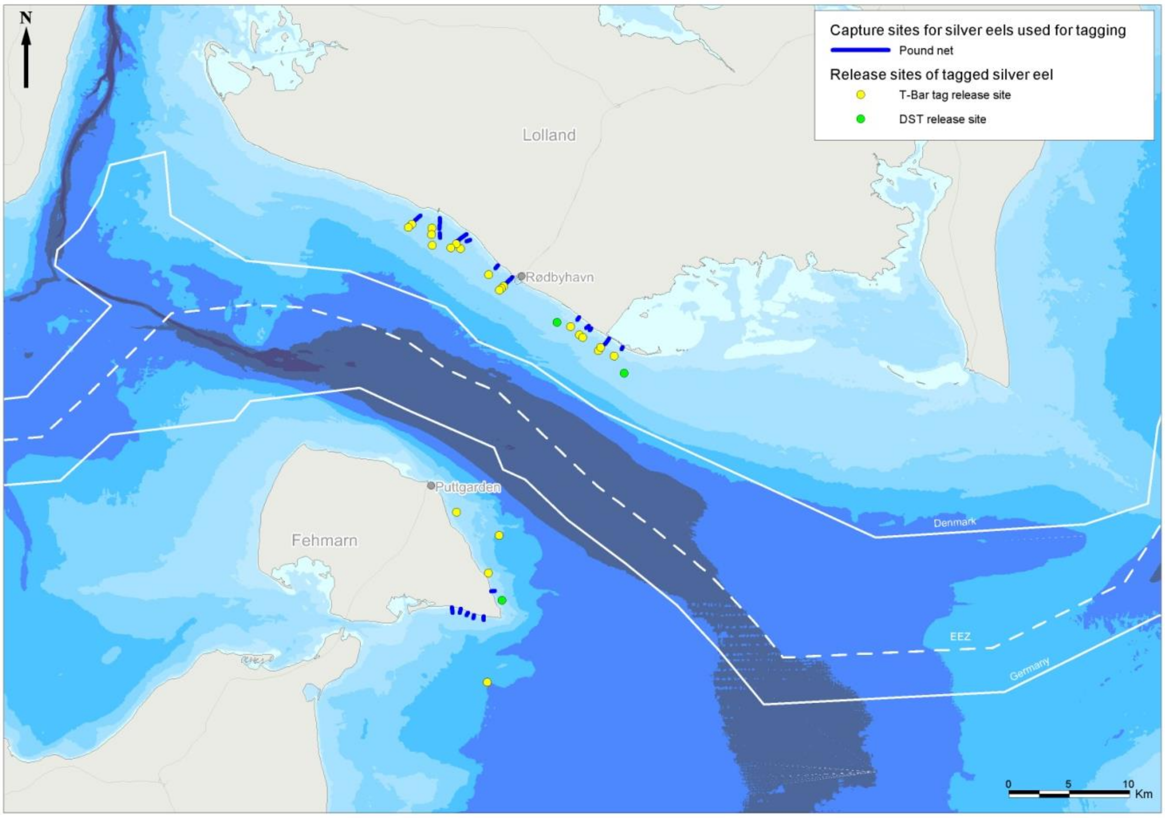


Figure 3.16: Capture and release sites of tagged silver eel in autumn 2008.

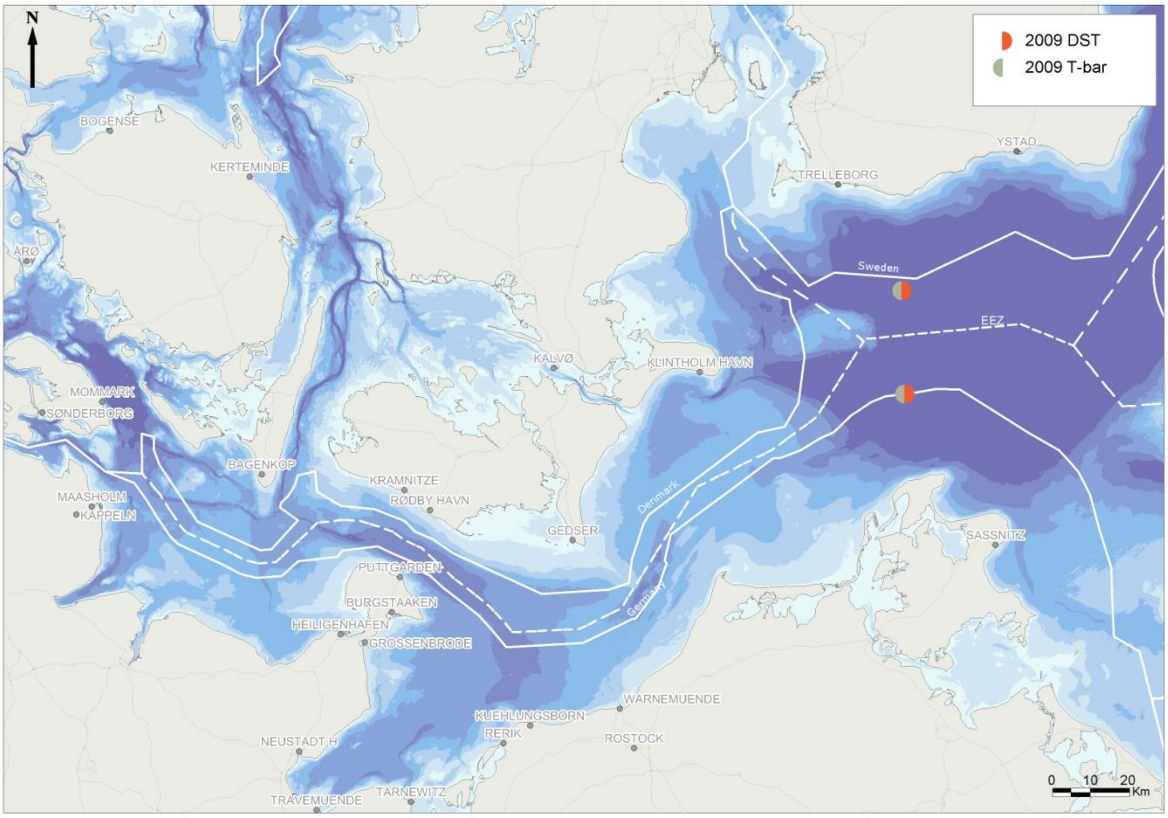


Figure 3.17: Release sites for tagged siver eel in 2009. All eel were caught in pound nets along the coast of Lolland.

3.7.2 Data analysis

From the recapture of tagged eel, information on migration routes and average swimming velocities can be estimated.

The number of eels migrating through the Little Belt and the Great Belt was estimated from the mark-recapture data using standard methods described by Seeber (1973). This method is based on extrapolations from a defined subpopulation (the marked individuals) to the entire population.

Commercial landings of silver eel were registered from landings recorded by the Danish Ministry of Fisheries during the period from the release of the first tagged eel to the end of the migration period. These landings were registered only by weight, and conversion from weight to number was performed using the average weight of the silver eel caught in the tagging study.

The most likely migration routes followed by the DST tagged silver eel between release and recapture sites were modelled using the logged data on depth and temperature. This was done using 3D GIS software (Engage 3D Pro) in combination with interpolated data on time, depth and geographical position as calculated by the statistical application SPSS (IBM corporation, NY, USA).

The depth data were separated into periods with and without migration. The latter were identified as periods where the data log indicated that no vertical movement (≤1 meter within 15 min.) had occurred. It was assumed that the eel rested at the seabed during these stationary periods. Thus the recorded depth of the eel was assumed to reflect the depth of the sea. The maximum depth recorded during each of these stationary periods was compared with bathymetric data from the area whereupon backtracking of plausible positions could be performed. The extracted depth data were correlated to a bathymetric contour model based on a three dimensional grid with a resolution of 50x50 m.

Parameters describing diurnal migration behaviour of silver eel were derived using almanac data with point of origin at Rødbyhavn (Hermansen, 1998). Diurnal variation was defined according to nautical twilight.

3.8 Baseline methodology

In accordance with the guidelines of the Fehmarnbelt Fixed Link EIA manual the level of importance of key components has been assessed on the basis of the results of the baseline studies. The components assessed included the environmental sub-factors concerning fish outpointed in the scoping process: Atlantic cod, Western Baltic herring, European sprat, flatfish, shallow water species, European eel and protected species.

Important fish species included in the shallow water species and flatfish groups were determined during the baseline studies. Beside these outpointed fish species or groups of fish species whiting has also been included in the assessment, since the present baseline study establishes whiting as one of the most numerous fish species in the area.

The determination of importance level has been defined by two basically different premises:

- Components protected by legislation/conventions
- Components of importance for ecosystem functions

Criteria for the assessment have been defined and following general principles were applied:

Per definition protected species are of importance, and the rating criteria are defined by the type of protection on either international or national level. The rating regarding ecosystem functions is based on the ecological importance of a species or species component/stock (e.g. Western Baltic herring) present in Fehmarnbelt and its total area of distribution, being either far-reaching or local or unspecified. The criteria have been set on the significance of Fehmarnbelt for five life stages/functionalities among the fish species: spawning, egg- and larvae drift, nursery, feeding and migration. The overall assessment is based on the principle that the highest rated level for a specific function is valid.

In general the pelagic is considered a more unspecified habitat with a large regional distribution than benthic habitats. The importance of Fehmarnbelt for pelagic spawning and feeding species is thus generally rated lower compared to species utilizing benthic habitats. The rating is primarily based on magnitude/abundance although it for some species and functionalities not has been possible to assess this quantitatively. If a particular function of a species not take place in Fehmarnbelt it is not listed. E.g. whiting uses only Fehmarnbelt as nursery and migration area, while resident species goes through all life stages in the area but do not migrate.

The importance of Fehmarnbelt with respect to the protected species is included, but has only been assessed for European eel, sea stickleback and snake blenny. Both general knowledge and information about the remaining protected species in Fehmarnbelt were considered too limited. This apply to twaite shad, river lamprey, Atlantic salmon, sea trout, greater weaver, corkwing wrasse, ballan wrasse and painted goby, which either only have been observed in the area recently or caught in very few numbers during the baseline studies. However, in the overall assessment these species are included following the criteria for protected species.

For each environmental subfactor the rating of importance of each functionality, if relevant, is presented in a table. Regarding charts over importance of a specific function of a specific species in the area it has in some cases not been found relevant or appropriate to visualize, since most issues regarding fish are highly variable in time and space.

4. Baseline results

The species diversity of fish in the Baltic Sea is relatively poor when compared to fish communities in other ecosystems of similar size. This is partly a result of low salinities in the Baltic and partly a result of the relatively young geological age of the Baltic Sea (Hammer et al., 2008).

Although not directly comparable due to differences in size, the low species diversity in the Baltic Sea was demonstrated in the work of Remane and Schlieper (1971), where the authors compared species richness between the North Sea and the Baltic Sea. The results showed that only 69 species of fish were recorded in the Kiel Bay and Bay of Mecklenburg while species richness was almost twice as high in the North Sea with 120 recorded species.

Results from the present investigations showed that a total of 69 species were identified (Appendix 1) and that the most common fish were Atlantic cod (*Gadus morhua*), European sprat (*Sprattus sprattus*), Atlantic herring (*Clupea harengus*), whiting (*Merlangius merlangus*), dab (*Limanda limanda*), European flounder (*Platichthys flesus*), European plaice (*Pleuronectes platessa*), gobies (especially sand goby (*Pomatoschistus minutus*) and black goby (*Gobius niger*)), common sole (*Solea solea*) and hooknose (*Agonus cataphractus*). Still common, but more locally distributed, were small sandeel (*Ammodytes tobianus*) and rock gunnel (*Pholis gunellus*), which were found in more shallow waters along the coast of Fehmarn and Lolland. The fourbeard rockling (*Enchelyopus cimbrius*), was restricted to deeper waters of Fehmarnbelt. The Atlantic horse mackerel (*Trachurus trachurus*), which was occasionally recorded in the catches from the coastal areas along Fehmarn and Lolland, had a temporal but sometimes abundant distribution in the central parts of Fehmarnbelt.

Some less common species in the Fehmarnbelt were found exclusively in specific subareas. Species exclusively found in the central part of Fehmarnbelt incuded the reticulated dragonet (*Callionymus reticulatus*), European anchovy (*Engraulis encrasicolus*), snakeblenny (*Lumpenus lampraetaeformis*), red mullet (*Mullus barbatus*), painted goby (*Pomatoschistus pictus*) and pouting (*Trisopterus luscus*). In the shallow coastal areas of Fehmarn, four species, including worm pipefish (*Nerophis ophidion*), saithe (*Pollachius virens*), tadpole fish (*Raniceps raninus*) and poor cod (*Trisopterus minutus*), were recorded. Another four species, including river lamprey (*Lampetra fluviatilis*), thinlip grey mullet (*Liza ramada*), round goby (*Neogobius melanostomus*) and European perch (*Perca fluviatilis*), were only found along the coast of Lolland. The river lamprey is listed on Annex II of the EU Habitats Directive (92/43/EEC) but is not included in any of the SCI designations within the Fehmarnbelt area. The round goby is an invasive species of Ponto-Caspian origin in the Baltic Sea and was first recorded in the Gulf of Gdansk in the early 1990's (Skóra and Stolarski, 1993; Sapota, 2004).

A few species were exclusively found as pelagic larvae and included the fivebeard rockling (*Ciliata mustela*) and the snailfish (*Liparis liparis* and *Liparis montagui*). The majority of other fish species found in the Fehmarnbelt were recorded in more than one life stage (adult, juvenile, larvae and egg).

All species, except perch, are marine species which have their main distribution in marine or brackish waters. Perch is a freshwater species inhabiting a very wide range of habitats that includes estuarine lagoons. This species is widely distributed in the Baltic Sea area. One catadromous and two anadromous migratory species were recorded and included the European eel (*Anguilla anguilla*), sea trout (*Salmo trutta*) and salmon (*Salmo salar*).

4.1 Benthic and shallow water fish communities

4.1.1 General background

The composition of fish communities and the distribution of fish species at different life stages are strongly associated with habitat types. Habitats in Fehmarnbelt differ in terms of, e.g., substrate, seabed structure, type of vegetation, and benthic community assemblage. Thus, knowledge of the distribution of fish species in relation to different habitat types in Fehmarnbelt is important baseline information.

During the lifetime of the fish these habitats can change with the species age or can be used for specific tasks such as spawning and nursery. A variety of shallow water species are considered as a stationary species. These species usually spend their entire life cycle in a geographically restricted area. Other species such as e.g. the cod are dependent on structured habitats during the juvenile stage as they use them as nursery areas. Many parameters are important in habitat classification, including physical parameters such as current pattern, bathymetry, sediment, temperature etc., and also biological parameters such as the structure of the benthic communities etc. Knowledge on those key factors influencing the fish community is an important baseline for an impact assessment.

The construction and the presence of a fixed link across Fehmarnbelt may cause direct, indirect, permanent or temporary impact on habitats which will affect different fish species and their life stages with varying intensity. The preference of habitats can change between the life stages and there might be differences between feeding, spawning and nursery areas/grounds. The distribution of fish species depends on the habitat types (based on internal classification).

During the construction phase the different fish communities and especially the young life stages in the nursery areas will be influenced directly by sediment spill, noise, changes in hydrography and increased traffic activity. Furthermore, they will be affected indirectly by changes in the seabed structure as well as changes or loss of habitats and basic food resources (benthic organism/fishes). Especially the last parameter might have the largest impact on the structure of fish communities (e.g. on recruitment). Therefore, knowledge on key factors like sediment, benthic communities, temperature etc. as well as the status of structure of the fish communities is important for further impact assessments.

Mapping of fish species and fish communities provides the opportunity to visualize information of large data sets and to combine information of different sources. Both historical data and present data were used for mapping. The information from the habitat maps was used to identify the habitat preferences of demersal fish species in the area of Fehmarnbelt.

Different environmental pressures control the species composition and community structure of fish communities in shallow water habitats. Factors such as wave exposure and water exchange have a significant impact on the structure of the community. In addition, predation and competition for food between species, between development stages of species and between benthic organisms and the fish species living in the shallow water areas are factors structuring the community (Table 4.1).

Table 4.1: Environmental settings and existing pressures of significance to characteristic fish species (excluding cod and flatfish) in Fehmarnbelt.

Basic environmental setting	Variable hydrodynamics exposed shoreline	Sheltered conditions and a fairly stable environment with good access to food are generally acknowledged to enhance small fish recruitment (Nellen and Thiel, 1996). In this respect the environmental basic settings of Orther Bight, Binnensee and the lagoon of Rødsand are more optimal compared to the open exposed coast of Fehmarnbelt.
	Stratification	Eggs of nesting fish and fish which attach their eggs to the bottom substrate until hatching are not or only little affected by shifting horizontal stratification.
Food competitors	Interspecific	Many small fish feed on the same kind of food (small crustacean like mysids (*Neomysis sp*.), isopods, amphipods) (e.g. Thiel et al., 1996).
	Juvenile cod and flatfish	Juvenile cod and flatfish use the same habitats as the registered small fish species. Therefore they feed on the same prey (e.g. Evans, 1983; Thiel, 2001).
	Crustacean	Crustacean like the brown shrimp (*Crangon crangon*) and the common shore crab (*Carcinus maenas*) also occur in the same habitat types and show overlapping diet regimes in regard to many small fish species.
Predators	Cod / Flatfish	Cod is one of the most important predators in the Baltic Sea. Also during its juvenile life stages, fish is an important part of its prey. Flatfish are mainly feeding on benthic organisms during their early life stages. As they mature, they also feed on fish. Especially brill and turbot are important predators on small fish.
	Birds	Several bird species also feed on small fish in coastal waters. For example, some auk species (common guillemot, razor-billed auk and black guillemot), tern species and grebe species (great crested grebe, red-necked grebe and horned grebe) (Mendel et al., 2008).
Fishery		Typical shallow water species are not target for the commercial fishery but are often caught in by-catch by coastal water trawl fishery.
Eutrophication	Nutrient enrichment	Especially fish communities and young fish in coastal areas are affected by the increased nutrient input caused by anthropogenic influence (Thiel et al., 1996).
	Decreased water clarity	Although many small fish may spawn on a wide variety of substrata, macrophytes often seem to be preferred. A reduction in water clarity has generally reduced macrophyte vegetation, and hence reduced potential spawning sites.
Invasive species		The occurrence of invasive species affects the fish communities in the coastal waters of the Baltic Sea. As an example, the round goby migrates from the Black and Caspian Sea via rivers into the Baltic Sea. It affects local gobies by feeding on their eggs, juveniles and even on adults (Skora, 1997). Furthermore, the jellyfish *Mnemiopsis leidyi* has the potential to affects the recruitment success of several fish species in the Baltic Sea.

4.1.2 Baseline approach

The objectives regarding benthic and shallow water fish community were to map and collect sufficient information for the evaluation of need for additional studies on the distribution of fish species in the different habitat types and nursery areas. Further, the objective was to initialize a baseline study providing data for the preparation of the EIS for fish and fishery to assess the impact from the Fehmarnbelt Fixed Link on the fish communities and nursery areas.

To comply with the overall objectives the intermediate aim of the inventoring of fish communities are to:

- map fish communities in different habitats
- map nursery areas for key species
- obtain information on seasonal occurrence of species in relation to different life stages
- obtain information on rare species
- obtain information on key parameters influencing the occurrence of species

In this investigation, six different habitat types were identified within three different subareas (Fehmarn, Fehmarnbelt and Lolland). The classification of the gill-, fyke- and trawl net stations is based upon video screenings and previous investigations. In the region of Fehmarn and Lolland some stations were also classified by different depth ranges. The inventory studies and field activities on fish communities were initialised in May 2009 and ended in June 2010. To complete the investigations of the typical fish communities around Fehmarn and at the southern coast of Lolland, juvenile fish were sampled within their potential nursery areas during May and June 2010. The selection of the stations for this investigation was mainly based upon the station model of the formerly performed gill- and fyke net sampling. In addition, the shallow bays “Orther Bucht” and “Binnensee” were investigated. Preliminary investigations in this area indicate their importance as nursery areas for the fish community of Fehmarn.

4.1.3 Habitat structure and characterisation

Based on the multivariate analysis of fish communities (species composition), six different habitat types were identified within the three different subareas of Fehmarnbelt (“Fehmarn”, “Fehmarnbelt”, and “Lolland”, cf. Figure 3.4). Figure 4.1 illustrates the separation of fish communities in relation to habitat type and subarea.

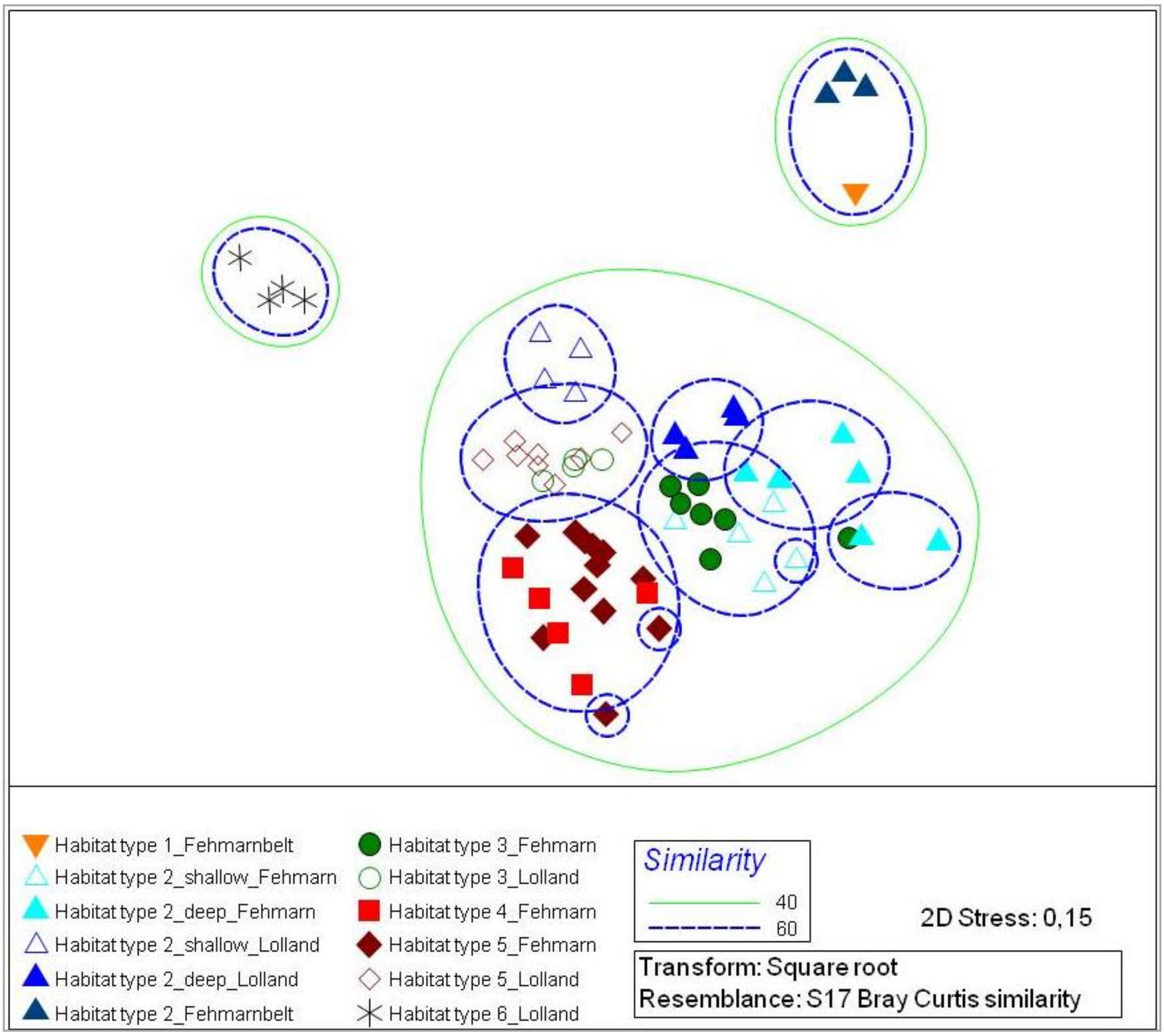


Figure 4.1: Multidimensional scaling diagram of fish community similarity at the different habitat types within the subareas Fehmarn, Lolland, and central part of Fehmarnbelt. Stations with similar species composition are close to each other, whereas the distance between stations with low similarity is great.

The EUNIS classification system includes eight marine habitat types for the European marine areas (Riecken et al., 2006). Each habitat type is divided into several specific habitat types. The habitat types identified during the baseline study corresponded to the following EUNIS habitat classes:

- Habitat type 1: sublittoral mud
- Habitat type 2: sublittoral sand
- Habitat type 3: sublittoral biogenic reefs
- Habitat type 4 and 5: Baltic moderately exposed infralittoral rock
- Habitat type 6: sublittoral macrophyte-dominated sediment

Although only small parts of the prevailing habitat types were investigated, the stations covered each of the aforementioned types sufficiently in the Fehmarnbelt area, and slight modifications of the habitat descriptions were possible according to the EUNIS types described (Table 4.2). The location of each station and the corresponding habitat type are shown in Figure 4.2.

Table 4.2: Classification of different habitat types at the stations around Fehmarn and at the southern coast of Lolland. * Depths from 3 – 7m. Please refere to figure 4.1 regarding location of stations.

	Habitat					
	Type 1 MS	**Type 2 S**	**Type 3 SMy**	**Type 4 SMyR**	**Type 5 VR**	**Type 6 SZ**
Short descrip-tion	mud and fine sand	sand and fine sand	sand and mussel beds (*Mytilus edulis*)	sand and mussels (*M. edulis*) on stones and blocks	vegetation on stones and blocks	sand and *Zostera marina*
Stations around Fehmarn		**< 7m*:** 4, 5, 7, 12, 13 **> 7m:** 9, 14, 15, 20, 26, 33	**< 7m*:** 3, 10, 11 **> 7m:** 1, 2, 6, 8	**< 7m*:** 30 **> 7m:** 31, 32, 34, 35	**< 7m*:** 16, 17, 18, 23, 24, 27 **> 7m:** 19, 21, 22, 25, 28, 29	
Stations in Feh-marnbelt	**12-14m:** 1	**17-28m:** 2, 3, DK				
Stations around Lolland		**2-3m:** 1, 2, 3, 4 **14-15m:** 5, 6, 7, 8	**7-8m:** 9, 10, 11, 12		**6-9m:** 13, 14, 15, 16, 17, 18, 19, 20	**1-2m:** 21, 22, 23, 24

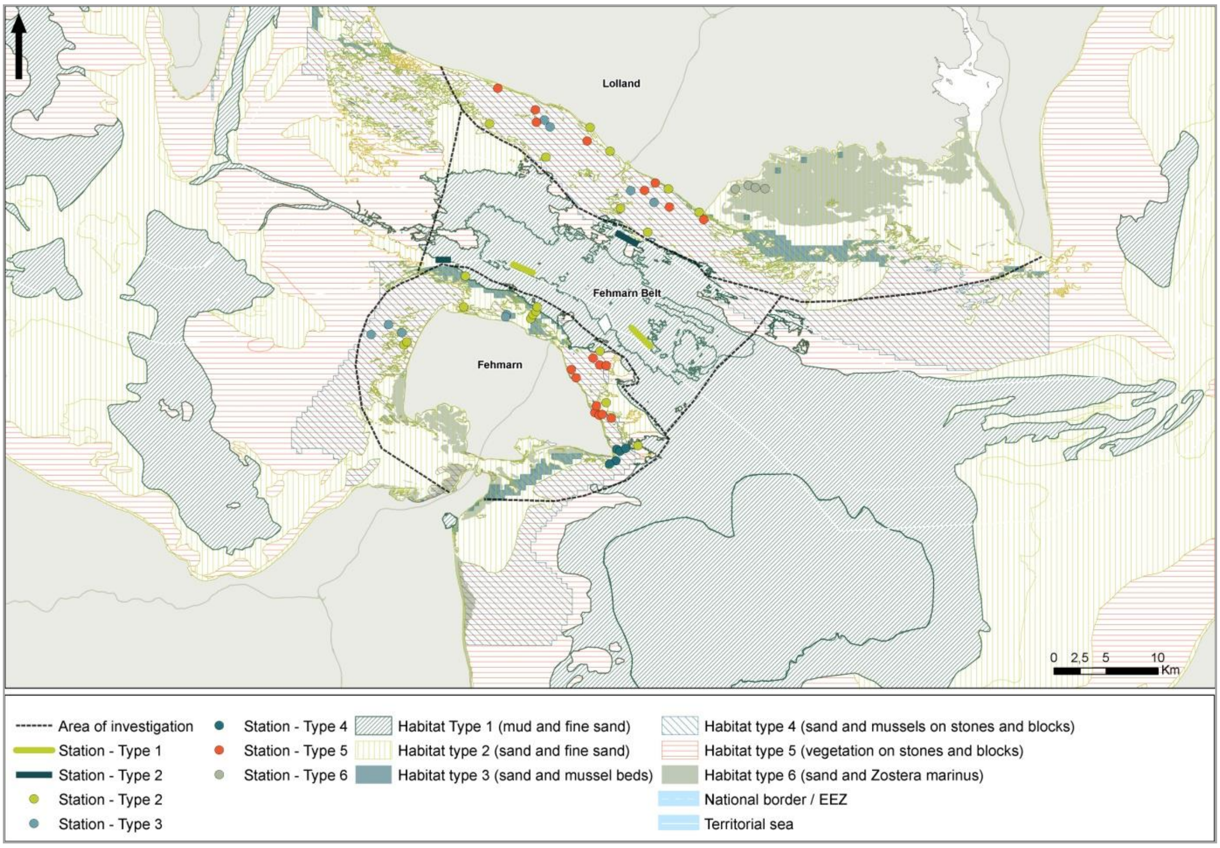


Figure 4.2: Habitat classification (see Table 4.2) of the stations in Fehmarnbelt and identified habitat types in Fehmarnbelt and adjacent areas.

4.1.4 Identification of fish communities

Nellen and Thiel (1996) distinguished between three different fish communities in the Baltic Sea; the pelagic community, the benthic community and the shallow water community. The fish communities were characterised by herring and sprat (the pelagic fish community); cod, plaice, flounder and other flatfish species (the benthic community), and stickleback, sandeel and pipefish species (the shallow water community).

The pelagic fish community is dealt with in chapter 4.2. In the present studies, the benthic fish community in the Fehmarnbelt area was dominated by the flatfish flounder, plaice and dab and by the semi-pelagic species cod and whiting. With a dominance of dab (74 % of the overall catch) they often represented more than 90 % of the total catch in hauls from subarea “Fehmarnbelt”.

The coastal areas along Fehmarn and Lolland had the highest species diversity in Fehmarnbelt (Shannon-Wiener index). Based on their habitat preferences, the benthic fish communities in each subarea were separated into groups. In subarea “Fehmarn” two groups were recognisable; fish community A was associated to highly structured habitats of mixed bottoms with mussels and vegetation (type 4 and 5) while community B was associated to habitats mainly consisting of sand with scattered mussel beds (type 2 and 3) (Figure 4.3). In subarea “Lolland” four different groups could be separated (Figure 4.4); fish community D which was associated to eelgrass meadows (type 6), E on sandy habitats in deeper parts (type 2), F on sand with mussels or stones with vegetation (type 3 and 5) and G on sandy habitats in shallow areas (type 2).

The main differences in fish communities and species diversity could be explained by habitat type, significant differences, however, were also found between different depths within the same habitat type (except for sandy habitats with scattered mussel beds - SMy type 3).

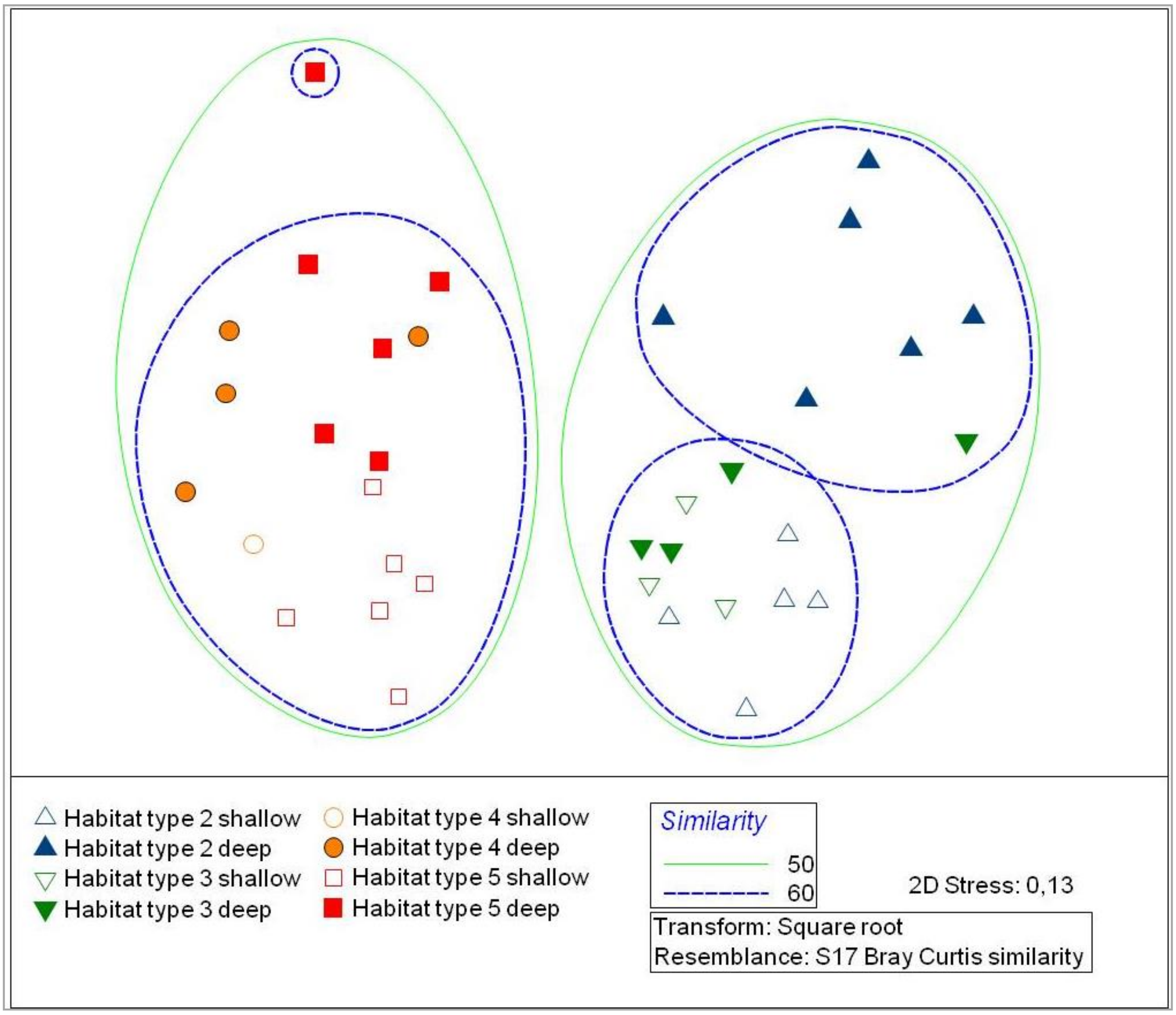


Figure 4.3: Fish community types associated with different habitat types in subarea "Fehmarn". Ordination (MDS) is based upon the species composition at each station; stations are characterised by habitat type and depth range.

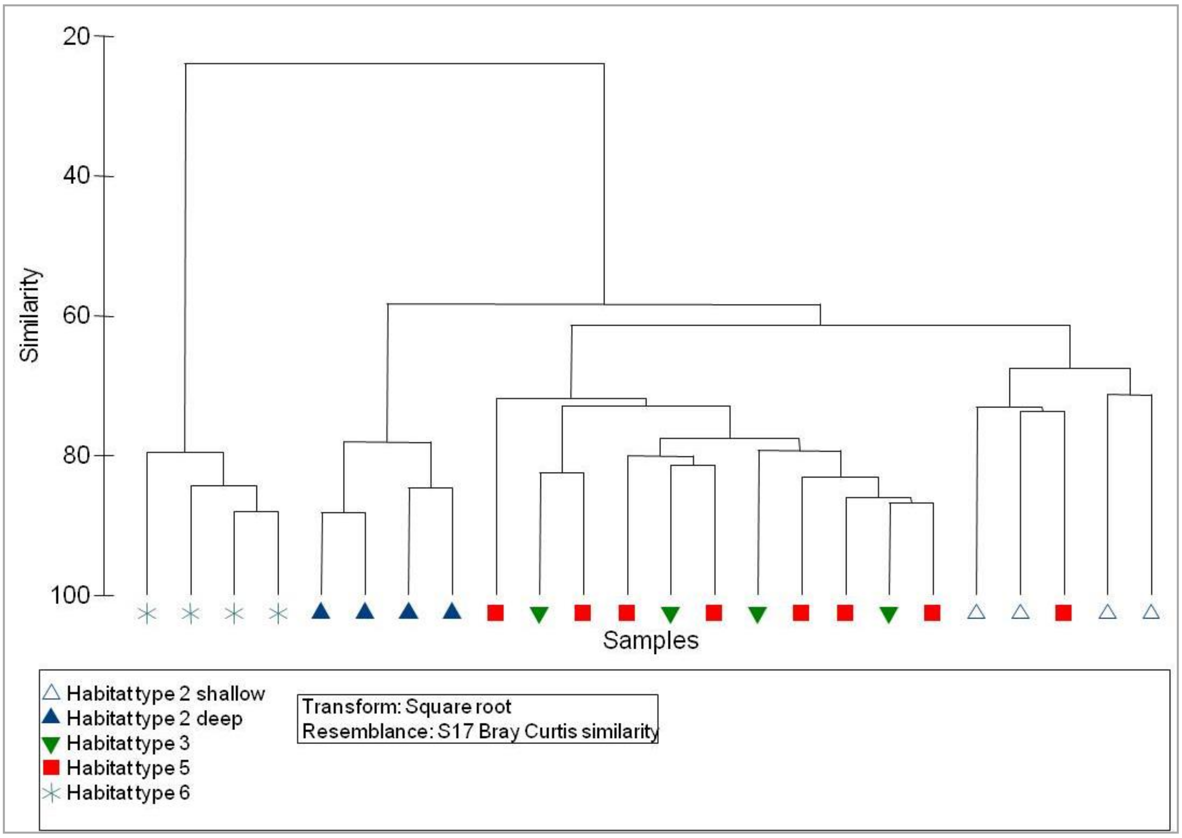


Figure 4.4: Dendogram of hierarchical clustering of the 24 stations at the southern coast of Lolland according to the similarity of the species composition at the stations. Four different fish communities, associated to different habitat types, are recognized at a similarity index at ca. 60%.

Although there were only minor differences in depth between stations in the deeper waters around Fehmarn and Lolland and the stations in the central part of Fehmarnbelt, the fish communities differed significantly. The differences found, however, may be partly due to differences in sampling equipment (gill net vs. bottom trawl - cf. section 3.1). In the central Fehmarnbelt there was a high similarity between fish species composition in muddy sand habitats (MS type 1) and in the sandy habitats (S type 2) so only one fish community (C) was identified (Figure 4.1).

The most common fish species were classified as being characteristic for the fish community in the three subareas of Fehmarnbelt (Table 4.3). The prevalence, abundance and biomass of these species were high during the entire sampling period. As Fehmarnbelt is a heterogeneous area with several habitats, the environmental parameters affecting characteristic fish species are diverse and a mixture of more or less interdependent factors structures the communities. Furthermore, some fish like cod, whiting and flatfish show migratory behaviour from nursery to feeding or spawning areas/grounds during their growth from juveniles to adults, whereas eelpout and smaller species like the hooknose, sticklebacks and gobies are more or less resident.

Table 4.3: Depth distribution of character species in the fish communities in the three subareas of Fehmarnbelt.

Species	Common name	Fehmarn		Fehmarn-belt	Lolland	
		water depth <2m	water depth >2m	water depth >10m	water depth <2m	water depth >2m
Gadus morhua	Cod		X	X		X
Merlangius merlangus	Whiting			X		
Limanda limanda	Dab		X	X		X
Platichthys flesus	Flounder		X	X		
Pleuronectes platessa	Plaice			X		
Ctenolabrus rupestris	Goldsinny wrasse		X			
Agonus cataphractus	Hooknose		X			
Zoarces viviparus	Eelpout					X
Myoxocephalus scorpius	Shorthorn sculpin					X
Gasterosteus aculeatus	Three-spined stickleback	X			X	
Ammodytes tobianus	Small sandeel	X			X	
Pomatoschistus minutus	Sand goby	X			X	

The observed fish communities were consistent with previous studies (Möller, 1984; Niemann, 1991; LANU, 1998; Kloppmann et al., 2003; Winkler and Schröder, 2003; Frieß, 2005; Hvidt et al., 2006).

4.1.4.1 Subarea "Fehmarn"

Except for mixed muddy bottom sediments (MS type 1) all habitat types were found in the subarea "Fehmarn". In these habitats dominant and characteristic species typically represented 77-83% of all individuals in the total catch and 70-88% of the total weight registered (FeBEC, 2010c). In general there were no significant differences in species richness between shallow water stations (< 7 m) and the stations at greater depths (7-19 m).

The highest number of species was found in areas with highly structured habitats consisting of mixed bottoms of sand, stones and blocks covered with vegetation or mussels (SMyR type 4, VR type 5). These habitat types were mainly found at the eastern and south-eastern coast of Fehmarn and were characterised by fish community A. This community was characterised and dominated by cod, followed by goldsinny wrasse, flounder, shorthorn sculpin and whiting whereas the abundance of other flatfish than flounder was low (Figure 4.5). Cod and flounder were recorded at all stations whereas goldsinny wrasse became more common with increasing depth. Within this subarea, some species like sea stickleback, wrasses and the gobies black goby and two-spotted goby were exclusively found within these habitats. In areas with mussels (SMyR type 4) the number of species was high at shallow water stations and declined with increasing depth.

Within these habitats significant differences in community structure were found between deeper waters and shallower waters. Gobies, flounder and great sandeel were all more abundant at the shallow water stations compared to the deep water stations, where whiting, hooknose, and goldsinny wrasse were more abundant.

In this subarea, cod represented the majority of the catch (CPUE) in every season. The CPUE of flounder decreased from summer to autumn and winter, due to the spawning migration of adults towards deeper waters where spawning takes place in January and February (Summers, 1979; Bos, 1999; Dietrich, 2004). Furthermore, a large decrease in the CPUE values of goldsinny wrasse was found from autumn to winter and no goldsinny wrasses were caught from January to March. Goldsinny wrasse was found to be inactive and hiding during the winter months.

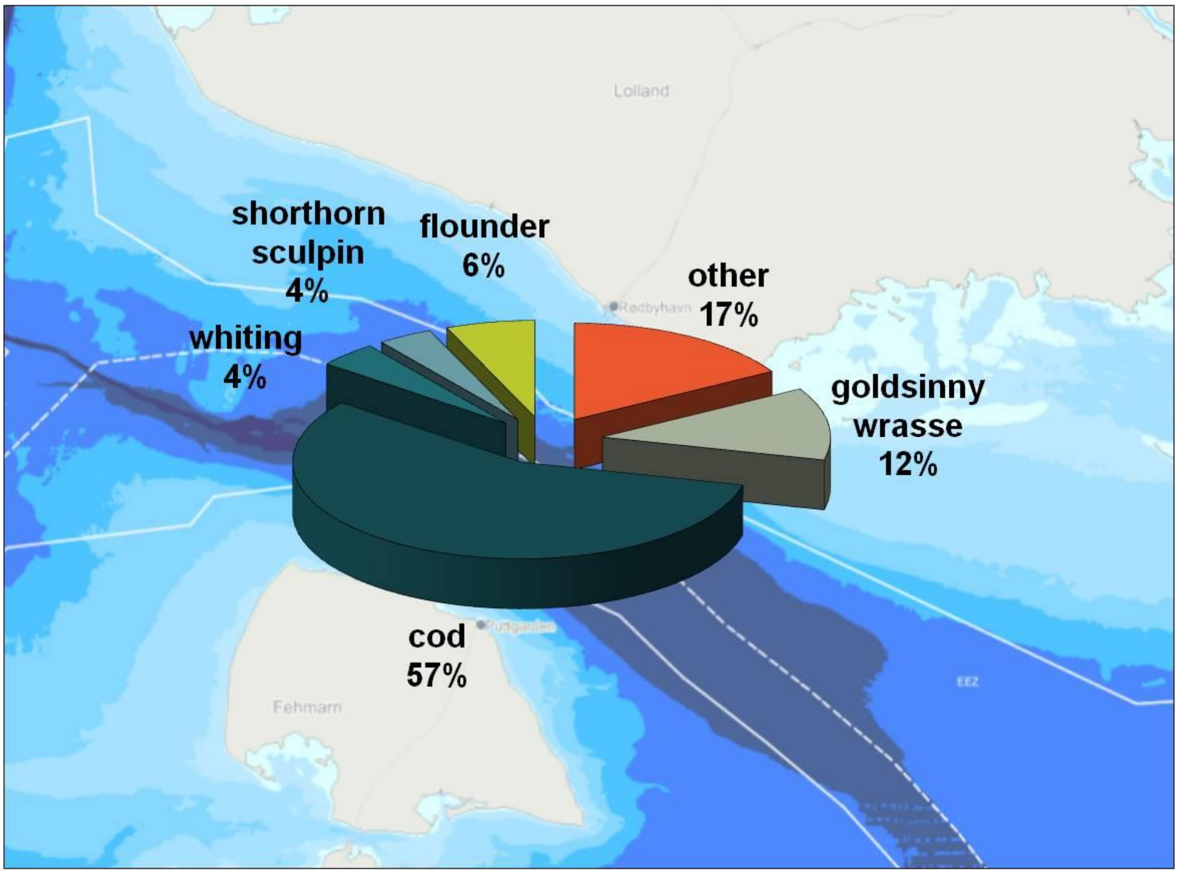


Figure 4.5: Relative species composition (percent of CPUE) of fish community A throughout the sampling period. Community A was found at habitat types 4 and 5 in subarea "Fehmarn".

A fish community B with slightly fewer species but with a higher diversity (measured by diversity indices) was identified in sandy habitats with or without scattered mussel beds (S type 2; SMy type 3). These habitats were mainly found along the western and north-western coast of Fehmarn (Figure 4.2). Fish community B was characterised by a dominance of the two flatfish species dab and flounder and high abundances of hooknose (Figure 4.6). The dominance of the character species was less pronounced than in community A. Other flatfish species like plaice, common sole and turbot were also more frequent in this community than in other areas.

The occurrence of common sole and turbot differed between seasons. There were no catches of common sole after October and no catches of turbot from December to March. The highest frequency and biomass of hooknose was also observed in habitat type 2 and 3. By contrast, the occurrence of cod was low.

Dab was the dominant species in deeper waters (> 7 m) whereas flounder dominated in shallower waters (<7 m), but the number of species did not differ significantly between the two zones. In the deeper parts of subarea "Fehmarn", the average abundance of dab was almost twice as high as in shallow waters. Also the hooknose and the sandeels were more abundant in deeper waters, although lesser sandeel almost exclusively was found in shallow waters.

The lowest abundance (CPUE value) within community B was found during autumn. The relative abundance of flounder was fairly high through all seasons but peaked during summer. Compared to the species composition in the other fish communities (A, C, D, E and F) the proportion of "other" fish species was relatively high. This was caused by a temporally high but overall limited abundance of some species; in summer and autumn large amounts of sandeel were caught whereas herring and sprat were responsible for the relatively high presence of other species in spring and winter. The catches of shorthorn sculpin increased during winter at the time of spawning (cf. Luksenburg et al., 2004).

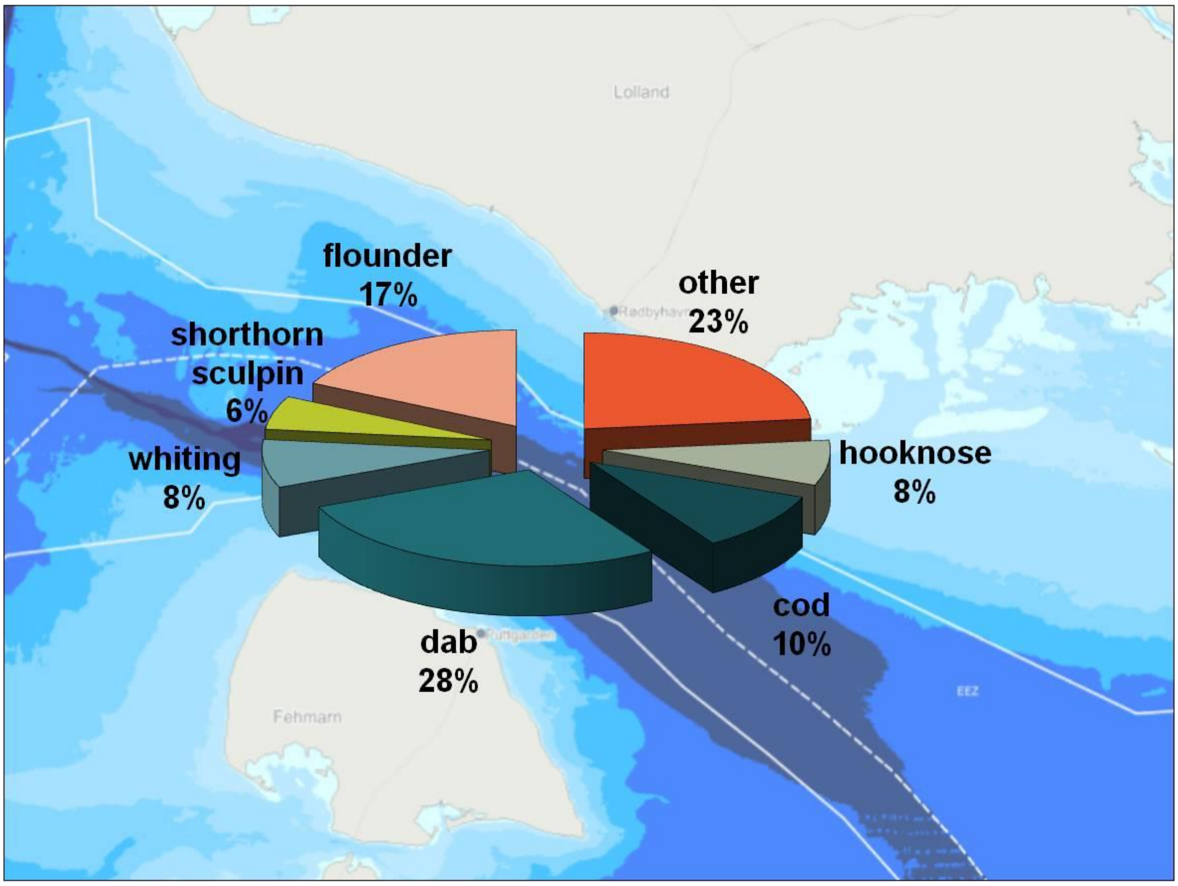


Figure 4.6: Relative species composition (percent of CPUE) of fish community B throughout the sampling period. Community B was found at habitat types 2 and 3 in subarea Fehmarn.

4.1.4.2 Subarea "Fehmarnbelt"

In the central part of Fehmarnbelt, only areas with muddy (MS type 1) and sandy (S type 2) habitats were found. The dominating species in these habitats was dab, which constituted ca. 70% of all individuals in the catches and about 68% of total weight. However, plaice, whiting, cod and flounder also contributed significantly to fish community C (Figure 4.7).

The relative abundance (CPUE values) of flounder in community C decreased temporarily during the summer and autumn due to fish migration to inshore feeding grounds (Summers, 1979; Bos, 1999; Dietrich, 2004). The relative abundance increased during the spawning season in winter, when the flounder migrated back to deeper waters. The same migration pattern, albeit less pronounced, was observed for cod and plaice.

The mean abundance and biomass of dab was higher in areas with fine grained sediment (MS type 1) than in habitats with a more sandy substrate (S type 2). The greater dominance of dab in areas with fine grained sediments, contributed to a significantly lower species diversity compared to areas with more sandy sediments. In the latter areas, the relative abundance of plaice, flounder, whiting and horse mackerel, as well as the total number of species, were higher.

Significant seasonal variations were found in this community, which in part was caused by variations in the relative abundance of horse mackerels. Horse mackerels were caught in high numbers in December, but only few were recorded in the other months.

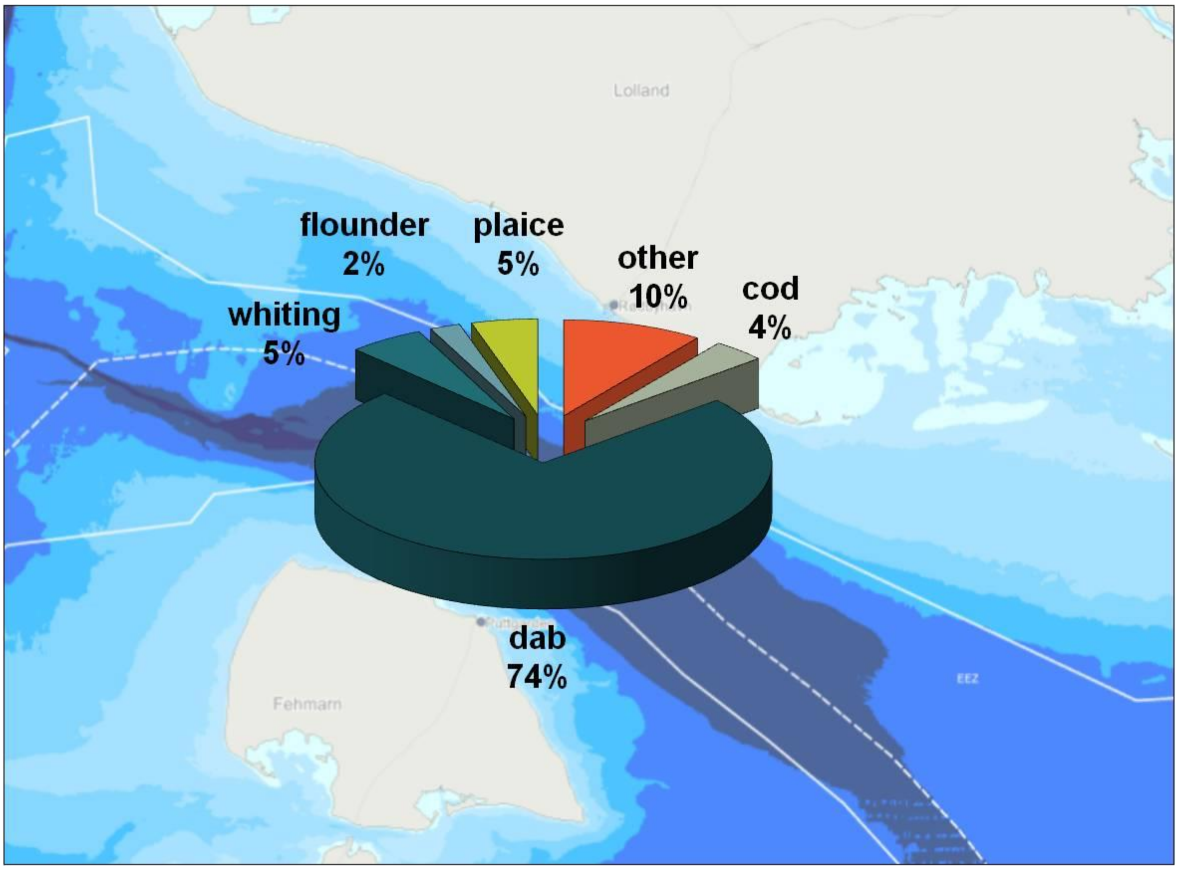


Figure 4.7: Relative species composition (percent of CPUE) of fish community C throughout the sampling period. Community C was found in the central parts of Fehmarnbelt (habitat types 1 and 2).

4.1.4.3 Subarea “Lolland”

The habitat types found along the coast of Lolland were more or less comparable to the habitat types registered at the coast of Fehmarn, although the fish communities were somewhat different. Four different habitat types were identified in subarea “Lolland”: sandy habitats (S type 2), sandy bottom with scattered mussel beds (SMy type 3), highly diverse habitat with stones and boulders covered with vegetation (VR type 5), and eelgrass beds (SZ type 6). Within each of these habitats a specific fish community could be identified.

In shallow water areas characterised by sandy bottoms with eelgrass meadows (type 6), the species composition was significantly different from the other investigated habitat types (Figure 4.1 and Figure 4.4). The very clear separation of fish community D may, however, be partly due to differences in sampling equipment (see section 3.1). Community D was characterised by smaller species such as three-spined stickleback, ninespine stickleback, black goby, eelpout and perch, which only occurred sporadically or were completely absent in the other habitats. The species diversity in this community was low, partly because of the presence of large numbers of three-spined sticklebacks (Figure 4.8).

A high amount of variation was present in the data from community D, and the number of species, dominance of species within catches, geographical location and seasonality varied between samples. This was partly due to a high variation in the catches of three-spined stickleback and black goby, which were relatively frequent in spring and summer, respectively, compared to the other seasons. The three-spined stickleback and the eelpout are residential species, which spend most of their life within a limited area where they spawn and feed in areas with seaweed. Relative frequencies were also affected by the migration of several fish species to deeper waters during winter. Cod was also present in this community and was dominant with respect to biomass.

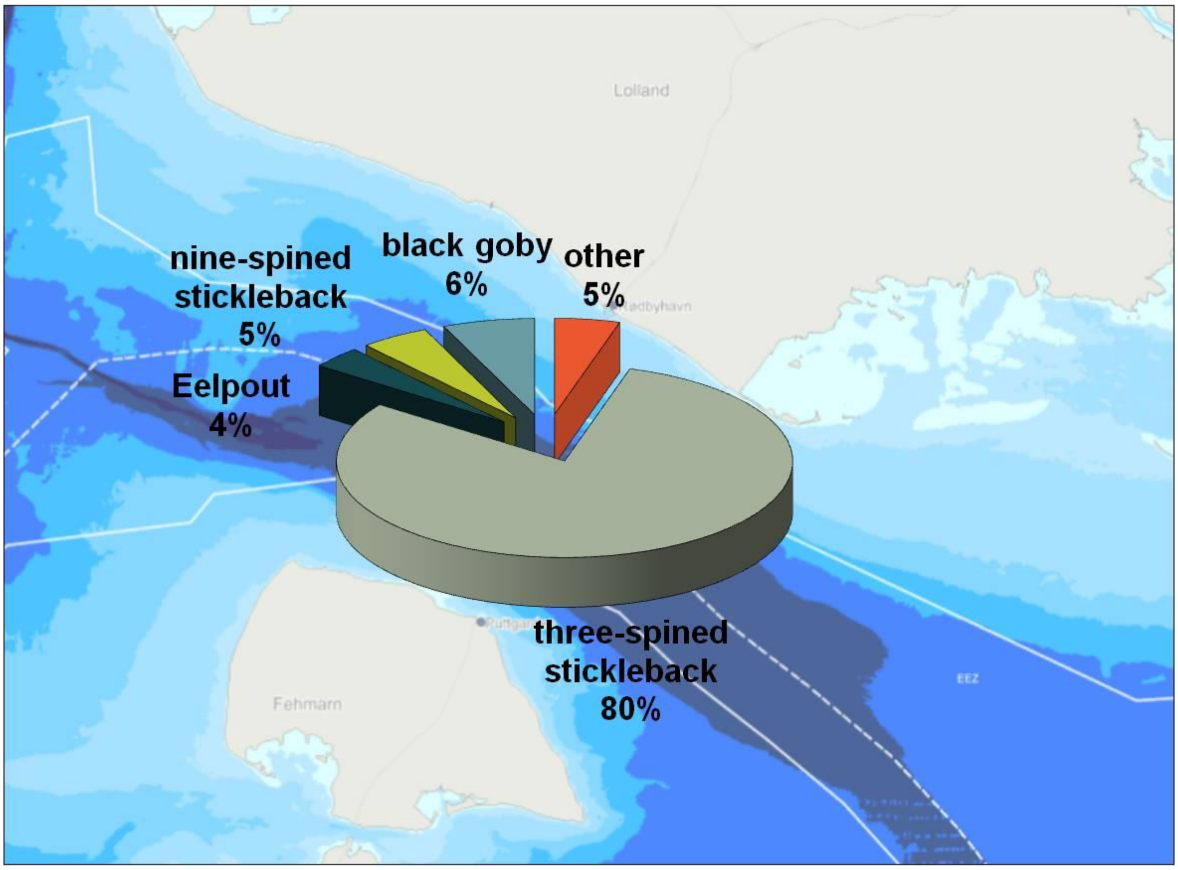


Figure 4.8: Relative species composition (percent of CPUE) of fish community D throughout the sampling period. Community D was found at habitat type 6 in subarea "Lolland".

Fish community E was present in sandy habitats (type 2) in deeper waters. This community was characterised by the presence and dominance of dab, whiting, hooknose, cod and short-horn sculpin, which altogether represented 78% of the total CPUE (Figure 4.9).

Along the coast of Lolland dab was only a characteristic and dominant species in areas with community E. In spring, dab was by far the most abundant species while whiting made up the highest share of the CPUE during summer and autumn. Whiting were found in lower numbers during winter as the species migrated to deeper waters. The relative frequencies of hooknose and shorthorn sculpin increased during winter as both species are resident species with winter breeding (Andriashev, 1986).

The number of species in this community was low compared to community G in sandy habitats in shallow waters (see below), where dab and hooknose were only found sporadically. In community E the frequency and weight of these species were significantly higher.

Community E was slightly different from the corresponding sandy bottom community in sub-area "Fehmarn" (fish community B), mainly because of the relatively low frequency of flounder.

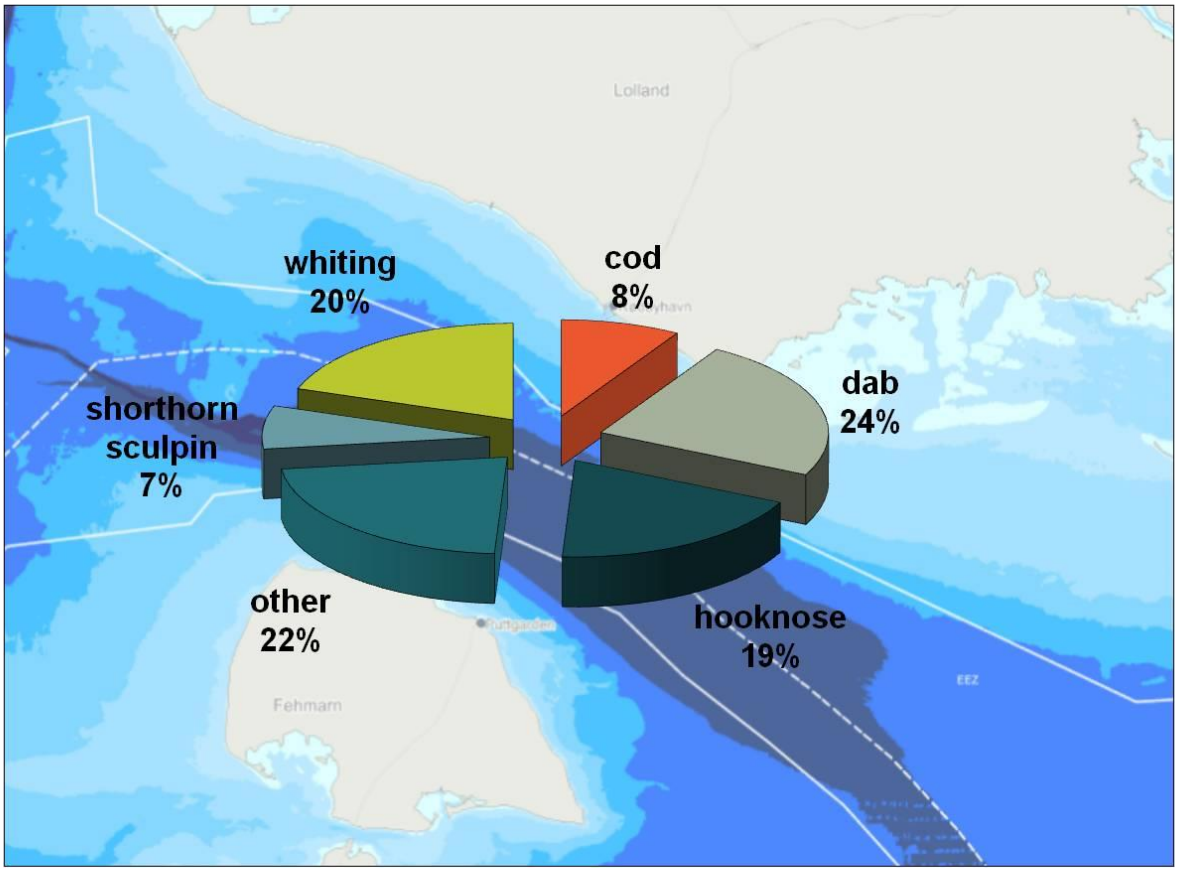


Figure 4.9: Relative species composition (percent of CPUE) of fish community E throughout the sampling period. Community E was found at habitat type 2 deep in subarea ”Lolland”.

Fish community F was found in highly structured habitats, such as areas of sandy bottom with mussel beds (SMy type 3) and areas with vegetation on stones and blocks (VR type 5), at depths of 6-9 m. Character species were cod, eelpout, shorthorn sculpin, whiting and goldsinny wrasse (Figure 4.10).

Community F was characterised by high species diversity, and compared to other fish communities the relative abundance of “other” species was high throughout the year. In particular, high numbers of longspined bullhead in winter increased the proportion of “other” species. Like the shorthorn sculpin, the longspined bullhead migrates to relatively shallow water areas to spawn during winter. In contrast, whiting almost disappeared in winter because they migrate to deeper waters. The relative abundance of cod and goldsinny wrasse in these habitats were significantly higher than in areas with sandy habitats.

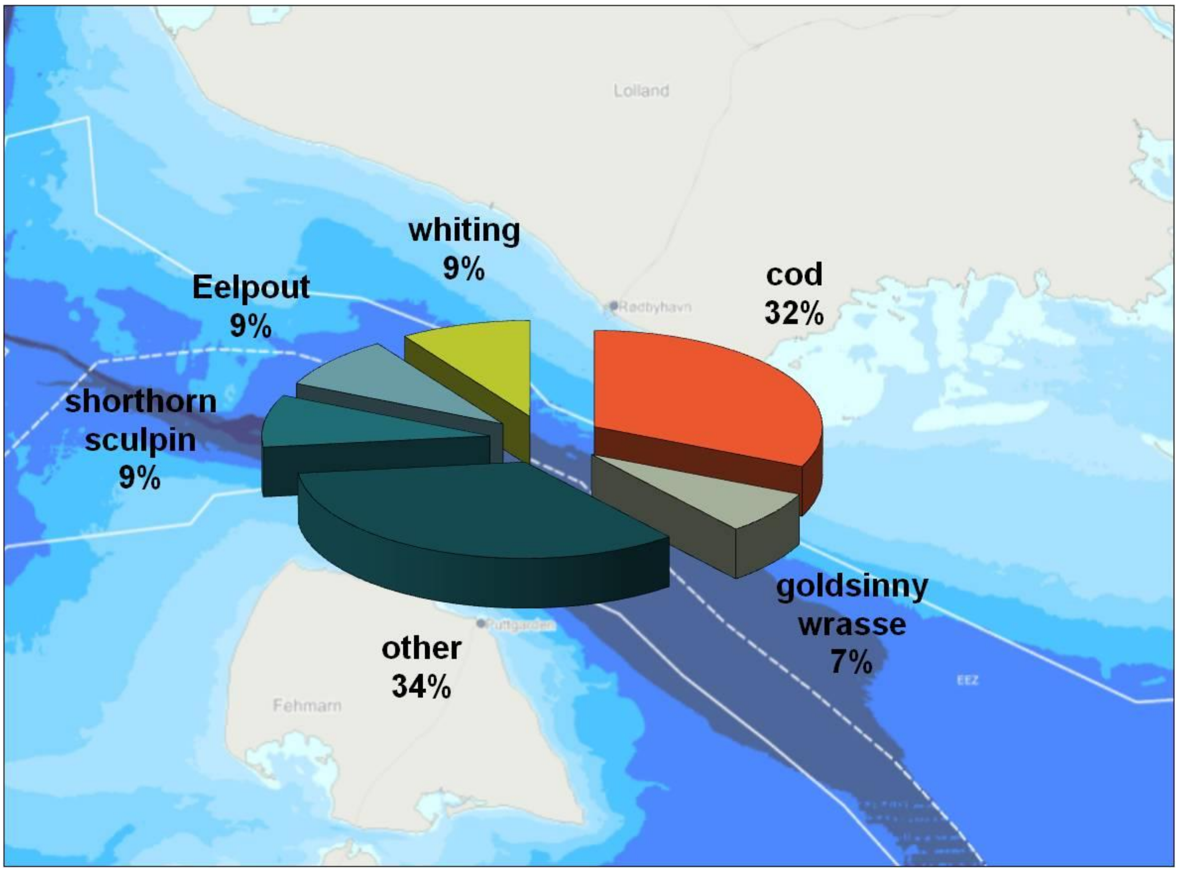


Figure 4.10: Relative species composition (percent of CPUE) of fish community F throughout the sampling period. Community F was found at habitat types 3 and 5 in subarea "Lolland".

The most diverse fish community G in subarea "Lolland" was found in shallow sandy habitats (S type 2). The dominating species in this community were cod, whiting, great sandeel, short-horn sculpin and eelpout, which together represented 53% of the total catch (Figure 4.11). The community was significantly different from the community found in sandy habitats at greater depth and is more similar to fish community F than to fish community E (cf. the clustering in Figure 4.4).

Cod were relatively frequent throughout the year whereas whiting almost disappeared during winter. The relative abundance of great sandeel was highest during the summer whereas the species was virtually absent in winter when it retracts to deeper waters. During autumn and winter the abundance of shorthorn sculpin increased because the species migrates to shallow water areas to spawn.

Like in fish community F the species diversity and the proportion of "other" species was very high. In spring (March) herring were recorded in high numbers. Longspined bullhead migrates to shallow waters in autumn to spawn, contributing to the high proportion of other species. Another species with a high occurrence in autumn was the sea stickleback. Sea stickleback spawns in May and June (Kaiser et al., 1992) and most of the adults die after spawning. In September, the CPUE of this species increased again because the juvenile fish at this time had become large enough to get caught.

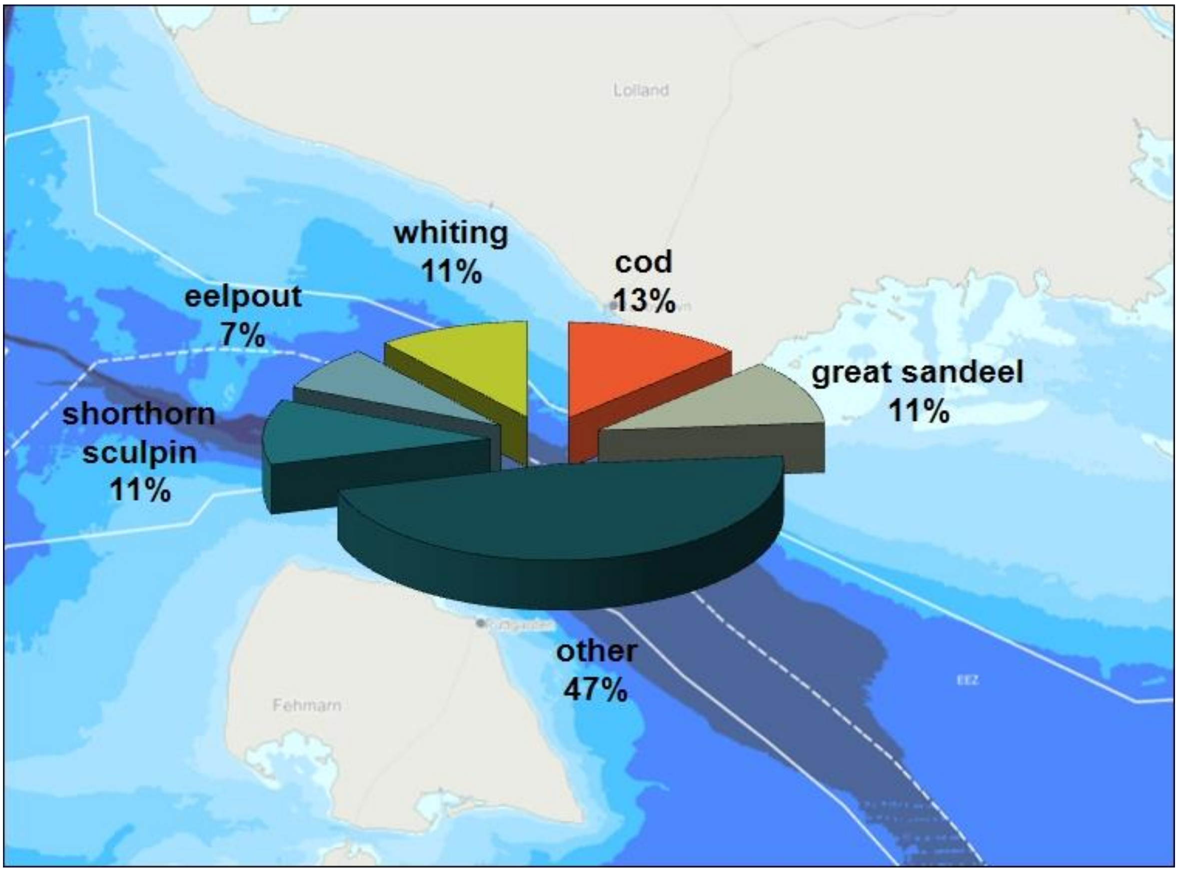


Figure 4.11: Relative species composition (percent of CPUE) of fish community G throughout the sampling period. Community G was found at habitat type 2 shallow in subarea "Lolland".

4.1.5 Spatial distribution of common species

Cod and whiting were the most abundant and dominant species found in the investigated subareas of Fehmarnbelt. They were most abundant in the highly structured habitats in deeper waters along the coasts of Fehmarn and Lolland. The highest catches (CPUE) of cod were registered at deep water stations with mixed substrate and mussel beds (SMyR type 4) and at stony habitats covered with vegetation (VR type 5) along the eastern and south-eastern coast of Fehmarn. Along the coast of Lolland, numbers of cod were also much higher in structured habitats than in sandy habitats. The highest catches of whiting were registered in the central subarea Fehmarnbelt. Due to the different fishing methods, the results of the trawl fishery are not comparable to the gillnet survey. Whiting were more abundant along the coast of Lolland than along the coast of Fehmarn and were found in fair numbers also in sandy habitats. No whiting were found in areas with eelgrass meadows.

Dab was the most numerous species among the flatfish. The highest amount (CPUE) of dab was caught in subarea "Fehmarnbelt" at deep water stations with sandy habitats (S type 2). Dab were more abundant in sandy habitats than in the other habitat types and occurred only sporadically in the catches from the complex habitat types. Flounder were found in all subareas but were most abundant in the central parts of Fehmarnbelt. In shallower waters, the species was most abundant on sandy bottoms (S type 2) or on mixed sandy bottoms with scattered mussel beds (SMy type 3). Only small numbers of flounder were caught in subarea "Lolland" compared to subarea "Fehmarn". Plaice were most abundant in the central part of Fehmarnbelt. Like in the other flatfish species, the highest numbers of plaice were found on sandy bottoms (S type 2) or on mixed sandy bottoms with scattered mussel beds (SMy type 3).

Goldsinny wrasse was most abundant in highly structured habitats (SMyR type 4 and VR type 5) along both coasts but numbers were higher along the coast of Fehmarn compared to the coast of Lolland. No goldsinny wrasse was observed in the central part of Fehmarnbelt.

Shorthorn sculpin was widely distributed and was only absent in areas with eelgrass beds (SZ type 6). The species was most abundant in the highly structured habitats (VR type 5) along both coasts. No shorthorn sculpin was observed in the central part of Fehmarnbelt.

Hooknose was most abundant in deeper waters with sandy bottoms (S type 2) or on mixed sandy bottoms with scattered mussel beds (SMy type 3) along the coast of Fehmarn and Lolland. Hooknose was only observed sporadically in the central part of Fehmarnbelt.

Eelpout occurred in all three subareas where it was found in all habitat types except stony bottoms covered with mussels (SMyR type 4). The highest CPUE values were registered at the coast of Lolland in areas with sandy bottom and eelgrass meadows (SZ type 6) where it was one of the most abundant species. In this habitat, the three-spined stickleback was by far the most numerous species. The three-spined stickleback was, however, completely absent from the central parts of Fehmarnbelt and only occurred sporadically in the other habitat types.

The habitat choice of fish depend on a combination of factors such as habitat structure and availability, food supply, predation and inter- and intraspecific competition. Specific requirements for feeding, shelter or spawning often determine the dependence on a habitat. Additionally, for some species habitat choice vary between season and life stages.

The suitability of habitats for the shallow water fish species were mapped during the present baseline study. The suitability index is based on catch data and habitat types in the shallow water community. The habitat suitablility for small sand eel, three-spined stickleback and shorthorn sculpin are illustrated in Figure 4.12-Figure 4.15.

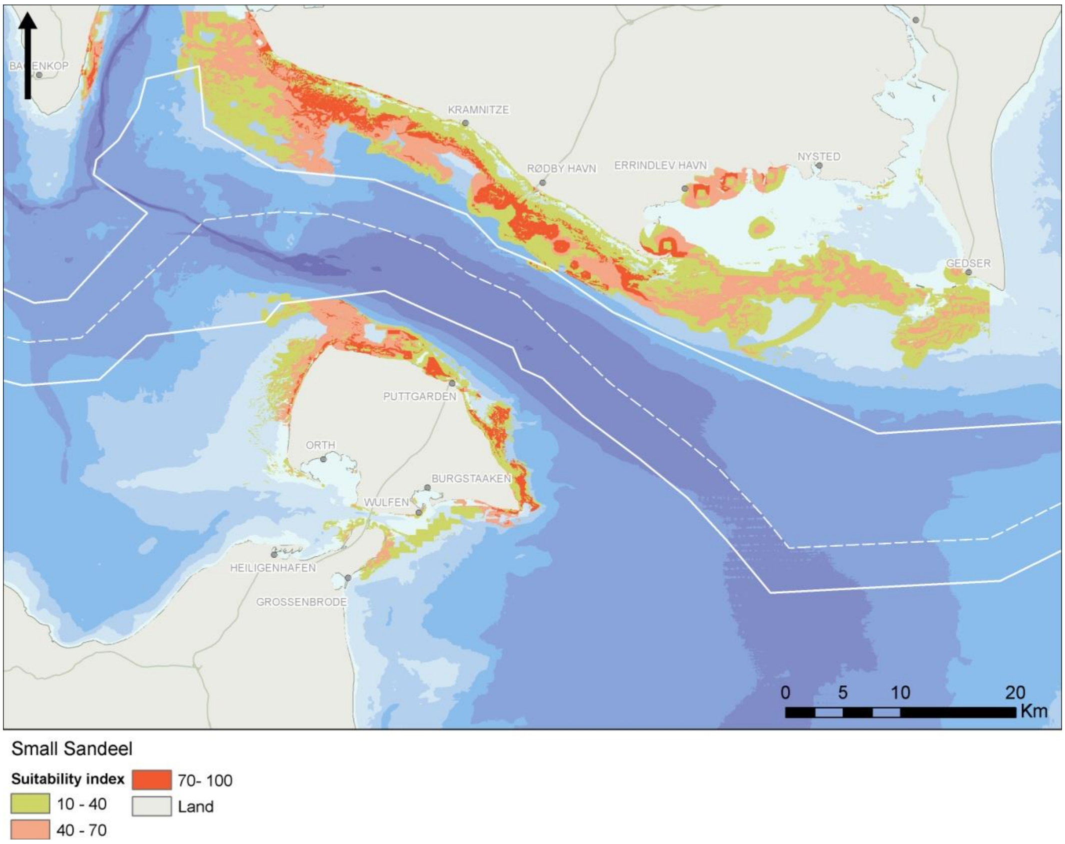


Figure 4.12: Habitat suitability for small sandeel in the shallow water fish community in Fehmarnbelt.

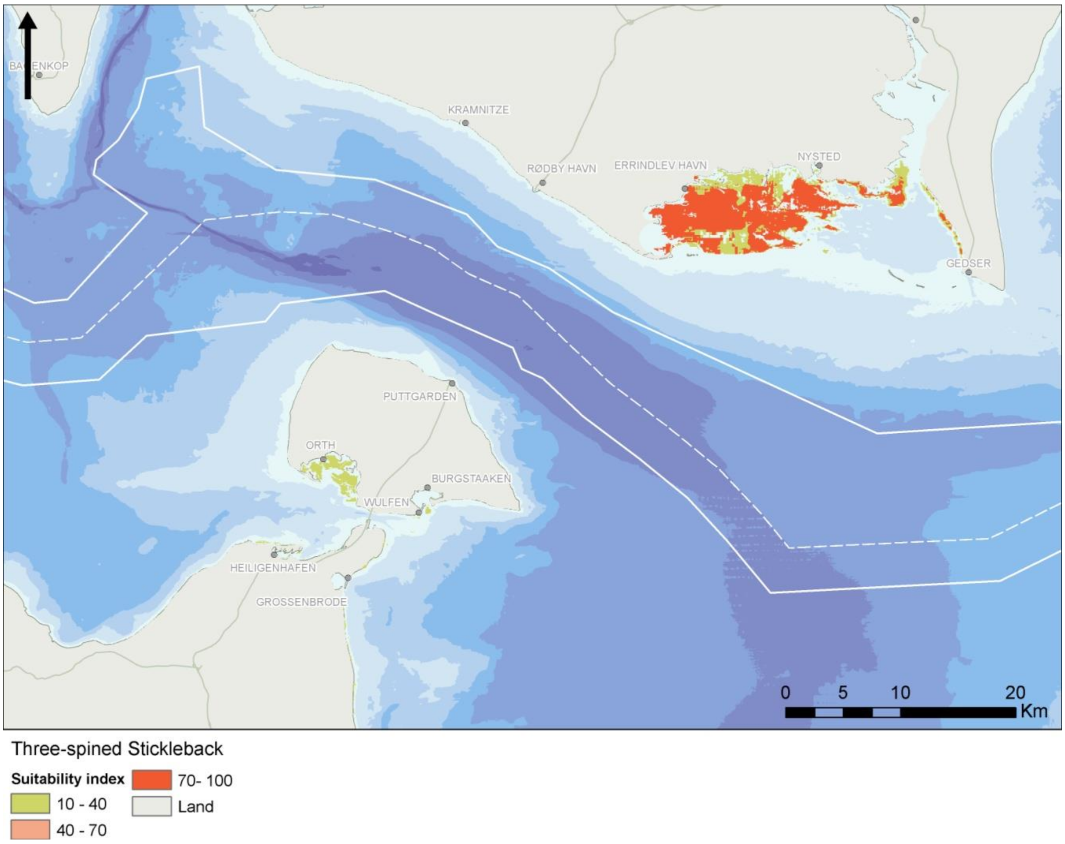


Figure 4.13: Habitat suitability for three-spined stickleback in the shallow water fish community in Fehmarnbelt.

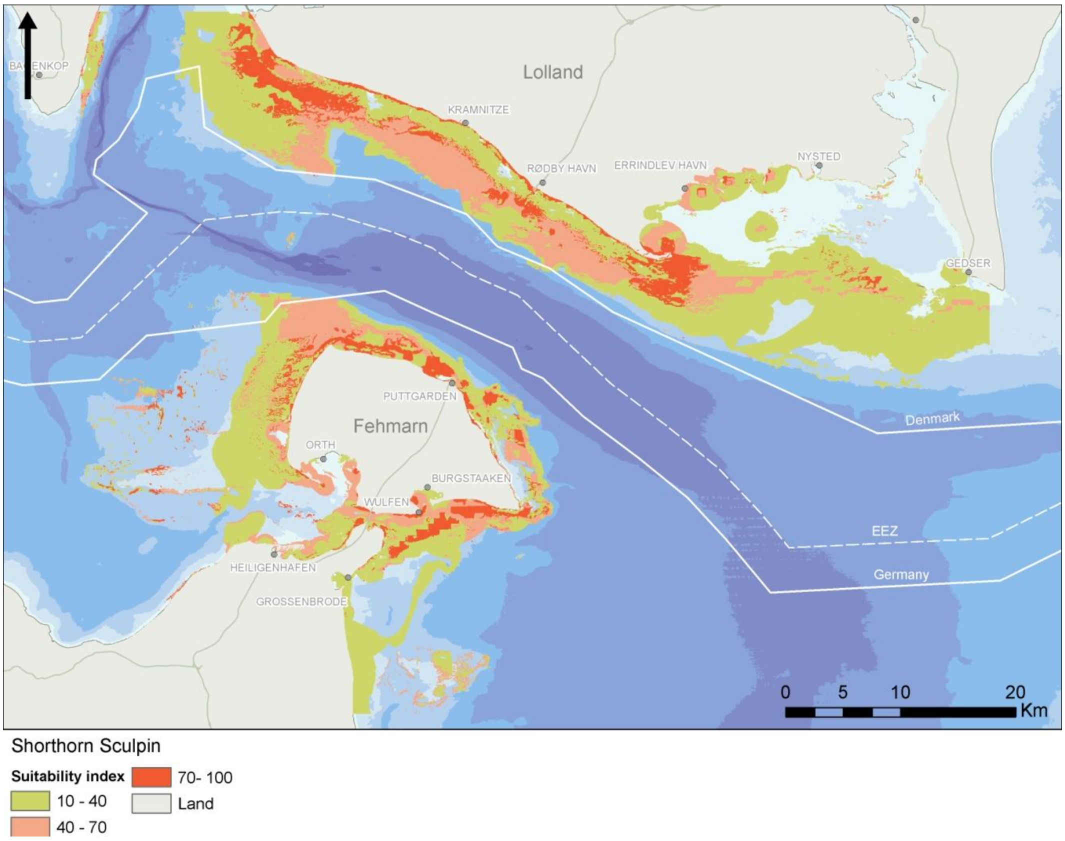


Figure 4.14: Habitat suitability for shorthorn sculpin in the shallow water fish community in Fehmarnbelt

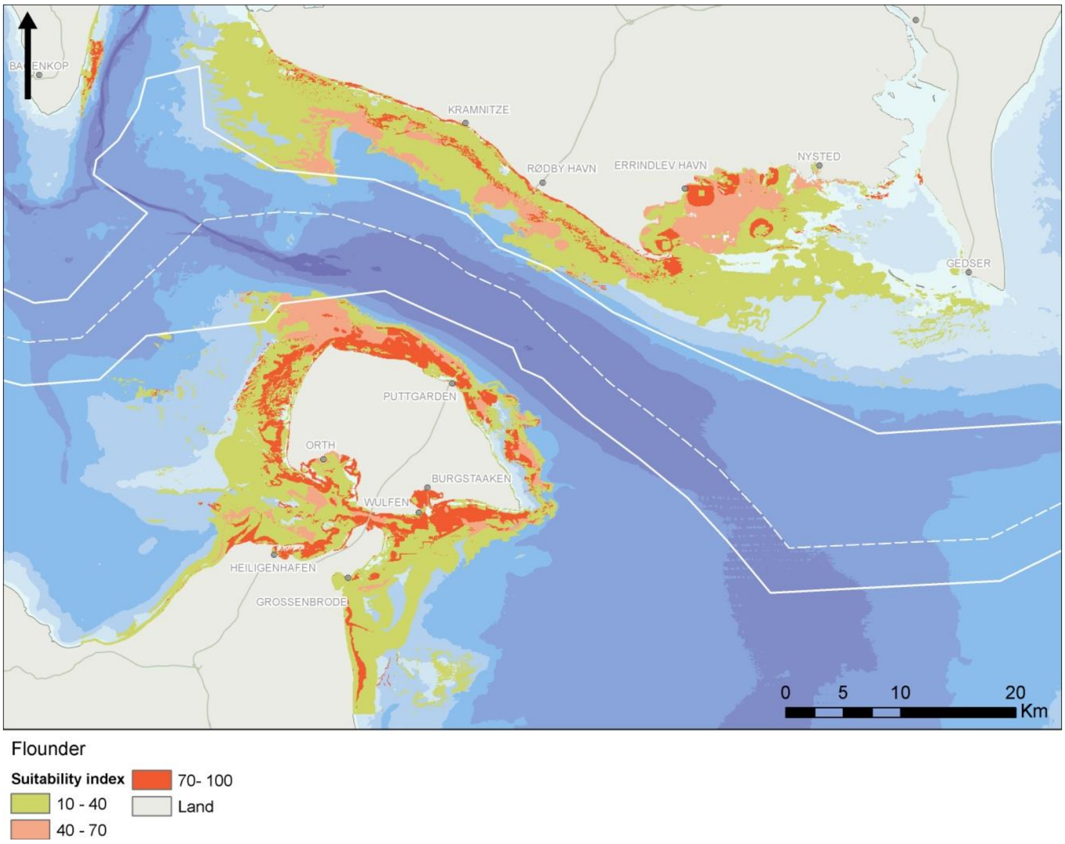


Figure 4.15: Habitat suitability for juvenile flounder in the shallow water fish community in Fehmarnbelt.

4.1.6 Temporal distribution of common species

The temporal distribution of cod varied between subareas and habitats. In subarea Fehmarn, catches of cod showed a strong seasonality in areas of complex bottoms (SMyR type 4). Here the numbers of cod increased through the summer and autumn and peaked during winter (November - December) whereas cod biomass peaked in February - March; in April both numbers and biomass decreased. In subarea Fehmarnbelt, significantly higher numbers and biomass were registered during the spawning time in February compared to the other months. In subarea “Lolland”, by contrast, cod was most abundant (numbers and biomass) during summer and autumn followed by a continuous decline until they reached a minimum in February.

The distribution of whiting was largest during autumn. In subarea “Fehmarnbelt” the abundance and biomass of whiting was significantly higher in February than in any other month whereas the species was virtually absent from the shallower coastal areas during the winter.

The catches of dab showed a high temporal variation (both abundance and biomass) in subarea Fehmarnbelt where the species was dominant. The highest catches in this subarea were recorded in September - October and the lowest in June and January.

Flounder were relatively more frequent in the deeper parts of Fehmarnbelt in winter than during other seasons. Coastal catches increased from March until August - September, thereafter declining until spring. For plaice, coastal catches were highest in autumn while the catches from subarea “Fehmarnbelt” were highest in spring.

The highest catches of goldsinny wrasse were recorded during summer and autumn at depths of 5-15 m.

Shorthorn sculpin was common in both subarea "Fehmarn" and subarea "Lolland" during autumn and winter. By contrast, the species was only caught occasionally during the summer.

Hooknose was widely distributed and was caught in the highest numbers during autumn in the coastal areas of subarea "Fehmarn" and subarea "Lolland". Some movement towards deeper waters (>15 m) in winter was apparent. In subarea "Fehmarnbelt" the hooknose was found in relatively low numbers throughout the year.

The highest catches and the widest distribution of eelpout were registered during spring. Catches declined during summer and autumn and the lowest numbers were recorded in winter.

The three-spined stickleback, which was primarily caught in shallow water with eelgrass meadows of subarea "Lolland", was most abundant in March and April.

An overview of seasonal changes in the depth distribution of some common species in the coastal areas of Fehmarn and Lolland is presented in Figure 4.16 - Figure 4.19.

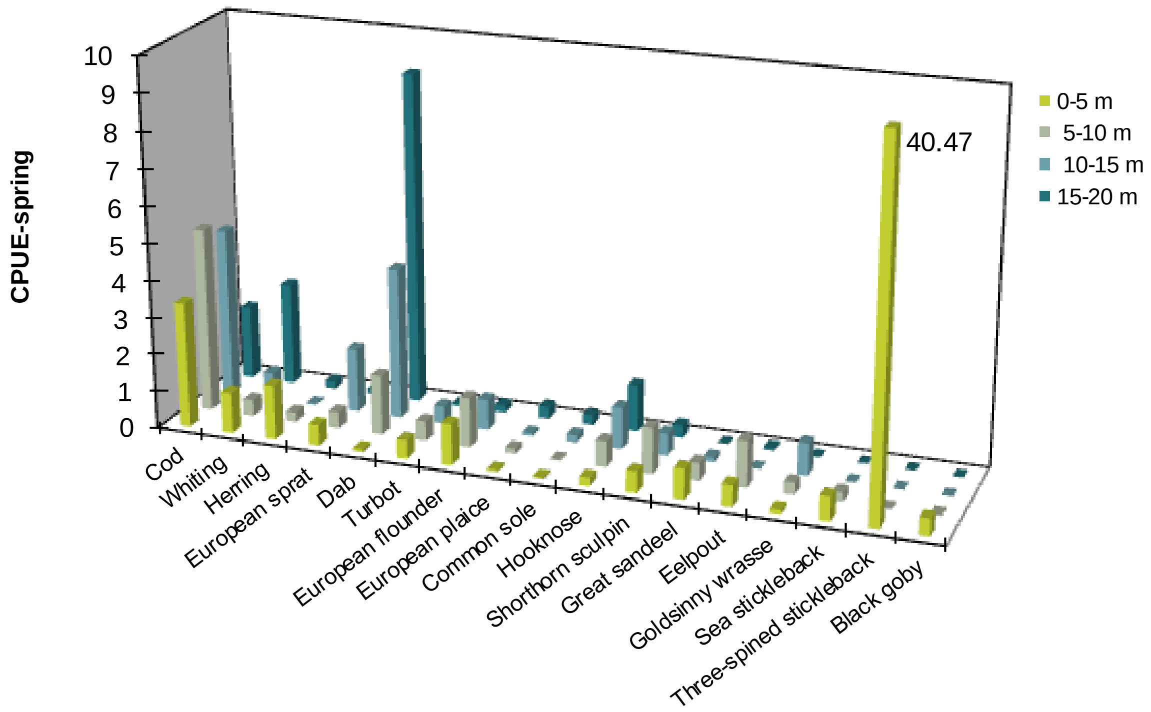


Figure 4.16: Depth distribution of common fish species in the coastal areas of Fehmarn and Lolland observed during spring.

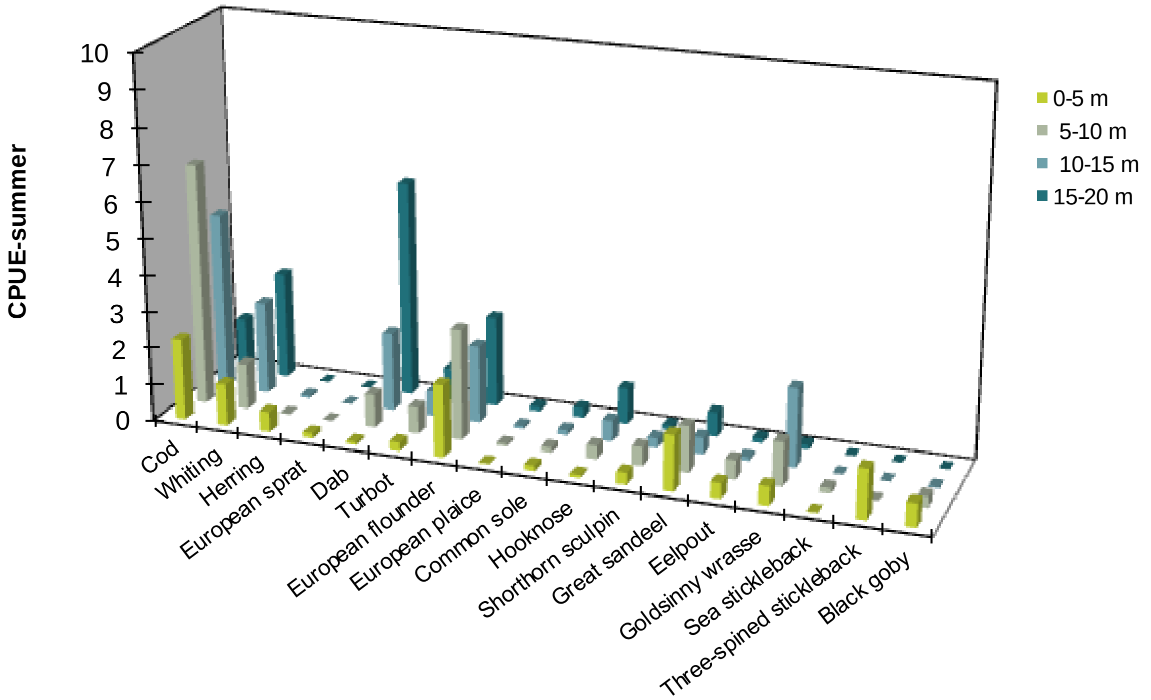


Figure 4.17: Depth distribution of common fish species in the coastal areas of Fehmarn and Lolland observed during summer.

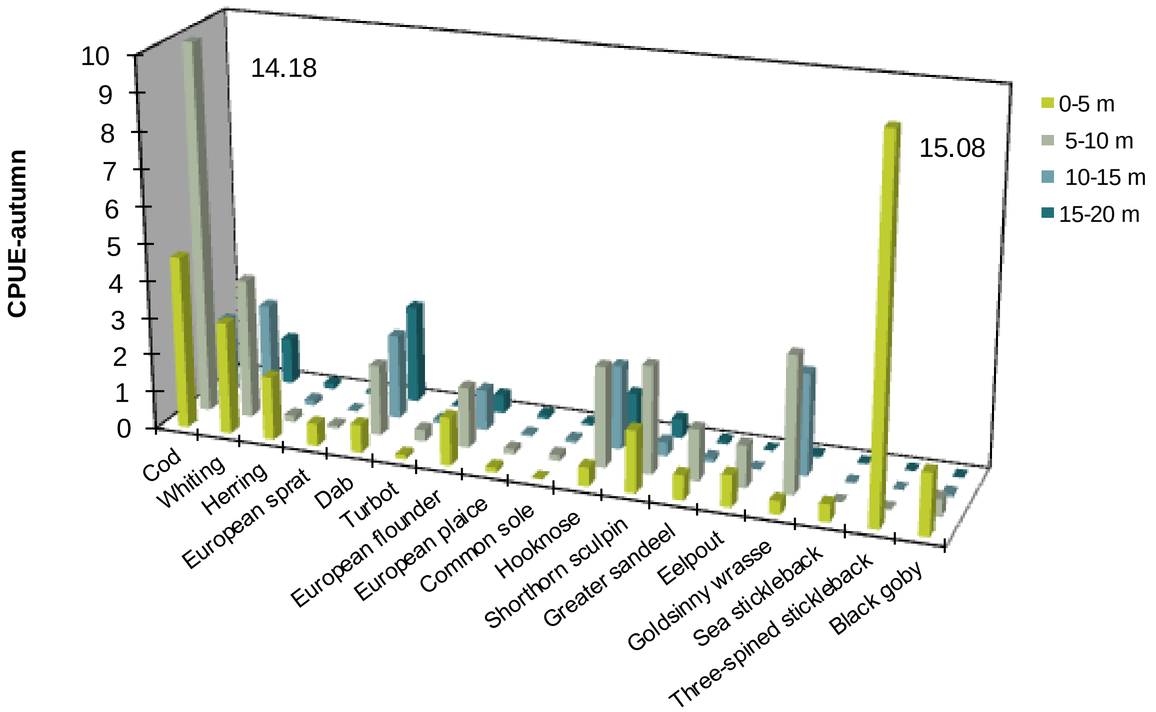


Figure 4.18: Depth distribution of common fish species in the coastal areas of Fehmarn and Lolland observed during autumn.

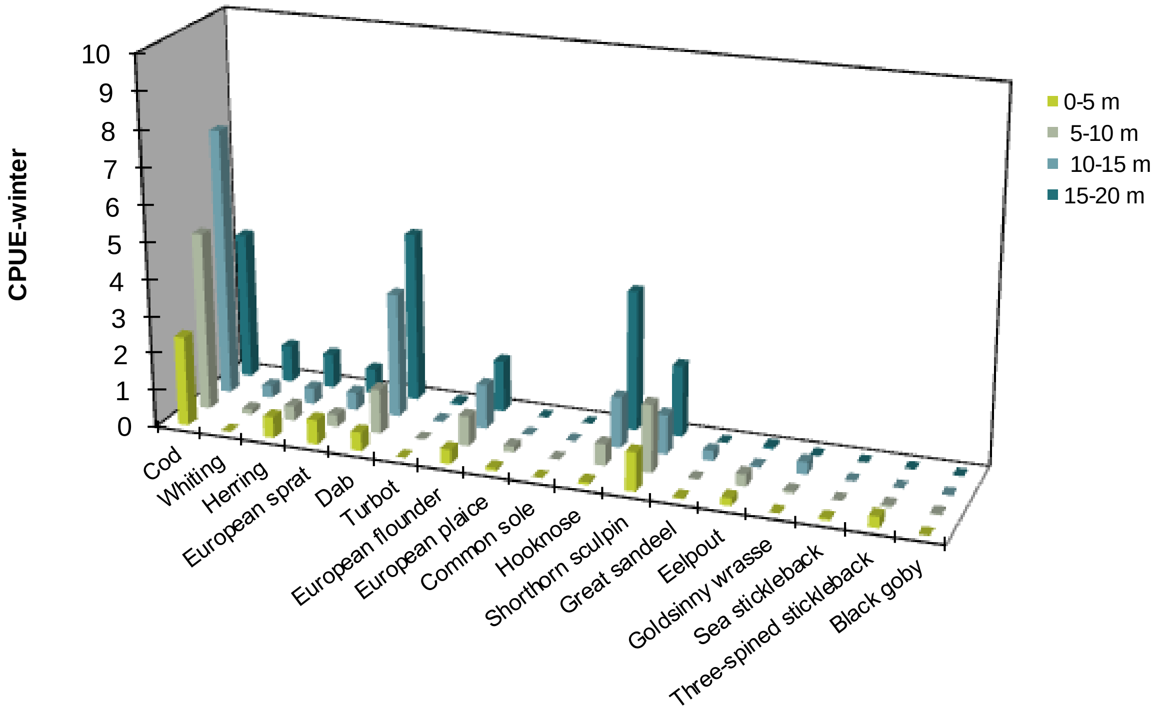


Figure 4.19: Depth distribution of common fish species in the coastal areas of Fehmarn and Lolland observed during winter.

4.1.7 Fish community in the surf zone

In addition to the abovementioned studies of the shallow water fish communities, an analysis of the fish community in the surf zone (< 2 m depth) was performed based upon the beach seine net sampling in coastal areas in May and June 2010 (Figure 3.4). Although the major aim was to collect juvenile fish within their nursery areas, the data also provided useful information about the composition of the fish community in the very shallow water zone (< 2 m depth). The results from the present survey of the fish community in the surf zone were largely comparable with the findings of Nellen and Thiel (1996).

In general small fish like sticklebacks, gobies and sandeels dominated, although some differences between the communities along the coasts of Fehmarn and Lolland were found. Juvenile pelagic fish like herring and sprat were also abundant in this community.

Along the coast of Fehmarn small sandeel, Nilsson’s pipefish, sea trout and ninespine stickleback were exclusively found at depths less than 2 m. This was also the case for transparent goby at the coast of Lolland.

The most common species in the surf zone was sand goby, which at both coasts was present at more than 80% of all stations. Species such as flounder, eelpout and plaice seemed to be more common along the coast of Fehmarn than at the coast of Lolland (Figure 4.20 and Figure 4.21), whereas three-spined stickleback was more common along the coast of Lolland.

Nilsson´s pipefish was very common in the surf zone along the coast of Fehmarn but was virtually absent along the coast of Lolland. Several less common species were only recorded along one of the coastlines. Some character species from other fish communities (e.g. long-spined bullhead and shorthorn sculpin) were only present in catches from the coast of Lolland.

The small sandeel was more common in May than in June, whereas all other species were present in higher numbers in June.

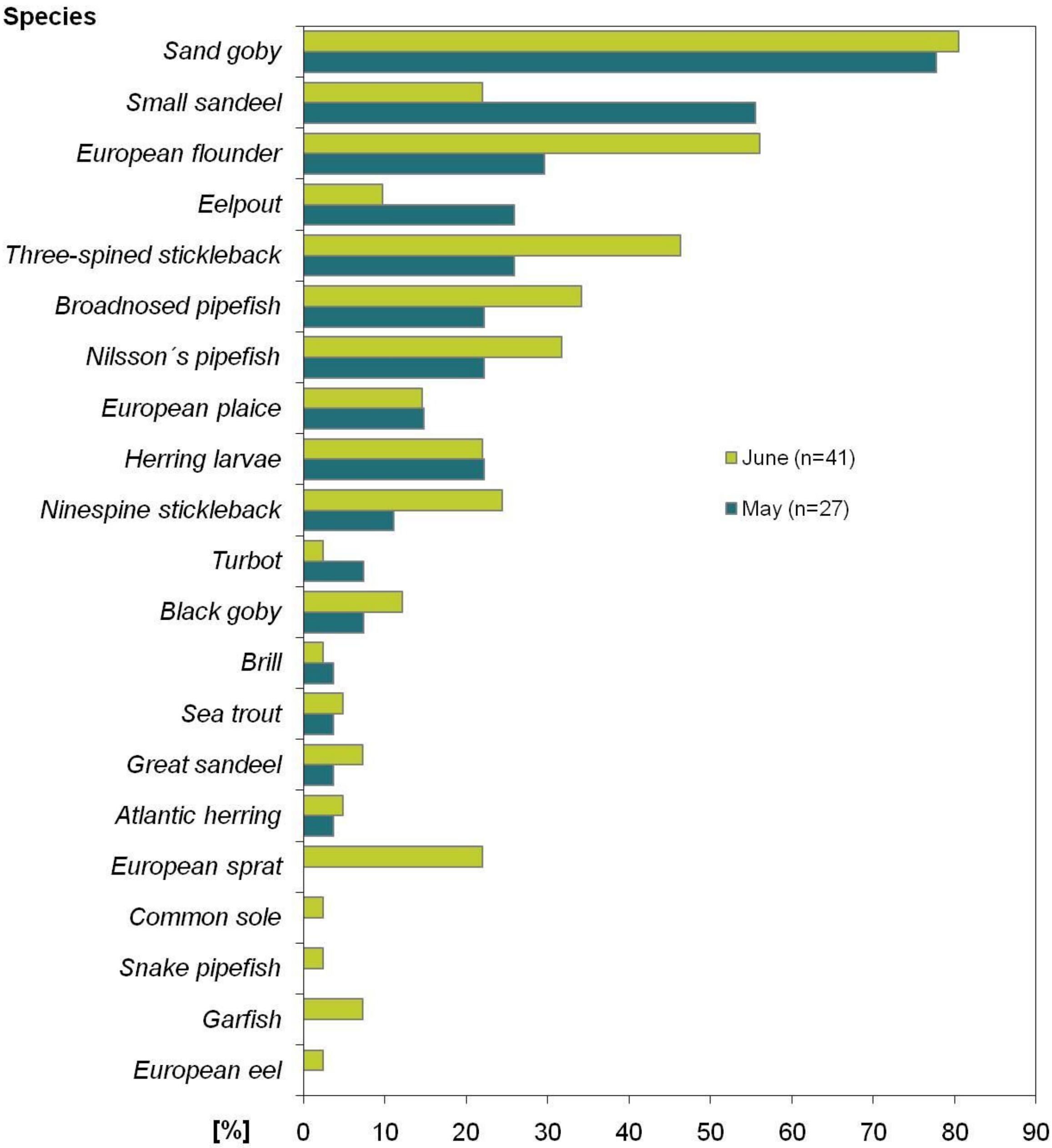


Figure 4.20: Frequency of occurrence of 21 species caught at 14 beach seine net stations around Fehmarn in May and June 2010. n = number of hauls.

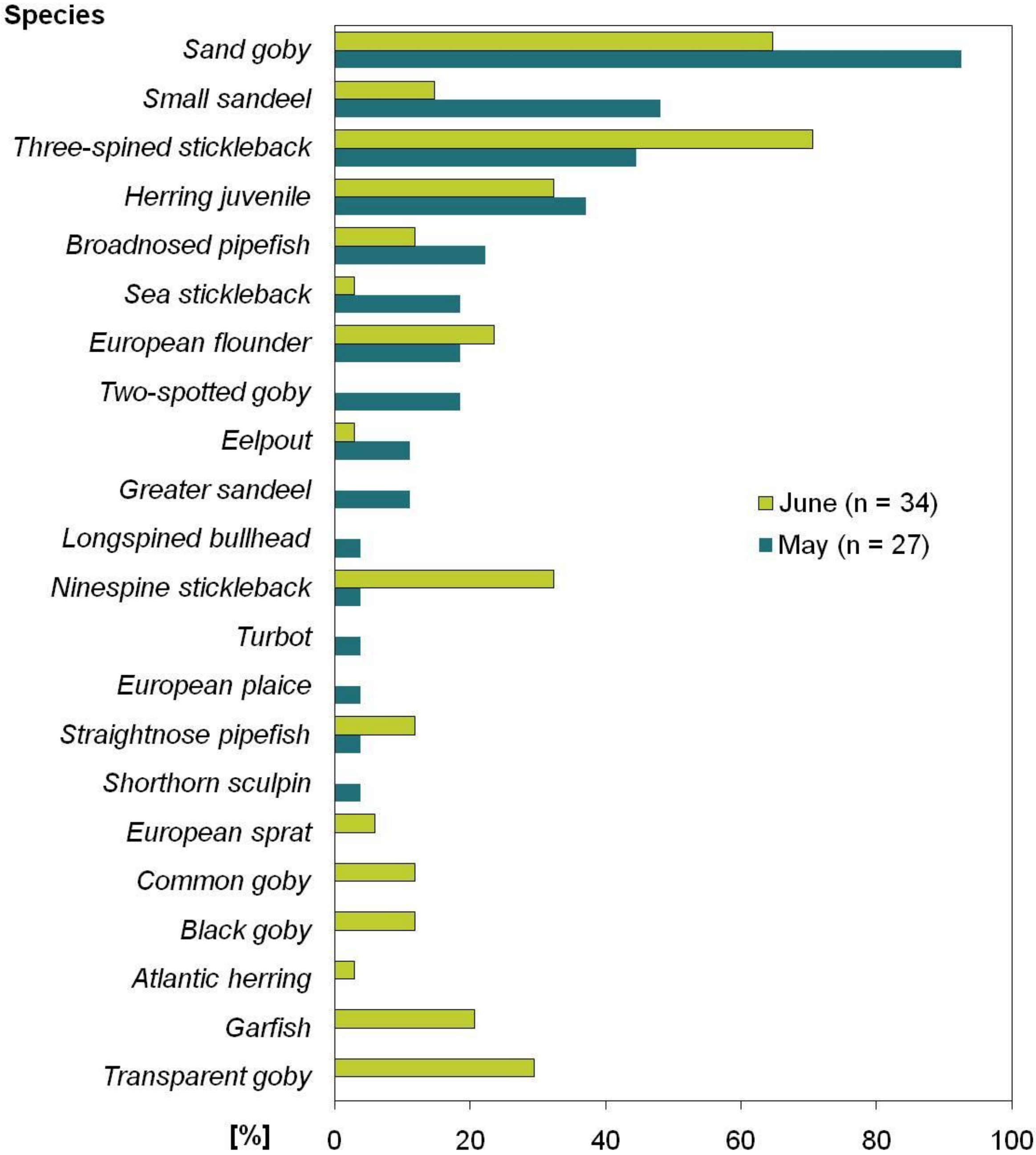


Figure 4.21: Frequency of occurrence of 22 species caught at 14 beach seine net stations along the south coast of Lolland in May and June 2010. n = number of hauls.

The abundance and biomass of fish varied greatly between stations; see Figure 4.22 (Fehmarn) and Figure 4.23 (Lolland).

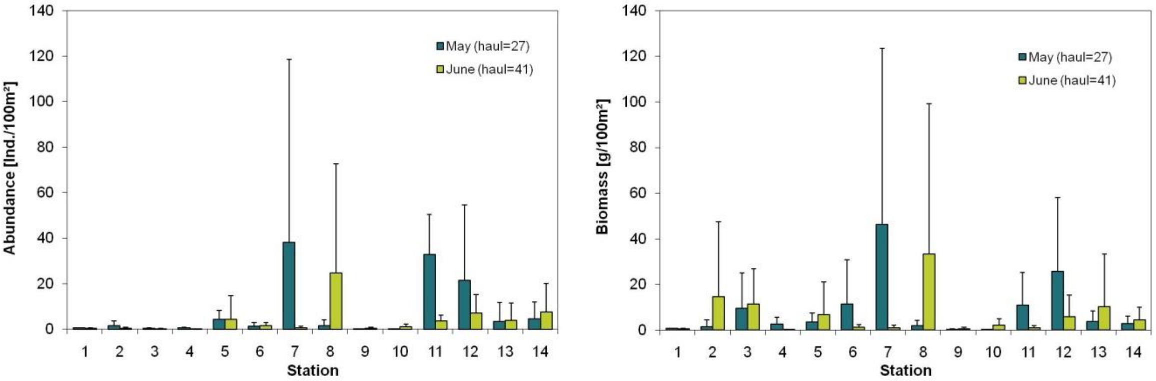


Figure 4.22: Total abundance and biomass of all fish caught at the beach seine net stations around Fehmarn. n = number of hauls. Errorbars shows the standard deviation.

Sand goby represented the majority of the total biomass at most stations along the coast of Fehmarn. The species was particularly dominant in the shallow and sheltered bays Orther Bucht and Binnensee (stations 11 - 14). Flounder, three-spined stickleback, ninespine stickleback, broadnosed pipefish and snake pipefish were also more abundant in the sheltered areas than at the more exposed coasts. Furthermore, the sheltered bays seemed to be important as nursery areas for plaice and other species such as garfish, herring and sprat. On the exposed coast in the north-eastern part of Fehmarn (stations 7 and 8), sand gobies were very rare and the small sandeel represented the majority of the total abundance and biomass from the catches.

Several species, which were not found during the fish community surveys (section 4.1.2), were found as juvenile specimens during the nursery area surveys in the surf zone. Examples included turbot, brill, lesser sandeel, great sandeel and sand goby.

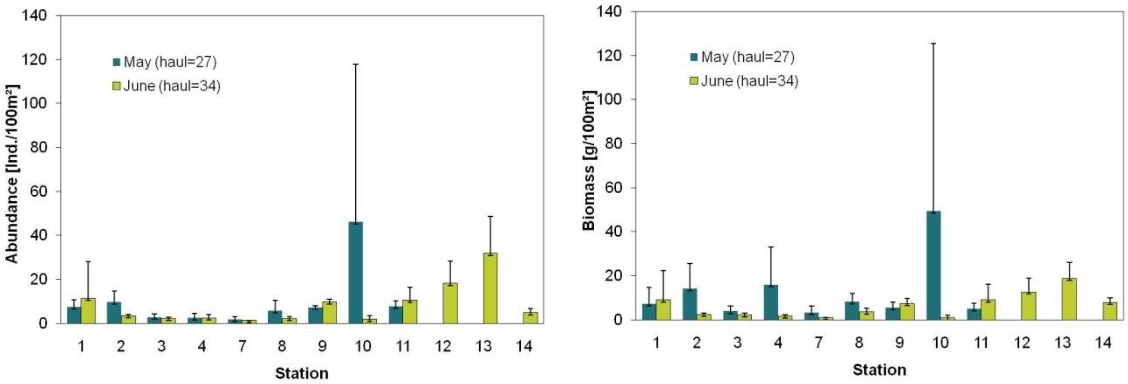


Figure 4.23: Total abundance and biomass of all fish caught at the beach seine net stations at Lolland. n = number of hauls. Errorbars shows the standard deviation.

The sand goby was also very common along the coast of Lolland and was found on all stations. Likewise, sand goby represented the majority of the abundance and biomass at station 9 to 14 in the Rødsand area where relatively high abundances and biomasses were registered (Figure 4.23).

Sand goby was also the dominant species in the YOY-trawl investigation at the coast of Lolland. A total of 17 species of fish, five of which were flatfish, were recorded during this survey (Table 4.4). The shallow water sandy bottom areas were found to be important nursery areas for plaice, flounder, turbot, sole and brill, although the relative abundance of the young flatfish was low compared to that of the sand goby.

Table 4.4: Relative abundance of species registered in the YOY-trawl survey in July 2009 at the coast of Lolland.

Common name	Scientific name	
Sand goby	*Pomatoschistus minutus*	95.33%
Small sandeel	*Ammodytes tobianus*	1.48%
European plaice	*Pleuronectes platessa*	0.84%
European flounder	*Platichthys flesus*	0.41%
Broadnosed pipefish	*Syngnathus typhle*	0.35%
Three-spined stickelback	*Gasterosteus aculeatus*	0.32%
Sea stickleback	*Spinachia spinachia*	0.29%
Turbot	*Psetta maxima*	0.26%
Sole	*Solea solea*	0.14%
Ninespine stickleback	*Pungitius pungitius*	0.12%
Atlantic herring	*Clupea harengus*	0.12%
Great sandeel	*Hyperoplus lanceolatus*	0.09%
Common goby	*Pomatoschistus microps*	0.09%
Black goby	*Gobius niger*	0.06%
Brill	*Scophthalmus rhombus*	0.06%
Two-spotted goby	*Gobiusculus flavescens*	0.03%
Nilsson’s pipefish	*Syngnathus rostellatus*	0.03%

4.1.8 Fish communities baseline conclusion

The main results of the baseline fish community surveys may be summarized as follows:

- Six different habitat types and seven different fish communities were identified in Fehmarnbelt.
- A total of 57 fish species were recorded during the fish community surveys. Nine of these species are red listed in Germany and two are red listed in Denmark.
- Sandy and mixed bottoms with mussel beds (habitat type 2+3) were dominant in the western and north-western part of Fehmarnbelt. In these areas flatfish such as dab and flounder dominated. The highest abundance and biomass of whiting and hooknose were also found in these habitat types.
- Structured habitats with mixed bottom of sand with stones and blocks with mussel beds (habitat type 4+5) were found in the eastern and south-eastern part of Fehmarnbelt. Cod was the dominating species in these habitats. Other characteristic species for these habitats were sea stickleback, wrasses (mainly goldsinny wrasse) and black goby.
- Areas with sandy bottom and eelgrass meadows (habitat type 6) were only found in subarea Lolland. This habitat was dominated by characteristic shallow water species such as sticklebacks (especially three-spined), eelpout and several species of goby.
- In the central part of Fehmarnbelt, the overall dominating species in muddy and sandy habitats was dab. Other important species found at habitats with fine grained seabed (type 1) were whiting, cod and plaice. In sandy habitats (type 2) plaice, whiting and flounder were important and horse mackerel were caught in high numbers in December.
- Shallow areas along both coasts were dominated by small fish species such as sand goby, small sandeel and three-spined stickleback.
- Juvenile stages of most commercially important fish species (e.g. flounder, plaice, turbot, brill, herring and sprat) utilise the shallow water areas as nursery areas.
- The importance of Fehmarnbelt and adjacent areas for shallow water species is listed in Table 4.5.
- Areas of potential importance for fish species in the shallow water fish community are shown in Figure 4.24. This map is based upon a classification of functional importance for species that are characteristic for the shallow water community. Criteria for this classification are the importance of the areas as; spawning area/ground, for the drift of larvae, as nursery area or for migratory behaviour. As can be seen on the map, the coastal areas are of medium importance for the shallow water fish communities.
- Most shallow water species are opportunists with short life spans and early maturity, designed for the variable conditions in the shallow waters. These abilities make a fast recovery likely after any crucial impact, and the importance of the present shallow water community is hereby moderate.
- Most shallow water species are resident and issues concerning migration or eggs and larvae drift are not important.

Table 4.5: Importance of Fehmarnbelt and adjacent areas for shallow water species in relation to spawning, eggs and larvae drift, nursery, feeding and migration. - = not relevant

Environmental component	spawning	egg-larvae drift	nursery	feeding	migration	overall
Shallow water species	medium	minor	medium	medium	-	medium

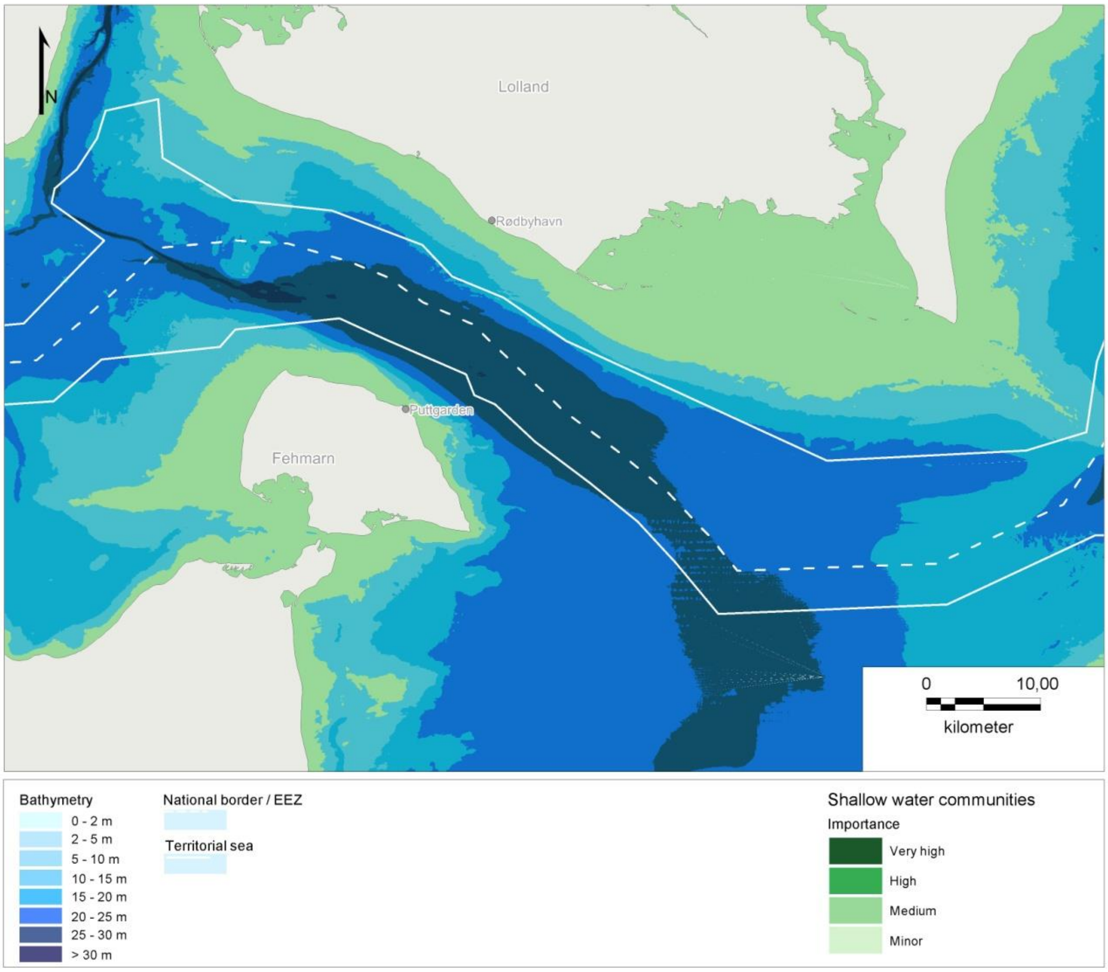


Figure 4.24: Sites of potential importance for shallow water fish communities.

4.2 Pelagic fish community

The pelagic fish community in the Fehmarnbelt includes at least 10 species. Of these, herring, sprat, whiting and cod were found to be the most abundant. Other pelagic species occasionally found in high numbers are garfish (*Belone belone*) and Atlantic horse mackerel (*Trachurus thrachurus*).

4.2.1 Baseline approach

The results of the pelagic fish community in the Fehmarnbelt area were provided by acoustic surveys during periodic surveys covering a large part of the central Fehmarnbelt and continuous surveys covering the areas close to the proposed alignment for the future Femarnbelt Fixed Link. The hydro acoustic studies provide only information about densities of pelagic communities in general and were therefore supplemented by calibrating trawl surveys providing information about the relative species composition and biomass of the pelagic community.

4.2.2 Densities and distribution of pelagic fish

A total of 36 species was registered from the trawl catches (Appendix 1). The total number of fish caught in the 40 trawl hauls performed was 695,694 resulting in a total trawl biomass of 11.25 tonnes.

Overall means of 14.07 (SE = 0.87) and 15.19 (SE = 0.89) tonnes per square nautical mile (nm^{-2}) were registered with the 120 kHz and 38 kHz transducers, respectively. The slightly higher densities estimate with the 38 kHz system can be a result of differences in the beam-ray. The differences in variance between the two echo sounder systems were negligible.

It was found that the pelagic fish – sprat and herring – do not aggregate in the corridor of the alignment during the main migration period for spring spawning herring, migrating from the spawning grounds in the Baltic towards feeding areas in the Kattegat in the spring. However, the system is very dynamic and the periodic survey in the spring does not conclusively prove whether this area is important or not for the pelagic community. Some fishermen in the area have experienced a slow westward migration of clupeids of approximately 3-5 nautical miles per day starting in April. It is therefore very likely that high densities of clupeids, found north-east of Fehmarn in April-May will migrate towards the west and cross the alignment corridor.

4.2.2.1 Trawl data

The species composition of the pelagic fish community varied with the season (Figure 4.25 and Figure 4.26). Clupeids made up the highest share of the total biomass in spring and summer whereas cod was most abundant during the winter. Whiting was abundant and represented a high part of the total biomass of pelagic fish at all seasons. Cod and whiting are considered semi-pelagic species living close to the bottom or in the pelagic.

Sprat was the most abundant purely pelagic species in the catches but was totally absent in several hauls during the winter surveys. This is a consequence of the spatial behavioural pattern of sprat, which spends the winter in the deeper parts of the central Baltic Sea but move to shallower areas during spring and summer to feed and spawn (Peck and Möllemann, 2008).

The high percentage of clupeids in the April-May, 2009 periodic survey is a consequence of gear selectivity. During the survey a pelagic trawl was used targeting pelagic fish only. In later surveys the TV3 trawl was used and a much higher proportion of the semi-pelagic species were caught. Especially in the periodic February-March survey almost no clupeids were caught and whiting represented more than 75% of the trawl biomass (Figure 4.26).

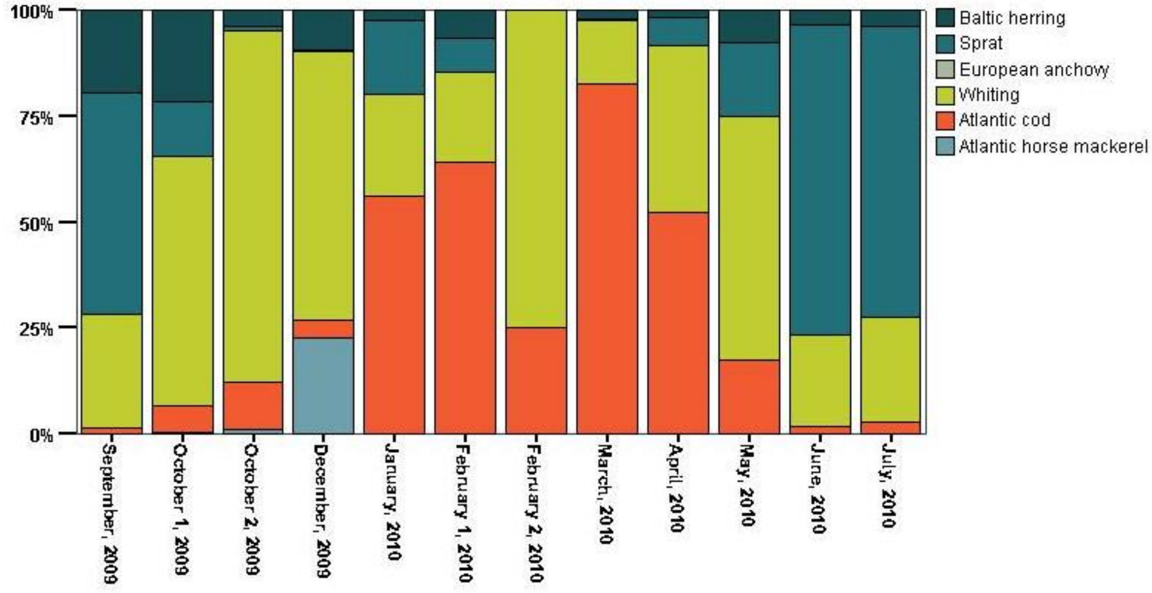


Figure 4.25: The percentage (weight) distribution of pelagic fish caught in trawl hauls during the continuous surveys. Each column represents one night and one day haul during each survey. European anchovy represented a very small proportion of the total catch and is therefore not visible on the figure.

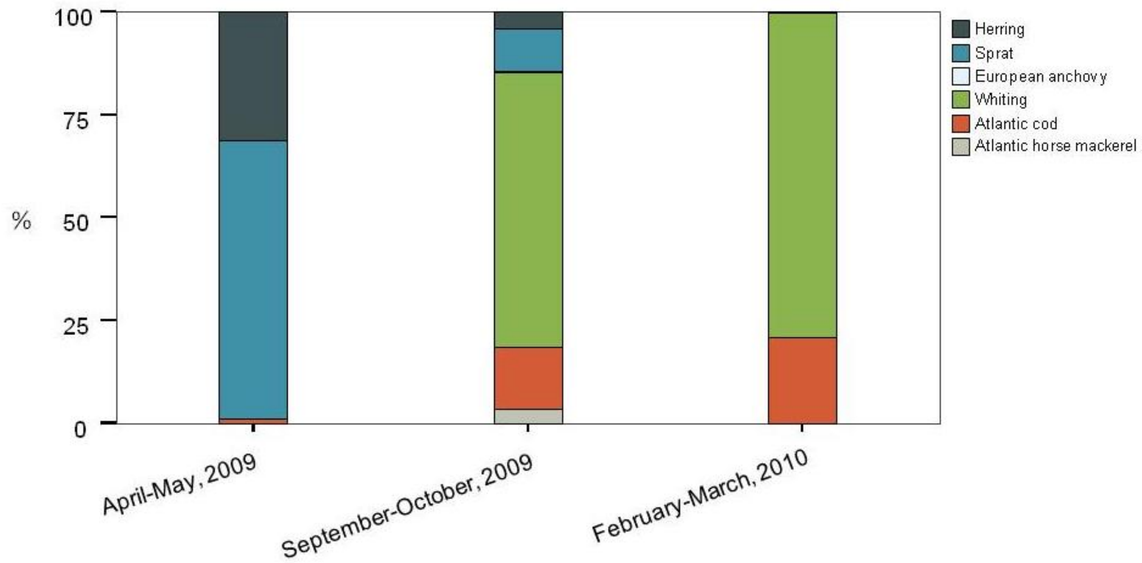


Figure 4.26: The percentage (weight) distribution of pelagic fish caught in trawl hauls during the periodic surveys (8 hauls in April-May, 4 hauls in October-November and 4 hauls in February-March). European anchovy represented a very small proportion of the total catch and is therefore not visible on the figure.

During daytime clupeids are often located close to the bottom. In order to sample both pelagic and demersal species a TV3 trawl was used as a tradeoff. The TV3 trawl should be suitable for catching both pelagic and semi-pelagic species, thus providing a reliable species composition of these species, and should also provide information of benthic (demersal) species like flatfish to be used in the description of benthic fish communities. However, according to the catches in the trawl surveys no significantly greater proportion of clupeids were observed during the day compared to the night hauls. This may be explained by the schooling behaviour, which makes clupeid species capable of avoiding a trawl net with a relatively narrow vertical opening (2.3 m in this case). A comparison of the day and night hauls showed no significant differences in neither species composition nor length distribution.

In relative terms, the catches in the TV3 trawl provide information of the seasonal changes and distribution of the pelagic and semi-pelagic fish community in the Fehmarnbelt. In general, the results of the trawl hauls in October were similar to the findings in the BITS survey in 2009. However, the proportion of horse mackerel caught in the BITS survey was higher than in the present study.

4.2.2.2 Hydro-acoustic data

At the continuous surveys, average biomasses of 14.86 (SE ± 1.92; N=11,968) and 14.45 (SE ±1.85; N=13,087) tonnes nm^{-2} were found with the 38 kHz and 120 kHz equipment, respectively. These mean values include data from all continuous surveys but there were great differences between the surveys. The highest values were found in April and the lowest values were found in late February (Figure 4.27).

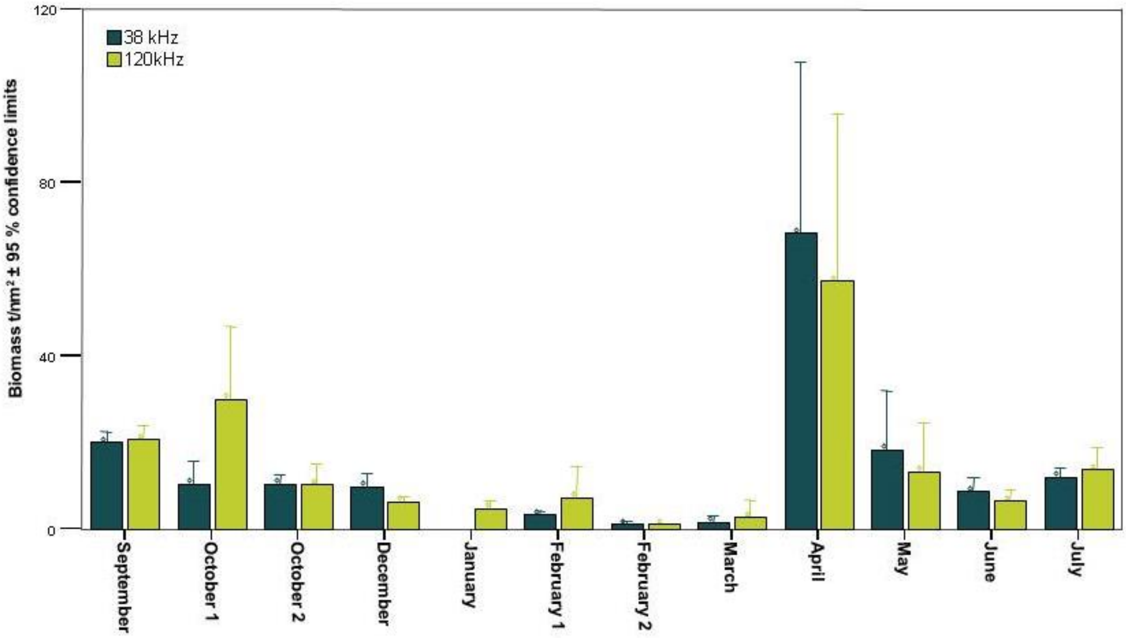


Figure 4.27: Mean biomasses (tonnes nm^{-2}) found at each of the continuous surveys, as measured by the 38 and 120 kHz hydro-acoustic equipment.

At the three periodic surveys, average biomasses of 15.46 (SE ± 0.57; N=15,545) and 13.77 (SE ± 0.64; N=18,002) tonnes nm^{-2} were found with the 38 kHz and 120 kHz equipment, respectively (Figure 4.28). As at the continuous surveys, the highest biomass was found in April-May, whereas the two other sampling periods showed very similar average biomasses. The very low biomasses recorded at the continuous surveys in February-March were not apparent in the periodic surveys, which covered a larger area.

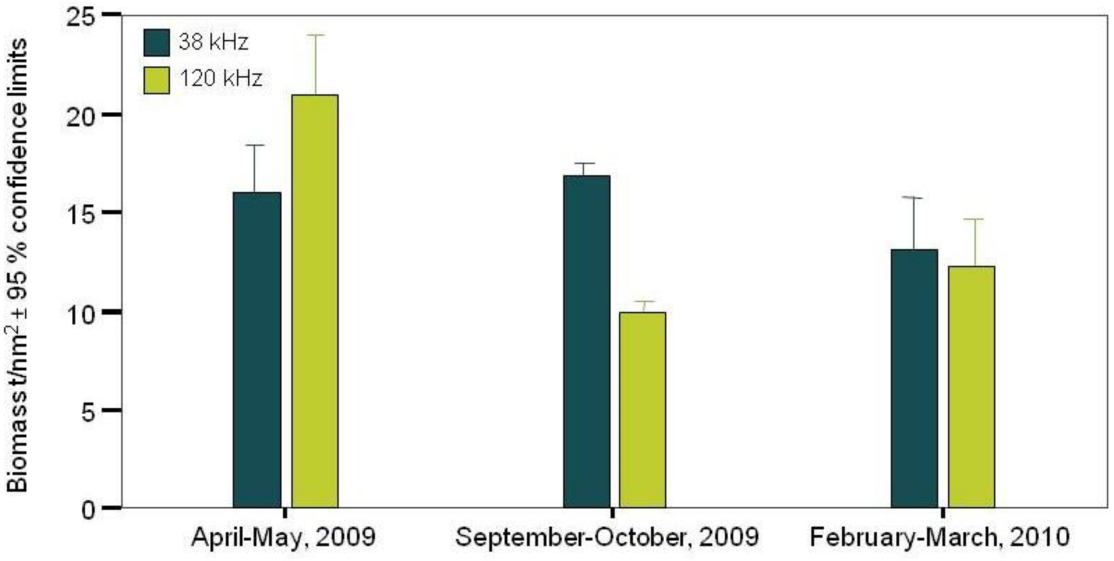


Figure 4.28: Mean biomasses (tonnes nm^{-2}) found at each of the periodic surveys, as measured by the 38 and 120 kHz hydro-acoustic equipment.

A high seasonal and spatial variability in the distribution pattern of the pelagic fish community in Fehmarnbelt was found at the periodic surveys. This was expected because the purpose of the surveys was to cover three specific incidents in the pelagic environment, viz. the spawning migration of herring and sprat in spring, feeding of gadoids and clupeids in autumn, and spawning of cod in late winter.

In April-May 2009, pelagic fish were concentrated in two areas, one east and one northwest of Fehmarn (summarizing the results from the 120 kHz and 38 kHz systems; Figure 4.29 and Figure 4.30). At the time of survey the pelagic fish were thus aggregated in the southeastern part of the surveyed area but also to some extent within the corridor of the proposed alignment.

Herring and sprat made up 32% and 66%, respectively, of the biomass in the trawl catches during the April-May survey. The semi-pelagic species cod and whiting were undoubtedly also present but were only caught in small amounts with the pelagic trawl used at this survey.

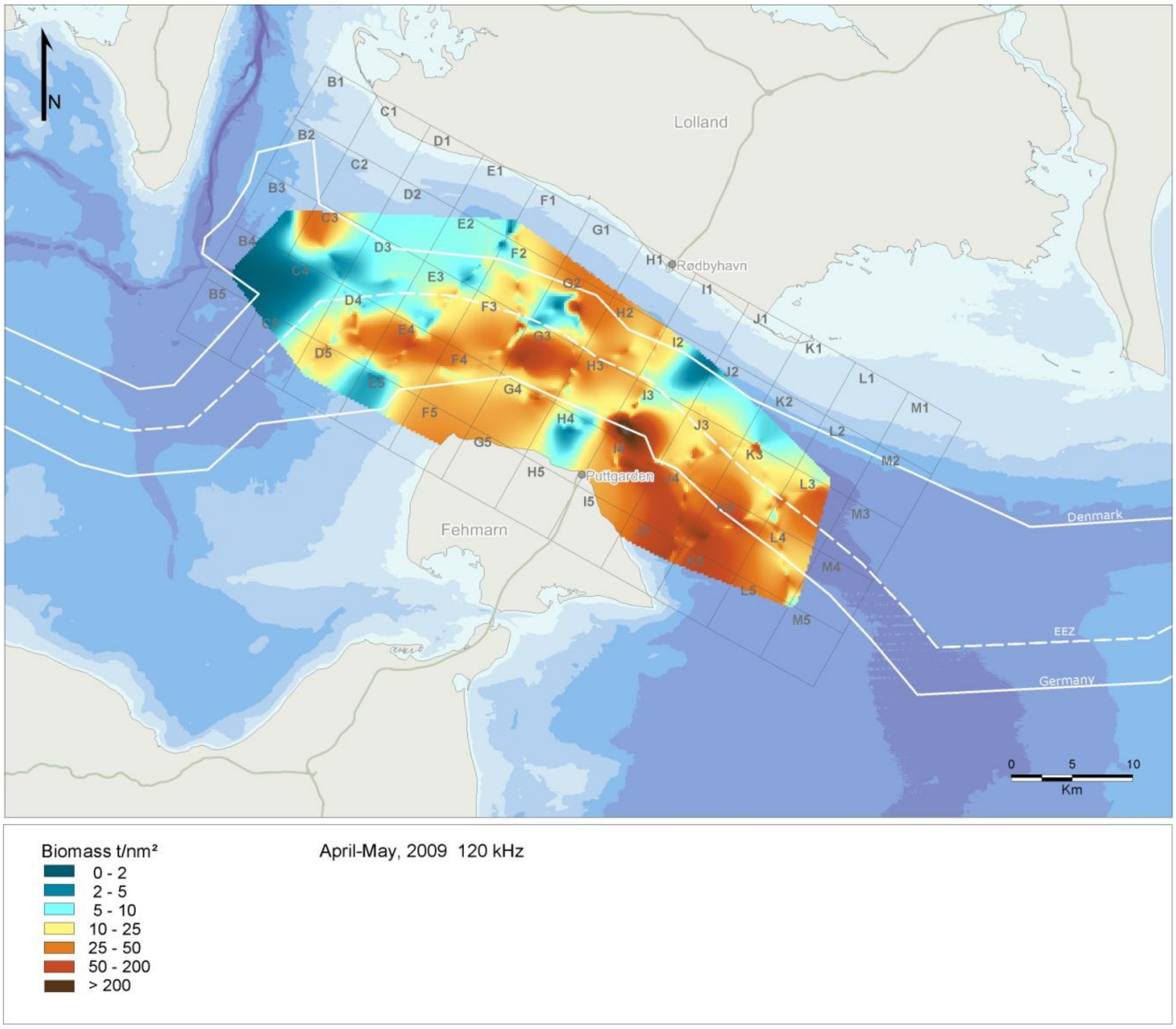


Figure 4.29: The spatial distribution of pelagic fish in Fehmarnbelt in April-May 2009, estimated with the 120 kHz system.

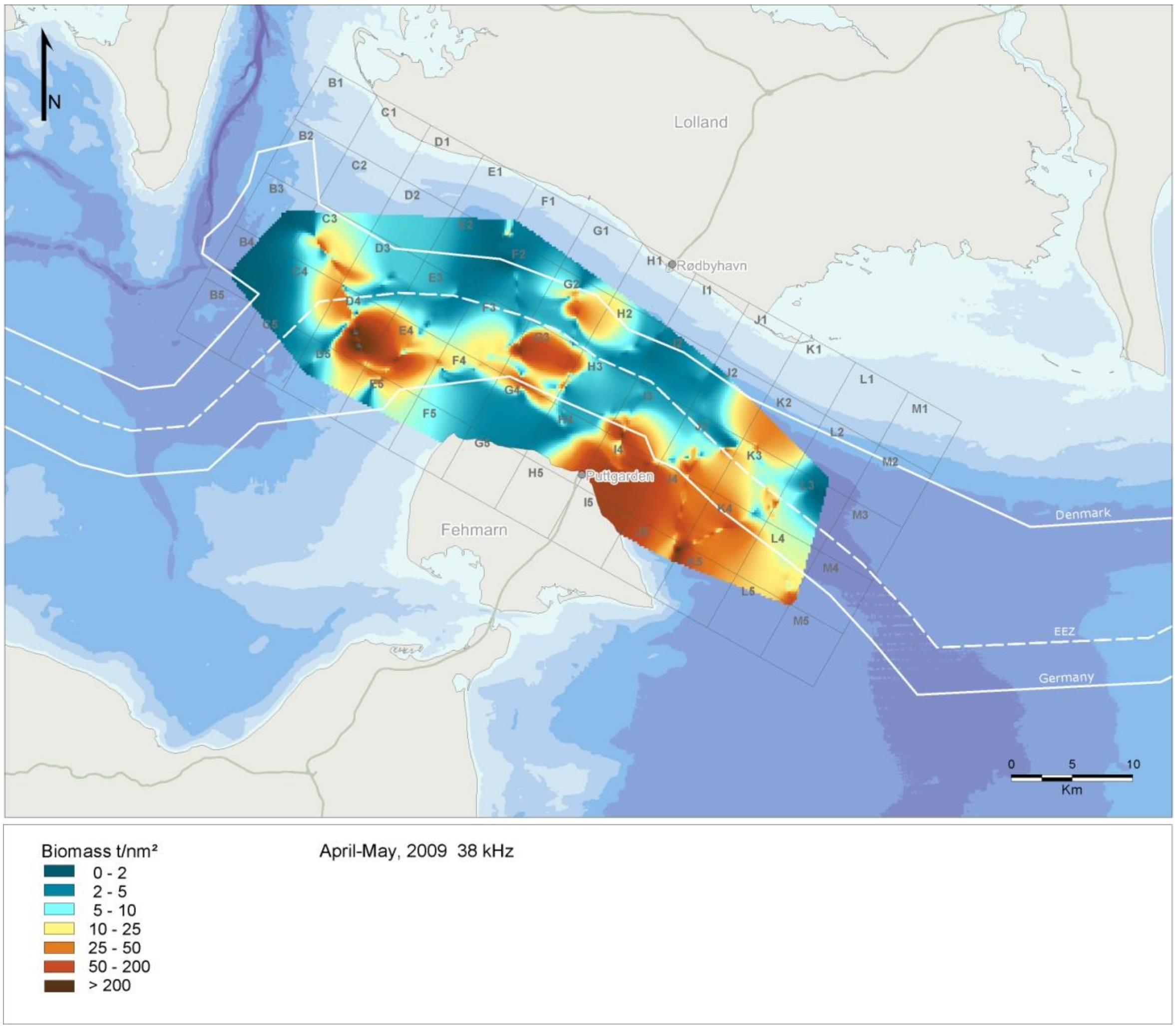


Figure 4.30: The spatial distribution of pelagic fish in Fehmarnbelt in April-May 2009, estimated with the 38 kHz system.

At the September-October periodic survey, an area within the alignment corridor turned out to hold the highest densities of pelagic fish, but densities were also high within a large area east of the proposed alignment (Figure 4.31 and Figure 4.32).

A high weight proportion of gadoids (85%), especially whiting, was recorded in the four trawl hauls from the September-October survey. The species composition caught in the trawl was similar to that in the BITS survey, but might not reflect the actual species distribution of pelagic fish in the Fehmarnbelt during autumn very well. Data from the continuous surveys performed during September-October (Figure 4.25) indicate that a substantial change in species composition occurred during this period, from a relatively high share of clupeids in September to a very low share in late October. As a consequence of this it is impossible to evaluate how well the trawl data represented the actual species distribution.

Results from the SOLEA surveys performed with a pelagic trawl in the beginning of October 2009 (ICES, 2010a) showed that the catches in the hauls located closest to the area of interests were very low (3.4 kg per ½-hour). The relative abundance of gadoids and clupeids in this haul were 1% and 72%, respectively, of the total catch of pelagic fish.

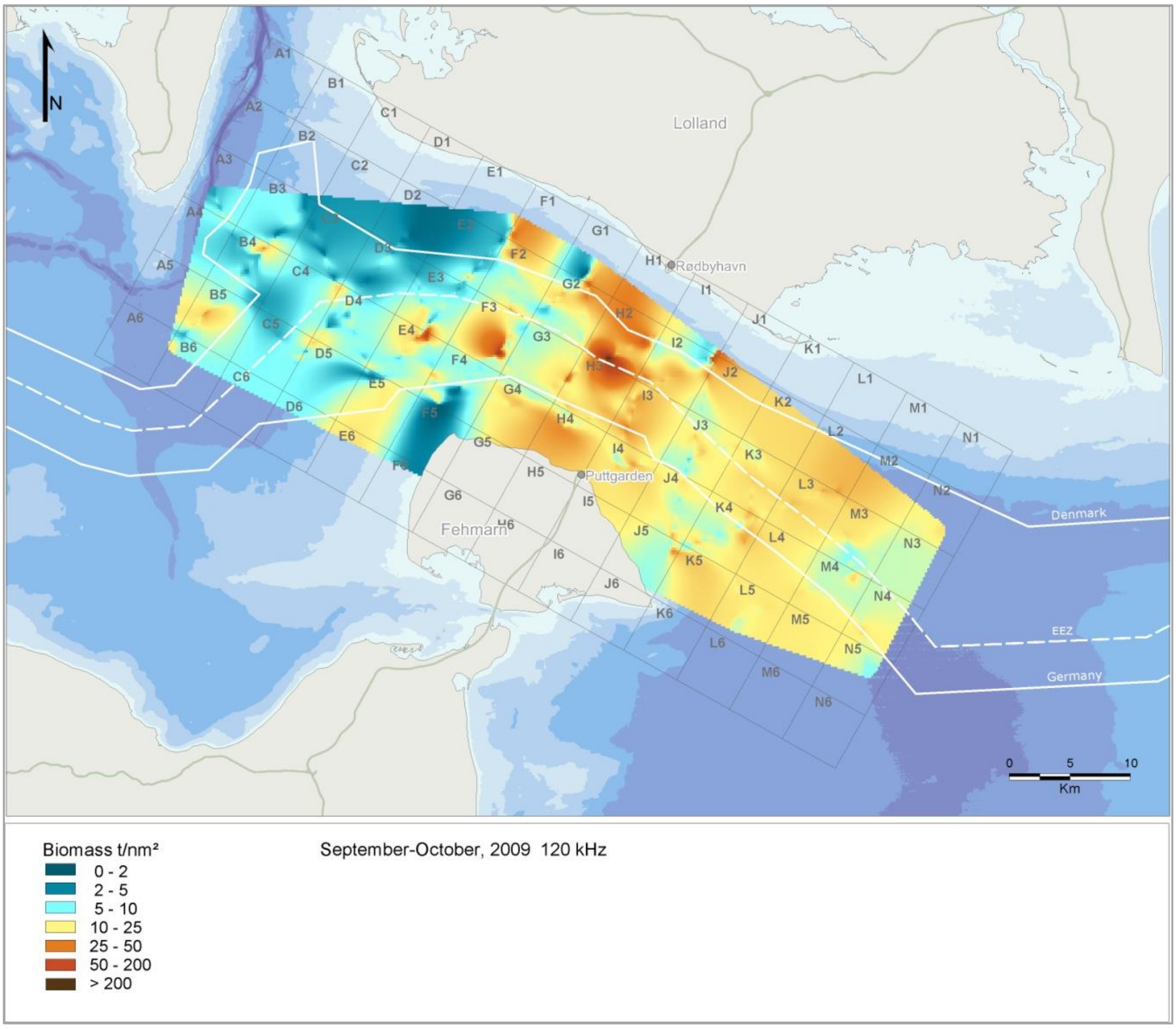


Figure 4.31: The spatial distribution of pelagic fish in Fehmarnbelt in September-October 2009, estimated with the 120 kHz system.

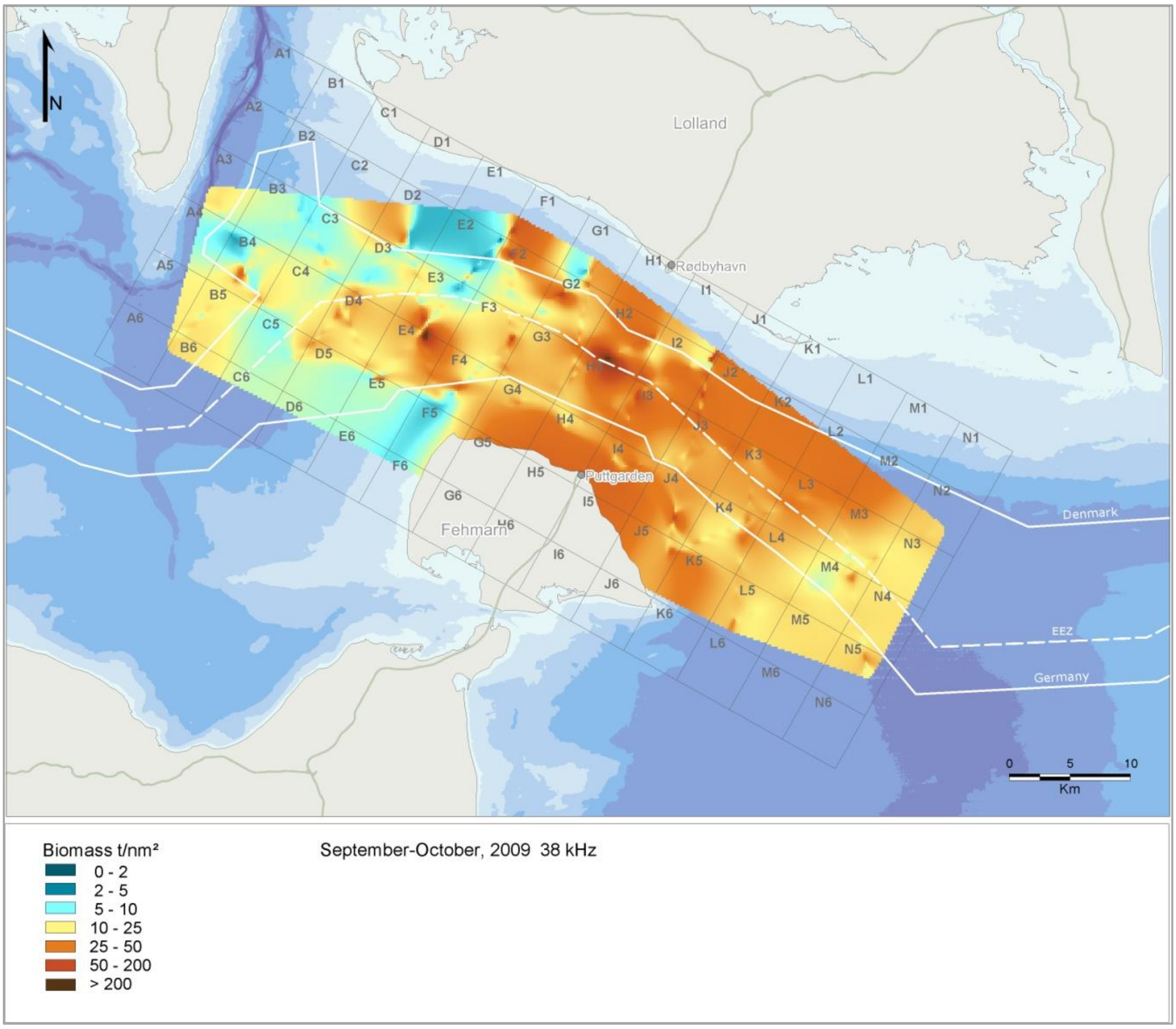


Figure 4.32: The spatial distribution of pelagic fish in Fehmarnbelt in September-October 2009, estimated with the 38 kHz system.

The results from the February-March 2010 survey showed some dissimilarity in the distributions and densities revealed by the two frequencies. This difference was supposed to be due to a temporary malfunction on the 38 kHz system. Consequently, only results from the 120 kHz system were considered (Figure 4.33).

Several hot spots for pelagic fish were apparent during this survey. The highest densities were found within a large area east of the proposed alignment, but also some smaller areas south-east of Langeland and in the southern part of the Great Belt showed high biomasses of pelagic fish.

The gadoids were the dominant group of pelagic and semi-pelagic fish caught in the trawl hauls during the February-March survey. Gadoids made up approximately 99% of the total catch of pelagic and semi-pelagic fish, with whiting accounting for approximately 75%. It is assumed that the high proportion of gadoids versus clupeids reflects the actual composition of the pelagic community at that time reasonably well, as sprat are known to aggregate in the deeper parts of the Baltic Sea during winter and most western Baltic herring winter in Øresund (Nielsen et al., 2001; Stepputtis, 2006). Furthermore, cod are known to aggregate in the western part of the Baltic Sea in late winter to spawn.

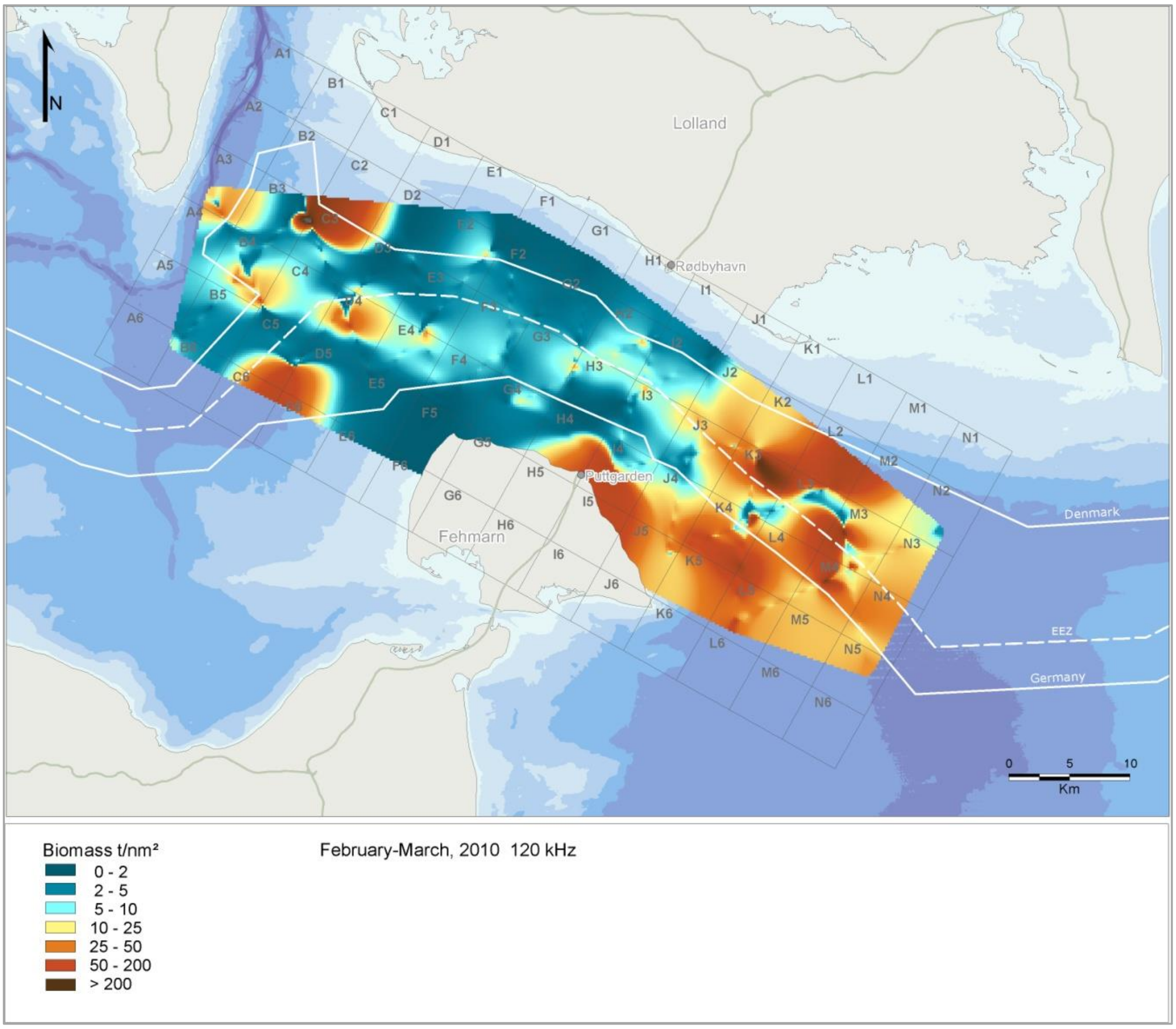


Figure 4.33: The spatial distribution of pelagic fish in Fehmarnbelt in February-March 2010, estimated with the 120 kHz system.

The seasonal variation in distribution patterns in the pelagic community was demonstrated by the continuous survey series (Figure 4.36). Averaging the densities over the 12 surveys, the highest densities of pelagic fish were recorded on the German side of the Fehmarnbelt (Figure 4.34 and Figure 4.35).

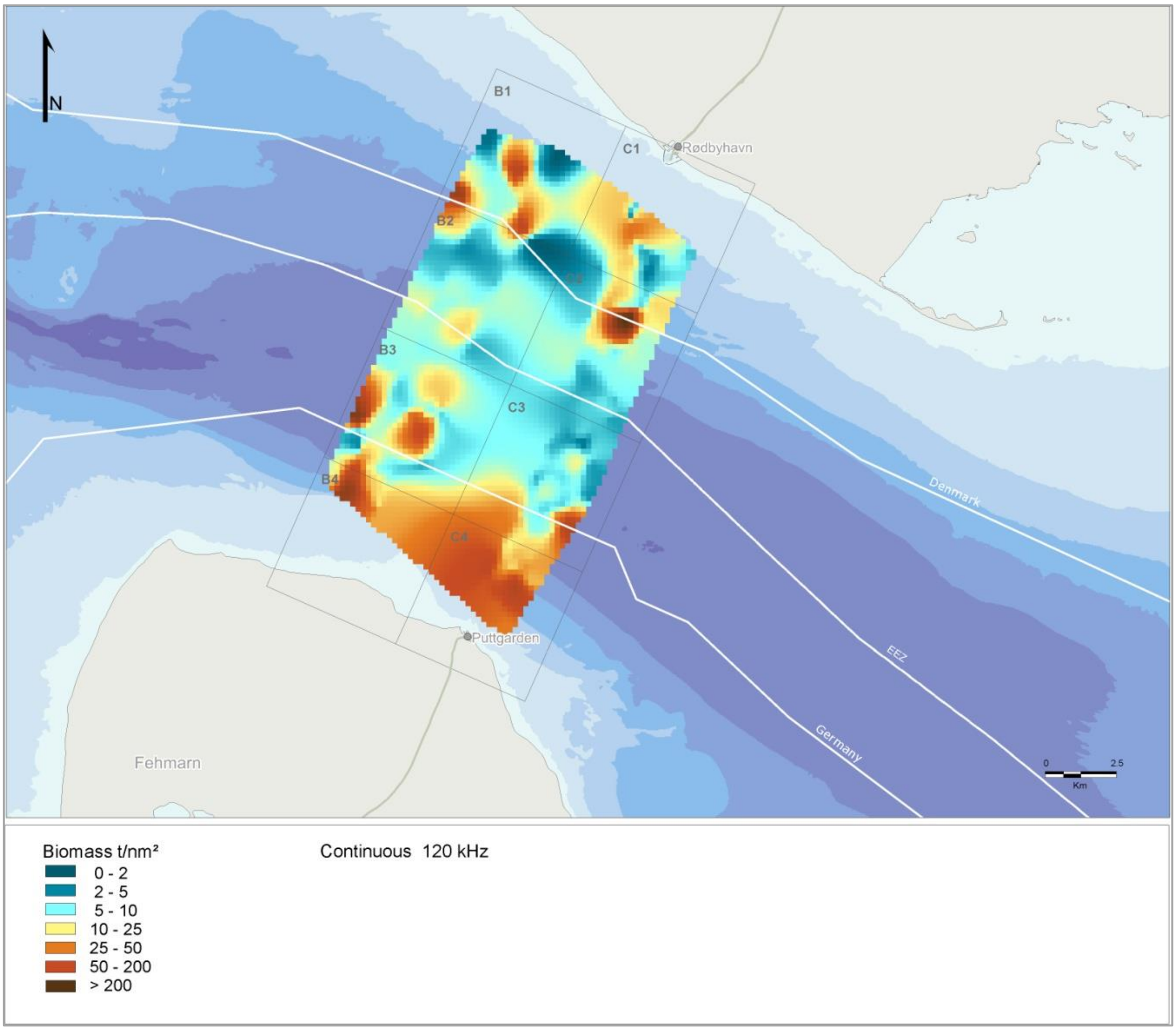


Figure 4.34: The average spatial distribution of pelagic fish along the corridor of the proposed route. Densities were estimated with the 120 kHz system and averaged over the 12 surveys.

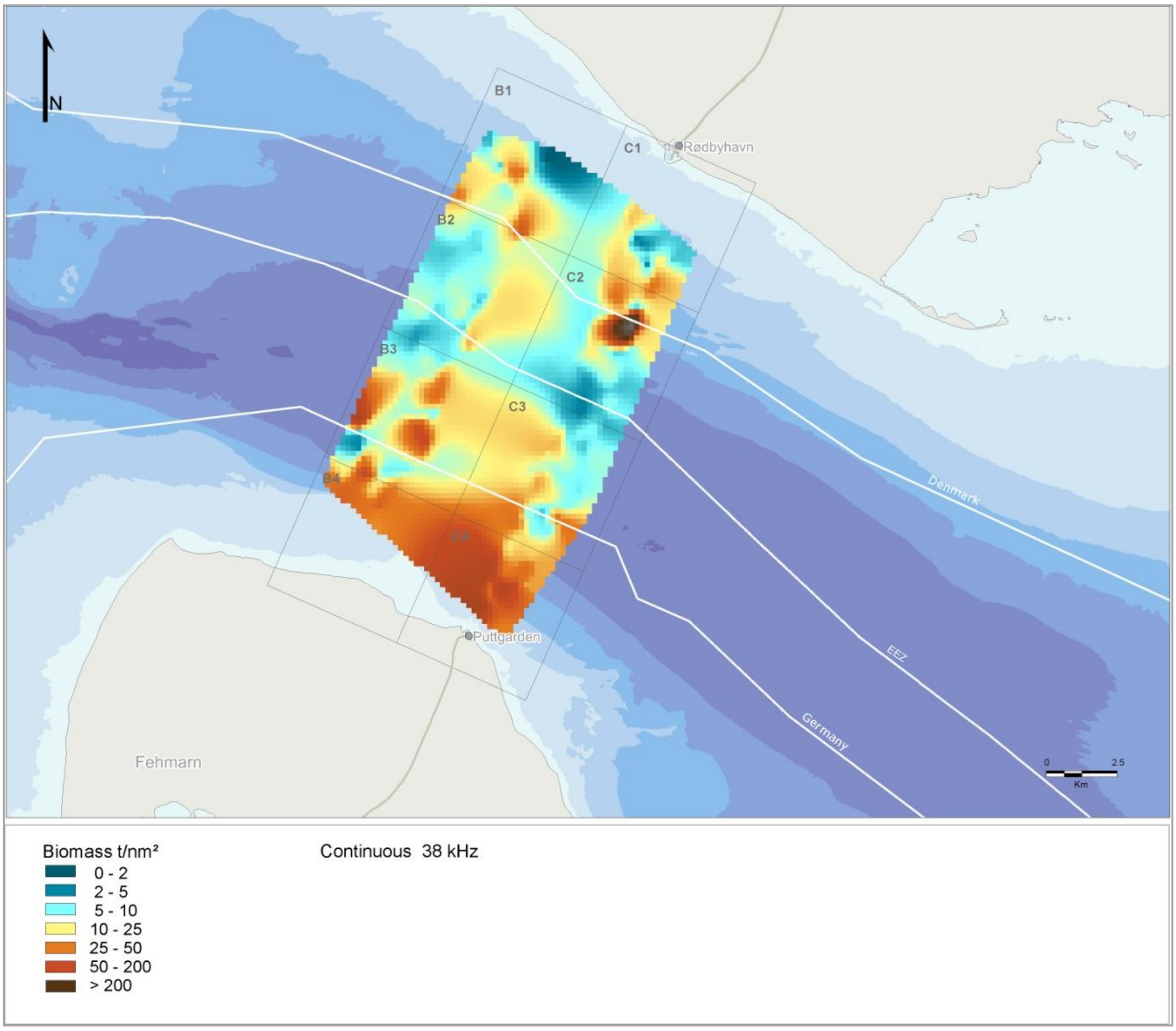


Figure 4.35: The average spatial distribution of pelagic fish along the corridor of the proposed route. Densities were estimated with the 38 kHz system and averaged over the 12 surveys.

The spatial distribution of pelagic fish along the corridor of the proposed alignment varied strongly during the year (Figure 4.36). The differences between the surveys were assumed to be mainly due to changes in species composition and densities and seasonal changes in habitat preferences for some species. Different hot spots were found in Fehmarnbelt during the season. The surveys in December, January and early February showed the highest densities of pelagic fish in the deeper and open water areas and the lowest values in some of the coastal areas. This pattern was supposed to be a consequence of low temperatures forcing the fish towards the deeper areas and/or it may reflect the life cycles of pelagic fish. Densities of pelagic fish were very low in late February and March. From April to September high densities were recorded along the bathymetric slope at the northern coast of Fehmarn, whereas in October (two surveys) the highest densities were found in some areas along the coast of Lolland.

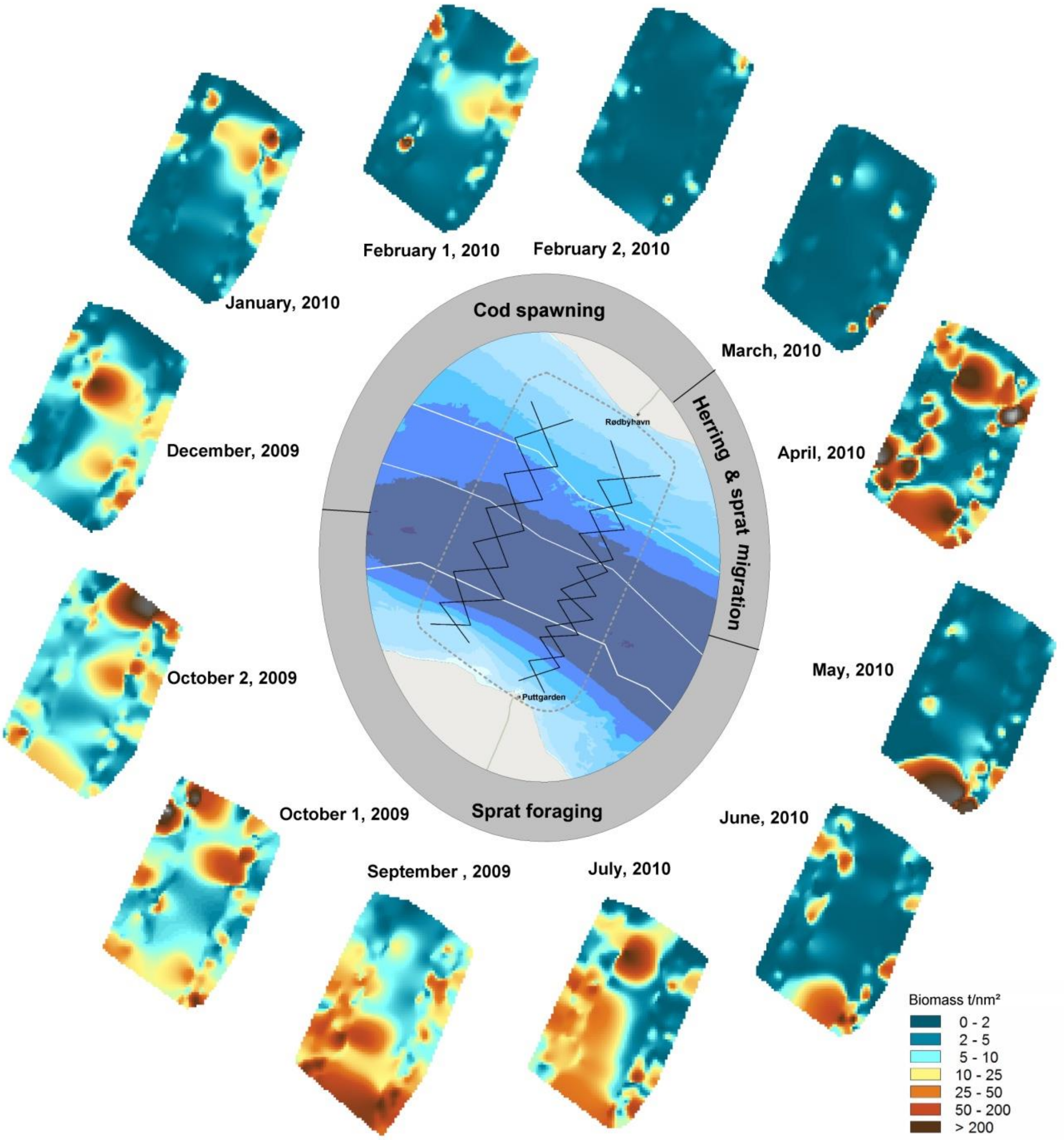


Figure 4.36: The spatial distribution of pelagic fish around the expected alignment corridor throughout the season, and biological occurrences that may influence the species composition and abundance in the pelagic community.

The trawl data may be used to assess the seasonal changes in species composition and they are supported by fishery statistics. The trawl data indicate that whiting are present in high relative abundances throughout the year (Figure 4.25). Cod are nearly absent during the summer but contribute with relatively high densities during winter.

Using the trawl data to calculate the relative biomasses of pelagic fish induces some biases. The trawl results from the first periodic survey are evaluated to have the highest comparability because the pelagic trawl sampled exactly the same water column that the echo sounder was sweeping. The number weighted Target Strength (TS) calculated from this survey is expected to be a good estimate of the mean TS of the pelagic fish community during the survey, and thus of the density biomass estimate. However, some size selectivity may occur because larger individuals have a higher capability to escape the trawl net. To compare both the continuous and periodic surveys to other surveys, S_A values may be the best parameter as this is pure physics.

Comparing the estimated biomass densities from the ”SOLEA” surveys with the periodic September-October and the continuous October surveys seems reasonable. Comparison was made to the ICES sub-squares 38G0, 38G1 and 37G1 for the 38 kHz system that was also used in the ”SOLEA” surveys (ICES, 2008a; ICES, 2009a and ICES, 2010a). The average S_A value from the periodic survey in September-October 2009 was very similar to the average values recorded at the ”SOLEA” surveys in 2008 and 2009 (Table 4.6). The S_A values from the two continuous surveys are comparable to the values found for the ICES sub-square 38G1. The S_A value from the early October survey was lower and the S_A value from the late October survey was higher than the values from the ”SOLEA” survey in 2009. However a mean of the two continuous surveys was 37.3 (m^2/nm^2), only slightly higher that the value in the ”SOLEA” estimate from ICES sub-square 38G1.

Table 4.6: Comparison of S_A values from the surveys with data from the ”SOLEA” survey (ICES, 2008a; ICES, 2009a and ICES, 2010a). * Periodic survey partly covering all three ICES sub-squares.

Survey	*37G1*	*38G0*	*38G1*
	Mean S_A (m^2/nm^2)	Mean S_A (m^2/nm^2)	Mean S_A (m^2/nm^2)
September-October 2009, 38 kHz		72.6*	
October 1 2009, 38 kHz	-	-	25.4
October 2 2009, 38 kHz	-	-	49.2
”SOLEA”, 2009, 38 kHz	113.3	71.8	30.4
”SOLEA”, 2008, 38 kHz	84.2	49.8	96.2
”SOLEA”, 2007, 38 kHz	164.2	46.7	55.5

Comparing the values in the ICES sub-division 22, covering the Fehmarnbelt area, with values from other sub-divisions in the Baltic Sea in the years 2007-2009 shows a general pattern of low densities of pelagic fish in sub-division 22 (Figure 4.37). Highest densities through all three years were found in the Øresund within sub-division 23. Especially in 2007 and 2008 extreme high S_A was found in sub-square 40G2 showing values of 1,382.1 m^2/nm^2 and 806.1 m^2/nm^2, respectively (ICES, 2008d; ICES, 2009b and ICES, 2008a). In 2009 the S_A values in Øresund were more moderate with a mean of 395 m^2/nm^2 (Figure 4.37). This year sub-division 24 also showed high values with a mean S_A of 233 m^2/nm^2.

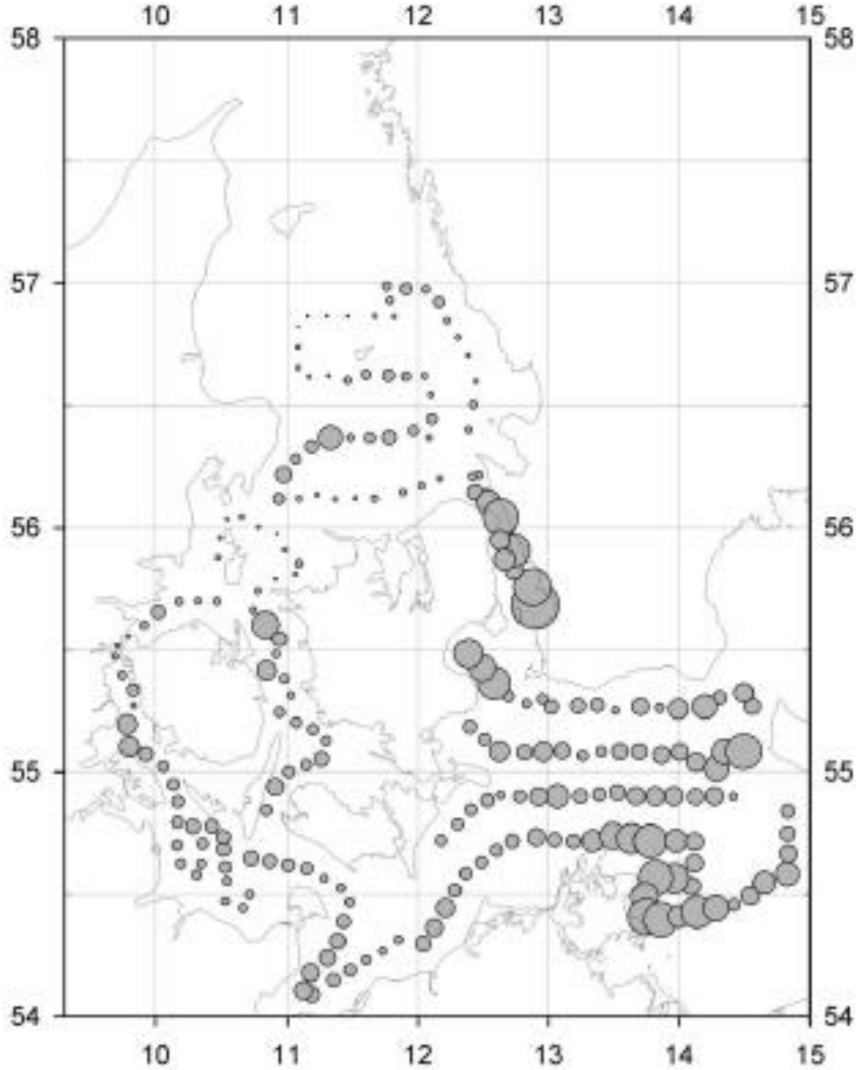


Figure 4.37: Distribution of S_A values obtained during the acoustic survey of RV SOLEA in October 2009. Source: ICES (2010a).

The estimated density values found at the present surveys are considerably lower that most mean values of herring found in the Øresund by Nielsen et al. (2001) during a 6 year period from 1993-1998 (6.92 - 733.89 tonnes nm^{-2}). In other areas dominated by sprat, such as Lough Hyne (Ireland), a mean density of 61.07 tonnes nm^{-2} has been found (Knudsen et al., 2009).

The pelagic fish are migrating within or through the Fehmarnbelt. It is difficult to map specific migration patterns from the hydro-acoustic surveys. However, based on the results from the hydro-acoustic surveys it is assumed that the distribution pattern of the pelagic fish community, primarily clupeids, in April-May partly reflects the beginning of the post-spawning migration to feeding areas outside the Fehmarnbelt.

The low number of herring caught in spring 2010, may indicate that the Rügen herring after spawning migrates back through Øresund to the feeding grounds in Kattegat and the southwestern part of the North Sea.

4.2.3 Pelagic fish baseline conclusion

The baseline results regarding the pelagic fish community in the Fehmarnbelt area may be summarized as follows:

- The pelagic fish community in the Fehmarnbelt includes at least 10 species. Of these pelagic species such as herring and sprat and the semi-pelagic whiting and cod were found to be most abundant. Occasionally high numbers of Atlantic horse mackerel were recorded. The pelagic fish community in the Fehmarnbelt varies greatly throughout the year.

- The densities of pelagic fish found in the Fehmarnbelt are lower than the densities found in other areas in the Baltic Sea, including Øresund. However, the density values from the October surveys are comparable to the S_A values from the SOLEA surveys in the Fehmarnbelt area.

- Cod spawn in Fehmarnbelt in December-March. The continuous surveys, covering the area around the proposed alignment corridor, showed low densities of pelagic fish during this period, compared to other times of the year. The February-March periodic survey also showed low densities in this area, whereas higher densities were recorded both east and west of this corridor. This indicates that the area close to the proposed alignment is of only minor importance as a spawning ground for cod compared to other areas in the Fehmarnbelt.

It is not possible to track the migration of pelagic species, including the Rügen herring, from the results. It seems however unlikely that the majority of herring migrates through the Fehmarnbelt to the feeding areas in the Skagerrak and Kattegat. This is because all estimated biomasses in spring were low compared to Øresund combined with low proportions of herring in the trawl catches in April-May 2009 and in spring 2010 (see section 4.4.6.2 for further details).

4.3 Cod

4.3.1 General background

Atlantic cod (*Gadus morhua*) is a marine, cold water and semi-pelagic species. Two different cod stocks are found in the Baltic Sea, the western cod stock, subspecies *Gadus morhua morhua* occurring west of Bornholm, including the Belt Sea and Øresund, and the eastern stock *Gadus morhua callarias* occurring in the Baltic proper (east of Bornholm).

Cod stocks in the Baltic Sea live on the limit of their ecologically distribution, where the salinity decreases from west to east, and the water in the eastern and northern parts (the Bothnian Sea and the Gulf of Finland) is brackish. This is one of the reasons for the reduced growth of cod in the Baltic Sea, where cod from the western stock grow faster than cod from the eastern stock.

The large horizontal salinity gradient between the Baltic Sea and the North Atlantic Ocean, through the Belt Sea, Kattegat and the North Sea, has led to genetic differentiation in cod (Nielsen et al., 2003). Reproduction of Baltic cod stocks is also adapted physiologically to the lower salinity, especially in the eastern cod stock. Cod eggs are pelagic and in order to obtain neutral buoyancy and avoid sinking into deeper oxygen-depleted layers, eggs from the eastern Baltic stock are larger than eggs from the western stock.

For management use a boundary of the distribution areas of the two stocks was defined along the 15°E latitude, which runs through the island of Bornholm (Figure 4.38). For the management of the stocks and the setting of the total allowable catches (TACs) it is important to clearly identify the degree of stock transfer and mixing between areas (Hammer and Zimmermann, 2004).

The 15°E latitude is also the border between the ICES statistical subdivisions 24 and 25 in the Baltic Sea (Figure 4.38). However, it is scientifically not clear where the true biological border between the two stocks is situated and how much and under which conditions the two stocks are mixing. The Arkona Sea (ICES Subdivision 24) is described as the transition zone between the two stocks and is a known spawning area of both stocks.

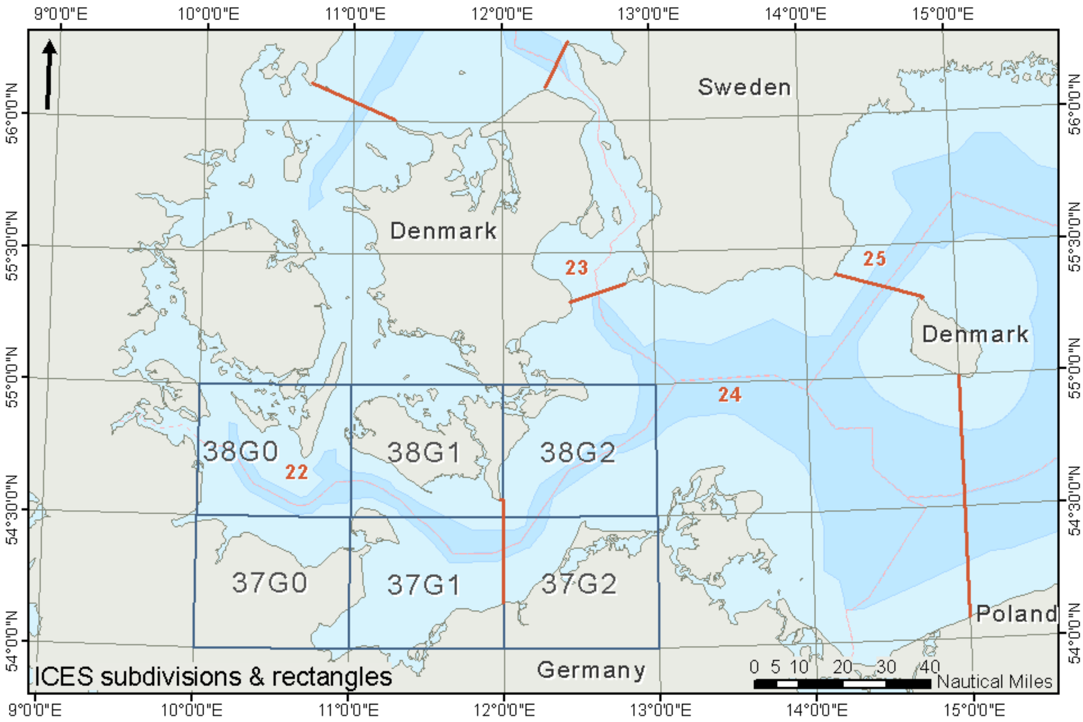


Figure 4.38: Map of the western Baltic Sea including the outlines of ICES subdivisions (SD) 22, 23 and 24 and the near field (ICES 37G1 and 38G1) and regional field (ICES 37G0, 38G0, 37G2 and 38G2) of Fehmarnbelt.

Cod is subject to an intensive commercial fishery in the Baltic Sea including the Fehmarnbelt area (FeBEC, 2013), and management plans for the cod stocks in the Baltic Sea and the fisheries exploiting those stocks are established by EU with the aim to reduce the fishing mortality by 10% each year (Council Regulation No. 1098/2007).

The cod stock in the western Baltic (ICES subdivisions 22-24) is a main component of the ecosystem in the Baltic Sea and has enormous social and economic relevance in the western Baltic States (FeBEC, 2011c). It is however still in danger of having reduced reproduction capacity, due to a low spawning stock biomass (SSB).

The SSB of cod in the western Baltic Sea has declined from 42,000 tonnes in 1994 to 21,000 tonnes in 2008 and the recruitment shows a similarly clear downward trend (Figure 4.39). With considerable variations the recruitment decreased continuously since the beginning of the 1970s. The two latest year classes, 2008 and 2009, have been close to average of the last ten years, but the year classes 2004 to 2007 were weak. Considering the entire time-series, it is evident that since the late 1990s only year classes below average occurred.

However, the natural variability of the abundance of fish stocks is the result of a variety of factors, and the recruitment (year-class strength) as such seems to be less dependent on the spawning stock biomass but more on the prevailing salinity and oxygen values as well as feeding conditions (food availability of suitable prey organisms during the larval phase).

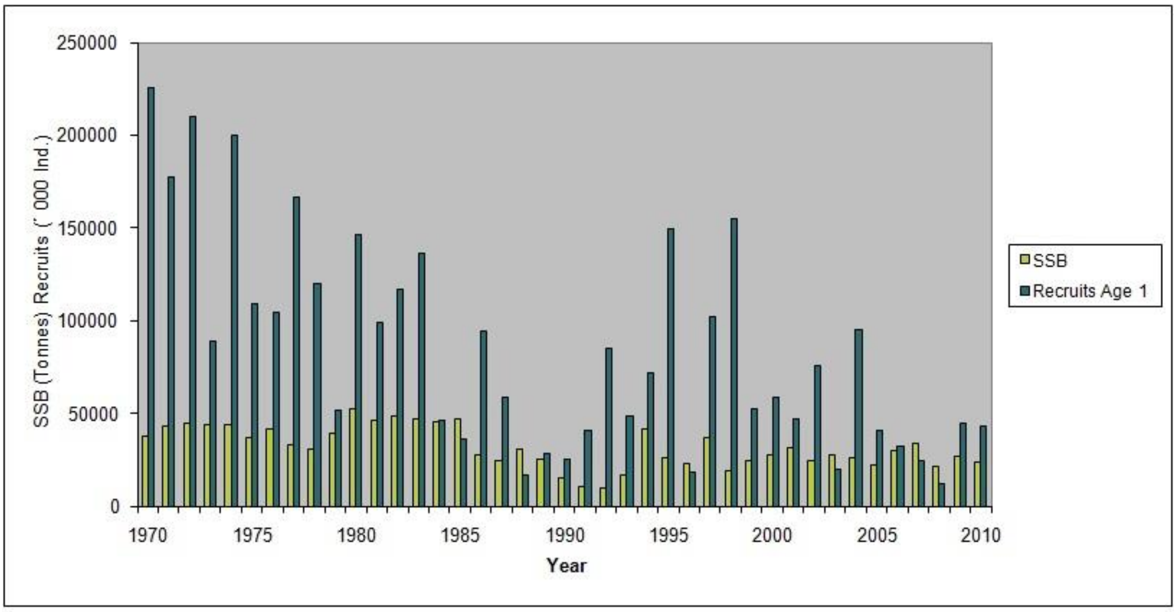


Figure 4.39: Spawning stock biomass (SSB) in tonnes of cod in the western Baltic Sea and the number of recruits age group 1 (ICES, 2010a).

Compared to the eastern stock defined as belonging to ICES Subdivision 25-32, the spawning stock biomass of the western cod stock is considerably lower. However, landings of cod in the western Baltic are relatively high, indicating a movement of adult cod from the eastern Baltic to the western stock.

At present the distribution of cod in the eastern Baltic Sea is limited to subdivision 25 (Bornholm Sea), SD 26 and the southern part of SD 28 (Gotland Sea). Successful reproduction has not occured in the Gdansk and Gotland Deeps during the last decades and is now limited to the Bornholm Basin. The reproductive failure in the Gotland Deep (SD 28) due to a decrease in salinity and oxygen has reduced recruitment to the northern distribution area (SD 28-32) (ICES, 2010a). The recruitment of the eastern stock is more driven by environmental factors like salinity, oxygen supply and food availability than the western stock.

The drift of early life stages of Baltic cod is almost exclusively in eastward direction, but the size of the drift and the impact on the stock structure are still not well known. Furthermore, tagging studies from the Baltic Sea have shown that migration of adult cod is highly individual, ranging from resident specimens to specimens moving shorter or longer distances in various directions.These factors indicates that a considerable mixing of cod stocks occurs in the Baltic Sea, especially in the Arkona Sea because both stocks use this as a spawning area. The time of peak spawning differs between the two stocks (temporal separation).

In the following table the environmental settings and existing pressures that can be of importance for cod are listed.

Table 4.7: Environmental settings and existing pressures of significance to cod in the Fehmarnbelt area.

Basic environmental setting	Variable hydrodynamics exposed shoreline	Fairly stable environmental conditions with good access to food enhance the recruitment of cod (Bleil et al., 2009). The selection of their spawning grounds is based upon certain criteria (Hammer et al., 2007). Depending parameters are: Oxygen content, salinity and current which drift their eggs and larvae to nursery grounds (Voss et al., 1999).
	Stratification	Cod of the western Baltic cod stock spawns from February till May in the area of Fehmarnbelt. Therefore, the drift of cod eggs are possibly affected by stratification as well as cod larvae and juveniles individuals. Due to the well-mixed waters in Fehmarnbelt, oxygen depletion rarely occurs.
	Salinity	Cod eggs of the western cod stock need salinities between 15 and 22 psu for development (Nissling and Westin, 1997). Therefore, the salinity level is an important criterion for cod recruitment. Due to the good exchange of surface and bottom water in the area of Fehmarnbelt, salinity is not a limiting factor for spawning of western Baltic cod.
Food competitors	Interspecific	Juvenile life stages feeds on the same kind of benthic prey like flatfish, whiting and other small fish (small crustacean like mysids (*Neomysis sp*.), isopods, amphipods) (Aro, 2000). This leads to interspecific food competition with e.g. turbot, brill and whiting.
	Birds / Mammals	Adult cod feeds mainly on fish like sprat and herring which is also utilized as prey for mammals (e.g. seals and harbor porpoise) and birds (e.g. cormorant) (Andersen et al., 2007).
	Crustacean	Crustacean like the brown shrimp (*Crangon crangon*) and the common shore crab (*Carcinus marnas*) also occur in the same habitat types and show diet niche overlapping in regard to juvenile cod.
Predators	Clupeids / Flatfish	Clupeids are feeding on pelagic eggs and larvae of cod (Aro, 2000). Flatfish are mainly feeding on benthic organisms during their early life stages. As they mature, they also feed on fish. Especially brill and turbot are important predators of small fish, including juvenile cod.
	Birds / Mammals	Several birds (e.g. common guillemot, great crested grebe and razor-billed auk) and mammals (e.g. seals and harbor porpoise) also feed on small fish in coastal waters (Mendel et al., 2008) (Andersen et al., 2007).
Fishery		Mortality from fisheries of cod in the western Baltic sea is very high. In the mid-80s the stock collapsed. Therefore, several protective measures were introduced in the 1990s. Due to this the western Baltic cod stock recovered. The registered catch-weights in 2006 were almost as high as in times before the stock collapsed (FeBEC, 2013; ICES, 2010c).
Eutrophication	Nutrient enrichment	Especially fish communities and young fish in coastal areas (including cod) are affected by the increased nutrient input from anthropogenic contributors (Thiel et al. 1996).
	Decreased water clarity	A reduction in water clarity has generally reduced macrophyte vegetation, and hence reduced potential habitat for especially young cod (Warren et al., 2010).
Invasive species		The occurrence of invasive species affects the fish communities in the coastal waters of the Baltic sea. For example the jellyfish *Mnemiopsis leidyi* has the potential to affects the success of fish species in Fehmarnbelt.

4.3.2 Baseline approach

Baseline studies focused on the western Baltic cod (*Gadus m. morhua*), which is the cod stock present in the Fehmarnbelt area. The objectives of the baseline studies were to identify:

- Spawning areas
- Spawning period
- Nursery areas
- Migration

Different methods were used to investigate these issues (see chapter 3 for a detailed description of the methods).

Eggs and larvae surveys were carried out from October 2008 to March 2010 and samples were collected during 12 surveys. Subsequently, species were identified and the developmental stage of eggs and larvae was determined. A hydrodynamic back-tracking model was developed in order to identify possible spawning areas.

Gonads of adult cod were collected from local fishermen during April-August 2009 and during January/February 2010 and from trawl samples from the hydroacoustic surveys (see section 3). The maturity stages were determined in order to identify temporal patterns of spawning cod as well as the spatial distribution of spawning cod.

During the habitat mapping surveys in 2009 and 2010 potential nursery areas in Danish and German coastal and shallow waters were investigated by catches from fyke nets, beach seine nets and young-of-the-year trawl (YOY-trawl).

With the objective of identifying migration patterns of western Baltic cod, a total of 338 individuals were tagged and released in the spawning area in Fehmarnbelt in February and March 2010. 295 cod were tagged with T-bar tags and 43 with Data Storage Tags (DST).

4.3.3 Spawning

Cod spawns in open waters and the eggs and larvae are pelagic. The species is a batch spawner and spawns 17-19 batches during a spawning period of approximately two months (Kjesbu, 1989). Main spawning sites in the western Baltic Sea are the deeper areas below the 20 m depth contour in the central parts of the Kiel Bight, Fehmarnbelt and Mecklenburg Bight (Figure 4.40). The importance of the Mecklenburg Bight as a spawning ground for cod was previously underestimated or has increased during recent years, but also the Lübecker Bight and Fehmarnbelt seem to be important as spawning grounds. In these areas the 20 m depth contour is close to the coast. Another important spawning area is the deeper parts (below 40 m) in the Arkona Sea, which is a known mixing area of the two stocks. Especially from this area, larvae from the western stock are prone to drift into the eastern Baltic Sea and to mix with the recruits of the eastern Baltic stock (Bleil et al., 2009).

Although the western cod stock is smaller than the eastern cod stock, the spawning areas in the western Baltic, including Mecklenburger Bight and Fehmarnbelt, seem also to be important for recruitment to the eastern stock in the entire Baltic Sea due to the pronounced eastward drift of early life stages (Bleil and Oeberst, 2007; Hinrichsen et al., 2009; Kraus et al., 2009).

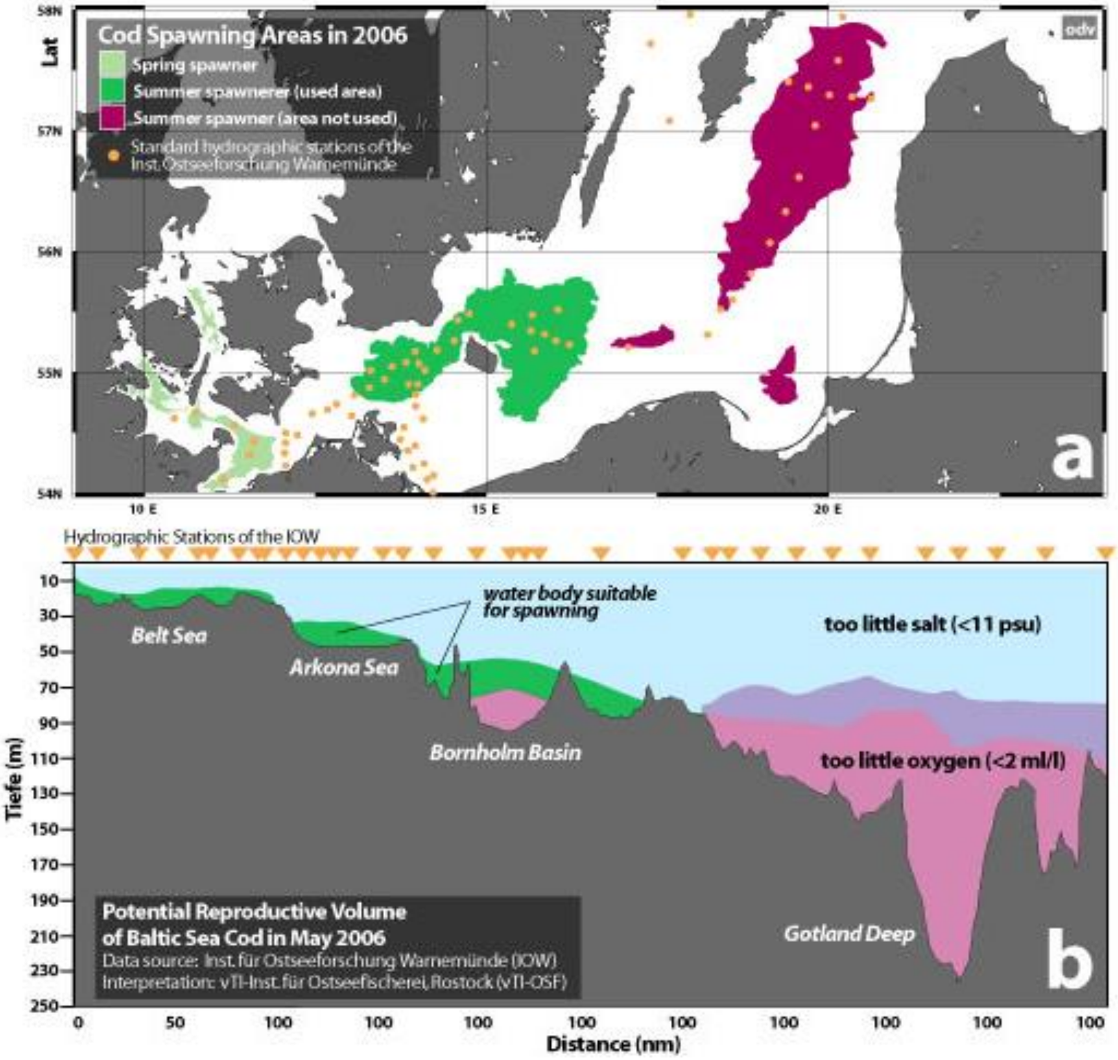


Figure 4.40: Main spawning areas of cod (a) and the potential reproductive volume in the Baltic Sea (b) Source: Hammer et al. (2007).

The timing of spawning differs between the two cod stocks, separating them reproductively. The spawning period for the western stock is from February to May with a peak in March-April. The eastern stock spawns during the period June to September with a peak in June-August (Bleil et al. 2009). Some differences between the two stocks are summarized in Table 4.8.

Table 4.8: An overview of known differences between western and eastern Baltic cod.

Western Baltic cod	**Eastern Baltic cod**
Main spawning mid February to May	Main spawning June to September
Minimum salinity 15 PSU	Minimum salinity 11 PSU
Main spawning areas Kiel Bight, Fehmarnbelt and Mecklenburger Bight	Main spawning area in the Bornholm Basin
Stock declined severely since 1970s	Stock declined severely since 1970s
Total allowed catch13,700 tonnes in 2009	Total allowed catch 48,600 tonnes in 2009
Spawning stock biomass 20,000 tonnes in 2009	Spawning stock biomass 100,000 tonnes in 2009
Non-existing buffer capacity of the parental stock makes the stock vulnerable.	

Spawning is restricted to the areas where salinities are sufficiently high to allow successful fertilisation (Westin and Nissling, 1991) and to attain neutral buoyancy of eggs (Vallin and Nissling, 2000). Furthermore, an oxygen concentration of at least 2 ml/l is required for successful egg development (Wieland et al., 1994) see Figure 4.40b.

Differences in salinity requirements for successful spawning exist between the two stocks. Activation of the spermatozoa occurs at ≥11 to 12 PSU for eastern Baltic cod and at ≥15 to 16 PSU for western Baltic cod, and neutral egg buoyancy is obtained at 14.5 ± 1.2 PSU and at 20 to 22 PSU, respectively (Nissling and Westin, 1997). Hence, stock interactions may be possible in the western spawning areas where salinity requirements for both stocks are fulfilled but not in the eastern spawning areas where the low salinity prevents successful spawning of western Baltic cod.

The most important climatic and hydrographical influences on cod population dynamics are related to shifts in salinity and oxygen concentrations (ICES, 2010b). Salinity and oxygen content in the Baltic Sea depend on saltwater inflow from the Kattegat and North Sea via the Belt Sea and to a minor extent also via Øresund (Matthäus and Schinke, 1994). Such inflows are rather irregular but between 1897 and 1979 the frequency of these inflows was approximately once per year. Since then the frequency has decreased to approximately once per decade (Schinke and Matthäus, 1998). The limited saltwater inflow from the North Sea has reduced the reproductive zone of cod in the area east of Bornholm, and during the last decades cod reproduction has only been successful in the Bornholm Basin and the Slupsk Furrow (ICES Subdivision 25).

Apart from the absolute size of the parental stock, a balanced age structure of the spawning stock biomass is in general important for the reproduction of cod. It is of particular importance that the cod stocks have a sufficiently high proportion of older specimens (Marteinsdottir and Thorarinsson, 1998) since the quality of spawned eggs of young females are generally lower than those of older females. Thus, the survival rate of eggs of young female cod is generally lower, especially in the Baltic (Vallin and Nissling, 2000; Trippel et al., 2005). The eggs of young females are not only smaller but also the hatched larvae are smaller and have a lower survival rate. Furthermore, the fecundity increases with size. The stock of the western Baltic cod consists presently mainly of age group 2 and 3, which start spawning at age 2 at a length of 30 - 35 cm (Figure 4.41 and Figure 4.42).

Figure 4.41: Female cod in the western Baltic Sea. In the front a cod of the prevailing size classes (age groups II-III), which dominate the spawning stock biomass, and behind this a rare old specimen. © M. Bleil, vTI (2003).

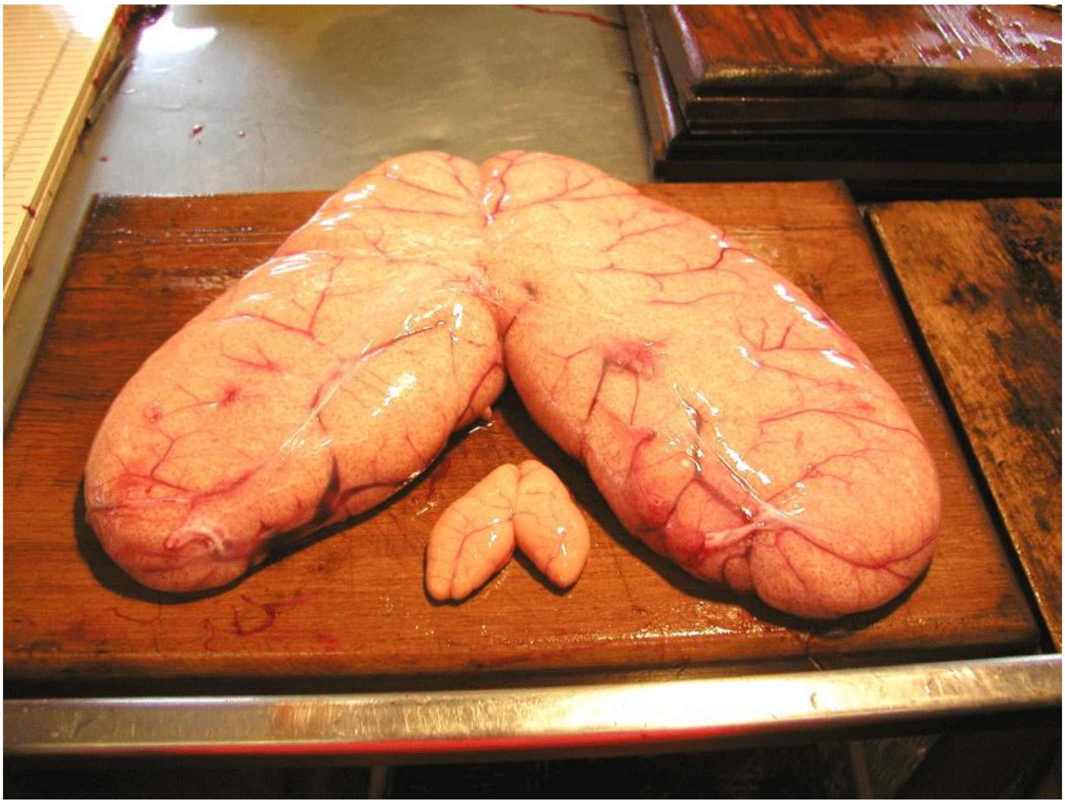


Figure 4.42: The gonads of the cod in Figure 4.41. © M. Bleil, vTI (2003).

4.3.3.1 Results of the baseline studies on cod spawning

The baseline studies identified spawning grounds and spawning periods of cod in Fehmarnbelt based on investigations of the maturity of cod and on investigations on the abundance of cod eggs and larvae.

During the investigations in 2009 and 2010 cod was mainly caught from December to March, and during this period the majority of the caught cod were identified as spawning (Figure 4.43). In the same period, the relative weight of gonads (GSI) peaked and remained at a high level (Figure 4.44). A few spawning individuals were caught in April and May.

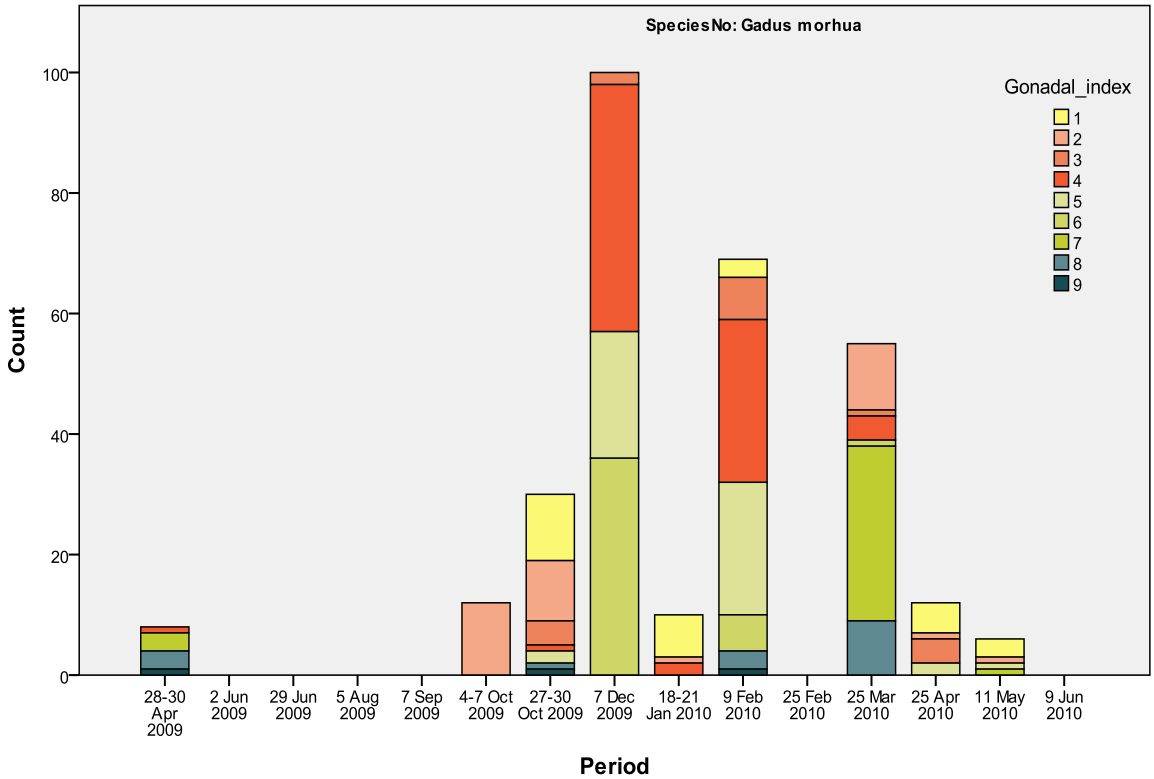


Figure 4.43: Maturity index of cod (both sexes) from April 2009 to June 2010. 1 = juvenile, 2 = preparation, 3 = ripening 1, 4 = ripening 2, 5 = initiation of spawning, 6 = main spawning period, 7 = cessation of spawning, 8= regeneration1, 9 = regeneration 2, 10 = degeneration.

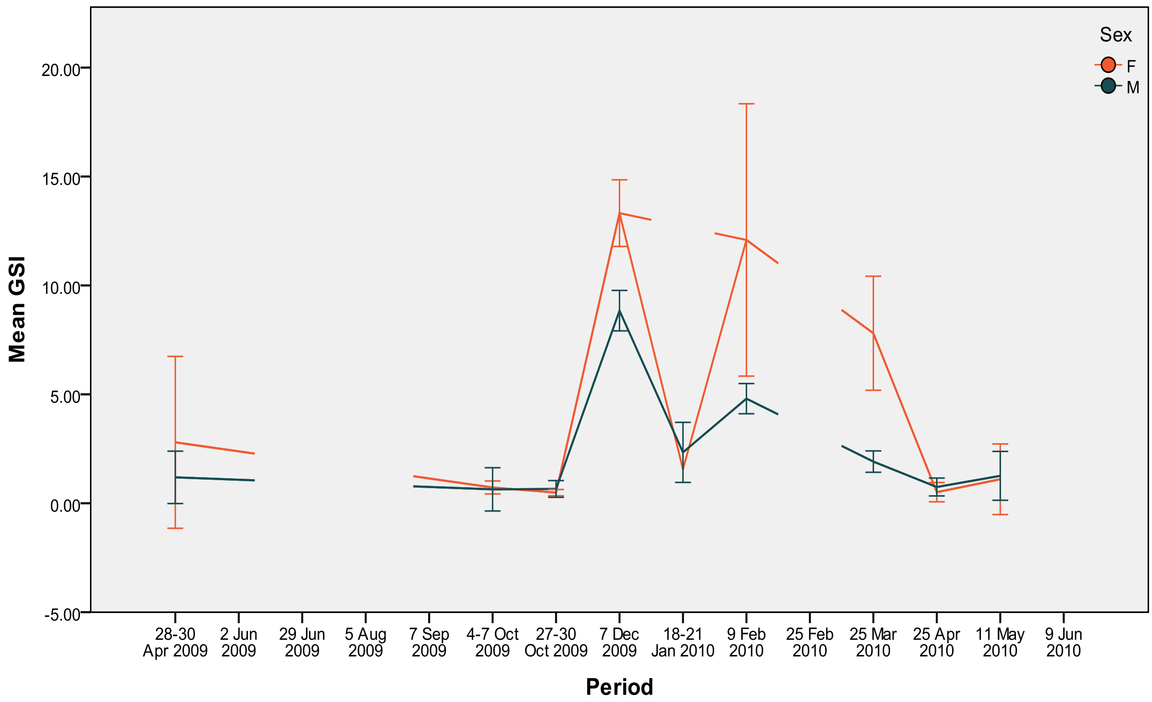


Figure 4.44: Mean gonadosomatic index (GSI = gonadal wet weight as a percentage of total wet weight) of cod. Female - red, Male - blue. Errorbars: ± 2 SE.

Data on the quality of roe sold by a local fisherman fishing in the central part of Fehmarnbelt at the ground "Øjet" during the spawning seasons 2008/2009 and 2009/2010 showed that roe quality B (with hydrated oocytes, corresponding to the main spawning stage) was sold from December in the 2008/2009 season and from January in the 2009/2010 season (Figure 4.45 and Figure 4.46). In both seasons quality B roe was sold at least until the end of March. This registration of roe quality is routinely performed by fishermen, as quality B roe is sold at a reduced price. The drop in GSI in January is due to low number (<10) of cod caught in this month.

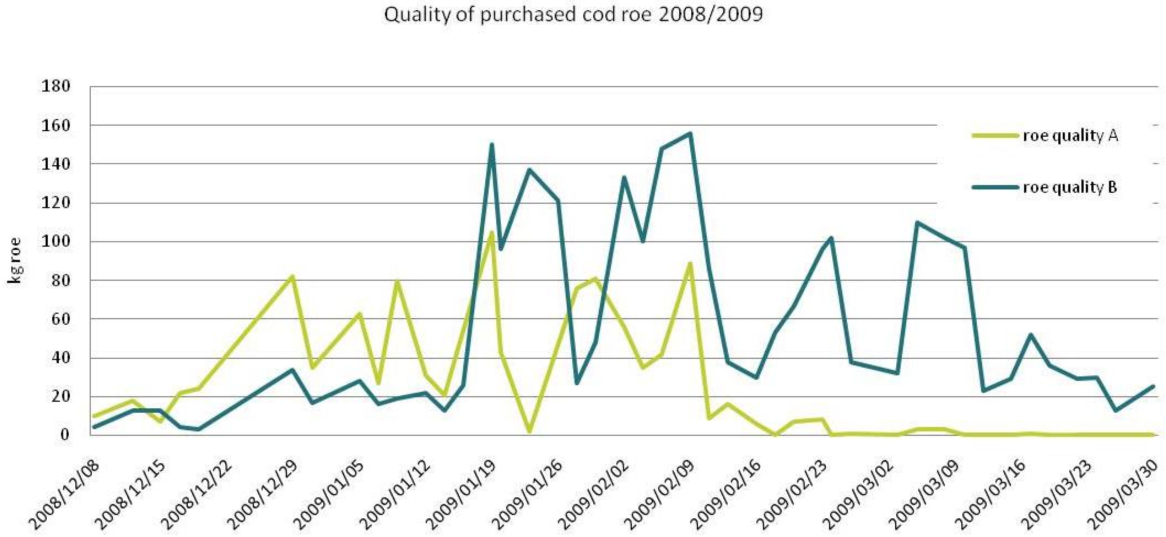


Figure 4.45: Quality of cod roe sold by a fisherman during winter 2008/2009. All cod were caught in Fehmarnbelt. Quality A is roe without presence of hydrated oocytes. Quality B is roe with hydrated oocytes, corresponding to the roe found in maturity stage 6 – main spawning period.

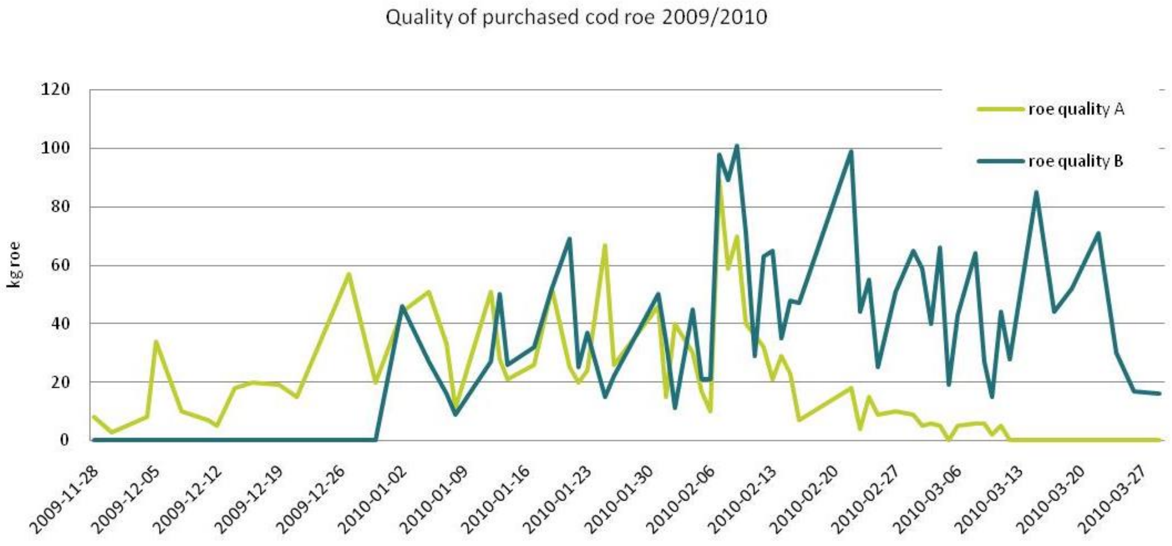


Figure 4.46: Quality of cod roe sold by a fisherman during winter 2009/2010. All cod were caught in Fehmarnbelt. Quality A is roe without presence of hydrated oocytes. Quality B is roe with hydrated oocytes, corresponding to the roe found in maturity stage 6 – main spawning period.

The investigations of maturity index and gonadosomatic index as well as the quality of roe sold by a local fisherman indicate that the main spawning season of cod in Fehmarnbelt is December to March. Previous studies have identified peak spawning in Kiel Bay in February-March and in Mecklenburger Bight in March-April (Bleil et al., 2009).

4.3.4 Eggs and larvae

Cod eggs have an incubation time of about 14 days at ambient temperatures of 4-6°C (Wieland et al., 1994). During this time the eggs drift freely in the water column. The depth at which they float depends on the salinity and the size of the eggs (Wlodarczyk and Horbowa, 1997). After hatch the larvae rise to the surface to fill the swim bladder with air. Thereafter they remain in the water column at variable depths and prey on plankton of suitable size. As soon as they have reached a length of 3-6 cm the larvae undergo a metamorphosis and acquire the proportions and pigmentation of the adults. During this period the fish drifts towards the shores and the juveniles seek shelter in the dense algal vegetation of the sub-littoral zone. After 3 months, with increasing size, the juveniles leave the shelter of the sub-littoral macroalgae vegetation and enter the deeper sub-littoral zones, i.e. 10 to 40 m in the western Baltic, depending on the bottom structure and the habitat.

During the eggs and larvae surveys from March 2009 to March 2010, cod eggs were mainly present during February and March but occurred in the catches until August (Figure 4.47). A great majority of the cod eggs were found in the deep waters (>10 m) of Fehmarnbelt, especially off the northern coast of Fehmarn and in the deep waters between Langeland, Lolland and Fehmarn (Figure 4.48). These results correspond well with previous investigations of the temporal and spatial distribution of western Baltic cod.

A quality assurance of the species identification of the eggs was performed by gelelectrophoretic analysis. Gelelectrophoretic analysis makes separation between eggs from cod and whiting possible. All gadoid eggs collected from March to August 2009, which were analysed, were identified as cod eggs.

The laboratory experiments on egg buoyancy showed that the density of early stage cod eggs varied between 1.014 – 1.016 g/cm^3. See FeBEC (2010b) and FeBEC (2011f) for further results from the buoyancy experiments.

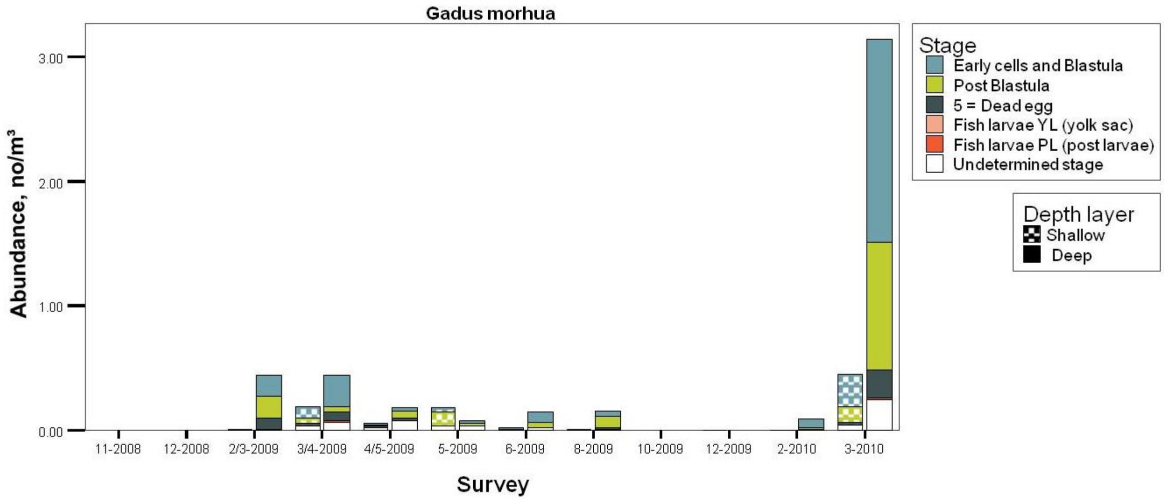


Figure 4.47: Average density (mean number/m^3) of different stages of cod egg and larvae in 12 surveys from October 2008 to March 2010.

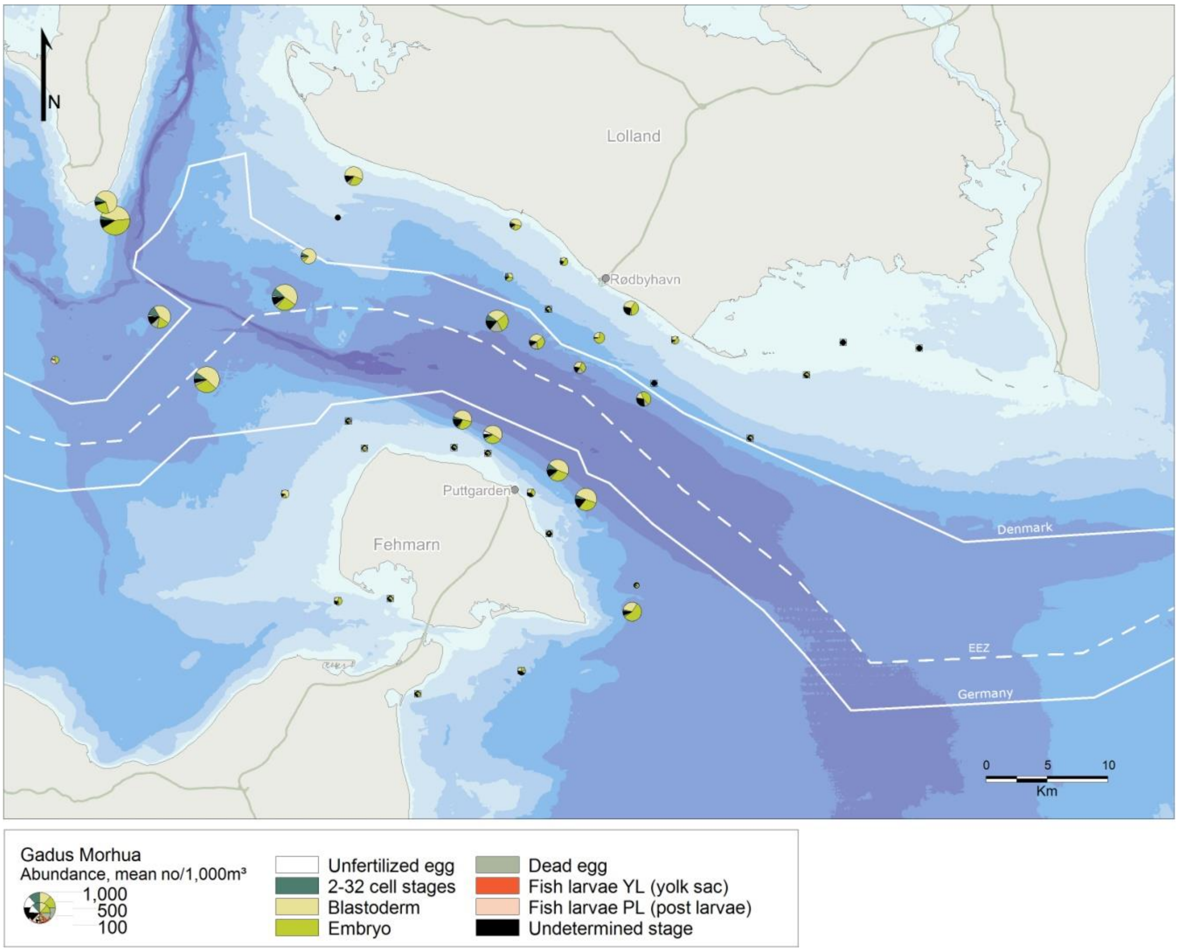


Figure 4.48: Average abundance of eggs and larvae of cod in Fehmarnbelt October 2008 – March 2010.

The average egg density found in Fehmarnbelt in March 2010 was 3 cod eggs per m^3, corresponding to approximately 25 eggs per m^2, which is only slightly lower than the density recorded during the peak of the spawning seasons in the Bornholm Basin 1969-1996 (Wieland et al., 2000).

The density of cod eggs and larvae does not necessarily reflect the production of cod eggs in Fehmarnbelt. The daily egg production was calculated from the density of various cod egg stages combined with a calculated mortality (FeBEC, 2011b) and the total annual cod egg production was estimated at $3.973*10^{11}$ cod eggs (Table 4.9).

Table 4.9: Estimated annual egg production in the whole sampling area of Fehmarnbelt from March 2009 to March 2010.

COD	Annual production (eggs per m^3)	2.5 and 97.5 quantiles	Estimated volume of sampling area (m^3)	Eggs per year in the sampling area
Shallow water (depth <10 m)	2.9	$0.7\text{-}2*10^6$	$20.5*10^9$	$0.594*10^{11}$
Deep water (depth > 10 m)	21.8	$6.3\text{-}2*10^{12}$	$15.5*10^9$	$3.379*10^{11}$
Total sampling area			$36*10^9$	$3.973*10^{11}$

The fecundity of female cod is size and age dependent (Kosior and Strzyzewska, 1979; Kjesbu et al., 1996; Kraus, 1997; Marteinsdottir and Steinarsson, 1998). However, based on an estimated average fecundity of a female cod in the Baltic Sea of 978 oocytes per g female body weight (Bleil and Oberst, 2005) it was estimated that a total of approximately 400 tonnes of female cod spawns in the Fehmarnbelt area.

In relation to the spawning stock biomass (SSB) of the entire western Baltic Sea (ICES areas 22, 23 and 24) of approximately 20,000 tonnes, it is estimated, under the assumptions that all eggs spawned are viable and that the body weight of male and female cod in the area are similar, that at least 4% of the SSB in the entire western Baltic Sea spawns in the area of Fehmarnbelt. Most likely not all eggs spawned are viable, in which case the proportion spawning in the Fehmarnbelt area will be higher.

The spawning grounds of cod in the Fehmarnbelt area were identified by back-tracking of the eggs (see section 3.4.5.4).

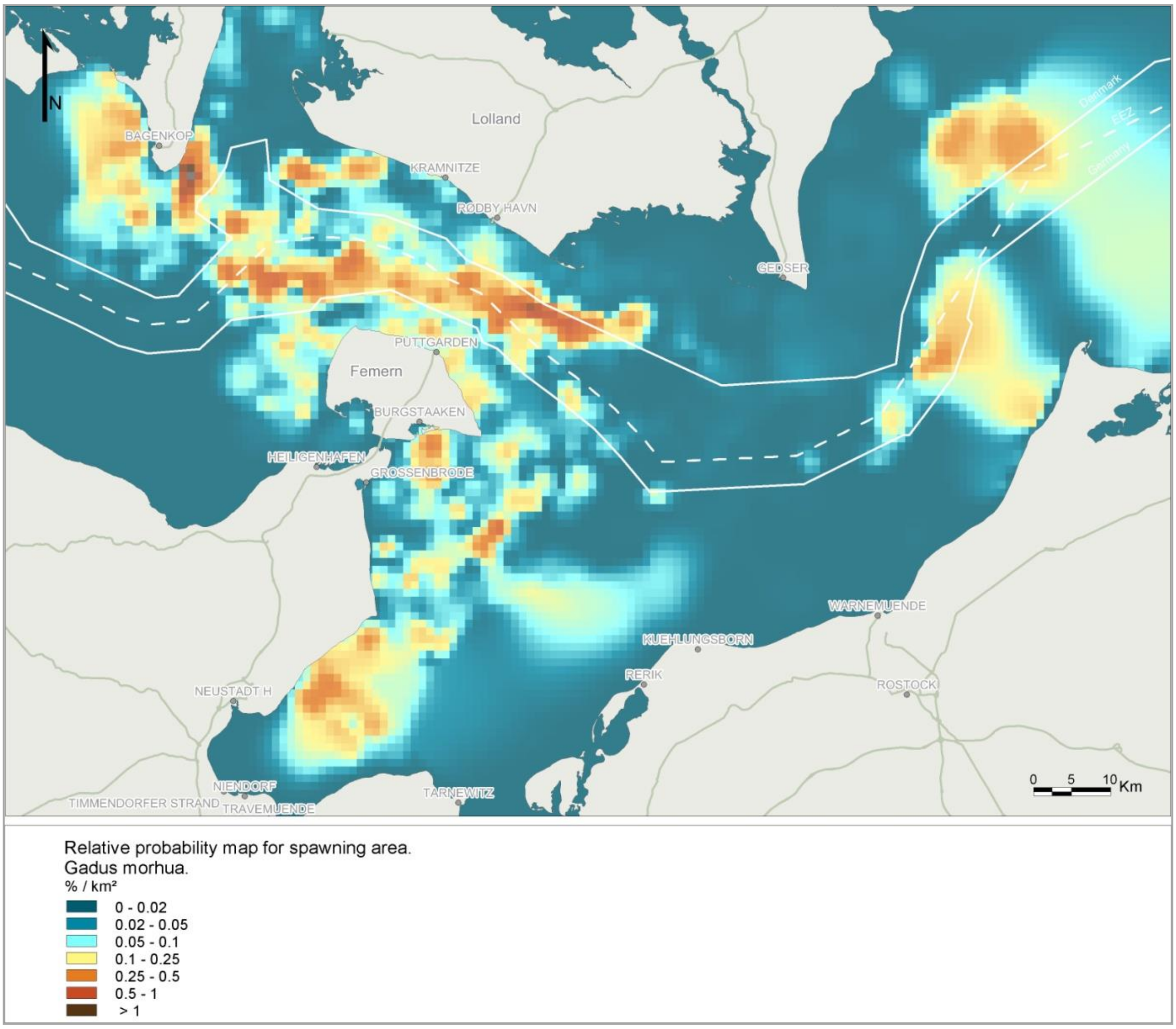


Figure 4.49: Back-tracked spawning grounds of cod (*Gadus morhua*) in Fehmarnbelt March 2009 until March 2010.

Potential hotspots of cod spawning in Fehmarnbelt (Figure 4.49) were found in the deeper parts of Fehmarnbelt and in the area between Fehmarn and Langeland. Besides the potential hotspots, cod spawning was found in the Belt Sea near Langeland, Mecklenburger Bight and western part of the Arkona Bassin, which correspond well with the spawning ground identifications of e.g. Bleil and Oeberst (2000). The identification of cod spawning corresponds with the catch of adult cod in deep central parts of Fehmarnbelt and north and east of Fehmarn.

The prevailing currents have a strong influence on the fate of the eggs and larvae and the retention of these in the spawning areas (e.g. MacKenzie et al., 1996a; Hinrichsen et al., 2001b; Köster et al., 2005). The eggs and larvae are subject to the current patterns of their environment until they undergo the metamorphosis and convert from a pelagic to a semi-pelagic live. This pelagic phase can take up to two or three months.

The main surface current in the western Baltic Sea is directed towards west and north, transporting water with low salinity out of the Baltic into the Kattegat, i.e. it is the main drainage of the Baltic Sea. Thus, it might be assumed that a large proportion of pelagic eggs and larvae are moved out of the Baltic Sea into the Kattegat. However, Hinrichsen et al. (2001a) utilized a three-dimensional circulation model to show that eggs and larvae are subject to a wind-driven drift into the Baltic Sea at westerly winds. Such movements do not occur in the upper surface layer but rather in the deeper and more saline water layers where eggs and larvae occur. This trend was not only found for larvae from the Arkona Basin, but also for larvae from the different Belt regions, Kiel Bight and Mecklenburg Bight. From all these areas, eggs and larvae may drift through the Arkona Basin and into the central Baltic Sea (Hinrichsen et al., 2001a).

Wind-driven transport from the Øresund and the Great Belt into the Baltic Sea is only possible in situations of strong westerly winds, whereas eastward transport of eggs and larvae from Kiel Bight and Mecklenburg Bight occurs also at moderate westerly winds. In total the eastward transport may cause a significant drift of cod egges and larvae. Oeberst (2001) found that during the period 1993 – 2000, 10 to 90% of the one-year old cod caught by research vessels in the Bornholm Basin were spawned in the previous year in the Belt Sea.

Despite this large-scale drift most of the larvae of the western stock remain in subdivisions 22 and 24, i.e. in the western Baltic (Oeberst 2001). When the fish reach a size of >5 cm they become more mobile, are able to catch faster prey and to escape predators. At this stage of life the juvenile cod starts migrating along the coast and this migration is repeated throughout the adult life (Figure 4.50).

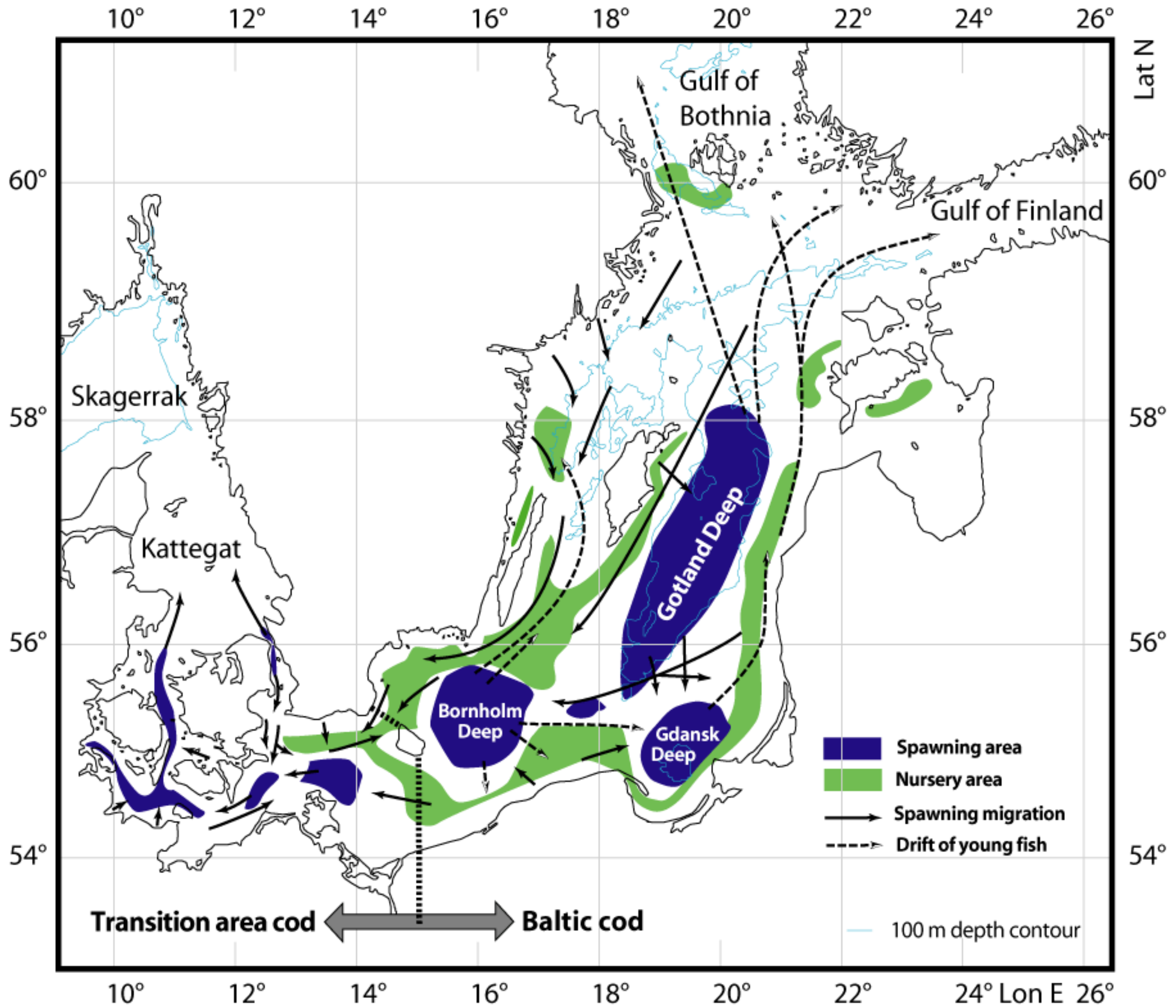


Figure 4.50: Spawning sites of cod in the western and central Baltic Sea, migration routes of adult cod and the known nursery areas in the Baltic Sea. Source: Aro (2000) modified from Bagge and Thurow (1993). Note: During the last decades the Gdansk Deep and the Gotland Basin have not been considered important spawning areas due to the decrease in salinity and oxygen following the lack of inflows from the North Sea.

During their pelagic life cod larvae are vulnerable to a number of predators, including different species of medusae, which may have a significant impact on the survival rate of larvae and thus on the recruitment of juvenile cod. Some medusae also have a potential impact on the fish larvae as competitors for prey. The invasive species *Mnemiopsis leidyi* has been suspected to be an important predator on early life stages of Baltic cod. However, a recent study demonstrated that the predation pressure of this invasive ctenophore was negligible and that it did not constitute any direct threat to the Baltic cod (Jaspers et al., 2010).

The most important and abundant predatory medusa found in the samples was *Mnemiopsis leidyi* (FeBEC, 2011b). This invasive medusa was most abundant in late autumn when it cleared up to 35% and 10% of the water volume per day in 2008 and 2009, respectively. During summer *Aurelia aurita* were present clearing up to 7% of the water volume per day. However, predation from medusae on cod egg and larvae was estimated to be less than 5% during the entire spawning season and thus of insignificant importance.

Also the availability of prey for the larvae has a significant impact on the recruitment success (Wieland et al., 1994). The main prey of first feeding larvae of cod is various copepod nauplii and copepodites (Last, 1978; Voss, 2002). Cod larvae are visual predators and thus day length (available time for prey search) and prey patchiness are important factors determining the lower limits of prey density at which growth of newly hatched cod larvae can occur. Prey densities of 5-10 nauplii/l or occasionally even as low as 1-2 nauplii/l are considered sufficient for growth of cod larvae (Munk, 1997; Kristiansen, 2006).

The total density availability of suitable prey was >30 individuals/l during the hatching season of cod in the Fehmarnbelt area (Figure 4.51). Also the quality of the prey community was high with densities of copepod nauplii and copepodites of >8/l during the hatching season. Thus, starvation of cod larvae was not likely.

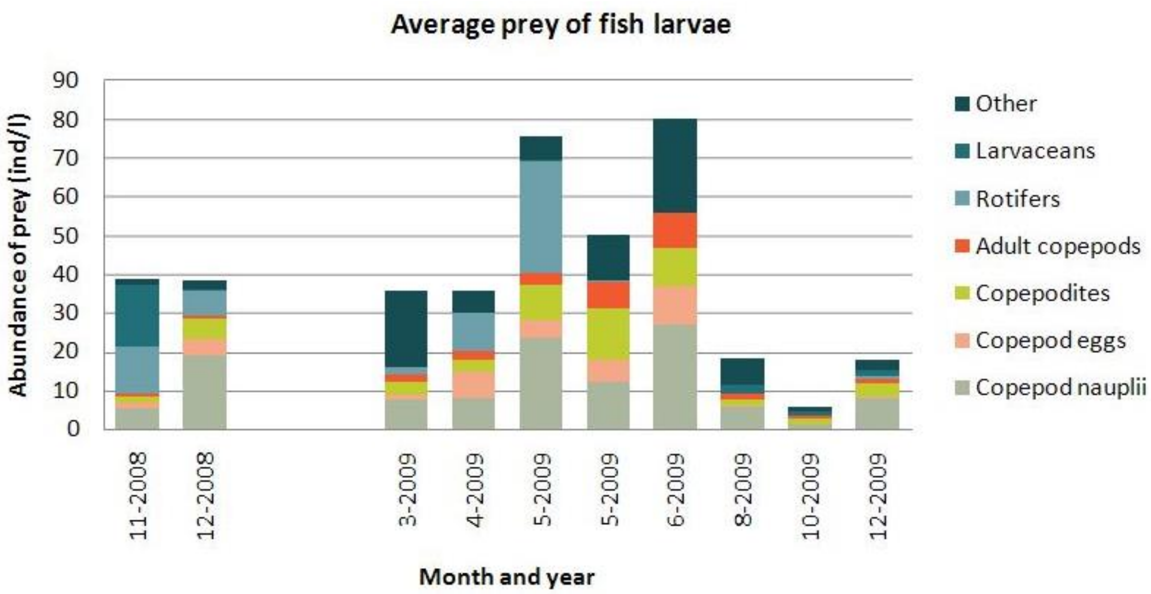


Figure 4.51: Abundance of available prey (number/ l) for fish larvae during 10 surveys in 2008 and 2009.

4.3.5 Nursery and feeding

There are still considerable knowledge gaps concerning the distribution of the pelagic pre-metamorphosis stages of cod and the subsequent early benthic (demersal) stages. There is also limited knowledge about the habitat requirements and the food composition of the juvenile cod during their early life in the Baltic. Little is known about the distribution of juvenile cod and the carrying capacity of the sub-littoral shelter and nursery areas. One of the main problems in research in this field is that there are no commercial or scientific catch statistics for cod under 10 cm and also no local habitat investigations on the abundance of juveniles near the coast.

Some information on the distribution and habitat preferences of juvenile cod is available from the fish community surveys (see section 4.1). When combining the catches of cod during gill, fyke and trawl net surveys, it appears that juvenile cod were caught mainly in subarea "Lolland" but also to some extent in subarea "Fehmarn" (Table 4.10). Adult cod were caught mainly in subarea "Fehmarnbelt" and a strong peak was seen in early spring. In subarea "Fehmarn" both adult and juvenile cod were caught, with a peak in catches in summer and early spring on habitat type "Sand and mussel beds on stones and blocks". The majority of juvenile cod were caught in subarea "Lolland", primarily during summer and autumn. Thus the coast of Lolland seems to be an important nursery ground for juvenile cod in the western Baltic Sea. This is in good accordance with results from Bauer et al. (2010). Furthermore, locations around the coast of Fehmarn also act as nursery grounds for juvenile cod. The predicted habitat suitability for juvenile cod is illustrated in Figure 4.52.

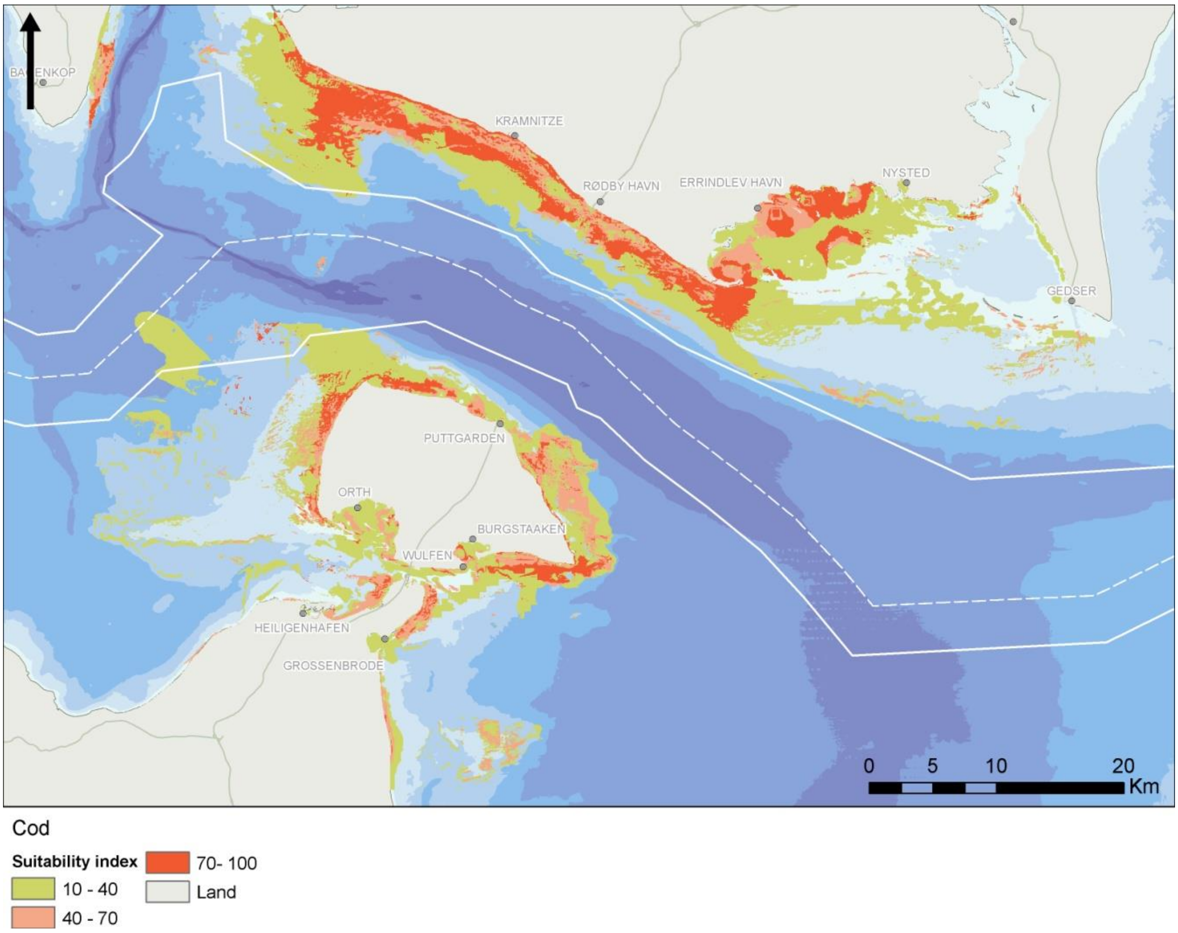


Figure 4.52: Habitat suitability for juvenile cod in the shallow water fish community in Fehmarnbelt.

The distribution, abundance and habitat preferences of cod in coastal areas were assessed from the results of the gill net surveys.

During the monthly gill net surveys in the coastal areas of Fehmarnbelt cod was very abundant (CPUE) and was one of the most dominant species. However, the abundance of cod smaller than 15 cm was very low with the highest CPUE (0.3) in autumn. No seasonal variations in the CPUE of adult cod were observed during the gill net surveys (Figure 4.53).

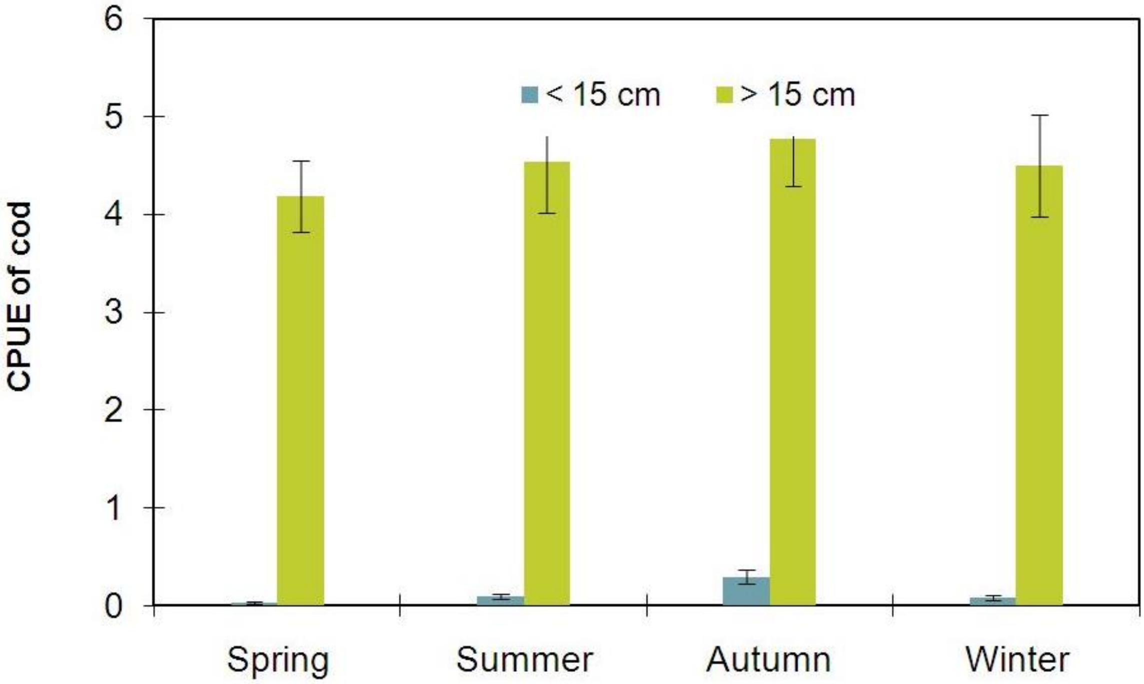


Figure 4.53: Average seasonal CPUE of two size classes of cod (smaller and larger than 15 cm) from monthly surveys with biological gill nets in the coastal areas of Fehmarnbelt, May 2009 – April 2010. Errorbars shows the standard deviation.

The catches of cod in coastal waters varied between habitats (Figure 4.54). The majority of cod were caught at 5 – 10 m depth in habitats consisting of a mix of sand, stones, mytilus and vegetation where they can seek shelter and feed. The lowest abundance was found in areas with eelgrass and/or sand (without stones, vegetation, mytilus etc.) (Figure 4.54).

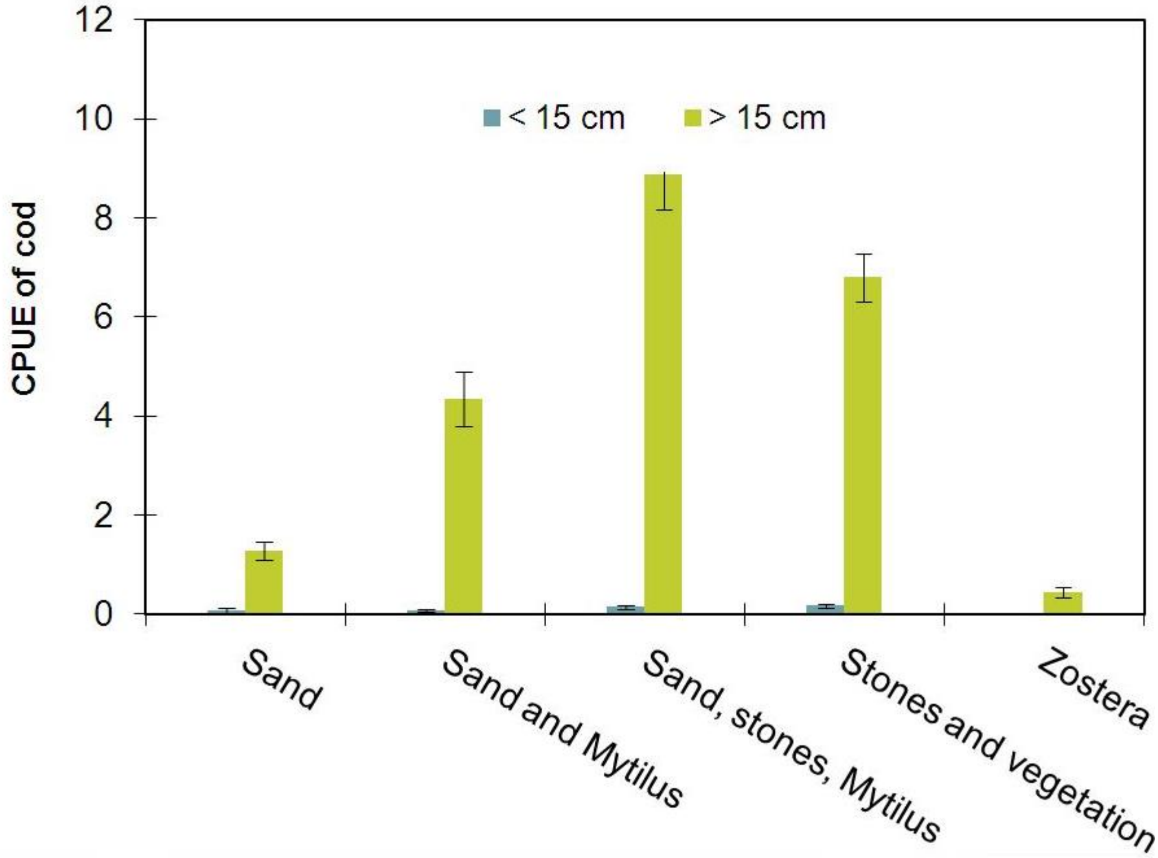


Figure 4.54: Average CPUE of two size classes of cod from monthly surveys with biological gill nets in different coastal habitats of Fehmarnbelt, May 2009 – April 2010. Errorbars shows the standard deviation.

Cod was one of the dominant species in the deep central waters of Fehmarnbelt. The abundance of cod in the TV3 trawl catches was highest in February and March, especially in the second survey in the end of February (Figure 4.55). This corresponds well with the peak of spawning for cod in the Western Baltic Sea. The vast majority of cod were caught in the TV3 trawl during daytime.

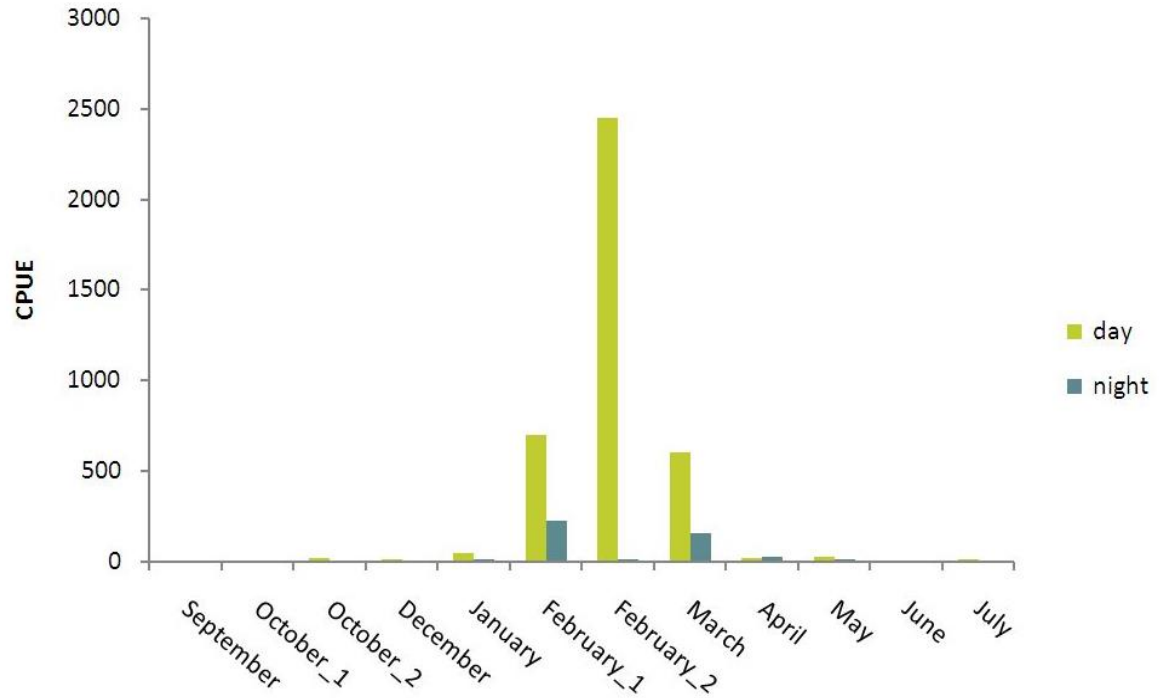


Figure 4.55: Average CPUE (g/1000m^3) of cod from 12 continuous surveys with TV3 trawl in Fehmarnbelt, September 2009 to July 2010.

Table 4.10: Catch of juvenile and adult cod during gill, fyke and trawl net surveys performed as part of the fish community surveys. Catches are separated in relation to habitat types and subareas.

Habitat type	Subarea Lolland	Subarea Fehmarnbelt	Subarea Fehmarn
Sand and fine sand	Mainly juveniles; majority caught in summer and autumn	Mainly adults, peaking in early spring (spawning)	
Sand and mussel beds	Mainly juveniles; majority caught in summer and autumn		
Sand and mussel beds on stones and blocks			Juveniles and adults; peak in summer and early spring (spawning)
Vegetation stones and blocks	Mainly juveniles; majority caught in summer and autumn		Juveniles and adults, dis-tributed evenly throughout the year

4.3.6 Migration

Cod are distributed throughout the western Baltic, from shallow to deep waters, with a tenden-cy towards greater depth during winter (Thurow, 1970; Oeberst, 2008). After the onset of ma-turity, adult cod undertake distinct migrations towards specific spawning and feeding areas as a part of their seasonal cycle.

In the western Baltic, cod undertake extensive migrations between feeding and spawning grounds (Otterlind, 1985). Spawning migrations in the Belt Sea are generally directed towards the Southern Kattegat and the Danish Belts (Bagge, 1969; Otterlind, 1985). Berner (1967) and Berner (1971b) tagged cod in Mecklenburger Bight and showed that they dispersed along the German/Polish coasts during the first one to six months while the cod recaptured later (6-17 months) seemed to have undertaken feeding migrations towards Møn. The fish moved towards Kiel Bight, the Little Belt and especially the Great Belt and Southern Kattegat during early winter (Berner, 1967).

Cod tagged in the Arkona Sea exhibited a quite different migration pattern. In general, small fish seemed to be rather stationary, indicating that migration of adults was associated with spawning (Berner, 1967; Berner, 1974). Adult cod tagged in the Arkona Sea migrated in both westerly and easterly directions, even east of the Bornholm Basin (Berner, 1967; Berner, 1971a; Otterlind, 1985). Otterlind (1985) observed migrations towards Kattegat, primarily through the Belts (Otterlind, 1985). It has been hypothesized that the direction of the migration of cod from the Arkona Sea depends on environmental conditions, especially salinity, prior to spawning. Cod move west when the salinity in the Arkona Sea is low prior to spawning, while they tend to move east when salinities are high (Otterlind, 1985). Berner (1985) found that cod tagged in the Arkona Sea in January-April moved west and cod tagged in May-August moved east while cod tagged in September-December tended to stay in the Arkona Sea. This could indicate that both stocks spawn in the Arkona Sea.

The establishment of a fixed link between Lolland and Fehmarn might impact the spawning migration of the western Baltic cod stock. Several cod spawning grounds have been located in Fehmarnbelt and offspring from the local spawning are believed to contribute significantly to the recruitment of the eastern Baltic cod stock (Oberst, 2008). Any servere impact on the cod spawning migration in Fehmarnbelt caused during construction and operation of the fixed link might thus impact the recruitment of the Baltic cod stock. In order to map the migration patterns of the spawning cod in Fehmarnbelt, a tagging experiment was initiated in February 2010.

In the present study a total of 23 recaptured cod marked with T-tags were registered until 25th of March 2011 corresponding to a recapture percentage of 8%. The location of the recapture positions are shown in Figure 4.56. During the first period three cod were recaptured in Fehmarnbelt within the first two weeks after the release and two cod were caught in the nearby Mecklenburg Bight after 6-7 days. During March 2010 two cod were recaptured in Fehmarnbelt, one cod were recaptured in the Great Belt north of the bridge and another cod were recaptured south of Langeland. In April one cod were recaptured north of Kieler Bight and in May and June two cod were registered in Mecklenburg Bight and one in Langeland Belt. In July two cod were recaptured in Fehmarnbelt and in September a cod were recaptured in the straight between Bornholm and Sweden (FeBEC, 2011g).

During the spawning season in January and February 2011 one cod were recaptured in Haderslev Fjord in Little Belt, one cod south of Ærø, two cod south-west of Langeland and three cod were recaptured in Fehmarnbelt within a nautical mile from their release position.

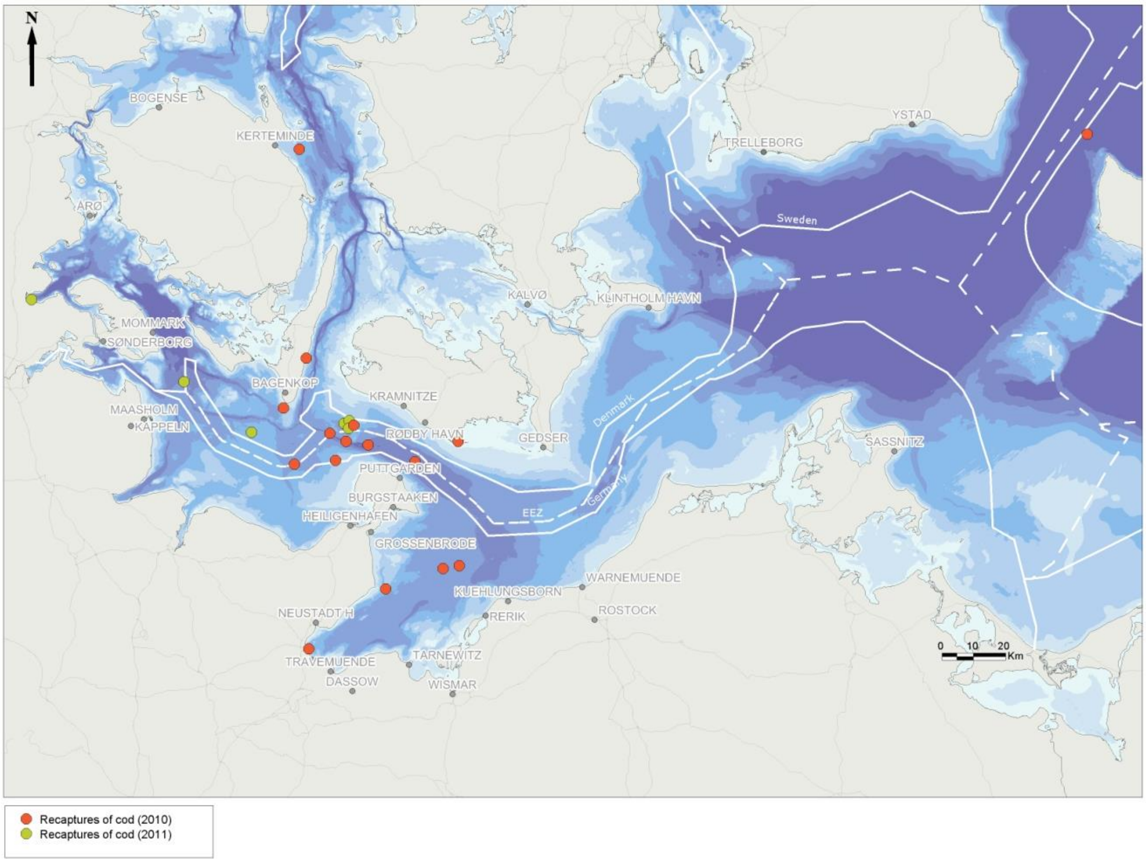


Figure 4.56: Recapture location of cod marked with T-tags in Fehmarnbelt in February-March 2010.

Five DST-tagged cod were recaptured (recapture percentage 13%) but only records of data from two tags could be downloaded. One was recaptured very shortly after release close to the release location and one was recaptured after 4 month still in the Fehmarnbelt area. The registered depth and temperature from the later is shown in Figure 4.57.

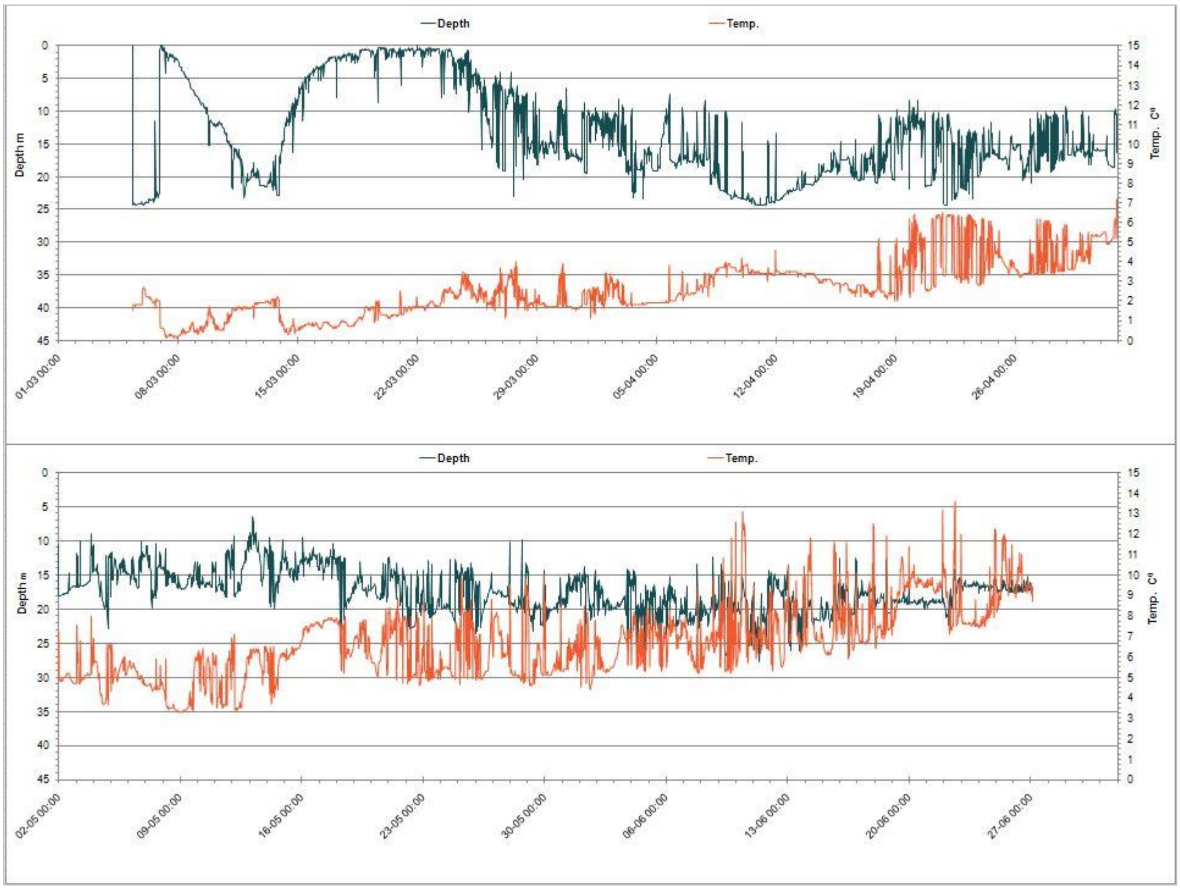


Figure 4.57: Registered depth and temperature during four month from a tagged cod, DST- M11341, released 5th of March and recaptured 27th of June in Fehmarnbelt 2010.

It was not possible to back-track the movements of the cod, but the rather uniform daily maximum depths indicate, that the cod stayed in the Fehmarnbelt area. Apart from short periods in March 2010 the cod was not approaching the surface during the four month between tagging and recapture. No clear diurnal behaviour was registered, but vertical movements of 5-10 m during the day were registered very frequently, presumably connected to feeding activity. The vertical movements were related with changes in the registered temperature typically of 3-5 C^{o} indicating, that the cod were crossing the thermocline while feeding (FeBEC, 2011g).

The results of the cod tagging studies indicates, that the spawning cod in Fehmarnbelt, at least for some of the population, exhibit a kind of homing, i.e. returning to the same spawning site in subsequent years. Three out of seven recaptures in January-March 2011 were registered very close to the release location the year before, and it can not be excluded, that the remaining four cod would have migrated back to spawn. The spawning cod in Fehmarnbelt migrate to different feeding areas. Some cod stay in the Femarnbelt area all year, while other cod migrate to more distant feeding areas from Bornholm to all over the western Baltic area including the Belt Sea. Besides the Fehmarnbelt area, most feeding cod were recaptured in Mecklenburg Bight. This is in accordance with the findings of Berner, (1980a; 1980b), who concludes from a number of tagging experiments, that the general spawning migration from Mecklenburg Bight in the period January-April is north-west through Fehmarnbelt. In another study, cod were tagged on the feeding grounds in Hohwackter Bight in Kieler Bight in November 1961 (Thurow, 1963). These cod were recaptured at different spawning sites in February and May including several locations in the deeper parts of Little Belt and Langeland Deep. In April and May the majority of the recaptures were reported from the feeding grounds in the Southern Kieler Bight, where the originally were released. This indicates a kind of “reversed homing” which means that a population of cod might share the same feeding grounds in successive years but prefer different spawning sites. In this case a cod population can be classified in two ways; from the spawning ground and from the feeding ground.

On the other hand comprehensive translocation experiments including cod from the Kattegat region to Gotland in the Baltic proper showed that cod did not return to the original catch location after translocation to distant waters (Otterlind, 1980). Otterlind concludes that adaption to the hydrodynamic and hydrographic conditions on the release location apparently have higher priority for the cod than any drift of homing making the released cod behave like the local cod population. Many of these translocation experiments were performed over large distances and significant salinity gradients e.g. from Kungsbackafjorden in Kattegat to Nexø on Bornholm, and this might have impacted the navigation of the cod.

No simple pattern in the cod migration in the south-west Baltic Sea was observed and a number of sub-populations exist defined from specific spawning areas and/or feeding areas. A significant part of the cod spawning in the western part of Fehmarnbelt seems to disperse to separate feeding areas ranging from Bornholm to the Belt Sea outside the spawning season with the major feeding area in Mecklenburg Bight. It seems that the majority of the cod returns to the same spawning ground in successive years. This implies that a part of the cod population feeding east of Fehmarnbelt have to migrate through the belt to their preferred spawning grounds.

4.3.7 Cod baseline conlusion

The baseline results regarding cod in the Fehmarnbelt area may be summarized as follows:

- Fehmarnbelt is an important spawning ground for the western Baltic cod.
- Main spawning period was December–March, which is a bit earlier compared to previous investigations of the spawning season of western Baltic cod. In all, spawning individuals were registered from October to May.
- Average egg density in Fehmarnbelt in March 2010 was 3 cod eggs per m^3, corresponding to approximately 25 eggs per m^2, which is only slightly lower than the density recorded during peak of the spawning season in the Bornholm Basin 1969-1996.
- From estimated annual egg production of the entire sampling area it is reasonable to estimate that 800 tonnes of cod spawn in the investigated area. Since the spawning stock biomass (SSB) of the entire western Baltic has been estimated at 20,000 tonnes since 1995, it is assumed that at least 4% of the spawning biomass in the entire western Baltic Sea spawns in the investigated area.
- When backtracking early stage cod eggs caught in Fehmarnbelt they were mainly spawned in deep central areas of Fehmarnbelt, the Belt Sea near Langeland, Mecklenburger Bight and the western part of the Arkona Bassin.
- Starvation by cod larvae or heavy predation on egg and larvae by medusas was not likely during the investigated period.
- Juvenile cod were presented in summer and autumn in shallow coastal German and Danish waters of Fehmarnbelt. In the deeper, central parts of Fehmarnbelt a peak in catches of adult cod were seen in February and March 2010, convergent with the main spawning period.
- The southern coast of Lolland is an important nursery ground for cod during summer and autumn. Additionally, the the coast of Fehmarn is to a minor extent used as a nursery area during summer and autumn.
- The results of this investigation correspond well with the spawning area identifications in other investigations in the western Baltic. This supports the importance of the Fehmarnbelt for recruitment to the western Baltic cod stock and possible recruitment to the declining eastern stock in the Baltic Sea.
- No simple pattern in cod migration was observed.
- Adult cod migrate towards different feeding area outside Fehmarnbelt but the major feeding area was Mecklenburg Bight.

- Adult cod return to spawning areas in the south-western Baltic Sea.
- Areas of potential importance for spawning, nursery and foraging of cod in Fehmarnbelt and adjacent areas are shown in Figure 4.58, Figure 4.59 and Figure 4.60. The deeper areas are of high importance for spawning, the more shallow and coastal areas are of medium importance as nursery grounds whereas the deeper areas of Fehmarnbelt are of minor importance for foraging of cod.
- The importance of Fehmarnbelt and adjacent areas for cod is listed in Table 4.11.
- Cod recruited from local spawning grounds in Fehmarnbelt may contribute significantly to the eastern Baltic cod stock. Thus, spawning migration, spawning grounds as well as drift of eggs and larvae important.
- Local cod nursery areas and feeding areas are of less importance to the regional cod stock allowing higer acceptable reduction rates.

Table 4.11: Importance of Fehmarnbelt and adjacent areas for cod in relation to spawning, eggs and larvae drift, nursery, feeding and migration.

Environmental component	spawning	egg-larvae drift	nursery	feeding	migration	overall
Atlantic cod	high	high	medium	medium	high	high

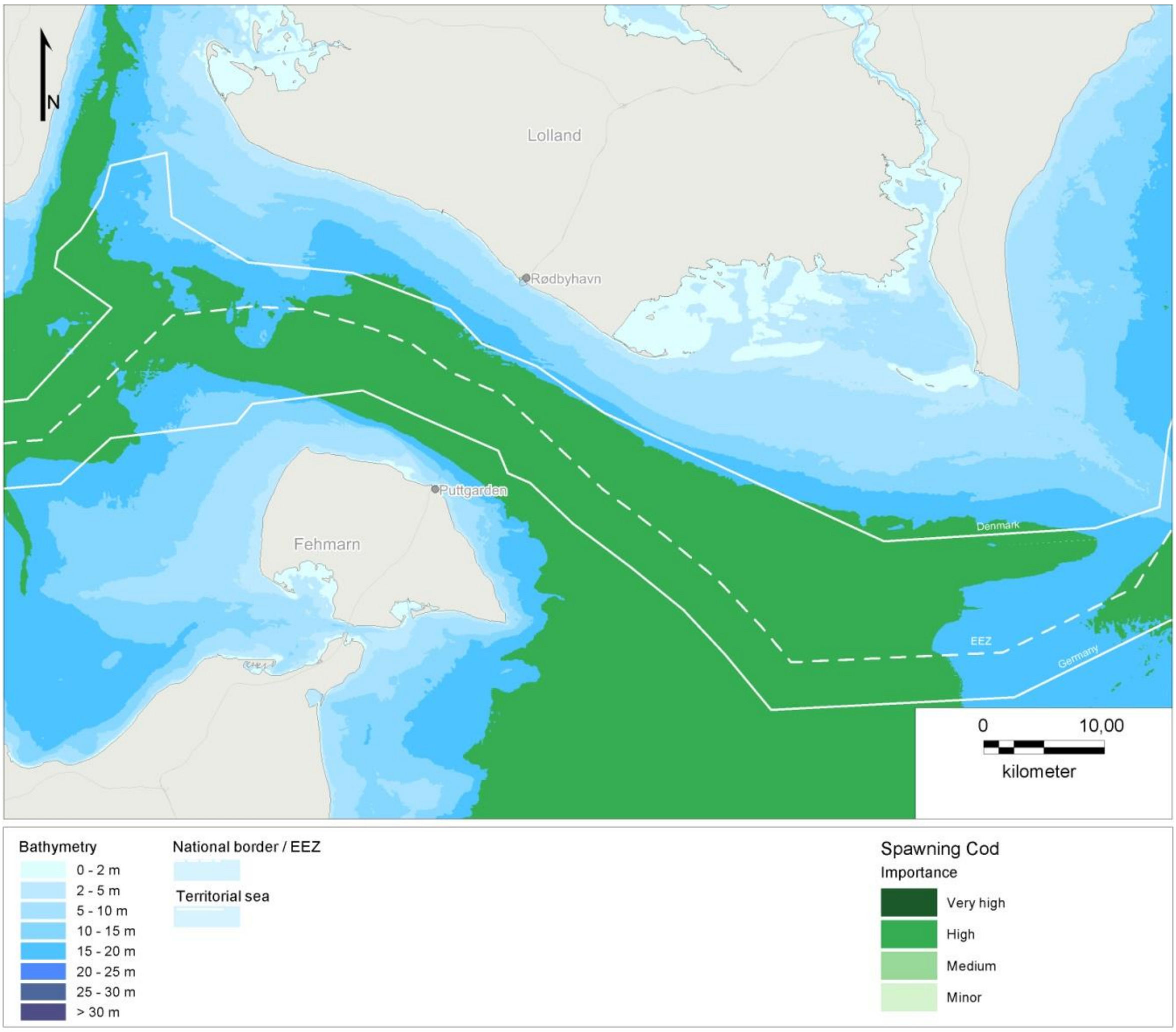


Figure 4.58: Areas of potential importance for spawning of cod in Fehnmarnbelt and adjacent areas.

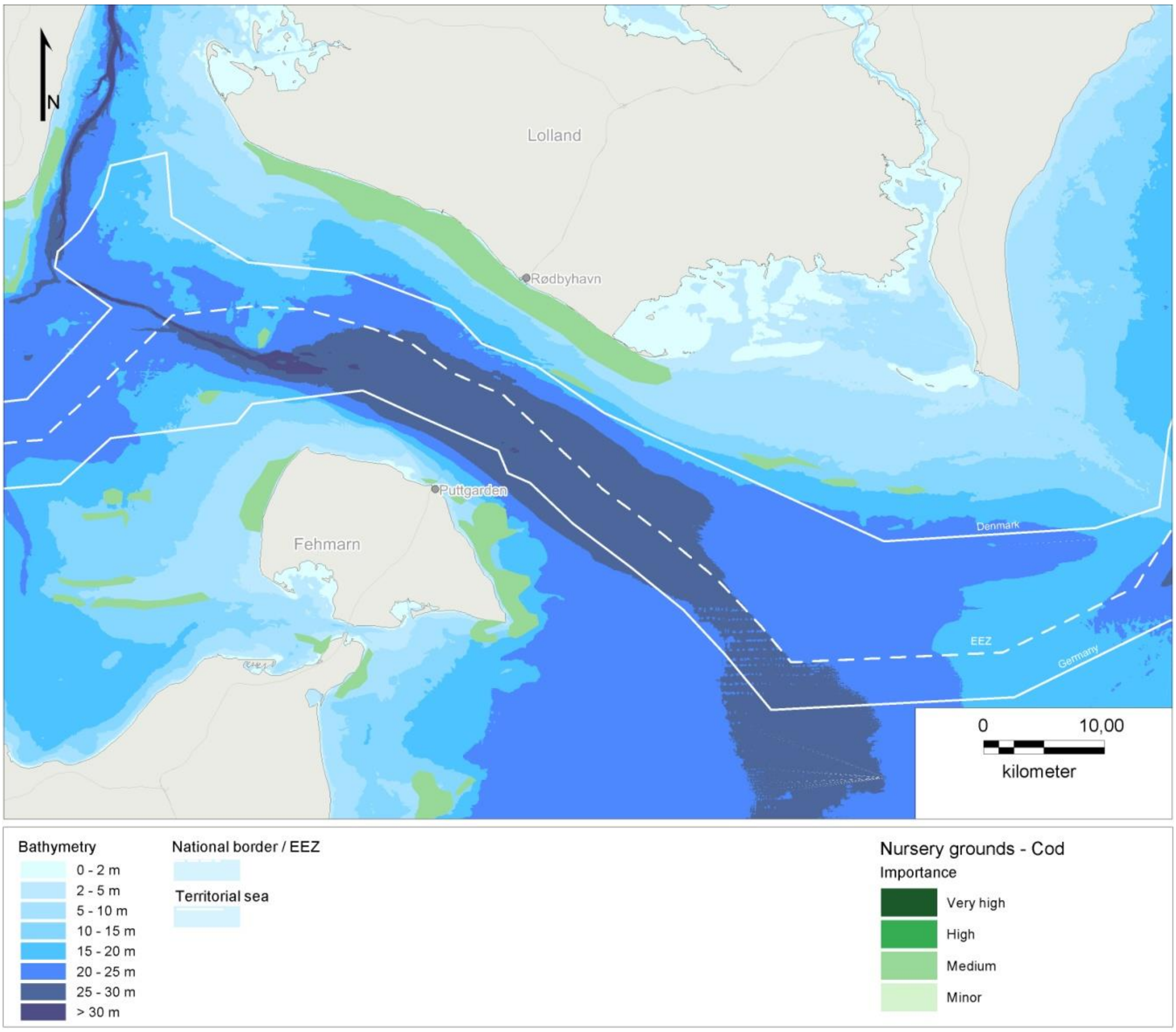


Figure 4.59: Areas of potential importance as nursery grounds for cod in Fehnmarnbelt and adjacent areas.

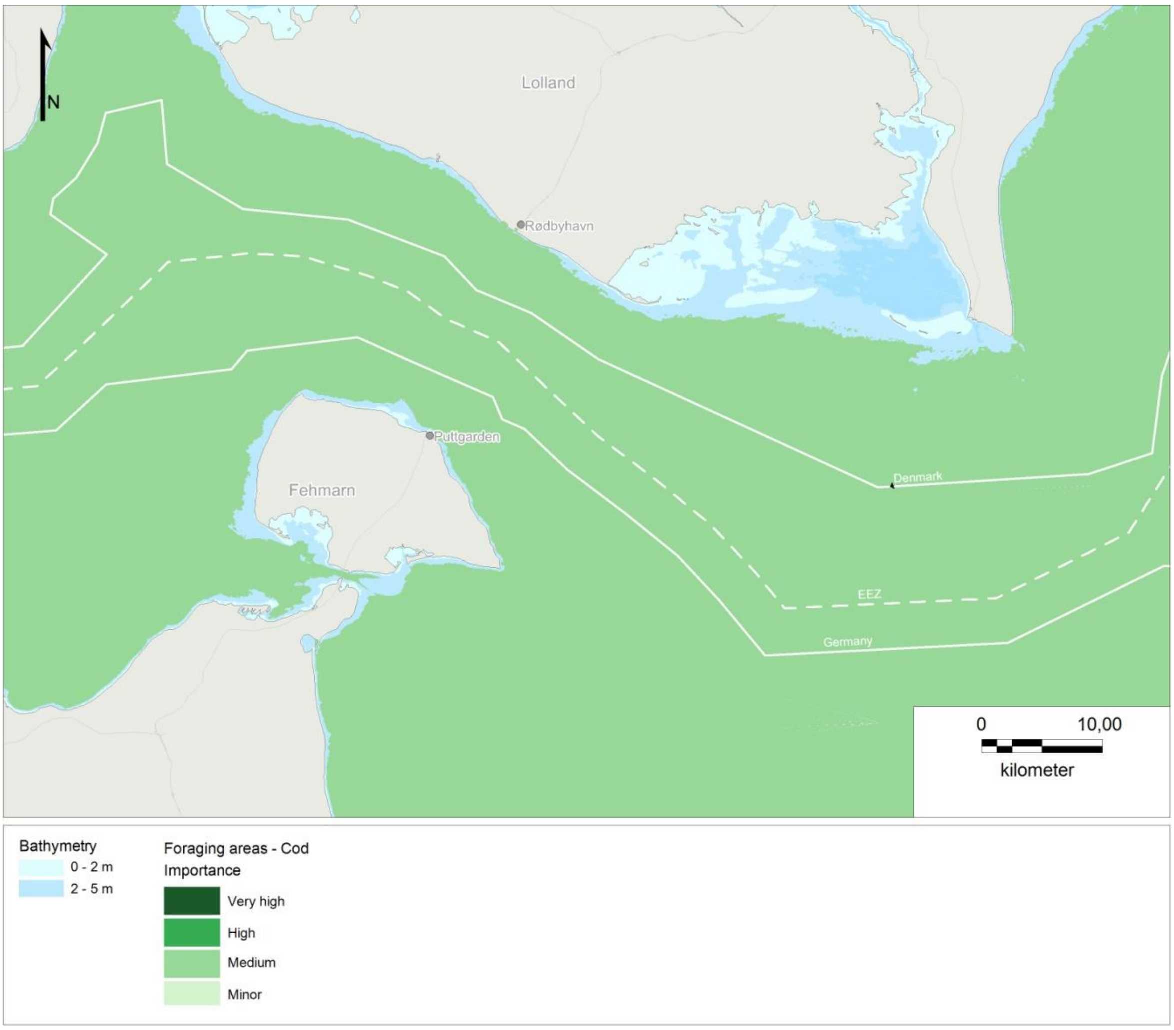


Figure 4.60: Areas of potential importance as foraging grounds for cod in Fehnmarnbelt and adjacent areas.

4.4 Whiting

4.4.1 General background

Whiting (*Merlangius merlangus*) is a gadoid species like cod but is more pelagic (benthopelagic) compared to cod. It is one of the most abundant and widely distributed gadoids in the North Sea but is only an occasional visitor in the Baltic Sea contrary to cod. It has a very opportunistic feeding strategy, exploiting shrimps, crabs, molluscs, small fish, bristle worms and squids as food items (Fishbase, 2011). Whiting feed exclusively at dusk and dawn (Rindorf and Gislason, 2005). The stock found in the Baltic is presumably a part of the North Atlantic stock. The present baseline study showed that whiting are found in Fehmarnbelt throughout most of the year in great numbers often dominating in the catches.

In the following table the environmental settings and existing pressures that can be of importance for whiting are listed.

Table 4.12: Environmental settings and existing pressures of significance to whiting in the Fehmarnbelt.

Basic environmental setting	Variable hydrodynamics exposed shoreline	Eggs and larvae of whiting are transported to Fehmarnbelt by current from Kattegat and Skagerrak (Treasurer and Ford, 2010). Stable environmental conditions with good access to food enhance recruitment of whiting, but no spawning sites are known in the Baltic Sea. The closest spawning grounds are located in Kattegat, where spawning primarily takes place during spring.
	Stratification	Drifting eggs and larvae of whiting are potentially affected by stratification as well as juveniles. Due to the well-mixed waters of Fehmarnbelt, oxygen depletion rarely occurs.
	Salinity	The salinity level is an important criterion for whiting. Due to decreasing salinity levels, whiting is rarely found east of the Arkona Sea. However, the salinity level in Fehmarnbelt is not limiting for the distribution of the species.
Food competitors	Interspecific	Juvenile specimen feeds on the same kind of prey as flatfish, cod and other small fish. Adult whiting mainly feeds on fish. This leads to interspecific food competition with e.g. turbot, brill and cod.
	Birds / Mammals	Adult whiting mainly feeds on fish like sprat and herring which is also utilized as prey by marine mammals (e.g. seals and harbor porpoise) and birds (e.g. cormorant) (Andersen et al., 2007).
	Crustacean	Crustacean like the brown shrimp (*Crangon crangon*) and the common shore crab (*Carcinus maenas*) occur in the same habitat types and show overlapping diet preferences with juvenile whiting.
Predators	Clupeids / Flatfish /	Clupeids are feeding on pelagic eggs and larvae of whiting. Flatfish are mainly feeding on benthic organisms during their early life stages. As they mature they also feed on fish. Especially brill and turbot are important predators on small fish, including juvenile whiting.
	Birds / Mammals	Several birds (e.g. common guillemot, great crested grebe and razor-billed auk) and mammals (e.g. seals and harbour porpoise) also feed on small fish in coastal waters (Mendel et al. 2008) (Andersen et al., 2007).
Fishery		Mortality caused by fisheries of whiting in the western Baltic Sea is relatively low as it is only caught as by-catch.
Eutrophication	Nutrient enrichment	Fish communities and young fish in coastal areas (including whiting) are affected by the increased nutrient input caused by anthropogenic influence (Thiel et al., 1996).
	Decreased water clarity	Reduction in water clarity has generally reduced macrophyte vegetation. Whiting prefers more sandy and gravel covered open spaced areas (Atkinson et al., 2004). Therefore, decreasing water clarity is not likely to affect the preferred habitats of whiting.
Invasive species		The occurrence of invasive species affects the fish communities in the coastal waters of the Baltic sea. For example the jellyfish *Mnemiopsis leidyi* has the potential to affects the success of fish species in Fehmarnbelt.

4.4.2 Baseline approach

The objective of the baseline studies did not specifically adress whiting but, it is included here in a separate chapterter to keep the distinction to cod as whiting occurs together with cod in the hydro acoustic, and the biological gill net habitat surveys. (see chapter 3 for detailed description of the methods).

Gonads of adult whiting were collected from local fishermen during April-August 2009 and during January/February 2010 and from trawl samples from the hydro acoustic. The maturity stages were determined in order to identify spawning activity, although this not was expected in Fehmarnbelt and adjacent areas.

Eggs and larvae surveys were carried out from October 2008 to March 2010 and samples were collected during 12 surveys. Subsequently, species were identified and cod and whiting were separated by gel electrophoretic analysis.

During the habitat mapping and acoustic surveys from May 2009 to April 2010 whiting were continuously caught in gill nets as well as in the calibrating trawl hauls.

4.4.3 Spawning

Whiting spawns pelagic eggs, but no spawning grounds of whiting have been identified east of Skagerrak (Muus and Nielsen, 1999). Within the known spawning grounds in the North Sea and Skagerrak the major spawning period is spring (Treasurer and Ford, 2010).

Environmental factors – temperature and salinity – appear to influence the geographical extent of spawning whiting distribution, whereas local abundance levels are primarily controlled by internal factors, i.e., population size and spatial segregation between ages.

Whiting do not spawn in the proper Baltic Sea (HELCOM, 2011a) and presumably spawning is insignificant in the western Baltic Sea. Particularly young whiting may though be numerous in inner Danish waters (Clausen et al. 2002), as in Fehmarnbelt, but main spawning areas of whiting is located west of Kattegat (Muus et al 2006, Loots et al 2010). Aspects regarding spawning, eggs and larvae or adult feeding are thus of minor or non importance.

In addition, various fish species migrate from time to time from the North Sea into the Baltic Sea. Such species include whiting (Merlangus merlangus), European anchovy (Engraulis encrasicolus), mackerel (Scomber scombrus) and grey mullets (e.g. Liza ramada). Due to unfavourably low salinity conditions, marine visitors are unable to form self-sustaining populations in the Baltic Sea.

4.4.3.1 Results of baseline studies on whiting spawning

Whiting were found in varying abundance throughout the year. According to the maturity index of the whiting that were caught and analysed, only an insignificant number of whiting may have spawned in Fehmarnbelt (Figure 4.61).

A quality assurance of the species identification of the eggs was performed by gelelectrophoretic analysis. Gelelectrophoretic analysis makes separation between eggs from cod and whiting possible. All gadoid eggs collected from March to August 2009, which were analysed, were identified as cod eggs.

No whiting eggs (verified by gelelectrophoresis) or larvae were found in the samples from the Fehmarnbelt area. The relative weight of gonads of whiting remained low until February where the female gonadosomatic index increased (Figure 4.62). This corresponds well with the relatively high number of ripening individuals identified by gonad staging during this period.

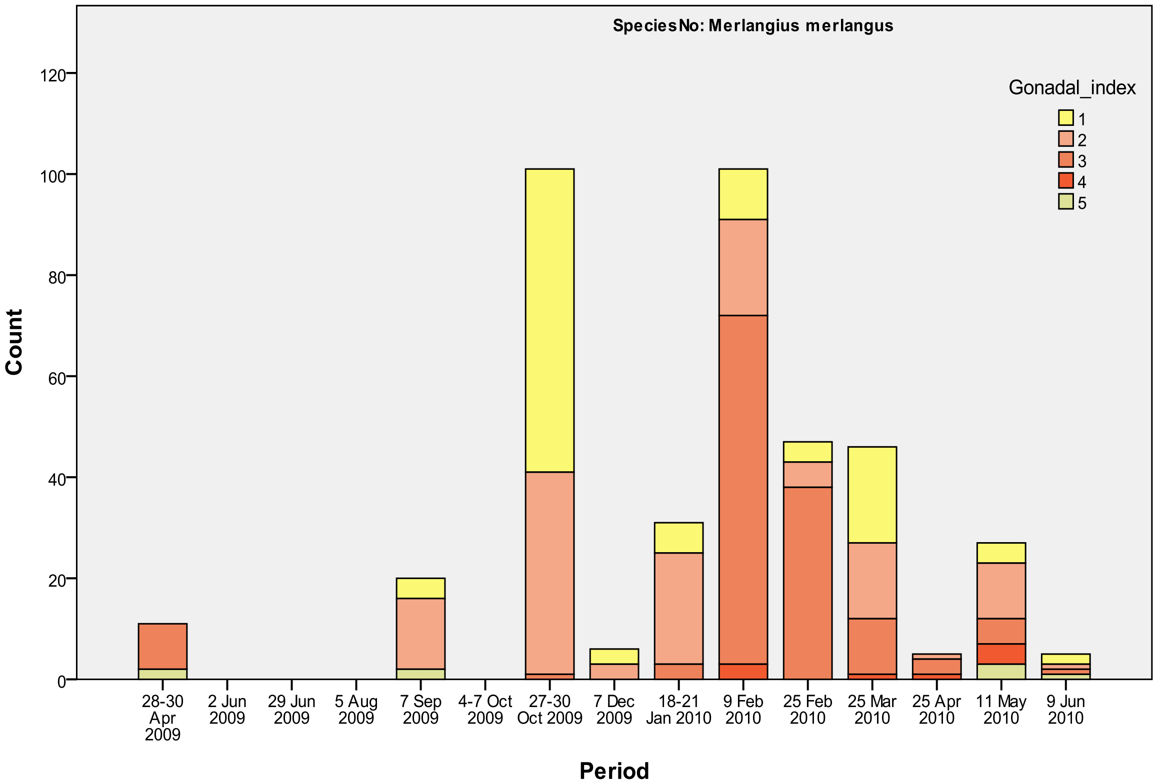


Figure 4.61: Maturity index of whiting (both sexes) from April 2009 to June 2010. 1 = juvenile, 2 = preparation, 3= ripening, 4 = spawning, 5 = regeneration.

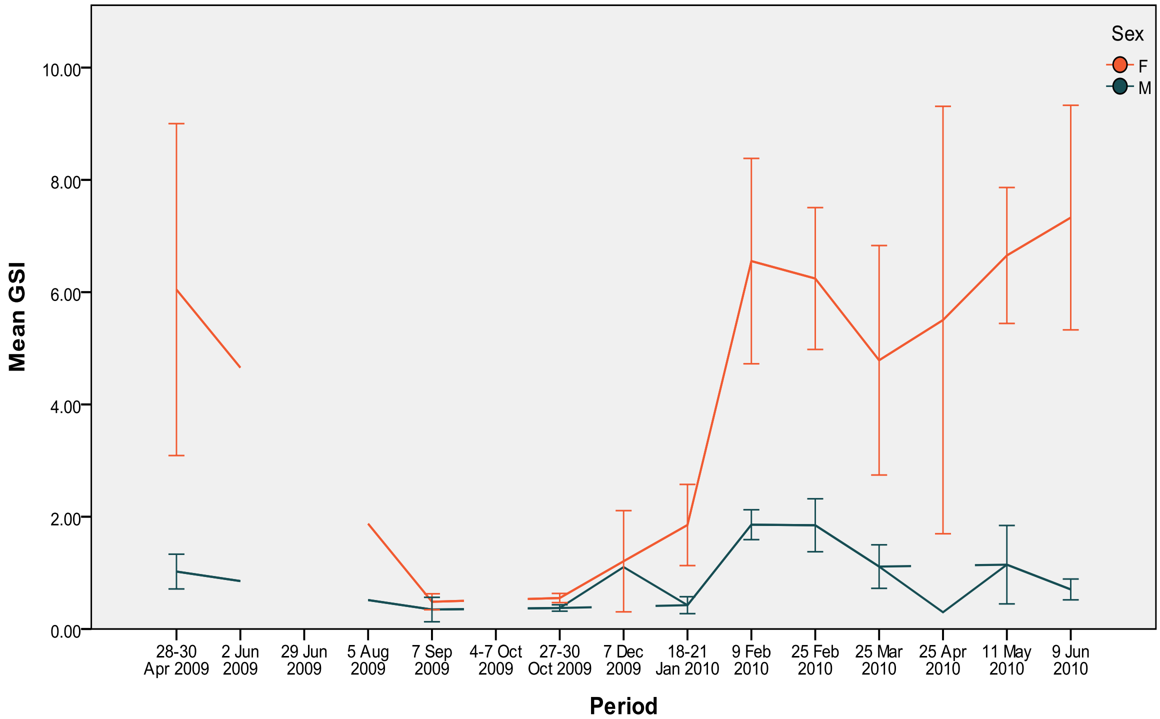


Figure 4.62: Mean gonadosomatic index (GSI = gonadal wet weight as a percentage of total wet weight) of whiting. Female (F) – red, Male (M) – blue. Errorbars: ± 2 SE.

4.4.4 Nursery and feeding

Whiting was one of the dominate species observed during the fish community surveys and accounted for 4 to 20 % of the CPUE. For further details on the abundance and distribution of whiting in the benthic fish communities see chapter 4.1.

The results from the gill net surveys were used to assess the distribution, abundance and habitat preferences of whiting in coastal areas.

The CPUE of whiting in the gill net surveys were relatively high, and on average whiting constituted approximately 5 % and 10 % of the total gill net catch along the German and Danish coast, respectively. Generally, whiting represents a larger share of the fish community along the coast of Lolland. However, the total catch of whiting was only slightly larger compared to the coast of Fehmarn. Catches of whiting < 15 cm was sparse with a maximum density of approximately 0.7 per unit effort in the autumn (Figure 4.63). However, the vast majority of the whiting caught were juveniles smaller than 25 cm.

The abundance (CPUE) of whiting increased from spring to autumn and the lowest abundance were observed during the winter months (Figure 4.63). No whiting were caught with gill nets in the coastal areas on both the Danish and german coast in February to March. The low abundance in winter and spring respectively corresponds well with the knowledge of whiting spawning in the North Sea during spring. This indicates that whiting migrates towards spawning areas in the North Sea during winter and early spring. Whiting larger than 15 cm were most abundant in the gill net catches, but were primarily smaller than 25 cm.

The monthly length distribution of whiting caught in the gill nets showed an appearance in September of a new year-class at 10-15 cm in the shallow water. These were probably spawned during spring unless the growth of whiting is very poor during the first year.

Catches from coastal waters varied between habitats (Figure 4.64). Both juvenile and adult whiting preferred sandy habitats compared to habitats with vegetation, stones and mussels. No whiting were found in habitats with eelgrass.

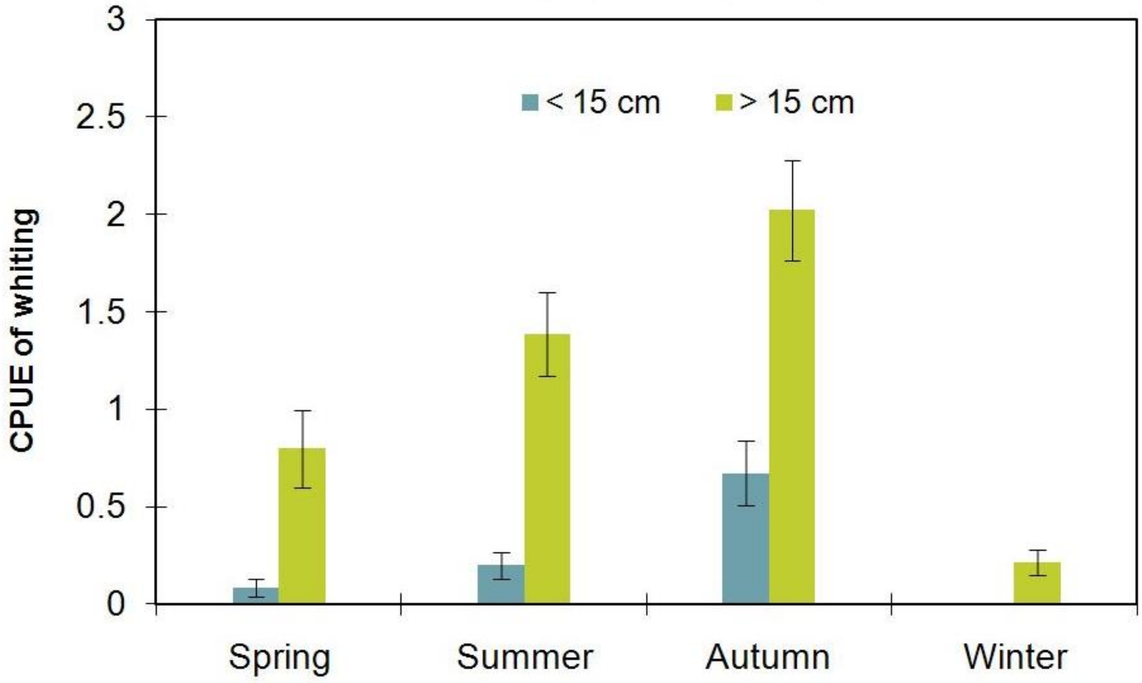


Figure 4.63: Average seasonal CPUE of two size classes of whiting (smaller and larger than 15 cm) from monthly surveys with biological gill nets in the coastal areas of Fehmarnbelt, May 2009 to April 2010. Errorbars shows the standard deviation.

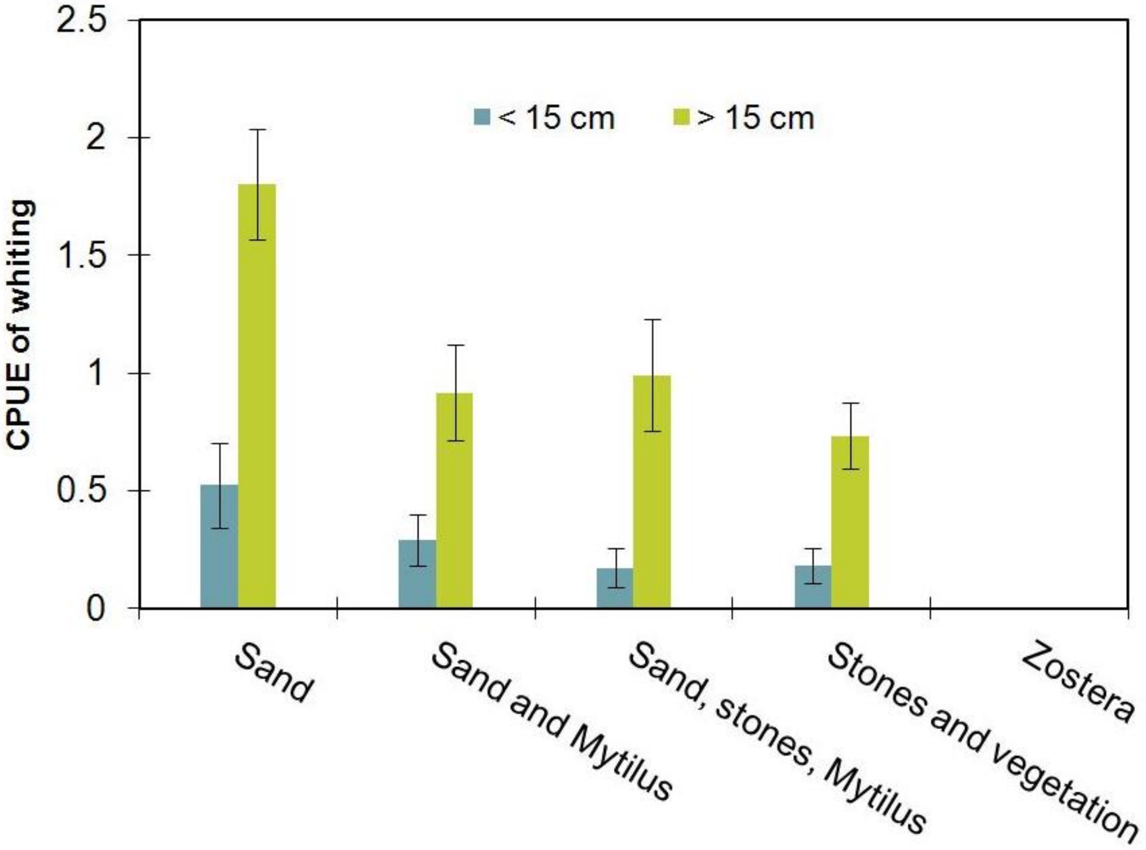


Figure 4.64: Average CPUE of two size classes of whiting from monthly surveys with biological gill nets in different coastal habitats in Fehmarnbelt, May 2009 to April 2010. Errorbars shows the standard deviation.

Whiting was one of the dominant species in the deep central parts of Fehmarnbelt. The vast majority of whiting caught in TV3 trawl during the 12 coninuous surveys in Fehmarn Belt were caught during daytime in February (2010) (Figure 2.1). The length distribution ranged from 6 to 45 cm but the majority of the fish were smaller than 30 cm. The same trends were seen in the catches from the three deep stations in Fehmarnbelt trawl during the habitat mapping surveys from October 2009 to April 2010. The catches of whiting in the TV3 trawl in the second survey in the end of February were almost tree times larger compared to cod.

The length distribution of whiting caught in TV3 trawl illustrates that the youngest year-class was caught in September (5-6 cm) whereas the largest whiting (average 25 cm) were caught in February. The vast majority was smaller than 30 cm.

0-group whiting migrates towards shallow water areas along the coast during fall. They stay here until the next spring where they migrate back to the open sea. Whiting becomes mature at 2 years age at a minimum length of approximately 20 cm (Clausen et al. 2002, Gerritsen et al., 2003, Loots et al. 2011).

The maturity index of a subsample of whiting caught during the continuous surveys was determined (Figure 4.61). The vast majority were ripening (stage 3) in February where the highest abundance of whiting in the deep central waters were observed. No whiting were caught were caught in the gill nets in February and March. Thus, it coul be hypothesized that they migrate from shallow water areas towards the deeper more central waters of Fehmarnbelt during the early spring.

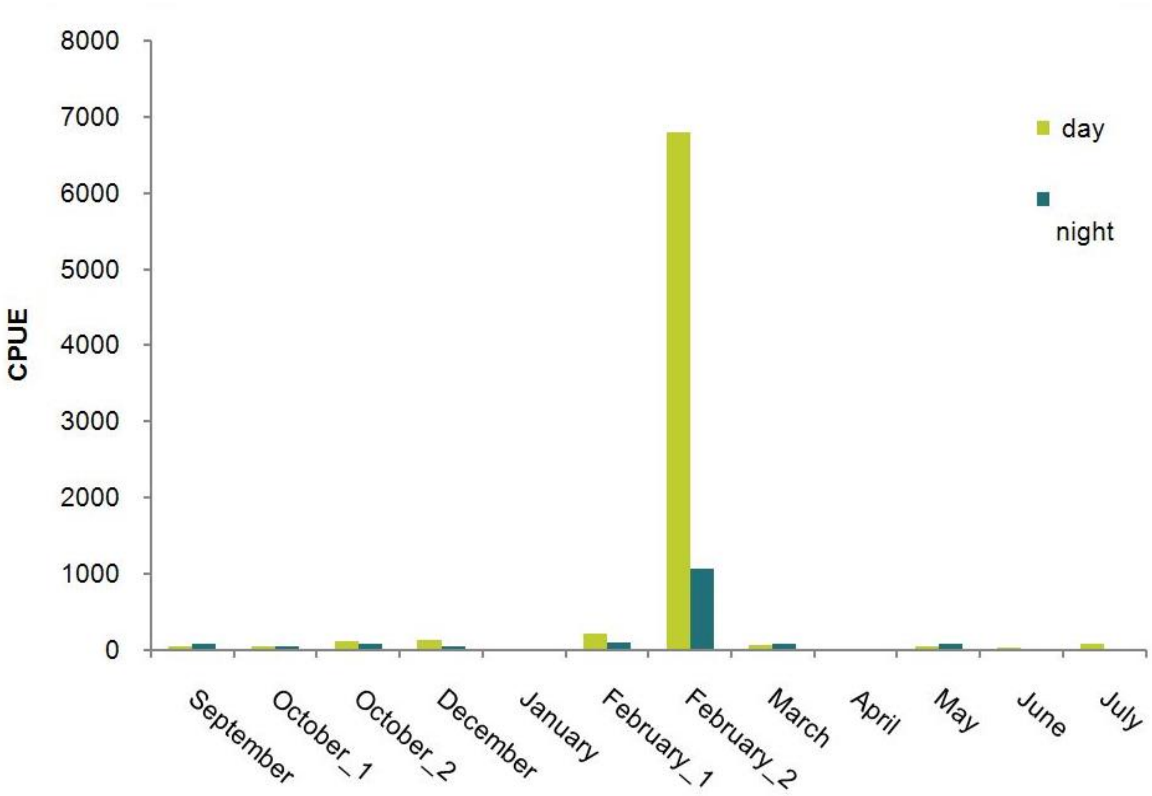


Figure 4.65: Average CPUE (g/1000 m^2) of whiting from 12 continuous surveys with TV3 trawl in Fehmarnbelt, September 2009 to July 2010.

Additionally, seasonal landings of whiting from Fehmarnbelt and the Western Baltic in 2007-2009 peaked strongly in either March or April. During 2010 the vast majority of whiting caught in the Western Baltic Sea were landed in March and they were primarily caught in Fehmarnbelt. Whiting seem to be very abundant in Fehmarnbelt during a short period in the spring- This corresponds well with highest CPUE observed in the end of February during present study.

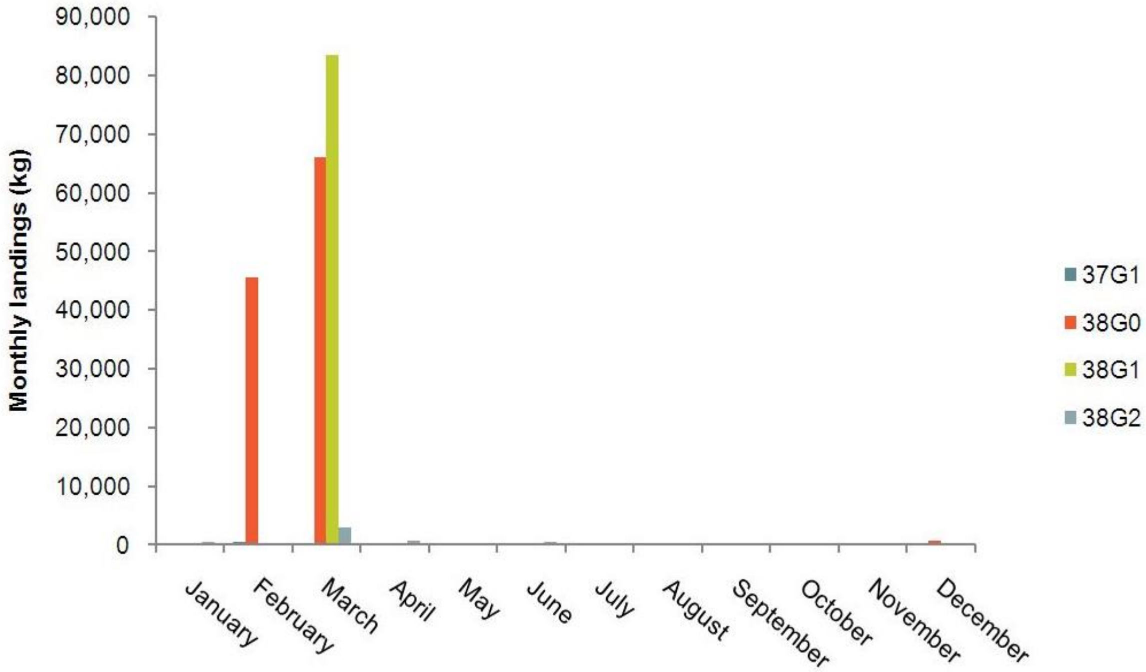


Figure 4.66: Seasonal landings (kg) of whiting caught in the western Baltic Sea during 2010 - ICES square 37G0, 38G0, 38G1 and 38G2. No whiting were caught in ICES square 37G1 and 37G2. For details on ICES squares see Figure 4.38. Note, Fehmarnbelt is included in 38G1.

Alltogether, this indicates that juvenile whiting are using the shallow water areas of Fehmarnbelt and other areas in the Baltic Sea as nursery areas. Furthermore, first-time ripening whitings from the Baltic Sea seem to aggregate in the deep areas of Fehmarnbelt during early spring migrating towards Skagerrak and the North Sea to spawn in spring.

4.4.5 Migration

Whitings were recorded in high numbers in Fehmarnbelt during the baseline studies. Most of the Fehmarnbelt is an attractive area for this species, which prefers sand and gravel sea beds (Atkinson et al., 2003). Despite the fact that whiting are very common in the western Baltic Sea and occur in high densities, only sparse information on the migration of whiting within the area exists. The stock found in the Baltic is presumably a part of the North Atlantic stock.

Whiting are pelagic and perform several migrations during their lifetime. As the eggs hatch the first migration begins and the larvae are transported towards the Danish waters by water currents but also by swimming. This migration is often performed beneath jellyfish that are used as protection (www.FishBase.org; Muus et al., 1998). Juvenile whiting use the Danish waters as a nursery area and may spend at least 1-2 years in the coastal waters of Denmark before they migrate back to the North Sea.

For further details on migration see chapter 4.4.4.

4.4.6 Whiting baseline conclusion

The baseline results regarding whiting in the Fehmarnbelt area may be summarized as follows:

- Whiting were abundant in the deep waters of Fehmarnbelt especially in February.
- No spawning grounds of whiting in Fehmarnbelt and adjecent areas were identified
- Only an insignificant number of whiting might spawn in Fehmarnbelt and adjecent areas
- No whiting eggs were identified

- Whiting preferred sandy habitats without stones, vegetation and mussels
- Whiting avoid habitats with eel grass
- The importance of Fehmarnbelt and adjacent areas for whiting is listed in Table 4.13.
- Whiting do not spawn east of Skagerrak and the numerous whiting found in Fehmarnbelt were primarely juveniles which have migrated from the spawning grounds west of Kattegat. Aspects regarding spawning, eggs and larvae or adult feeding are thus of minor or non importance.
- Whiting may use the shallow coastal areas of Fehmarnbelt as nursery area which corresponded well with previous studies. Aspects in relation to nursery area might thus be of importance.
- First-time spawning whiting from the Baltic Sea seem to aggregate in the deep central waters of Fehmarn during early spring probably ready to migrate towards spawning grounds.

Table 4.13: Importance of Fehmarnbelt and adjacent areas for whiting in relation to spawning, eggs and larvae drift, nursery, feeding and migration. - = not relevant.

Environmental component	spawning	egg-larvae drift	nursery	feeding	migration	overall
Whiting	-	-	minor	-	medium	medium

4.5 Herring

4.5.1 General background

Historically two major herring stocks have been distinguished in the western Baltic: the Western Baltic Spring Spawning (WBSS) herring, which spawns in February-May in shallow waters (<12-15 m), and the Western Baltic Autumn Spawning (WBAS) herring, which spawns during September-November at greater depths of about 10-20 m. Both stocks are regarded as "open sea stocks", which undertake annual migrations between the feeding grounds in Skagerrak and in the eastern North Sea and the spawning grounds in the western Baltic (ICES, 2007a). In addition to these two major stocks, there are a number of local spring and winter spawning herring stocks that only migrate between local feeding and spawning grounds in the western Baltic Sea.

Legal frameworks concerning the management of the herring fishery are put forth by the EU Common Fishery Policy (CFP). TACs (Total Allowable Catches) and quotas are presented to the Commission by the STECF (Scientific, Technical and Economic Committee for Fisheries), which to a great extent depends on advice from ICES. ICES annually assesses the western Baltic herring stocks in Division IIIa and Subdivisions 22-24, which provides the basis for advisory and fishery management plans concerning the stocks. The legal framework concerning herring is summarized in Table 4.14.

Table 4.14: Legal framework outlining the management of the herring stocks. CFP = EU Common Fishery Policy.

Issue	GE legal framework	DK legal framework	Guidelines/advice
Fishery	CFP	CFP	ICES, division IIIa and subdivisions 22-24.
			European Commission, Council Regulations stipulate fishing opportunities for certain fish stocks and groups of fish stocks applicable in the Baltic Sea
			EU, Council Regulation (EC) No 2187/2005 for the conservation of fishery resources through technical measures in the Baltic Sea, the Belt Sea and the Øresund, amending Regulation (EC) No 1434/98 and repealing Regulation (EC) No 88/98
Conservation	HELCOM List of threatened and declining biotopes and species		HELCOM Red List of threatened and declining species of lampreys and fishes of the Baltic Sea (HELCOM, 2007). The WBAS-herring is red listed in Germany and is considered endangered in the Baltic as a whole

The stock status, as assessed by ICES in 2009, is that the biomass of the spring spawning herring stock (WBSS) in subdivisions 22-24 has been relatively stable since 1995 (ICES, 2009a). However, recruitment to the stock has consistently declined from 2003 to 2008, and poor year classes in combination with increasing pressure from the fisheries have lead to an all-time low spawning biomass of around 105,000 tonnes in 2009 (ICES, 2010d). However, herring larvae surveys in 2009 indicate an increase in recruitment that year, which may help reversing the downward trend (ICES, 2010d).

The main spawning area for the spring spawning herring in the western Baltic is considered to be Greifswalder Bodden at Rügen (Biester, 1979; Biester, 1989; Klinkhardt, 1996), which is located approximately 200 km east of Fehmarnbelt. Even though an often used synonym for the western Baltic herring is the Rügen herring, recent genetic and morphological studies reveal that several genetically distinct populations exist in the western Baltic (Bekkevold et al., 2005; ICES, 2008b; EU-FP5, 2009).

The autumn spawning herring stock (WBAS) has declined strongly since the 1970´s (ICES, 2007a), and consequently the stock has been red listed in Germany (Fricke et al., 1996). Considering the Baltic as a whole, the status of the stock is assessed as “endangered” (HELCOM, 2007). There is no ICES assessment of the autumn spawning herring stock due to insufficient data. Furthermore, there is no specific regulation of fishery on the autumn spawning herring stock.

The small autumn-spawning herring stocks in ICES Subdivisions 22-24 presumably have spawning areas located in the coastal area of Mecklenburg Bay, on the banks of the Arkona Basin and along the coast of Bornholm (Rechlin, 1967; Nielsen, 1996) as well as in the outer and inner waters of the Greifswalder Bodden (Scabell, 1988; Klinkhardt and Reschke, 1980; Klinkhardt, 1996). At present information on the stock is very sparse because of their low numbers.

In general, it is agreed that autumn spawning herring spawn in deeper and more open sea areas whereas the spring spawning herring normally prefer to spawn in shallow coastal or inner coastal waters (Rechlin, 1967; Klinkhardt, 1996). Several studies have shown that herring may spawn on a wide variety of substrates except soft sediments, and that herring tend to spawn at, or near, the same site every year (Scabell, 1988; Aneer, 1989; Klinkhardt 1996; Kääriä et al., 1997). Baltic herring seem to prefer spawning on vegetation rather than on pebbles and stones, although the type of preferred vegetation may change over time (Scabell, 1988; Aneer, 1989).

The larval stage can last several months (Blaxter, 1969) and passive drift may bring juvenile herring to nursery areas far away from their original spawning grounds. In general, juvenile herring tend to have their nursery areas in shallow waters such as in bays and fjords, separate from the adults. When herring are approximately two years old they move into deeper waters and join the adults in their feeding and spawning migrations. These migration patterns are generally regarded as being relatively constant over periods of several years, but whether the routes are genetically determined or the juveniles adapt their migration behaviour from adults is not known (Brophy, 2006; Bekkevold et al., 2007). Very little is known about the migration of juveniles from nursery areas to feeding areas.

Both juveniles and adult herring are primarily pelagic and their distribution is affected by hydrographical features such as temperature, depth of the thermocline, mixing, frontal systems and the abundance and composition of the zooplankton on which they feed. Larvae feed on copepod nauplii and micro-zooplankton, while juveniles feed on *Pseudocalanus*, *Paracalanus* and *Temora* copepodites and small meroplankton. Adult herring feed on *Calanus*, *Temora*, *Oikopleura*, Schizopoda, amphipods, mysids, young fish such as juvenile sandeel *Ammodytes* spp. and fish eggs (Casini et al., 2004; Möllmann et al., 2004). Herring tend to gather near the surface at night to feed on zooplankton and are mostly dispersed throughout the water column during the day.

Fehmarnbelt forms a heterogeneous area with several habitats and the environmental conditions that are affecting herring populations are diverse. In the following Table 4.15 environmental settings and existing pressures of importance for herring are listed.

Table 4.15: Environmental settings and existing pressures of significance to herring in Fehmarnbelt.

Basic environmental setting	Variable hydrodynamics exposed shoreline	Sheltered conditions and a fairly stable environment with good access to food are generally acknowledged to enhance WBSS herring recruitment (Otterlind, 1984; Scabell, 1988; Aneer, 1989; Kääriä, 1997; Nielsen, 1999; ICES, 2008b). In this regard, the environment at Orther Bight and the lagoon of Rødsand appear to be more optimal compared to the open exposed coastline along Fehmarnbelt.
	Stratification	Since herring eggs are attached to the bottom substrate until hatching they are less affected by horizontal stratification compared to species with pelagic drifting eggs.
	Salinity	Herring eggs, particular of the WBSS stock, are normally exposed to moderate salinities of 5-9 psu (Greifswalder Bodden; Scabell, 1988) compared to 6-30 psu in Fehmarnbelt (measured during the survey). Herring eggs are fairly resistant against salinity fluctuations (Klinkhardt, 1996).
Food competitors	Feeding areas	The most important competitors for food are expected to be found outside of Fehmarnbelt.
	Sprat	Sprat is a serious competitor for food, particularly among young herring in the southern Baltic and in the Baltic proper (Casini et al., 2004; Möllmann et al., 2004). A change in zooplankton communities caused by an increased primary production and/or climate change is believed to have favoured sprat in comparison to herring in the Baltic (Möllmann et al., 2004, Möllmann et al., 2005; Rose, 2005; ICES, 2005).
Predators	Cod	Cod is one of most important predators of herring in Kattegat and the Baltic (Barros et al., 1998; Johansen, 2002; Enin and Gröger, 2004). A large decrease in cod populations in these waters in the last decades has reduced predation pressure on herring considerably. However, the latest stock increase of cod in the Baltic and western Baltic may have increased predatory pressure again.
	Mammals	A decline in abundance of fish-eating mammals in the 20th century has reduced mammal predation pressure on herring (Elmgren 1989; Thurow, 1997, MacKenzie et al. 2002). However, since hunting of seals was banned in 1976, the seal population has increased by about 10% annually, only temporarily disrupted by outbreaks of phocine distemper virus disease in 1988 and 2002 (Teilman, 2006; Härkönen, 2008).
Fishery		Mortality due to fishing is believed to have been one of the major factors leading to the low spawning stock biomass in 2009 (ICES, 2010d).
Eutrophication	Nutrient enrichment	Especially fish communities and young fish in coastal areas are affected by the increased nutrient input caused by anthropogenic influence (Thiel et al., 1996).
	Anoxia	Anoxia affects egg mortality and has been suggested to have contributed to the significant decline in the western Baltic autumn spawning herring (Rechlin, 1991), and amongst herring in the Baltic sea in general (Aneer, 1985).
	Decreased water clarity	Although western Baltic herring may spawn on a wide variety of substrata, macrophytes are often preferred. Reduction of water clarity has generally reduced macrophyte vegetation coverage, and hence reduced the area of potential herring spawning sites (Scabell, 1988; Klinkhardt, 1996).
Invasive species	Mnemiopsis	The occurrence of invasive species affects the fish communities in the coastal waters of the Baltic sea. For example the jellyfish *Mnemiopsis leidyi* has the potential to affects the success of fish species in Fehmarnbelt.

4.5.2 Baseline approach

The overall objectives of the baseline studies have been to focus on the significance of Fehmarnbelt to the recruitment of the western Baltic herring stock, including its importance as a spawning and nursery area for autumn and spring spawning herring, and on the significance of Fehmarnbelt as a passage route for migrating herring on their way to and from feeding areas in the Kattegat/Skagerrak and the North Sea. The baseline investigations therefore included the collection of data related to different life stages of herring with the purpose of addressing the following issues:

- Identification of spawning grounds and spawning herring in the area
- Identification of herring larvae drift in the area
- Identification of herring nursery grounds in the area
- Identification of migration routes through the area

Since the knowledge about herring in the Fehmarnbelt area was limited, information obtained from field investigations was used as a primary source to describe the baseline conditions. The field studies used a wide variety of sampling techniques, including screening of herring abundance in open and coastal waters by means of hydro acoustics, trawls, pound nets, herring gill nets and monitoring gill nets, as well as screening of the sea bottom after spawning beds, and bongo trawling after herring larvae. See chapter 3 for further description of the methods used.

The location and timing as well as the frequency of surveys were determined from a general knowledge of the seasonality among herring, from historical data and from data presented in the herring feasibility study carried out in Fehmarnbelt in 1997 (Riber and Raschke, 1999). Historical data, particularly data concerning Greifswalder Bodden and the Rügen herring (Biester, 1979; Scabell, 1988; Biester, 1989; Klinkhardt, 1996), were also used to form a basis for comparative analysis.

In addition, to determine individual population affiliation otoliths were analysed and genetic analysis of tissue from herring were performed.

4.5.3 Spawning

Based on habitat modelling and information from fishermen, the Fehmarnbelt feasibility study from 1997 (Riber and Raschke, 1999) identified possible spawning sites for spring spawning herring along the coast of Fehmarn and Lolland, including the Rødsand Lagoon. Possible spawning sites for autumn spawning herring were restricted to the southeastern coast of Fehmarn and parts of the Mecklenburg Bight. Even though updated information from fishermen indicated a decline in spawning activity, the locations for the present baseline studies were primarily based on the proposed areas from the 1997 study. However, in view of the significant size of the area and since herring spawning beds can be relatively small several methods were combined to cover the coastline. Besides finding actual spawning beds, the presence of spent herring and particularly herring larvae would also be a strong indication of spawning activity.

The Fehmarnbelt area was screened for spawning herring and spawning sites by:

1. Registrations of gonad maturity among herring caught in local fishermen's pound nets or in trawl hauls performed as part of the hydro-acoustic surveys.
2. Gill net surveys ("spawning herring surveys"), which were used to locate herring that were spawning capable, spawning or already spent, in an attempt to locate specific spawning sites.
3. Video screening of the sea bottom to detect actual spawning beds or potential spawning substrate.
4. Estimation of the amount of spawned eggs (if any) at identified spawning beds.

5. Determination of presence and abundance of herring larvae and backtracking of these larvae to the spawning sites.
6. Identification of herring stock affiliations by genetic analysis of adults and larvae. This was done to help assessing whether the adult herring were local spawners or were migrating through Fehmarnbelt and to assess if the larvae had drifted into the the Fehmarnbelt area from more distant spawning grounds.

4.5.3.1 Spawning season

The maturity index as well as the Gonado-Somatic Index (GSI) of herring caught during the hydro-accustic surveys from April 2009 to June 2010 is shown in Figure 4.67 and Figure 4.68.

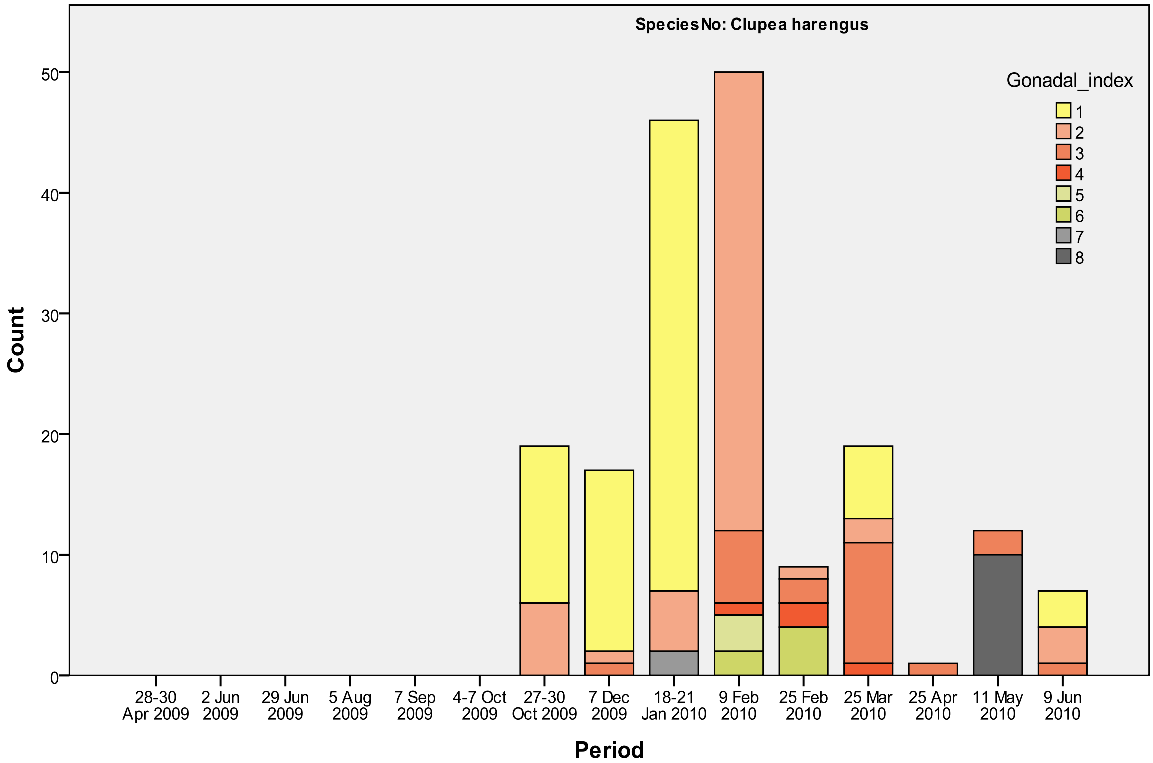


Figure 4.67: Maturity index of herring caught from April 2009 until June 2010. 1 = juvenile, 2 = early maturation, 3= mid maturation, 4 = final maturation, 5 = spawning capable, 6 = spawning, 7 = spent-recovery, 8 = abnormal.

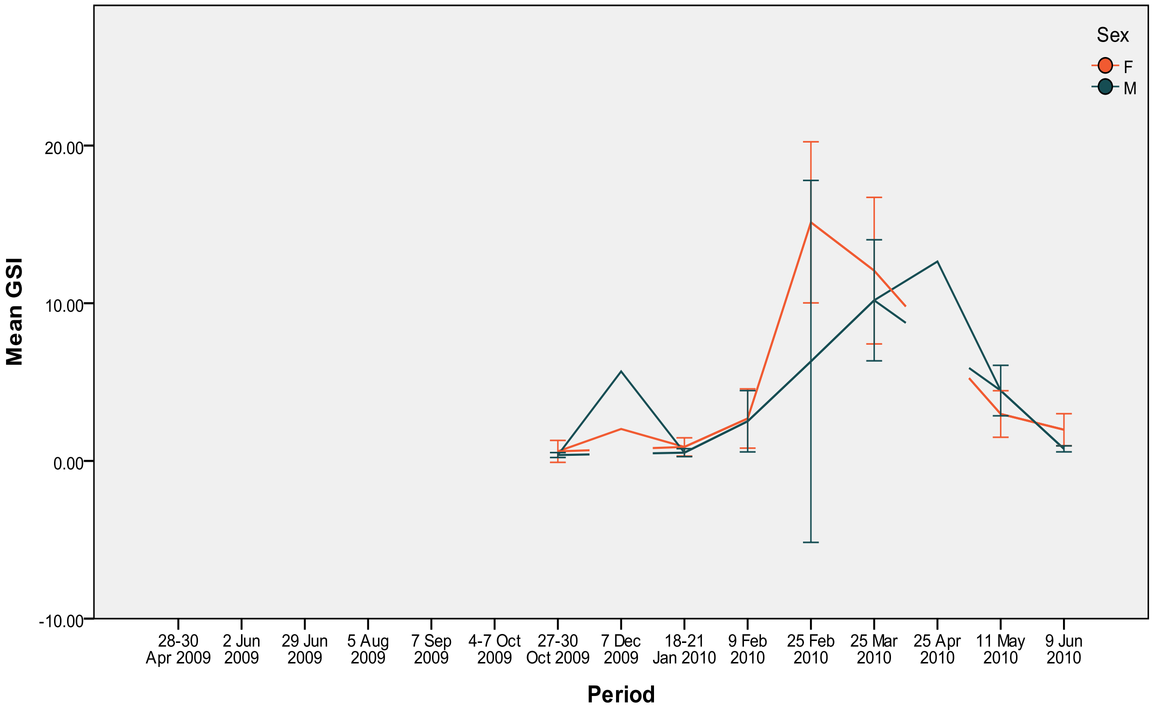
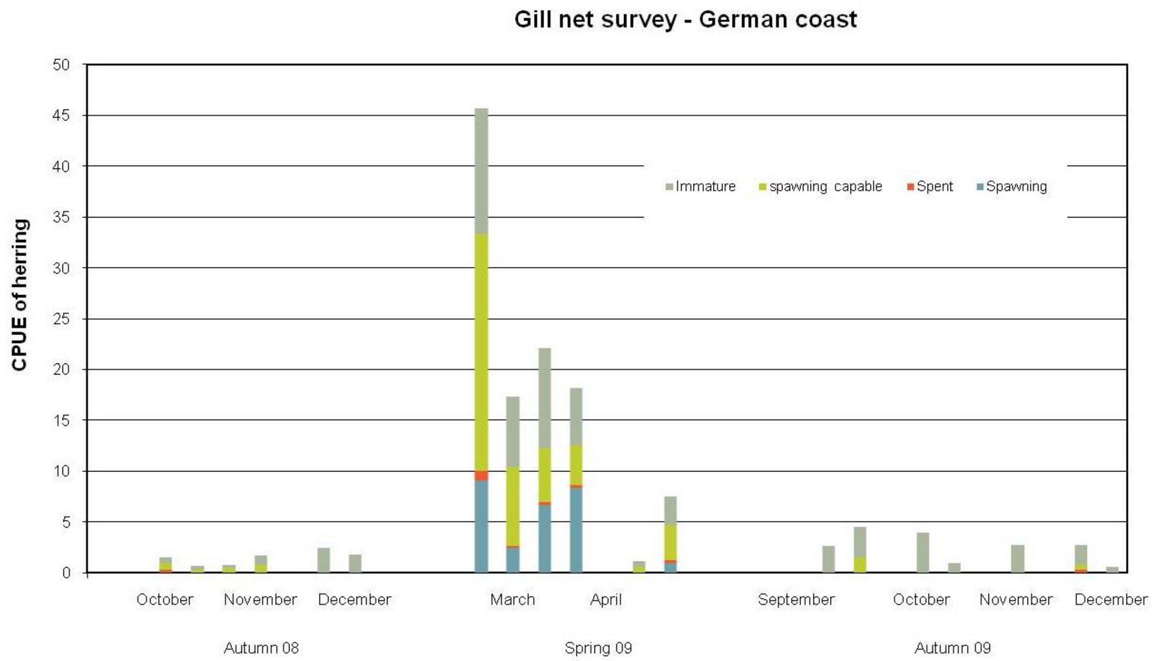


Figure 4.68: Mean GSI of herring (gonadal wet weight as a percentage of total wet weight). F = Female, M = Male. Errorbars: ± 2 SE.

In these surveys herring were only caught between late October and early June. Active spawners and individuals prepared to spawn were only caught in February while spent herring were present in May. The Gonado-Somatic Index also indicated that spawning occurred between February and May.

Analysis of the maturity of the gonads among herring caught in the targeted gill net surveys showed that a number of herring were spawning in spring (March - April) but no conclusive trends to determine spawning time more precisely could be found. The majority of herring caught in the autumn surveys in 2008 and 2009 in the Fehmarnbelt area had immature gonads, and only a few were either with free running milt and roe or recently spent (Figure 4.69). However, several herring were spawning capable (Bucholtz et al., 2008), particularly along the coast of Lolland in autumn 2009. But since this stage may last for several months (Iles, 1964), it is possible that these herring would not spawn until spring.



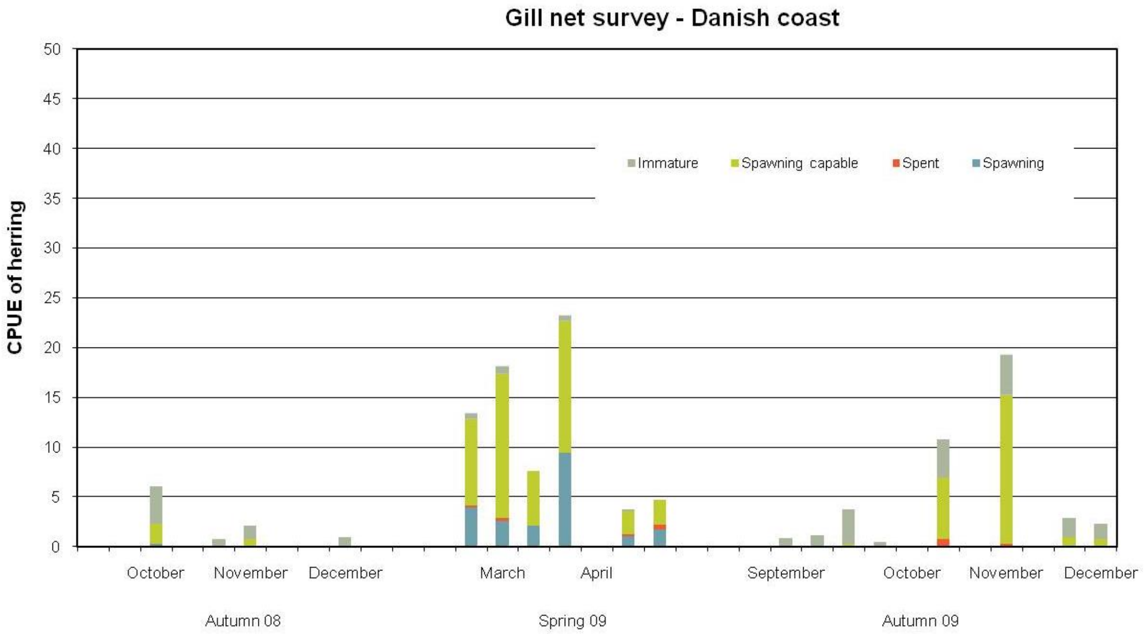


Figure 4.69: Weekly average CPUE (Catch Per Unit of Effort) of herring in different maturity stages. Data from the herring gill net surveys along the coast of Fehmarn and Lolland in the autumn 2008, the spring 2009 and the autumn 2009.

The herring caught in spring had significantly larger and more mature gonads, and the density of herring (CPUE, Catch Per Unit of Effort) was significantly higher than in the autumn surveys (Figure 4.69). Nevertheless there was still no clear trend in gonad maturity and, similar to the autumn survey, very few spent herring were caught. However, a considerable number of herring had free running roe and milt, but since this may have been provoked by the stress of being caught, no firm conclusions could be drawn from these data.

The very low number of spent herring indicates that spawning activity in the Fehmarnbelt area is very limited. The percentage of spent herring reached a maximum in mid-April and was at that time 6.9% of the weekly catch. This was 10 times less than what was observed in a similar investigation at Sprogø, which is a known herring spawning ground near the Great Belt

Bridge. At this site the share of spawning and spent herring clearly increased during spring and reached a maximum of 70% spent herring in late April (COWI, 1996).

The presence of higher numbers of spent herring in gill net surveys in Fehmarnbelt in the spring of 1997 (Riber and Raschke, 1999) suggests that spawning in the Fehmarnbelt area was more frequent at that time.

Herring caught in gill nets were also examined for occurrence of the nematode *Anisakis sp.* This nematode infects herring on their feeding grounds in Kattegat and Skagerrak and is used as a tag parasite of herring migration between Danish inland waters (van Deurs and Ramkjær, 2007). The high percentage of infected herring, especially in spring (Figure 4.70), indicates that the majority of herring present in Fehmarnbelt have their feeding grounds in Kattegat, Skagerrak and the North Sea, and arrive at or pass through Fehmarnbelt in the spring.

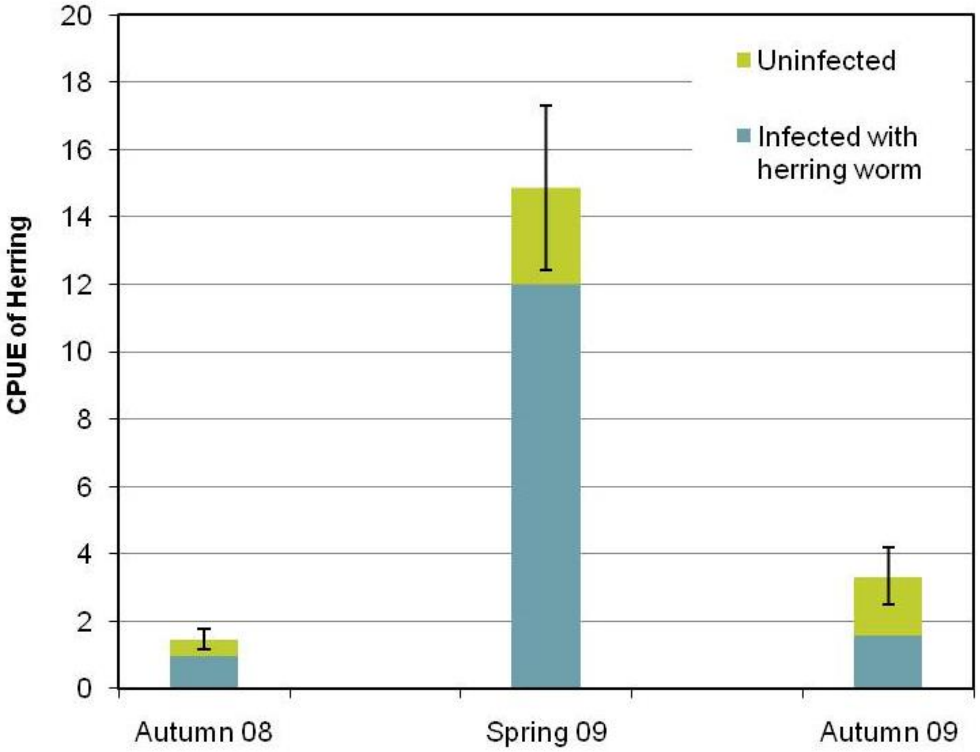


Figure 4.70: The average CPUE (Mean ±SE) of herring in autumn 2008, spring 2009 and autumn 2009 caught during the gill net surveys along the coast of Fehmarnbelt. The CPUE is grouped into uninfected herring and herring infected with the parasitic nematode *Anisakis sp*.

4.5.3.2 Otolith microstructure analysis of adult herring

The majority of the herring analysed were categorised as spring spawners both among the individuals caught in the autumn and spring (67% and 100%, Figure 4.71). When analysing for the effect of sampling month on the assigned spawning type, the timing of the sampling had a significant effect on which spawning types were seen in the samples (ANOVA, $F(5,92)=5.09$, $p<0.001$, Figure 4.71). Thus, the winter spawners found in the samples in November and December were most likely to spawn in winter (GSI >6). Whether these individuals were going to spawn near-site could however not be resolved with the present analysis.

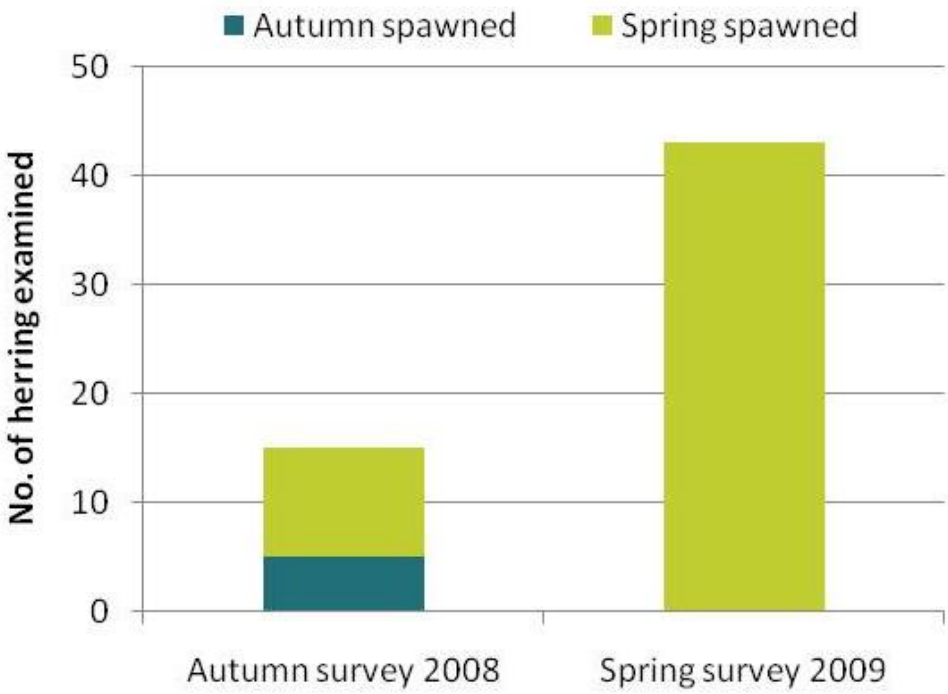


Figure 4.71: The distribution of spawning types of herring (autumn and spring spawned) in the subsamples taken in Fehmarnbelt 2008-2009.

4.5.3.3 Spawning sites

Catches of herring were significantly higher during spring than during autumn and varied between locations (Figure 4.72). The mean CPUE was higher at the Fehmarn coast than at the Lolland coast but the difference was not statistically significant; nor was there any significant difference between the CPUE in Orther Bight and the CPUE along the general coastline. By contrast, CPUE of herring in the lagoon of Rødsand was significantly lower than the average density due to a large numer of zero catches.

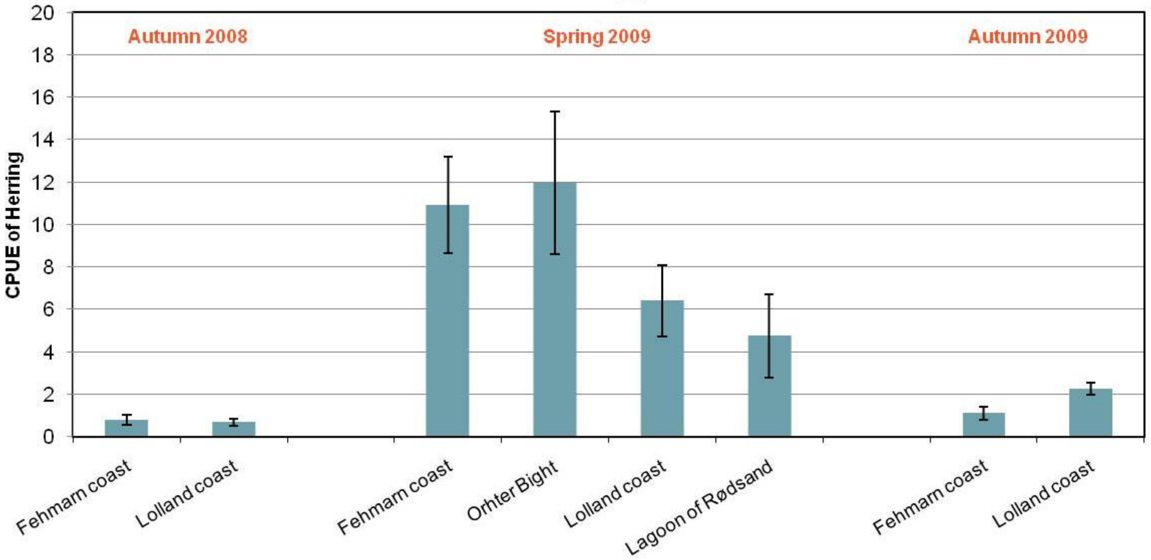


Figure 4.72: Average CPUE (mean ±SE) of herring caught during the gill net surveys along the coast of Fehmarn and Lolland in the autumn 2008, the spring 2009, the autumn 2009 and in the bight of Orther and the lagoon of Rødsand in the spring 2009.

No spawning sites were found during the screenings of the sea bottom for herring spawning beds in autumn 2008, spring 2009 and autumn 2009.

During the spring survey, intensive screening was performed using both hand-held and remote video cameras. A total of 290 transects amounting to a total distance of 145 km along the coasts of Fehmarn and Lolland, as well as in the more protected areas of Orther Bight and the Rødsand Lagoon, were screened. Although no herring eggs or spawning grounds were detected, suitable spawning substrates were widely distributed throughout the studied areas. Red algae were particularly common along the majority of transects in relatively dense patches, but also eelgrass and seagrass were frequently observed east of Fehmarn and especially in the Rødsand lagoon (Figure 4.73 and Figure 4.74).

Figure 4.73: Left: stones covered with red algae at a depth of 11 m found off the east coast of Fehmarn, October 2008. Right: red algae beds at a depth of 5 m observed west of Kramnitze harbour, Lolland, March 2009.

Since autumn spawning of herring is assumed to occur at greater depths than in spring, the screenings in the autumn were performed at depths of 8-20 m where sand and clay are generally predominant. However, particularly in the areas east of Fehmarn, boulders and stones with macrophytes were rather frequent while patches of red algae alternating with mussel banks were found at many sites off the coast of Lolland (Figure 4.74).

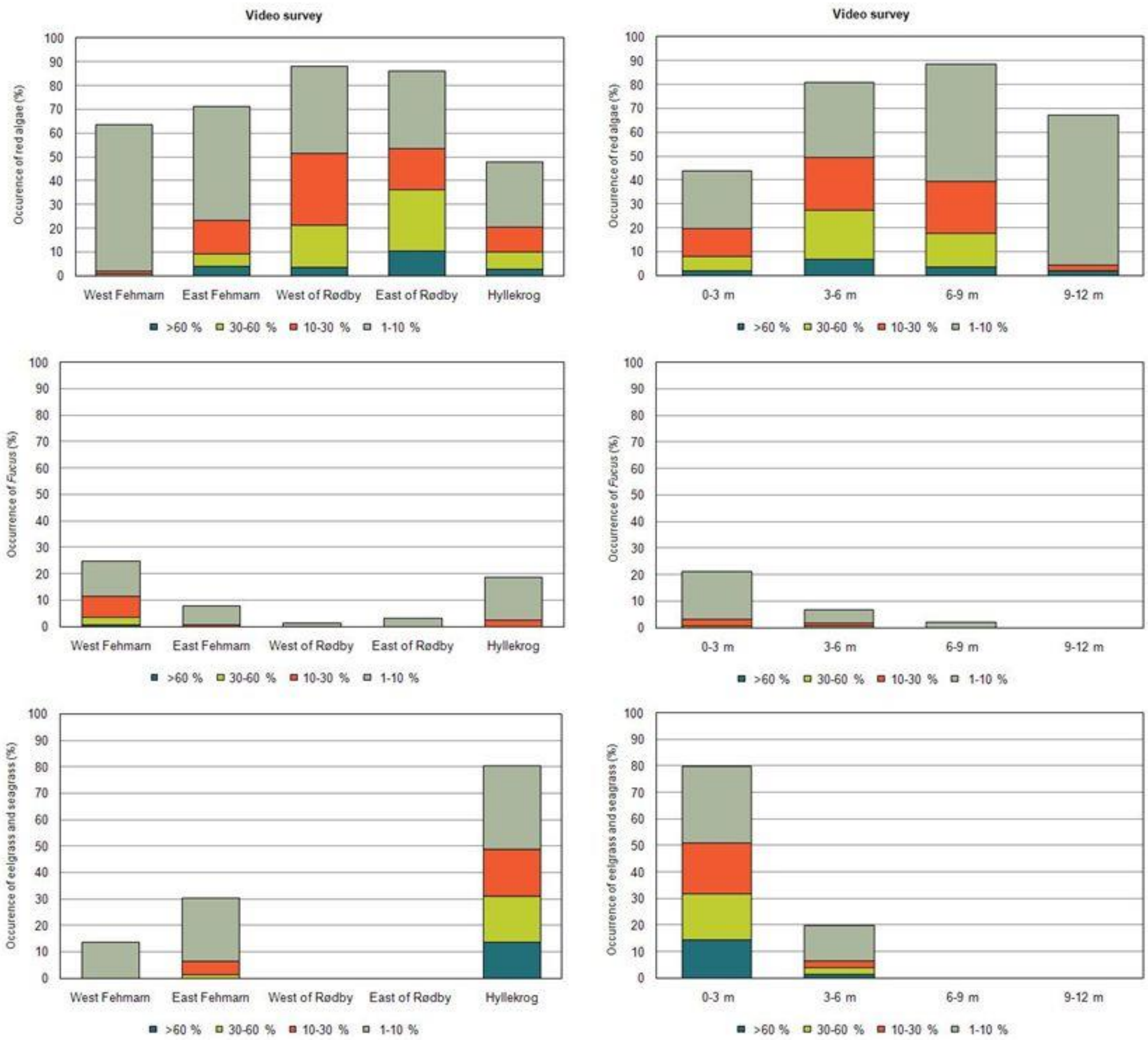


Figure 4.74: Left collumn: Cover of red algae, Fucus, eelgrass and seagrass from the videoed transects in different coastal areas of Fehmarnbelt in March-May 2009. Right collumn: Cover of red algae, Fucus, eelgrass and seagrass from the videoed transects in different depth zones in the coastal areas in Fehmarnbelt in March-May 2009.

Despite the existence of suitable spawning substrates, strong currents and the exposed character of most of the coastline around Fehmarnbelt may render the area less suitable for herring spawning. A detrimental effect of strong water currents on the survival of herring eggs and larvae during the spring spawning season was described by Scabell (1988) for the spawning areas of Greifswalder Bodden.

4.5.4 Eggs and larvae

Although a total of 290 transects of approximately 500 m each were surveyed along the coasts of Lolland and Fehmarn, no herring eggs were found (cf. above).

Occurrence of herring larvae was examined at 12 bongo trawl surveys performed between October 2008 and March 2010. Figure 4.75 gives an overview of the average density (no./m^3) of herring yolk sac larvae and post larvae found during these surveys. The density of herring larvae was significantly lower in autumn than in spring. In April and May, a high proportion of the larvae were yolk sac larvae and thus in the very early stages of development.

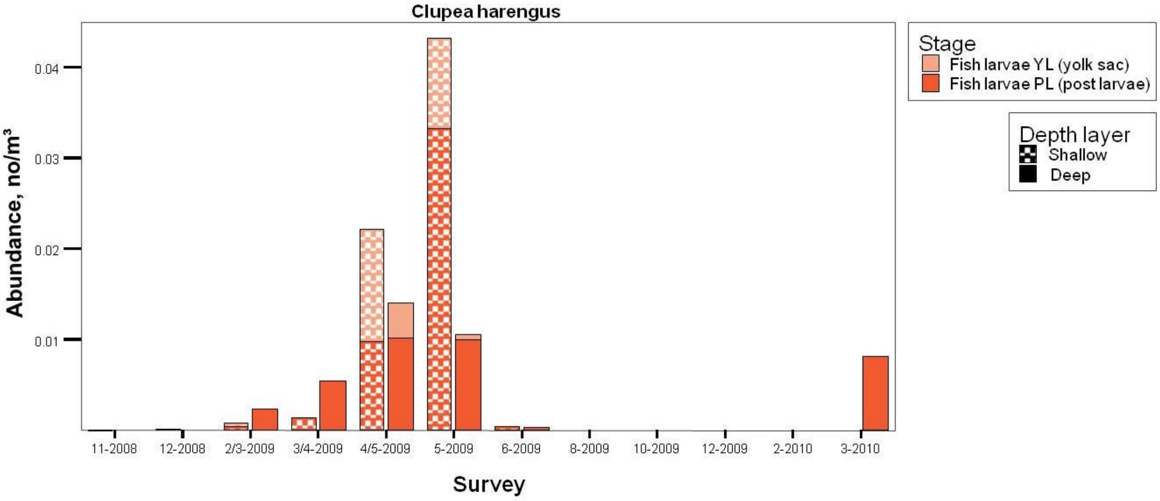


Figure 4.75: Average densities (no./m^3) of yolk sac and post larvae of herring in 12 surveys performed between October 2008 and March 2010.

4.5.4.1 Autumn spawning herring

Only 5 herring larvae were caught during the 2008 autumn survey and the average density of larvae was approximately 0.0001/m^3 (Figure 4.75). In the 2009 autumn survey no herring larvae were caught (FeBEC, 2011d).

The age of the caught larvae was considered to be approximately 13-18 days according to the developmental stage of the larvae and the temperature from hatch to catch (Russell, 1976). Only one of the larvae still had a yolk sac. Details on the caught herring larvae are shown in Table 4.16.

Table 4.16: Data on catch position, date, time, estimated age and catch depth of the 5 autumn spawned herring larvae caught in Fehmarnbelt.

Autumn Spawning Herring						
Station no.	N pos WGS	E pos WGS	Date	Time	Estimated Age (days)	Catch depth (m)
2	54,69667	10,94475	07-11-08	11:37	13	9
6	54,64238	11,28421	07-11-08	15:30	13	5
8	54,61849	11,35123	01-12-08	11:35	14	9
10	54,58642	11,42746	01-12-08	12:51	16	5
24	54,1699	11,5912	04-12-08	10:37	18	5

Based on the catch position, date, time, estimated age and catch depth, the route of each herring larva may be backtracked to the area where it was hatched by means of a hydrodynamic model (see section 3). However, as the uncertainties associated with backtracking increase dramatically with increasing age of the larvae, no reliable backtracking of the 13-18 days old autumn spawned larvae could be performed. Pilot backtracking runs indicated that the herring larvae were probably spawned outside the Fehmarnbelt area (FeBEC, 2011b), but no firm conclusions concerning the origin of the larvae may be drawn.

4.5.4.2 Spring spawning herring

The density of herring larvae during the spring survey was much higher than the density of herring larvae in the autumn. However, the density of herring larvae (yolk sac and post larvae) during the spring survey of 2009 never exceeded an average of 0.05 herring larvae/m^3 and a maximum of 0.25/m^3. Larvae were caught mostly in shallow waters (Figure 4.75) over most of Fehmarnbelt (Figure 4.76). To compare, Rehnberg et al. (2009) found that densities of spring spawned herring larvae at 5 different surveys at Greifswalder Bodden ranged from 0.2-2.7

herring larvae/m^3 and in the Kiel Fjord, IFM Geomar observed maximum values of 2.2 larvae/m³ (mid May) in 2005, 2.5 larvae/m³ (late May and June) in 2006 and 3.6 larvae/m³ (early June) in 2007 (pers. comm., Dr. Christoph Petereit, Leibniz Institute of Marine Sciences, IFM-GEOMAR).

The densities of herring larvae found in Fehmarnbelt during this baseline investigation were thus approximately ten times lower than densities found at spawning grounds in Greifswalder Bodden and Kiel Fjord.

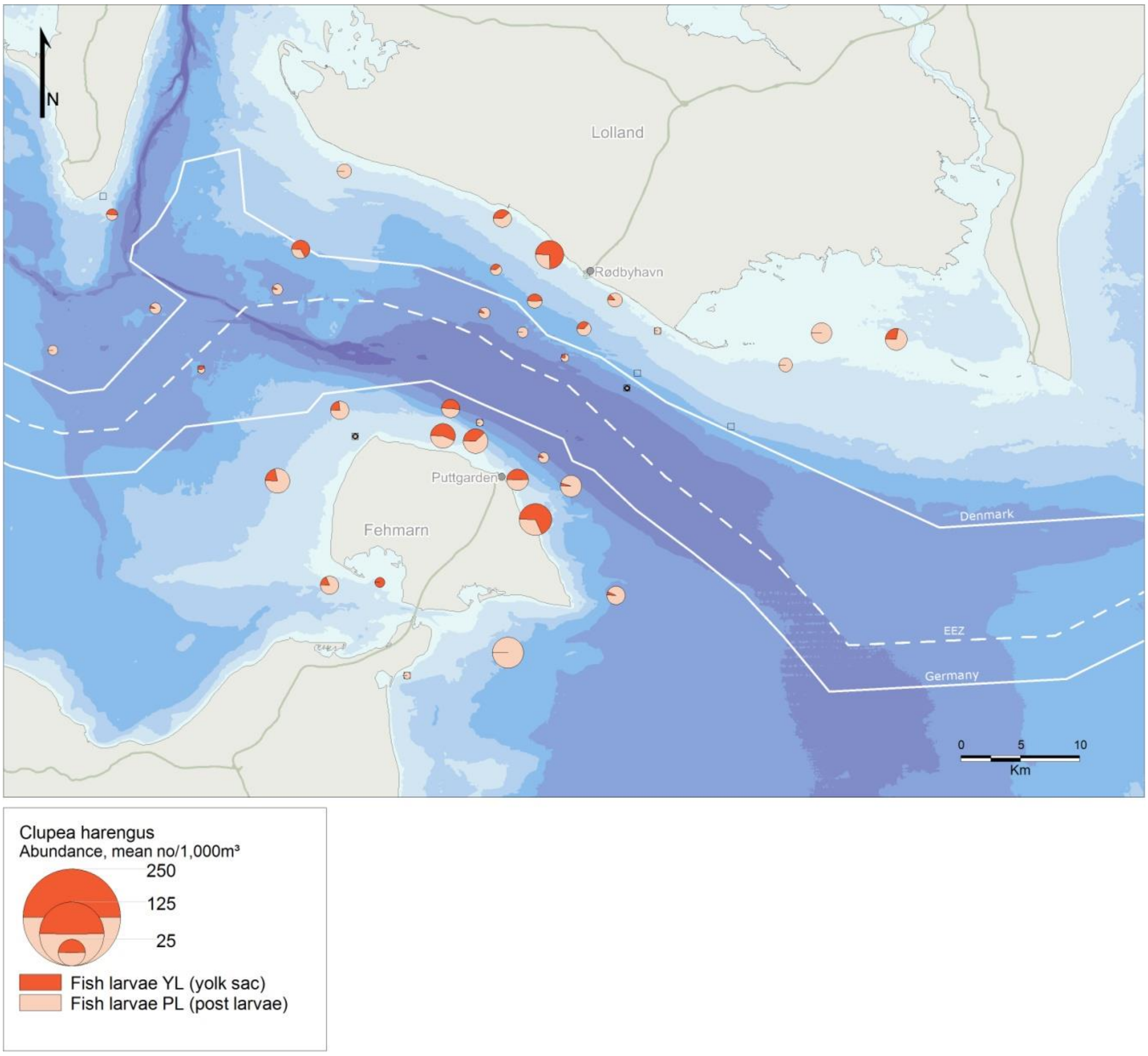


Figure 4.76: Average abundance (no./1,000 m^3) of herring larvae (*Clupea harengus*) in Fehmarnbelt from November 2008 to March 2010.

A map of possible spawning grounds in the Fehmarnbelt area was constructed by backtracking of the caught yolk sac larvae, taking mortality from hatch to catch (McGurk, 1986) and larval densities at the catch site into consideration (Figure 4.77). The results of the backtracking suggest that the larvae were mainly spawned in the shallow water areas along the southern coastline of Lolland and along the northern and eastern coastline of Fehmarn. The probability of spawning having occurred in any particular 1x1 km square was however low (Figure 4.77); this is in good accordance with the results of the video surveys where no spawning beds were detected.

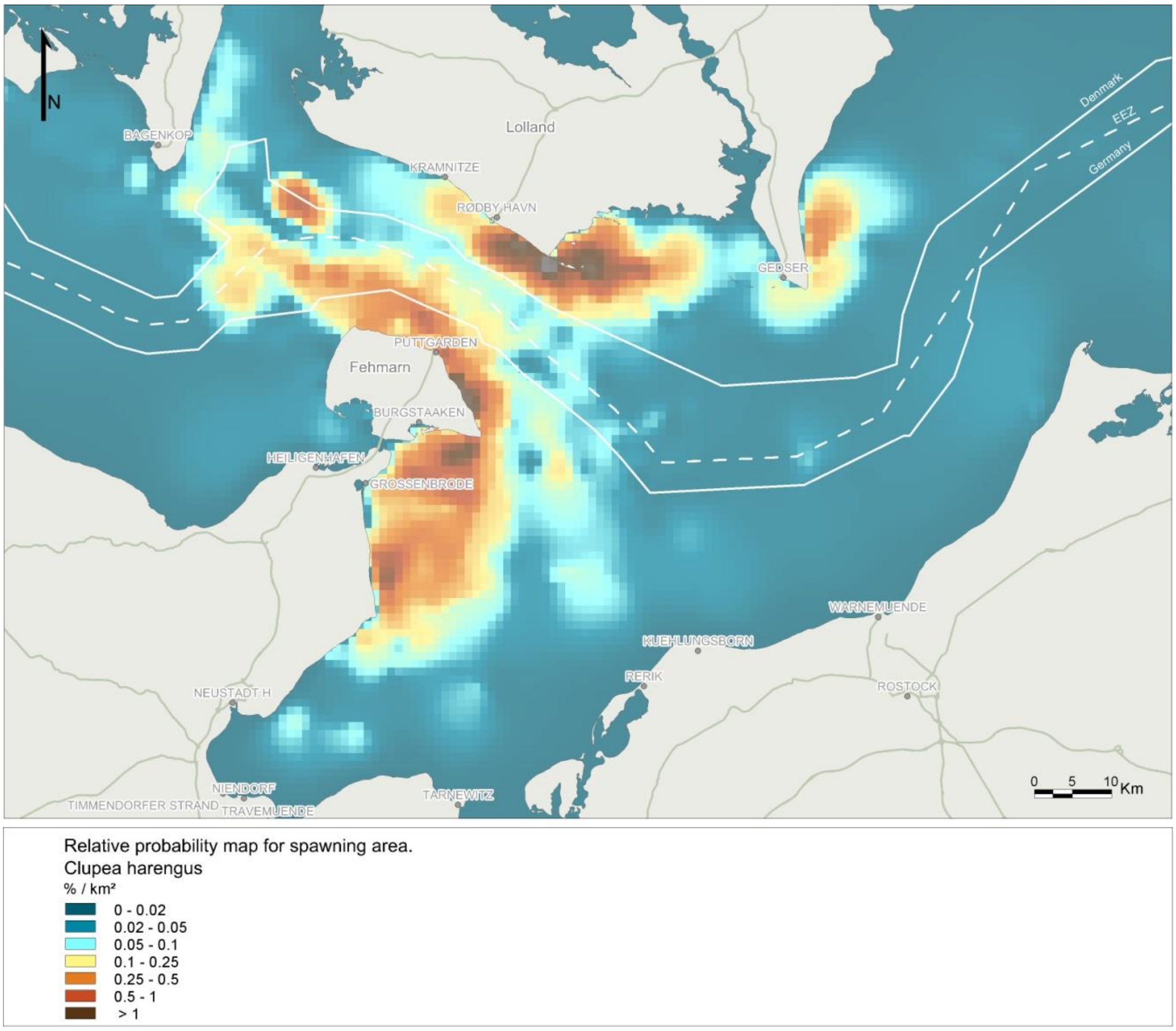


Figure 4.77: Relative probability map indicating spawning areas of spring spawning herring, when combining backtracking of yolk sac larvae, mortality from hatch to catch and the density of yolk sac larvae at the catch site during the main spawning period.

Recent information from a local fisherman suggests that a small herring spawning site is located in the Rødsand Lagoon although this was not verified during the video surveys.

4.5.4.3 Herring larval condition

The condition of herring larvae was assessed from RNA/DNA ratios. The RNA/DNA ratio depends on factors such as temperature, salinity, oxygen, turbidity, starvation vs. non-starvation and parental fish stock parameters (e.g. spawning condition). Therefore the RNA/DNA ratio parameters should only be considered as a guideline to evaluate the larval condition and not as an absolute measure.

The measured RNA/DNA ratios (2.2 - 2.3) of herring larvae from Fehmarnbelt were in the same range as the RNA/DNA ratios found at the reference station (Kiel Kanal where food is known to be plentiful). The measured values were higher than the RNA/DNA ratios of ≤1.4 found in the Kiel Bay (Clemmesen, 1994) and ranged well above the RNA/DNA ratios of starving Baltic herring larvae of comparable length in a microcosm experiment; the latter larvae had RNA/DNA ratios below 0.8 (±0.2). Since only a few larvae or no larvae were caught at each sampling station, no meaningful comparisons could be made between stations.

4.5.4.4 Prey availability and predation from gelatineous plankton

During the herring spawning season in spring the average density of mesozooplankton was found to be sufficiently high (more than 50 individuals of prey per l; see Figure 4.51) to sustain larval growth. Herring larvae mainly feed on copepod nauplii and copepodites of which the density was 10/l during the spawning season.

Mnemiopsis leidyi, *Aurelia aurita* and other gelatineous plankton only exhibited a limited predation pressure on herring larvae and their food resource as the average clearance rates were below 7% per day (see section 4.3 for further details).

4.5.5 Nursery and feeding

The results from the monthly gill net surveys were used to asses the distribution, abundance and habitat preferences of herring in the coastal areas. Open water populations were assessed using the results from the hydro-acoustic surveys.

In general, the CPUE of herring in the gill net surveys was low, and on average herring only constituted approximately 2% and 4% of the total gill net catches along the German and Danish coast, respectively. Thus, the coastal waters of Fehmarnbelt seemed to be little utilized by herring for feeding or nursery. Catches of juvenile herring (less than 15 cm) were particularly sparse, with a maximum density of approximately 0.1 per unit effort in the summer months (Figure 4.78).

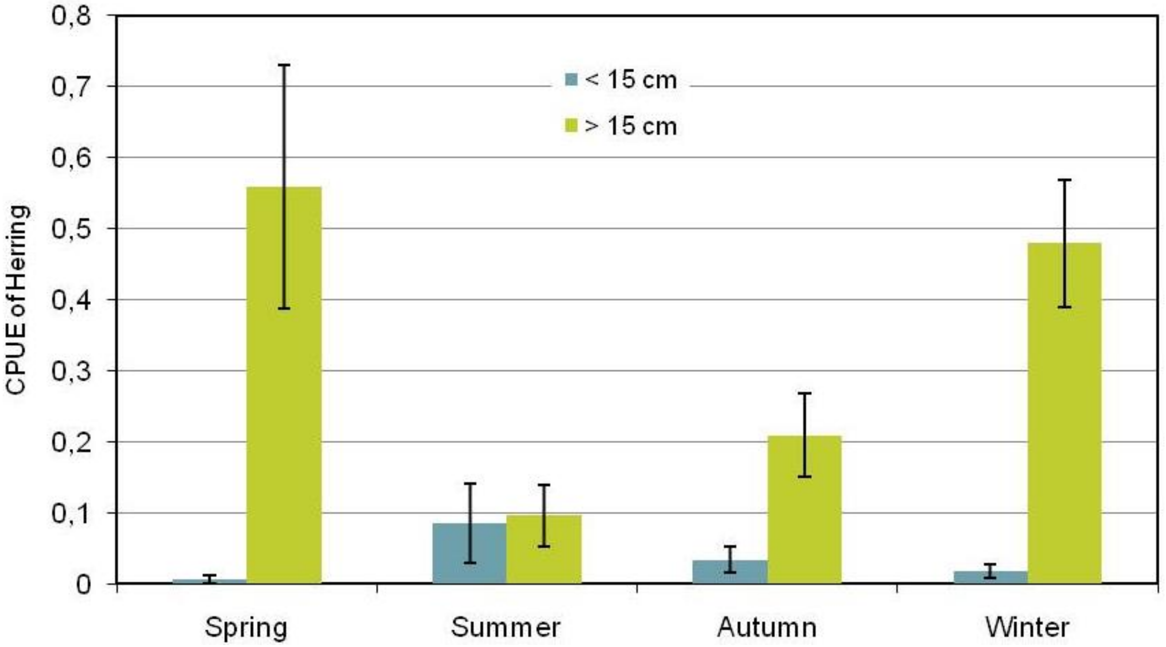


Figure 4.78: Average seasonal CPUE of two size classes of herring (smaller and larger than 15 cm) from monthly surveys with biological gill nets in the coastal areas of Fehmarnbelt, May 2009 - April 2010. Errorbars shows the standard deviation.

The abundance (CPUE) of adult herring was significantly higher in spring (during spawning migration) and in the winter months, compared with the low abundances during summer and autumn. By contrast, the highest abundance of the small “juvenile” herring was found during the summer months.

Catches from coastal waters varied between habitats (Figure 4.79). Juvenile herring strongly preferred sandy habitats in shallow water compared to habitats with vegetation and sandy habitats at greater depth. Similarly, adult herring were most abundant in shallow sandy habitats, although they were also observed in habitats with a cover of eelgrass or macroalgae. Densities of both small and large herring were significantly lower in habitats with mussels.

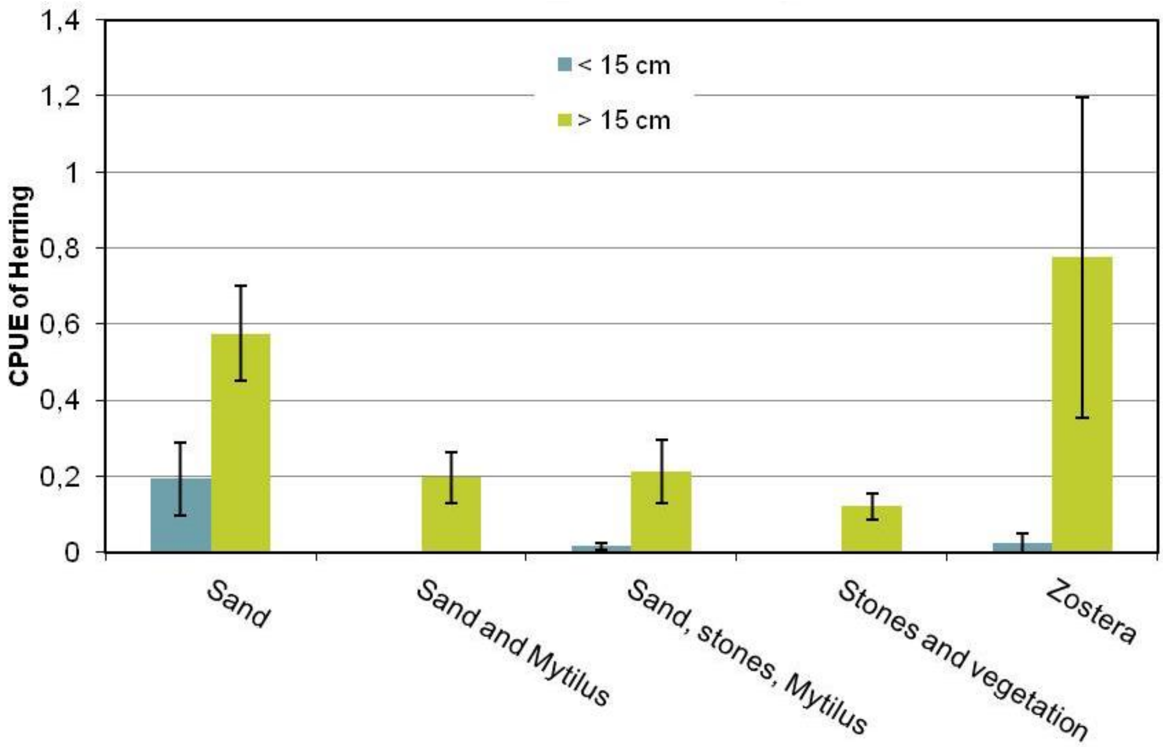


Figure 4.79: Average CPUE of two size classes of herring from monthly surveys with biological gill nets in different coastal habitats in Fehmarnbelt, May 2009 - April 2010. Errorbars shows the standard deviation.

4.5.6 Migration

As mentioned in section 4.4.1, most herring in the western Baltic are regarded belonging to "open sea stocks" which migrate between feeding grounds in the Skagerrak and the eastern North Sea and spawning grounds in the western Baltic. Several more or less resident and spawning herring components are present in many fjords and bays of the western Baltic, but very little are known about their migration in local waters (ICES, 2010d). Most of these local stocks spawn in the spring, but small winter and autumn spawning components are also present.

For the open sea stocks it is believed that the herring begin their seasonal migrations when they are 1-2 years of age. At that age the juvenile herring starts to migrate towards feeding areas in the southern Kattegat during the early summer months. These herring then move south in July and August, and from August to March they are found wintering in high abundance in the Øresund. Wintering areas may also be found in the Belt Sea, but several studies indicate that the Øresund is the major wintering area for the Rügen-herring component (Jönsson and Scabell, 1986; Nielsen, 1996). From the Øresund the herring moves south to the spawning grounds in March-April, where the largest size groups of herring seem to migrate before the smaller size groups (Nielsen et al., 1999). The decreasing abundance in the Øresund in the spring generally corresponds with the peak timing of landings in the fishery at the spawning grounds in the waters around Rügen.

The northwards migration back to the feeding grounds after spawning is not very well documented. Tagging experiments of Rügen herring from Greifswalder Bodden pointed towards a major route back through the Øresund, while herring primarily from the western part of Rügen and Mecklenburg seemed partly to migrate through the Belts (Jönsson and Scabell, 1986). However, no conclusive results could be drawn regarding this migration from the intensive monitoring programme in the Øresund in the years 1993-1998 during the construction of the

Øresund Bridge. Though, there were some indications of a continuous migration of spawned herring from March to May, no distinct temporal development could be distinguished for the spent herring (Nielsen, 1996). Fishery data contributes little to the knowledge since herring fishing through the summer is very scarce both in Øresund and in the Belt Sea. In particular, the present baseline has aimed to address the significance of the "back migration" route through Fehmarnbelt to the feeding areas for Rügen herring, due to limited information of this migration.

The baseline surveys indicated that the abundance of herring in the Fehmarnbelt area was higher in the spring 2009 and 2010 compared to other seasons, particularly the autumn 2008 and the winter 2009-2010. This suggests that herring visits the area in the spring, and all though the herring larvae abundance was low the egg- and larvae survey indicated that at least some of the herring spawn in Fehmarnbelt. Other herring may have been migrating, either on their way to or from spawning grounds around Rügen for example, and part of the baseline was therefore to screen the genetic affiliation of herring caught in the Fehmarnbelt.

4.5.6.1 Genetic analyses of herring samples from Fehmarnbelt

The analyses indicated that there was good statistical power for assigning individuals to each of the three regions:

1) North Sea

2) Western Baltic (i.e. spring spawning populations from the North Sea-Baltic Sea transition zone, covering locations from the Skagerrak to the western Baltic including Rügen and presumably local populations from the Fehmarnbelt area) and

3) Baltic Sea (from Hanö Bay to the Bothnian Bay).

Genetic assignment analyses of the 43 herring indicated that relatively few herring had 'pure' either North Sea or Baltic genetic signatures and mainly resembled western Baltic and Rügen herring (Figure 4.80). Although sample sizes were limited, there was a tendency for more herring collected in autumn/winter to have 'North Sea'-signatures, than collections in spring. Based on the current data it was not possible to determine if the 'North Sea'-signature herring represented transient migrants from the North Sea or Skagerrak, or whether they represent local winter spawning populations with genetic origin in the North Sea, as Bekkevold et al. (2007) hypothesized for winter-spawning herring from the Lillebælt area. No herring had a genetic signature that suggested that it did not belong to any of the baseline populations against which samples were matched. That means that there was no evidence in the current data that any fish belonged to a genetically highly differentiated population (e.g. a unique local population). However, it is also stressed that the statistical power for detecting local weakly differentiated populations is limited with the applied method.

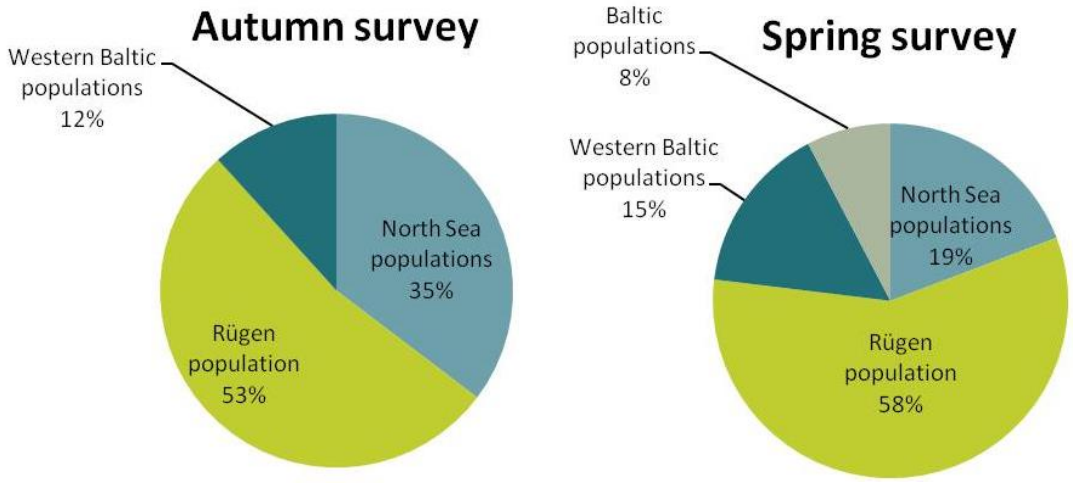


Figure 4.80: Numbers of individual herring assigning genetically to either North Sea, W. Baltic Sea, Rügen and Baltic Sea populations in samples collected in Fehmarnbelt autumn/winter 2009 and spring 2009.

In an unbiased self-assignment test, 77% of western Baltic herring assigned correctly, and respectively 88% and 79% of North Sea and Baltic Sea herring assigned to correct origin. In comparison, correct self-assignment to region ranged between 90-99% when a 300 snp panel was applied. This shows that the applied 30 snp panel only exhibited a ca. 10-15% decrease in individual assignment power in comparison with a panel ten times larger. In the current analysis, it was further of interest to determine if it was possible to separate herring spawned at the region’s major spawning location at Rügen from herring from other local populations. This was examined using a simulation analysis in which baseline data were self-assigned distinguishing between Rügen herring and other western Baltic spring spawning herring. This analysis indicated that 70% Rügen herring self-assigned correctly, 95% North Sea herring assigned correctly, 78% Baltic herring assigned correctly, and 57% of western Baltic spring-spawners assigned correctly. The relatively high proportion of mis-assigned herring from western Baltic samples mainly wrongly assigned to either Rügen or Baltic populations. This indicates that whereas herring from Rügen tend to assign correctly, there is relatively high risk of mis-assigning (non-Rügen) herring from spring-spawning populations in the western Baltic. However, mis-assignments will generally be to other western Baltic or Baltic populations.

Apart from revealing several populations, supporting the proposition made by Bekkevold et al. (2005) of a more complex puzzle of multiple herring populations than previously assumed, the results indicate that a relatively high proportion of the herring present in Fehmarnbelt are Rügen herring. The proportion was almost as high in the autumn as in the spring, which may indicate some overwintering in the area of this component or even presence of migrating autumn spawning Rügen herring. However, according to the habitat mapping survey and the herring gill net survey the abundance of herring in the autumn 2008 and 2009 was very low compared to the spring.

4.5.6.2 Abundance of migrating herring

According to the hydro-acoustic surveys the total fish density was in general very low in Fehmarnbelt in 2009-2010 with a mean annual average between 13.77 and 15.46 t/nm^2. Compared to monthly average densities found in Øresund in 1993-1998 of herring alone the total fish density in the Fehmarnbelt was many times lower, particularly in the autumn and winter (Figure 4.81). Since Øresund and Fehmarnbelt are comparable in area there seems little doubt that Fehmarnbelt plays an insignificant role as herring overwintering location matched against Øresund. This implies a minor significance as a migration route for Rügen herring on their way to spawning grounds in accordance with very low fish densities in February and March.

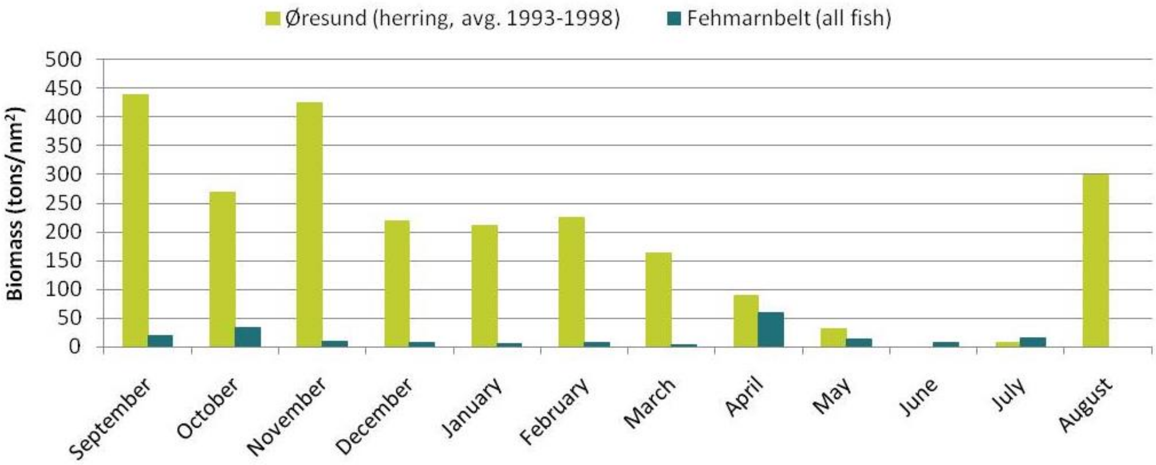


Figure 4.81: Monthly average biomass of herring in Øresund in the years 1993-1998 (data from Nielsen et al., 1999, representing 27 acoustic surveys. Not all months are represented every year) and monthly total fish biomass in Fehmarnbelt 2009-2010.

In the late spring, when the Rügen herring migrates back to the feeding grounds, the densities are more comparable. Since landings from the commercial fishery at the spawning sites at Greifswalder Bodden normally peak in March-April (Nielsen, 1999) it is reasonable to expect that the majority of the migration back to the feeding grounds most years takes place April-May. Estimated herring biomasses in Fehmarnbelt based on the calibrating trawl surveys and biomasses found in the Øresund in these two months are shown in Figure 4.87. As can be seen the estimated herring biomasses in Fehmarnbelt are considerably lower than in Øresund pointing towards a likewise insignificant migration of Rügen herring back to feeding grounds.

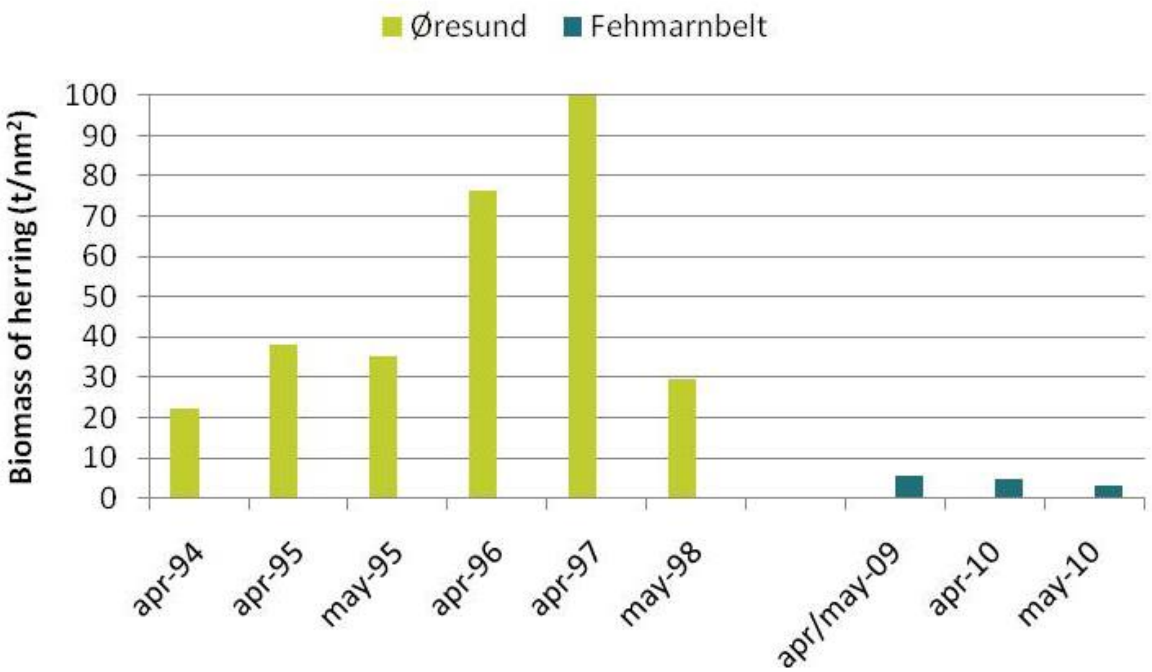


Figure 4.82: Monthly biomass of herring in Øresund in April and May in the years 1993-1998 (data from Nielsen et al., 1999) and monthly biomass of herring in Fehmarnbelt in April and May 2009-2010.

However, several reservations should be taken concerning this conclusion. First, it should be taken into account that the spawning biomass of the western Baltic spring spawning herring according to ICES in 1994 was more than twice as high as in 2009 (235.874 tonnes respectively 105.234 tonnes, ICES 2010d). Second, the very high herring biomass in April 1997 in Øresund was considered a pronounced delay in the decline of herring this year (Nielsen, 1999). Third, the calibrating trawl surveys in the present baseline study based on the TV3 bottom trawl used in April and May 2010 may have underestimated the proportion of herring compared to more semi pelagic species. While herring accounted for respectively 2% and 8% in these two months they constituted 30% in the pelagic calibrating trawl in April/May 2009 (Figure 4.29-Figure 4.30). This proportion might seem more plausible, particularly in the view that herring in Fehmarnbelt has been the dominant species in Danish landings all three months from March to May in the period 1998-2008 (FeBEC, 2013). Adjusting for a greater spawning biomass in the 90ties and omitting the value from April-97 the estimated herring density in Fehmarnbelt of 5.6 t/nm^2 in April/May 2009 corresponds to 10-58% of the densities found in Øresund with an average of 25%. Given a comparable area of Øresund and Fehmarnbelt, and given that the amount of non-migrating herring is in the same range in the two waters, this in turn could imply that 20% of the Rügen herring migrating to the north passes Fehmarnbelt.

Finally it should also be mentioned that the local biomass of a migrating population is dependent on the turnover in the area. With a standing biomass of 5 t/nm^2 and a cruising speed of one body length pr. second 2/3 of the time the total herring biomass passing Fehmarnbelt over a period of 60 days could amount to 23.000 tonnes corresponding to a little more than 20% of the herring spawning biomass as assessed by ICES in 2009.

Despite the overall small estimates of herring it can therefore not be concluded that Fehmarnbelt has minor importance as a migration passage way for the Rügen herring. Taken the above mentioned issues into account the migration from spawning to feeding grounds may amount to 1/5 or even more compared to Øresund which must be considered relative significant.

4.5.7 Herring baseline conclusion

The baseline results regarding herring in the Fehmarnbelt area may be summarized as follows:

- Very low densities of spent herring and herring larvae during autumn, as well as no success in detecting spawning beds by video screening, indicates that autumn spawning activity in Fehmarnbelt is marginal or non-existing. The red listed autumn spawning herring seems to be present in low numbers in Fehmarnbelt, but spawning probably occurs elsewhere.
- A dominance of herring with immature gonads suggests that most of the herring present in autumn are spring spawners.
- Small numbers of spent herring were caught during spring but no herring spawning grounds were detected despite intensive screenings of the sea bottom. However, backtracking of newly hatched herring larvae indicated that spawning sites for spring spawning herring exist in Fehmarnbelt.
- Very few herring yolk sack larvae were found compared to areas with known spawning sites. Thus, spring spawning activity in the Fehmarnbelt area is supposed to be limited.
- Larval RNA/DNA ratios and data on prey density indicate that starvation of herring larvae in the area was unlikely during the study period. Nor were there any signs of heavy predation from gelatineous plankton.
- Although some juvenile herring were found in shallow waters during summer and autumn, the Fehmarnbelt area seems to be little utilized for nursery and feeding.
- Similar percentages of herring with and without herring worm infection during autumn indicate the presence of both local herring stocks and migrating herring from the open sea stocks. Analysis of individuals sampled in the autumn assigned genetically to Rügen (53%), North Sea (35%) and Western Baltic (12%) populations.
- A high abundance of mature herring infected with herring worm indicates the presence of migrating spring spawners in Fehmarnbelt in spring. Analysis of individuals sampled this season assigned genetically to Rügen (58%), North Sea (19%), Western Baltic (15%) and Baltic (8%) populations.

- Fehmarnbelt probably plays only a minor role as a wintering location and as a migration route to spawning grounds for the Rügen herring component. Fehmarnbelt might though have some significance as passage way for this component from spawning grounds back to feeding grounds in the late spring.
- The importance of Fehmarnbelt and adjacent areas for herring is listed in Table 4.17.
- Areas of potential importance for the migration and spawning of herring in Fehmarnbelt and adjacent areas can be seen on Figure 4.83 and Figure 4.84. Small areas around the coast of Fehmarn and the southern coast of Lolland are of minor importance for herring spawning. It can be seen on the map that Fehmarnbelt is considered as of hih importance for the migration of herring, as a considerable part of the Rügen herring component may use Fehmarnbelt as passage way between spawning and feeding grounds.
- In general, Fehmarnbelt has no specific importance as spawning, nursery and feeding ground to any of the present herring stocks.
- There is a possibility, however, that Fehmarnbelt acts as the major passage water for the Rügen herring in their way back from the spawning grounds at Rügen to the feeding grounds in Kattegat/Skagerrak and the North Sea. A decline in the migration back to feeding grounds does not directly imply a decline in the recruitment, as the major spawning migration takes place in Øresund. The spawning biomass could be affected, but the recruitment is not proportional to the spawning biomass.

Table 4.17: Importance of Fehmarnbelt and adjacent areas for herring in relation to spawning, eggs and larvae drift, nursery, feeding and migration.

Environmental component	spawning	egg-larvae drift	nursery	feeding	migration	overall
Herring	minor	minor	minor	minor	high	high

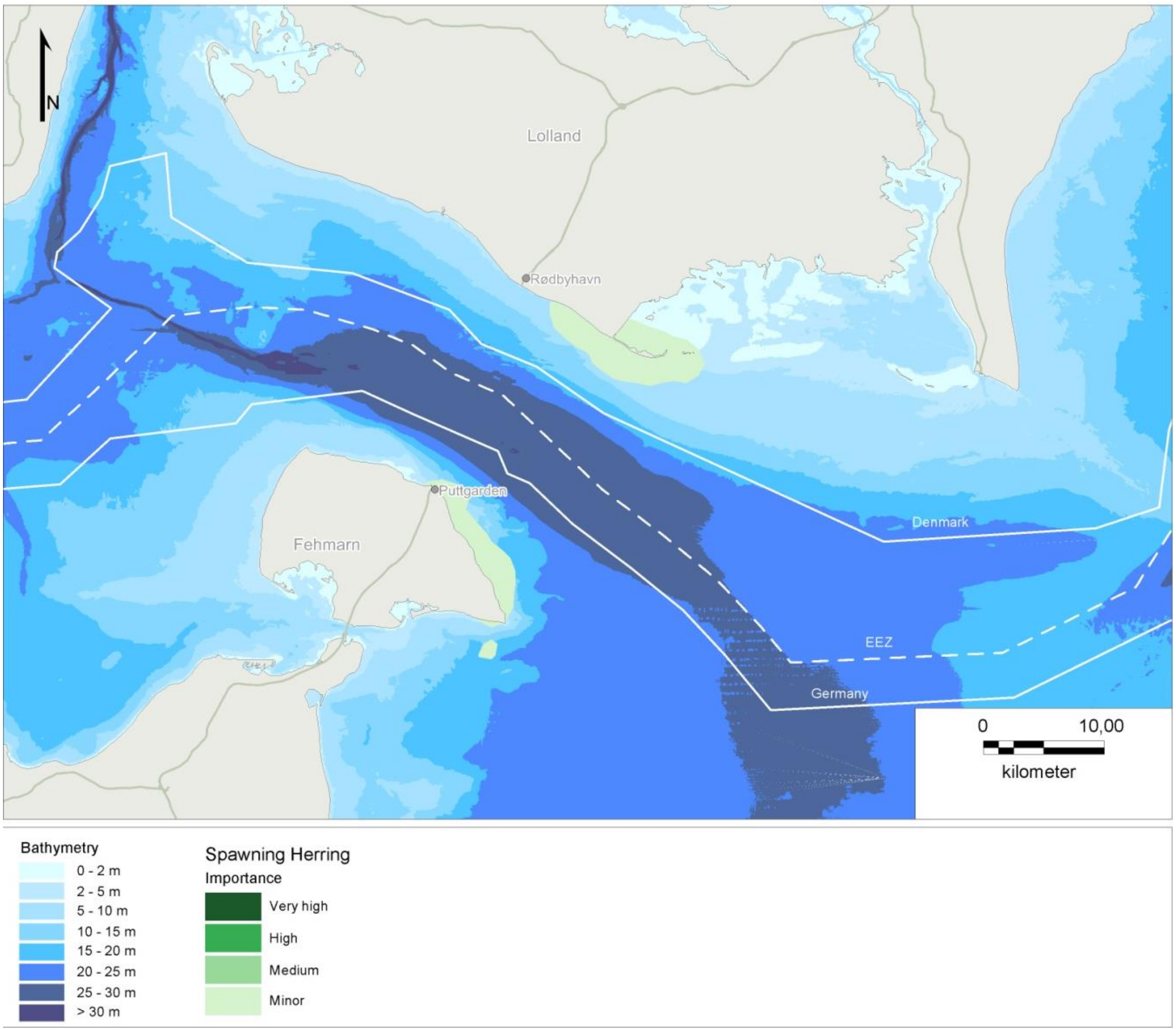


Figure 4.83: Areas of potential importance for the spawning of herring in Fehmarnbelt and adjacent areas.

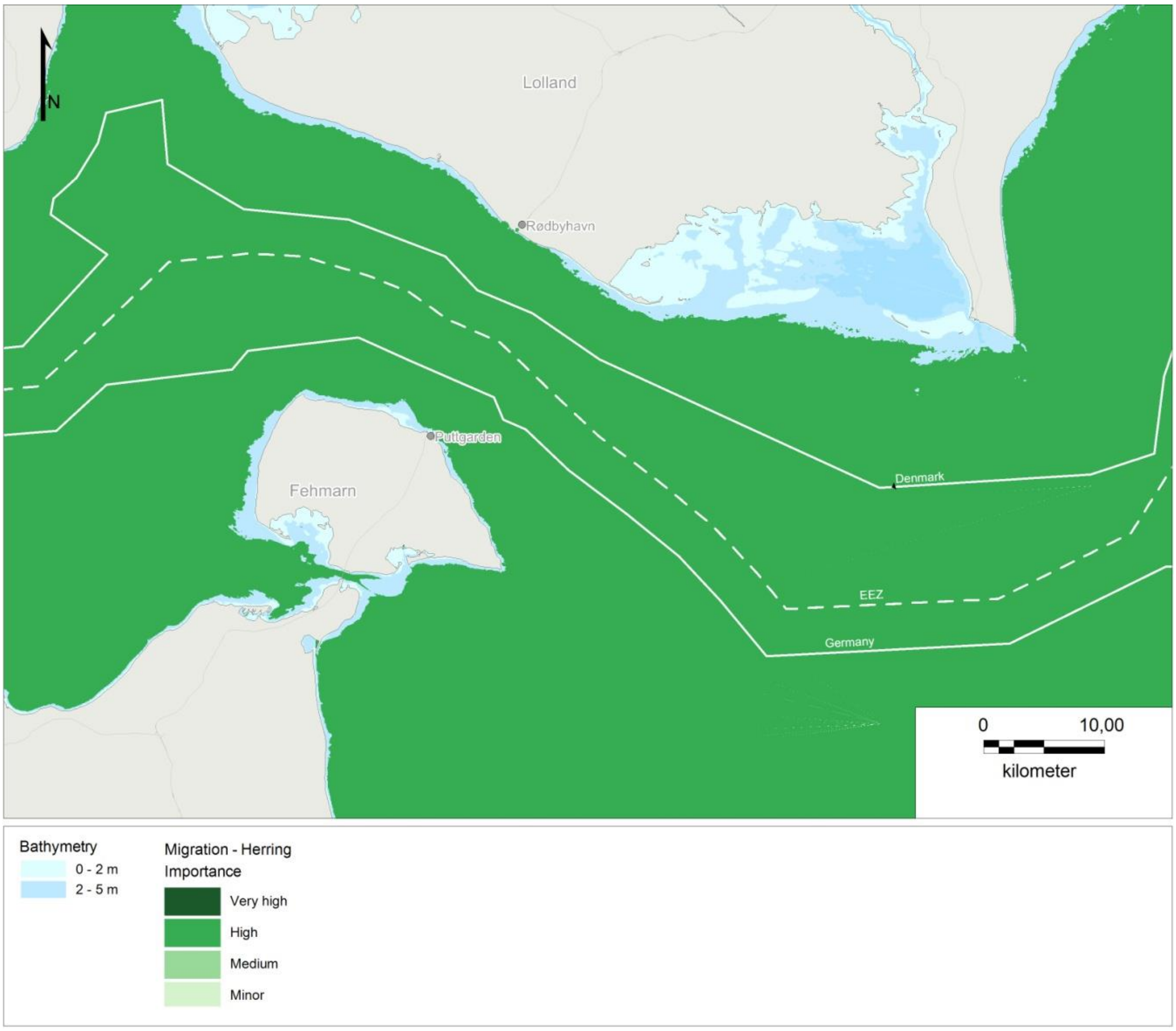


Figure 4.84: Areas of potential importance for the migration of herring in Fehmarnbelt and adjacent areas.

4.6 Sprat

4.6.1 General background

Sprat (*Sprattus sprattus*) is like herring a continuously migrating species. Although the boundaries are indistinct and stocks are mixing, sprat in the Baltic Sea may be separated into three stocks that are restricted to subareas in (1) the Belt Seas and the western Baltic, including the region of the Bornholm Basin, (2) the Gdansk Deep and the Gotland Deep area, (3) the northern region including the Gulf of Finland (Aro, 1989; Hinrichsen et al., 2005). Within the different stocks, sprat migrates into the deeper basins of the Baltic Sea (Bornholm Basin, Gotland Basin and Gdansk Deep) in autumn. In these basins they are found below the halocline during winter and move back to shallower waters in early spring (Stepputtis, 2006).

In general, the biology of sprat is very similar to that of herring with respect to pelagic school forming and migratory behaviour. There are, however, dissimilarities in their spawning and foraging behaviour. Sprats are batch spawners that spawn 8 to 10 times during the season and the eggs are pelagic. Also, sprat generally feed during the daylight hours on smaller food items than herring (Alheit, 1988; Cardinale et. al., 2003; Möllmann et al., 2004).

The structure of the fish community in the Baltic Sea has changed greatly over the last 20 years, from a cod dominated to a sprat dominated community (Köster, 2003, cited in Stepputtis, 2006). Thus, at present sprat plays a key role in the Baltic ecosystem as a prey species for cod and whiting but also as a predator on lower trophic levels and on cod eggs (Möllmann and Köster, 2000). The predation on cod eggs is found to be a stabilising factor for a sprat dominated system.

In addition to the biological interactions, sprat in the Baltic is also controlled by temperature as the egg mortality increases at temperatures below 5°C. Also the gonad development is slow in cold water. Thus, sprat in the Baltic Sea may live near the northern limit of their distribution range (Stepputtis, 2006).

In the following table, environmental conditions and existing pressures that can be of importance for sprat, is listet.

Table 4.18: Environmental conditions and existing pressures of potential significance to sprat in the Fehmarnbelt area.

Basic environmental conditions	Variable hydrodynamics Exposed shoreline	Sheltered conditions and a fairly stable environment with good access to food are generally acknowledged to enhance sprat recruitment (Ojaveer and Kalejs, 2010). Sheltered and protected bays appear to be more optimal compared to the open exposed coastline along Fehmarnbelt.
	Stratification	Sprat is a pelagic spawner, and eggs and juvenile specimen can therefore potentially be affected by stratification of the water masses in Fehmarnbelt. However, due to the often well-mixed waters of Fehmarnbelt, stratification mainly occurs at the deeper parts.
	Salinity	A sprat egg normally tolerates a wide range of salinity levels (salinity level ≥ 4 psu) and is resistant to fluctuations in salinity (Ojaveer and Kalejs, 2010).
Food competitors	Feeding areas in Kattegat/Skagerrak and North Sea	Major competitors for food for the migrating sprat are expected to be found outside the Fehmarnbelt in Kattegat, Skagerrak and the North Sea.
	Herring	Young herring is a serious food competitor in the southern Baltic and Baltic proper (Casini et al., 2004; Möllmann et al., 2004). However, recently the competitive pressure by herring has been reduced due to a decreasing abundance of herring (Möllmann et al., 2004, 2005; Rose, 2005; ICES, 2005).
Predators	Cod	Cod is among the most important predators of herring and sprat in Kattegat and in the Baltic Sea (Barros et al., 1998; Johansen, 2002; Enin and Gröger, 2004, Stepputtis 2006). A marked decrease in cod populations in these waters in the last decades has reduced predation pressure on herring and sprat considerably. However, the latest stock increase of cod in the Baltic and western Baltic has assumingly increased predatory pressure again.
	Mammals	A marked decline in the abundance of fish-eating mammals in the 20th century has reduced mammal predation pressure on clupeids species (Elmgren, 1989; Thurow, 1997; MacKenzie et al., 2002). However, since hunting of seals was banned in 1976, the seal population has increased by about 10% annually, only temporarily disrupted by outbreaks of phocine distemper virus disease in 1988 and 2002 (Teilman, 2006; Härkönen, 2008).
Fishery		The mortality of sprat due to fishery is comparatively low because the commercial fishery on sprat has decreased significantly (Ojaveer and Kalejs, 2010).
Eutrophication	Nutrient enrichment	Sprat is affected by the increased nutrient input caused by anthropogenic influence (Thiel et al., 1996).
	Decreased water clarity	A reduction in water clarity has generally reduced macrophyte vegetation cover. As sprat is a pelagic spawner, a decrease in water clarity is not likely to affect the spawning success of sprat.
Invasive species		The presence of invasive species can potentially affect the recruitment of sprat.

4.6.2 Baseline approach

Sprat were found in high abundances in the investigations of the pelagic fish communities in the Fehmarnbelt area, particularly during the summer half (see section 4.2). In addition to the results from the hydro-acoustic surveys with associated trawl hauls, the description of the seasonal distribution of sprat is mainly based on the studies on eggs and larvae (FeBEC, 2011b). These studies aimed at identifying spawning seasons and possible spawning areas for sprat in Fehmarnbelt.

4.6.3 Spawning

During the main spawning season in April, May and June, a relatively high percentage of thesprat caught in trawl hauls during the hydro-acoustic surveys were staged as spent or active spawners with a high degree of maturity (Figure 4.85 and Figure 4.86). Since sprat generally spawn 8-10 times during the season, the investigated fish represented a mix of maturity indices covering all stages from “early maturation” to “spent”. Most spawning apparently occurred in May.

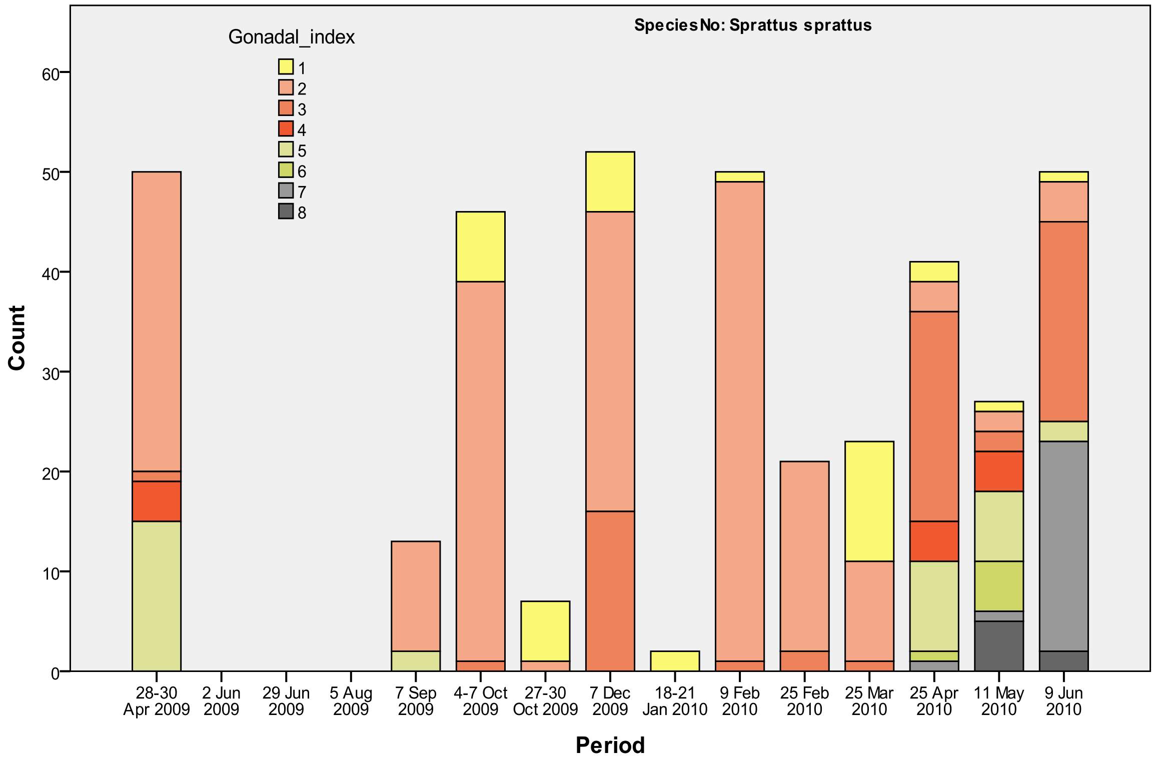


Figure 4.85: Maturity index of sprat from April 2008 until June 2009.1 = juvenile, 2 = early maturation, 3= mid maturation, 4 = final maturation, 5 = spawning capable, 6 = spawning, 7 = spent, 8 = abnormal.

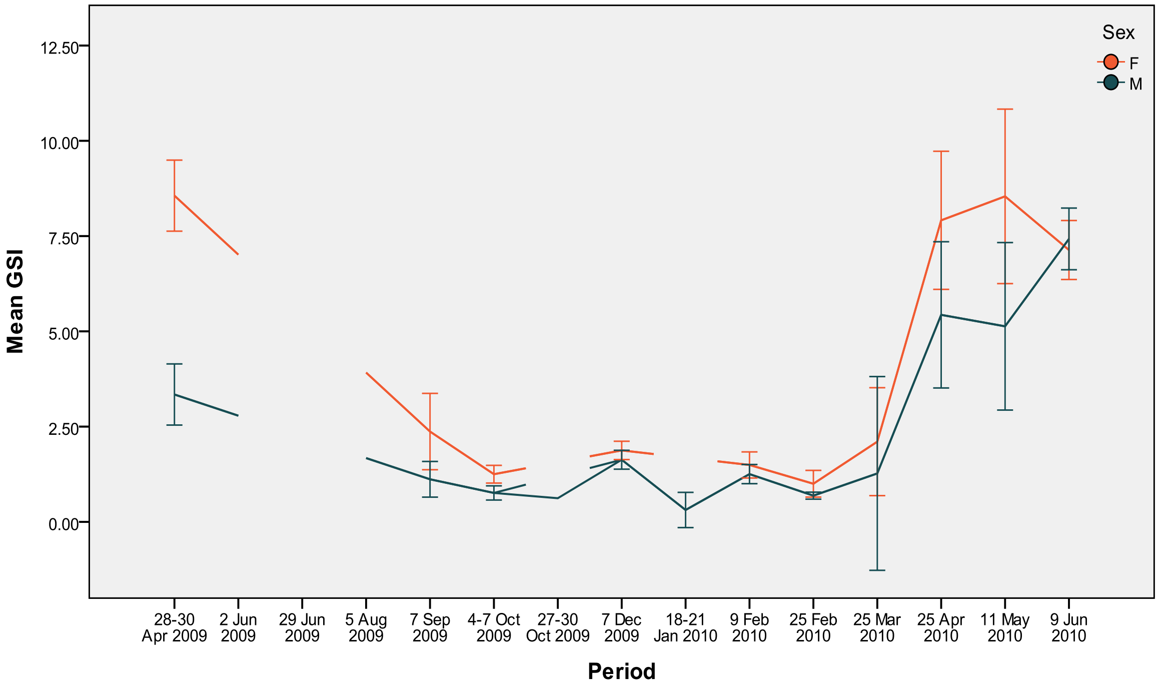


Figure 4.86: Mean gonado-somatic index (GSI) of sprat males (M) and females (F) from April 2009 until June 2010. GSI (gonadal wet weight/total wet weight) *100%. Fish were caught in Fehmarnbelt during FEBEC's acoustic surveys. Errorbars: ± 2 SE.

4.6.4 Eggs and larvae

Sprat eggs were present from April until August (Figure 4.87). The highest densities were found at the survey in May, with an average egg density of 8 eggs per m^3. Densities of sprat eggs were similar to densities recorded during the main spawning period in the central Baltic Sea (Gotland Deep) 1976-1996 (Köster et al., 2003a). Eggs and larvae were found all over Fehmarnbelt (Figure 4.88), but densities of eggs were much higher in areas of deep water than in shallow waters.

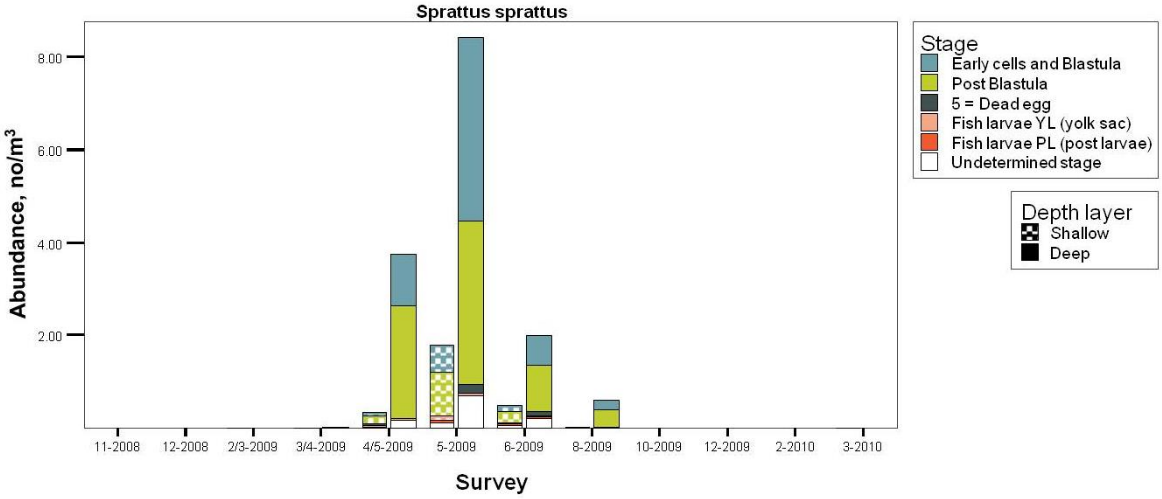


Figure 4.87: Average densities (no./m^3) of different stages of sprat eggs and larvae in 12 surveys from October 2008 until March 2010.

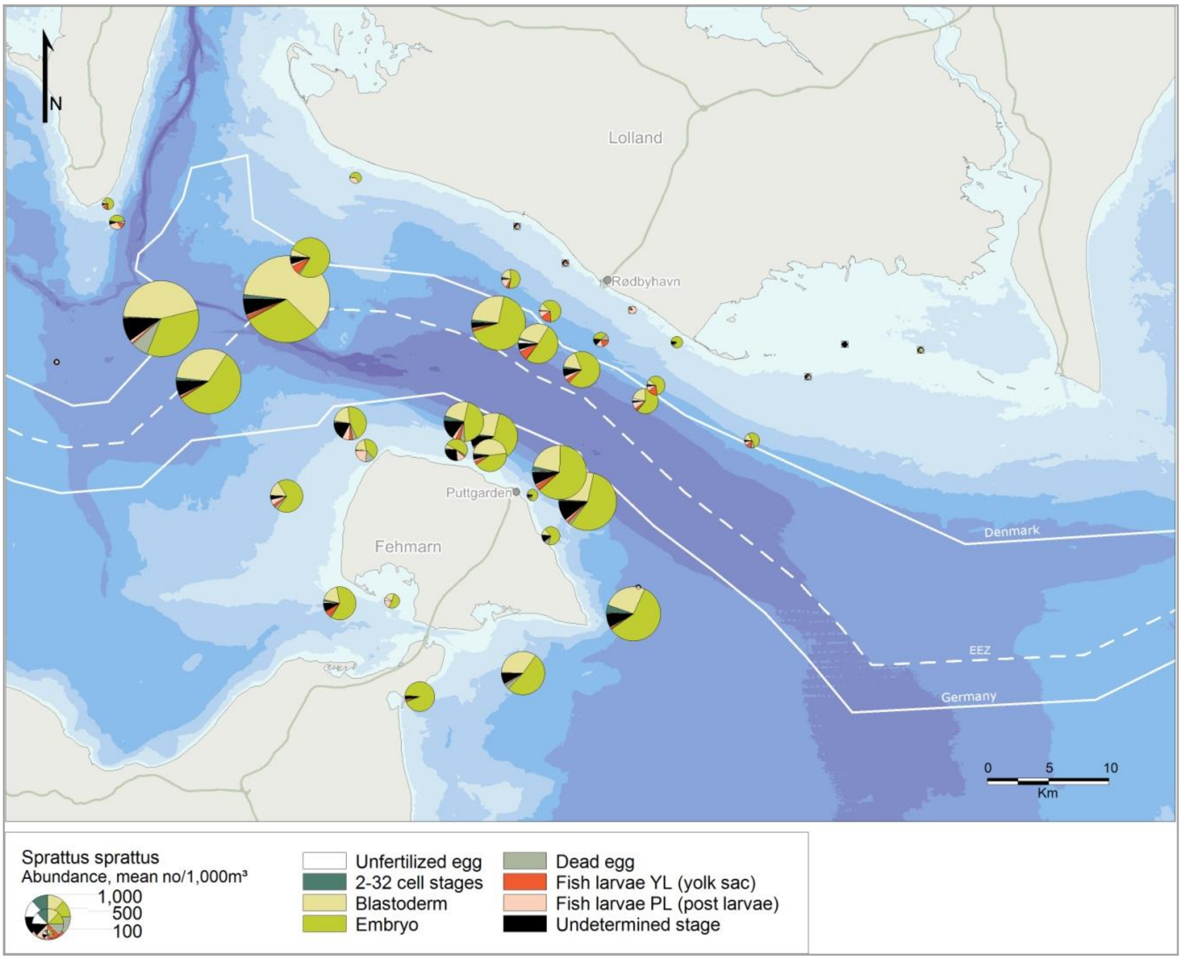


Figure 4.88: Average abundance of eggs and larvae of sprat in Fehmarnbelt from October 2008 until March 2010.

The daily egg production was estimated from the density of different sprat egg stages caught at each survey, combined with an estimated mortality rate (Engell and Pedersen, 2011).

The annual average egg production per m^3 in deep and shallow waters respectively were calculated. Based on these figures and the estimated water volumes in each compartment, the total annual production of sprat eggs within the Fehmarnbelt area was estimated at $1.307*10^{12}$ eggs (Table 4.19).

Table 4.19: Estimated annual egg production of sprat in the whole sampling area of Fehmarnbelt.

SPRAT	Annual production (eggs per m^3)	2.5 and 97.5 quantiles	Estimated volume of sampling area (m^3)	Eggs per year in the sampling area
Shallow water (depth <10 m)	6.8	1.5 -45.8	$20.5*10^9$	$0.139*10^{12}$
Deep water (depth > 10 m)	103.8	14.5-80,000	$15.5*10^9$	$1.168*10^{12}$
Total sampling area			$36*10^9$	$1.307*10^{12}$

The average weight of mature female sprat caught during the acoustic surveys was 13.7 g and their average length was 12.5 cm (n = 194). Sprat of age group II with a corresponding length of 12.4-12.9 cm was in other studies in Kiel Bay found to spawn 27,000 eggs on average per year per female (Alheit, 1988).

Assuming that all eggs shed by the female are viable (which is not always the case), the number of female sprat spawning in the investigated area may be estimated at $6.5*10^{7}$ ($1.747*10^{12}$ eggs / 27,000 eggs per female). If the average weight of a female is 13.7 g, the biomass of female sprat spawning in the area is approximately 890 tonnes. Assuming that the biomass of male sprat spawning in the investigated area is equal to the biomass of the females, it is estimated that approximately 1,800 tonnes of sprat are spawning in Fehmarnbelt. In case not all eggs leaving the female are viable, the spawning biomass within the investigated area will be higher.

The spawning stock biomass (SSB) of sprat in the entire Baltic Sea (ICES area 22-32) has been estimated at approximately 800,000 to 1,200,000 tonnes between 2000 and 2008 (ICES, 2008c, ICES, 2008e). It may thus be assumed that approximately 0.2% of the spawning biomass of sprat in the entire Baltic Sea spawns in the investigated area.

Major sprat spawning sites in the Fehmarnbelt area were identified by backtracking of the eggs to a presumed spawning ground, taking the abundance of sprat eggs in various stages at each catch site and the estimated egg mortality into account. Hotspots of sprat spawning were found in the deeper parts of the central Fehmarnbelt, mainly in the southern parts. Other spawning areas were found in the deeper part of Mecklenburg Bight and in the Belt Sea near Langeland (Figure 4.89).

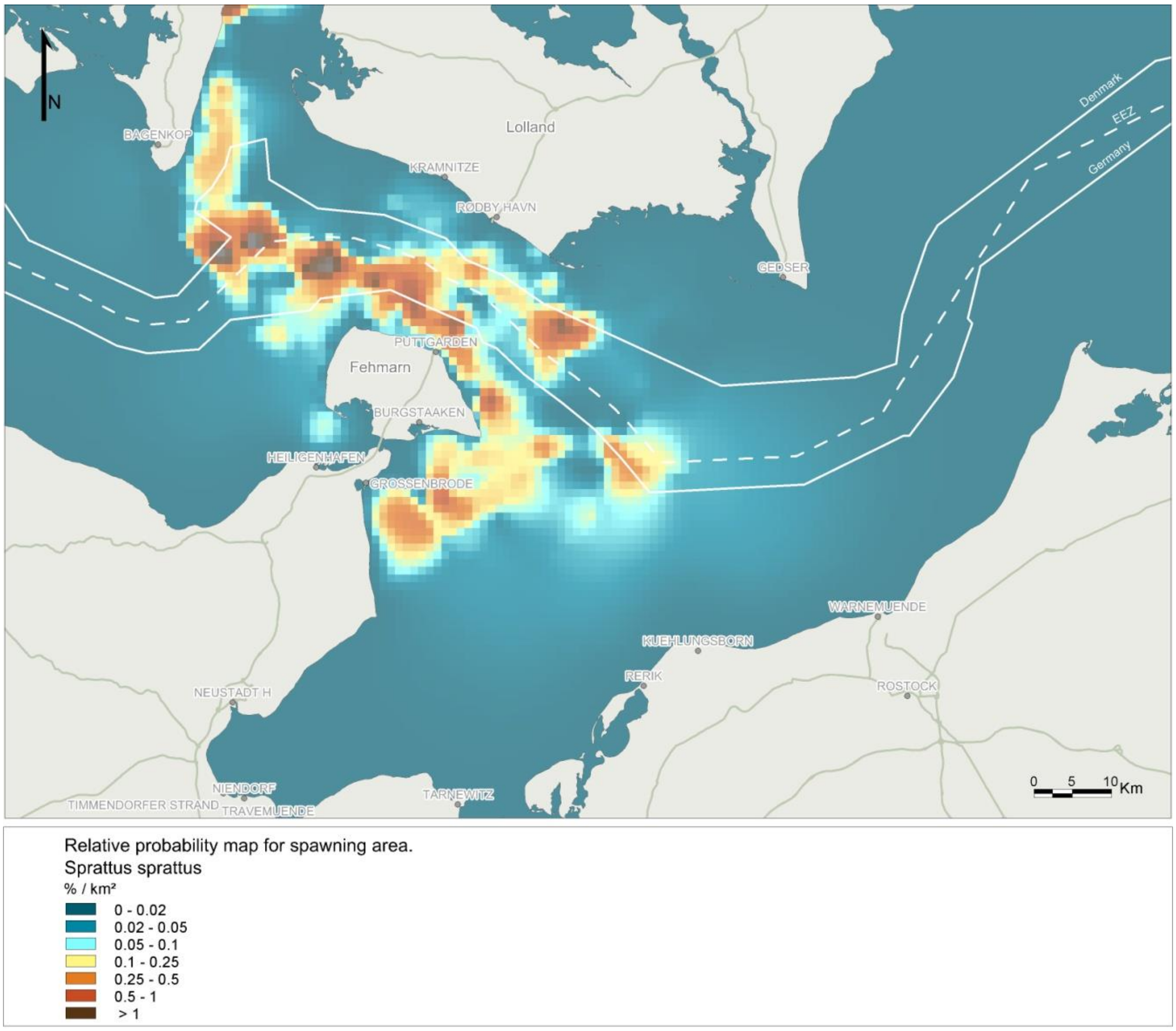


Figure 4.89: Map showing relative probabilities of spawning of sprat (*Sprattus sprattus*), prepared by combining backtracking of specific egg stages (zygote to balstula stages), mortality from spawning to catch and the abundance of specific egg stages at the catch site.

4.6.4.1 Larval growth

Availability of prey for the larvae has a significant impact on the survival of larvae and low prey availabilities lead to starvation. Analyses of larval condition, as measured by RNA/DNA ratios, showed that the ratio for the analysed sprat larvae was within the interval of 1.5-3, which is above the limit for negative growth (FeBEC, 2011b). The sprat larvae (length range 3.9-16.5 mm) found in the Fehmarnbelt area appeared to be rather small compared with other areas. However, sprat larvae of similar length and growth rates were also found in the German Bight (Huwer, 2004; FeBEC, 2011b).

Measurements of prey density during the hatching season of sprat also showed that the average density of suitable food of plankton organisms was sufficient to sustain growth. Sprat larvae mainly feed on copepod nauplii and copepodites, the combined density of which was approximately 30 nauplii and copepodites/l during the main hatching season in May-June, declining to 8/l in August (Figure 4.51).

Predators, including species of medusa, which can have a significant potential impact on the survival rate of larvae, had average clearance rates below 5% per day and therefore was not expected to play a significant role in reducing survival rates of sprat larvae.

4.6.5 Sprat baseline conclusion

The baseline results regarding sprat in the Fehmarnbelt area may be summarized as follows:

- Sprats were mainly recorded in the Fehmarnbelt area from spring to autumn. During the winter half, the sprat are found in the deeper parts of the Baltic Sea.
- The spawning season for sprat in Fehmarnbelt was during the summer from April until August, with most spawning taking place in May.
- Densities of sprat eggs (average density 8 eggs per m^3 during the May survey) were similar to densities recorded during the main spawning period in the Gotland Deep in the central Baltic Sea.
- Approximately 1,800 tonnes of sprats were estimated to spawn in the Fehmarnbelt area, accounting for about 0.2% of the total spawning biomass in the entire Baltic Sea.
- All stages of sprat egg and larvae were found all over the Fehmarnbelt area, but mostly in the deep and central parts. Hotspots of spawning were identified in the deeper parts of Fehmarnbelt and in deeper parts of Mecklenburg Bight and the Belt Sea.
- Food availability was considered sufficient to maintain growth and measurements of larval condition showed no indications of starvation. Predation from medusa on eggs and larvae was insignificant.
- The importance of Fehmarnbelt and adjacent areas for sprat is listed in Table 4.20.
- Areas of potential importance for the spawning of sprat in Fehmarnbelt and adjacent areas can be seen on Figure 4.90. It can be seen on the map that most of Fehmarnbelt, except the shallow coastal areas, are of medium importance for the spawning of sprat. This is because sprat is a pelagic spawner.
- Fehmarnbelt acts as a spawning site for sprate, and due to the high ecological importance of sprat in the area, any aspects of sprat recruitment i.e. migration, spawning and eggs and larvae drift have some importance.
- Local nursery and feeding areas are only of minor importance.

Table 4.20: Importance of Fehmarnbelt and adjacent areas for sprat in relation to spawning, eggs and larvae drift, nursery, feeding and migration.

Environmental component	spawning	egg-larvae drift	nursery	feeding	migration	overall
European sprat	medium	medium	minor	minor	medium	medium

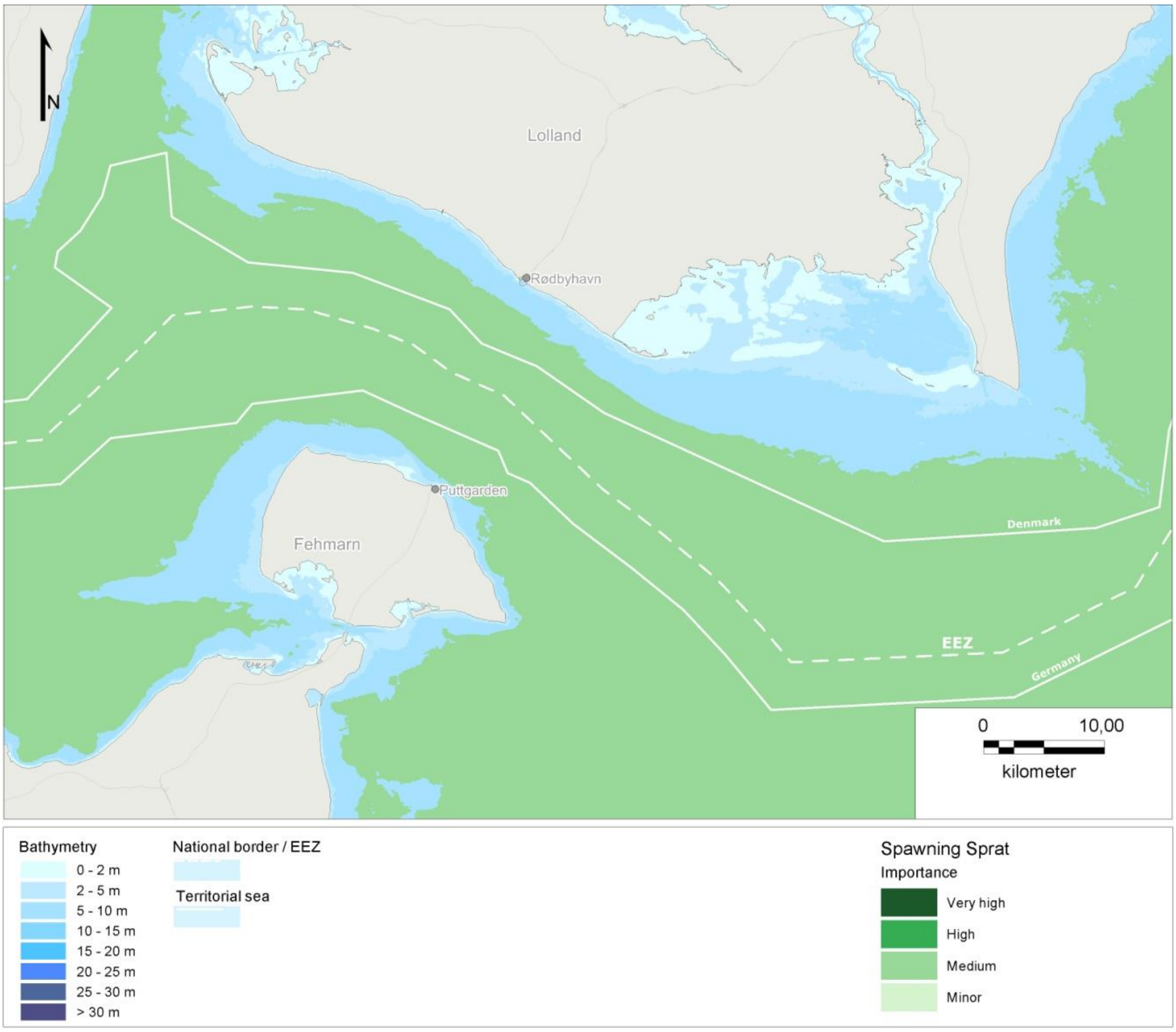


Figure 4.90: Areas of potential importance for the spawning of sprat in Fehmarnbelt and adjacent areas.

4.7 Eel

4.7.1 General background

The European eel (*Anguilla anguilla*) occurs in fresh and brackish waters in almost all of Europe and Northern Africa including the Mediterranean Sea and the Baltic Sea. The Danish sounds and belts are important passages for the European eel between the Baltic Sea and the North Sea. This applies both to glass eel and elvers arriving from their passage over the Atlantic from the Sargasso Sea, where the European eel is believed to spawn, and to the migration of silver eel back to the spawning grounds.

The obligation to ensure passage for glass eel and silver eel is even more imperative in the light of the historical minimum of the European eel stock, which has declined continuously since the 1950s in most European waters (Figure 4.91). Recruitment of glass eel is also at a historical low level and the steep decline, which has been apparent since 1980, seems to continue (Figure 4.92). In the Baltic, the recruitment of yellow eel is now less than 10% of the observed recruitment in the 1950s and 1970s. Despite the marked stock decline, fishing effort and mortality continues to be high both on juvenile (glass eel) and older eel (yellow and silver eel) (FAO/ICES, 2009). Decreased landings in combination with continuously high fishing mortality are a strong indication of reduced stock size.

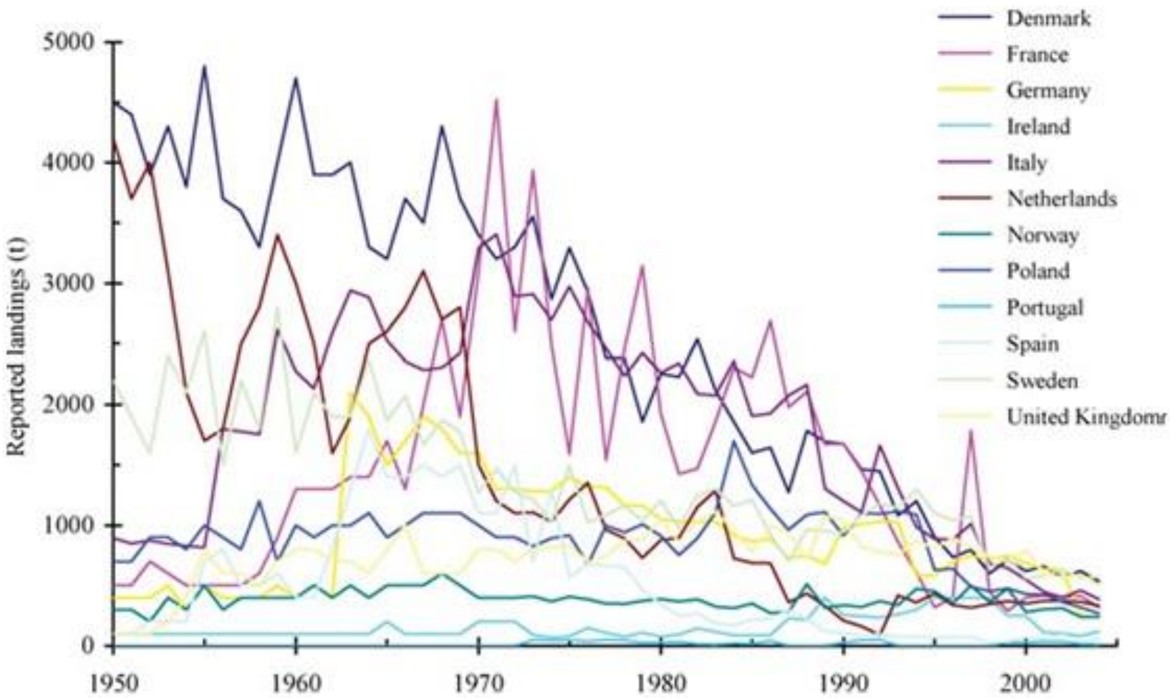


Figure 4.91: Trends in data on landings of European eel reported to the FAO. This graph shows all series that started in 1950 or before. Source: FAO/ICES (2009).

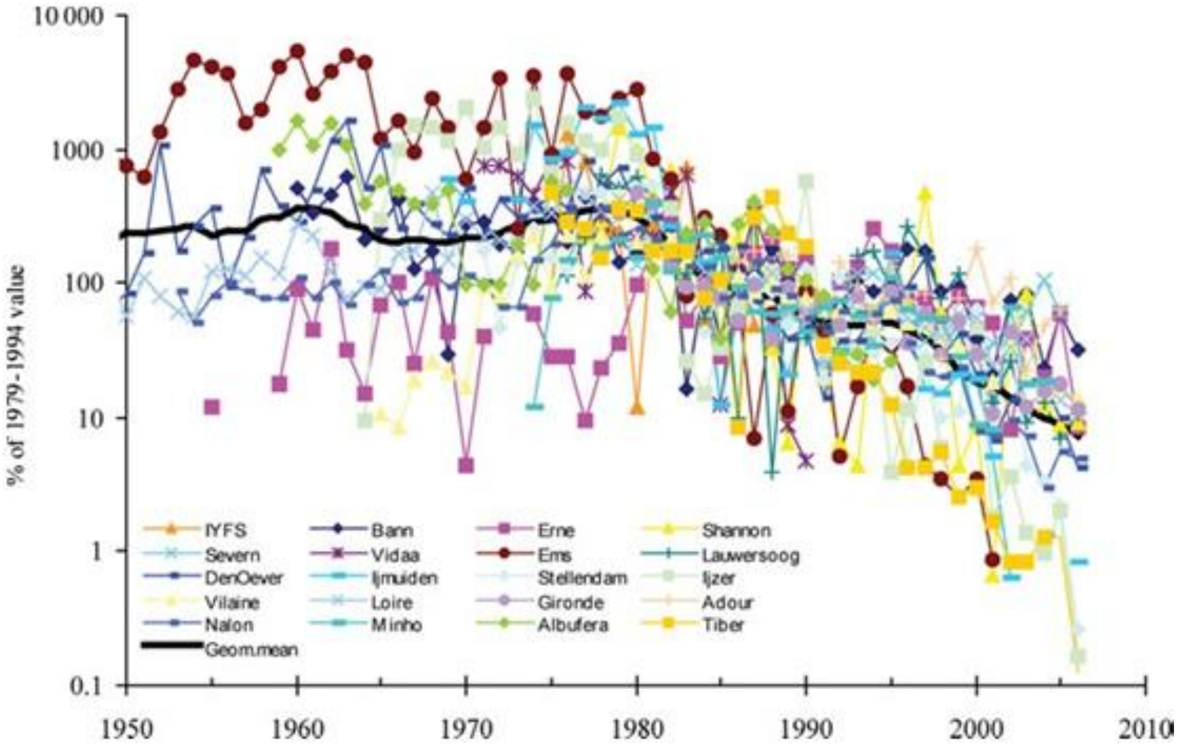


Figure 4.92: Trends in indices of catch per unit effort (CPUE) of European glass eel. Source: FAO/ICES, (2009).

<u>International legislation</u>
The European eel is red listed in most European countries, including Germany and Denmark, and is included on the OSPAR List of threatened and/or declining species and habitats (The convention for the Protection of the Marine Environment of the North-East Atlantic, Agreement 2008-6) (OSPAR, 2010). In addition European eel is listed on Annex II of CITES (Convention on International Trade of Endangered Species), which means that glass eel cannot be exported from the EU unless the export is deemed not to harm the stock. Additionally, an EU member state wishing to export glass eel to third countries must have an approved eel management plan:

The European Commission has recently set tough measures for the protection of the eel as a consequence of the alarming population trend and the goal is to restore the stocks to historical levels. In 2007, Article 2 of the Council Regulation (EC) No. 1100/2007 was adopted in which it was stated that EU member states should set up measures that allow 40% of the pristine level of the stock to escape to the sea. Each EU member state has set up a national eel management plans (EMP's) at river basin level in order to demonstrate how they intend to reach the target. The regulation does not require that member states implement identical measures, even if these measures are to be implemented in the same river basins by various administrative entities. EU member states propose measures such as:

- Setting management targets based on an assessment of potential silver eel production under conditions of no anthropogenic mortality and high (pre-1980) levels of recruitment.
- Estimating the present silver eel production in relation to this target (i.e. estimate compliance with the management target).
- Developing and taking the management actions that are necessary to achieve or maintain compliance.

- Collecting data sufficient to support step 1 to 3, and to demonstrate whether compliance will be achieved in the future, i.e. that the actions identified in the EMP will lead to the recovery of the eel population.

In addition, EU member states who permits catch of glass eel (juvenile eel <12 cm) shall reserve 35% of their catch for restocking within the EU during the first year of the application of the EMP. This percentage shall increase with at least 5% per year and a level of 60% shall be achieved in 2013.

German eel management plan

The German EMP consists of a set of plans covering nine river basins. For each river basin, pristine and current escapement has been estimated and measures towards the achievement of the escapement target have been proposed. Restocking is the main tool for reaching the target. Additionally, increased minimum landing size, temporal closure of fishing and effort reduction in coastal waters through site restrictions on pound nets were incorporated in the plans. As a national average Germany reported that they currently achieved 56% silver eel escapement as compared to the reference condition. The basic estimates of both pristine escapement and current escapement have, however, been questioned by ICES (2010). Furthermore fishing for eel less than 12 cm is illegal in Germany.

Danish eel management plan

The Danish EMP aims to obtain 40% of pristine silver eel escapement in the freshwater habitat. The plan incorporates the introduction of a framework for managing an extensive reduction in fishing effort, management measures for mitigating structural eel mortality, improving habitat conditions and a plan for re-establishing eel stocks. The plan included an introduction on the 1st July 2009 of a license system, which limits each fishermen or entity, fishing for commercial purposes, to a limited number and type of gear and fishing season. The system includes routine compulsory registration and reporting and measures for strengthened control efficiency (Ministry of Food, Agriculture and Fisheries, 2008). The Danish plan only briefly mentions the important issue of eel originating from Baltic countries being caught by the Danish fishery. Furthermore glass eel fishing is illegal in Denmark.

The decline in the European eel stock has drawn much attention, and a multitude of factors have been suggested as being responsible for this development. Among these are anthropogenic stressors such as overfishing, pollution, habitat loss and barriers to migration, but diseases and parasites as well as oceanic and climatological factors are also meant to be contributing to the failure of eel recruitment (Friedland et al., 2007; Durif et al., 2010).

Turbines of hydroelectric-power plants present a barrier for glass eel heading upstream to good habitats while yellow and silver eel heading downstream to the coast can be drawn into the turbines with detrimental effect. In addition, dam constructions, weirs and drained watercourses are blocking migration routes and cutting off paths to good habitats. Discharges of pollutants and other substances have all contributed to deteriorating feeding habitats and water quality.

Eels are prone to accumulate pollutants including PCBs and DDTs in its tissues. The accumulated toxins might affect eel fertility or cause deformities in their offspring, making them less viable as they utilize their fat reserves during the long migration to their spawning grounds in the Sargasso Sea. Pollutants might also stress eels, making them more susceptible to diseases and parasites, which in turn reduce their reproductive success.

Anguillicola crassus is a nematode that infects the swim bladder of the yellow and silver eels. The nematode probably originates from eastern Asia and has reached Europe with ballast water in the 1980s (ICES/EIFAC, 2008, Sjöberg et al., 2009). The nematode larvae are eaten by copepods and small fish species, which are an important food source for eels. Once the nematode larvas reach the intestine, it passes through the intestine wall and into the abdomen, where it attaches to the inside wall of the swim bladder and develops into an adult nematode. The nematodes infect and damage the swim bladder, affecting the eel's swimming ability and reducing its chance of reaching the Sargasso Sea.

Table 4.21 lists environmental settings and existing pressures of significance to eel in Fehmanbelt.

Table 4.21: Environmental settings and existing pressures of potential significance to European eel in the near area of Fehmarnbelt.

Basic environmental setting	Variable hydrodynamics Exposed shoreline	Yellow eel habitats are most often associated with estauries, fjords, protected bays and inland waters. In this respect the environmental basic settings of Orther Bight and the lagoon of Rødsand are more optimal as nursery and feeding areas compared to the open exposed coast of Fehmarnbelt. Glass eel and silver eel migration are both suggested to be related to tidal streams, i.e. water discharge.
	Stratification	Eels are more resistant than other fish species to low oxygen concentrations (Mc Kenzie, 2003).
	Salinity	Different life stages of eel are adapted differently to salinity. Glaseels and silver eels are strong osmose regulators tolerating abrupt transfer into widely different salinities, while fully pigmented elvers suffered significantly mortality in full salinity sea water, and show preference for fresh water (Crean et al., 2005; Edeline et al., 2009).
Food competitors		Yellow eels have a broad food preference. In saline areas amphipods, polychaetes, bivalves and shrimps are important food items. Consequently fish species preferring benthic invertebrates and epifauna may be serious competitors when abundant. Silver eel do not eat while migrating.
Predators	Cormorants, marine mammals	Cormorants are considered serious predators on eels in many fjords and inland waters and makes up 10% -15% of the total diet in fresh water (Simon, 2011). According to Dorow & Ubl (2011) there was for 2007 a removal of eel by cormorants of about 81 tonnes in the coastal area of Mecklenburg-Vorpommern. Other potential predators are marine mammals.
Fishery		Fishing mortality is believed to have had major significance for the decline of the Europeen eel stock (ICES, 2010e).
Pollution	PCB/dioxins	The Yellow eel is exposed to anthropogenic pollution during the long migration through continental areas. This may result in embryonic defects and to the accumulation of toxic substances (Dorow and Ubl, 2011).
Anthropogenic constructions	Transverse built	The migration of eels is severely restricted in the European river systems by many transvers structures. Particularly the migration to the sea is very limited (Dorow and Ubl, 2011).

4.7.2 Baseline approach

The importance of Fehmarnbelt as a passageway was considered a key issue in the present baseline study, as it is the only major alternative to Øresund as an escapement route for silver eel from the entire hinterland of the Baltic Sea. Hence, barriers to passage may impair the escapement of the spawning migration of silver eel and thereby the recovery of the stock. The passage of glass eel and elvers has not been part of the present baseline, although it could be argued that this migration is likewise critical. The migration into the Danish waters is more or less random and was thus considered very difficult to assess.

The general approach to the baseline description of the European eel in Fehmarnbelt was to focus on the individual behaviour of migrating silver eel, and to estimate the amount of silver eel passing the Fehmarnbelt as well as the relative abundance of yellow eel. The overall approach of describing and evaluating eel implied therefore gathering data related to silver eel migration and yellow eel feeding grounds. The following issues have been considered:

- Identification of eel nursery and feeding grounds in Fehmarnbelt.
- Identification of the significance of silver eel migration in Fehmarnbelt.
- Identification of timing of silver eel migration.
- Identification of individual behaviour of migrating silver eel.

Different methods were used to investigate these issues (see chapter 3 for a detailed description of the methods).

The baseline study involved field inventories in 2008 and 2009 consisting of tagging experiments and analysis of fishery data from different parts of Danish waters, i.e. the main escapement routes through Øresund or the Belt Sea. In addition, results from previous tagging experiments with silver eel from a number of Baltic countries have been compared with the results from the present baseline study (FeBEC, 2011e).

To identify individual eel behaviour, data storage tags (DSTs) were used whereas ordinary sequential numbered T-tags primarily were used for estimating the number and the preferred migration route of silver eel. The time of the investigations was predetermined by the period for main silver eel migration in Danish and German waters from September until December, while the location of the campaigns differed according to the objectives of the specific investigation.

Relative abundances of yellow eel were estimated following the Danish NOVANA fish survey, including the standardized fyke net programme (Strand, 2006) undertaken in September 2009. Catches per unit effort (CPUE) were compared to values found in several other Danish coastal waters. In addition, landings of yellow eel from local harbours in the Fehmarnbelt and from different parts of Danish waters were included in the analysis.

4.7.3 Spawning, eggs and larvae

The life cycle of the European eel (Figure 4.93) is still not fully understood but eel eggs are found in spring and early summer in the Sargasso Sea between Bermuda and Cuba, approximately 7,000 km from the Baltic Sea. The details of spawning are unknown as a mature eel has never been found in the Sargasso. However, the spawning area and timing can be backtracked from the presence of progressively larger larvae found at increasing distances from one point source in the Sargasso Sea.

Within a few days after spawning eel eggs hatch into transparent blade shaped larvae (Leptocephali), which drift to Europe on the Gulf Stream and the North-Atlantic Drift. Growing larger they gradually change to an active vertical migration behaviour catching the currents travelling across the Atlantic. In November to April, after 8-9 months in the Atlantic, the larvae reach European continental waters between southwest Europe and northwest Africa and metamorphose into 50mm long unpigmented glass eel. Most of the glass eel enter coastal waters, estuaries and rivers via the Bay of Biscay, but relatively few glass eel reach the coasts in northern Europe.

Glass eel drift into coastal waters darkening in color and become elvers (50-70 mm). At this point there is clear developmental shift in salinity preference, with glass eels preferring 100% sea water, semi-pigmented elvers showing no clear preference and fully pigmented elvers preferring fresh water. As the eel develops into yellow eels and after 5 - 20 years in brackish or fresh water, the eel become sexually mature; their eyes grow larger, their flanks become silver and their abdomen white. In this stage the eel are known as silver eel, and they begin their migration back to the Sargasso Sea to spawn. It is assumed that adult eel die after spawning.

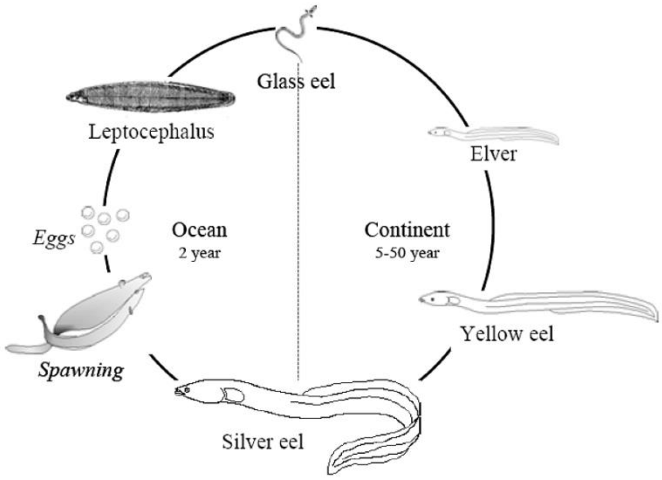


Figure 4.93: The life cycle of the European eel *Anguilla Anguilla*. Source: FAO/ICES (2009).

The European eel has for many years been considered a panmictic species with no significant differentiation into genetically distinct population, but with the application of genetic methods in studies of eel this has been questioned and debated by several authors. ICES Working Group on “the Application of Genetics in Fisheries and Mariculture” stated in 2007 that there now is sufficient evidence available to suggest that small but significant levels of genetic diversification exist in European eel and that this diversity should be protected (ICES, 2007e). However, lately Palm et al. (2009) found no temporal component of genetic differences between maturing adult silver eel sampled from contrasting ends of the continental range in Europe.

This either indicates that there is no geographical separation of spawning grounds in the Sargasso Sea between northern and southern European eel, and/or that it is random where the offsprings end up at the European coast.

4.7.4 Nursery and feeding

Juvenile eel inhabit a variety of brackish and fresh waters such as estuaries and coastal lagoons as well as rivers, streams and lakes with access to the sea. They typically live in benthic habitats, under stones or in crevices, in vegetation or even in the mud. The European eel diet includes almost the entire aquatic fauna (freshwater as well as marine). In more saline areas amphipods, polychaetes, bivalves and shrimps are important food items, but fish may also be part of the diet.

Eel fishery in Denmark takes place all over the country, but 95% of the catches are reported from marine waters, mostly from fjords and coastal bays, while 5% is reported from freshwater

(Ministry of Food, Agriculture and Fisheries, 2008). As in Kattegat, Øresund and the belts, landings of yellow eel from the Fehmarnbelt have declined dramatically (Figure 4.94).

The Danish landings from Fehmarnbelt have decreased from 5-8% of the total landings in the late 1970s and 1980s to 1% in 2008 and 2009. Furthermore, the German coast landings of yellow eel are also very limited.

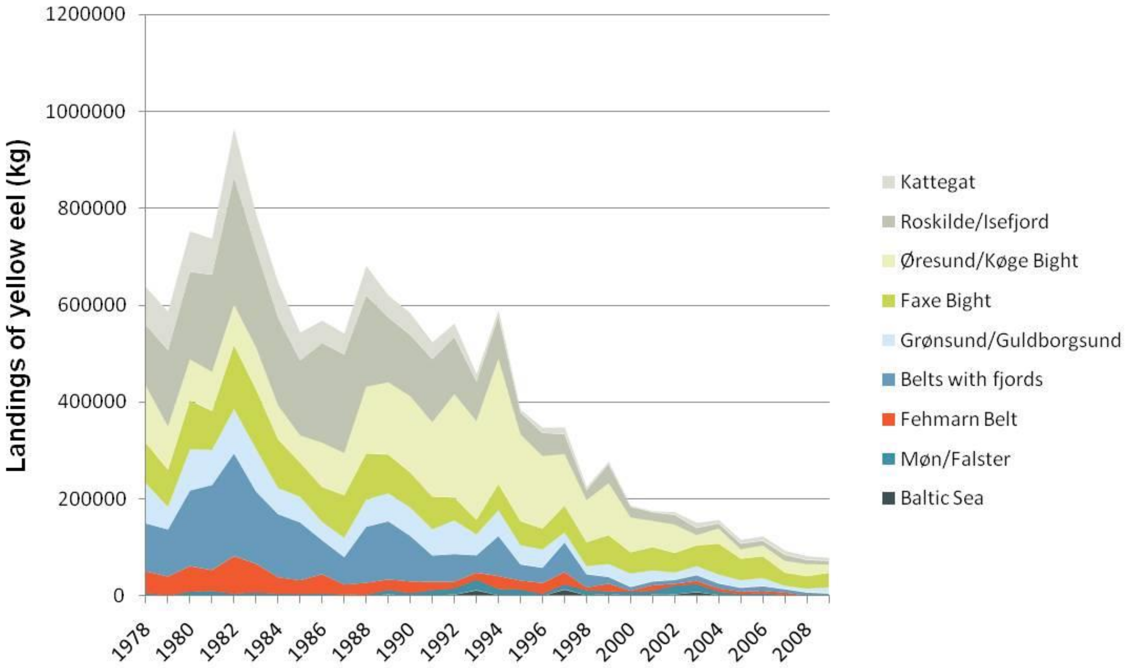


Figure 4.94: Annual landings of yellow eel from different Danish waters in Kattegat, Øresund and the western Baltic Sea (data from The Danish Directory of Fisheries).

The majority of the yellow eel caught by Danish fishermen in Fehmarnbelt are landed in harbours located in the Lagoon of Rødsand. Hence, Errindlev and Nysted harbours accounts for more than 90% of the total landings in the period 1978-2009 (Figure 4.95). Contrary, the majority of silver eel are landed in harbours in Kramnitse and Rødby, which indicate that yellow eel are found in much higher abundances in the lagoon of Rødsand compared to the open coast. The lagoon of Rødsand is a more protected habitat with plenty of eel grass beds in most of the lagoon, which supports the hypothesis of the lagoon being a suitable habitat for yellow eel.

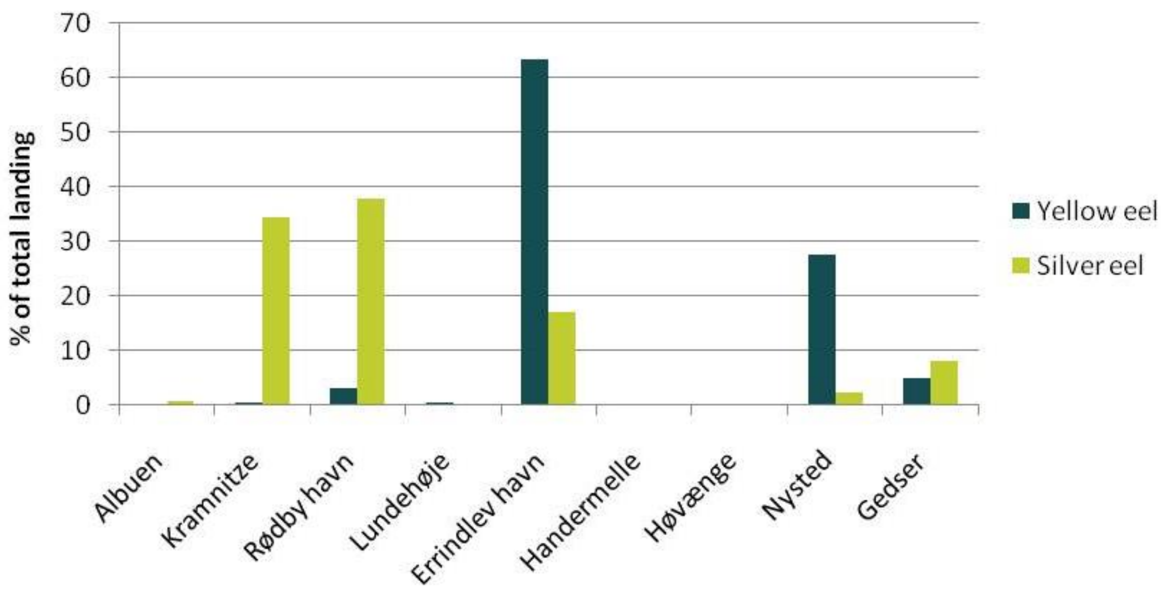


Figure 4.95: Average distribution of landings of yellow eel and silver eel in the Danish harbours of Fehmarnbelt area in 1978-2009 (data from The Danish Directory of Fisheries).

However, very sparse landings in 2008 and 2009 strongly indicate that the lagoon at present is very poor in yielding eel, a fact that local fishermen emphasize. The NOVANA fyke net survey in September 2009 confirmed the low abundance with a CPUE of yellow eel among the lowest registered, and with record low catches at the two open coasts of Fehmarnbelt (Figure 4.96).

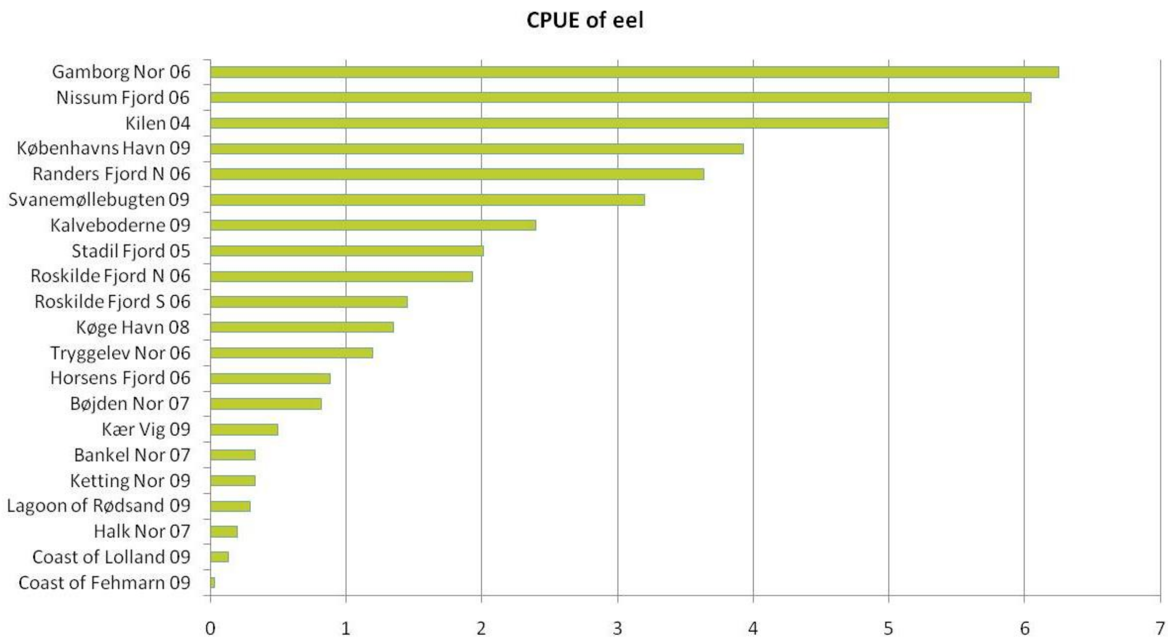


Figure 4.96: CPUE of yellow eel from several Danish brackish waters found by means of the standardized NOVANA fyke net survey in August-September (data from FiskBase, Miljøportalen and FoelBase).

4.7.5 Migration

All silver eel leaving the Baltic Sea have to pass either Øresund or the Belt Sea on their way to the Atlantic. The latter includes either Fehmarnbelt or the small sounds Ulfsund, Grønsund or Guldborgsund, which seperates the islands Møn and Sealand, Møn and Falster or Falster and Lolland, respectively.

The migration normally starts in late summer and silver eel occur from August to December in Danish waters with a peak in the landings in October. According to fishery statistics this trend is also seen in Fehmarnbelt where the largest landings generally are seen during October (Figure 4.97). Especially in 2008 and 2009 the vast majority were landed in October, while November has been the second most important landing month during the last decade. Before the mid 1990s the landings in September were higher compared to November, indicating either a shift in the fishery pressure or a later arrival of silver eel to the Fehmarnbelt. Decreasing temperatures at the end of summer has been suggested to trigger the silvering process of eel, and studies have shown that downstream migration starts earlier during cold summers (Vøllestad, 1988; Dürif and Elie, 2008). The general temperature increase in recent years may therefore have induced a delay in the arrival of silver eel to Danish waters.

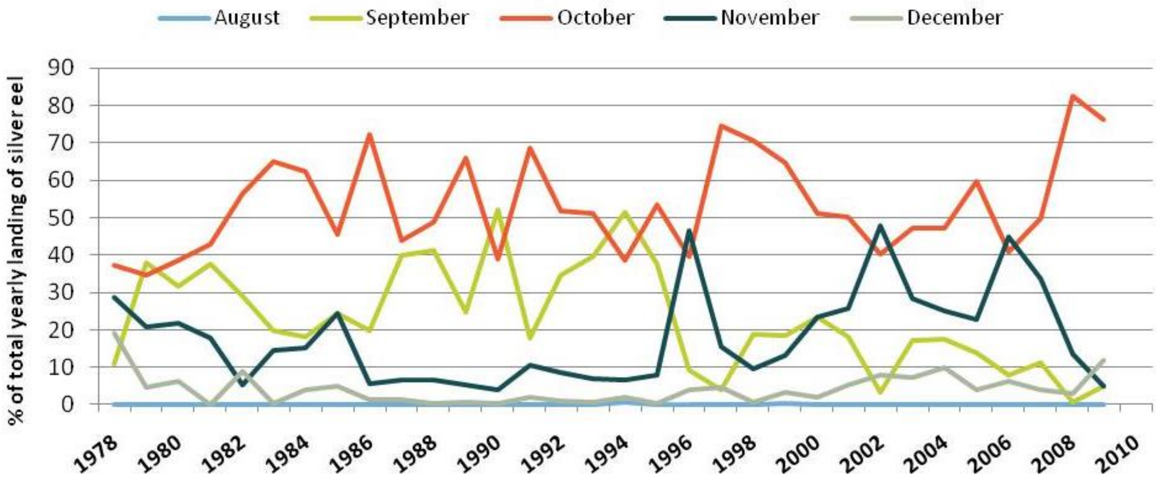


Figure 4.97: Percentage of total annual landings of silver eel in Fehmarnbelt from 1978-2009 in the months from August to December (data from The Danish Directory of Fisheries).

Commercial landings of silver eel in specific Danish waters reveal that approximately 2/3 of the landings are recorded along the eastern migration route out of the Baltic Sea through Øresund (Figure 4.98). The proportion have increased dramatically from the mid 1990s as a result of increased landings in Køge Bight and decreased landings in the Belt Sea. This may be caused either by a change in the main passage route for silver eel or by a change in the fishery mortality in the specific waters. As with fishery statistics in general, landings of silver eel are a result of several factors including fishery pressure, and the landings are therefore only indicative for the relative significance of the specific migration routes of the silver eel.

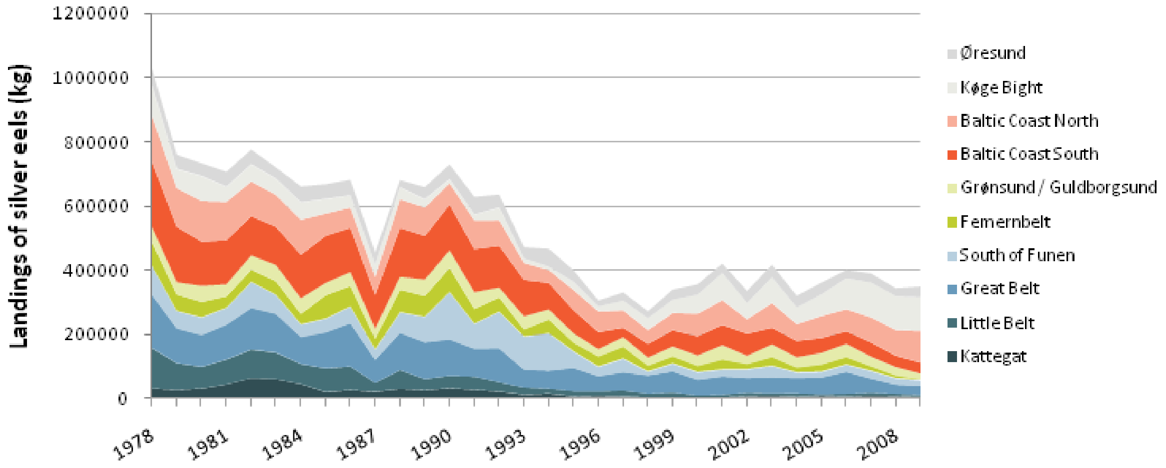


Figure 4.98: Annual landings of silver eel from different Danish waters in Kattegat, Øresund and the western Baltic Sea (data from The Danish Directory of Fisheries).

During the baseline study tagging and recapture campaigns were carried out in 2008 and 2009 in order to evaluate the main migration routes of the silver eel. The experiments included release of 3,540 T-bar tagged and 304 DST tagged eel in Fehmarnbelt in 2008, and in the Arkona Basin in 2009 (Table 4.22). In the latter campaign the eel were captured on the south coast of Lolland and transported approximately 150 km north-east and released at two locations approximately 20km south of the Swedish coast at Trelleborg and 20 km north of the German coast at Rügen. The number of recaptured eel was approximately 10% for the T-bar tags and 20% for the DSTs with some differences between the two campaigns and the location of release.

Table 4.22: Number of released and recaptured T-bar tagged and DST tagged silver eel in Fehmarnbelt 2008 and the Arkona Basin 2009.

Release location	T-bar tag	Recaptured	%	DST-tag	Recaptured	%
Coast of Fehmarn 2008	699	66	9.4	30	4	13.3
Coast of Lolland 2008	1,156	190	16.4	74	11	14.9
20 km north Rügen 2009	771	36	4.7	101	22	21.8
20 km south Trelleborg 2009	914	76	8.3	99	23	23.2
Total	3,540	368	10.4	304	60	19.7

Figure 4.99 shows the recapture positions of the T-bar tagged eel both in 2008 and 2009 in relation to release positions. This gives an overall picture of the main routes the eel had chosen. As expected most of the tagged eel released in the Fehmarnbelt in 2008 migrated northwest through the Belt Sea, although a few had headed towards Øresund. In 2009, the majority of eel migrated northwest into Øresund, albeit they originally were caught in Fehmarnbelt and released in the Arkona Basin. This indicates that silver eel do not follow a pre-determined route either through Øresund or the Fehmarnbelt imprinted as juvenile or genetically determined.

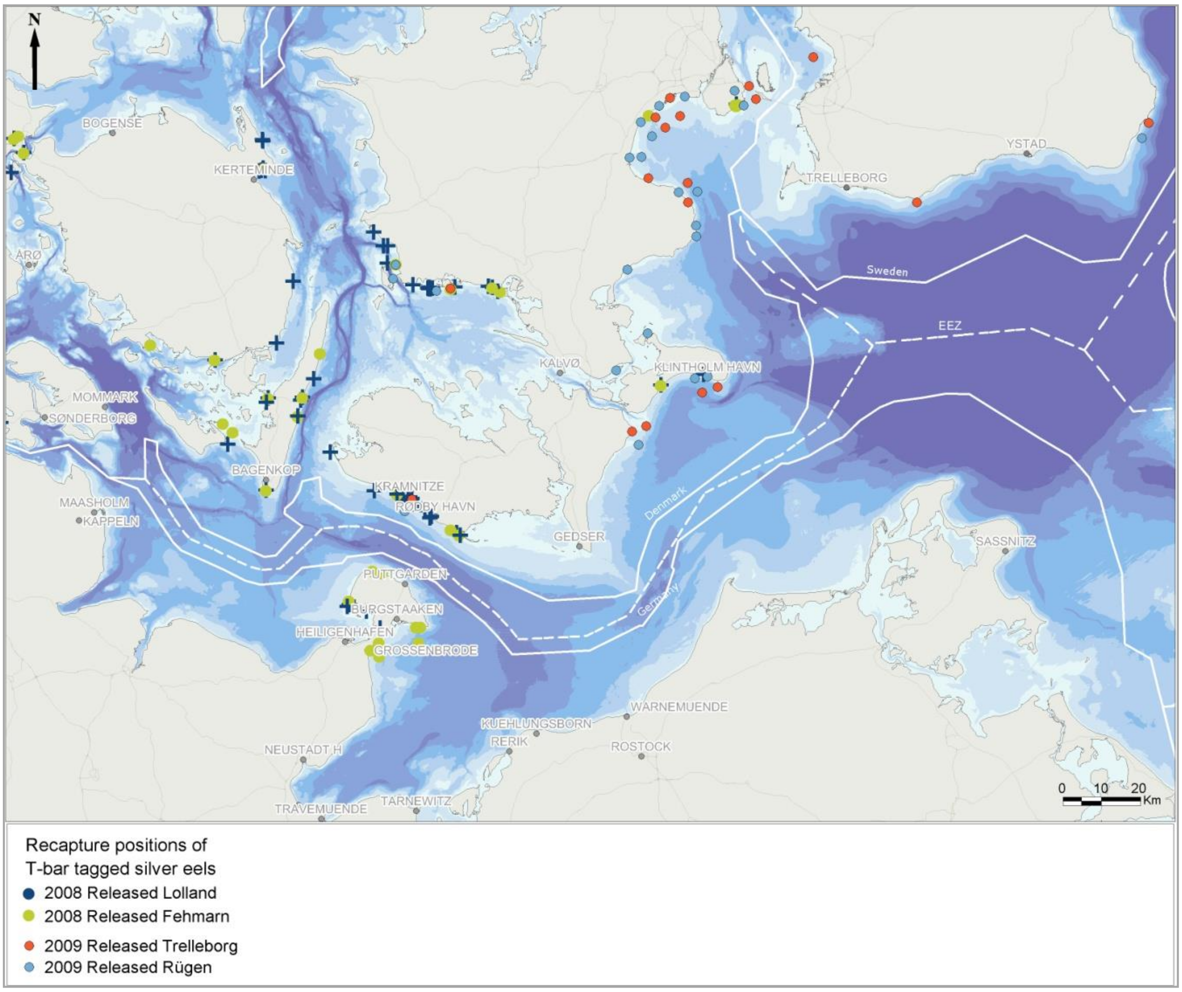


Figure 4.99: Recapture positions of T-bar tagged silver eel released at the coast of Fehmarn and Lolland in October-November 2008, and north of Rügen and south of Trelleborg in October 2009.

The location of the release areas seems to be of some importance for the chosen route of migration. This is supported by the main route chosen by eel released at the respective coasts indicating greater preference for directions associated with the coasts. Accordingly, eel released at the coast of Fehmarn preferred to a greater extent the Little Belt compared to eel released at Lolland, where the majority headed through the Great Belt (Figure 4.100). Although most eel went through Øresund in 2009, there was a similar tendency that eel released north of Rügen migrated further west compared to eel released further north i.e. south of Trelleborg.

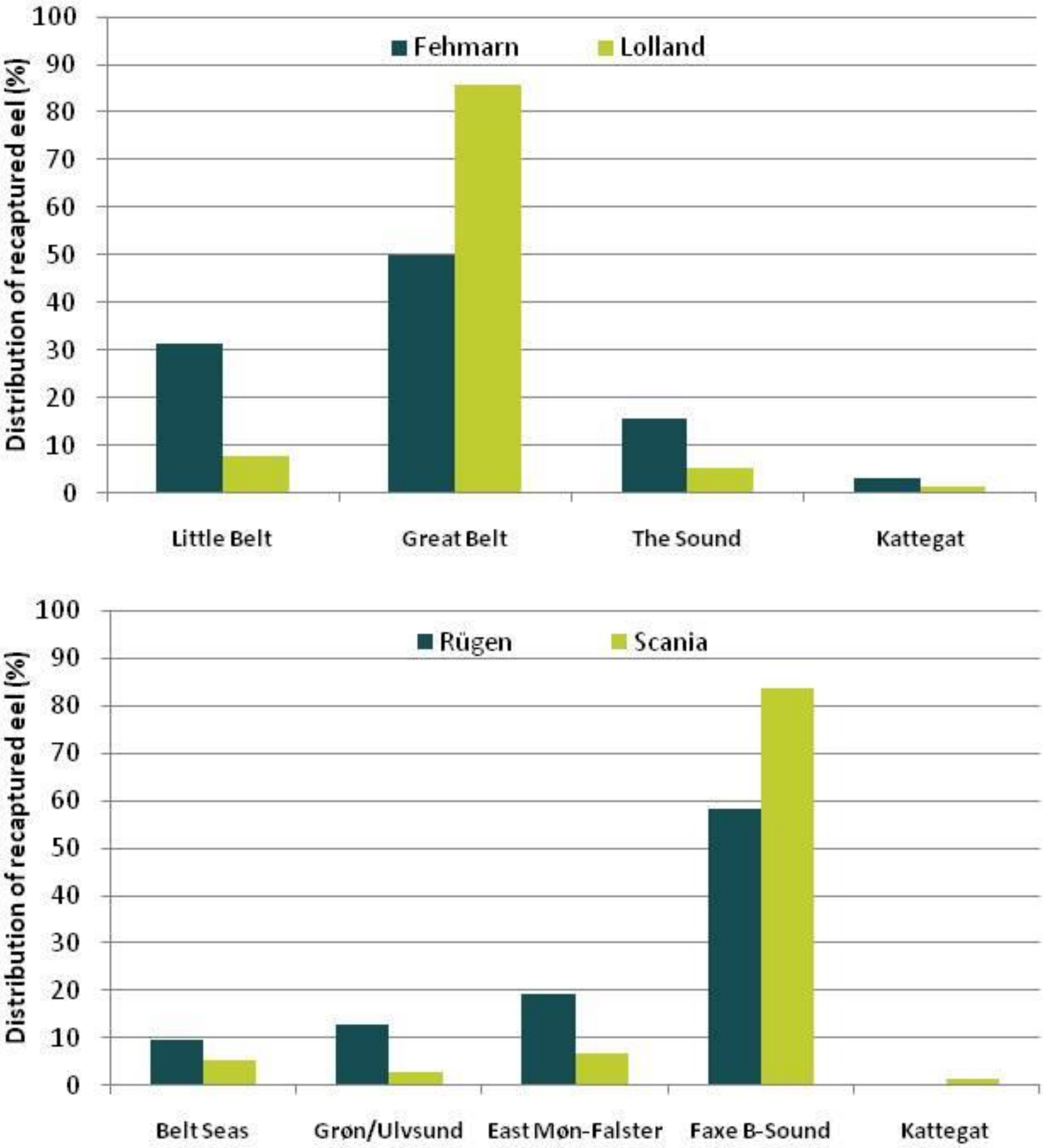


Figure 4.100: Distribution of recaptured T-bar tagged silver eel released at the coast of Fehmarn and Lolland in October 2008, and off the German coast north of Rügen and the Swedish coast south of Trelleborg, October 2009.

Since the fishery pressure in the concerned waters is unknown, the distribution of recaptured eel may not disclose the actual distribution of eel among the migration routes. However, given that the migration is unidirectional and combining commercial landings with population estimates based on marking-recapturing equations, the fishing pressure in the Belt Sea in 2008 was approximated. Hence, 1.7 million silver eel were calculated to have passed Fehmarnbelt in 2008 corresponding to a total biomass around 1,600 tonne (FeBEC, 2009b). The estimate is based on several presumptions and most likely represents an overestimate.

The objective of the 2009 tagging experiment was also to estimate the migration through Øresund, respective to the Fehmarnbelt. However, the presumption of similar behaviour among marked and unmarked eel, referring to catchability, was not fulfilled (FeBEC, 2010d). Hence, tagged eel released off Rügen were underrepresented in the commercial landings in the Belt Sea compared Øresund, i.e. disproportionately few tagged eel compared to not tagged eel had migrated through Fehmarnbelt. The transportation and the release in the middle of the Arkona Basin, where the currents often are diffuse, may have contributed to this. However, the average recapture rates in 2008 and 2009 were approximately the same (6.9% in 2008, when omitting local recaptures, and 6.7% in 2009). This indicated a fairly even fishery pressure in the different waters.

Given the same fishery pressure in Øresund as in the Belt Sea, the biomass of Baltic eel passing Danish waters in 2008 could be estimated at 5,800 tonne, of what approximately 33% had migrated through Fehmarnbelt, while 60% had migrated through Øresund, and at least 7% through the small alternative sounds as Ulvsund, Grønsund and Guldborgsund (FeBEC, 2010d). The biomass could not be estimated for 2009, but given the same fishery pressure, the recorded landings along each migration route reveal the relative importance of each way. According to the landings a maximum of 28% of the migrating silver eel in 2009 had chosen the Fehmarnbelt passage way while 66% had migrated through Øresund and at least 6% through the small alternative sounds. It should be emphasized that these values for the relative importance of each migration route relies on equal fishery pressure. Several efforts were made to further evaluate this assumption, but the available data were insufficient (FeBEC, 2011e).

A total of 15 and 45 DST-tagged eel were recaptured in 2008 and 2009, respectively. This corresponded to an average recapture rate of 19.7% (Table 4.22). The rate was remarkably high in 2009 compared to 2008, which primarily was due to capture of eel in gill and trammel nets in open water in the center of Øresund. Eel with the rather large DSTs were evidently detained in the fishing gears, which was not the case with the T-bar tagged eel. However, the overall picture of chosen routes of the DST-tagged eel was comparable to the T-bar tagged eel (Figure 4.101 and Figure 4.102).

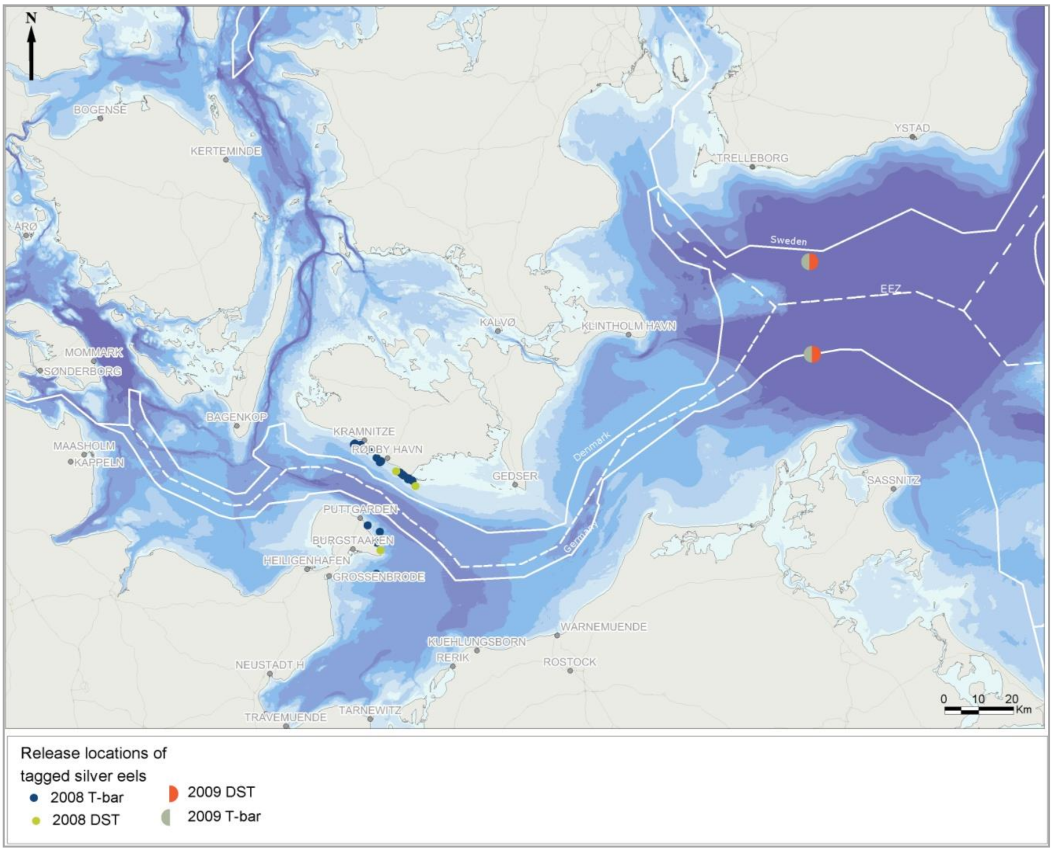


Figure 4.101: Release positions of tagged silver eel at the coast of Fehmarn and Lolland in October-November 2008 and north of Rügen and south of Trelleborg October 2009.

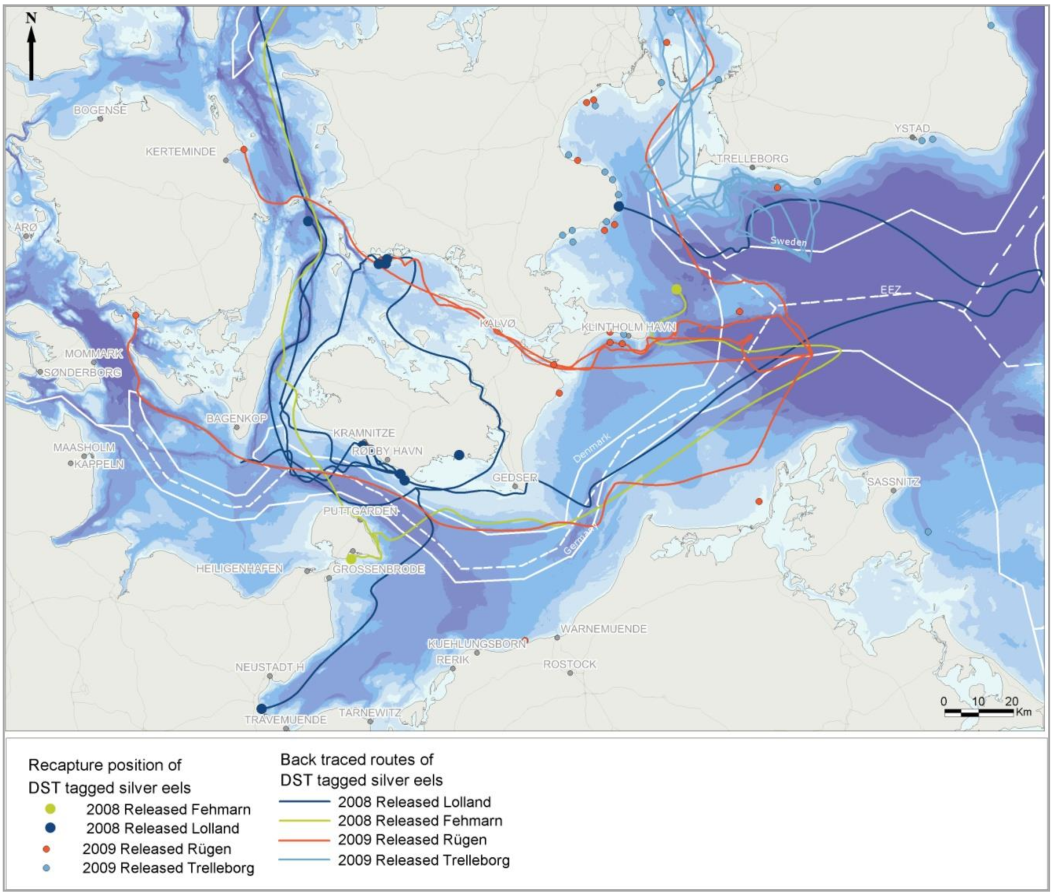


Figure 4.102: Recapture positions and backtracked routes of DST tagged silver eel released at the coast of Fehmarn and Lolland in October-November 2008 and north of Rügen and south of Trelleborg October 2009. Colours represent the release position while the position of the dot on the map illustrates the recapture position.

The majority of recaptured eel in 2008 migrated through the Great Belt. In 2009 Øresund was the preferred route of the Swedish released eel (94%), while less than half of the Rügen released eel migrated on this route. Among the latter, 25% were caught in Fehmarnbelt or further in the Belt Sea, while 15% were caught passing the small sounds, and 15% were caught on the Baltic south coast. Only a single Swedish eel was caught on the Baltic south coast, and none were caught further westwards on the routes through the Belt Sea.

Most recent tagging experiments from the Baltic have been performed on migrating Swedish silver eel and only few experiments have been performed with natural silver eel from the southern Baltic countries. The Swedish tagging experiments of silver eel showed that the vast majority of eel released on the Swedish east coast, migrate south along the coast where they migrate north through Øresund after reaching the Swedish south coast (Westin, 1990 and Westin, 1998).

In contrast, silver eel originating from stocked eel from Gotland migrated further south where they migrated through the Belt Sea or Øresund in about equal amounts after reaching the Baltic south coast (Westin, 1998). Furthermore, the study showed that the navigation abilities were poorer in wild eel with reduced olfactory sense. Thus, Westin (1998) suggested that stocked eel, lacking olfactory imprints from their way across the Baltic to freshwater locations, cannot use smell as a cue and instead must use the less reliable cue of declining water temperature.

Similarly, a tagging experiment off the Polish coast (Karlsson et al., 1988) which was performed with silver eel originating from stocked eel in the Masurian lakes, showed that there was a low recapture rate, around 10%, and only 40% of these eel chose the outlet through Øresund. Limburg et al. (2003) showed from analysis of strontium and calcium contents in eel otoliths, that silver eel, which had previously been stocked and raised in fresh water, were almost exclusively found in the Fehmarnbelt area compared to an area north of Øresund, although they only corresponded to 24% of the registered eel. These results support that silver eel from the southern Baltic area, which primarily originate from stocking campaigns, migrate through the Belt Sea.

These observations are in good accordance with the present study, where silver eel caught at the south coast of Lolland and released off the south coast of Sweden mainly chose the northern migration route through Øresund, while eel released off Rügen were distributed more evenly between Øresund and Belt Sea. This indicates that eel on a local scale do not have a predestinated migration route but presumably navigate at least partly in accordance with present conditions of currents, salinity and temperature.

Individual behaviour

Backtracking of the most likely migration routes were performed for all the recaptured DST-tagged eel from the 2008-campaign, while ten recaptures were selected from the 2009-campaign (Figure 4.102). Although many of the eel had taken rather direct routes, several also displayed detours, and the variation in average swimming speed was great. In 2008 two silver eel migrated eastwards, and depths of up to 48m were registered indicating a detour to the Arkona Basin before entering the southern Øresund, where they were caught. The distance travelled from the Fehmarnbelt, for eel migrating westward, varied greatly with recaptures from south of Langeland and Zealand to the central part of Kattegat. One eel had initially taken an eastward direction crossing Rødsand, and then northwards through Guldborgsund ending up on the south west coast of Zealand, while another eel headed southwards and was recaptured in Mecklenburg Bay at Lübeck.

Routes of ten eel released in 2009 at the German and Swedish coast were backtracked. Three Swedish eel from the first release at the coast of Sweden and recaptured in the Øresund north of the Øresund Bridge, initially had some navigational problems in the waters south of Sweden before they headed north after entering Øresund of the peninsula of Falsterbo. The two backtracked Swedish eel from the second release followed identical routes. In the beginning they headed north towards shallow water, where they followed the coast westward to a point south of Falsterbo. Then they left the coast and migrated south-west towards deeper water in the centre of the entrance to Øresund, where they turned north to their recapture locations outside Malmø and Ven.

One eel from the first German release went straight through Fehmarnbelt to Fåborg without any delay. The eel migrated 274 km in less than 8 days corresponding to a mean travelling distance of almost 34 km/day. Two eel from the same release were recaptured in the Great Belt at Kerteminde and Aggersø Sund. Both went through Grønsund and thereby passed the Fejø Bridge and later the Storstrøms Bridge on their way to the Great Belt. The eel recaptured at Kerteminde had travelled 194 km in 9.6 days which correspond to a travelling speed of 20.2 km/day, while the eel recaptured at Aggersø had an average swimming speed of 10 km/day. One of the two backtracked eel from the second German release went northwards through the Øresund. After three days of migration this eel rested at a depth of 20 m for 8 days before resuming the northward migration. The other backtracked eel from this release was recaptured in Grønsund after 16.7 days. This eel had several resting periods on depths ranging of 10-20 m resulting in a very low mean daily travelling distance of 6 km.

Preferred depth

The daily maximum depths recorded by the DSTs indicate whether the eel prefer shallow or deeper waters. According to the logged depths the DST-tagged eel migrated preferably in deep waters. Frequency diagrams of the daily maximum depths showed hence that the eel spent more than half the time exceeding depths of 20-25 m and less than 10% of the time at depths shallower than 10 m (Figure 4.103). Mean daily maximum depth was 22.2 m in 2008 and 23.7 m in 2009.

Figure 4.103: Accumulated frequency diagram of daily maximum depth of 14 DST-marked silver eel migrating 156 days in 2008 and 41 DST-marked eel migrating 577 days in 2009.

Vertical movements

The DSTs logged temperature and depth every second minute. A significant trend among most of the tagged eel was that recorded depths, and to some degree temperatures, varied considerably more during the dark hours than during daytime. The depths were in general greater during daytime compared to the night. Figure 4.104 shows an example of logged data during three weeks from a tagged eel from the 2008-campaign with dark hours and moon phases added to the graph to facilitate interpretation. Hence, regarding the specific eel caught north of Djursland, a pattern with periods of stable and greater depths in the daytime, probably corresponding to the sea bottom, alternating with varying depths from the surface to 15-25 m below surface during the dark hours can be identified. Moreover, when the stable daytime depth exceeds 16-18 m the temperature often increased as well.

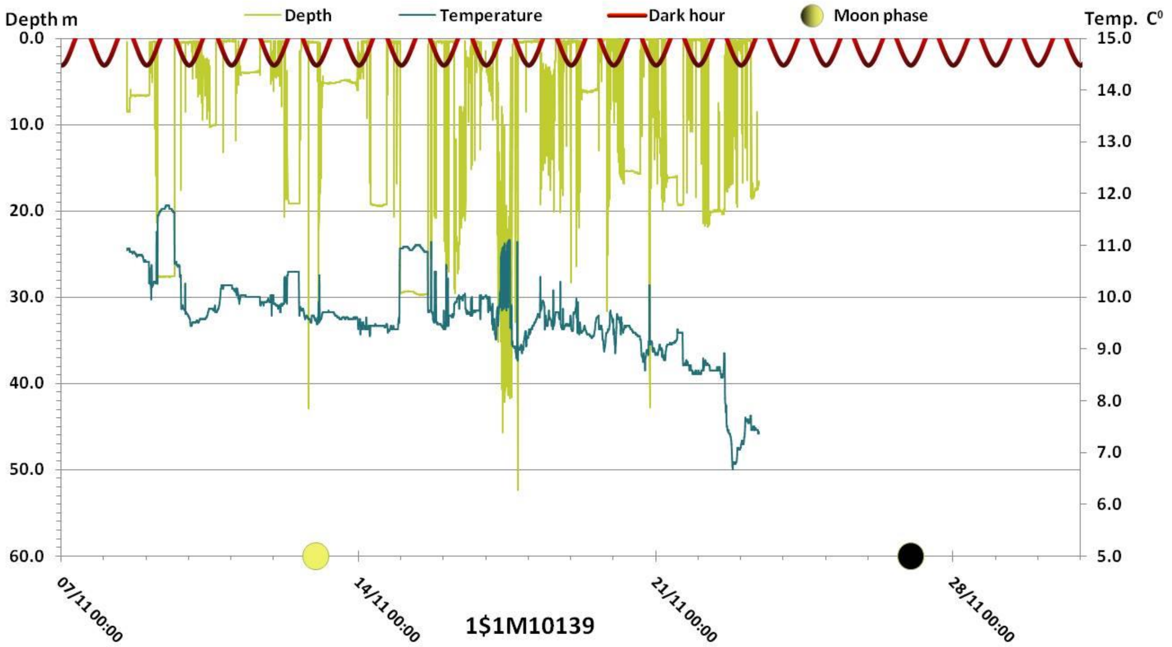


Figure 4.104: Logged data from a DST tagged eel released at the coast of Lolland and recaptured in the Kattegat in 2008 displaying alternating patterns in depth distribution between dawn and dusk.

The average frequency of vertical movements exceeding 5 m within 2 minutes showed a significant diurnal variation in behaviour with considerable more activity during the dark hours than at daytime (Figure 4.105). During the night the eel mainly stayed near the surface but made regular dives to greater depths 1-2 times every hour of approximately 5 minutes duration depending on depth.

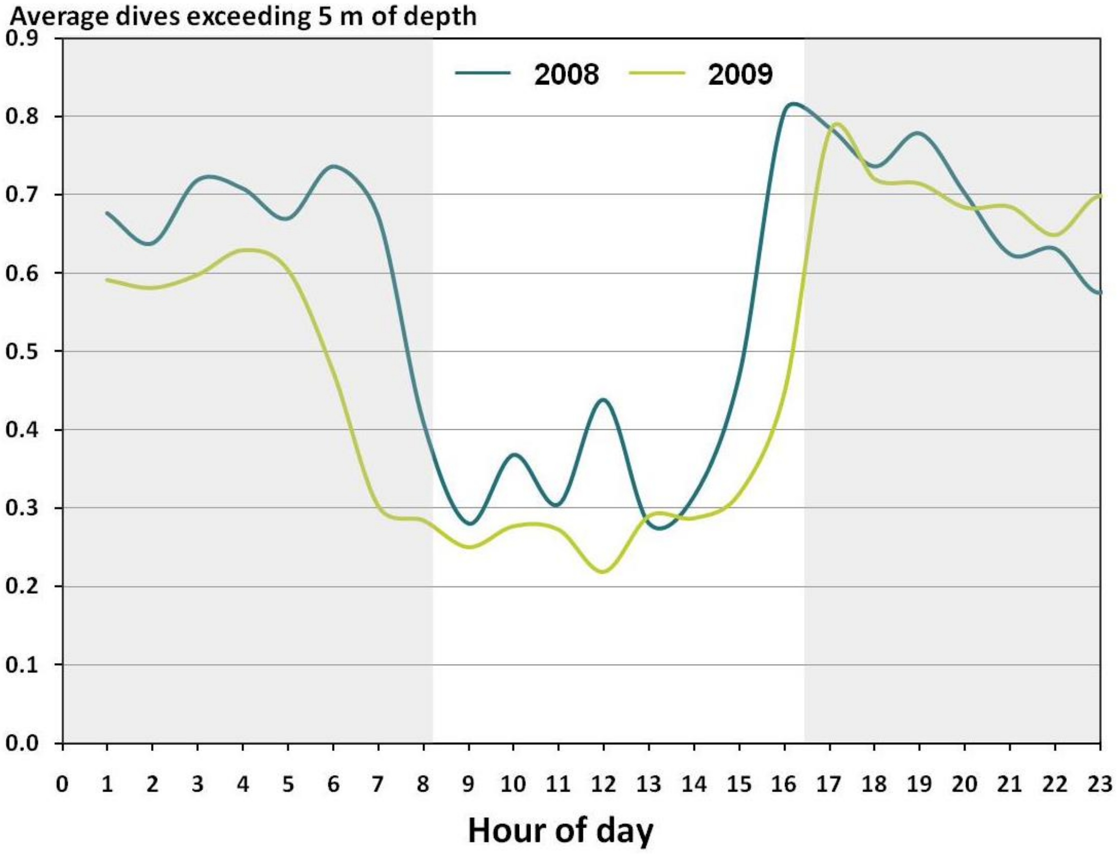


Figure 4.105: Average frequency of vertical movement exceeding 5 m/h of 14 eel tagged with DSTs released in Fehmarnbelt in 2008 and 41 DST tagged silver eel released in the Arkona Basin in 2009.

The patterns indicate that silver eel prefer to migrate during the dark hours, where they swim near the surface, while they tend to rest on the seabed during daytime. While swimming they make frequent dives to the bottom or to the thermocline. Westerberg et al. (2007) found in a similar study using DSTs the same migration pattern among silver eel migrating along the Swedish east coast.

Resting periods and daily distances

Some of the eel had occasional periods with very low vertical activity during night as well as day, presumably indicating low swimming activity. This is illustrated by an eel released south of Sweden and recaptured 28 days later in Øresund east of Ven (Figure 4.106). After short periods with low activity following the release in the Arkona Basin the eel stayed for nearly ten days on ten meters depth probably in the southern part of Øresund.

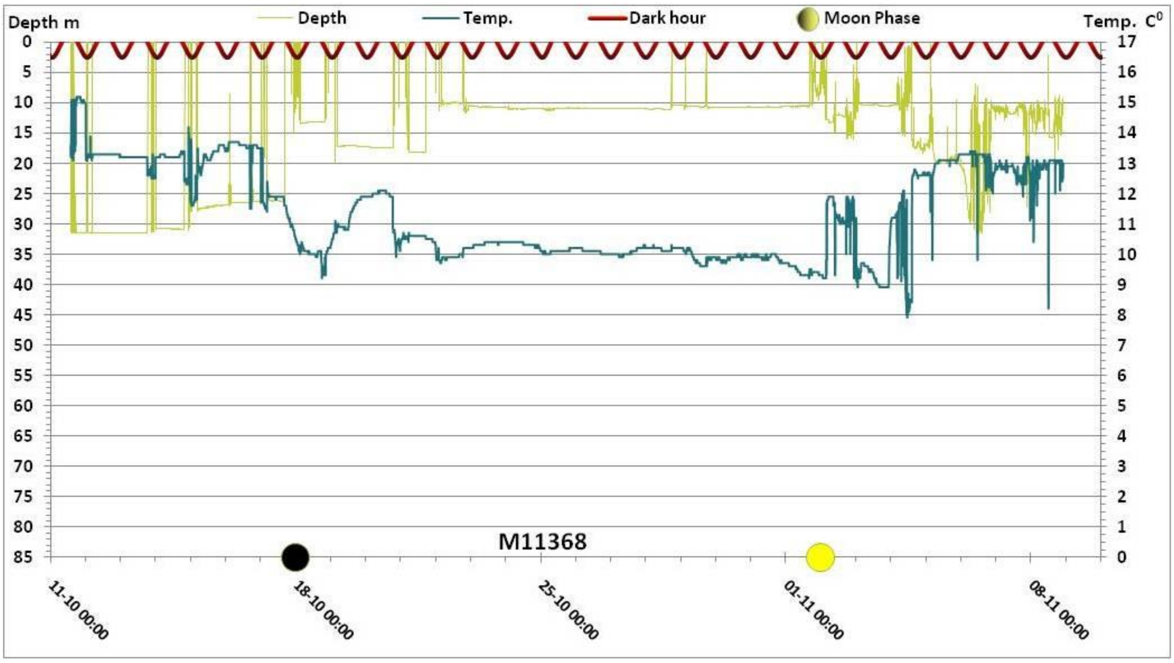


Figure 4.106: Data from a DST-tagged eel released south of Sweden October 2009 and recaptured in Øresund east of Ven. Several periods of low vertical movements were registered.

These periods of low activity were more pronounced in 2009 compared to 2008. The eel rested or had nights with no activity averaged 19.4% of the nights in 2009, and 7.5% in 2008. The more extended resting periods are most probably the reason for a smaller average daily swimming distance, amounting to 11.7 km/day in 2009 compared to 21.1 km/day in 2008.

Recent studies have estimated silver eel swimming speed to be 16 km/day along the Swedish east coast (Westerberg et al., 2007), and Westin (1998) found daily migrating distances of 6.7-6.9 km/day calculated as the shortest possible distance between release and recapture. In a summary of 100 years of Swedish tagging experiments an average of 11.64 km/day was found (Sjöberg and Petersson, 2005). Low migration speed has been recorded among migrating formerly stocked eel released at Gotland along the Baltic south coast and the Belt Sea (Westin, 1998). The daily migration speed in the Atlantic Ocean is assumed to be significantly greater. Hence, a Dutch experiment demonstrated that silver eel could be induced to swim continuously (day and night) at a current velocity of 0.4 m/s, which correspond to a migration distance of 35 km/day (van den Thillart et al., 2008).

The variation in migration speed found in the present study is most likely a result of differences in resting periods or detours taken, rather than differences in active swimming speed. The records of depth and temperature among the recaptured DST tagged eel showed frequent periods with no changes, indicating periods with no swimming activity. This was found among the majority of the recaptured eel in 2009, and could last up to ten consecutive days. The frequent resting periods might have been caused by stress under the tagging procedure and transportation. However, there were also significant differences among the eel at the two release occasions, both regarding migration routes, migration behaviour and recapture rates. Prevailing water current conditions at the release sites in the Arkona Basin in the days following the two release occasions could to some extent explain some of the differences (FeBEC, 2010d). Thus, the currents following the two release dates were weak and diffuse or even going east, and a few days after the second release, northern currents prevailed in most of the basin except for the most southern parts.

It is evident that silver eel migrate downstream in freshwater to reach the sea, and several studies have shown that ebb and tide affects migration patterns of silver eel (e.g. Ibbotson et al., 2002). Furthermore, a migration in relation to the currents in the brackish Baltic Sea might be an important navigational tool out of the Baltic. This may explain the apparent need for vertical migrations from the stagnant bottom water to the surface during swimming, as the eel presumably hereby are more able to determine the strength and direction of the surface current. Swimming along the current would also optimize their swimming efficiency, which is regarded as an important issue considering the extreme migration distance, and a sufficient energy supply in form of lipids is assumed to be critical for the eel.

Based upon studies of the energy cost of swimming for eel (van Ginneken and van den Thillart, 2000) and measurements of lipid content in silver eel, Limburg et al. (2003) calculated the migrational potential of eel with different habitat history assuming that 60% of the lipids are reserved for gonadal development. They found that the migration potential varied between 4,938 km and 7,149 km. Taken into account that the distance to the Sargasso Sea, depending on the start location and the chosen route, is in the range of 6,500-7,500 km for eel migrating from the southern and central Baltic, any behavior serving to minimize energy consumption will be advantageous.

The preference to migrate with the surface current could explain the observed distribution of recaptured eel in Danish waters in the present baseline study. The direction of the prevailing surface currents in the northern Arkona Basin is west and north through Øresund. In the southern part, the current goes west and south through the Fehmarnbelt or the small sounds and further through the Belt Sea, or it turns west and north through Øresund. Thus, the majority of the silver eel migrating along the Swedish south coast would choose Øresund if they follow the surface current. Eel migrating along the Baltic south coast would migrate through the Belt Sea or through Øresund depending on the present current conditions in the Arkona Basin.

Besides seeking an energetic advantage by using the stronger currents near the surface, swimming near the surface at night and resting at the bottom during the day might be an adaptation to a relatively high predation risk in coastal waters during daytime. The frequent dives to the bottom or to the thermocline while swimming in the surface at night cannot be explained by survival or energetic advantages. However, this behaviour could possibly be related to navigational issues.

4.7.6 Eel baseline conclusion

The European Commission has recently taken drastic measures for the protection of the heavily declined European eel stock with the objective to restore the stock to pristine levels. Being member states Germany and Denmark have set up national eel management plans (EMP´s). Fehmarnbelt comprises a potential main escapement route for silver eel migration out of the Baltic Sea giving rise to a responsibility of securing free passageway.

The overall baseline conclusion regarding the significance of Fehmarnbelt for the European eel is that the Belt Sea has some importance as passageway for migrating silver eel, although the majority of eel leaving the Baltic presumably migrate through Øresund. The eel seem to prefer migrating near the surface over deep water areas performing frequent dives during the night from the surface layers to either the bottom or thermocline, while they rest at the bottom during the daytime.

The baseline description of eel in the Fehmarnbelt area can be summarized as:

- The area has minor importance as a feeding ground for yellow eel.
- Silver eel migration occur from August- December and peaks in October.
- Silver eel migrating along the Swedish coast prefer Øresund as their main route, while silver eel migrating along the Baltic south coast to a greater extent selects the southern route through the Belt Sea.
- The choice of route between Øresund and Fehmarnbelt does not appear to depend on imprinting during the juvenile stage. The final route may therefore mainly depend on the present conditions regarding water currents and salinity in the Arkona Basin.

- The north-eastern route through Øresund was presumably the most important migration route for the silver eel leaving the Baltic Sea in 2008-2009. Most likely not more than 30% of the Baltic silver eel used Fehmarnbelt as migration route.
- Silver eel prefer migrating over deeper waters.
- Silver eel migrate preferably during the dark hours and rest at the bottom during daytime.
- While swimming near the surface silver eel perform frequent dives to the sea bottom or to the thermocline.
- Eel rest from time to time for days.
- Migration speed is highly variable. In active migration the speed is approximately 0.4 m/s corresponding to at least 17 km/day.
- The importance of Fehmarnbelt and adjacent areas for eel is listed in Table 4.23.Areas of potential importance for the migration of eel in Fehmarnbelt and adjacent areas can be seen on Figure 4.107. It can be seen that Fehmarnbelt is of very high importance for the migration of eel, as a considerable part of the silver eel migrating from the Baltic Sea most likely uses Fehmarnbelt as a passage way to their spawning grounds**.**
- The location of Fehmarnbelt as one of the few possible gateways to the Atlantic Ocean makes a free passage very important for the migrating silver eel in the Baltic Sea and likewise for the upstream migrating elvers. The blocking of the passage may have international consequences, and an acceptable reduction limit is accordingly low.
- Local eel nursery and feeding areas are of minor importance in the area.
- Spawning is not a relevant issue as it presumably takes place in the Sargasso Sea.

Table 4.23: Importance of Fehmarnbelt and adjacent areas for eel in relation to spawning, eggs and larvae drift, nursery, feeding and migration. - = not relevant.

Environmental component	**spawning**	**egg-larvae drift**	**nursery**	**feeding**	**migration**	**overall**
European eel	-	-	minor	minor	very high	very high

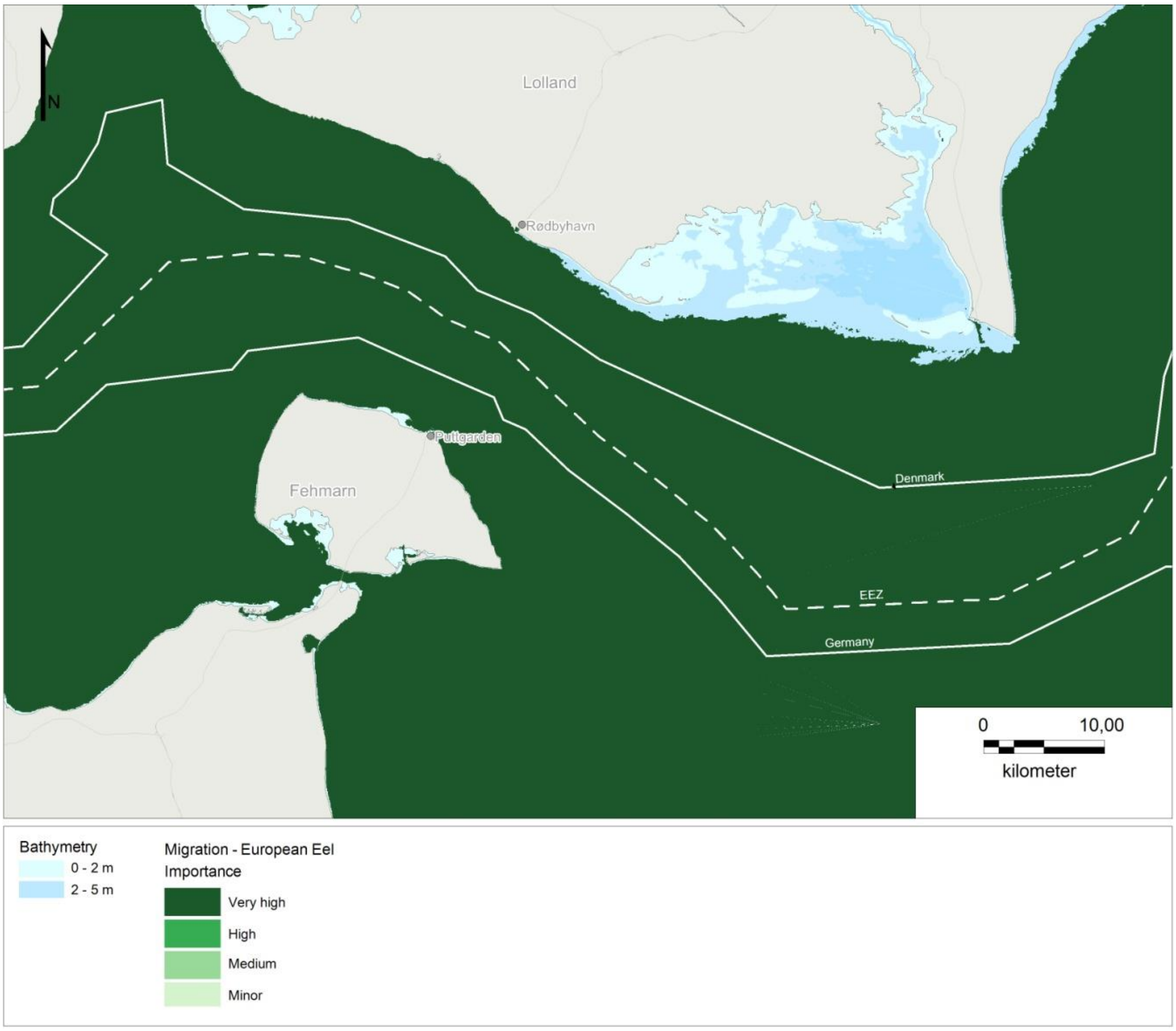


Figure 4.107: Areas of potential importance for the migration of eel in Fehmarnbelt and adjacent areas.

4.8 Flatfish

4.8.1 General background

During the baseline studies in Fehmarnbelt and adjacent areas ten species of flatfish were observed, and the most abundant species were dab (*Limanda limanda*), flounder (*Platichthys flesus*), plaice (*Pleuronectes platessa*) and turbot (*Psetta maxima*). Less abundant flatfish species registered were American plaice (*Hippoglossoides platessoides*), sole (*Solea solea*), brill (*Scophthalmus rhombus*), witch flounder (*Glyptocephalus cynoglossus*), Mediterranean scaldfish (*Amoglossus laterna*) and lemon sole (*Microstomus kitt*).

Flounder and dab are distributed in most of the western Baltic Sea. Although the stock structures for these two species are not completely known, a genetic study of flounder indicated that there are three different major populations or stocks (Skagerrak/Kattegat, southwest and eastern Baltic) rather than a high number of small stocks (Florin and Höglund, 2008). Studies of the stock structure of dab suggest the existence of several separate stocks of dab (reviewed in Florin, 2005). The proportion of landings of both flounder and dab has been increasing in recent years suggesting the abundances of both of these species have been increasing.

Furthermore, the population structure of plaice is still not known but the strong fluctuations in the abundance in the fisheries indicate occasional immigration and emigration of these species from local western Baltic stocks and Kattegat. Additionally, this is supported by the fact that local plaice populations in the western Baltic are considered to be at low levels with limited recruitment (ICES, 2008b).

Observations of landings from the fisheries show that turbot and brill mainly occur in the western and southern parts of the Baltic, including the area around Fehmarnbelt. Since 2000 the landings of turbot have been decreasing suggesting that the overall abundance in the western Baltic Sea have been declining.

Distribution of sole beyond the Kattegat into the Baltic Sea is limited by salinity which decreases further eastward. Sole are therefore found only in low abundances in the Belt Sea and the Øresund (ICES, 2009b). However, there has been an increasing abundance of sole caught in the western Baltic fisheries since 2007 (ICES, 2008b), suggesting that the abundance of this species in the western Baltic Sea and Belt area has been increasing. Sole are more abundant in Kattegat than Skagerrak and spawning areas are believed to be found in Kattegat and Skagerrak (ICES, 2009b).

Eggs and larvae of the dominant flatfish species flounder, plaice, turbot, dab and sole are all pelagic. According to Riber and Raschke (1999), dab, flounder and plaice spawn in the deeper and central parts of Fehmarnbelt and the Mecklenburger Bight.

In the following table, environmental settings and existing pressures of importance for flatfish species present in the Fehmarnbelt area, is listed.

Table 4.24: Environmental settings and existing pressures of significance for flatfish in the Fehmarnbelt area.

Basic environmental setting	Variable hydrodynamics exposed shoreline	Fairly stable environmental conditions with good access to food which enhance the recruitment of flatfish species. Several flatfish species spawn in Fehmarnbelt (Riber and Raschke, 1999). The selection of their spawning grounds is based upon certain criteria. Depending parameters are: Levels of dissolved oxygen, salinity and special current conditions which transport eggs and larvae to nursery grounds (Florin, 2005).
	Stratification	Most flatfish species spawn in spring and/or winter. Stratification in the Baltic Sea takes only place in summer and autumn at deep waters. Therefore, the pelagically drifting eggs of most flatfish species are not affected by stratification. Juvenile flatfish, on the other hand, are possibly affected by stratification. However, due to the good exchange of surface and bottom waters, oxygen depletion rarely occurs.
	Salinity	Most of the present flatfish species can tolerate the varying salinity levels (6 – 30 psu) in the Fehmarnbelt. However, American plaice has a lower tolerance to salinity fluctuations but its distribution is limited to the Beltsea (SD 22) (Winkler and Schröder, 2003). Overall speaking, the salinity level is not critical for flatfish recruitment.
Food competitors	Interspecific	During juvenile life stages, many flatfish species feed on the same kind of prey. Several small fish share the same food source (small crustacean like mysids (*Neomysis* sp.), isopods, amphipods) (e.g. Thiel et al., 1996).
	Cod	Juvenile cod partly use the same habitats as juvenile flatfish species and thus have an overlap in prey species (Florin, 2005). Furthermore, adult cod are competing for food with some flatfish species. For example, brill and turbot are share prey species with adult cod (Florin, 2005).
	Crustacean	Crustacean like the brown shrimp (*Crangon crangon*) and the common shore crab (*Carcinus meanas*) also occur in the same habitat types and shows an overlap in diet in regard to juvenile flatfish (20 – 50 mm) (Evans, 1983).
Predators	Cod / Clupeids / Flatfish	Cod is one of the most important predators in the Baltic Sea. Also during its juvenile life stages other fish species are an important part of its prey. Flatfish are mainly feeding on benthic organisms during their early life stages. As they mature they also feed on fish. Especially brill and turbot are important predators on small fish. Clupeids are feeding on pelagic eggs and larvae .
	Birds	Several bird species also feed on small fish (e.g. juvenile flatfish) in coastal waters. For example, some auk species (common guillemot, razor-billed auk and black guillemot), tern species and grebe species (great crested grebe, red-necked grebe and horned grebe) (Mendel et al., 2008).
Fishery		Commercial fisheries in the Baltic Sea mainly focus on cod and herring. However, flounder and plaice are affected but only as by-catch in relatively high amounts. Common sole, turbot and brill were also caught as by-catch.
Eutrophication	Nutrient enrichment	Especially fish communities in coastal areas are affected by the increased nutrient input caused by anthropogenic contributors (Thiel et al., 1996).
	Decreased water clarity	Deterioration in water clarity has generally reduced macrophyte vegetation, and hence reduced potential spawning, feeding and nursery sites for many fish species and other benthic organisms. Many of these organisms are potential prey for various flatfish species.
Invasive species		The occurrence of invasive species can potentially affect fish communities in the coastal waters of the Baltic sea.

4.8.2 Baseline approach

The main objectives of the baseline investigations of flatfish in Fehmarnbelt and adjacent areas were to:

- Estimate the seasonal timing and extent of flatfish spawning.
- Identify the location of potential spawning areas and nursery grounds.
- Estimate the abundance and distribution of different flatfish species.
- Estimate the habitat preference of different flatfish species.

The baseline investigations included:

- Gonad assessment to determine maturity and spawning season.
- Larvae bongo trawl surveys - to determine the presence and abundance of eggs and larvae.
- Backtracking the drift of eggs according to age and current regimes to estimate possible spawning areas.
- Gill net surveys to determine abundance, distribution and habitat preferences.

For further description of the methods see chapter 3 Baseline methodology.

4.8.3 Spawning

Several flatfish species spawn in Fehmarnbelt (Riber and Raschke, 1999) but no preferred spawning grounds are known (Frieß, 1987; Müller, 1988; Bagge and Steffensen, 1989). The choice of spawning grounds is based upon certain criteria. Important parameters are oxygen, salinity and specific current conditions which influence the drift of eggs and larvae to optimal nursery grounds. Plaice spawn in the Baltic Sea during winter (December-February) and successfull spawning occurs regularly in the deeper parts of the Arkona and Bornholm Basin (reviewed in Florin, 2005). For the pelagic spawning flounder, salinity of neutral egg buoyancy suggest that successful spawning may occur regularly in Øresund, the Arkona and Bornholm Basin (Nissling et al., 2002). Flounder spawns between February and April in the North Sea, Skagerrak and Kattegat whereas the spawning is delayed eastward and northward in the Baltic Sea and in general the spawning period is from April to June around Gotland (reviewed in Florin, 2005). Successful spawning of dab in the Baltic Sea may occur in the Øresund, the Arkona Basin and occasionally in the Bornholm Basin (Nissling et al., 2002). The spawning period for dab is extended from February to May in Kattegat and March to June in ICES SD22 (reviewed in Florin, 2005). Turbot is a summer spawner and spawns from May to August in the North Sea. The species has adapted to the low salinity in the Baltic and spawns successfully up to the Sea of Åland (reviewed in Florin, 2005).

The most abundant commercial species (i.e. plaice, flounder, dab and turbot) were caught by fishermen and during trawling in connection with the hydro-acoustic surveys. The gonadal development was assessed to determine maturity and the gonado-somatic index (GSI) of the flatfish.

An overview of the spawning seasons of the most common flatfish registered during the baseline study in Fehmarnbelt is given in Figure 4.108. The patterns for the individual flatfish species are based on gonadal development maturity stage 4, which represent spawning individuals. This figure does not present results from the few brill and sole which appeared as spawning capable in June.

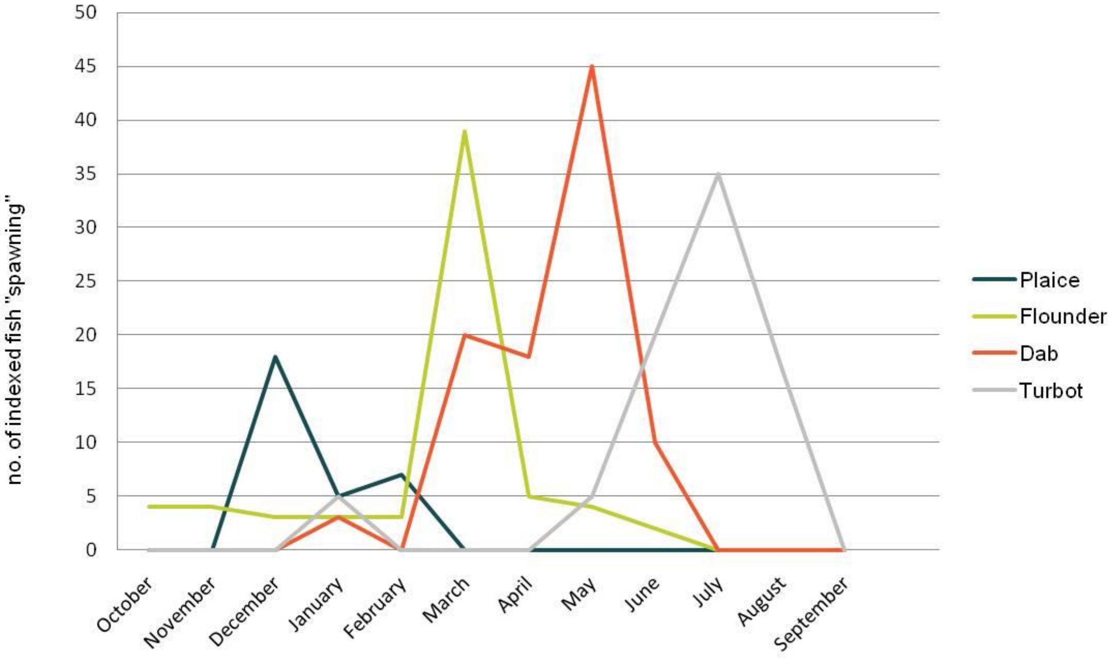


Figure 4.108: An overview of the spawning seasons of the most common flatfish in Fehmarnbelt. The values represent number of investigated fish determined as spawning (maturity stage 4). The fish were caught by a local fisherman and during hydro acoustic surveys.

Plaice mainly spawn during the winter months from December to February (Figure 4.109 and Figure 4.110). However, spawning plaice were also observed from March to May, although during this period the vast majority of the gonads were regenerated indicating that the majority of the plaice have been spawning previous during the year. The highest GSI was registered in December and February which corresponds with the months where most of the spawning individuals were determined (Figure 4.109 and Figure 4.110).

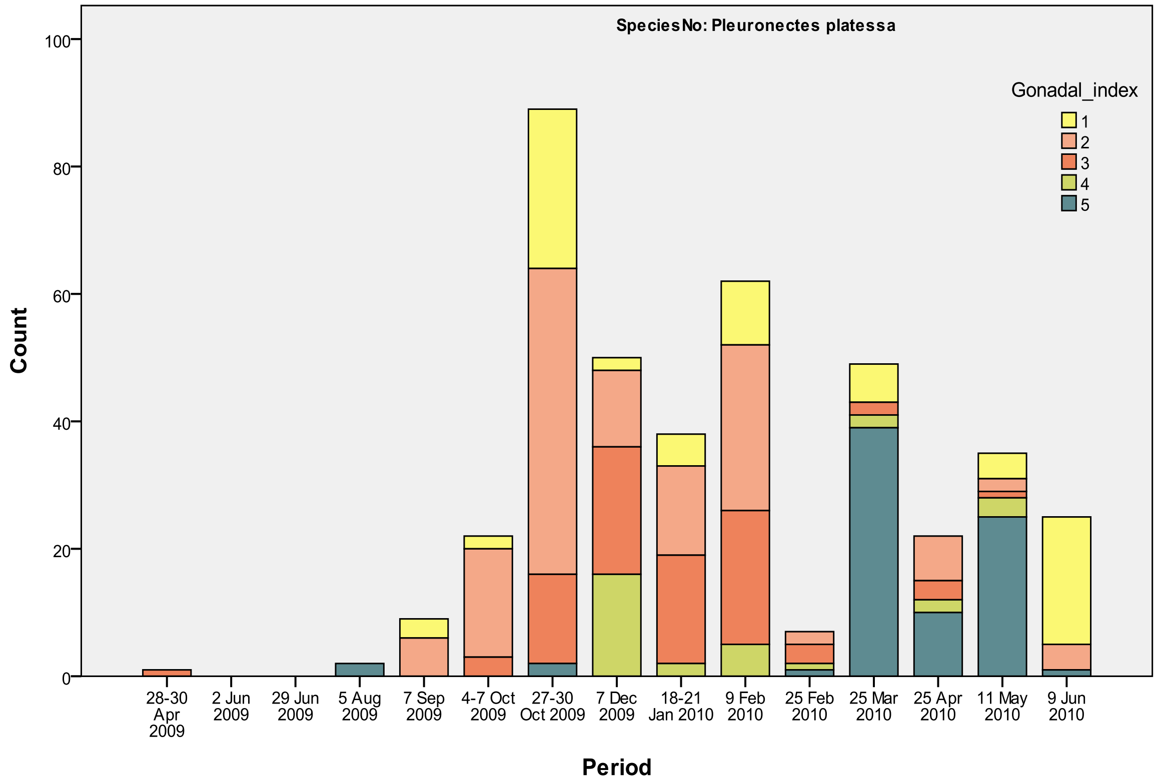


Figure 4.109: Maturity index of plaice (both sexes) from April 2009 to June 2010 caught by a fisherman and during hydro-acoustic surveys. 1 = juvenile, 2 = preparation, 3= ripening, 4 = spawning, 5 = regeneration.

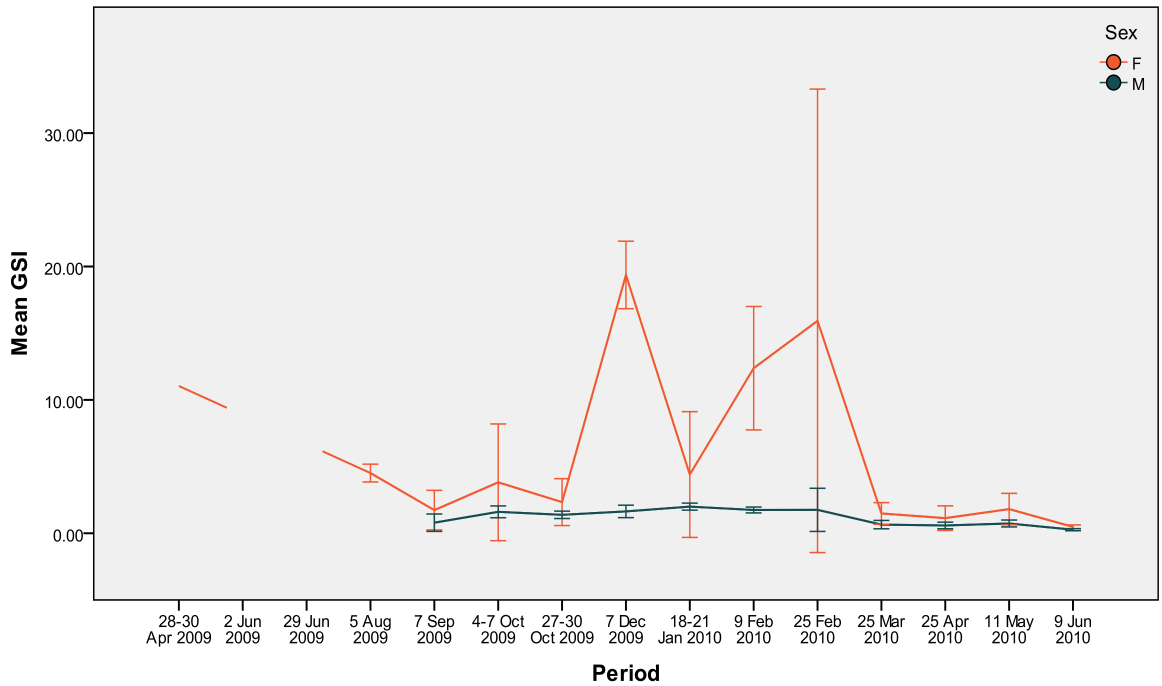


Figure 4.110: Mean monthly gonadosomatic index (GSI = gonadal wet weight as a percentage of total wet weight) of plaice. Female - red, Male - blue. Errorbars: ± 2 SE.

From October to February the gonads in a majority of the flounder were ripening. According to gonad maturity, flounder primarily spawned in March (Figure 4.111 and Figure 4.112) although a few spawning flounder were found during the period from October to May. From March to

June the gonads in about one third of the fish were spent and the gonads in many of the flounder were regenerating. During the period from December to March the highest GSI were measured (Figure 4.112).

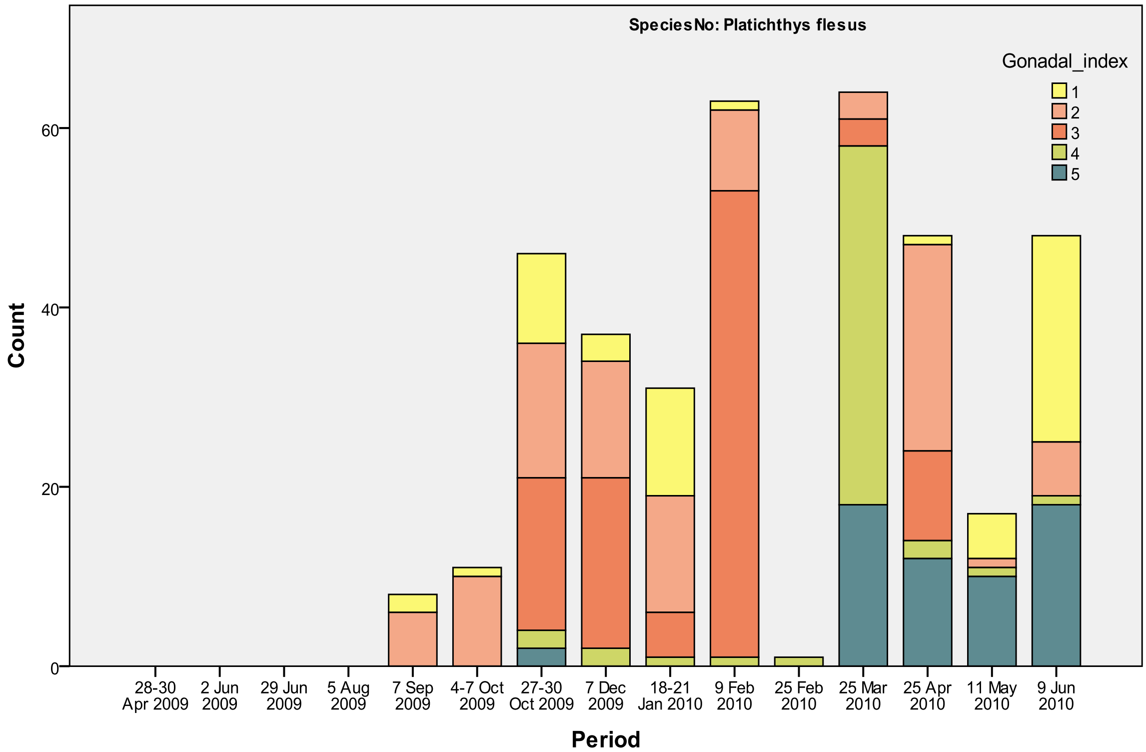


Figure 4.111: Maturity index of flounder (both sexes) from April 2009 to June 2010 caught by a fisherman and during hydro-acoustic surveys. 1 = juvenile, 2 = preparation, 3= ripening, 4 = spawning, 5 = regeneration.

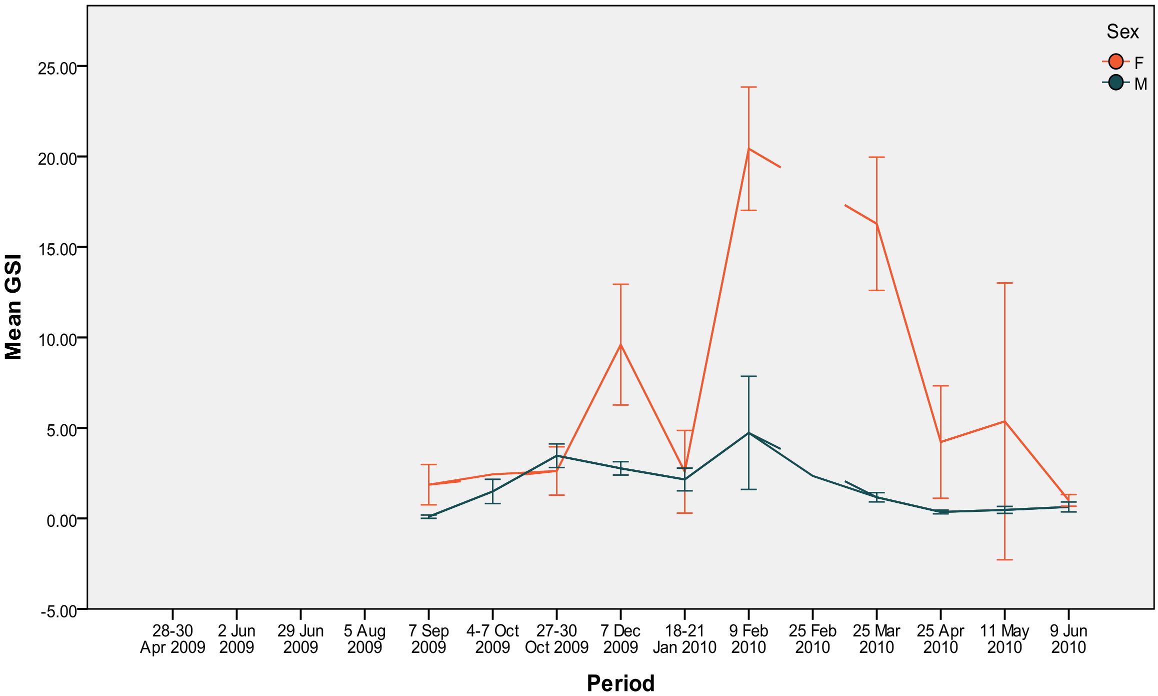


Figure 4.112: Mean monthly gonadosomatic index (GSI = gonadal wet weight as a percentage of total wet weight) of flounder. Female - red, Male - blue. Errorbars: ± 2 SE.

Dab spawned primarily from March to May 2010 however spawning individuals were also found in June 2009 (Figure 4.113). The GSI value peaked in May where the largest number of spawning individuals was caught (Figure 4.114).

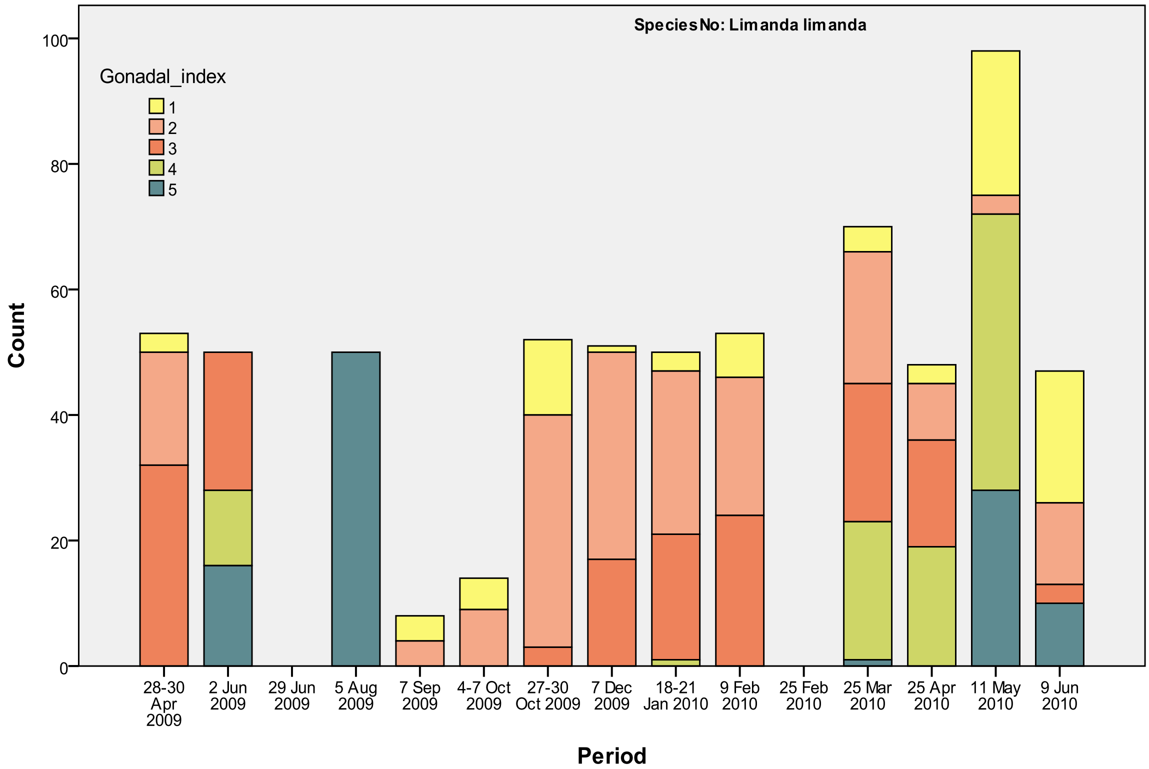


Figure 4.113: Maturity index of dab (both sexes) from April 2009 to June 2010 caught by a fisherman and during hydro-acoustic surveys. 1 = juvenile, 2 = preparation, 3= ripening, 4 = spawning, 5 = regeneration.

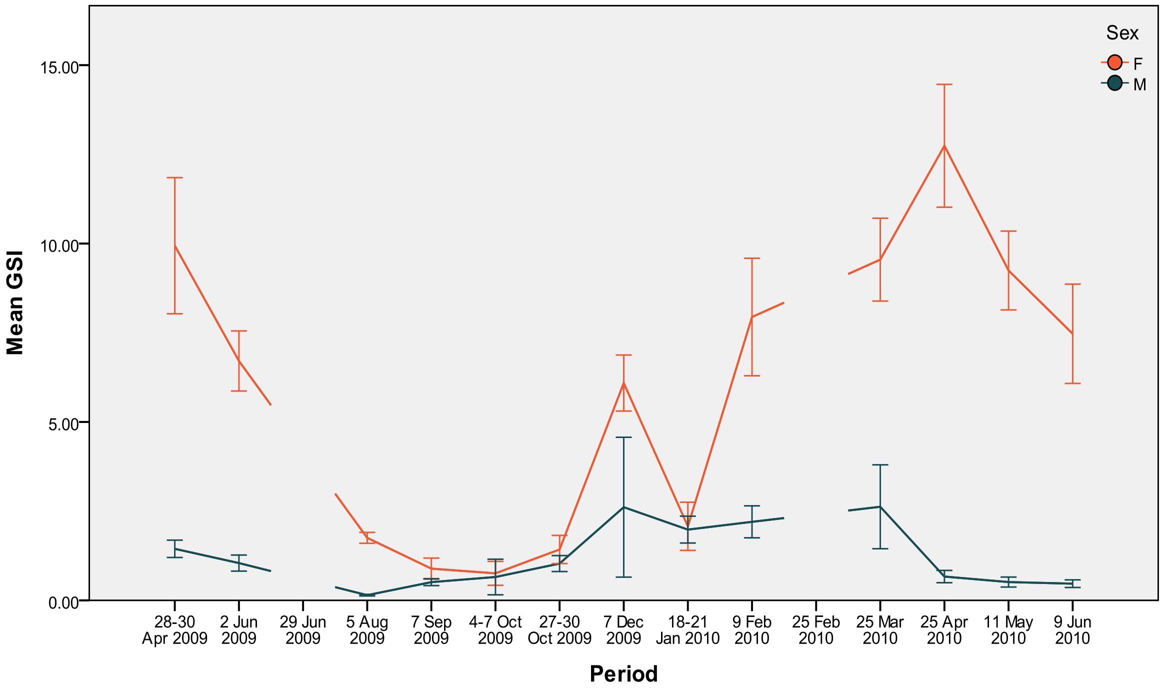


Figure 4.114: Mean monthly gonadosomatic index (GSI = gonadal wet weight as a percentage of total wet weight) of dab. Female - red, Male - blue. Errorbars: ± 2 SE.

Turbot mainly spawned during the summer months from June to August but a few spawning individuals were observed in September and January (Figure 4.115). Furthermore, the highest GSI were observed during these months (Figure 4.116).

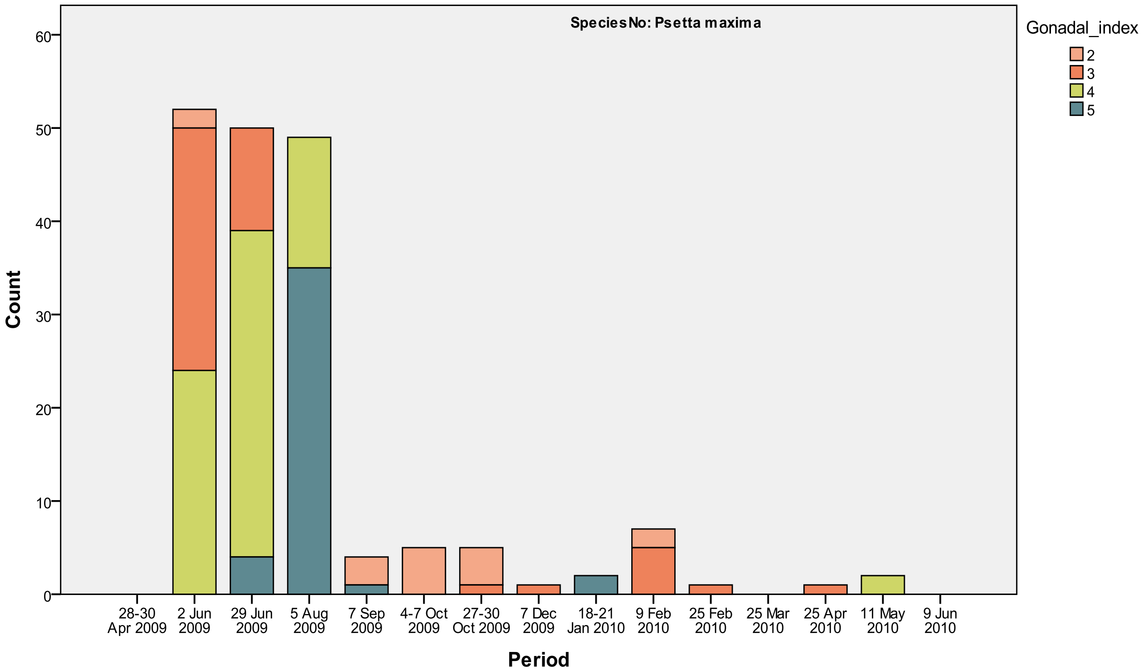


Figure 4.115: Maturity index of turbot (both sexes) from April 2009 to June 2010 caught by a fisherman and during hydro-acoustic surveys. 1 = juvenile, 2 = preparation, 3= ripening, 4 = spawning, 5 = regeneration.

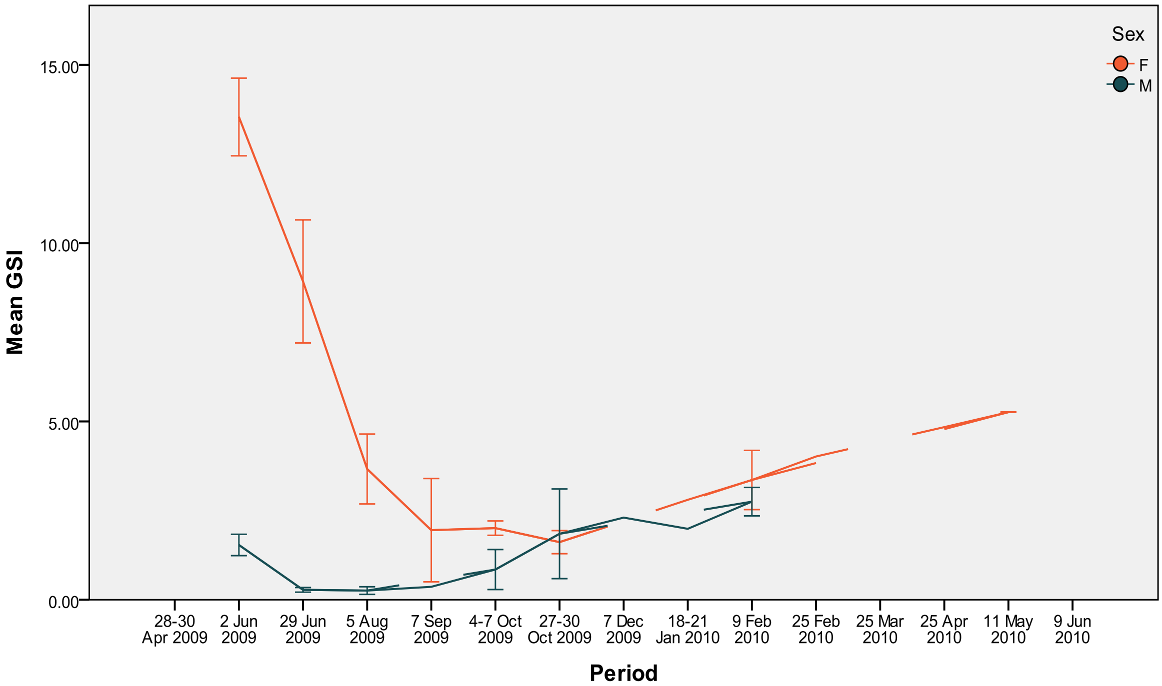


Figure 4.116: Mean monthly gonadosomatic index (GSI = gonadal wet weight as a percentage of total wet weight) of turbot. Female - red, Male - blue. Errorbars: ± 2 SE.

4.8.4 Eggs and larvae

Some fish species in the Baltic Sea such as dab and flounder have adapted to the lower salinity in the water of the Baltic Sea and enabled their eggs to stay floating by taking up more water and lower their density. This means that the eggs are larger the further into the Baltic Sea from Øresund. The eggs of plaice are only marginally larger compared to the North Sea and turbot do not seem to have this adaptation at all (Florin, 2005).

Flatfish larvae are symmetric with eyes placed in normal positions and upright swimming mode. As juveniles they undergo metamorphosis and switches from pelagic, plankton feeding state to benthic, benthos feeding lifestyle (Florin, 2005).

Eggs and larvae of flatfish were caught throughout Fehmarnbelt and were present almost the entire year. An overview of the densities of eggs and larvae from the different species and the main spawning periods is presented in Table 4.25. The densities of eggs were in general much higher in the deep water compared to the shallow water.

Table 4.25: Overview of densities of eggs and larvae in the spawning season of the observed flatfish species in Fehmarnbelt.

	Main spawning season	Average egg densities (eggs/m^3) in deep waters during the main spawning season	Larvae densities (larvae/m^3) in deep waters in main spawning season
Plaice	December-March	1	0.02
Flounder	February-April	5	0.06
Dab	May–July	11	0.06
Witch flounder	March	0	<0.005
American plaice	March-April	0	<0.005
Turbot	July-August	<0.005	<0.005
Sole	June-August	0	<0.005

Eggs from plaice and flounder can be seperated by the size (diameter) of the eggs whereas gelelectrophorese was implemented in order to differentiate between flounder and dab eggs. The gelelectrophoretic analysis was implemented as a quality assurance of the macroscopic determination and not all eggs and larvae were analysed by gelelectrophorese. Only dab eggs and larvae caught from April to June, plaice eggs and larvae from March to May, flounder eggs and larvae from March to April, turbot eggs and larvae in June and sole larvae in July/August were analysed. Additionally, no sole eggs were identified. An overview of the number of fish eggs and larvae caught March to August 2009 and identified by gelelectrophoresis is presented in Table 4.26.

Table 4.26: Fish eggs/larvae identified by gelelectrophorese from surveys from March to August 2009.

	Survey period					
Species	3 - 20 March	20 March - 4 April	21 - 30 April	11-20 May	15 -29 June	28 July - 6 August
Plaice	8/2	4/1	8/2	3/0		
Flounder	7/0	17/28	28/1			
Dab			121/0	143/0	1/1	0/3
Turbot					7/4	
Sole						0/2

Dab eggs were identified by gelelctrophoretic analysis and subsequently the most abundant egg diameter was determined and ranged from 0.85-1.05 mm (Figure 4.117).

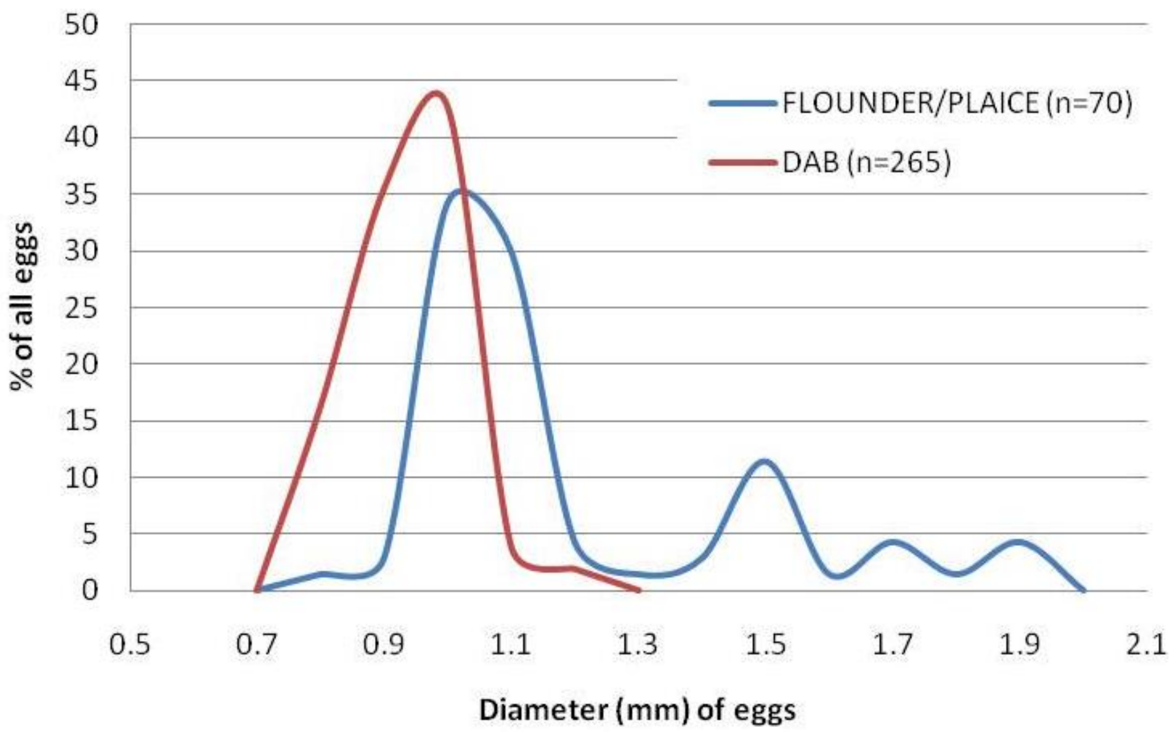


Figure 4.117: Egg size of dab eggs (red) and flounder/plaice eggs (blue) caught in Fehmarnbelt 2009 - species determined by gelelectrophoric analysis with adult fish as standards.

It was not possible to differentiate between flounder and plaice eggs by gelelectrophoresis alone, but as the diameter of flounder eggs are <1.3 mm in the Western Baltic Sea and plaice are >1.3 mm (Heinen, 1911) it was possible to seperate the species by combining information from the gelectrophoretic analysis and egg size (Figure 4.117).

The results of the gelelectrophoretic analyses of flounder and dab eggs were compared with the diameter of eggs from these two species. This comparison showed that the diameter of eggs from flounder and dab were almost similar. Thus, it was not possible to separate these two species only by macroscopic measurement of the diameter but gelelectorphoretic analysis was neccesary.

4.8.4.1 Plaice

The density of plaice eggs and larvae were highest in March however, the density was considerably higher in March 2010 compared to March 2009 (Figure 4.118). In general, the densities were highest in the deep waters and eggs were most abundant in deep waters between Langeland and Fehmarn. Plaice eggs were also found along the coast of Fehmarn and Lolland (Figure 4.119).

It was not possible to find egg densities of plaice from the Baltic Sea in the literature for comparison, however, the magnitude of the densities were the same as observed at spawning grounds in the southern North Sea (Van der Land, 1991).

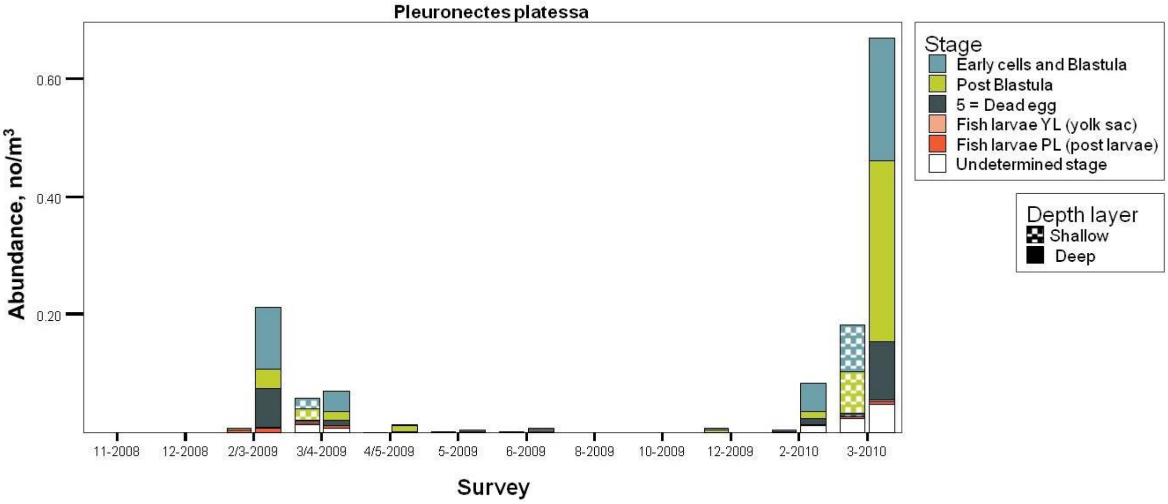


Figure 4.118: Average density (mean number/m^3) of different development stages of plaice eggs and larvae caught during 12 surveys from November 2008 to March 2010. The x-axis represents the survey periods (month and year of the survey).

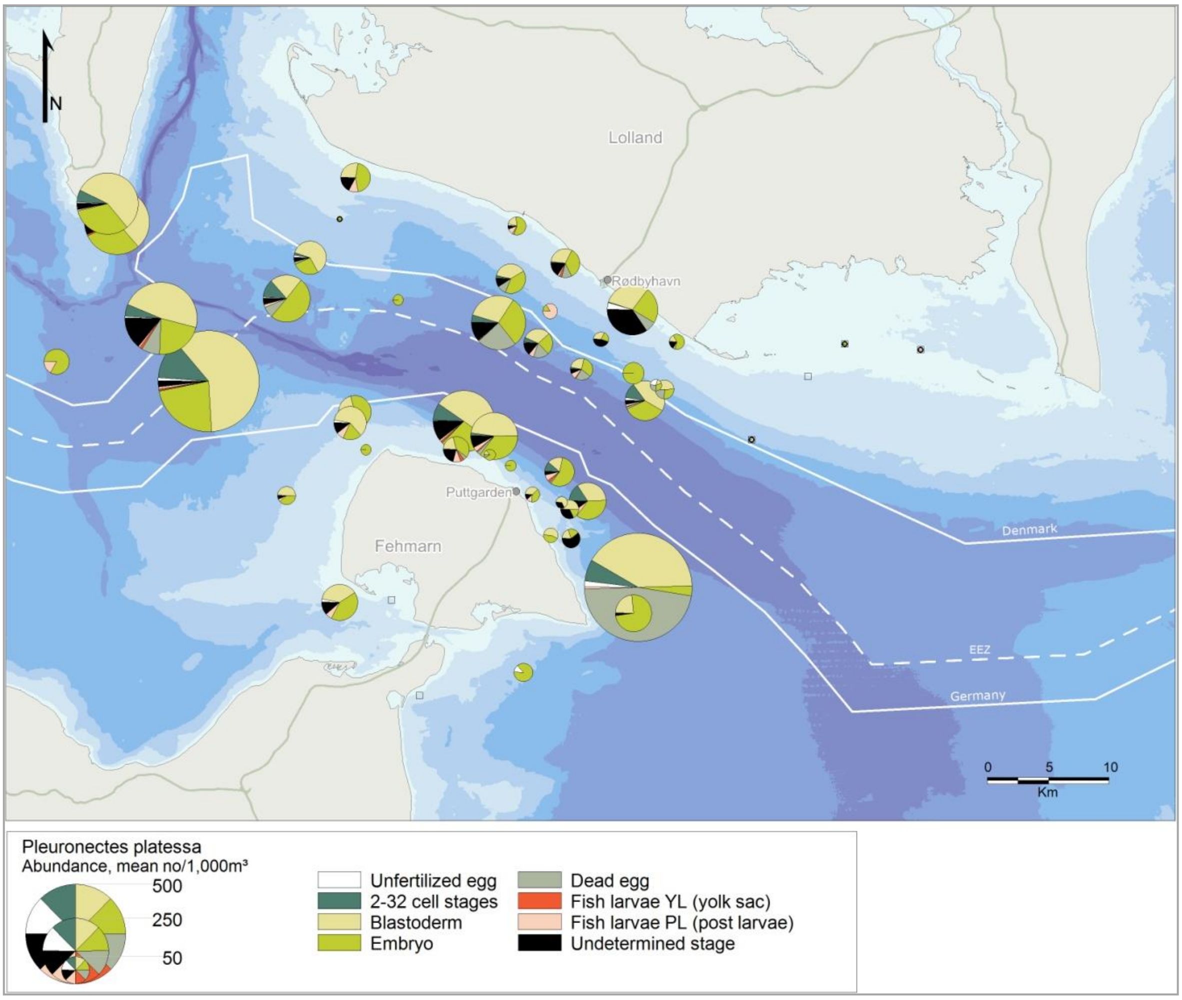


Figure 4.119: Average abundance of plaice eggs and larvae from November 2008 to March 2010.

The laboratory experiments on egg buoyancy showed that the density of early stage plaice eggs varied between 1.0118 – 1.0154 g/cm^3 which equals salinities between 15.3 and 19.9 psu (at neutral buoyancy). The majority of spawned eggs from one female had a density that corresponded well to the density of the water near the pycnocline. This indicates that plaice eggs are neutrually buoyant at this depth which ensures good oxygen conditions. See FeBEC (2011f) for further results from the buoyancy experiments.

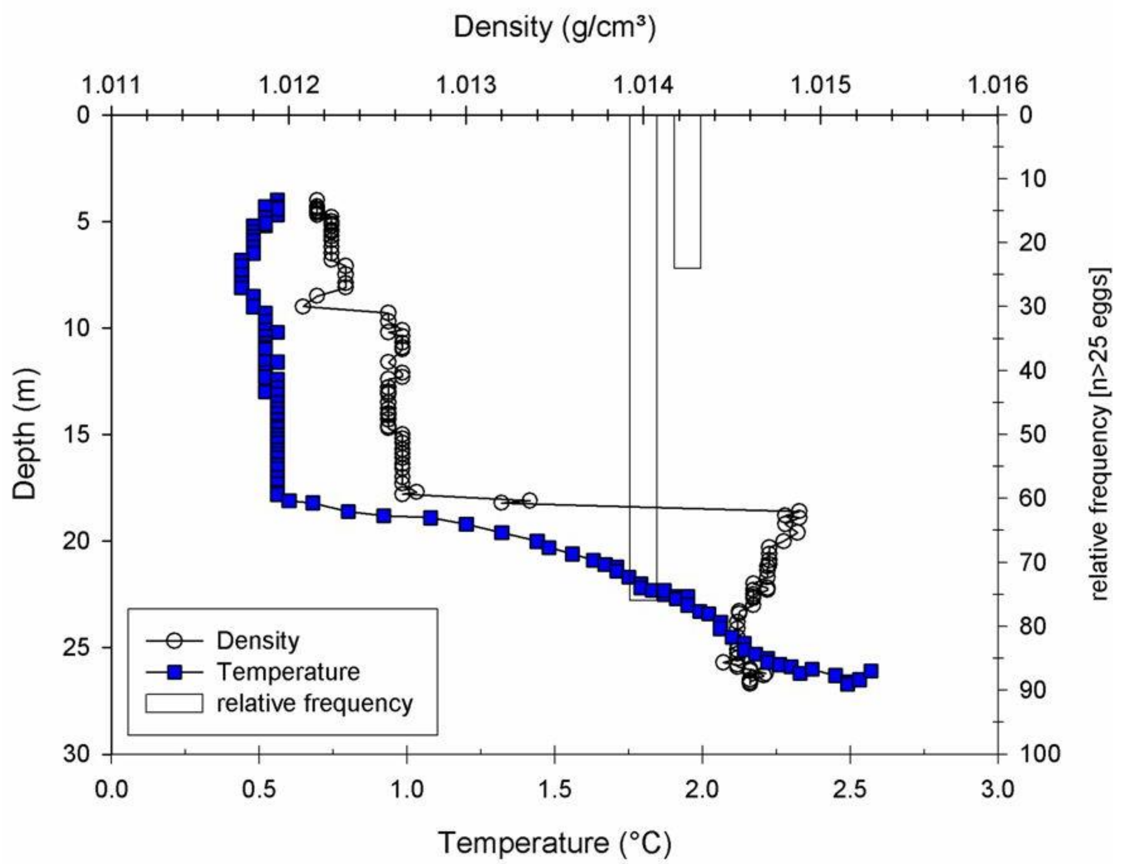


Figure 4.120: Vertical temperature and water density profile of one fishery station (Weissniss Channel) during the experimental period. The relative frequency distribution of the density measurements of one plaice egg batch fertilized at 20 PSU and 2°C (n>25 eggs; Female 32cm total length) is included. Source: FeBEC (2011f).

The majority of the plaice egg production took place from January to March and the total annual plaice egg production was estimated to $8*10^{10}$ plaice eggs (Table 4.27).

Table 4.27: Estimated annual egg production of plaice in the entire sampling area of Fehmarnbelt.

PLAICE	Annual production (eggs per m^3)	2.5 and 97.5 quantiles	Estimated volume of sampling area (m^3)	Eggs per year in the sampling area
Shallow water (depth <10 m)	0.6	$0.3\text{-}6*10^{11}$	$20.5*10^9$	$1.3*10^{10}$
Deep water (depth > 10 m)	4.8	2-13	$15.5*10^9$	$7.4*10^{10}$
Total sampling area			$36*10^9$	$8.7*10^{10}$

The average weight of mature plaice caught during the acoustic surveys was 296.3 g for females (n = 160). Armstrong et al. (2001) estimated that ripening female plaice in the Irish Sea with a weight of 296.3 g produced approximately 70,000 eggs.

Assuming that the fecundity of plaice in Fehmarnbelt is equal to the fecundity found by Armstrong et al. (2001), and that all eggs shed by the female are viable (which is not always the case), it is estimated that roughly $8*10^{10}$ eggs/7,000 eggs/female or $1.14*10^6$ females spawn in the entire investigated area. If the average weight of each female is 296.3 g, the weight of female plaice spawning in the investigated area is approximately 338 tonnes. Not all eggs shed are viable, thus the spawning biomass or number of females spawning in the investigated area is considered as a minimum.

Hydrodynamic modelling of plaice eggs were implemented in order to gain information on plausible location of important spawning areas in the area of Fehmarnbelt (Figure 4.121). The results indicate that early stage plaice eggs caught in the sampling area are spawned in the deeper parts of Fehmarnbelt and a large area between Langeland and Fehmarn as well as around Fehmarn.

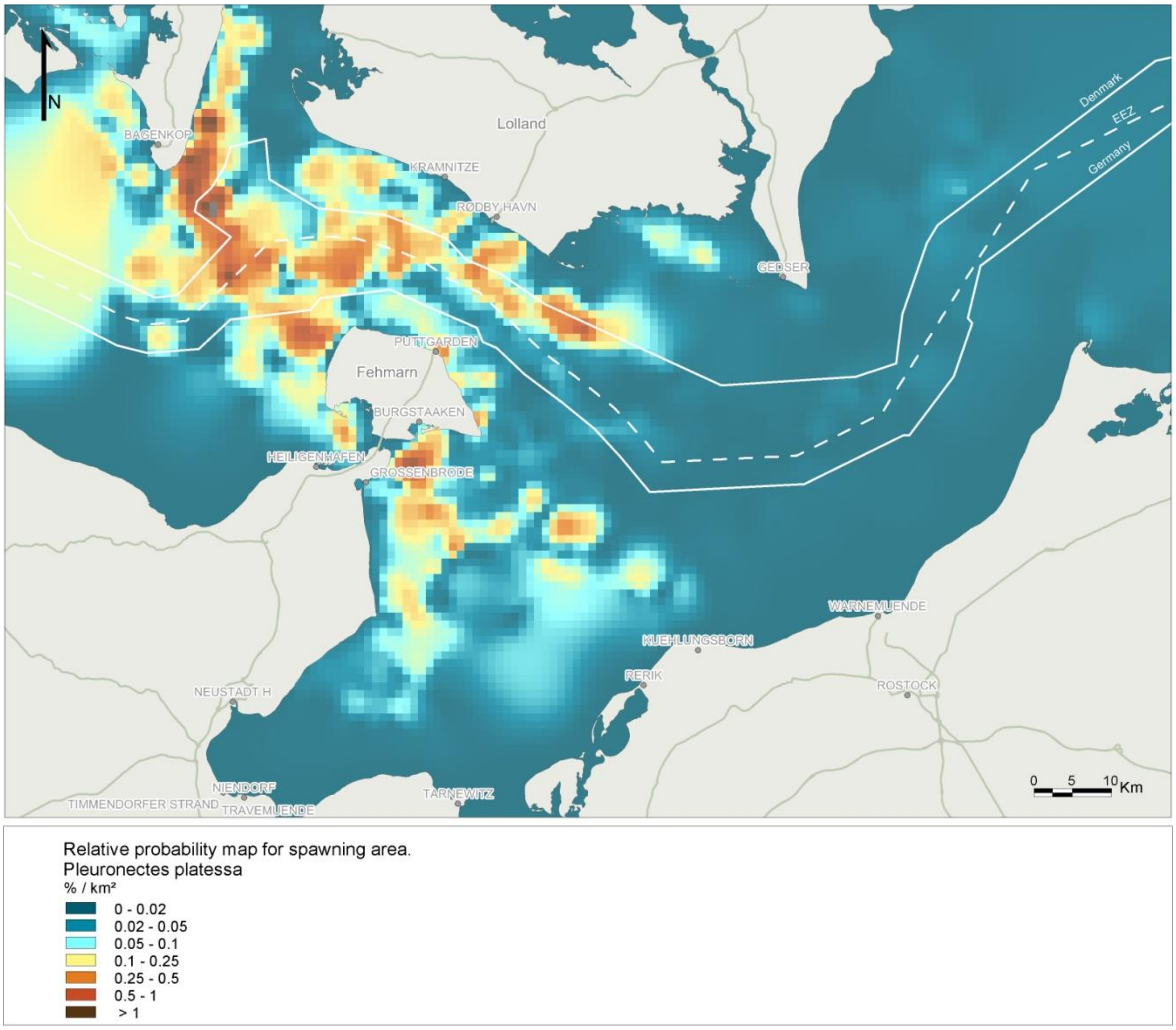


Figure 4.121: Map showing the estimated distribution of spawning grounds of plaice in Fehmarnbelt and area. Data derived from backtracking eggs according to their developmental stage and hydrographic regimes.

Prey availability and predation from gelatineous plankton on flatfish eggs and larvae were investigated during the baseline studies. During the period (January – March) in continuation of peak spawning of plaice, the average density of mesozooplankton was sufficiently high to sustain larvae growth (15-30 individuals of prey/l see Figure 4.51). The densities of mesozooplankton are averages thus it is important to notice that the distribution of mesozooplankton is patchy. Plaice larvae mainly prey on larvaceans of which the most important are *Oikopleura dioeca* and various stages of copepods (Last, 1978). Both prey items were available for plaice larvae during these investigations.

4.8.4.2 Dab and flounder

As not all eggs were analysed by gelelectrophoretic analysis, separating dab and flounder eggs, the results from these studies are described as one.
The densities of dab/flounder eggs were highest from March to May, with a peak in average egg density (12 eggs/m^3) in May. The average egg densities of dab/flounder in shallow and deep water are presented in Figure 4.122.

The gelelectrophoretic analysis on a proportion of the eggs showed that flounder eggs were present until April whereas dab eggs were present in April and May. During the entire season egg densities were highest in the deep waters and are widely distributed the study area (Figure 4.122 and Figure 4.123). No literature on the density of dab and flounder eggs in Fehmarnbelt from previous studies for comparison were found, however, the egg densities in Fehmarnbelt were of the same magnitude as egg densities at spawning grounds in the southern North Sea (Van der Land, 1991). The laboratory experiments on egg buoyancy showed that the density of early stage cod eggs was 1.015 g/cm^3, which corresponds to a salinity of 19.9 psu (at neutral buoyancy). See FeBEC (2010b) and FeBEC (2011f) for further results from the buoyancy experiments.

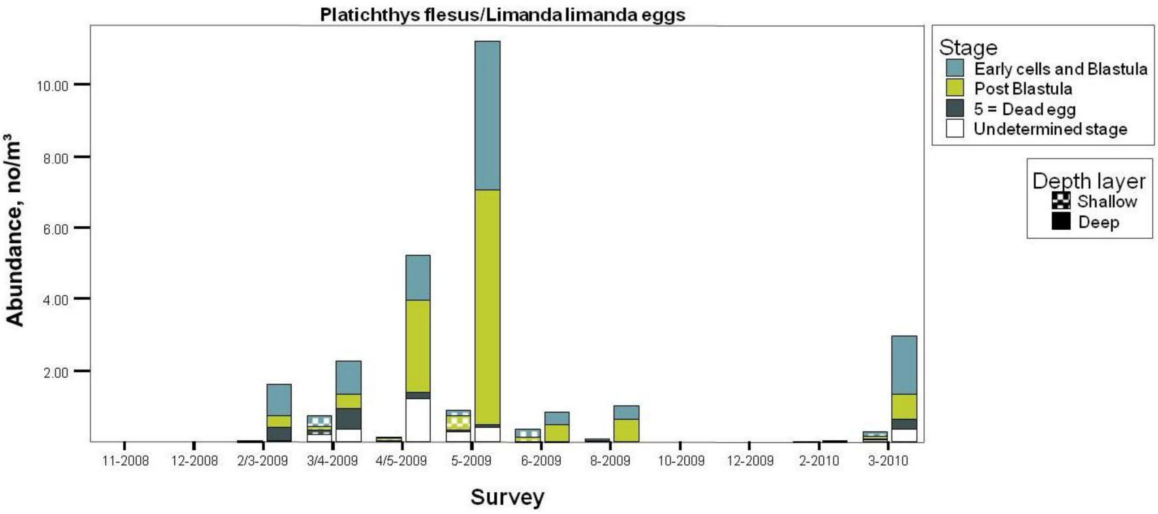


Figure 4.122: Average density (mean number/m^3) of different development stages of flounder and dab eggs caught during 12 surveys from November 2008 to March 2010. The x-axis represents the survey periods (month and year of the survey).

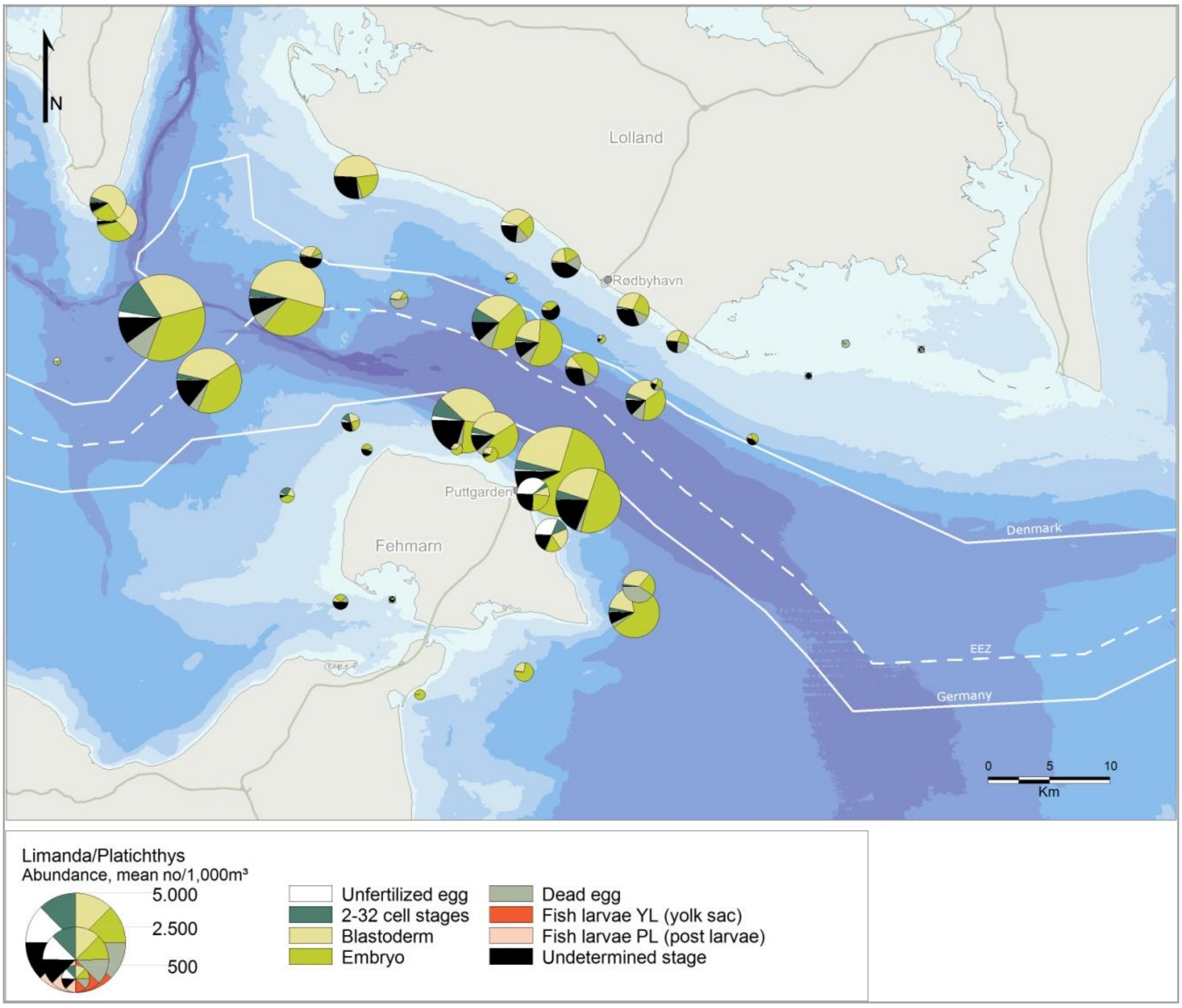


Figure 4.123: Average abundance (number/1,000m^3) of flounder and dab eggs in Fehmarnbelt from November 2008 to March 2010.

Contrary to the eggs of dab and flounder all larvae of the two species were separated macroscopic. Flounder larvae were primarily present from March to May in both the deep and shallow waters of Fehmarnbelt and adjacent areas (Figure 4.124 and Figure 4.125).

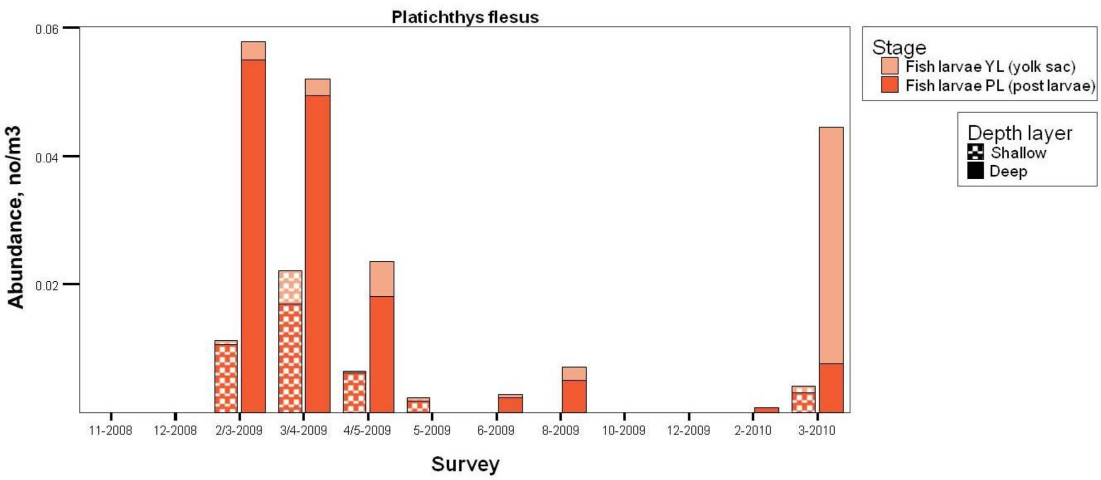


Figure 4.124: Average density (mean number/m^3) of different stages of flounder larvae caught during 12 surveys from November 2008 to March 2010. The x-axis represents the survey periods (month and year of the survey).

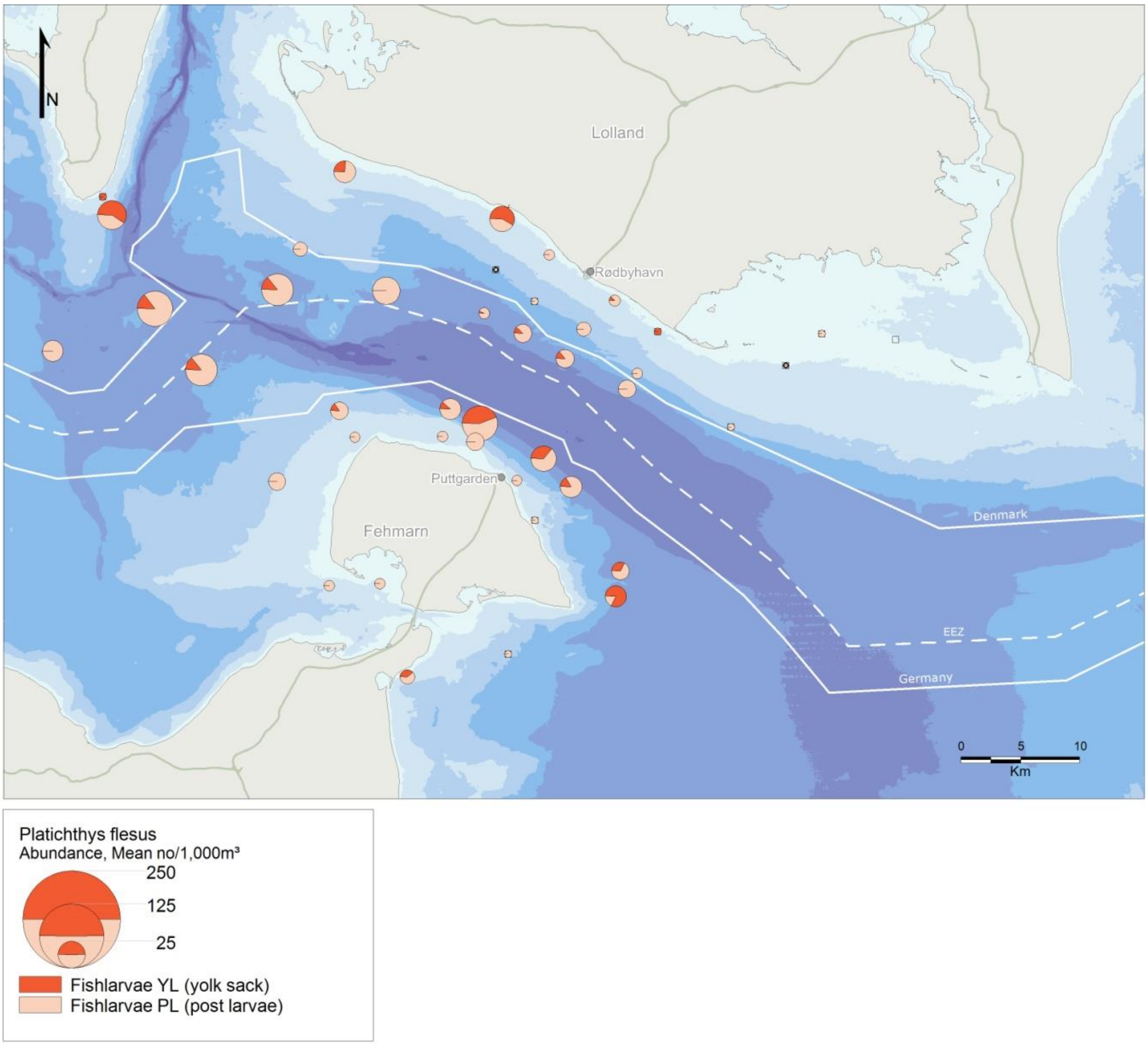


Figure 4.125: Average abundance (number/1,000m^3) of flounder larvae in Fehmarnbelt from November 2008 to March 2010.

Dab larvae were primarily present from May to August in the deep central waters of Fehmarnbelt and adjacent areas (Figure 4.126 and Figure 4.127).

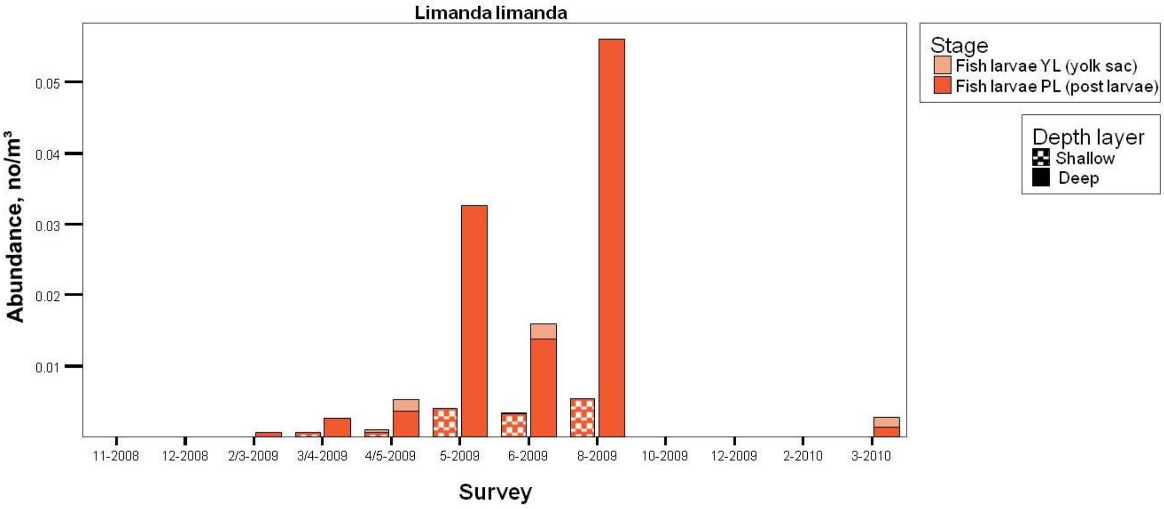


Figure 4.126: Average density (mean number/m^3) of different stages of dab larvae caught during 12 surveys from November 2008 to March 2010. The x-axis represents the survey periods (month and year of the survey).

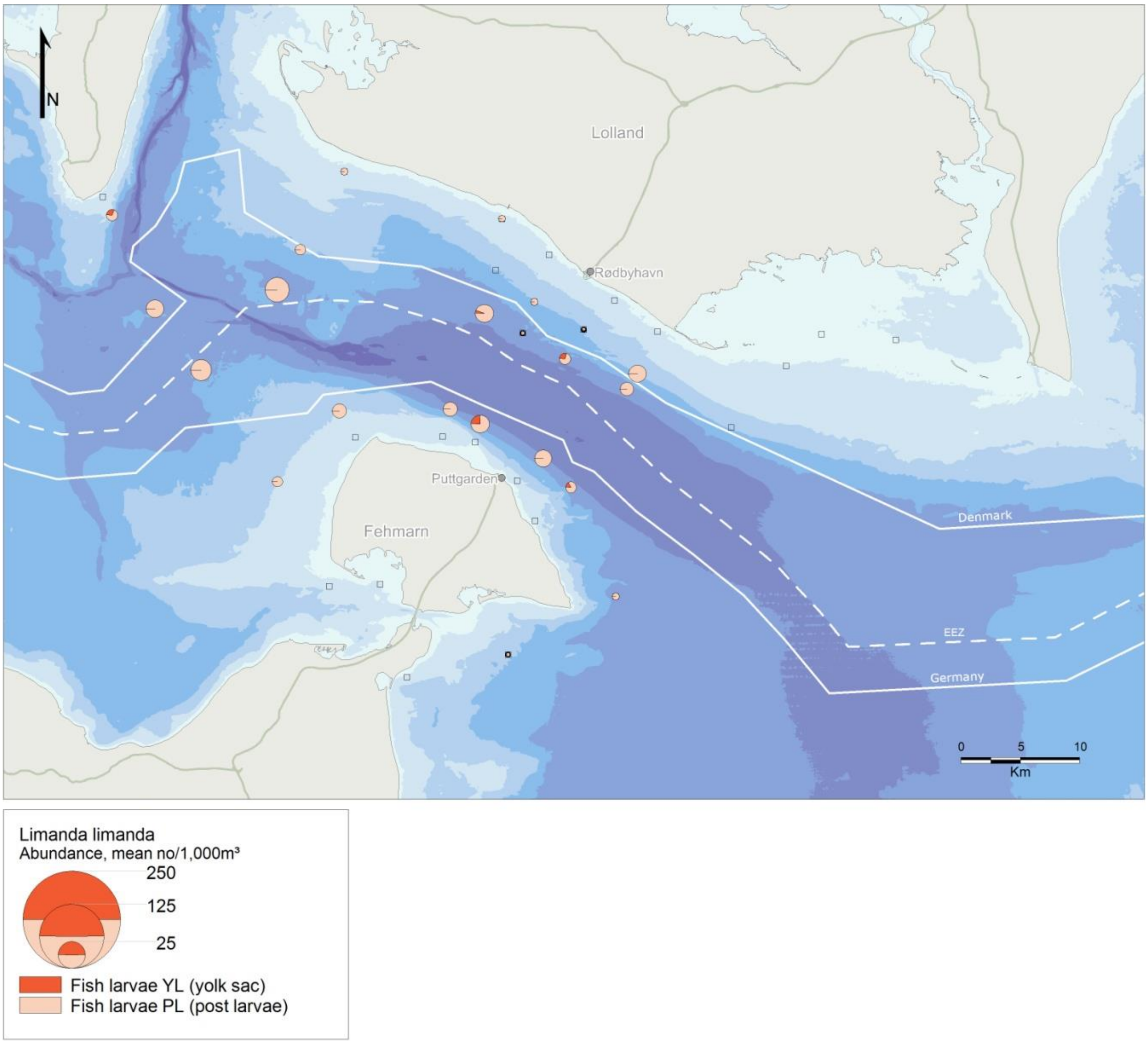


Figure 4.127: Average abundance (number/1,000m^3) of dab larvae in Fehmarnbelt from November 2008 to March 2010.

The majority of the flounder/dab eggs are produced from March to August in deep water, starting with flounder spawning season and ending with dab spawning season.

Annual flounder/dab egg production in the entire sampling area was estimated to $2.203*10^{12}$ eggs when multiplying the average annual production/m^3 in shallow and deep water with the total water volume.

Table 4.28: Estimated annual flounder/dab egg production in the entire sampling area of Fehmarnbelt.

DAB/FLOUNDER	Annual production (eggs per m^3)	2.5 and 97.5 quantiles	Estimated volume of sampling area (m^3)	Eggs per year in the sampling area
Shallow water (depth <10 m)	27.5	7-120	$20.5*10^9$	$5.63*10^{11}$
Deep water (depth > 10 m)	105.8	41-295	$15.5*10^9$	$16.4*10^{11}$
Total sampling area			$36*10^9$	$22.03*10^{11}$

Hydrodynamic modelling of flounder/dab eggs were implemented in order to gain information on plausible location of important spawning areas in the area of Fehmarnbelt (Figure 4.128). The results indicate that early stage flounder/dab eggs caught in the sampling area were spawned in areas along the northern and eastern coastline of Fehmarn and in a large area between Langeland and Fehmarn.

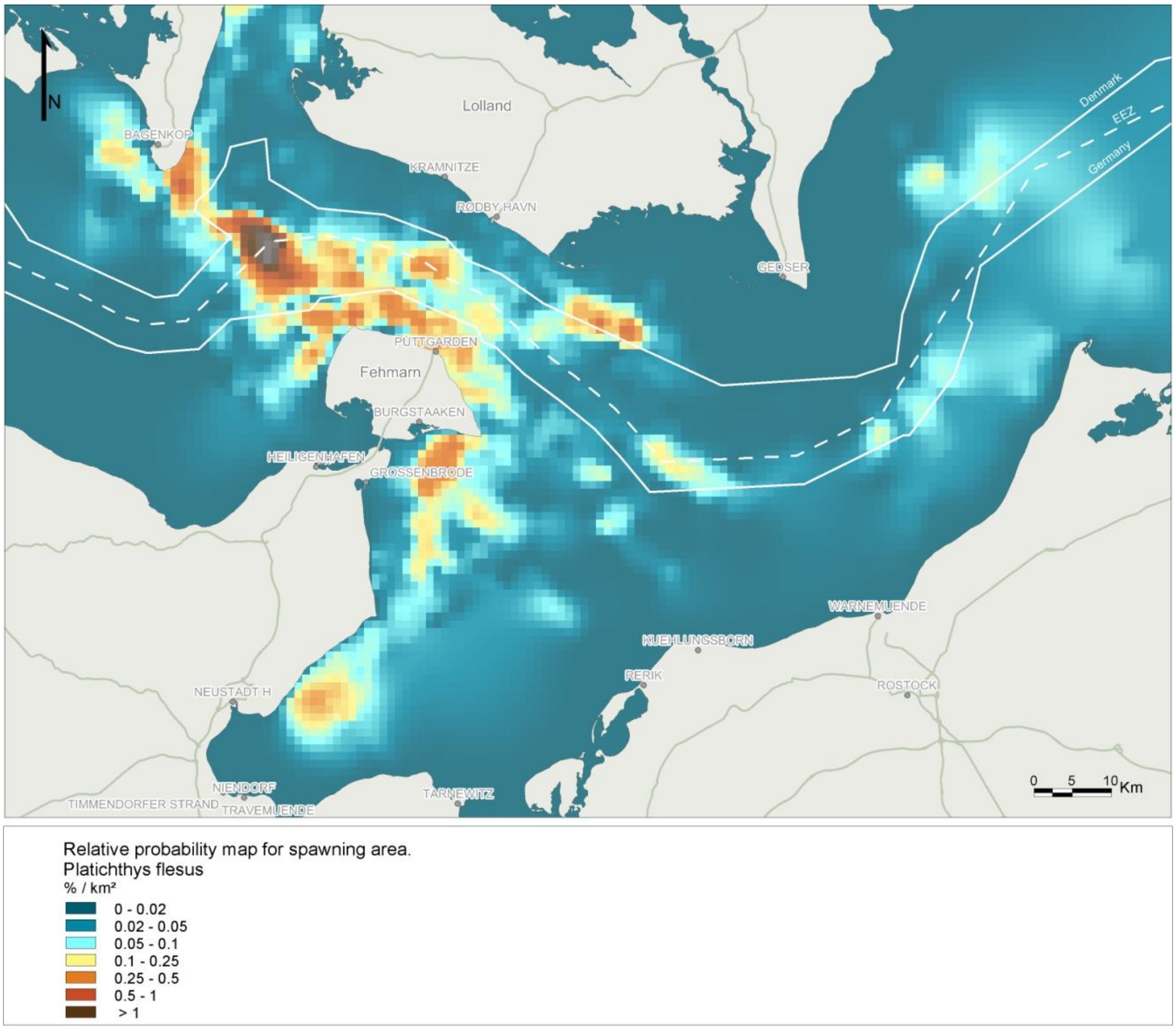


Figure 4.128: Map showing the estimated distribution of spawning grounds of flounder/dab in Fehmarnbelt and area from March 2009 to March 2010. Data derived from backtracking eggs according to their developmental stage and hydrographic regimes.

Prey availability for flounder and dab larvae as well as predation from gelatineous plankton on eggs and larvae were investigated during the baseline studies. Flounder larvae preys on a wide range of planktonic organisms including phytoplankton, polychaete larvae, lamellibranch larvae, copepod larvae as well as *Oikopleura dioica*. Whereas the main prey items for feeding dab larvae are nauplii and copepodite stages of various copepods but in particular *Temora longicornis* (Last, 1978). The total density of available prey was >15 individuals/l during the hatching season of flounder and dab in the Fehmarnbelt area. The concentration of naplii and copepodites was >8 individuals/l during the hatching period. The various prey items were available for flounder and dab larvae during these investigations.

Mnemiopsis leidyi, Aurelia aurita and other gelatineous plankton only exhibited a limited predation pressure on the fish eggs and larvae communities and their prey with average clearance rates below 7%/day. However, interannual fluctuations in clearance rate may occur.

The condition of dab larvae were investigated during the baseline studies. Dab larvae in sufficient numbers (11) were only caught at one station (station 17) in July. LePecq RNA:DNA ratios ranged from 1.83 to 3.13 with a mean ratio of 2.42 (± 0.36 s.d.). No studies on dab larvae using RNA:DNA ratios as a condition factor have been published from the Baltic Sea, however, some field studies from other areas exists.

Malzahn et al. (2007) investigated the nutritional conditions of dab larvae on the Helgoland Roads, North Sea and found similar LePecq RNA:DNA values ranging from 1.4 to 3 for larvae of the same length (4-6 mm) as those analysed in the baseline study. In contrast, Lee and colleagues, who investigated the condition of dab larvae in the Irish Sea (Lee et al., 2006) and in relation to a mixing front (Lee et al., 2007), measured much higher LePecq RNA:DNA values over the entire size spectrum of the analysed larvae. However, only a few larvae were from the same small size class as those from the baseline study.

All three of the comparative studies mentioned, described increasing RNA:DNA ratios with increasing larval length up to a point (dome-shaped relation). Thereafter ratios dropped at larval lengths between 11 to 13 mm (Lee et al., 2006).

4.8.4.3 Other flatfish

Larvae of witch flounder (*Glyptocephalus cynoglossus*), sole (*Solea solea*) and American plaice (*Hippoglossoides platessoides*) were present in low numbers. Witch flounder were only registered in March (max density approximately 0.005/m^3), American plaice larvae were present from March to May (max density approximately 0.001/m^3), and sole larvae were found from June to August (max density approximately 0.02/m^3). The larvae were observed in both shallow and deep water but the highest abundances were registered in the deep water. The average densities of larvae of witch flounder, sole and American plaice in the different surveys are illustrated in Figure 4.129-Figure 4.131.

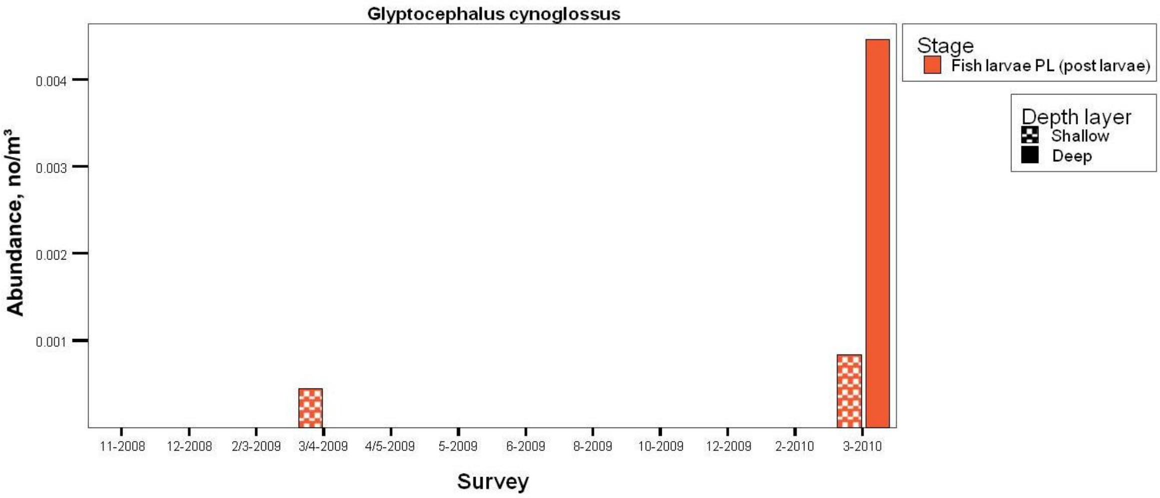


Figure 4.129: Average density (mean number/m^3) of different stages of witch flounder larvae in 12 surveys from November 2008 to March 2010.

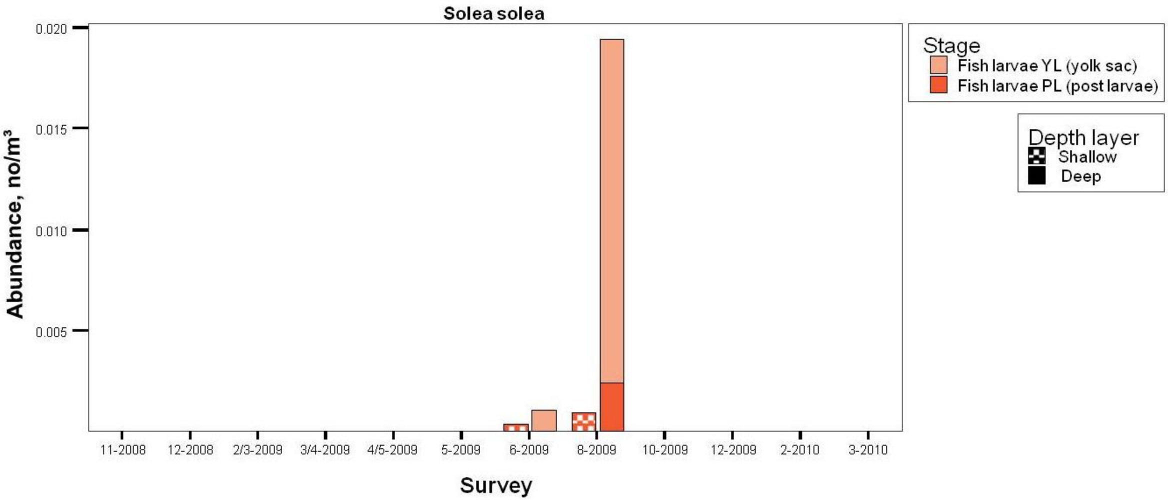


Figure 4.130: Average density (mean number/m^3) of different stages of sole larvae in 12 surveys from November 2008 to March 2010.

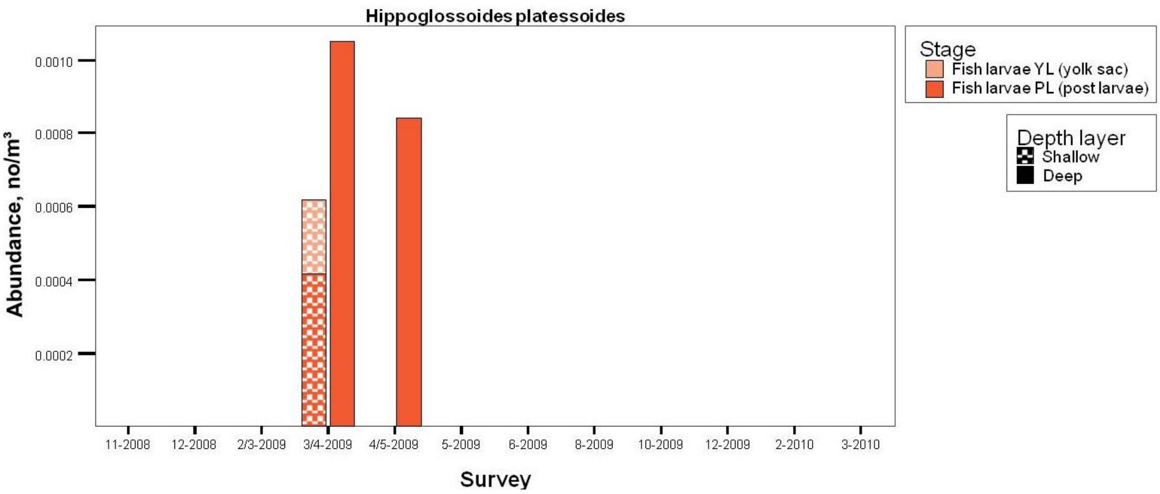


Figure 4.131: Average density (mean number/m^3) of different stages of American plaice egg and larvae in 12 surveys from November 2008 to March 2010.

4.8.5 Nursery and Feeding

The type of sediment has a strong influence on the distribution and abundance of flatfish (Gibson and Robb, 1992; Rogers, 1992; Gibson, 1994; Amezcua and Nash, 2001). Most flatfish prefer habitats with sand, where they can bury and hide more easily. In addition, water depth, water temperature, vegetation and food availability, which depend strongly on the sediment type, also play an important role for flatfish (Power et al., 2000; Vinagre et al., 2005; Le Pape et al., 2007). E.g. turbot prefer habitats with sand bottoms to gravel or vegetation.
The most common flatfish around Fehmarnbelt were flounder, plaice and dab, especially in subarea Fehmarnbelt and Fehmarn. Contrary the abundance of both juvenile and adult flatfish was low in the area near Lolland with exception of dab (mainly age class 2+), which was common in the deeper areas with sand and fine sand (habitat type 2).

The distribution of 0-group juveniles (YOY-individuals) at stations in the three subareas is shown in Table 4.29. Only 0-group dab, plaice, flounder and turbot were observed during the study period (May 2009 to June 2010). Flounder, plaice and turbot 0-group individuals were already observed in May, whereas 0-group individuals of dab not were observed until September. The abundance of 0-group dab was greater in Fehmarnbelt compared to stations near Fehmarn. No 0-group dab were observed in subarea Lolland which could be due to the preference of juvenile dab for deeper nursery areas contrary to juvenile flounder and plaice. As juvenile dab grow they tend to migrate into shallower regions (Bolle et al., 2001).

Table 4.29: Distribution of 0-group flatfish at the various sampling stations in the three areas: G-gill net stations (gill-and fyke net stations), B-seine stations (beach seine net stations), T-trawl stations (trawl stations).

Area	Station	L. limanda	P. flesus	P. platessa	P. maxima
Fehmarn	G02				
	G06			4	
	G07			4	
	G08			8	
	G10			8	
	G11		0.5	20	
	G12				100
	G13			4	
	G14	20			
	G15	40		8	
	G16				
	G19	20			
	G20	20			
	G29				
	B03			8	
	B05		27.1		
	B09		0.5		
	B10		2.4		
	B11		44.9		
	B12		5.3		
	B13		6.8	32	
	B14		10.6		
Lolland	G03				50
	B03		10		
	B07				50
	B12		70		
	B13		10		
	B14		10		
Fehmarnbelt	T01	71.1			
	T02	4.4			
	T03	2.2			
	TDK	22.2			

The majority of the 0-group juvenile flatfish observed during the study period were flounder. They were caught in shallow (<2 m) waters near Lolland and Fehmarn in habitat type 1 (mud and fine sand) and 2 (sand and fine sand), which were more protected against the wind and waves. 0-group plaice were registered both in shallow (<2 m) and slightly deeper (>3 m) waters and were mainly present at stations with sand and fine sand. Only three 0-group turbot were caught during the investigation period.

The results from the gill net surveys indicates that the distribution of the three most common flatfish dab, plaice and flounder depend on their length (age) and the type of habitat present.

Juvenile flounder were mainly observed at stations that were more protected against wind and waves. By contrast, adult flounder were more common at the exposed stations. There was no clear pattern in the preference of flounder for habitat type in subarea Fehmarn and Lolland. The majority of flounder caught in subarea Fehmarnbelt were adults and only few juvenile occurred in the catches (Figure 4.132).

Juvenile plaice were more abundant at the sheltered locations, while juvenile and adult plaice had comparable CPUE values at the exposed stations. Adult plaice were far more common than juvenile plaice at stations in Fehmarnbelt (Figure 4.133).

Adult dab were more abundant than juvenile dab in all three subareas (Fehmarn, Lolland and Fehmarnbelt). The proportion of juvenile dab was relatively highest in the deeper Fehmarnbelt (Figure 4.134), which correspond with previous studies of juvenile dab.

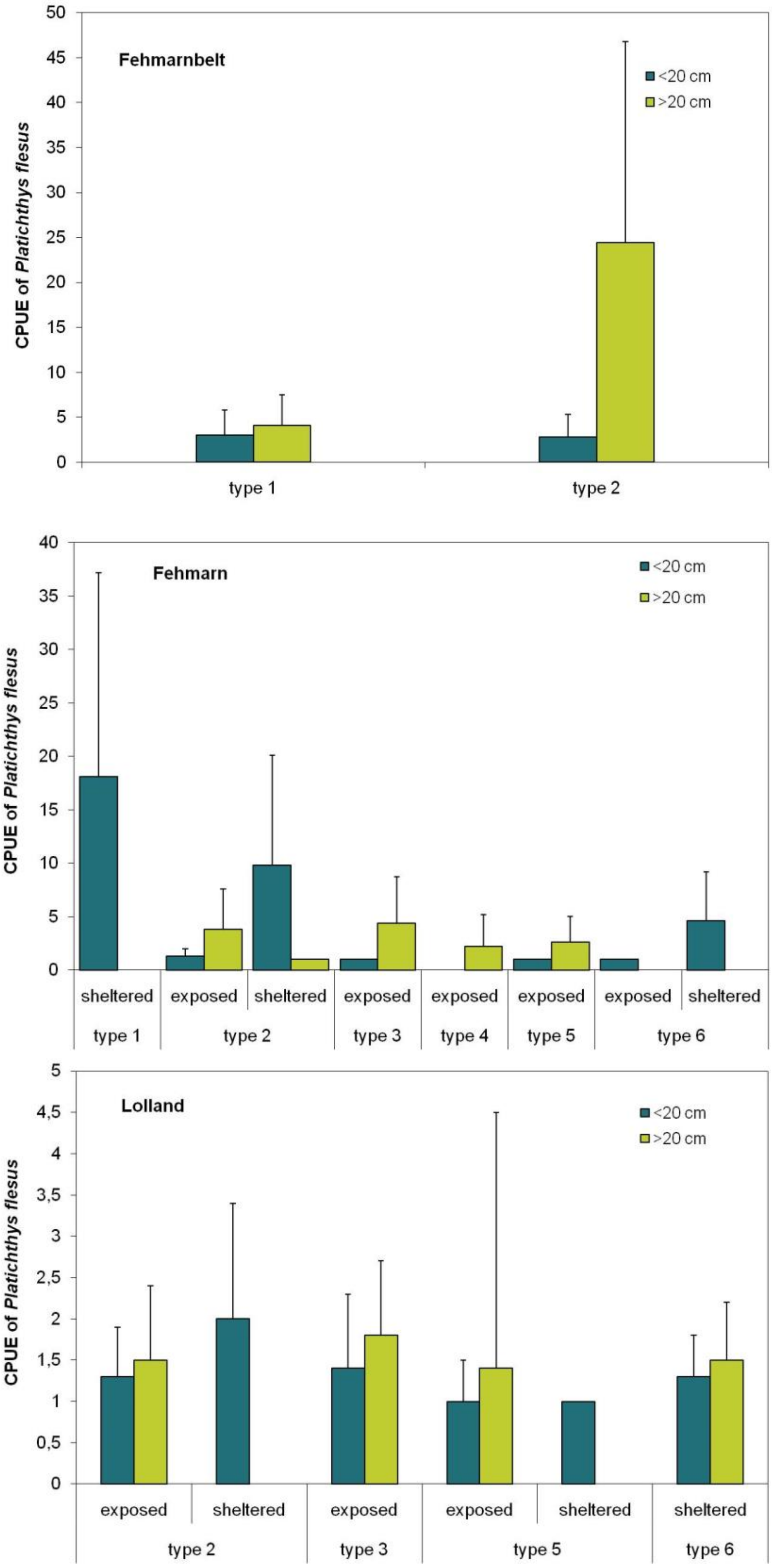


Figure 4.132: Mean CPUE (Catch Per Unit Effort) of juvenile (length <20 cm) and adult (length >20 cm) flounder in the period May 2009 to June 2010 in relation to habitat type and degree of exposure (exposed: exposed to wind and waves, sheltered: protected from wind and waves). See section 4.1.1 for a description of the different habitat types. Errorbars shows the standard deviation.

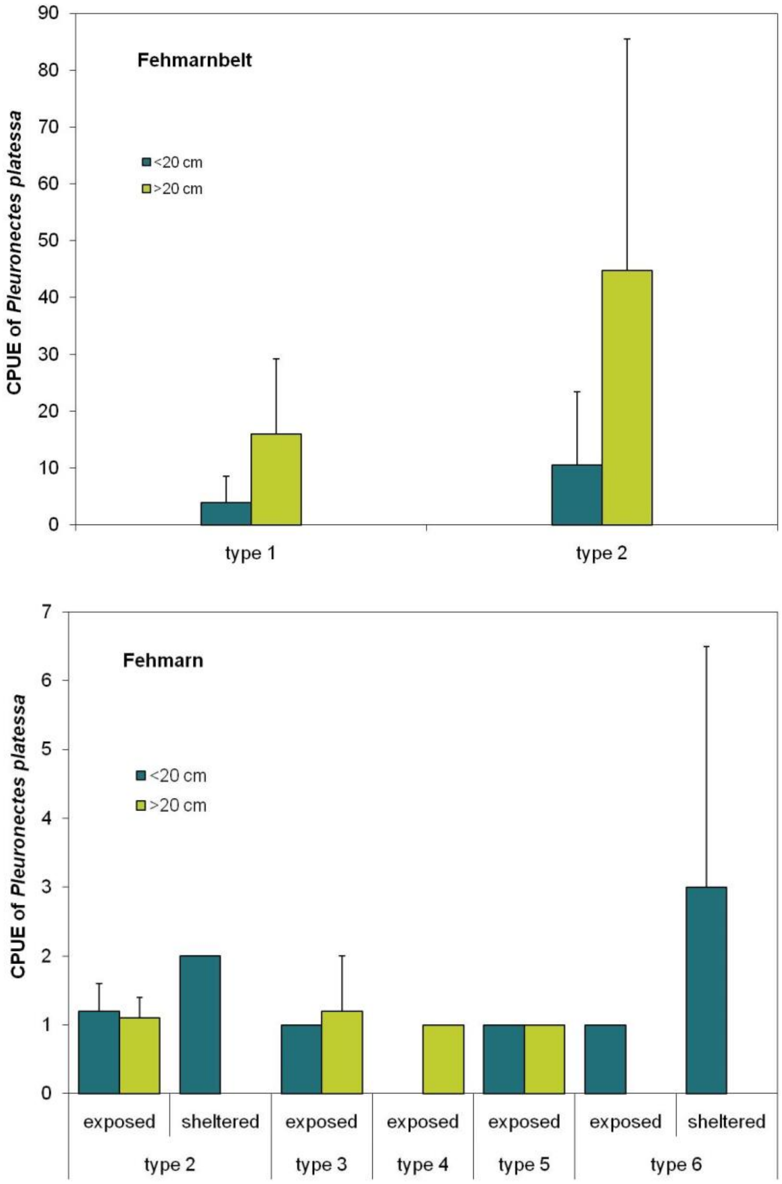


Figure 4.133: Mean CPUE (Catch Per Unit Effort) of juvenile (length <20 cm) and adult (length >20 cm) plaice in the period May 2009 to June 2010 in relation to habitat type and degree of exposure (exposed: exposed to wind and waves, sheltered: protected from wind and waves). See section 4.1.1 for a description of the different habitat types. Errorbars shows the standard deviation.

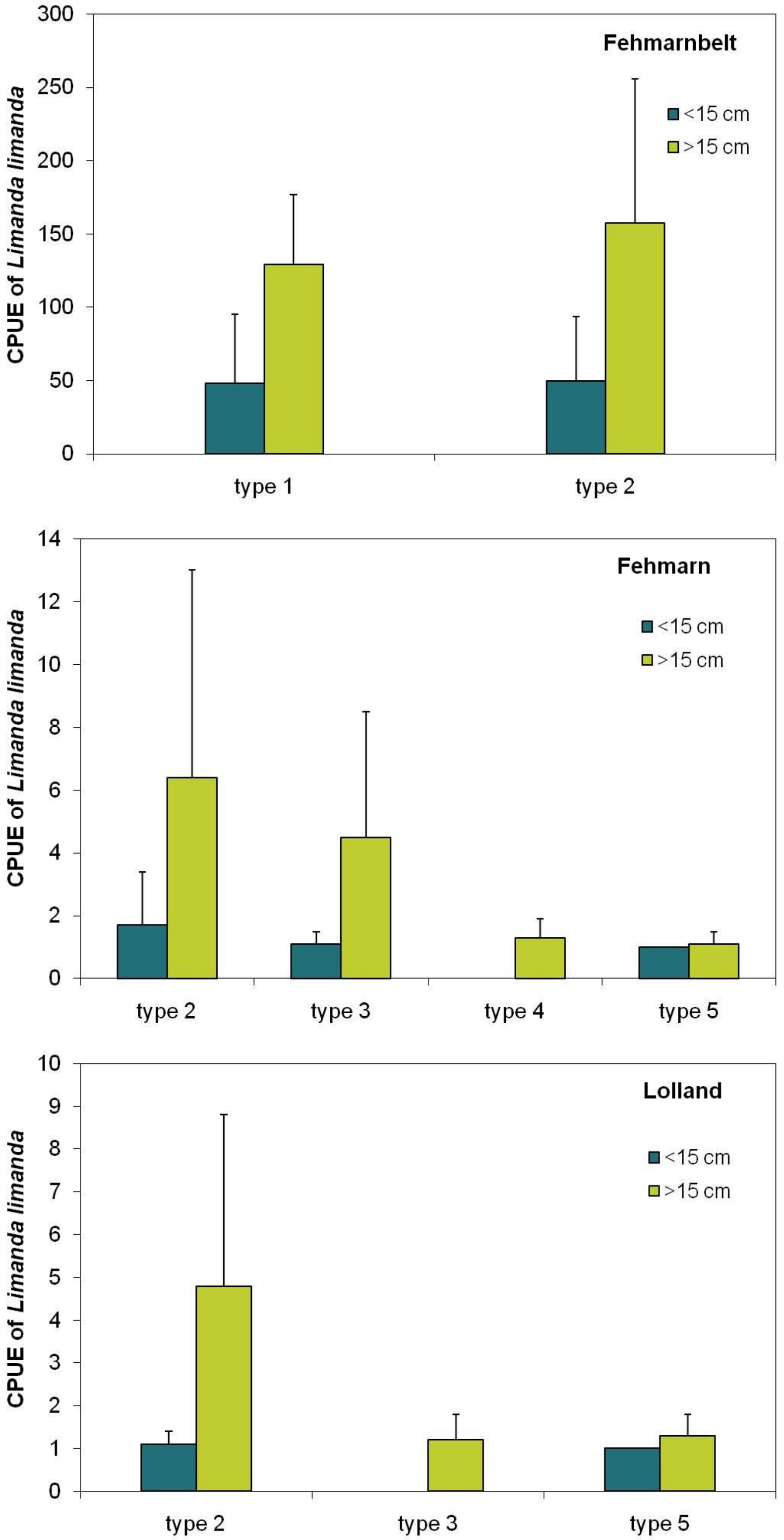


Figure 4.134: Mean CPUE (Catch Per Unit Effort) of juvenile (length <15 cm) and adult (length >15 cm) dab in the period May 2009 to June 2010 in relation to habitat type. See section 4.1.1 for a description of the different habitat types. Errorbars shows the standard deviation.

The results indicate that juvenile flounder and plaice preferred the shallow and sheltered areas in subarea Fehmarn and to a lesser extent Lolland as nursery areas. This could be due to subarea Lolland is slightly more exposed to wind and waves than Fehmarn. Flounder and plaice generally migrated into the open and deeper waters as they mature, whereas juvenile and adult dab in general preferred deeper waters than flounder and plaice. However, dab, primarily adults, used the coastal areas of Fehmarn and Lolland as feeding and nursery areas, except the very shallow waters (<2 m).

The abundance of both juveniles and adults of other flatfish species such as turbot, brill and sole observed in the study area was very low compared to the dominating species dab, flounder and plaice. However, it is assumed that the nursery and feeding areas of these species are found within the study area.

Three other species of flatfish, the Mediterranean scaldfish (*Arnoglossus laterna*), witch flounder (*Glyptocephalus cynoglossus*) and American plaice (*Hippoglossoides platessoides*) were occasionally present in the catches. For all three species, the Belt Sea is considered to be at the limit of their distribution into the Baltic Sea (Muus and Nielsen, 1999), where they rarely are observed (Winkler and Schroeder, 2003).

Results from the TV3 trawl surveys (Figure 4.135) indicated that the most abundant and prevalent flatfish species in the deeper waters of the Fehmarnbelt were dab followed by flounder and European plaice. These species were caught during all seasons. Dab constituted the vast majority of the catches throughout the year. Turbot and sole were also observed throughout most of the year, although in considerably less abundances, especially during the spring and summer. American plaice was registered throughout the whole sampling period except during the fall. There were only few catches of less abundant species such as brill, Mediterranean scaldfish and lemon sole, which were caught in Fehmarnbelt during the winter months (December and March).

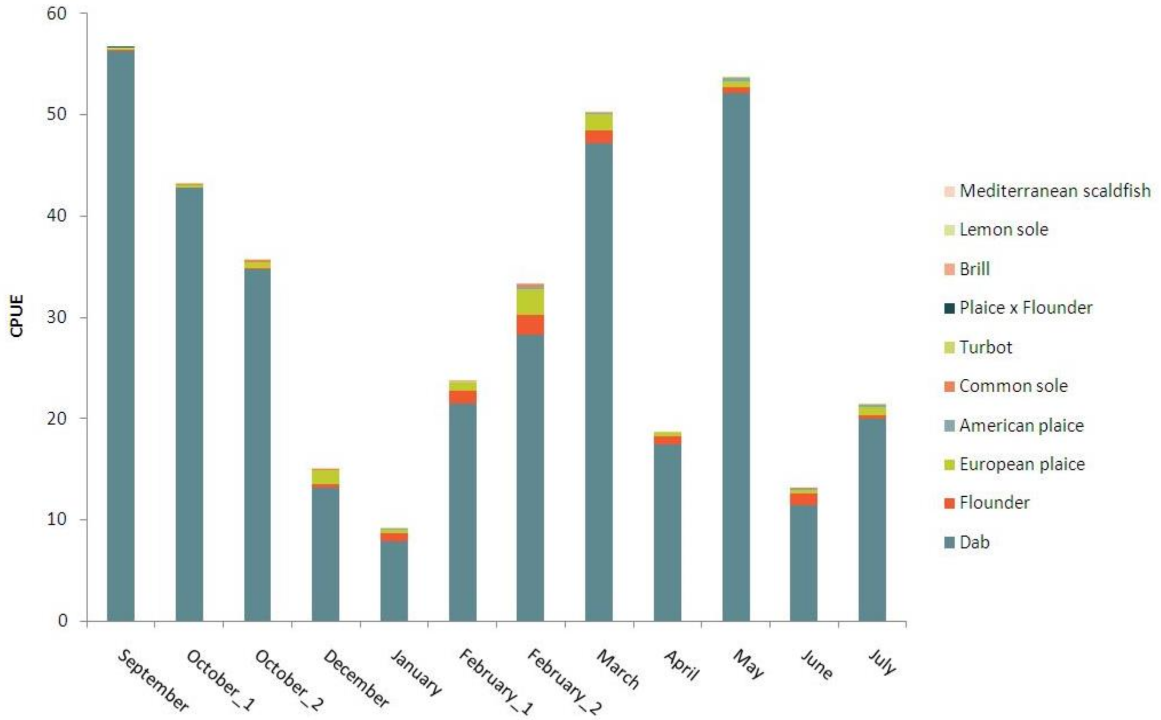


Figure 4.135: CPUE (no./1000 m2) of different flatfish species caught in the continuous surveys in Fehmarnbelt with a TV3 trawl approximately once a month from September 2009 to July 2010.

Dab was also highly dominant among the flatfish species caught in biological gill nets during the habitat mapping survey. The vast majority was larger than 15 cm. They preferred habitats with sand or sand and Mytilus edulis in deep water 15-20 m throughout the year. However, few dab were caught in shallow water during autumn and winter.

The vast majority of flounder caught during the habitat mapping surveys were larger than 15 cm and the highest abundance was observed during summer. Flounder preferred habitats with sand or sand and Mytilus edulis but was also observed in areas with stones and vegetation. During spring they were most abundant in shallow water (0-10 m). The highest abundance in summer was observed at 5-10 m depth but they were also abundant at other depths. In autumn and winter flounder was most abundant in deep water (10-20 m).

Plaice caught during the habitat mapping surveys were mainly larger than 15 cm. However, individuals smaller than 15 cm were also observed throughout the year especially during autumn. Habitats with sand or sand and Mytilus edulis were preferred by plaice larger than 15 cm. Individuals smaller than 15 cm also preferred habitats with sand, stones and Mytilus edulis. During spring, summer and autumn plaice were mainly caught in deep waters (15-20 m). In contrast, they were only found in shallow water (0-10 m) during winter.

4.8.6 Migration

The migration of most flatfish is performed on primary a local scale, when mature flatfish migrates to deeper water for spawning. Similarly, the majority of flatfish species move from the shallow water areas during the colder months of the year. Diurnal movements often occur as flatfish move into shallow waters at night to feed and back to deeper waters during the day. With the exception of dab, most of the juvenile flatfish of the most common species observed in Fehmarnbelt (flounder, plaice and turbot) prefer nursery habitats in shallow water and gradually move into deeper water as they grow. In contrast, juvenile dab settle in deeper waters and gradually use shallow waters for feeding as they grow and mature.

Turbot, brill and sole perform short migrations to deeper waters during autumn and winter and returns to shallower water in early summer to spawn. In contrast, flounder and plaice generally feed in shallow water and migrate to spawn in deeper waters. Furthermore, flounder and plaice in the Arkona basin move eastward in autumn and westward during spring.

4.8.7 Flatfish baseline conclusion

The overall results from the baseline studies of the flatfish species present in Fehmarnbelt including their abundance, distribution, and the importance of Fehmarnbelt as a spawning area can be summarised as follows:

- Ten flatfish species were registered and the most abundant flatfish in Fehmarnbelt and adjacent areas were dab, plaice, flounder and turbot.
- Dab were highly more abundant compared to other flatfish species. Especially in the TV3 trawl catches from the deep central waters of Fehmanrbelt.
- Plaice spawned during winter, flounder in spring, dab in the spring/summer and turbot during summer.
- All developmental stages of plaice, flounder and dab eggs and larvae were found in Fehmarnbelt, primarily off the coast of Lolland and Fehmarn and in the area between Fehmarn and Langeland.
- High densities of plaice, flounder and dab eggs were found in the Fehmarnbelt and adjacent areas.
- Backtracking of eggs to possible spawning grounds indicated that the area in and around Fehmarnbelt, primarily in the deeper waters between Langeland (west of Fehmarnbelt) and Fehmarn, is an important spawning area for plaice, flounder and dab.
- Eggs of turbot were found sporadically in Fehmarnbelt, and larvae of turbot, witch flounder, sole and American plaice were also found in Fehmarnbelt.
- The low abundance and clearence rate of the gelatineous plankton predators suggested that they did not constitute an important threat to flatfish eggs and larvae.
- Juvenile flounder and plaice are most abundant in the shallow and sheltered stations in subarea Fehmarn and to a lesser extent Lolland.
- Adult flounder and plaice are most abundant in the deeper more exposed areas of Fehmarnbelt.
- Juvenile and adult dab were most abundant in the deeper areas of Fehmarnbelt, although some adults were present in the coastal areas (depths >2 m) of Fehmarn and Lolland.
- The abundance of juvenile and adult turbot, brill and sole in Fehmarnbelt and adjacent areas were very low.
- Adult dab, flounder and plaice were abundant all year in the deeper parts of Fehmarnbelt.
- American plaice, turbot and sole were present throughout most of the year, although in considerably less abundances, especially during the autumn (American plaice), spring and summer (turbot and sole).
- There were only sporadic catches of the less abundant species as brill, Mediterranean scaldfish, witch flounder and lemon sole.

- The importance of Fehmarnbelt and adjacent areas for flatfish is listed inTable 4.30.
- Areas of potential importance for spawning and nursery ground for flatfish species in Fehmarnbelt and adjacent areas can be seen on Figure 4.136 and Figure 4.137. It can be seen on the map that the deeper areas of Fehmarnbelt is considered as of medium importance for the spawning of flatfish, whereas shallow coastal areas are of minor importance as nursery grounds.
- There is some spawning of flatfish in the deeper parts of the Belt, but the area is not believed to be of significant importance.
- Flatfish are rather local and migration is thus not an important issue.
- Only relatively few settled flatfish larvae were registered on the local beaches and nursery and feeding grounds are of medium importance.

Table 4.30: Importance of Fehmarnbelt and adjacent areas for flatfish in relation to spawning, eggs and larvae drift, nursery, feeding and migration.

Environmental component	**spawning**	**egg-larvae drift**	**nursery**	**feeding**	**migration**	**overall**
Flatfish	medium	medium	medium	medium	minor	medium

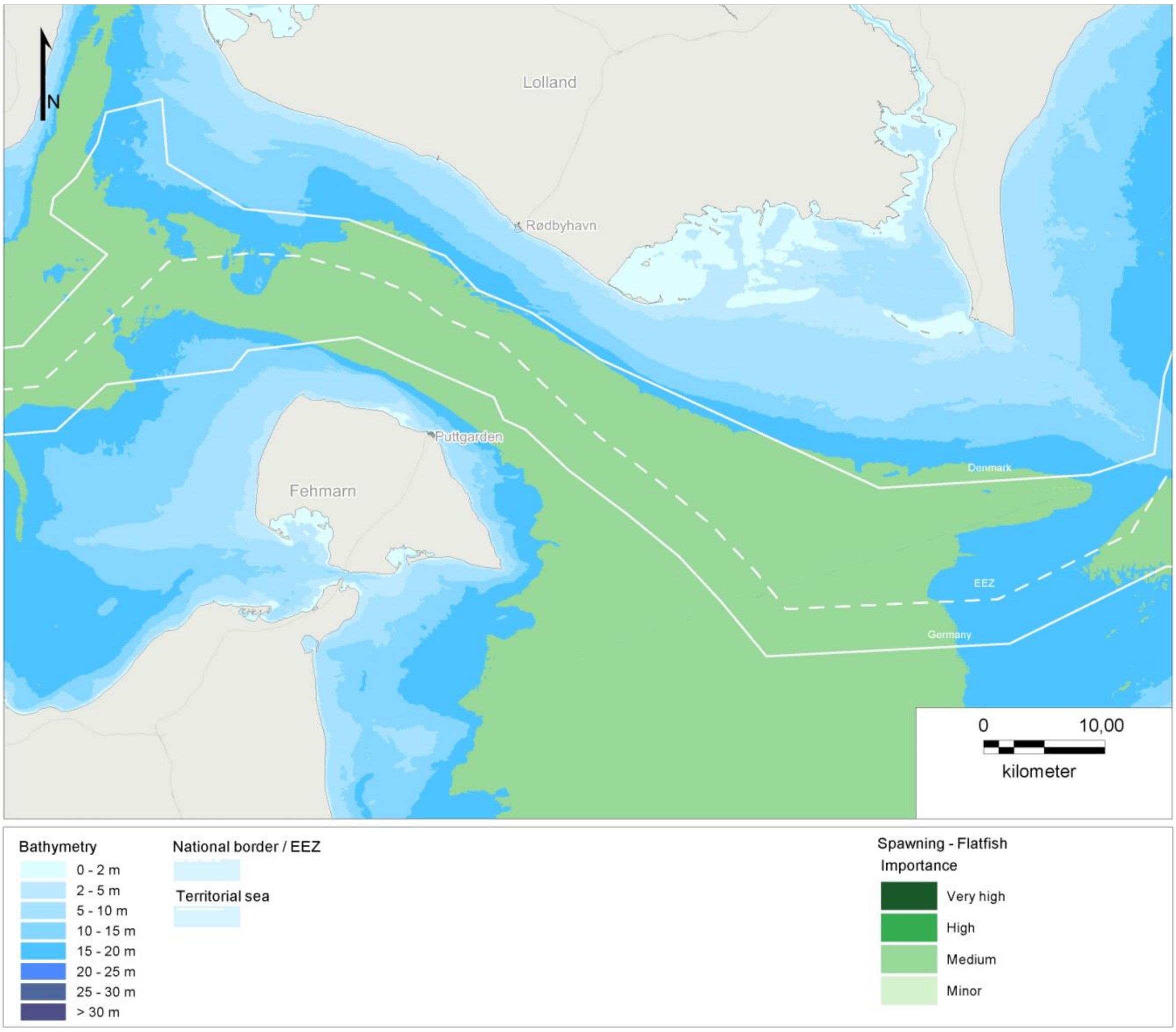


Figure 4.136: Areas of potential importance for the spawning of flatfish species in Fehmarnbelt and adjacent areas.

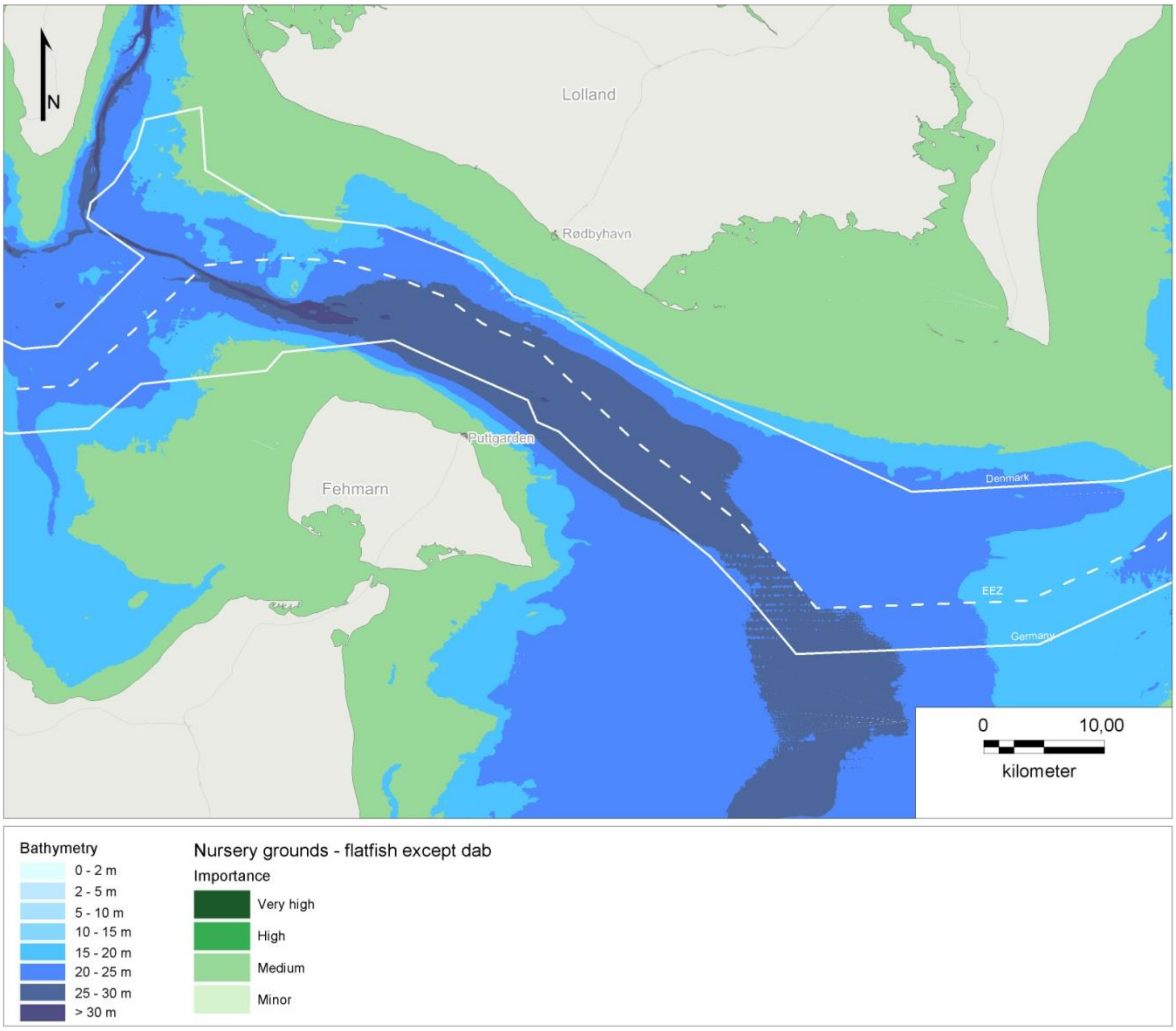


Figure 4.137: Areas of potential importance as nursery grounds for flatfish species, except dab, in Fehmarnbelt and adjacent areas

4.9 Other species spawning in Fehmarnbelt

4.9.1 General background

During the baseline studies species, not dealt with in previous studies, like hooknose (*Agonus cataphractus*), fourbeard rockling (*Enchelyopus cimbrius*), rock gunnel (*Pholis gunellus*) and seasnail were observed in Fehmarnbelt and adjacent areas. These species were either abundant or characteristic for specific fish communities. Furthermore, besides cod, herring, sprat and flatfish several other species were found in samples from the eggs and larvae survey in Fehmarnbelt and adjacent areas indicating spawning activities in the areas. Additionally, larvae of the red listed species snakeblenny (*Lumpenus lampraetaeformis*) were also caught. See chapter 4.10.2.1 for further description of the snakeblenny.

Many of the species that characterizes the shallow water communities of Fehmarnbelt are benthic spawners and were during the surveys found abundantly as larvae (chapter 4.1.7 and Appendix 1).

Table 4.31: Shallow water benthic spawners in the shallow water community recorded as larvae.

Common name	Scientific name
Small sandeel	*Ammodytes tobianus*
Herring	*Clupea harengus*
Black goby	*Gobius niger*
Great sandeel	*Hyperoplus lanceolatus*
Shorthorn sculpin	*Myoxocephalus scorpius*
Straightnose pipefish	*Nerophis ophidion*
Sand goby	*Pomatoschistus minutus*
Nilsson's pipefish	*Syngnathus rostellathus*
Broadnosed pipefish	*Syngnathus typhle*
Longspined bullhead	*Taurulus bubalis*

In the following table, environmental settings and existing pressures of importance for “other” species are listed.

Table 4.32: Environmental settings and existing pressures of significance to “other” fish species in the Fehmarnbelt area.

Basic environmental setting	Variable hydrodynamics exposed shoreline	Sheltered conditions, structured sea bottom and a fairly stable environment with good access to food are generally acknowledged to enhance fish recruitment of several species such as sea-stickleback, ballan wrasse, corkwing wrasse, rock gunnel and sea snail. Open spaced areas (without structuring elements) with fairly stable environmental conditions and good access to food are generally acknowledged to enhance fish recruitment of several species such as four bearded rockling, snakeblenny and painted goby. Anadromous migratory fish species, such as sea trout and Atlantic salmon are most often associated with estuaries, fjords, protected bays and inland waters. In this respect the environmental basic settings of Orther Bight and the lagoon of Rødsand are more optimal as nursery and feeding areas compared to the open exposed coast of Fehmarnbelt.
	Stratification	Eggs of nesting fish and fish which attach their eggs to the bottom substrate until hatching are not, or only little affected by shifting vertical stratification. Pelagic spawning species can possibly be affected by stratification, as long as they spawn in summer or autumn, where stratification of Fehmarnbelt is highest.
Food competitors	Interspecific	Many of the aforementioned fish species (see basic environmental setting) feed on the same kind of benthic food (Muus and Nielsen, 1999). In case they occur at the same habitats, they are food competitors. The pelagic species sea trout and Atlantic salmon are food competitors because they feed on the same kind of pelagic prey. They also compete with all other species in the area which mainly feed on fish (e.g. cod, whiting, brill and turbot).
	Cod and Flatfish	Cod and flatfish use the same benthic habitats as some of the aforementioned fish species (sea stickleback, ballan wrasse, corkwing wrasse, rock gunnel, sea snail, fourbeard rockling, snakeblenny and painted goby). Therefore they potentially feed on the same prey.
	Crustacean	Crustacean like the brown shrimp (*Crangon crangon*) and the common shore crab (*Carcinus maenas*) occur in the same habitat types and show overlapping diets with many of the “other” fish species.
Predators	Cod / Flatfish	Cod is one of the most important predators in the Baltic Sea. Also during its juvenile life stages, fish is an important part of its prey. Flatfish are mainly feeding on benthic organisms during their early life stages. As they mature they also feed on fish. Especially brill and turbot predate on small fish.
	Birds / Mammals	Several bird species also feed on fish in coastal waters. For example, some auk species (common guillemot, razor-billed auk and black guillemot), tern species and grebe species (great crested grebe, red-necked grebe and horned grebe) (Mendel et al., 2008). Also marine mammals such as seals and harbor porpoise feed on fish. Therefore they are also predating on most of the “other” fish species (Andersen et al., 2007).
Fishery and migration barriers		Only salmonoids are interesting for the commercial fishery. The mortality caused by fisheries of the most mentioned species is very low fish is only caught as by-catch. The salmonoids stock is comparatively small in the western Baltic Sea. As a consequence, no special salmonoids fishery takes place. Salmonoids are often being blocked in its migration up-stream.
Eutrophication	Nutrient enrichment	Especially fish communities and young fish in coastal areas are affected by the increased nutrient input caused by anthropogenic influence (Thiel et al., 1996). Fish species which occur close to the shore line (e.g. sea trout and sea-stickleback) are more affected by the impact of nutrient enrichment than species living further away rom the coast.

	Decreased water clarity	Although many small fish species may spawn on a wide variety of substrata, macrophytes are often preferred. A reduction in water clarity has generally reduced macrophyte vegetation, and hence reduced potential spawning sites for species which prefer structured habitats (e.g. corkwing wrasse, sea stickleback and rock gunnel).
Invasive species		The occurrence of invasive species affects the fish communities in the coastal waters of the Baltic sea. As an example, the round goby migrates from the Black and Caspian Sea via rivers into the Baltic Sea. It affects local gobies by feeding on their eggs, juveniles and even on adults (Skora, 1997). Furthermore, the jellyfish *Mnemiopsis leidyi* has the potential to affect recruitment success of fish species in Fehmarnbelt.

4.9.2 Baseline approach

The overall baseline approach was to identify species spawning in the Fehmarnbelt area besides the most abundant cod, herring, sprat and flatfish. Furthermore, the abundance and important areas of spawning of these species were investigated.

Eggs and larvae surveys were carried out from October 2008 to March 2010 and samples were collected during 12 surveys. Subsequently, species were identified and the developmental stage of eggs and larvae was determined. A hydrodynamic backtracking model was developed in order to identify possible spawning areas if possible.

4.9.3 Eggs and larvae

4.9.3.1 Fourbeard rockling (*Enchelyopus cimbrius*)

The maximum length of the fourbeard rockling is 40 cm and it is of no interest for the commercial fishery due to the small size and easily decaying flesh. Fourbeard rockling is mainly found on fine grained soft bottom sediments in deep areas below 20 m.

The fourbeard rockling was much more abundant in the egg and larvae study, where it was found as one of the most dominant species, compared to catches from the habitat mapping surveys in the area of Fehmarnbelt.

Heinen (1911) found fourbeard rockling eggs in the Baltic Sea from February to August, with highest densities from February to May.

In the present study fourbeard rockling eggs were found in Fehmarnbelt from February to August. The highest densities were found during March/April with a maximum average egg density in deep waters of approximately 0.3 eggs/m^3 (Figure 4.138). Eggs and larvae were caught all over Fehmarnbelt with higher egg densities in deep waters compared to shallow waters. Larvae were only caught in low numbers during the year. The highest abundance of the eggs was observed off the coast of Fehmarn and in an area between Fehmarn and Langeland (Figure 4.139).

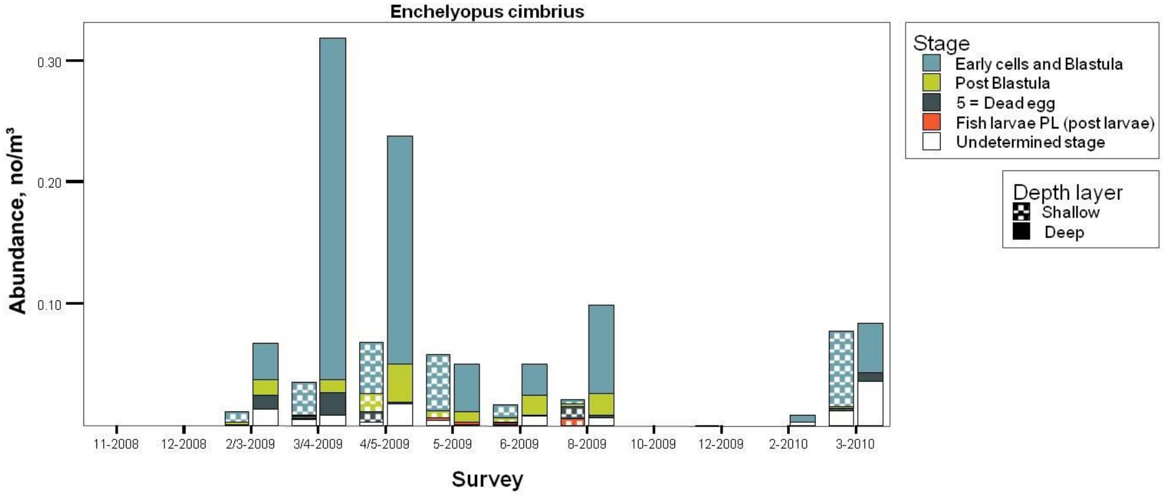


Figure 4.138: Average density (mean number/m^3) of different stages of egg and larvae of fourbeard rockling in 12 surveys from November 2008 to March 2010.

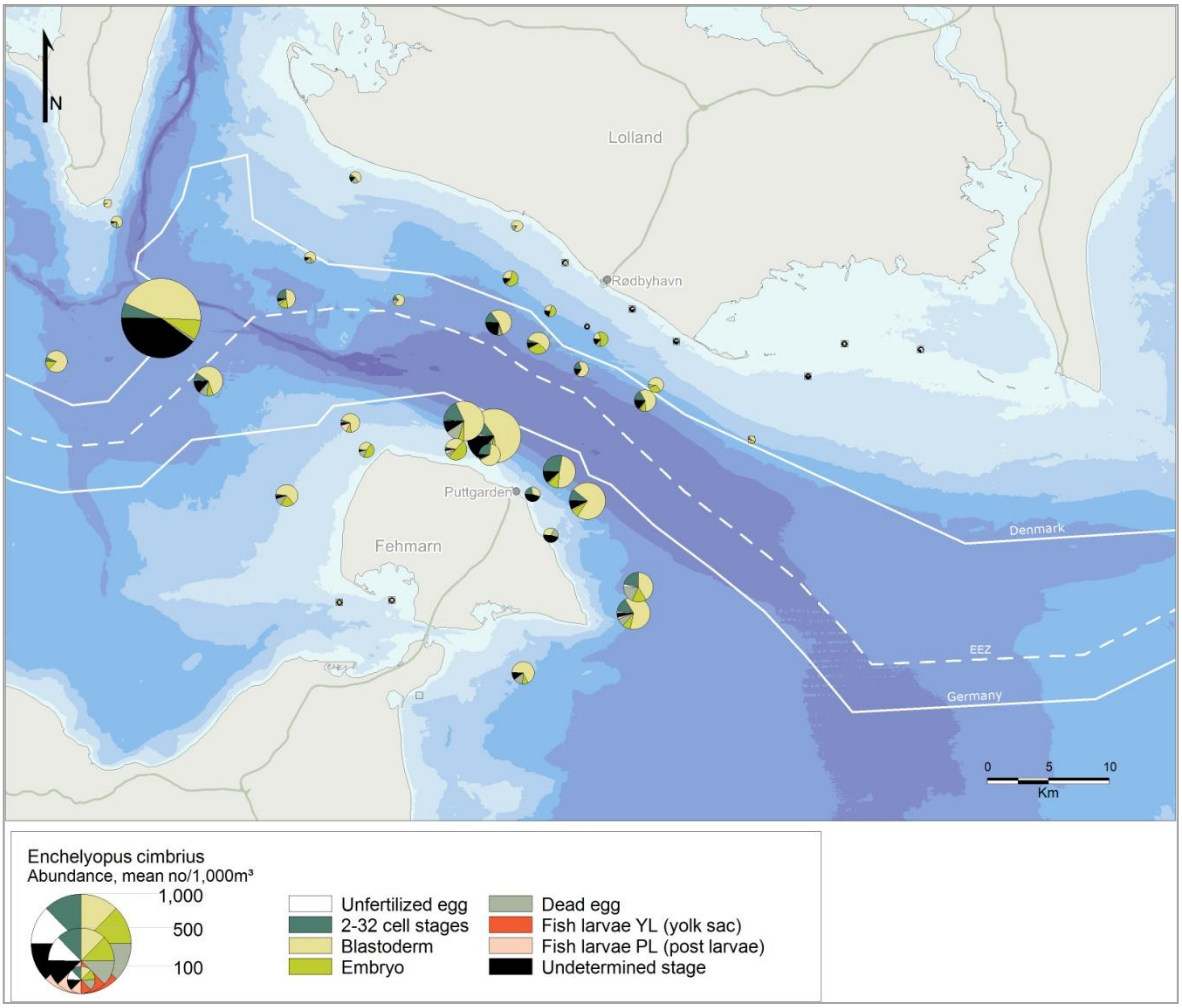


Figure 4.139: Average abundance (number/1,000 m^3) of eggs and larvae of fourbeard rockling in Fehmarnbelt March 2009–March 2010.

The variation in the egg mortality rate was 0.14 to 0.63 per day in shallow water and 0.22-0.79 in deep waters. The average annual egg production in the entire sampling area is estimated to be $4.539*10^{11}$ rockling eggs using the average annual production/m^3 in shallow and deep water (Table 4.33).

Table 4.33: Estimated annual egg production of fourbeard rockling in the sampling area of Fehmarnbelt.

FOURBEARD ROCKLING	Annual production (eggs/m^3)	Estimated volume of sampling area (m^3)	Estimated annual egg production in sampling area (eggs/year)
Shallow water (depth <10 m)	3.8	$20.5*10^9$	$0.779*10^{11}$
Deep water (depth > 10 m)	23.1	$15.5*10^9$	$3.580*10^{11}$
Total sampling area		$36*10^9$	$4.359*10^{11}$

Fourbeard rockling has a maximum fecundity of 45,000 eggs/year/female (www.fishbase.org). Thus, it was estimated that minimum of $9*10^6$ females of fourbeard rockling are spawning in the entire Fehmarnbelt area assuming that all eggs spawned are viable. Most likely not all eggs are viable indicating that the spawning biomass is under-estimated.

Relative hotspots of fourbeard rockling spawning in Fehmarnbelt area was found in the slope of the coastal areas along the northern and eastern coastline of Fehmarn, and in the north-western part of Mecklenburger Bight (Figure 4.140).

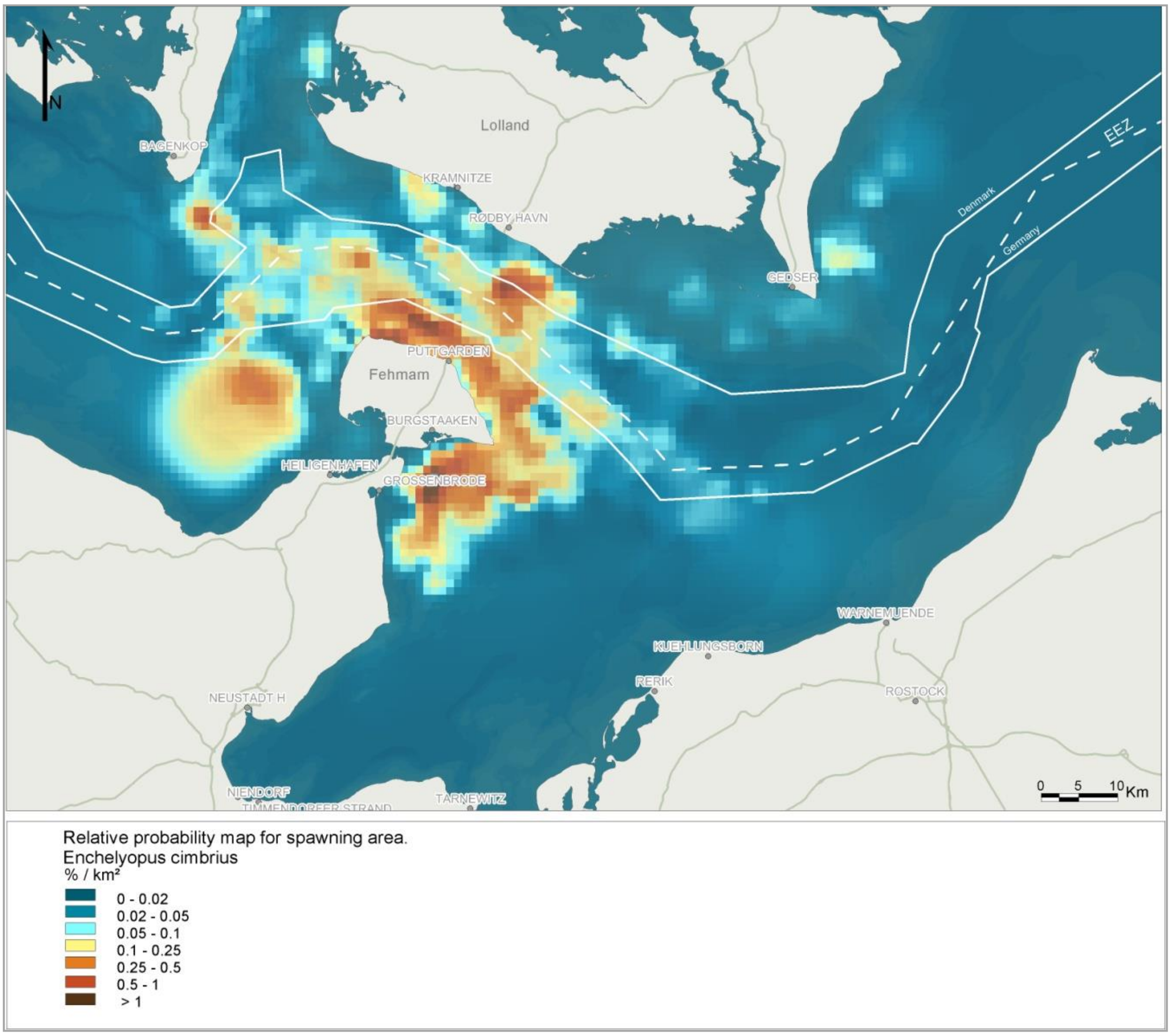


Figure 4.140: Relative probability of spawning area of fourbeard rockling in Fehamrnbelt and adjacent area from March 2009 to March 2010. Data derived from backtracking of eggs according to their development stage and hydrographic regimes.

4.9.3.2 Seasnail (*Liparis liparis, Liparis montagui*)

Seasnail fish are small non-commercial species with a maximum length of 15 cm. They spawn in both shallow and deep waters during winter and deposit the eggs on the bottom. Development time before hatch is 6-8 weeks.

During the present study the seasnail fish were only found as larvae but the larvae were present all over Fehmarnbelt from February to May. The highest densities were registered in March and April but in all, the abundance was low (maximum approximately 0.003 no./m^3). Striped seasnail (*Liparis liparis*) and montagus seasnail (*Liparis montagui*) were registered. Densities were highest for the more common striped seasnail in the deep waters (Figure 4.141).

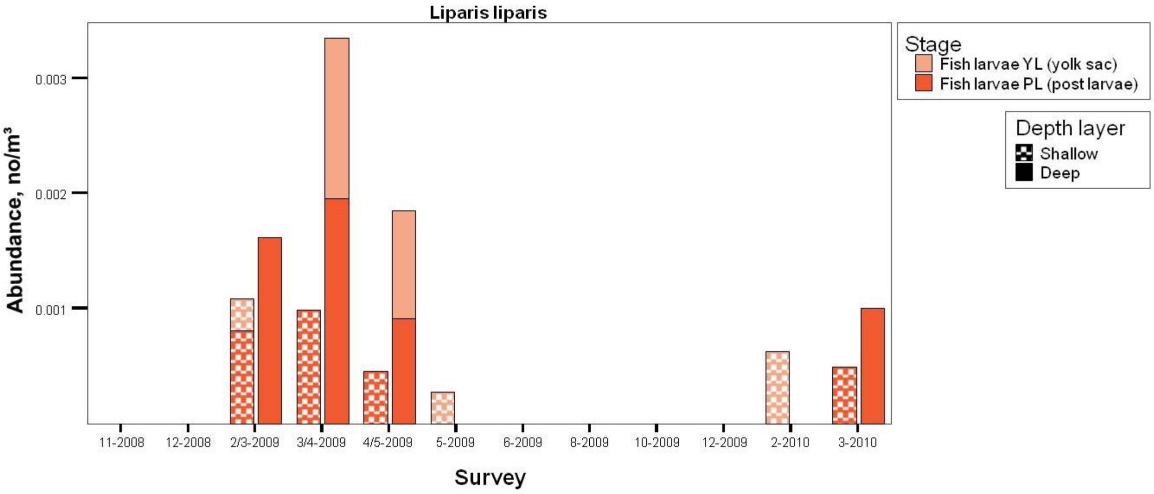


Figure 4.141: Average density (mean number/m^3) of different stages of seasnail fish larvae in 12 surveys from November 2008 to March 2010.

4.9.3.3 Rock gunnel (*Pholis gunellus*)

The rock gunnel is a benthic spawner which lives in habitats with rocks and vegetation. In the present study larvae of rock gunnel were found in both deep (>10 m) and shallow (<10 m) waters in February and March (Figure 4.142). This is consistent with findings of rock gunnel larvae in the western Baltic Sea by Heinen (1911). Only post larval stage of rock gunnel was observed. The abundance was highest in 2010 compared to 2009 and the maximum density found was 0.025 larvae/m^3.

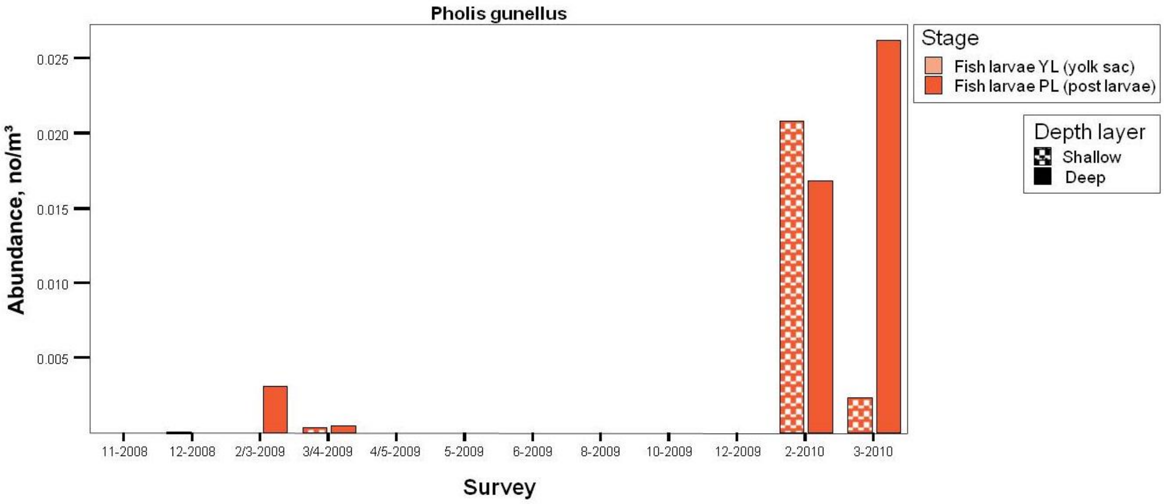


Figure 4.142: Average density (mean number/m^3) of rock gunnel larvae in 12 surveys from November 2008 to March 2010.

Rock gunnel was caught during the investigations of the shallow water fish communities. The suitability of habitats in shallow water was mapped as illustrated on Figure 4.145. The suitability index is based on catch data and habitat types in the shallow water community. The most suitable habitats for rock gunnel were found along the south-western coast of Lolland.

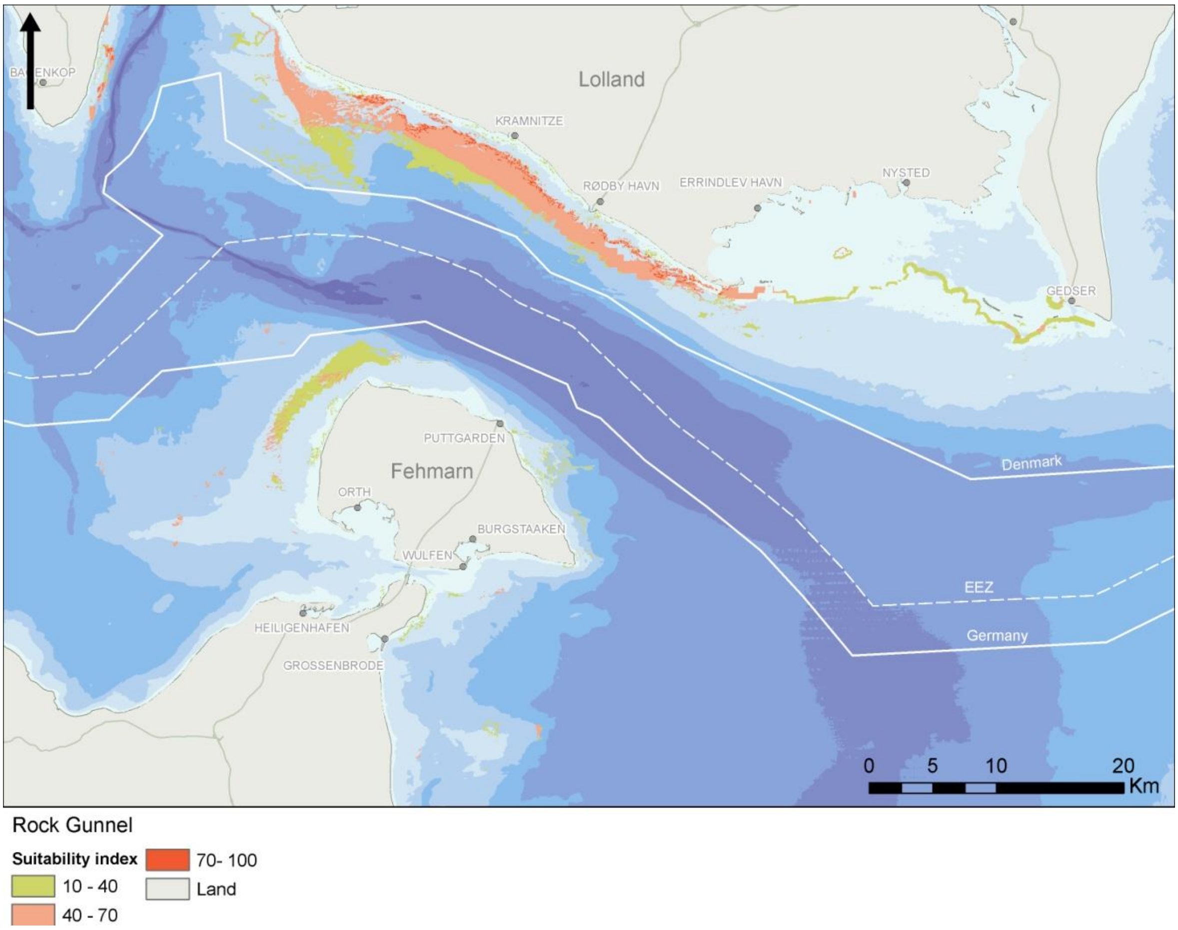


Figure 4.143: Habitat suitability for rock gunnel in shallow water fish community in Fehmarnbelt.

4.9.3.4 Hooknose (*Agonus cataphractus*)

Hooknose is known to live on soft bottoms in both shallow and deep waters. Hooknose was one of the most characteristic species in the Fehmarnbelt area. The main distribution of hooknose was found in the deeper parts of Fehmarnbelt, where it was most common in areas with sand or finer sediments.

Hooknose larvae were present in the early spring with maximum densities in deep waters in Februar and March during both years (maximum density 0.008/m^3 in 2009 and 0.019/m^3 in 2010).

Hooknose was caught during the investigations of the shallow water fish communities. The suitability of habitats in shallow water was mapped as illustrated on Figure 4.144. The suitability index is based on catch data and habitat types in the shallow water community. Suitable habitats for hooknose were found along the coast of Lolland and Fehmarn.

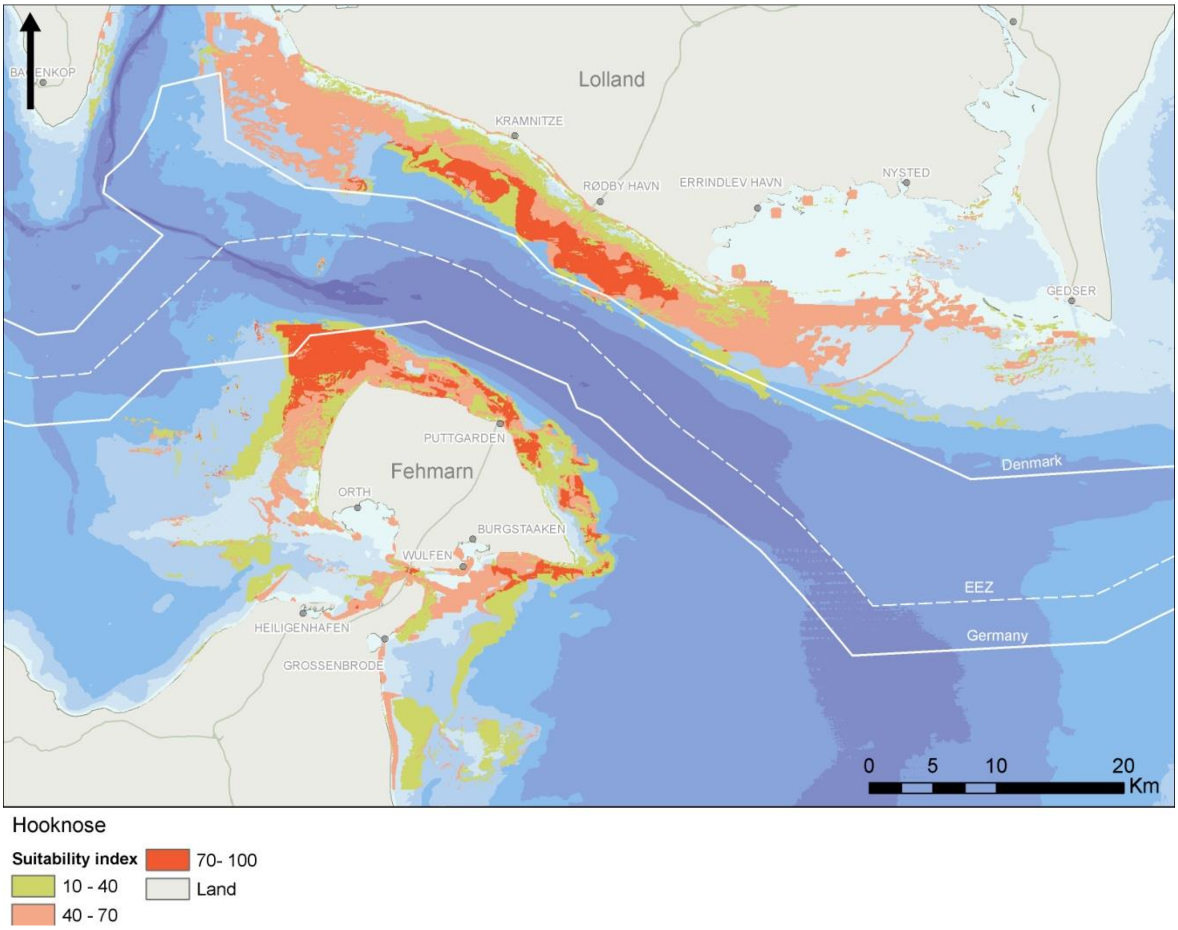


Figure 4.144: Habitat suitability for hooknose in shallow water fish community in Fehmarnbelt.

4.9.3.5 Gobies

The most numerous larvae of all benthic spawners were larvae of sand goby. Larvae of other benthic spawners were found in relatively low densities, except for larvae of herring and small sandeel that were found in moderate densities.

The larvae of gobies were found in relatively high densities, especially sand gobies, and were found in a maximum average density of 0.035/m^3 in June. Sand goby larvae were mainly hatched from June to August, and were numerous throughout the sampling area (Figure 4.145 and Figure 4.146).

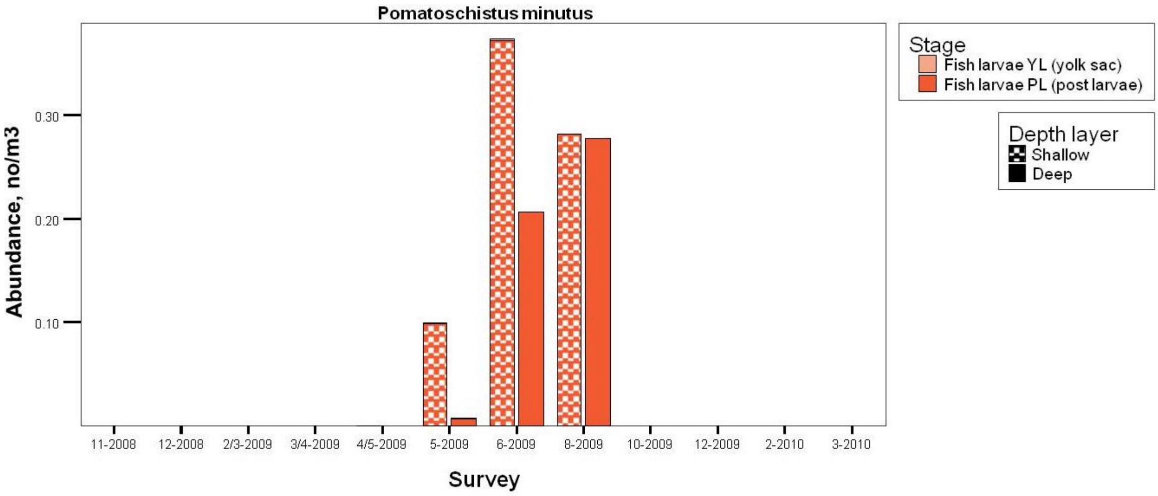


Figure 4.145: Average density (mean number/m3) of gobies – Gobidae larvae (mainly *Pomatoschistus minutus*) larvae in 12 surveys from November 2008 to March 2010.

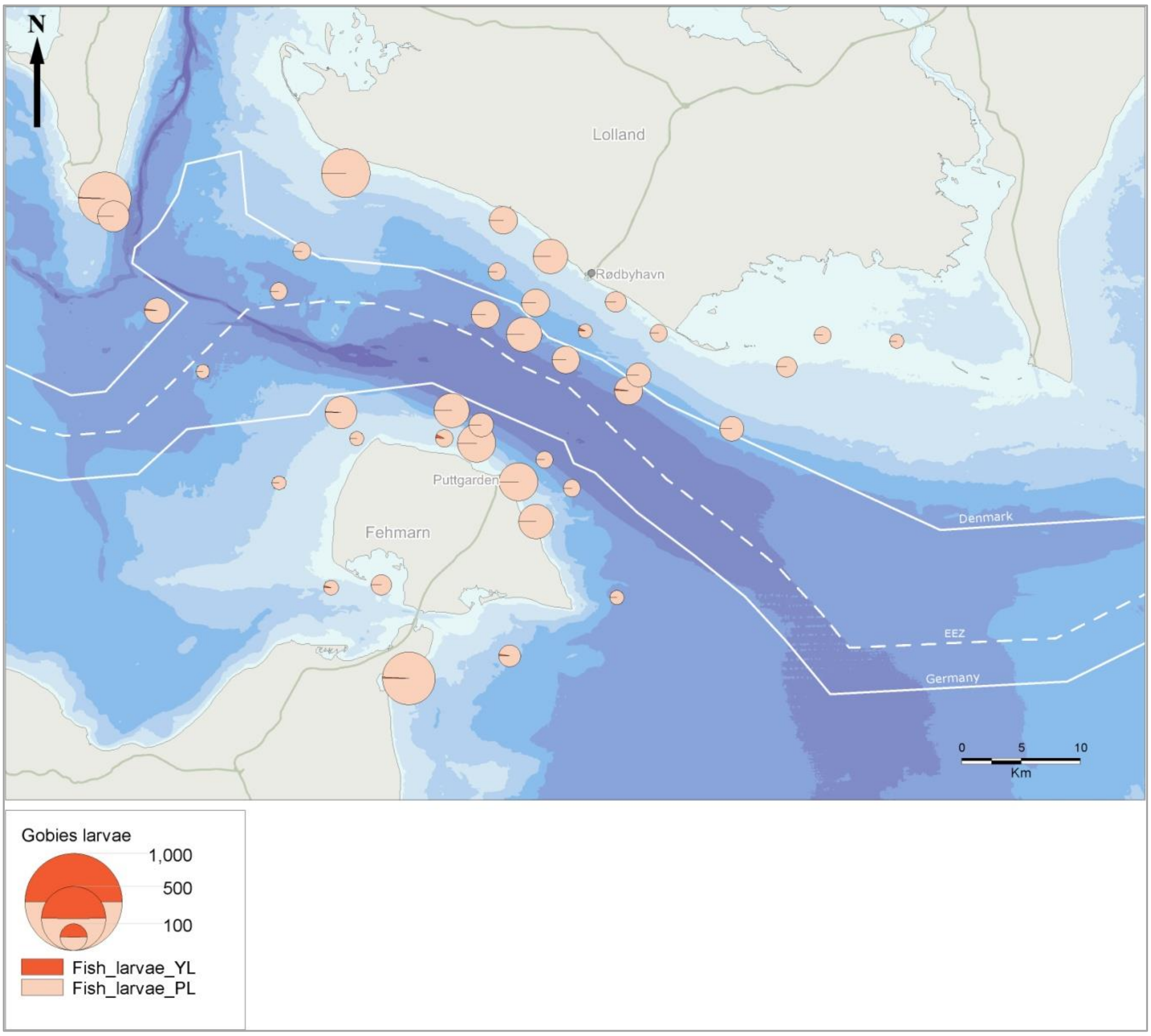


Figure 4.146: Spatial distribution and average abundance (number per 1,000 m^3) of gobies – Gobidae larvae (mainly *Pomatoschistus minutus*) in Fehmarnbelt from October 2008 until March 2010.

From the biochemical condition analyzes it was shown that all gobiid larvae had RNA:DNA ratios exceeding the laboratory determined starvation thresholds of 0.6 (Engell and Pedersen, 2010).

Gobies were caught during the investigations of the shallow water fish communities. The suitability of habitats in shallow water in relation to black goby was mapped as illustrated on Figure 4.151. The suitability index is based on catch data and habitat types in the shallow water community. Suitable habitats for black goby were primarely found along the coast of Lolland, especially in the area near Rødsand.

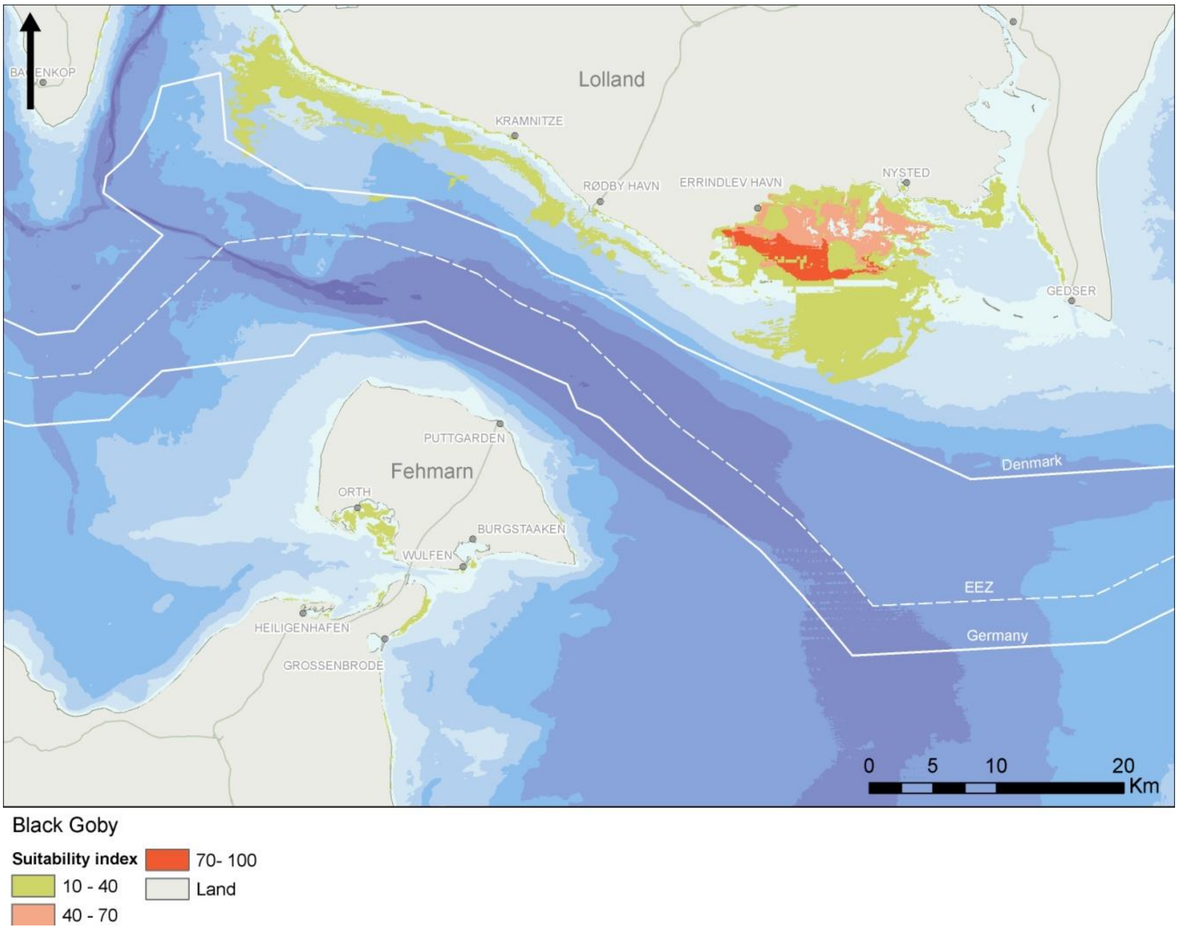


Figure 4.147: Habitat suitability for black goby in shallow water fish community in Fehmarnbelt.

4.9.3.6 Sandeel

The most important sandeel species was small sandeel (*Ammodytes tobianus*) which were found in moderate densities during the egg and larvae surveys. Larvae of lesser sandeel (*Ammodytes marinus*) and great sandeel (*Hyperoplus lanceolatus*) were less numerous.

Small sandeel larvae were most numerous in shallow waters in May (Figure 4.148 - Figure 4.149) where newly hatched larvae also were found. Small sandeel are often found burried in the sand during winter and during day time. The species will, when the water currents are sufficiently high, leave the bottom where it gathers in schools and prey on zooplankton. Presumably, the species spawn in both spring and autumn.

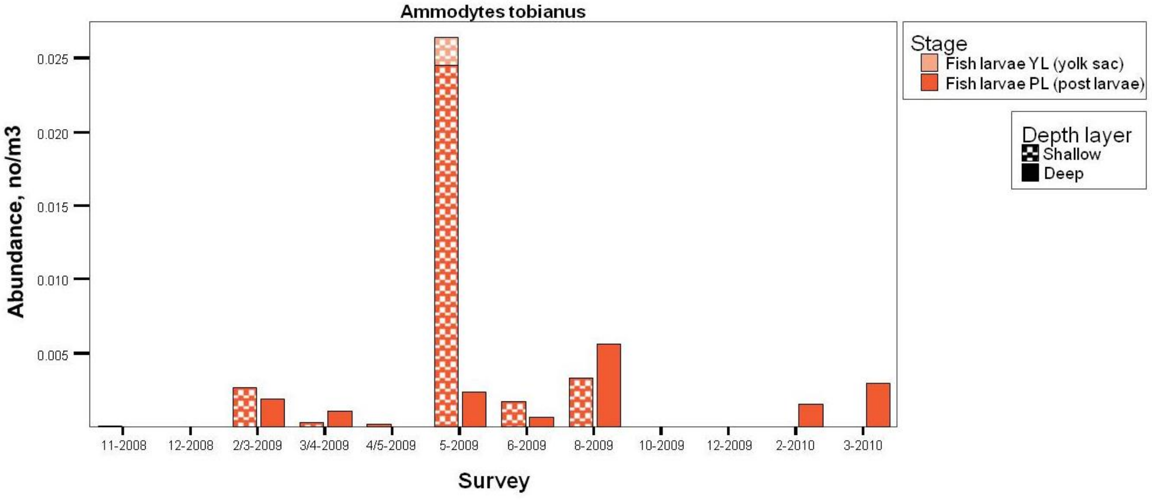


Figure 4.148: Average density (mean number/m^3) of larvae of small sandeel larvae in 12 surveys from November 2008 to March 2010.

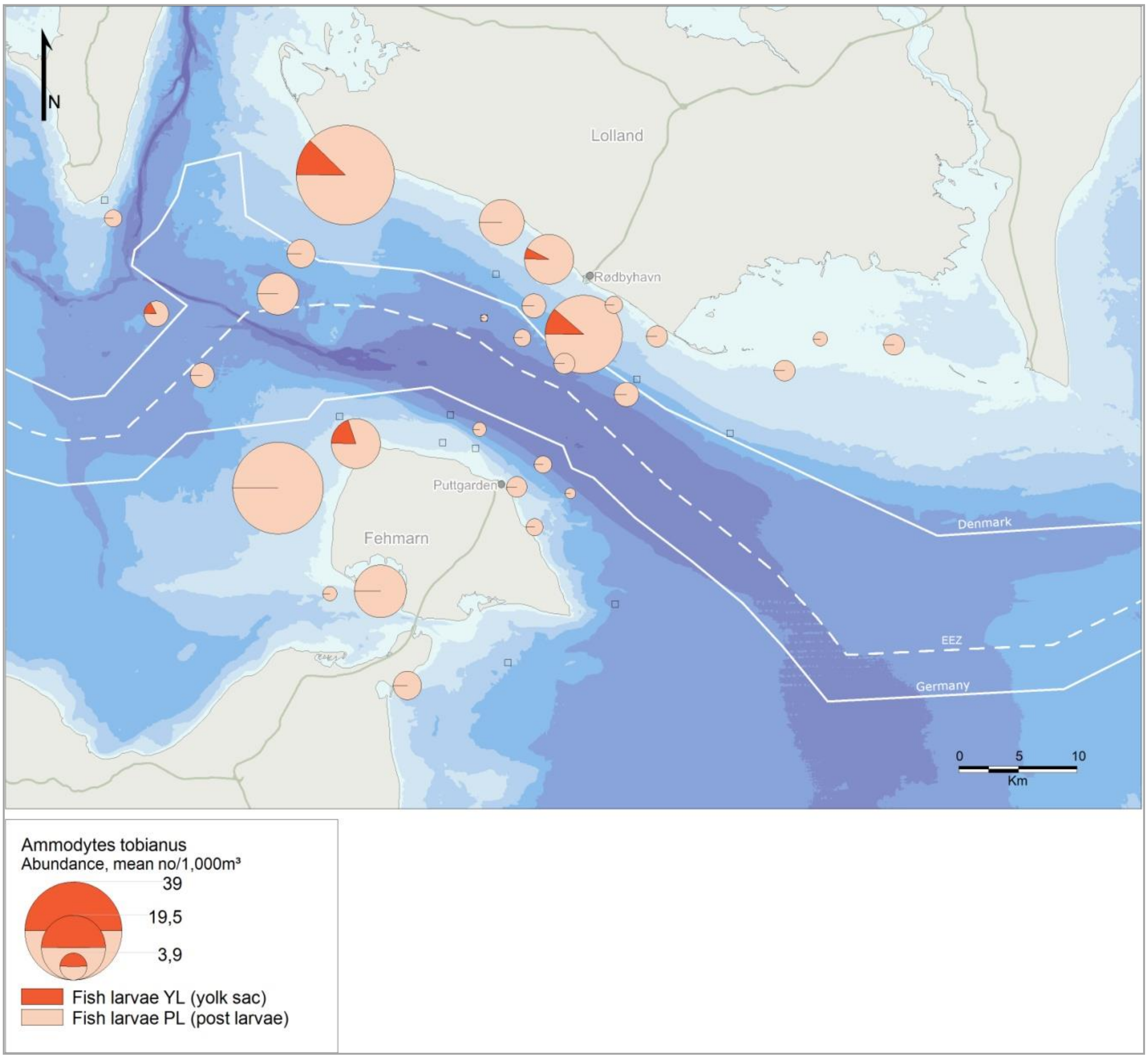


Figure 4.149: Spatial distribution and average abundance (number/1,000 m^3) of larvae of small sandeel in Fehmarnbelt from October 2008 to March 2010.

Sandeel were caught during the investigations of the shallow water fish communities. The suitability of habitats in shallow water in relation great sandeel was mapped as illustrated on Figure 4.150. For mapping of small sandeel see Figure 4.12. The suitability index is based on catch data and habitat types in the shallow water community. Suitable habitats for great sandeel were widespread along the coast of Lolland and Fehmarn.

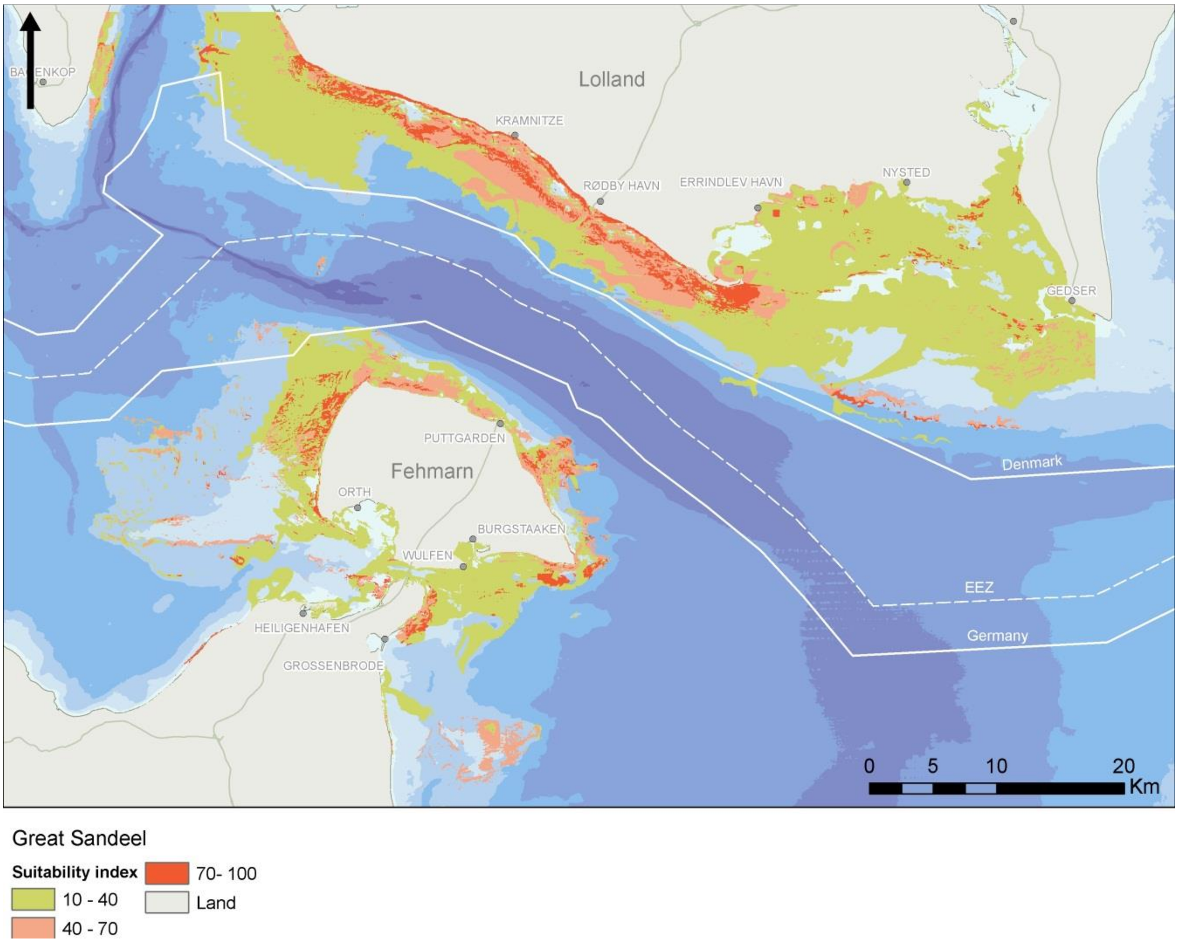


Figure 4.150: Habitat suitability for great sandeel in shallow water fish community in Fehmarnbelt.

4.9.3.7 Sculpins (Cottidae)

Longspined bullhead (*Taurulus babulis*) and shorthorn sculpin (*Myoxocephalus scorpius*) were only found occasionally in the catches from the shallow water community, but their larvae were however, characteristic and abundant in shallow waters along the coast of Lolland, especially in highly structured habitats.

The longspined bullhead is known to live between rocks and seaweeds in deep and shallow waters. The larvae of the species were found in high numbers in both deep and shallow waters from February to June (Figure 4.151).

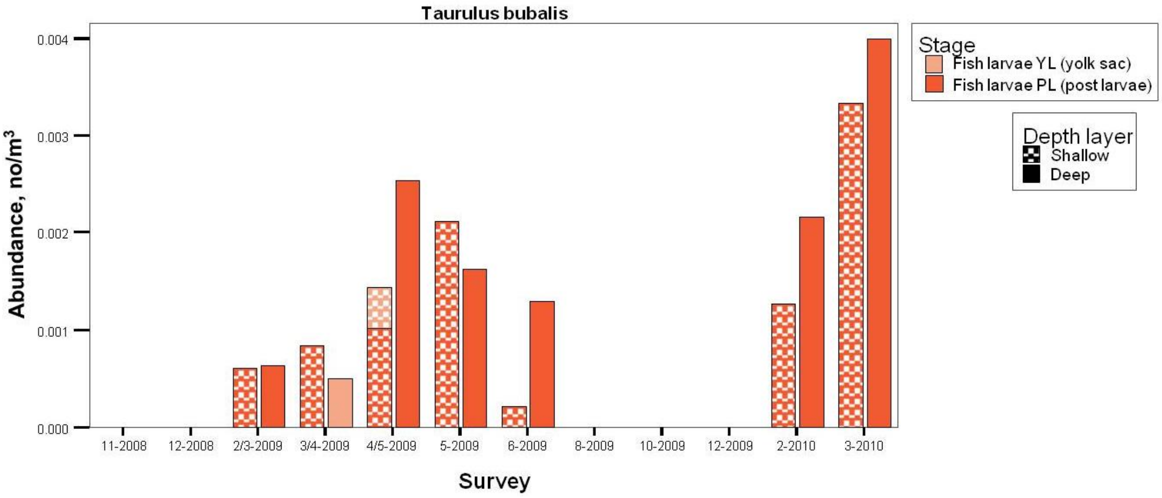


Figure 4.151: Average density (mean number/m^3) of different stages of larvae of longspined bullhead in 12 surveys from November 2008 to March 2010.

Shorthorn sculpin is also known to live between stones and algae, even in very shallow waters. Larvae of shorthorn sculpin were most abundant in the Fehmarnbelt area in shallow waters from February to April (Figure 4.152).

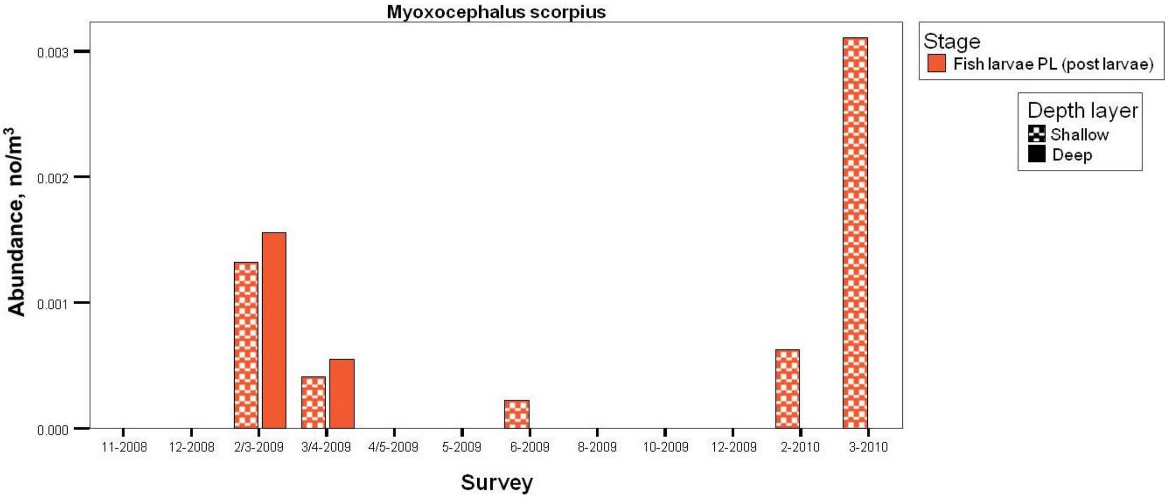


Figure 4.152: Average density (mean number/m^3) of different stages of larvae of shorthorn sculpin in 12 surveys from November 2008 to March 2010.

Sculpins were caught during the investigations of the shallow water fish communities. The suitability of habitats in shallow water in relation to longspined bullhead was mapped as illustrated on Figure 4.153. For mapping of shorthorn sculpin seeFigure 4.14. The suitability index is based on catch data and habitat types in the shallow water community. Suitable habitats for longspined bullhead were primarely found along the sout-western coast of Lolland.

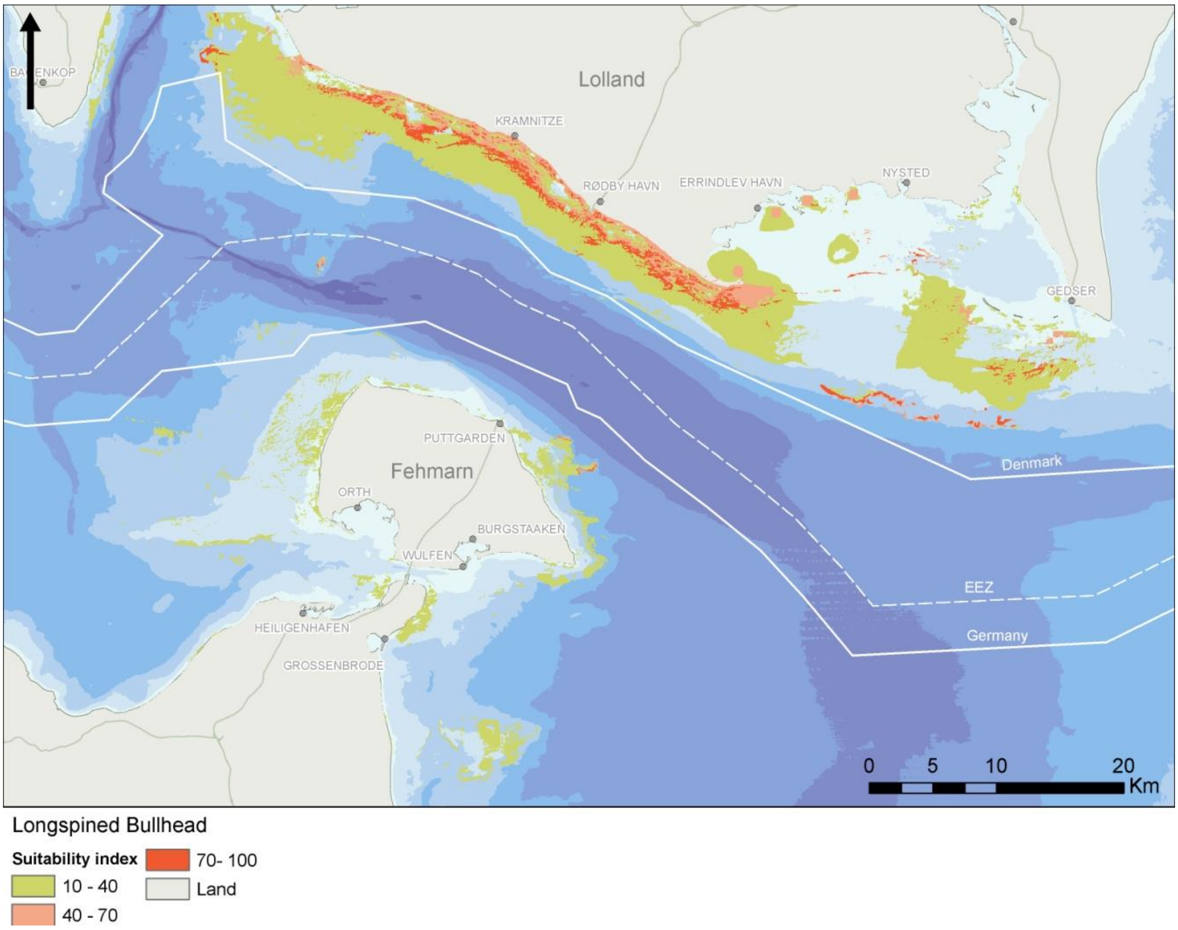


Figure 4.153: Habitat suitability for longspined bullhead in shallow water fish community in Fehmarnbelt.

4.9.4 Baseline conclusion

The baseline results regarding other species spawning in the Fehmarnbelt area may be summarized as follows:

- Beside cod, herring, sprat and flatfish eggs and/or larvae of five other species were caught: Fourbeard rockling, seasnail, rock gunnel, hooknose and the red listed snakeblenny.
- Eggs of fourbeard rockling were most abundant. Highest egg density (0.3 no./m^3) in March/April.
- Minimum $9*10^6$ females of fourbeard rockling spawned in the area of Fehmarnbelt.
- Possible spawning areas of fourbeard rockling were the slope of coastal area off Fehmarn and Mecklenburg Bight.
- Only larvae of seasnail were caught in the entire area during February and May.
- Only post larval stage of rock gunnel was registered in February-March.
- Only larvae of hooknose were caught mainly in the deep waters in February-March.

4.10 Legally protected species

4.10.1 Natura 2000 and legally protected species in Fehmarnbelt

Only a few of the fish species listed in Annex II and/or Annex IV of the Habitats Directive (Council Directive 92/43/EEC) are known from or are expected to occur in the Danish or German parts of the Baltic Sea. EU Member States are obliged to designate Special Areas of Conservation (SCIs) to protect sites that are essential to the life and reproduction of fish species listed in Annex II and to ensure that the habitats of the species within these sites are not deteriorated. Strictly speaking, however, Annex II species are not protected outside those SCIs where they form part of the reasons for designation. By contrast, species listed in Annex IV (e.g. sturgeon and houting) are strictly protected within all of their natural range.

The proposed route crosses the German Natura 2000 site (SCI) Fehmarnbelt (DE 1332-301) (Figure 2.1). However, no fish species are included in the reasons for designation of this Natura 2000 site or other nearby sites (Pedersen et al., 2009). According to Thiel & Winkler (2007) and Kloppmann et al. (2003) there are no preferred habitats of Annex II fish species in the area of the SCIs. The abundance of Annex II fish species in the Baltic Sea is generally low, and occurrence of Annex II species is mostly restricted to the southern Baltic Sea.

The relevant protected species of potential occurrence in the Fehmarnbelt area, which are listed in Annex II or Annex IV, are mainly anadromous species (i.e., species migrating from sea to freshwater to spawn) (Table 4.34).

Table 4.34: Protected Annex II and Annex IV species of potential relevance for the Fehmarnbelt area, in part cited in Thiel and Winkler (2007) added by further references. FB: Fehmarnbelt, MB: Mecklenburg bight, KB: Kiel bight, GB: Great Belt. * specimens stored in an ichthyological museum collection, reference on catch date is missing. ¤ species also listed in Annex IV. # listing under Annex II and IV only applies to anadromous populations in certain sectors of the North Sea.

		Feh-marn belt	Nearby Findings	Reference	Possible im-pacted life stages
			Migrating species		
Common name	***Latin name***				
Sturgeon	*Acipenser sturio* ¤		Considered extinct in DK and DE	Thiel & Backhau-sen (2006) Naturstyrelsen (2011)	
North Sea houting	*Coregonus oxyrin-chus* ¤ #	-	Marine stocks may be extinct	www.fishbase.org www.iucnredlist .org	
Allis shad	*Alosa alosa*	(-)	WB, Guldborg Sound (1990) single specimen	Thiel & Winkler (2007)	Adults
Twaite shad	*Alosa fallax*	+	MB (2004), single specimen FB (2008) 2 specimens FB(2004) 1 specimen	OSF (2004) Hvidt et al., 2005	Adults
River lamprey	*Lampetra fluviatilis*	+	WB (1980, 1997) 1 specimen. A spawning site near Lübeck GB (1999) 1 specimen FB (2004 and 2003) 2 speci-mens	Walter (1997) Thiel & Winkler (2007)	Adults
Sea lamprey	*Petromyzon mari-nus*	(-)	WB (1989) 1 specimen KB (after 2000) 1 specimen Lübeck (after 2000) 1 specimen FB (2008) 1 specimen	Walter (1997) Thiel & Backhau-sen (2006) Rasmussen (pers. com.,2008)	Adults
			Freshwater species		
Atlantic salm-on	*Salmo salar*	(-)	Listing only applies to freshwater occurence		
North sea houting ¤ #	*Coregonus oxyrin-chus*	-	Very restricted distribution in DK/DE	Thiel & Backhau-sen (2006) Sø-gaard et al. (2003)	
Asp	*Aspius aspius*	-	Not found in DK	Lelek (1987)	
Bullhead	*Cottus gobio*	-	Considered extinct in DK	DMU (2010)	
Weatherfish	*Misgurnus fossilis*	-	Very restricted distribution in DK	Carl et al. (2004)	
White-finned gudgeon	*Romanogobio albi-pinnatus*	-	Distribution in East-Central and Eastern Europe	Lelek (1987)	
Bitterling	*Rhodeus amarus*	-	No actual populations in DK	Carl et al. (2004)	
Sichel	*Pelecus cultratus*	(+)	Very rare visitor in DK	Carl et al. (2004)	

Few records of migrating protected fish species listed in Annex II exist from the Fehmarnbelt and adjacent waters. There are no records of protected freshwater species in the main area of Fehmarnbelt, due to their limited salinity tolerance. The occurrence of the protected freshwater species such as asp *(Aspius aspius)*, spined loach *(Cobitis taenia)*, bullhead *(Cottus gobio)*, weatherfish *(Misgurnus fossilis)*, bitterling *(Rhodeus amarus)*, and sichel *(Pelecus cultratus)*, outside freshwater habitats, are restricted to the inner coastal areas within German Baltic waters, and to areas with lower salinities in more eastern regions of the Baltic Sea (Thiel and Winkler, 2007). Although, the Atlantic salmon (*Salmo salar)* is an anadromous species it is only protected according to the Habitats Directive at the spawning sites in freshwater areas. The white-finned gudgeon (*Romanogobio albipinnatus)*, which main area of distribution is the river Volga and Don catchment areas (Lelek, 1987), has not yet been observed in German or Danish Baltic waters, although there exists a population of this species in the river system of the Oder (Thiel and Backhausen, 2006).

According to Thiel and Backhausen (2006) and IUCN (www.iucnredlist.org), the original North Sea houting *(Coregonus oxyrinchus)* is considered globally extinct. However, small populations of fish that are morphologically similar to the original North Sea houting exist in the River Vidå and a few other rivers in south-eastern Jutland (Denmark) draining into the North Sea. These houting are morphologically and ecologically distinct from, but genetically very similar to, whitefish (*Coregonus lavaretus/maraena*) from other rivers and lakes in Jutland (Hansen et al., 2008). Whitefish from the Baltic region seem more distantly related to the “houting” and whitefish populations in Jutland although, they should all be considered as belonging to the same species (Hansen, 1997). The widespread whitefish in the Baltic region, including the anadromous stocks, is most frequently called *Coregonus lavaretus* (European whitefish); however, Kottelat and Freyhof (2007) restricts this name to the species occurring in lakes Bourget, Aiguebelette and Geneva in France and Switzerland and assigns the Baltic stocks to *C. maraena* (maraena whitefish). The Baltic “houting” populations are not protected under the Habitats Directive. Most of the records of “houting” (80%) in the Baltic Sea were obtained from the coastal waters off the Usedom Island, indicating a nearshore and restricted distribution of this species in the Pommeranian Bay. Spawning concentrations occur in the Szczecin Laggoon and adjacent waters (Thiel and Backhausen, 2006).

The sichel (*Pelecus cultratus*), although grouped as a freshwater species (Thiel and Backhausen, 2006), can be considered as a freshwater/brackish water anadromous species (Fishbase, 2010). The sichel is generally distributed around the Baltic Sea (Lelek, 1987), and it is the most frequent freshwater species found along the Baltic coast in Germany, where it is recorded from Greifswalder Bodden to the Dassower See at Lübeck. In Denmark records of the sichel are very sparse; it was recorded for the first time in Køge Bugt in 1960 (Dahl, 1961). Besides a record in the same area in 1961 (Dahl, 1961), no observations have been made since, and it is not listed in the Danish Annex II list (Søgaard et al., 2003; Skov- og Naturstyrelsen, 2010).

Besides the lack of knowledge on the occurrence of the protected species also information on habitat utilisation is sparse (Table 4.35). For example the knowledge about river lampreys (*Lampetra fluviatilis*) is limited to investigations at spawning places in rivers in Germany (Krappe, 2007). Data on the migration from the spawning areas to the sea are missing due to the behaviour of the lampreys and the difficulties in capturing pre-mature individuals (personal comment Krappe; Waaterstraat & Krappe, 2000). No spawning areas for sea lamprey are found in rivers discharging the Baltic Sea in Germany (Thiel et al., 2005 cited in Thiel and Winkler, 2007). Most of the records of river lamprey from German Baltic waters were obtained from the Szczecin Lagoon and adjacent waters, from waters around the Island of Rügen, from the Warnow estuary, and from the Mecklenburg and Kiel Bight (Thiel and Winkler, 2007) (Figure 4.154). The river lamprey was the only protected species recorded from the coast of Lolland in the surveys in 2009. Furthermore, knowledge on marine habitat preferences of river lampreys and sea lampreys is very sparse.

Thiel and Winkler (2007) described stony areas and reefs near the coast as habitats where sea lampreys could occur. Due to the difficulties of sampling in these areas with “normal “ fishing gear, methods like underwater video surveys and the use of divers were advised by Thiel and Backhausen (2006).

Table 4.35: Habitat use of the Annex II species in the Baltic Sea. *Additionally listed at Annex IV, **Additionally listed at Annex V

Species of annex II			
Common name	**Latin name**	**Habitat**	**Comments**
Sturgeon*	*Acipenser sturio*	?	extinct in the Baltic sea
Allis shad**	*Alosa alosa*	Pelagic	
Twaite shad**	*Alosa fallax*	Pelagic	
River lamprey**	*Lampetra fluviatilis*	Coastal	no knowledge (Thiel & Winkler 2007)
Sea lamprey	*Petromyzon marinus*	Coastal	no knowledge (Thiel & Winkler 2007)

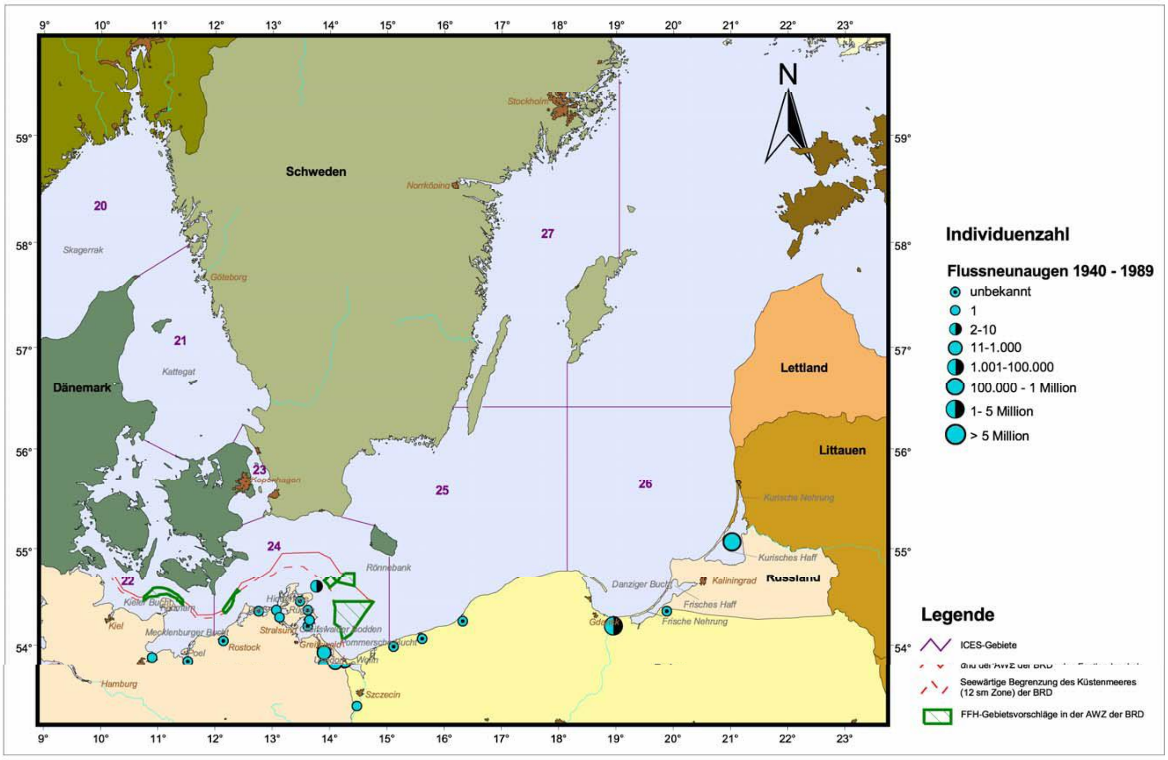


Figure 4.154: Distribution of the river lampreys (*Lampetra fluviatilis*) in ICES subdivision 20-27 in the Baltic Sea from 1940-1989. Source: Thiel and Winkler (2007).

The sturgeon (*Acipenser sturio*) is considered extinct in the Baltic, and the sturgeon species last recorded in individual catches in the Baltic in the 1990s was the Atlantic sturgeon (*Acipenser oxyrinchus)* (Thiel and Backhausen, 2006), which is not listed in the Annex II. A re-introduction of the Atlantic sturgeon, which genetic studies have shown to have replaced the native *Acipenser sturio* in the Baltic one thousand years ago, was started in the river Oder in 2007. As the project is in an early stage, it has not yet been possible to estimate the success of the re-introduction (http://www.sturgeon.de).

The twaite shad (*Alosa fallax*) mainly occurs in the eastern parts of the Baltic where a twaite shad stock can be found in ICES subdivisions 24, 25 and 26 (Thiel and Winkler, 2007). From May 2003 until November 2004, a total of 38 twaite shad were found at 14 different localities in the German EEZ northwest of the Rügen Island, as well as in the Pommeranian Bay and the Szczecin Lagoon and adjacent waters. Juvenile fish of age group 0 were caught at the Oder Bank and in the coastal waters off the Usedom Island (Thiel and Backhausen, 2006).

Given the recent records from German Baltic waters it is assumed that the Baltic population of twaite shad has been increasing since the middle of the 1990s after about 50 years of decline. The source of the population increase in German waters is thought to be the eastern twaite shad stock of the Curonian Lagoon (Thiel et al., 2007).

Migration of greater numbers of twaite shad from the North Sea into the Baltic Sea has not been observed (Thiel and Backhausen, 2006). Solitary migrating specimens have been found in the Fehmarnbelt on the Danish side (Figure 4.155). The twaite shad which are found in Kattegat and eastern Skagerrak (ICES subdivisions 20 and 21) are assumed to represent a separate stock (Maitland and Hatton-Ellis, 2003; Thiel et al., 2008), so migration through the Danish belts and Fehmarnbelt is probably of limited extent.

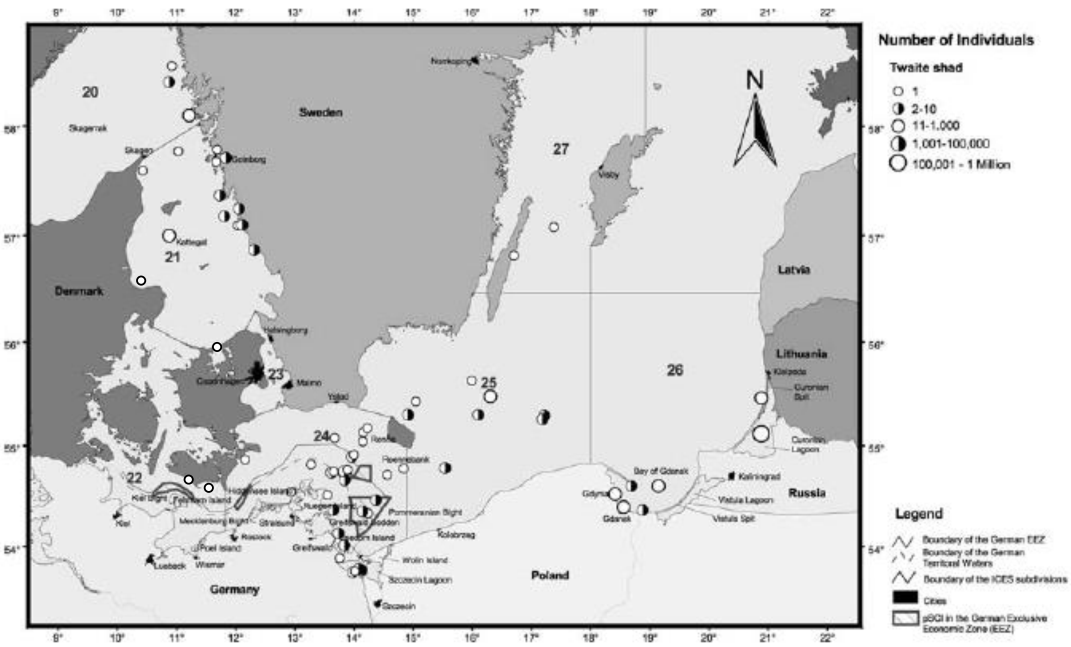


Figure 4.155: Distribution of records of twaite shad in the ICES subdivisions 20–27 of the Baltic Sea from 1990 to 2005. Source Thiel et al. (2008).

In Europe the allis shad (*Alosa alosa*) is distributed along the Atlantic coast from Norway to the Mediterranean, occurring in estuaries and lower reaches of rivers (Lelek, 1987). The species generally has a more western distribution than the twaite shad. In German and Danish coastal waters the allis shad is mainly found in the ICES subdivisions 20-24 (Thiel and Winkler, 2007). According to Thiel and Backhausen (2006), a specimen caught in the Strelasund in 1998 represents the only record of the species in German Baltic waters during the last 20 years.

4.10.2 Rare and red listed species

A total of 134 fish species are known from the Baltic Sea. Excluding migrating guest species a total of 76 of these species are living in the Baltic Sea. Of these 30% or 21 species are to be considered as endangered (Fricke et al., 1996; Fricke et al., 1998) and since the mid 1990s several HELCOM Contracting States have published national red lists of these threatened and declining fish species. These red lists only relate to the national territorial waters and does not include a list for the Baltic Sea in general.

Most of the fish are naturally cross boarder species making long feeding or spawning migration journeys. Furthermore, many of the endangered species have a high economic and environmental importance and several are of regional or even global importance. Subsequently, it was agreed (HELCOM, 2004) that a joint HELCOM Red List of threatened and declining species of the Baltic Sea areas was urgently needed. Since 2007 this HELCOM Red list is presented for the entire Baltic Sea. Accordingly the German Red List and the Danish Red List of threatened and declining species of lampreys and fishes are used, in the selection of relevant species found during the investigations from 2008-2010 in the Fehmarnbelt area (Table 4.36). It should be noticed that saltwater fish species that do not regularly enter Danish freshwater areas have not yet been considered for red listing in Denmark (Stoltze and Pihl, 1998; DMU, 2010).

The sources of danger for the threatened and declining species are numerous. The most important impact on the abundance of the species is fishery. Highly abundant fish species such as herring and cod are commercially exploited as target species. These stocks have declined significantly during the recent decades (Rechlin, 2003), but also species not regularly commercially exploited are threatened as they are caught as by-catch.

Another important threat to fish communities is loss of suitable habitats. This is particularly important for stationary species that have special requirements for different habitats during spawning and feeding. This is due to the enormous increase in the exploitation and reclamation of seabeds since the 1990's in the Baltic Sea for use in the offshore construction, offshore wind farms, coastal protection, harbours etc. or deterioration of seabeds due to dredging as well as sand and gravel extraction etc. Furthermore, increased eutrophication or pollution of the Baltic Sea has caused changes in habitats.

The autumn spawning herring is listed as critically endangered on the German Red List but can only be separated from the spring spawning herring by spawning time and genetic analysis. The autumn spawning herring have only been red listed in the Baltic Sea since recent decade (Fricke et al., 1996). The European eel was added to the Danish Red List in 2009 and is considered critically endangered on the national as well as on the global scale (IUCN, 2010).

Table 4.36: Red listed species found in the Fehmarnbelt 2008-2010. GRL1996 - German Red list according to Fricke et al. (1996); DRL1998 - Danish Red list according to DMU (2010); type: M - marine / D – diadromous; presence: ST - stationary / G – Guest; frequency: ra - rarely / re - regularly / of - often / vo - very often; categories of threat: RE - Regionally Extinct / CR - Critically endangered / EN – Endangered / VU – Vulnerable / TM - Threatened migrant / NR - Near threatened / RA – Rare (HELCOM, 2007).

Common name	Latin name	Type	Presence	Frequency	GRL1996	DRL1998	Threats
Snakeblenny	*Lumpenus lampretaeformis*	M	ST	ra	CR		Eutrophication/Construction/ Fishery
Sea stickleback	*Spinachia spinachia*	M	ST	re	EN		Eutrophication/Habitat loss
Corkwing wrasse	*Symphodus melops*	M	ST	ra	CR		Eutrophication/Habitat loss
Ballan wrasse	*Labrus bergylta*	M	G	ra	EN		Eutrophication/Habitat loss
Sea trout	*Salmo trutta*	D	ST	of	EN		Fishery/Eutrophication/ Construction/Habitat loss
Atlantic salmon	*Salmo salar*	D	ST	of	EN	EN	Fishery/Aquaculture/ Eutrophication/ Construction/Habitat loss
Greater weever	*Trachinus draco*	M	ST	ra	VU		Eutrophication/Habitat loss/ Fishery
European eel	*Anguilla anguilla*	D	ST	of	EN	CR	Fishery/Eutrophication/ Construction/Habitat loss/Parasites
Painted goby	*Pomatoschistus pictus*	M	ST	re	TM		Eutrophication/Habitat loss
Autumn spawning herring	*Clupea harengus* subsp.	M	ST	vo	CR		Fishery

The majority of the red listed species occurred only in the Fehmarnbelt area sporadically or in low numbers. But some species e.g. in particular the sea stickleback, was abundant and relatively widely distributed in the autumn (Table 4.37). These species are an essential part of the fish communities in the coastal regions of the Fehmarnbelt. Other species like corkwing wrasse, ballan wrasse and great weever showed a significant seasonal distribution.

Table 4.37: Temporal and spatial occurrence of the red listed species. Numbers of individuals caught during the habitat mapping survey.

Time		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Common name	**Latin name**	**Fehmarn**											
Snakeblenny	*Lumpenus lampretaeformis*												
Sea stickleback	*Spinachia spinachia*	9	2	1	2	3	6			70	16	9	1
Corkwing wrasse	*Symphodus melops*									4	1	2	3
Ballan wrasse	*Labrus bergylta*									3	4		
Sea trout	*Salmo trutta*					1	4						
Atlantic salmon	*Salmo salar*	3	2										1
Greater weever	*Trachinus draco*					1	1		3				
European eel	*Anguilla anguil-la*						1			1			
Painted goby	*Pomatoschistus pictus*												
		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
		Fehmarnbelt											
Snakeblenny	*Lumpenus lampretaeformis*	1			1	2	1		2		1		
Sea stickleback	*Spinachia spinachia*												
Corkwing wrasse	*Symphodus melops*												
Ballan wrasse	*Labrus bergylta*												
Sea trout	*Salmo trutta*												
Atlantic salmon	*Salmo salar*												
Greater weever	*Trachinus draco*								8	3	2	2	
European eel	*Anguilla anguil-la*												
Painted goby	*Pomatoschistus pictus*		7										

Table 4.31: *continued*

Time		**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Common name	**Latin name**	**Lolland**											
Snakeblenny	*Lumpenus lampretaeformis*												
Sea stickleback	*Spinachia spinachia*			8	35	32	5	1	1	47	20	7	5
Corkwing wrasse	*Symphodus melops*									3	9	1	
Ballan wrasse	*Labrus bergylta*												
Sea trout	*Salmo trutta*		5	1		3		2		1		1	
Atlantic salmon	*Salmo salar*												
Greater Weever	*Trachinus draco*												
European eel	*Anguilla anguil-la*				1	1	2	3	4	4			
Painted goby	*Pomatoschistus pictus*												

4.10.2.1 Snakeblenny (*Lumpenus lampretaeformis*)

The snakeblenny is a Nordic species and is classified as “critically endangered” in Germany (Fricke et al., 1996, Fricke et al., 1998). It is considered widespread and common in Denmark (Carl et al., 2004). HELCOM (2007) considers it “critically endangered” in the Baltic Sea but least concern in Kattegat and Skagerrak. The western Baltic is the southernmost distribution limit of the snakeblenny. The stock in the Baltic Sea is probably a relic of the last ice age. Thus, the stock in the Baltic Sea has always been relatively small. The snakeblenny lives in Y-formed tubes and prefers sandy areas at depths of 50–200 m (Gordon and Duncan, 1979). In the present study it was only caught at deep water stations in sandy habitats of subarea Fehmarnbelt. The species occurred regularly but the abundance was low (Table 4.37). The snakeblenny is a part of the deep water fish community in subarea Fehmarnbelt. Larvae were mainly caught in March but also during February low densities were registered, especially along the northern coast of Fehmarn (Figure 4.156). The main threats are eutrophication (oxygen depletion) and especially fisheries.

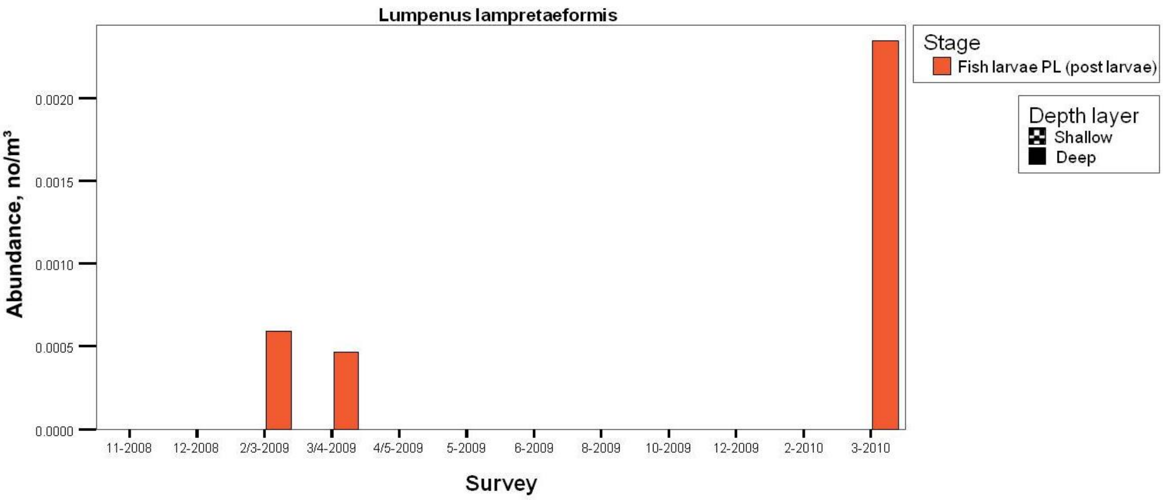


Figure 4.156: Average density (mean number/m^3) of different stages of snakeblenny larvae in 12 surveys from November 2008 to March 2010.

4.10.2.2 Sea stickleback (*Spinachia spinachia*)

The sea stickleback is classified as "endangered" in the German Red List (Fricke et al., 1996, Fricke et al., 1998) and as "vulnerable" in the Baltic as a whole (HELCOM, 2007). It is considered very common in Danish waters (Carl et al., 2004). The species prefers habitats covered with vegetation, where it can nest (Kaiser et al., 1992). In the present study, sea stickleback was relatively common in subarea Fehmarn and Lolland. It was caught throughout the year with the highest numbers in the autumn (Table 4.37). It was present in all types of habitats but mainly in habitats with eelgrass meadows. Especially the eelgrass meadow habitats at the southern coast of Fehmarn were preferred by the sea stickleback. The sea stickleback is an essential part of the fish communities in the coastal regions of Lolland and Fehmarn. The main threats are eutrophication (oxygen depletion) and loss of habitats.

The predicted habitat suitability for sea stickleback is illustrated in Figure 4.157.

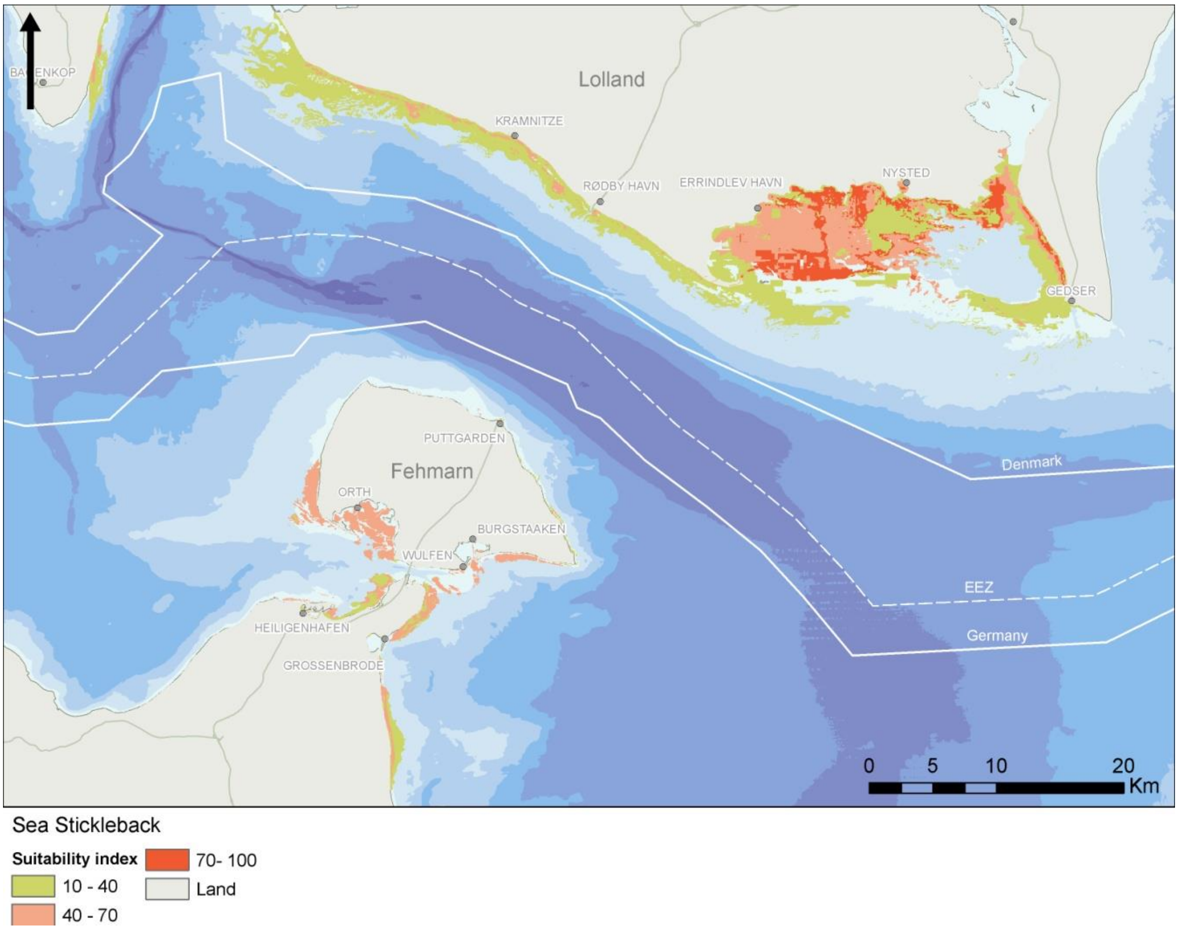


Figure 4.157: Habitat suitability for Sea Stickleback in the shallow water fish community in Fehmarnbelt.

4.10.2.3 Corkwing wrasse (*Symphodus melops*)

The corkwing wrasse is classified as "critically endangered" in the German Red List (Fricke et al., 1996, 1998). No firm data are available to assess its threat status in Danish waters (HELCOM, 2007) but Carl et al. (2004) considered it common. It is considered "vulnerable" in the Baltic as a whole but least concern in Kattegat and Skagerrak (HELCOM, 2007). The corkwing wrasse prefers rocky shores and reefs, and the western Baltic Sea is the distribution limit. Hence, the occurrence of the corkwing wrasse in the Baltic Sea is limited. The main areas of occurrence are rather warmer sea areas (Rui Beja, 1995; Collins et al., 1996). The species was caught in subarea Fehmarn and Lolland (Table 4.37). During the present study it was only registered during autumn (September – November/December) and occurred primarily in high structured habitats (VR type 5). The main threats are eutrophication (oxygen depletion) and loss of habitats.

4.10.2.4 Ballan wrasse (*Labrus bergylta*)

The ballan wrasse is classified as “endangered” in the German Red List (Fricke et al., 1996, 1998) as well as the Baltic as a whole (HELCOM, 2007). No firm data are available to assess its threat status in Danish waters (HELCOM, 2007), but Carl et al. (2004) considers the ballan wrasse a rather rare non-breeder. The western Baltic Sea is the distribution limit for this species. According to Winkler and Schröder (2003), the ballan wrasse is a rare guest in the Baltic. Hence, the occurrence is limited in the Baltic Sea. The main areas of occurrence are rather warmer sea areas (Rui Beja, 1995; Collins et al., 1996). The ballan wrasse was caught in small numbers and only in autumn (September/October) in subarea Fehmarn and Lolland (Table 4.37). Species like corkwing wrasse prefers highly structured habitats. The main threats are eutrophication (oxygen depletion) and loss of habitats.

4.10.2.5 Sea trout (*Salmo trutta*)

The sea trout is classified as “endangered” in the German Red List (Fricke et al., 1996) and as “vulnerable” in the Baltic as a whole (HELCOM, 2007). It was previously classified as “rare” in Denmark (Stoltze and Pihl, 1998), but due to the restocking and nature restoration programme it is no longer considered as a threatened species. During the present study sea trout was only caught in subarea Lolland and Fehmarn. In total, only 18 individuals were caught during several months of surveys. In subarea Fehmarn, the sea trout was caught exclusively during the beach seine net sampling period in May and June (Table 4.37). In contrast to the individuals caught in subarea Lolland, these individuals were juveniles in age-class I. Subarea Lolland and Fehmarn are used by sea trout as feeding grounds and as transit areas during the migration to fresh water areas. The main threats are eutrophication and loss of habitats (spawning and nursery grounds in freshwater), constructions (barriers for migration) and fishery (game fish).

4.10.2.6 Atlantic salmon (*Salmo salar*)

The Atlantic salmon is classified as “endangered” in Germany (Fricke et al., 1996), as “vulnerable” in the Danish red list (DMU, 2011) and as endangered in the Baltic as a whole (HELCOM, 2007). Salmon was only recorded in the gill and fyke net sampling period during the winter months (December to February) in subarea Fehmarn. Overall, only 6 individuals were caught (Table 4.37). In freshwater salmon is classified as an Annex II species in the EU Habitats Directive. Subarea Lolland and Fehmarn are used by salmon as feeding grounds and as transit areas during the migration to freshwater areas. The main threats are eutrophication and loss of habitats (spawning and nursery grounds in freshwater), constructions (barriers for migration) and fishery (game fish).

4.10.2.7 Greater weever (*Trachinus draco*)

The greater weever is classified as “vulnerable” in the German Red List (Fricke et al., 1996) as well as in the Baltic as a whole (HELCOM, 2007). It is considered common and widespread in Danish waters (Carl et al., 2004). Its southern distribution-limit in the Baltic Sea is located in the area near Kattegat. Thus, the occurrence in the Belt Sea is rare (Winkler and Schröder, 2003). During the baseline study it was only registered in subarea Fehmarn and Fehmarnbelt and occurred only sporadically. Overall, 20 individuals were caught (Table 4.37). This species prefers sandy habitats, where they remain buried in the seabed during the daylight hours (Damalas et al., 2010). The main threats are eutrophication (oxygen depletion), loss of habitats and fishery.

4.10.2.8 European eel (*Anguilla anguilla*)

The European eel is classified as “endangered” in the German Red List (Fricke et al. 1996; 1998) as well as the Baltic as a whole (HELCOM, 2007). It is considered “critically endangered" in the most recent Danish Red List (DMU, 2011). On a global scale it is also considered "critically endangered" (IUCN, 2010). Only 17 individuals were caught during the habitat mapping surveys from April to September. The European eel was primarily caught at stations in subarea Lolland (Table 4.37). 12 of the 15 individuals were caught in Hyllekrog at the stations in sandy areas with eelgrass meadows (SZ type 6). However, the European eel is relatively frequent in the area around Fehmarn. The threats for this species vary in the Baltic Sea. Next to the fishery (especially the fisheries on the juvenile life stages – glass eel – off the coasts of Ireland, France and Great Britain), barrier effects (migration) and pollution are also responsible for the decline in their abundance in German waters (Fricke et al., 1996). Eel fishery in the Baltic Sea is focused on different life stages of the eel. In summer, the fisherman focus on the yellow eel and in autumn they focus on the silver eel. The majority of the eel caught were yellow eel. The European eel mainly use the investigated area as a transit area (FeBEC 2009a). See chapter 0 for more detailed account on the species.

4.10.2.9 Painted goby (*Pomatoschistus pictus*)

Painted goby is classified as "threatened migrant" in the German Red List (Fricke et al., 1996; 1998) and as "vulnerable" in the Baltic as a whole (HELCOM, 2007). In Denmark it is known as a rather rare breeder, which has not been recorded east of Gedser (Carl et al., 2004). According to Winkler and Schröder (2003) this species is found regularly in the Baltic Sea. In the present study, only 7 individuals were caught in subarea Fehmarnbelt in February (Table 4.37).

4.10.3 Legal protected species baseline conclusion

The baseline results regarding legally protected species in the Fehmarnbelt area may be summarized as follows:

- None of the relevant Annex II and IV species preferred habitats within the area of Fehmarnbelt and the abundance were insignificant.
- In total, 9 red listed species were observed during the baseline study.
- The most abundant red listed species observed was the sea stickleback.
- Lowest species diversity and abundance of red listed species was observed in subarea Fehmarnbelt (3 species and 30 specimens). Subarea Fehmarn (7 species and 154 specimens) and Lolland (4 species and 205 specimens).
- The abundance of red listed species was in general low.
- The importance of Fehmarnbelt and adjacent areas for international protected species and red listed species (excepted eel – see chapter 0) is listed in Table 4.38.
- Present national or international protected species are per definition of great importance.
- A number of national redlistet species, like the sea stickleback are a member of the shallow water community and issues concerning spawning, nursery and feeding are thus important.
- Other species like sea trout and salmon uses Fehmarnbelt as passage water and issues regarding migration are therefore important. This applies also to the international protected river lamprey and twaite shad.

Table 4.38: Importance of Fehmarnbelt and adjacent areas for international protected species and red listed (excepted eel – see chapter 4.7) in relation to spawning, eggs and larvae drift, nursery, feeding and migration. - = not relevant, blank = not assessed, * not caught in baseline studies, but recently in local waters. ¤Please note, the table only contains redlisted species from the German Red List, except Atlantic salmon which also is listed on the Danish Red List.

Environmental component	**spawning**	**egg-larvae drift**	**nursery**	**feeding**	**migration**	**overall**
International protected species:						
River lamprey					medium	very high
Twaite shad*						very high
European sturgeon*						very high
Redlisted species¤:						
Sea stickleback	high	high	high	high	-	high
Atlantic salmon					medium	high
Sea trout					medium	high
Snake blenny						high
Corkwing wrasse						high
Ballan wrasse						high
Greater weaver						high
Painted goby						high
Autumn spawning herring						high

5. Climate change, fish and fisheries

Climate is always changing and throughout Earth's history the climate has alternated betweenn warm periods and ice. The last 10,000 years have been an interglacial period, characterised by relatively stable temperatures and is called the Holocene. However, the changes within the last century are characterised by an acceleration of temperature increase. Scientist agrees that a significant proportion of these changes are caused by human activity, mainly the increased release of carbon dioxide and greenhouse gas, and that this development will continue in the future (IPCC, 2007). The Intergovernmental Panel on Climate Change (IPCC, 2007) has released a fourth status report in 2007 and has announced the publication of the fifth report end of 2014. They described past global changes and expected future development based on a set of global climate models and different emission scenarios. Changes are regionally very different and climate modelling is able to reveal these regional differences. However, although global models depict these changes, the spatial resolution is low and thus not always exact enough.

Besides a general increase in temperature, both in the atmosphere and the water bodies, changes of the sea level and the salinity are predicted. Where the first is expected to rise in general (Nicholls and Cazenave, 2010), the latter will change very heterogeneous, depending on ice melting and change in fresh water discharge and precipitation (IPCC, 2007).

This chapter will describe observed and predicted changes for the Baltic Sea and the expected effect on the ecosystems, focussing on the fish community. Thus, the spatial resolution of global models might not be sufficient. For the Baltic Sea, the Baltic Sea Experiment (BALTEX), a regional project under the World Climate Research Programme (WCRP), was already started in 1992. This project investigated past climate change in the Baltic Sea region and several regional climate models have been developed to predict future changes. Results from the first phase from 1993 to 2002 have been published 2008 in a comprehensive Report (BACC, 2008).

Prognoses for Germany of possible changes in atmospheric parameters (temperature, precipitation, wind) are provided from the North German Climate Atlas (Norddeutscher Klimaatlas, 2011).

In the next sections, the geographical and climatologically characteristics of the Baltic Sea will be described and the potential changes in the atmosphere and hydrosphere are presented. Statement of absolute values for the prognoses will largely be avoided because uncertainties in the models as well as in the real technological and societal developments for the future (used as basic assumptions in the models) are large. Thus, for the most part, only trends will be reported. Current guideline values can be obtained from the respective internet portals of the described projects.

Changes are normally described as changes in average values. An increase in average temperature makes the occurrence of heat waves, such as the one in the summer of 2003, more likely, but at the same time does not exclude the possibility of extreme cold events (as in 2009/2010).

The main driver for the winter climate in Europe is the pattern of the North Atlantic Oscillation (NAO). The NAO describes the relative difference between the high-pressure area over the Azores and the low-pressure area over Iceland. The index for the winter months (normally December to February) can be used as a climate index for Europe. A positive NAO index (high pressure difference) results in strong west winds in Northern Europe, transporting warm and moist air. A negative NAO index leads to weakening of these westerly winds and results in colder, dryer winter. The prediction of the NAO index beyond a few days, however, is very unreliable making regional climate predictions for Europe very difficult. Moreover, climatic changes in the summer months are even more dependent on regional or even local factors and could not be predicted on scales from days to months. It is difficult to predict the changes in environmental settings in relation to the advancing climate change.

5.1 Global climate models (IPCC models) and regional models

The results and conclusions of the IPCC are based on analyses of twenty different global climate models, coupled to global ocean circulation models which have a spatial resolution of 100 – 150 km. To achieve a better resolution, regional models, using the driving data of the global models, have been developed. Due to the complex parameterization and the lack of some processes, it is still difficult to assess the quality of the projections, and absolute values have to be treated with care.

The most common global models used for and in Europe are ECHAM4/OPYC3 (Roeckner *et al*., 1999) from Germany and HADCM3 (Gordon *et al*., 2000) from Great Britain. For regional predictions in Europe, a set of approximately ten models is commonly used, with HIRHAM (Christensen *et al*., 1996) and RCAO (Döscher *et al*., 2002) being the most prominent ones. A full description of global and regional model used in the Baltic Sea Experiment is given in the BACC report (BACC, 2008).

In order to present the changes modelled, it is common practice to compare the annual average value of a range of years. In most cases the average value for the period 1961–1990 is used as the baseline and compared with the period 2071–2100.

5.1.1 IPCC Scenarios

The aim of the IPCC scenarios is to harmonize the driving data for all models used. The long-term development of anthropogenic emissions is based on highly complex dynamic systems, including demographic development, socio-economic development and technological change and it is thus hard to predict. The IPCC scenarios are equally possible alternative images of the future. In total 40 different scenarios have been used, based on four general storylines of future development. The first storyline was further split into three scenarios, thus a total of six scenarios can be distinguished (IPCC, 2000):

The A1 storyline describes a world with strong economic growth, a global population that will peak in the middle of the century, and rapid introduction of new and efficient technologies. This storyline is further split in three alternative scenarios of energy use, fossil intensive (A1F1), non-fossil energy sources (A1T) or a balanced use across all sources (A1B).

The A2 storyline describes a very heterogeneous world. Population continues to increase, but technological development is regional and slower than in other scenarios.

The B1 storyline describes a world similar to A1, with the same population development, but with a rapid transition towards a service and information economy with the introduction of clean and resource efficient technologies, but no additional climate initiatives.

The B2 storyline describes a world with moderate population growth, intermediate levels of economic and technological development, focusing on local and regional solutions. This scenario is oriented towards environmental protection and social equity.

To illustrate the consequences of the different scenarios, the projected change in global average temperature for each scenario is presented in Figure 5.1.

For the models and projections used in the present text, the emission scenarios A2 and B2 are primarily employed.

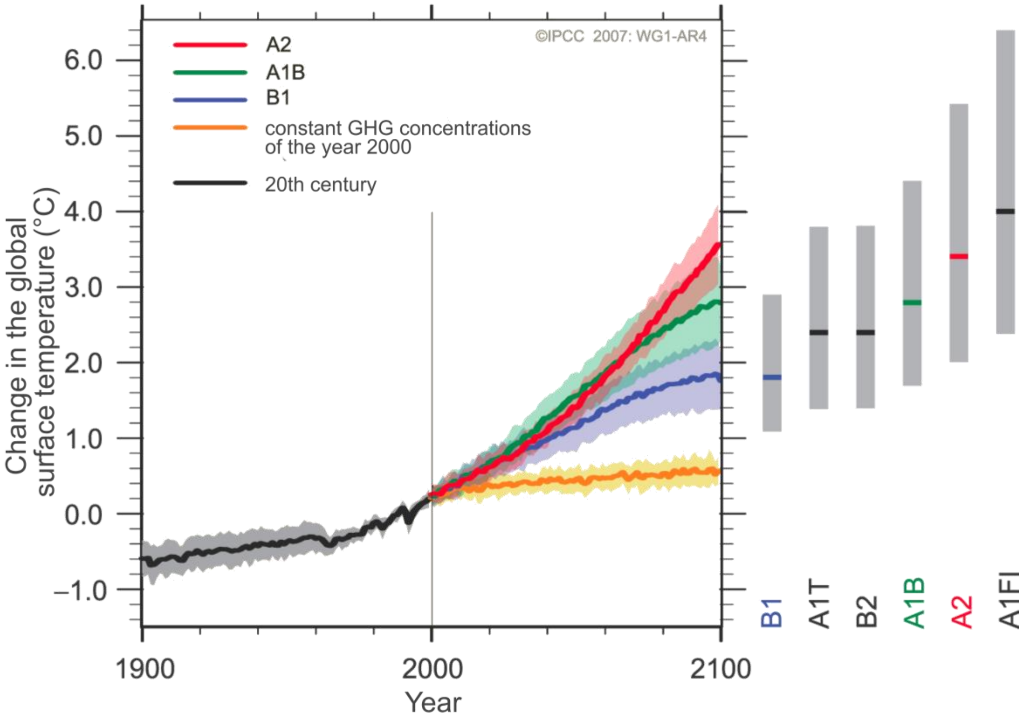


Figure 5.1: The solid lines represent the average results for various models of the global average temperature (with respect to 1980–1999) for the scenarios A2, A1B and B1 as a continuation of the modelling of the twentieth century. The shaded areas indicate plus/minus one standard deviation from the average of all model calculations for the respective scenario. The coloured bars on the right side represent the best estimates (grey bar = probable area) from the modelling runs on the left, as well as independent models and observation limitations. Source: IPCC (2007).

5.2 The Baltic Sea Area

The Baltic Sea is one of the largest brackish water areas of the world and is located in the northern temperate zone, embedded in the Northern atmospheric circulation system, with predominantly westerly winds. However, the region is not homogenous as two distinct climate types may bedistinguished. The largest part of the central and the northern area belongs to the continental temperate climatic zone, characterised by long and cold winters, with the mean temperature of the warmest month not lower than 10°C and that of the coldest month not higher than −3°C. The southern area belongs to the oceanic climate climatic zone, characterised by persistent westerly winds, and relatively mild, wet winters.

The bathymetry of the Baltic Sea is characterised by broad, shallow coastal areas and an array of deep basins. The connection between the Baltic Sea and North Sea is by several shallow and narrow straits with Fehmarnbelt being the southernmost one of them. Fehmarnbelt connects the Kiel Bight in the West with the Great Belt. The deep basins form a series of interlinked trenches from southwest to northeast, separated by shallow channels. These basins are namely the Arkona Basin, the Bornholm Basin, the Gdansk Deep, the Gotland Basin with the Landsort Deep at its northern most edge (459 m), and the Bothnian Sea. This morphology determines the general hydrology of the Baltic Sea. The river runoff and the precipitation lead to a freshening of the surface water, resulting in a horizontal salinity gradient from southwest to northeast, from almost marine conditions of 25 psu in the Kiel Bight to nearly freshwater conditions of less than 2 psu in the Gulfs of Bothnia and Finland. The constant freshwater inflow results in the discharge of 940 km3 brackish water/year to the North Sea. Occassionally, the Baltic Sea is subject to salt water intrusion from the North Sea. However, larger inflows, able to propagate through the deep basins, are less common. Strong inflows take place only under certain combinations of wind and water conditions. The inflow events have been quite regular, at least every fifth year, until the second half of the last century, but during the last decades it have been less common. The last two major inflow events were in 1993 and 2003.

The fresh water inflow at the surface and the saline water inflow in the deep also lead to a distinct vertical layering of water masses and permanent halocline in the basins. In summer, additionally a thermocline develops, which dissolves in autumn with wind driven mixing of the surface layer. This wind induced mixing is however not strong enough to ventilate the water body under the permanent halocline. Biogeochemical processes in the deep basins consume the dissolved oxygen and result in oxygen depleted zones, which sometimes lead to the formation of hydrogen sulphide. These water masses can only be renewed by inflow of North Sea water.

5.3 Specific changes in the recent past and predicted future development in the Baltic Sea

5.3.1 Atmosphere

Atmospheric CO_2 has increased considerably during the last century. CO_2 is a potent greenhouse gas and thus most likely contributes to the warming of the atmosphere and consequently of land and water masses.

The global increase in average air temperature during the last century has been recorded in the Baltic Sea. The increase of 0.08°C per decade was even higher than the global average of about 0.05°C per decade (IPCC, 2007). From 1871 to 2004 the increase was around 0.85°C (Figure 5.2). A steady warming at the beginning of the time series was followed by decreasing temperatures at the end of the 1930s, but from the 1980s onwards the increase was pronounced.

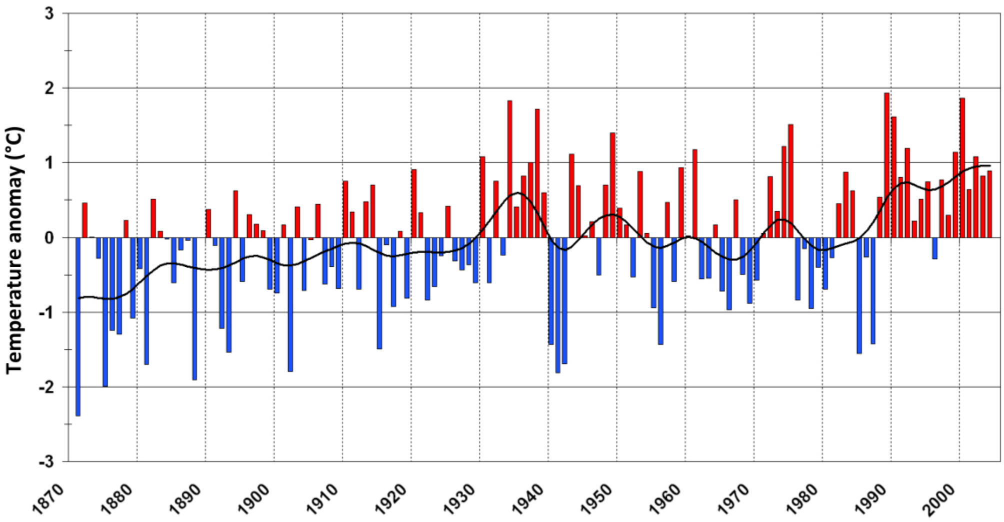


Figure 5.2: Air temperature anomalies over the Baltic Sea. The line is the five year running average. Source: BACC (2007).

Predictions from global models show an average year-round increase in temperature (as the difference between the average values of the periods 1961–1990 and 2071–2100) of 3-5°C. Regional models show a higher increase of 3-8°C in the northeast compared to the southwest (2.5-6°C). However, these models also show a large variability between runs, still indicating a high uncertainty. For example, a range of 1-10.5°C in spring is estimated (Meier, 2006).

Transport of air masses, and therefore wind and precipitation, dependent on the pressure areas over Europe and are thus closely linked to the North Atlantic Oscillation (NAO). A shift from negative to positive index values within the last 50 years resulted in an increase in wind intensity in winter (Hurrel and van Loon, 1997). Prediction of the NAO is hardly possible and thus a prediction of changes in wind strength is highly uncertain. Nevertheless a further increase, at least in the winter months, is supposed to be more likely than a steady state or even a decrease (Räisänen et al., 2003).

Furthermore, the close relation between the humidity of the air and the NAO makes the prediction of long-term trends very uncertain. The average annual precipitation in the Baltic Sea region is 750 mm. Lower values are observed over the sea and the north and northeast. A global increase of the average precipitation is assumed to be more likely as increasing temperatures will intensify the hydrological cycle. This will also result in larger differences between arid and humid areas, as the increase in humidity is more likely. Therefore, the already more humid southern Baltic Sea is supposed to face increasing precipitation in the winter month. The likelihood of extreme precipitation events might also increase (Christensen and Christensen, 2004).

5.3.2 Changes in the hydrosphere

Average water temperatures in the southwestern Baltic region do not show a clear trend from 1965–2008, neither at the surface nor in 40 m depth. The overall variability shows year-to-year differences of up to 4°C, within the range of 9°C to 16° at the surface and 3°C to 10°C in 40 m depth, indicating a highly variable environment (Figure 5.3). Predictions based on IPCC climate scenarios are in the range of 2°C to 4°C, as the difference between the average annual temperatures of the periods 1961–1990 and 2071–2100. It is expected that the increase will be larger in the northeastern area (Omstedt and Axell, 2003; Döscher and Meier, 2004), where particularly the winter months might be warmer and a decrease in ice coverage is likely (Meier, 2006).

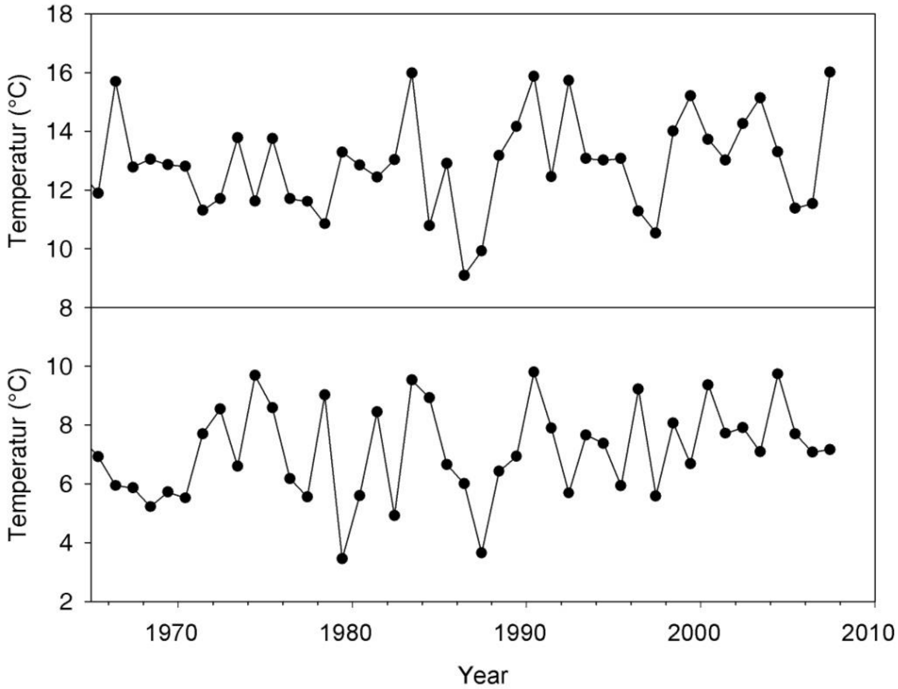


Figure 5.3: Water temperature in June for the southwestern Baltic Sea; upper panel surface, lower panel in 40 m depth. Please note the different scales. (Data from ICES oceanographic database).

Salinity in the Baltic Sea is mainly driven by fresh water input from rivers and precipitation at the surface and the inflow of high saline North Sea water in the deep. This difference results in the development of a permanent halocline in the deep basins. A long term strictly positive or negative trend was not observed in surface salinities, although a temporary drop in deep water salinity was observed locally (Figure 5.4). Pronounced year-to-year fluctuations are related to inflow events from the North Sea (Figure 5.5). These inflow events are the result of complex multiple factors and the prediction of these events is hardly possible. The frequency of these events, however, has dropped considerably since the last three decades and the last two major inflows have been 1993 and 2003. Precipitation and river runoff are predicted to increase in the future and thus a general decreasing trend of surface salinity is likely, but cannot be quantified reliable. Some models predict a decrease in salinity of up to 50%, whereas others indicate only a minor decrease (Meier et al., 2006; Omstedt and Axell, 2003) or even an increase (Hansson et al., 2010).

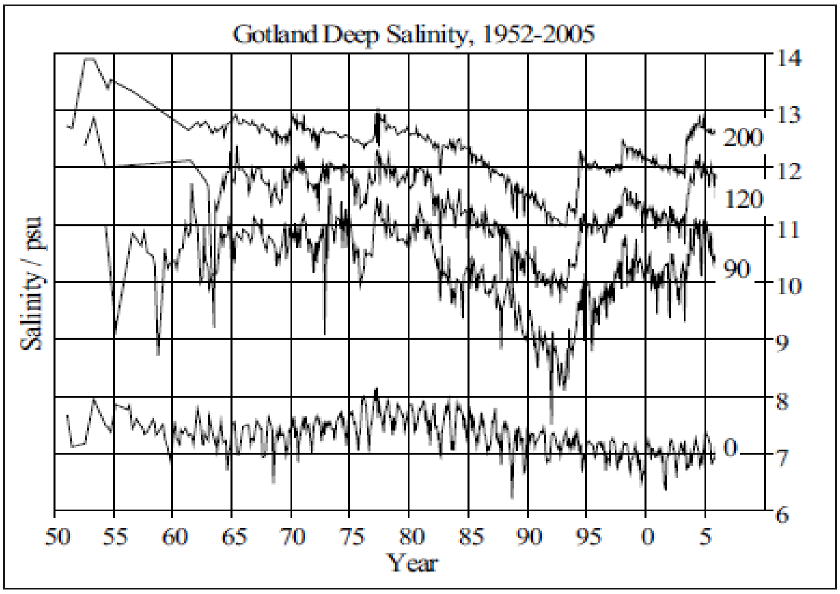


Figure 5.4: Observed salinity in the Gotland Basin at 0, 90, 120, and 200 m water depths from 1952 to 2005. Source: Feistel et al. (2008).

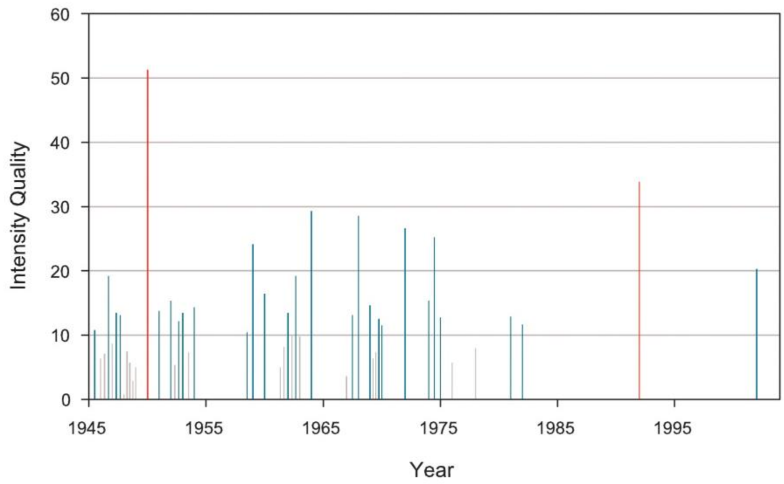


Figure 5.5: Relative intensity of inflow of North Sea water into the Baltic Sea. Source: Schinke and Matthäus (1998).

The permanent halocline in the deep basins prevents the mixing of the upper and lower water masses and thus the vertical exchange of oxygen. Due to biogeochemical processes at the bottom, the dissolved oxygen is reduced and sometimes even totally consumed, creating oxygen depleted areas with hydrogen sulphide (Fonselius and Valderrama, 2003). Oxygen depleted zones are not restricted to the deep basins. In near-coastal shallow waters a stable thermocline develops in spring due to increase in surface temperature and together with anthropogenic eutrophication resulting in high biological productivity and oxygen consumption, which also results in extensive low oxygen zones. These oxygen depleted zones can be extensive (Figure 5.6) and have an extensive effect on the ecosystem. It is assumed that future increase of temperature in summer together with decreasing wind intensities will lead to an increase of oxygen depleted zones in near-coastal areas (Kauppila et al., 2003). However, the inflow of North Sea water and the future level of eutrophication can hardly be predicted and thus the level and spatial extend of future depleted zones remains unclear. Eutrophication might increase when extreme precipitation events increase the river runoff and the input of nutrients.

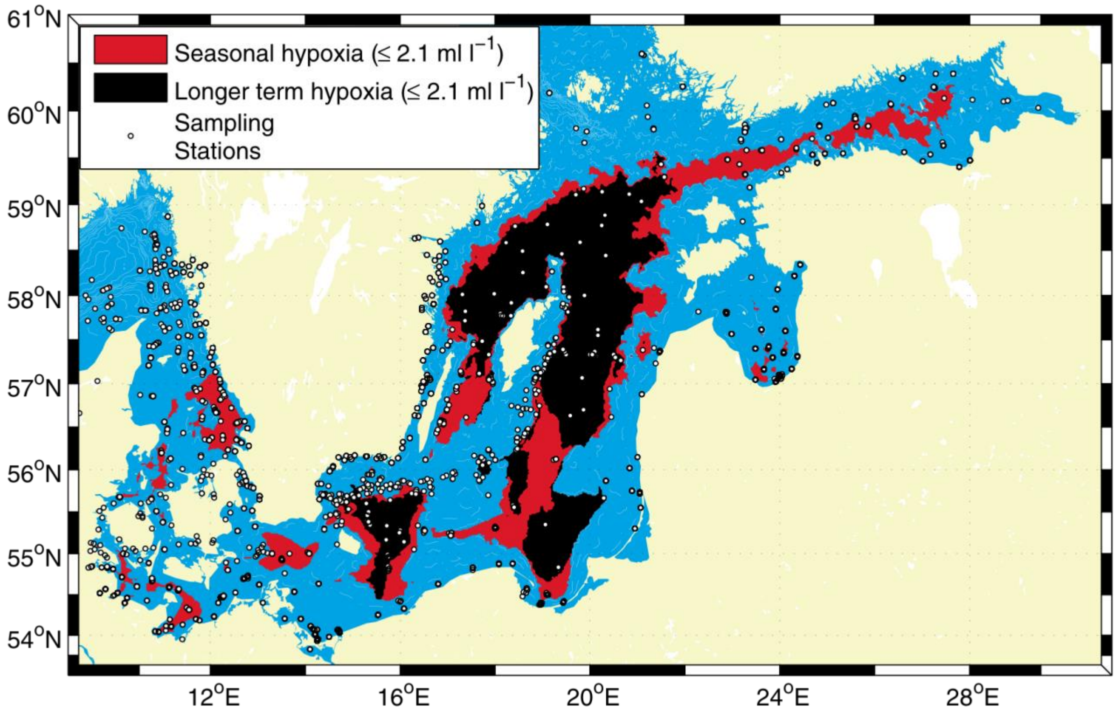


Figure 5.6: Extent of seasonal hypoxia (red) and long-term hypoxia (black) during 2001–2006. Source: HELCOM (2009).

Carbon dioxide does not only contribute to global warming. During the last century, the world's oceans have absorbed approximately half of the anthropogenic produced CO_2. The consequence was a drop in the pH value of the surface water of around 0.1 units (Hjalmarsson et al., 2008). With continuing emission of CO_2 this decrease is expected to continue. The total level of the pH and seasonal as well as inter-annual fluctuations differ largely between areas, even within the Baltic Sea. In the Gotland Basin a seasonal fluctuation of 0.8 units (from 7.8 to 8.6) was observed from 1994 to 2007, with only minor year-to-year fluctuations and without a long-term trend (Omstedt et al., 2010). Although an average decrease of pH values could be expected over the long term, quantitative estimates are uncertain.

Thermal expansion and melting of ice on land causes an increase of global sea-levels. The rise will not be uniformly distributed, but locally very different (Nicholls and Cazenave, 2010) and a reliable prediction is currently very difficult due to numerous interactions between the open ocean, marginal seas and the land and ice masses.

5.3.3 Impact of climate change on the marine environment

Abiotic changes in the marine environment have direct and indirect effects on the biota. Physiological, morphological or behavioural changes of individuals will spread through the population to the ecosystem and vice versa (Figure 5.7) (Harley et al., 2006). Thus, complex changes in the system from the basis of the food web to fish and the dependent fishing industry can be expected. Changes will have an effect on productivity, i.e. primary production and subsequently secondary and tertiary, through direct de- or increase, or change in timing (phenology), on distribution and thus on species and ecosystem composition (biodiversity).

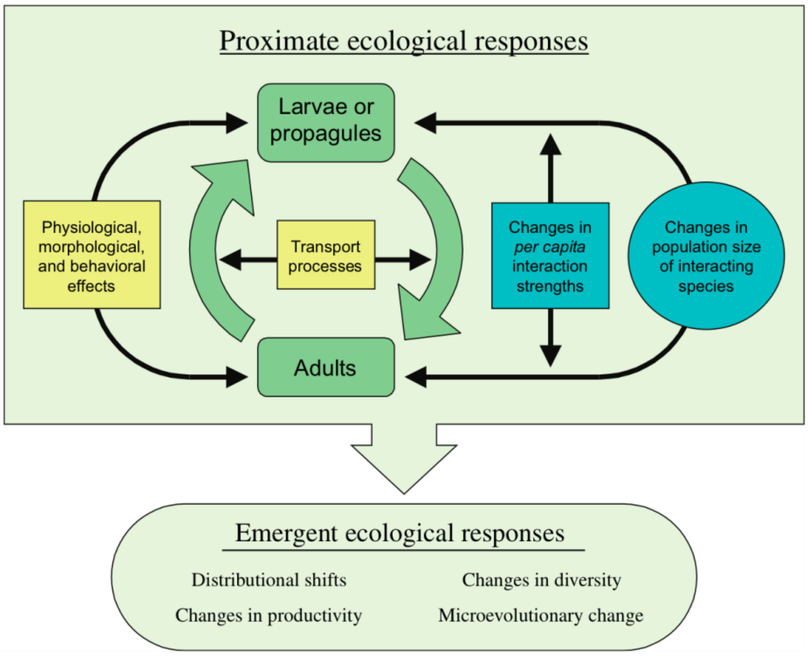


Figure 5.7: Potential ecological reactions to climate change. Source: Harley et al. (2006)

The effect of global warming on primary production is already manifold. Behrenfeld et al. (2006) have reported a decline in global productivity, which might be linked to regional strengthening of stratification of the water column, and a subsequent reduction of upwelling of nutrients. This reduction will not be uniformly distributed global and even an increase might occur regional. Especially the northern latitudes will most likely experience an increase due to reduction in ice coverage and a prolongation of the growth period (Arrigo et al., 2008). Europe might experience an increase in wind and thus a coastal upwelling with increased coastal primary production (Dickson et al., 1988). Another factor, which will be influenced by warming, is the timing of peak production in spring, i.e. change in the phenology, which was already found to be moved forward in time (Edwards and Richardson, 2004). The uptake of carbon dioxide and the increase in pH will also affect primary production, but the overall effect, however, is difficult to assess as experiments show contradicting results, depending on the setup, i.e. single species or multispecies experiments and level of CO_2 concentration (Doney et al., 2009). Many experiments have shown the detrimental effect of increased carbon dioxide uptake of seawater on calcifying organisms (Hall-Spencer et al., 2008).

Secondary production, i.e. zooplankton, will also be influenced directly via physiological consequences of warming and acidification, but also through changes in timing and spatial distribution of their prey, resulting in changes in plankton abundance, community structure, the timing of seasonal abundance and their geographical range (Hays et al., 2005). One prominent example is the shift in total abundance of two Calanus species in the North Sea and the change in their relative contribution (Figure 5.8), which likely affect cod recruitment (Beaugrand et al., 2003). The different response to climate signals within different functional groups and trophic levels has already led to a change in synchrony of timing between primary, secondary and tertiary production in the North Sea (Edwards & Richardson, 2004).

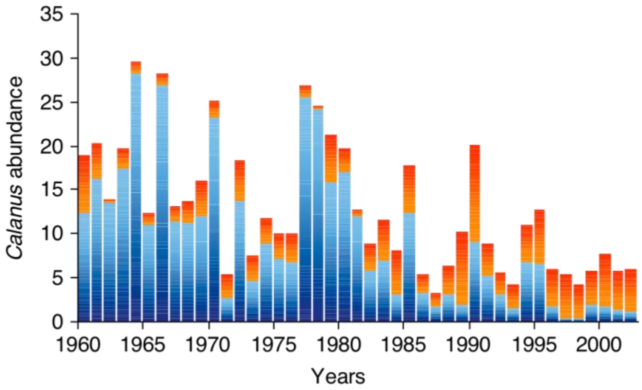


Figure 5.8: The abundance of two Calanus species in the North Sea and their relative contribution per year; blue – *Calanus finmarchicus*, red – *Calanus helgolandicus*. Source: Hays et al. (2005)

The changes in primary and secondary production have a secondary effect on fish recruitment via the food web. Already in 1914 Hjort recognized that the interannual fluctuations in cod recruitment were related to the timing of the production of the food for larval fish. Cushing (1990) proposed the temporal match/mismatch hypothesis referring to climate-induced coupling/decoupling of these phenological relationships.

Although changes in a wide variety of abiotic and biotic variables affects fish, the major factor will most likely be temperature, since most fish are thermal conformers and their body temperature is effectively that of the ambient water (Jobling, 1997). Thus, a change in ambient temperature might lead to expansion of the geographical range or displacement. Perry et al. (2005) has reported shifts in boundaries of 60 North Sea fish species. The change was most pronounced in blue whiting with a northward shift of around 800 km. The migration of southern species like sardines and anchovies into the North Sea (Alheit and Hagen, 1997) and a displacement of water masses can lead to a change in the species assemblages (Ehrich et al., 2009).

Many species are heavily exploited, and the effect of increased water temperature on fluctuations in abundance remains uncertain and speculative, and a distinction of direct causal relations between environmental temperature and distribution pattern is difficult (Jensen, 2003). Maravelias and Reid (1995) and Misund et al. (1998) showed the influence of water temperature and salinity on the migration of herring, but both argue that the impact also could be indirect through a shift in the prey availability. The changes could affect even different populations of the same species. Drinkwater (2005) shows the influence of temperature on recruitment of several stocks of Atlantic cod, as well as the extension of the geographical range off Greenland from 1900 to 1930 (Drinkwater, 2006).

Furthermore, the ability and speed at which fish and planktonic communities can genetically adapt to regional climate warming is not known (Hoepffner et al., 2006). Möllmann et al. (2005) have described relationships among climate, copepods and pelagic fish growth in the Baltic Sea (Figure 5.9). Herring condition resulted from a combined effect of changes in the feeding environment for herring and increased competition with sprat, while sprat condition appeared to be primarily determined by intraspecific competition.

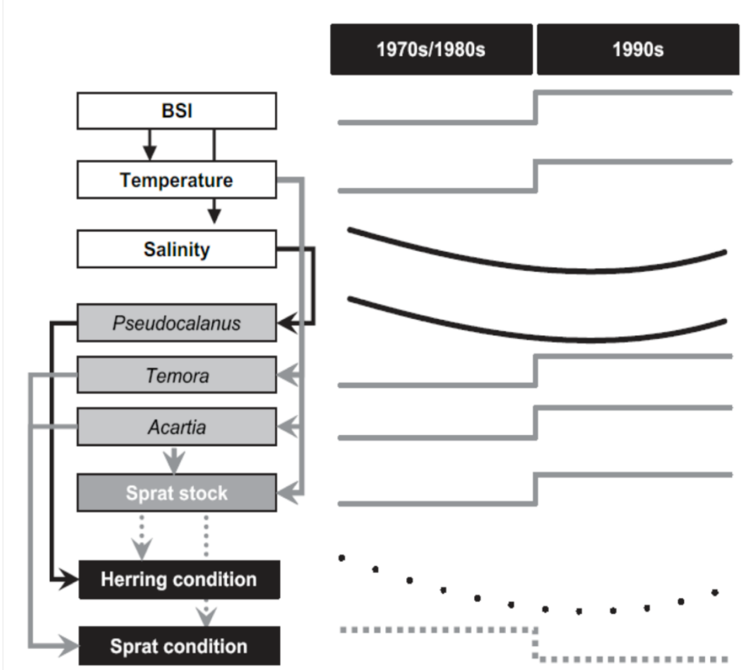


Figure 5.9: Schematic description of relationships among climate, copepods and pelagic fish growth. Left panel: Relationships among variables; right panel: Resulting idealized time-trends; grey lines and arrows represent temperature-driven processes, black lines and arrows represent salinity-driven processes. Source: Möllmann et al. (2005). Abbreviation: BSI – Baltic Sea Saltwater Intrusion.

5.3.4 Invasive species

Biological invasion has become one of the major elements of global change, altering biodiversity and function of natural ecosystems, causing significant economic damage. Invasions in both terrestrial and aquatic systems have shown that successful introductions of exotic species may render previously stable systems unbalanced and unpredictable. However, only a limited number of exotic species are able to establish and adapt to the conditions of recipient ecosystems. The success of establishment and the consequences of invasions are difficult to predict because of the role environmental variability plays in determining the outcomes of invasion (Helmuth et al., 2006). Climate changes directly affect system specific attributes and therefore act as a filter to modulate the risk of and responses on invasion.

Until now, it is believed that no new marine fish species were introduced in the North-East Atlantic and adjacent seas (Nehring, 2003). Nevertheless, in the freshwater systems almost 70 non-native species have been introduced, mainly intentionally, during the last century. Nehring hypotheses further, that although no new marine species have been established in northern waters, southern species that had been found seldom in the past have increased. For the Levantine Sea (south-east Mediterranean) over 60 fish species of Indo/Pacific origin have been introduced due to the opening of the Suez Canal and some of them have already replaced native species (Goren and Galil, 2005). Although this area has no direct effect on European fisheries, it shows how dramatically a species shift can alter an ecosystem.

Several warm fish species have invaded cold water ecosystems and cold species, which used to be relatively abundant in warm water ecosystems have become very scarce or have disappeared (Alheit and Hagen, 1997; Perry et al., 2005). Shifts have been shown in several cases (Bombace, 2001; Dulcic et al., 1999; Francour et al., 1994). However, since the considered species are often heavily exploited, the establishment of direct causal relationships between temperature and distribution pattern is difficult (Jensen, 2003). Reliable prognoses on the probable development of fish stocks due to climate change effects are only possible for some intensively investigated species e.g. Atlantic cod (Drinkwater, 2005). Separation from other impact factors is difficult.

Prominent examples of invasive species in the Baltic Sea range from phytoplankton, *Prorocentrum minimum* (Hajdu et al., 2000), jellyfish, *Mnemiopsis leidyi* (Javidpour et al., 2006), cladocerans, *Cercopagis pengoi* (Ojaveer and Lumberg, 1995) and fish, *Neogobius melanostomus* (Skora and Stolarski, 1993). HELCOM (2011b) has stated that "Over 120 non-native aquatic species have been recorded in the Baltic Sea to date, and around 80 of these have established viably reproducing populations in some parts of the Baltic" (Figure 5.10).

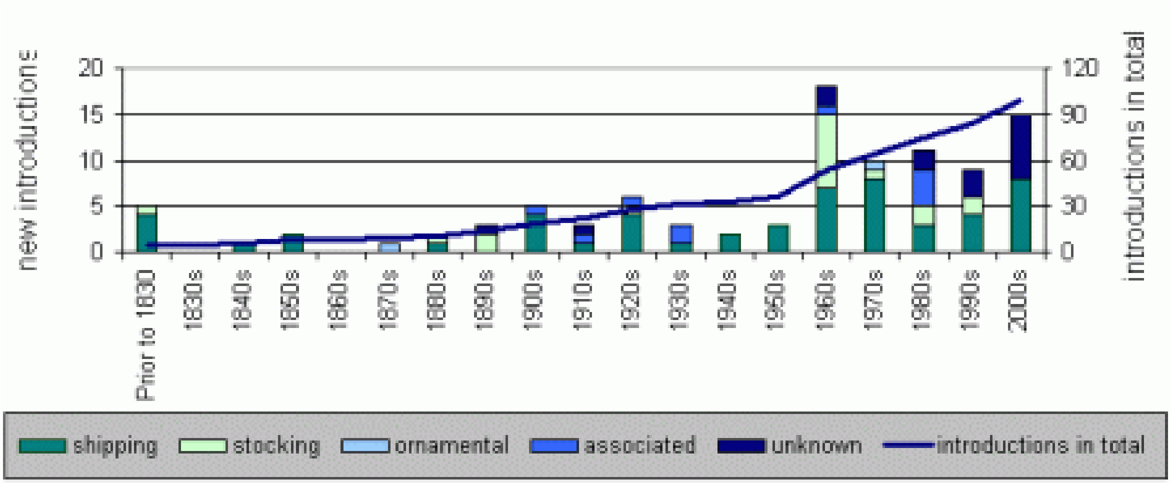


Figure 5.10: Introduction of new species into the Baltic Sea. HELCOM (2011b)

5.3.5 Economic implications for industrial fishery

Climate change can have severe economic implications on industrial fishery. Some estimation indicated (with a low level of confidence) that global marine production might increase but not more than 10% during the period until 2050 (Sarmiento et al., 2004). In contrast, observations from satellite and large-scale plankton samplings have shown declines in phytoplankton and chlorophyll during the last 20-50 years (Brander, 2010). Assuming that commercial fishery is directly linked to marine production, an increase or decrease in productivity of 10% would result in an economic gain or loss of more than € 200 million (Clemmesen et al., 2008). It is, however, difficult with the current state of knowledge to make quantitative predictions of changes in global marine production due to climate change because of the large numbers of interactions occurring. For example, a decrease in one species is likely accompanied by a corresponding increase of another species and the effect will not occur equally, but with great regional differences.

5.4 Specific impact on cod, sprat and herring

5.4.1 Cod

Climate-driven changes in environmental conditions may influence cod populations directly (e.g. growth, distribution) and indirectly (e.g. changes in food and predators, and the drastic decline in the eastern Baltic cod stock since 1980s has been related to a climate-driven reduction in reproductive success in combination with increasing fishing pressure (Köster et al., 2003a). World-wide, a large amount of knowledge has been gained concerning such effects (mainly temperature increase) and the impacts on cod populations.

Temperature change has been shown to influence the distributional range of a population (Drinkwater, 2005), spawning time (Kjesbu et al., 2010), as well as spawning sites (Sundby and Nakken, 2008). On a smaller spatial scale, habitat preference and behavior are influenced (Schaber et al., 2009). Large-scale climate signals (here: NAO) have been linked to cod recruitment (Brander, 2005; Stige et al., 2006). The outcome of temperature increase on individual growth (Brander, 2010) or population growth (Mieszkowska et al., 2009) is population-specific. Cod stocks living at the upper limit of their thermal tolerance range most probably experience decrease in growth and stock production rates (Bjornsson and Steinarson, 2002). Temperature change has also geographical explicit effects on cod recruitment. Populations located further to the north of the distributional range will likely benefit from temperature increase, while the southernmost populations (like Baltic cod) probably will suffer (Mantzouni and MacKenzie, 2010; Drinkwater, 2005). However, repeated phases of temperature increase have not always produced the same signal in population growth rates (Drinkwater, 2009).

Indirect effects of climate change act by changing the trophic structure and have been reported as temperature-dependent changes in larval food supply (Walkusz et al., 2011; Beaugrand et al. 2003; Beaugrand and Kirby, 2010) or altered predation rates due to predator-prey overlap (Kempf et al., 2009).

Due to the special hydrographic situation, climate change in the Baltic Sea poses some special challenges to cod. Contrary to other cod stocks, living in areas where salinities are sufficient to keep eggs buoyant in the surface layer, in the central Baltic cod eggs occur exclusively in the intermediate and bottom water, concentrating in a narrow depth range within or below the halocline (Kändler, 1944; Wieland and Jarre-Teichmann, 1997). Thus, the Baltic cod stock is subjected to a clear environmental influence on reproductive success during the egg stage based on oxygen conditions in the spawning basins (e.g. MacKenzie et al., 1996b). Baltic cod eggs are also subject to predation as high abundances of eggs are found in a relatively restricted area where they are heavily preyed upon by herring and sprat (Köster and Möllmann, 1997). The duration of the egg stages are temperature dependent (Wieland et al., 1994) and changes in ambient temperature will therefore cause changes in predation mortality. A few days after hatch, the larvae begin vertical migration through the halocline into less saline, shallower water layers to feed (Grønkjær and Wieland, 1997). Here they are subject to climate-driven changes in food supply and transport rates.

Distributional range as well as spawning sites of the adult stock is largely fixed in the semi-enclosed Baltic Sea, as spawning is restricted to the deep basins. However, small-scale changes in habitat choice are likely to occur (Schaber et al., 2009). Individual growth might be hampered, as consumption is decreasing with predicted decreases in mean ambient oxygen levels (Teschner et al. 2011). If food supply for adults increases as a result of indirect climate effects, the amount and quality of eggs produced might increase (Kraus et al., 2002). The seasonal timing of spawning can be influenced by either direct (Wieland et al., 2000) or indirect effects (Tomkiewicz et al., 2009).

Baltic cod eggs need a minimum of 2 ml/l oxygen for successful development (Nissling et al., 1994; Wieland et al., 1994). Further, a minimum salinity of 11 and 15 psu is needed for activation of spermatozoa and sub-sequent fertilization of eggs of eastern and western Baltic cod, respectively. Declining salinities and oxygen concentrations under anticipated climate change will therefore cause increased egg mortality. Furthermore, it will indirectly increase egg predation by clupeid fish (Köster et al., 2005) through stronger predator-prey overlap. Reduced egg developmental times under higher temperatures will probably not fully counteract this effect. Less frequent inflows of North Sea water will favour spawning of the eastern Baltic cod in the Bornholm Basin, due to frequent anoxic conditions in the spawning layer at the other spawning sites (e.g. Bagge et al., 1994; MacKenzie et al., 2000).

Cod larvae might increasingly suffer from food limitation, caused by the decline in abundance of their main prey (Voss et al., 2003) the copepod *Pseudocalanus acuspes* (Köster et al., 2005; Hinrichsen et al., 2002), as the abundance of this oceanic copepod is strongly correlated with salinity levels (Möllmann et al. 2003b). On the other hand, rapid larval transport to the coast is beneficial for survival (Hinrichsen et al., 2001; Voss et al., 1999) and thus recruitment strength. As transport mainly is wind-driven, higher wind speed associated with climate change will benefit recruitment. Cod juveniles will probably experience lower food abundance and smaller areas suitable for settlement (Hinrichsen et al., 2009).

In summary, climatic conditions in the past decade, as well as predicted climate changes are predominantly thought to be detrimental for Baltic cod recruitment strength and stock productivity, although some counteracting factors exist. Determining the relative contribution of overfishing and climate variability in causing the stock decline in the late 1980s is difficult (Figure 5.11; Eero et al., in press; Lindegren et al., 2010a). A healthy stock structure (Casini et al., 2008; Ottersen et al., 2006), sufficiently high stock size (Lindegren et al., 2010b) and the implementation of an adaptive management system, taking climate change into account (Lindegren et al., 2009, Lindegren et al., 2010b), will help to reduce negative effects of climate change on Baltic cod.

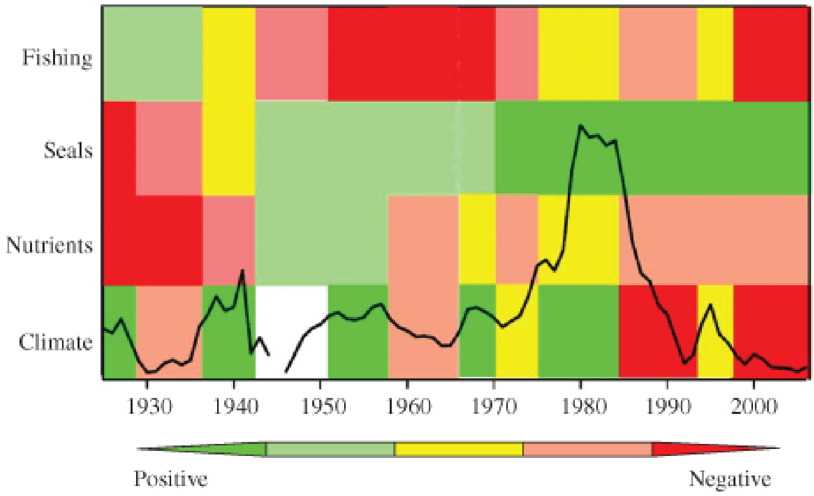


Figure 5.11: Factors affecting spawning stock biomass of eastern Baltic cod (solid line) from 1925 to 2006. The colors represent the influence (positive–negative) of different factors on cod biomass. Source: Eero et al. (2011).

5.4.2 Sprat

Baltic sprat is an ecologically important pelagic fish species (Rudstam et al., 1994; Kornilovs et al., 2001), being both a key prey species for top predators (e.g. cod and harbour porpoise) and predator on zooplankton and fish eggs (Arrhenius and Hansson, 1993; Bagge et al., 1994; Köster et al., 2003b). At present, sprat also represents the most abundant, commercially-exploited fish species in the Baltic Sea (ICES, 2010c). During the previous two decades, the management of Baltic sprat has been challenged by large stock fluctuations mainly caused by highly variable recruitment success. These recruitment fluctuations are not fully explained by sprat spawning stock biomass (Köster et al., 2003a; MacKenzie and Köster, 2004) but appear to be driven by a number of interacting environmental drivers. These environmental drivers are subject to climate change. Baltic sprat represents an example of a species occurring at the northern boundary of the geographical distribution (Muus and Nielsen, 1999) and is therefore especially vulnerable to cold temperatures. Sprat is adapted to marine environments, thus low salinity and associated oxygen conditions in the brackish Baltic Sea also can be critical. Finally, variable transport of passively drifting of early life stages is important.

Baltic sprat stock productivity has been linked to large scale climate variability (North Atlantic Oscillation, NAO), suggesting that winter-time NAO is coupled to temperature conditions in the Baltic (Mackenzie and Köster, 2004). Furthermore, temperature conditions have been shown to be positively correlated with recruitment strength. In recent years, more detailed, process-orientiated knowledge has been gained. This forms the basis to explore the effects of potential changes in climate-driven, environmental forcing on different sprat life stages.

The horizontal distribution of the adult stock component is variable between seasons and years (ICES, hydroacoustics). Only the far north-eastern part of the Baltic is in general avoided, due to extreme low salinity (Aro, 1989). Additionally, low temperatures as well as low oxygen levels limit the distributional range of adult sprat (Stepputtis et al., 2011). Increasing river run-off, leading to lower salinities in the north-eastern Baltic, or decreasing oxygen conditions due to less frequent inflows of North Sea water will therefore diminish suitable sprat habitat distribution or change the relative horizontal distribution. Climate-driven temperature change will influence spawning time. Cold winters in the Baltic delay peak spawning (Grimm and Herra, 1984; Karasiova, 2002), under climate change such events will most likely be less frequent. Stock reproductive potential is assumed to increase under increasing temperatures. This is due to anticipated better adult growth (Grauman and Yula, 1989; Parmanne et al., 1994) and condition, as higher temperatures are leading to higher abundance of suitable prey (Dippner et al., 2000; Möllmann et al., 2000). Furthermore, batch fecundity is positively correlated with food abundance in other small pelagics (Somarakis et al., 2004; Ganias, 2009), as observed for Baltic sprat (Haslob H, IFM-GEOMAR Kiel, pers. comm.).

Survival of the eggs is influenced through climate change by (i) direct impacts on mortality and (ii) through changes in egg developmental time or egg buoyancy.

Direct impacts on egg mortality due to salinity levels are presently still difficult to assess. The salinity of water experienced during egg fertilization might affect mortality in this life stage both directly, i.e. by setting a lower boundary for successful egg development, as well as indirectly, i.e. by influencing egg specific gravity and the depth of neutral buoyancy (Petereit et al., 2009). Egg incubation salinity had no impact on the development rate of eggs and thus does not influence predation risk by changing the duration of the egg stage. Climate-induced changes in salinity will therefore only have limited impacts on egg survival (Petereit et al., 2008).

Egg survival will be lower at oxygen concentrations of <2 ml/l (Nissling et al., 2003). According to the seasonal changes in vertical distribution (Nissling et al., 2003), eggs are in general more affected by potential low oxygen concentrations in spring. Using average conditions during peak spawning for a 30-year period (1970-2000) the relative importance of temperature and oxygen conditions was evaluated (Nissling et al., 2003). Results suggested that variability in temperature was the most important abiotic factor affecting egg survival in the Bornholm Basin (ICES SD 25), that mainly oxygen conditions determine the survival rate in the Gotland Basin (ICES SD 28), whereas variation in both factors influenced survival in the Gdansk Deep (ICES SD 26).

Ambient temperature strongly influences the duration of the stages of sprat eggs with increasing temperature resulting in more rapid egg development rates. Besides this indirect influence on mortality, laboratory studies indicated a pronounced direct impact of temperature on egg mortality, with lower mortality at higher temperature (Thompson et al., 1981; Nissling, 2004, Hinrichsen et al., 2007). Temperature-recruitment correlations based on 30 years of observations confirmed the impact of water temperature during the egg stages on sprat recruitment. For depth-month combinations in which sprat eggs typically occur, significant and positive correlations were detected between temperature and recruitment (Baumann et al., 2006a).

Strong positive correlations were observed between recruitment and temperature within surface waters during summer. This indicates a pronounced impact of temperature also on survival of larval/juvenile sprat that inhabit these water masses, presumably due to temperature-induced changes in growth rates (Baumann et al. 2006b,c). The relative importance of temperature for growth tends to decline with increasing fish size (Günther, 2008). However, temperature is inextinguishable linked to availability of food, and both factors simultaneously influence growth rates in the field. Availability of suitable food for sprat larvae and juveniles (Dickmann et al., 2007) is likely to increase with temperature increase (Möllmann et al., 2009). Only stronger, wind-driven transport rates might counteract the combined positive effects of increasing temperature and food availability under climate change. Increased transport to coastal areas is detrimental for recruitment success (Baumann et al., 2006a). Most recent environmentally sensitive stock-recruitment models therefore include temperature and a transport index (Bottom depth anomaly BDA; ICES, 2010f; Figure 5.12). Depending on relative change in these factors, long-term effects will be positive or negative.

Overall, present process understanding points to predominant positive effects of anticipated climate change on Baltic sprat stock dynamics and associated possible exploitation levels.

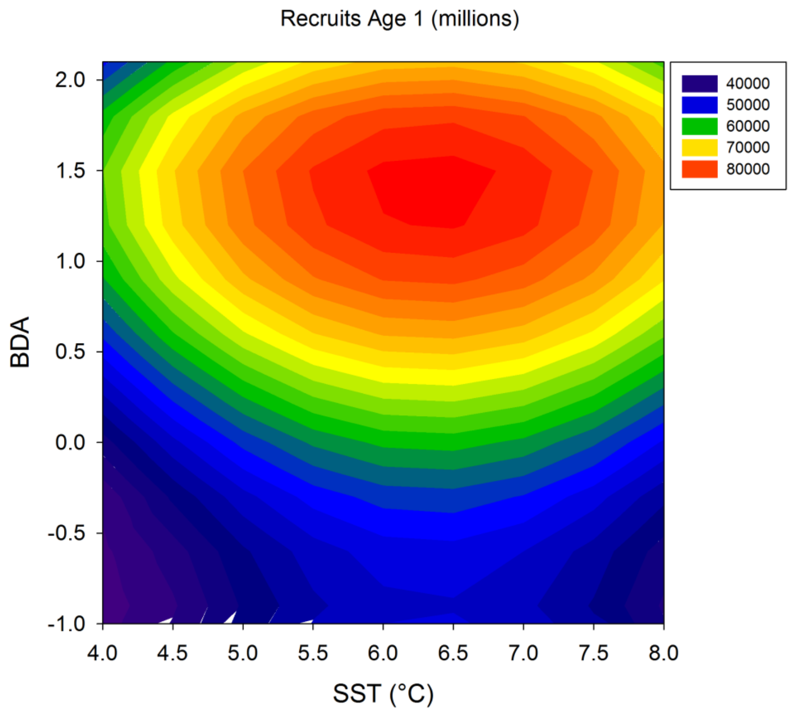


Figure 5.12: Sprat recruitment under climate change; number of recruits (age 1) in dependence of sea surface temperature in May (SST) and bottom depth anomaly (BDA, representing larval drift) for a fixed spawning stock biomass.

5.4.3 Herring

Herring is a key species in many temperate marine ecosystems (Blaxter and Hunter, 1982). As sprat, it forms a major link between top-predators (e.g. seals, cod) and zooplankton production (Casini et al., 2004). In the Baltic Sea a number of distinct herring populations exist (ICES, 2007d), which are of considerable economic importance. Fisheries of nine bordering countries heavily exploit the herring stocks. According to their regional distribution, the stocks inhabit quite different local ecosystems, characterized by a large range in conditions concerning salinity, temperature and zooplankton community (ICES, 2008e). Stock dynamics have been different due to variable exploitation rates and stock productivity. The by far largest stock unit, the central Baltic herring stock, has shown a pronounced decline in spawning stock biomass since the late 1970s (Cardinale et al. 2009). The decline in biomass is at least partly explained by a strong decrease in weight-at-age (ICES, 2009b). Contrary to the development of the central Baltic herring stock, the stocks in the Gulf of Riga and the Bothnian Sea herring showed an increase in SSB levels in the 1980s. Climate forcing seems to influence stock components in variable extend and in combination with other factors.

Herring stocks on the northern hemisphere are influenced in many ways by climate forcing: Changes in distribution patterns (Loeng and Drinkwater, 2007), including the loss of spawning sites (Graham and Harrod, 2009) have been reported in relation to increasing temperature. Migration patterns might change, leading to changes in energy transport rates from the ocean to coastal areas (Varpe et al., 2005). Several studies address growth changes (positive as well as negative) in adult herring as a direct (temperature) or indirect (food) response to climatic changes (Rose et al., 2008; Loeng and Drinkwater, 2007). Furthermore, recruitment success (e.g. Toresen and Oestvedt, 2000) and the amount of skipped spawning (Engelhard and Heino, 2006) have been identified to depend on temperature variability.

The Baltic Sea is among the best studied areas concerning the effect of environmental variability on herring recruitment and growth. Axenrot and Hansson (2003) established a link between the NAO as climatic index and Baltic herring recruitment. The importance of climatic signals for the production of the Gulf of Riga stock has been proven by Kotta et al. (2009). The influence of climate on recruitment of Baltic herring populations has recently been investigated by Cardinale et al. (2009) and Margonski et al. (2010). All recent developed stock-recruitment models including extrinsic factors significantly improved prediction ability (Margonski et al., 2010). Climate impact was represented in the models as either Baltic-specific climate indices (Baltic Sea Index - BSI) or water temperature. Temperature increase generally had a positive effect on recruitment in all cases, where temperature was kept as a predictor in the final models (Cardinale et al., 2009). However, stocks react differently and different sets of predictors have to be used.

Growth of Baltic herring has been shown to depend on climate forcing both direct as well as indirect. Möllmann et al. (2005) postulated that herring growth depend on food abundance and sprat biomass. The direct effect of salinity, in combination with an indirect effect of sprat competition (where sprat stock levels are likely to be influenced by climate), has been demonstrated by Casini et al. (2010). They show that growth of central Baltic herring (condition and weight-at-age) has shifted from being mainly driven by hydro-climatic forces (i.e. salinity) to an inter-specific density-dependent control. This shift in control is triggered by sprat abundance (acting as competitor).

The overall effect of projected climate change on Baltic herring stocks is hard to evaluate. Most probably the stocks will react in different ways – some might increase in stock production, abundance and fishing potential, other might decrease. In any case, the fate of the Baltic herring stocks seems closely linked to the stock dynamics of cod and sprat.

5.4.4 Species interaction

The central Baltic Sea can be described as a relatively simple ecosystem in terms of biodiversity of the higher trophic levels, i.e. the fish stocks. There is only one dominating piscivour, i.e. cod and two important planktivours, i.e. herring and sprat. However, even this rather simple system gains complexity, as numerous interactions between the different life stages exist (Figure 5.13). Adult cod prey on adult sprat and juvenile herring, but are also cannibalistic (the degree is depending on stock size and spatial overlap of age-classes). Adults of herring and sprat prey on cod eggs. Sprats are feeding on sprat eggs, i.e. are cannibalistic. Herring and sprat show food competition and adult sprat are able to exert top-down control on *Pseudocalanus acuspes*, the most important prey for cod larvae. In summary, the stock dynamics of all three species are closely linked and climate effects on one species will almost certainly also impact the other species.

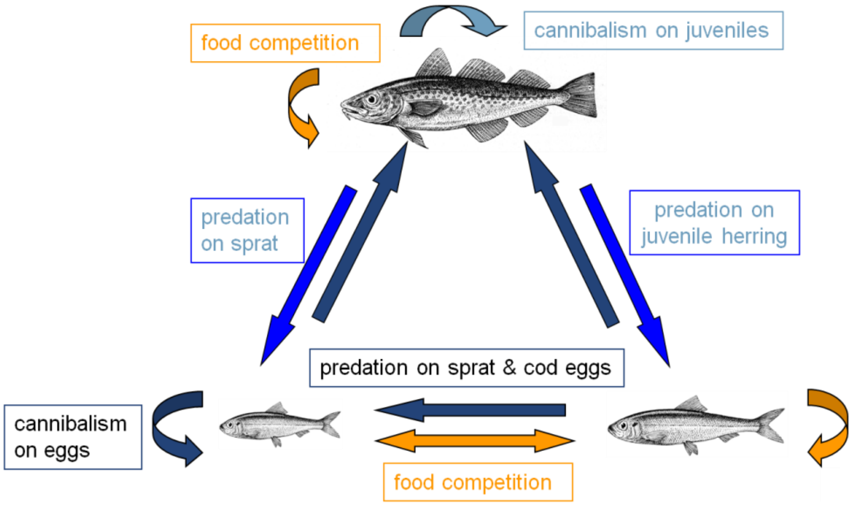


Figure 5.13: Simplified schematic diagram showing intra- and inter-specific relations between Baltic cod, herring and sprat. Source: Schnack (2003).

6. Applicability and credibility

High temporal and spatial variability are generally found in fish populations, and high interdependencies of environmental and interspecies factors and pressures exist, which influence the species composition and relative dominance between species in both demersal and pelagic fish communities. Dramatic fluctuations in the stock developments of the economically most important fish stocks – cod, herring, sprat, flounder and plaice - in the Baltic have been observed during the last century (Hammer et al., 2008). Long time series are therefore a necessary prerequisite for a proper assessment of species composition, abundance, recruitment, spatial distribution and spawning behaviour of fish populations in definite areas.

The baseline field investigations on fish communities in the Fehmarnbelt area were generally carried out during specific survey campaigns from autumn 2008 until summer 2010. Only a few surveys on specific topics covered in total more than one year of investigations, see Table 6.1.

The overall objectives of the baseline inventories were to update the knowledge on fish communities in the Fehmarnbelt area. For the economic and ecological most important species it was essential to clarify the importance of the Fehmarnbelt area as a spawning area, specifically the importance of spawning grounds for herring, cod and flatfish and to clarify the importance of the Fehmarnbelt area as migration route for the migrating species silver eel, cod and herring, and to evaluate the importance of the Fehmarnbelt area as nursery ground for especially flatfish and cod.

It is our opinion, despite the limited period of investigation during the baseline and knowledge of huge temporal and spatial variations in fish communities, that the results in combination with background information from literature provide appropriate and sufficient evidence and background information to determine the importance of the Fehmarnbelt area as spawning ground, migration route and nursery ground for the target species and fish communities in general. This information and results are essential for an appropriate impact assessment on fish communities from large constructions such as the building of the Fehmarnbelt Fixed Link.

Information of survival rates of eggs and larvae, larvae growth conditions, fecundity of spawning species and egg buoyancies obtained during the baseline study provides useful information and results for the future assessment and monitoring of impact from constructions and construction activities in connection with the establishment of the Fehmarnbelt Fixed Link.

During the investigations general and standard applied methodologies used in national monitoring programmes and scientific research programmes were applied. When evaluated, if standard methodologies were inappropriate or unsuitable only minor modifications from these methodologies were applied. For example, a new fixation method using Lugols solution was developed. This method improved the identification of developmental stages of fish eggs compared to the standard fixation method using acetate-buffered 4% formalin solution and was shown to be an effective fixation media for both fish eggs and larvae (Engell-Sørensen et al., 2012). Hydrodynamic models are increasingly being used as the basis for modelling fish early life history, and hydrodynamic backtracking of fish eggs and larvae by individual-based modelling was shown in this study to be appropriate in identifying possible spawning grounds and dispersal trajectories in the Fehmarnbelt area for different species on a number of eggs.

Table 6.1: Summary of field investigation campaigns during the baseline inventory.

Surveys/campaign no.		2008								2009									2010			
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
Egg and larvae		1	■	2			3-5	■	6	7	8	■		9	10	■	11	■	12				
Herring spawning	■	■	■	■			■	■					■	■	■	■							
Habitat mapping									■	■	■	■	■	■	■	■	■	■	■	■			
Nursery area													■	■	■	■	■	■	■	■			
Shallow water																					■	■	
Trawl, Fehmarnbelt																			■	■			
Silvereel migration, tagging experiments		■	■											■	■								
Cod migration, tagging experiments																		■	■				
Hydro acoustic. *Periodic*								1	■				2	■				3	■				
Hydro acoustic. *Continuous*													1	2-3		4	5	6-7	8	9	10	11	12

Tagging experiments using data storage tags (DST) have provided new information about the migration pattern and behaviour of silver eel and cod and showed that spawning and feeding migration routes are crossing the planned future fixed link across Fehmarnbelt, and that local cod populations actually spawn and display homing migration during spawning time in the Fehmarnbelt area.

More specific issues in some work packages are briefly discussed in the following sections.

6.1 Habitat mapping - Fish communities

The field investigations were carried out with classic sampling gear - gill nets, fyke nets, young of the year and windpark trawls - in accordance with national guidelines. Characterisation of habitat structure was based on a combination of video recordings of the seabed structure at the sampling locations together with the spatial distribution of benthic habitats available from the classification of benthic habitats within the Fehmarnbelt area made during the investigations on marine bottom fauna and flora. Sufficient similarities were found between the actual seabed habitat types and the predicted modelled habitat types, taking existing high variability in seabed structure into consideration. Especially for fish communities in shallow areas that are made up of a mixed seabed of stones, gravel and sand covered more or less by common mussels and vegetation, suitable or preferred habitat structure changes within short distances. Abundance and presence data and the modelled habitat types were used in the habitat suitability mapping.

The possible distribution patterns of typical and dominant species in the coastal fish community were shown to be reliable and provided sufficient information for the future assessment of impact on the economically most valuable and ecologically most important species from the construction and operation of the Fehmarnbelt Fixed Link, although a higher geographical coverage and more dense sampling grid would have improved the analysis and been preferable.

Habitat suitability mapping based on data from trawl surveys in different habitat types in deeper waters might have provided more detailed information on the distribution patterns of adult flatfish communities and other demersal species. However, most of these species are widely distributed and are considered to be less sensitive to impacts and disturbances from construction activities and thus these were not included as specific target species in the baseline investigations. Furthermore, the sediment in the deeper parts of the Fehmarnbelt area is rather homogenous and consists of fine grained sand or silt (mud, muddy sand or sandy mud). Thus, any differentiations in distribution patterns might only have been informative if information on other factors such as preferable ingested food items and food availability were available. These were, however not included in the baseline investigations.

6.2 Eggs and larvae studies

The primary aims of the egg and larvae studies were to detect spawning activities in the Fehmarnbelt area and determine transport of egg and larvae of ecological and economic important species through the belt. Spawning times and peak of spawning of herring, sprat, cod and flatfish species together with other common species have been verified in accordance with known literature. This has produced a detailed picture of the state of the art of the occurrence of early life stages of important fish species in the Fehmarnbelt area to be used in the future assessment of the impact from construction activities.

Daily egg production for the most important fish species including cod and several flatfish species have been estimated using the densities of varying egg stages combined with calculated egg mortalities. During this calculation biased results of the egg production was evidently introduced at the margins of the main spawning periods due to very high uncertainties and very high deviations in the calculations of mortalities, when only few eggs representing few life stages were registered. This is demonstrated in the figures by very high standard error bars.

Use of the individual based hydrodynamic model backtracking of eggs and larvae has identified spawning grounds for a number of common species in the Fehmarnbelt area, including cod. The basic use of DHI's well-validated Mike 3 hydrodynamic 3D model meets the fundamental requirement for the applicability with grid size resolutions fine enough to capture the appropriate horizontal mixing processes. However, the model assumes only passive drift, thus vertical swimming behaviour by larvae can influence the transport and the backtracked trajectories and might bias the results of e.g. the location of spawning grounds for herring.

6.3 Hydro acoustics - Pelagic fish communities

The spatial distribution patterns and assemblages of pelagic fish communities are very dynamic with a huge temporal variability. The primary aim of the investigations was to assess the importance of the Fehmarnbelt area as a feeding or spawning migratory route for herring, sprat and cod. One year of hydro acoustic surveys covering specific periods of spawning and feeding migrations have been performed according to standard principles. Adequate data have been obtained for the assessment of the temporal and spatial biomasses of the pelagic communities in the Fehmarnbelt area. Although differentiation in the hydro acoustic biomasses of different species was not completely adequate for scientific purposes and thus probably underestimated the proportion of pelagic species, we consider that the data supporting the evaluation of the pelagic community was sufficient for the purpose and the objective of this study.

The calibrating of hydro acoustic data depends largely on the reliability of the corresponding calibrating trawls. During the first hydro acoustic survey a pelagic trawl was used for calibrating the relative abundance of species, whereas in the following surveys a bottom trawl was used for this purpose. The reason a bottom trawl was used in later surveys was based on the interest of obtaining both information on the pelagic fish community as well as information on the benthic fish community in the central parts of the Fehmarnbelt area, which was not covered by the more specific surveys in the coastal areas of the belt.

6.4 Herring

Although no herring spawning beds were found in Fehmarnbelt, any conclusions on herring spawning in Fehmarnbelt have to take several other factors into consideration. Despite intensive video screening for spawning beds, particularly in the spring, only a small fraction of the sea bottom was actually investigated in comparison to the entire area. Methodologically, the reliance of the remote videoing to find spawning beds was proven to be viable, as the same method detected herring eggs in the Greifswalder Bodden in the spring 2009 without difficulties. Although this method was not tested statistically, it was considered an advantage to be able to screen a broader area of Fehmarnbelt with less effort. Furthermore, teams of divers supplemented the surveys in the spring of 2009, without detecting any herring eggs. Nevertheless, the probability of finding spawning sites depends not only on the surveyed area, but also on the size and shape of the spawning grounds, the time before hatching and the density of eggs in the spawning beds.

Backtracking of yolk sac larvae has identified some areas along the coasts in the Fehmarnbelt area where spring spawning herring spawn. The results might be biased due to vertical swimming behaviour of the larvae; however very newly hatched larvae have been registered, clearly demonstrating that spawning of herring takes place to some extent in the coastal areas of Fehmarnbelt.

Based on a simple predictive model of detecting spawning grounds, it was estimated, that spawning grounds corresponding to a minimum of 40 tonnes spawning herring could be detected on the Danish coast during the spring survey in 2009, if the spawning beds were small and densities of eggs in the spawning beds low (FeBEC, 2010a). Larger spawning beds with higher egg densities might be restricted in distribution and might therefore have less probability of been detected, than smaller more widely distributed spawning beds. It was estimated that up to 5,000 tonnes herring spawning in large spawning beds with high egg densities could have spawned in the area before spawning beds would have been detected. A spawning biomass of 5,000 tonnes represents 5% of the estimated 2009 biomass of the WBSS herring stock of around 105.000 tonnes according to ICES (ICES 2010).

The primary objectives of the herring gill net surveys were to determine spawning time and relative peak abundance of herring at potential spawning sites. Although only two standard herring mesh sizes were used, the results are considered to be sufficient for the evaluation of the matureness among herring, albeit no trend in the specific seasons, other than significant differences between autumn and spring spawners, were identified. However, registrations from pound nets and trawl hauls supported gill net survey results, and the lack of progression between the ratios of herring ready to spawn and spent herring can be attributed to migrating herring during their passage through Fehmarnbelt. Differences in peak relative abundance was difficult to determine because the effort was at the lower scale to produce statistically valuable results between each sampling occasion, in the specific seasons. Similarly, there were many stations without catches of herring, and on both coasts the distributions of the combined catches of bottom and floating nets did not follow normality.

The spring herring gill net and video surveys were restricted to one year, the spring 2009. While annual variation regarding spawning time may occur, depending on e.g. temperature etc., herring tend to be rather conservative about their spawning locations. Although the recruitment of the western Baltic spring spawning herring according to ICES assessments increased in 2009 (ICES, 2010), annual fluctuations in spawning biomass is not considered to have influenced the results of the present study.

Gill net surveys in general provide semi-quantitative data applicable in relative assessments. The selectivity of gill nets is highly determined by mesh size and catchability of specific species, which is primarily determined by fish morphology and behaviour. Taking these biases into consideration, however, the variability and the representability of the fish community in the catches with gill nets is often acceptable compared to many other types of gear (Müller and Jensen, 2000). As a passive gear, gill nets fish over time and “extend” its area of investigation depending on soak time. For a pelagic species such as herring, this may be considerable over a 12-24 h period. Moreover, gill nets have the advantage of not being habitat restricted by shallow water, vegetation, stones, boulders etc. enhancing the representation of it catches.

Genetic assignment analysis of herring caught during the surveys has provided new and important information of the origin of herring in the Fehmarnbelt area that is essential in the assessment of spawning and feeding migrations through Fehmarnbelt. High levels of assignments of origins for the spawning herring generally indicated that a relative proportion of the herrings present in Fehmarnbelt are represented by Rügen herring. Although, some considerations should be taken into account concerning the migration pattern and biomass calculations, a back spawning migration of 20% of the Rügen herring was estimated to migrate through Fehmarnbelt. This information is essential in the assessment of possible barrier effect due to construction activities in connection with the establishment of the Fehmarnbelt Fixed Link.

6.5 Eel

The present baseline of European eel in Fehmarnbelt has focused on spawning migration and on the significance of shallow waters as eel foraging grounds. The upstream migration of elvers and juvenile yellow eels through Fehmarnbelt into the Baltic has not been described, though this may have significance to the eel recruitment in the Baltic Sea. However, the upstream migration after settlement and transformation into the yellow eel stage is believed to be rather slow and diffuse (Ibbotson et al., 2002; Lasne and Laffaille, 2008). Furthermore, being south of The Belts as well as the Øresund, young eels in Fehmarnbelt may have come either way complicating evaluation of migration routes. Information of the importance of Fehmarnbelt to migration of elvers and juveniles into the Baltic Sea would however have qualified the baseline studies.

The abundance of yellow eels in the shallow waters of Fehmarnbelt was assessed by the Danish standardized fyke net survey in late summer. The survey returns semi quantitative estimates of the eel density restricted to the specific year and month, but dependent on recruitment, emigration and immigration, natural and fishing mortality, year to year fluctuations in recruitment and seasonal variation in migratory patterns, thus the representability of the results may be limited. However, despite a significant variability due to small catches, the conclusion of a sparse eel population on the exposed coasts of Fehmarnbelt and in the Lagoon of Rødsand Bight is believed to be fairly valid, although a statistical approach was not possible. The relatively low landings in the fishery data, strengthens this assumption.

Since silver eels from the entire Baltic Sea must pass Danish waters, this stresses the importance of evaluating the significance of Fehmarnbelt as a migratory route compared to alternative routes, mainly Øresund. However, the relative importance of Fehmarnbelt as a passage way was basically assessed on assumptions regarding fishing pressure along the specific routes, and the results should consequently be viewed in this light. The total number of migrating silver eels passing Fehmarnbelt was calculated to be 1.7 million eels in 2008.It should be emphasized that this most likely represents a maximum estimate (FeBEC, 2009b). Hence, estimates from mark-release-recapture experiments rely on several preconditions and the most critical of these if not fulfilled will lead to an overestimate.

Results from marking experiments rely on the assumption that marked eels behave like unmarked eels, which may have been critical, particularly in the 2009-campaign. In this study, the eels were captured along the coast of Lolland, marked and transported 150 km eastward and then released in the middle of the Arkona Basin, whereafter several of the eels showed signs of confusion during migration. Biases followed by marking and stresses of been caught and released, also requires cautious interpretations regarding migration patterns of individual behaviour. However, despite potentially forced stresses, the eels apparently still had the ability to navigate in reasonable directions as suggested by the majority of the recaptures being along a sensible migration route out of the Baltic Sea.

The results from the present studies suggested that the routes could depend on water current conditions, at least when passing the Arkona Basin. This exposes the possibility of year to year variations in migration patterns due to differences in weather conditions. Nevertheless, in the last decade there have only been minor variations in the landings of silver eels along the different migration routes in Danish waters, suggesting little variation in the migration pattern.

6.6 Cod

Tagging experiments of mature and spawning cod have shown a homing migration tendency toward spawning grounds, and backtracking of spawned eggs and findings of newly spawned eggs at different locations in the Fehmarnbelt verifies that cod spawn in the Fehmarnbelt area.

The tagging experiment however was not very comprehensive and the conclusions drawn are relying on rather few recaptured tagged cod. The genetically heredity of the cod in Fehmarnbelt has not been investigated, and the population relationship are therefore unknown. The young cod found in the nursery areas in the shallow waters of Fehmarnbelt might be the offspring of cod spawning in more distant areas. Furthermore, the offspring of cod spawning in Fehmarnbelt might have nursery areas far from Fehmarnbelt. Finally, adult cod foraging in Fehmarnbelt outside the spawning period may belong to another subpopulation. Tissue samples were taken from the spawning cod and from the young cod in shallow waters, but they have not been analysed yet. The results from these analyses would enlighten the heredity of the cod present in Fehmarnbelt.

Although some considerations should be taken regarding actual transport trajectories and egg production, a rather high proportion of the western Baltic cod spawns in the area. This information is very informative for the future assessment of impacts from the construction of the Fehmarnbelt Fixed Link and for the design of possible mitigating actions to protect the vulnerable cod stock in the western Baltic.

6.7 Rare and red listed species

A sufficient and credible evaluation of the spatial and temporal distribution of red listed species in the Fehmarnbelt area is limited because of the generally sparse occurrence and distribution of these species. Thus, in principle, the investigations did not focus on these species due to their anticipated low abundance and distribution. A higher fishing effort might have provided a higher frequency of these species and contributed to a higher number of observed species (Kube, 2000). However, compared with other studies and a high total number of species shown in the data collected in the investigations indicate that the investigations have been very extensive and can be considered sufficient in relation to the possible presence of red listed species. The investigations did reveal a comprehensive picture of the red listed species in the region of Fehmarn providing sufficient data to elaborate habitat suitability maps for certain important endangered stationary fish species to be used in the future impact assessment for the fixed link.

7. Baseline conclusion

Baseline data on fish ecology in Fehmarnbelt and adjacent areas were collected in the period 2008-2011 by the consortium FeBEC.

The purpose of the baseline study was to provide essential information on fish communities, fish migration and spawning of key fish species in the Fehmarnbelt region. Furthermore information on areas of nursery and feeding in Fehmarnbelt was obtained. This information is a prerequisite for the subsequent environmental impact assessment and will furthermore be used as a point of reference in a future monitoring programme.

The major findings of the baseline report are condensed below:

Benthic and shallow water fish communities. In total, 57 different fish species were registered during the mapping of fish communities in the area. The coast along Fehmarn had 43 species and was the most species-diverse area, compared to the 37 species registered along the coast of Lolland. The lowest number of species was found in the deeper areas of Fehmarnbelt where 35 species were registered. Ten of these species were only registered in the deeper parts of Fehmarnbelt.

The shallow water fish community (<2 m) was generally dominated by small fish such as sticklebacks, gobies and sand eel, but larval and juvenile stages of pelagic fish such as herring and sprat were also frequently registered. The fish community reflected a typical fish community of the Belt Sea, and subareas along the coasts of both Fehmarn and Lolland were shown to function as nursery grounds for several fish species.

The western and north-western sandy habitats near the coast of Fehmarn were dominated by flatfish species such as dab (*Limanda limanda*) and flounder (*Platichthys flesus*). In addition, the highest abundance of hooknose (*Agonus cataphractus*) and whiting (*Merlangius merlangus*) were also found in these habitats. The highly structured habitats with vegetation, stones and boulders along the eastern and south-eastern coast of Fehmarn were dominated by cod, whereas almost no flatfish species, except flounder, were caught within these habitat types. Beside cod, species such as sea stickleback (*Spinachia spinachia*), wrasses (mainly goldsinny wrasse (*Ctenolabrus rupestris*)) and gobies were characteristic for these habitats.

Cod was the dominant species along the coast of Lolland in the habitats with vegetation, stones and mussels, while dab and whiting were most numerous in sandy habitats. In the lagoon of Rødsand, the extensive eelgrass habitat was dominated by small fish species such as three- (*Gasterosteus aculeatus*) and nine-spined stickleback (*Pungitius pungitius*), eelpout (*Zoarces viviparus*) and several species of gobies.

The most dominating species in the deeper areas of Fehmarnbelt was dab, but whiting, cod and plaice (*Pleuronectes platessa*) were also numerous.

Abundance and biomass of fish was subject to seasonal variations. Thus, e.g. flatfish species tended to migrate to deeper waters during winter.

Overall Fehmarnbelt was assessed to be of medium importance for the shallow water fish species (for details see Table 7.1 to
Table 7.7).

The pelagic fish community. The pelagic fish community of Fehmarnbelt includes at least ten species with sprat, herring, whiting and cod as the most numerous. Considerable seasonal variability was present both in relation to abundance and species composition and occasionally pelagic species like garfish (*Belone belone*) and Atlantic horse mackerel (*Trachurus trachu-*

rus) were highly abundant. The density of pelagic fish in Fehmarnbelt was lower than what was observed in previous studies from e.g. Øresund.
The continuous surveys, covering the area around the determined route of the fixed link, showed low densities of pelagic fish in February-March compared to other times of the year. The February-March periodic survey also showed low densities in this area, whereas higher densities were recorded both east and west of this area. This indicates that the area close to the determined route of the fixed link is only of minor importance as a spawning ground for cod compared to other areas in Fehmarnbelt.

It is not possible to track the migration of pelagic species, including the Rügen herring, from the results. It seems however unlikely that the majority of herring migrates through the Fehmarnbelt to the feeding areas in the Skagerrak and Kattegat. This is because all estimated biomasses in spring were low compared to Øresund combined with low proportions of herring in the trawl catches in April-May 2009 and in spring 2010.

Cod. Two genetically different cod stocks are found in the Baltic Sea; the western cod stock occurring west of Bornholm including the Belt Sea and the Øresund, and the eastern stock occurring east of Bornholm.

Although the western cod stock is significantly smaller than the eastern stock, drifting larvae of the western stock spawned in Fehmarnbelt and Mecklenburg Bight is believed to contribute significant to recruitment in the eastern stock. The field investigation showed that Fehmarnbelt is an important spawning ground for the western Baltic cod with the primary spawning period from February to March, although results in 2009 showed that spawning continued at a low level throughout the summer.

Average cod egg density in Fehmarnbelt in March 2010 was 3 eggs per m^3, corresponding to approximately 25 eggs per m^2, which is only slightly lower than the density recorded during the peak of the spawning season in the Bornholm Basin from 1969-1996.

From the estimated annual egg production of the entire sampling area, it was calculated that approximately 800 tonnes of cod spawn in the investigated area. Since the spawning stock biomass (SSB) of the entire western Baltic has been estimated to be 20,000 tonnes since 1995, it is assumed that at least 4% of the spawning biomass in the entire western Baltic Sea spawns in Fehmarnbelt.

When backtracking early-stage cod eggs caught in Fehmarnbelt to their place of origin, it was found that they were primarily spawned in the deep central areas of Fehmarnbelt, the Belt Sea near Langeland, Mecklenburger Bight and the western part of the Arkona Basin. Spawning areas in the deeper, central parts of Fehmarnbelt was supported by a peak in the catches of adult cod convergent with the main spawning period in February and March 2010. During the hydro-acoustic surveys, it was shown that cod spawn in Fehmarnbelt in December-March. However, the surveys did not show any significant aggregations of cod during the spawning season.

Overall, these results correspond well with previously identified spawning grounds, and support the hypothesis that the Fehmarnbelt stock is important to the recruitment of the western Baltic cod stock, as well as possibly supplementing recruitment to the eastern stock in the Baltic Sea. Furthermore, tagging experiments have shown a tendency of homing towards spawning grounds in Fehmarnbelt.

The high density of juvenile cod present in the shallow coastal waters of Fehmarn and Lolland, indicate these areas as important nursery grounds.

Starvation by the cod larvae or heavy predation on egg and larvae by predatory gelatineous plankton did not appear likely during the investigated period.

Overall Fehmarnbelt was assessed to be of high importance for cod (for details see Table 7.1 to
Table 7.7).

Whiting. At first whiting was not outpointed as a key species but throughout the baseline studies whiting was often dominating in the catches from the deep central waters of Fehmarnbelt. Especially the trawl catches from the end of February 2010 was dominated by whiting. The majority of these whiting were in maturity stage 3 (ripening). Seasonal landings of whiting from 2007 to 2010 support the hypothesis of aggregation of whiting in the central parts of Fehmarnbelt in a short period during spring.

No spawning activity or whiting eggs were found in Fehmarnbelt and adjacent areas, which was expected. Whiting do not spawn east of Skagerrak and the numerous whiting found in Fehmarnbelt were primarily juveniles which have migrated from spawning grounds west of Kattegat. Aspects regarding spawning as well as eggs and larvae are thus of non or minor importance.

However, the large catches of mature whiting in the central part of Fehmarnbelt in early spring indicates a aggregation of whiting from the Baltic Sea migrating through Fehmarnbelt towards spawning grounds west of Kattegat. Furthermore, as the whiting primarily were smaller than 30 cm it seems like they use the Baltic Sea as a nursery area and leave the area when ready for first-time spawning.

Thus, Fehmarnbelt might be of medium importance for the spawning migration of first-time spawners in a limited period during early spring. It is only of minor importance as nursery area as whiting seem to use several areas in the Baltic Sea as nursery grounds.

Overall Fehmarnbelt was assessed to be of medium importance for whiting (for details see Table 7.1 to Table 7.7).

Western Baltic Herring. The baseline has identified at least three components of the Western Baltic herring stock:

- A very small component of autumn spawning herring, most likely just passing Fehmarnbelt to and from spawning and feeding areas,
- A moderate sized spring spawning herring component (primarily Rügen herring), most likely passing Fehmarnbelt to and from spawning grounds,
- A small more local spring spawning component.

Moreover, genetic analysis has identified components of North Sea herring and eastern Baltic herring. The Fehmarnbelt most likely plays a minor role compared to Øresund as a passage way or route between feeding areas in the Kattegat/Skagerrak and the North Sea and spawning grounds in the western Baltic.

Very low catches of herring and herring larvae in the autumn, as well as no observation of herring spawning activities, either by video screening or hydrodynamic backtracking, indicates none or very little autumn herring spawning activity in Fehmarnbelt. Correspondingly, the density of herring larvae in the autumn of 2008 was less than 0.001 per m^3. Furthermore, when backtracking their origin to spawning grounds, none of the larvae seemed to have been hatched from eggs spawned in Fehmarnbelt.

Although a significantly higher abundance of mature herring was present in the spring than the autumn, very few spent herring were caught. Furthermore, despite intensive screenings of the sea bottom no herring eggs were found. However, the density of herring larvae during the spring of 2009 was higher than in the autumn, albeit their density still did not exceed an average of 0.05 herring larvae per m^3. By backtracking eggs, probable spring spawning grounds could be identified along the southeastern and northeastern coast of Fehmarn. Larval densities indicated that there was a 10 fold lower abundance of larvae in Fehmarnbelt compared to spawning grounds in Greifswalder Bodden and Kiel Fjord. This suggests that the spring spawning activity in Fehmarnbelt most likely is limited.

There were no indications of starvation of herring larvae or that predatory gelatineous plankton constituted an important threat to eggs or larvae.

Overall Fehmarnbelt was assessed to be of high importance for herring, primarily due to migration (for details see Table 7.1 to
Table 7.7).

Sprat. The egg and larvae surveys revealed that sprat spawn in Fehmarnbelt from April to August. At the peak spawning period in May, the egg densities were similar to densities recorded during the main spawning period in the Gotland Deep 1976-1996 of the central Baltic Sea. Thus the deeper parts of Fehmarnbelt and adjacent areas are considered important spawning areas of sprat. A rough estimate of the spawning stock biomass, suggests that approximately 2,000 tonnes of sprat spawn in the investigated area. This would account for about 0.2% of the spawning biomass of the entire Baltic Sea.

Fehmarnbelt was found to function as both a nursery and feeding area for sprat. Sprat was recorded in the Belt from spring to autumn. In the winter period, sprat was mainly located in the deeper parts of the western Baltic Sea.

Overall Fehmarnbelt was assessed to be of medium importance for sprat (for details see Table 7.1 to
Table 7.7).

The European eel. The Danish sounds and belts are important for the migration of the European eel between the Baltic Sea and the North Sea.

In Fehmarnbelt, the migration of silver eel occurs from August to December and peaks in October. Tagging experiments revealed that Fehmarnbelt has some importance as a passage for migrating silver eel, although the majority of eel leaving the Baltic Sea presumably migrates through Øresund. It is likely that not more than 30% of the Baltic silver eel used Fehmarnbelt as a migration route in 2008 and 2009.

Silver eel migrating along the Swedish coast appear to prefer Øresund as their migration route, while silver eel migrating along the southern Baltic coast select the southern route through the Belt Sea to a greater extent. The preferred route does not appear to depend on an imprint during the juvenile stage, but rather on present water current and salinity conditions in the Arkona Basin.

Silver eel seem to prefer migrating in the deeper waters along their route. They swim near the surface during the dark hours and at night while frequently undertaking dives from surface layers to either the bottom or thermocline. During the day they mostly rest at the bottom. Migration speed is highly variable, depending on the frequency of resting periods. During active migration, the speed is approximately 0.4 m/s amounting to approximately 17 km/day.

A fyke net survey in autumn 2009 revealed that the Fehmarnbelt area only has minor importance as a nursery and feeding area for yellow eel.

A very little genetic difference among eel in European waters points toward only one population. This either indicates that there is no geographical separation of spawning grounds in the Sargasso Sea between northern and southern European eel, and/or that it is random where the offspring end up at the European coast. Local impacts on eel populations may consequently affect the whole area of distribution from northern to southern Europe.

Overall Fehmarnbelt was assessed to be of very high importance for the European eel, due to migration (for details see Table 7.1 to
Table 7.7).

Flatfish. Flatfish contribute significantly to the fish communities of Fehmarnbelt, and both nursery, feeding and spawning grounds are found in the area. Spawning of flatfish occur throughout most of the year, with plaice spawning in December-March, flounder in February-April, dab in March-July and turbot (*Psetta maxima*) and sole (*Solea solea*) in May–August.

Dab was highly dominant among the flatfish caught in the trawl in the deep central part of Fehmarnbelt throughout the year. Flounder and plaice were also abundant but dab was found in much more numerous amounts.

Fehmarnbelt is an important spawning area for flatfish, especially plaice, flounder and dab as suggested by the high egg densities and backtracking of their eggs to spawning grounds in Fehmarnbelt and nearby areas. All stages of plaice, flounder and dab eggs and larvae were found in Fehmarnbelt, while larvae of witch flounder (*Glyptocephalus cynoglossus*), sole, American plaice (*Hippoglossoides platessoides*) and eggs and larvae of turbot were only found sporadically.

The primary spawning sites of plaice were located in the deep parts of Fehmarnbelt and in an area between Lolland and Langeland. The female spawning biomass in the investigated area was estimated to be 338 tonnes. Spawning sites of flounder and dab were located in areas along the northern and eastern coastline of Fehmarn, and to a larger area between Langeland and Fehmarn.

Mesozooplankton densities and RNA/DNA levels did not indicate starvation of flatfish larvae, and predatory gelatineous plankton did not appear to constitute any important threat to eggs and larvae.

The Fehmarnbelt area is used as nursery- and feeding grounds by the three dominating flatfish species (plaice, dab and flounder) during their different life stages. Juvenile plaice and flounder primarily use the shallow and protected areas of Fehmarn and Lolland as nursery grounds, while dab prefer deeper waters. The exposed coastline of Lolland does not appear to have significant nursery grounds compared to Fehmarn. Feeding grounds of flounder and plaice are found on sandy areas along the coast, while the deeper part of Fehmarnbelt is mainly used as a transit area by adult flounder and plaice migrating from coastal feeding grounds at Fehmarn and Lolland and back to their spawning grounds. Feeding grounds of dab are located in the deeper areas of Fehmarnbelt.

Other juvenile and adult flatfish species, such as turbot, brill (*Scophthalmus rhombus*) and sole were also registered at the investigated areas of Fehmarnbelt, but their abundances were considerably lower compared to the three most abundant species. It is, however, assumed that these species also use Fehmarnbelt as nursery- and feeding grounds.

Overall Fehmarnbelt was assessed to be of medium importance for flatfish (for details see Table 7.1 to
Table 7.7).

Other species. Eggs and/or larvae of five other species besides cod, herring, sprat and flatfish were caught. These species were fourbeard rockling, seasnail, rock gunnel, hooknose and the red listed snakeblenny.

Red listed species. In total, nine red listed species (according to the German and Danish Red lists) were recorded during the investigations. These were, snakeblenny (*Lumpenus lampretaeformis*), sea stickleback, corkwing wrasse, ballan wrasse (*Labrus bergylta*), sea trout (*Salmo trutta*), Atlantic salmon (*Salmo salar*), greater weever (*Trachinus draco*), European eel and painted goby (*Pomatoschistus pictus*). In addition, autumn spawning herring is also listed as critically endangered on the German red list.

The majority of the listed species occurred at very low numbers. However, the seastickleback in particular, was frequently abundant in the autumn. Other species like corkwing wrasse, ballan wrasse and greater weever showed a significant seasonal distribution. The river lamprey (*Lampetra fluviatilis*) is listed in the EU habitats directive Annex II and small number of this species was caught in Fehmarnbelt by local fishermen during the baseline study period. Detailed considerations to the red listed species are addressed in the NATURA 2000 assessment.

Overall Fehmarnbelt was assessed to be of high importance for protected species (for details see Table 7.1 to
Table 7.7).

Importance. The overall objective with the baseline study was to evaluate the importance of Fehmarnbelt for the fish species and fish communities in the region. The guidelines of the Fehmarnbelt Fixed Link EIA manual were generally followed during the assessment of the importance.

The importance of the Fehmarnbelt area for selected fish species and fish groups with regard to protection, spawning, migration, foraging, nursery, drift of eggs and larvae etc are listed in Table 7.1 to
Table 7.7)

Table 7.1: Criteria for assessment of the importance of fish species/groups in relation to protection.

Importance	Criteria for assessment of the importance of fish species/groups in relation to protection	Species/groups
Very high	The species is protected by international Conventions, e.g. Natura 2000, Annex II or Annex IV species with reference to the Habitats Directive.	European river lamprey, European eel twaite shad European sturgeon
High	The species is protected under National legislation and/or included in the Red List of threatened species in Denmark or Germany.	snakeblenny, sea stickleback, corkwing wrasse, ballan wrasse, sea trout, Atlantic salmon, greater weever, painted goby, autumn spawning herring
Medium		
Minor		

Table 7.2: Criteria for assessment of the importance of Fehmarnbelt as a spawning area for the fish species/group.

Importance	Criteria for assessment of the importance of Fehmarnbelt as a spawning area for the species/group	Species/group
Very high	The main distribution of the spawning area is in Fehmarnbelt and is essential on a regional scale.	
High	The spawning area is of regional importance.	Atlantic cod, sea

		stickleback
Medium	The spawning area is of local importance.	flatfish, European sprat, shallow water species
Minor	The spawning area is either insignificant, unspecified or has a large regional distribution.	herring

Table 7.3: Criteria for assessment of the importance of Fehmarnbelt in relation to the dispersal of eggs and larvae.

Importance	Criteria for assessment of the importance of Fehmarnbelt in relation to the dispersal of eggs and larvae.	Species/group
Very high	Fehmarnbelt is essential for the exchange between different isolated regional stocks.	
High	Fehmarnbelt is an important link between regional stocks.	Atlantic cod, sea stickleback
Medium	Fehmarnbelt is important for the exchange between local stocks.	European sprat, flatfish
Minor	The drift of eggs and larvae is insignificant.	herring, shallow water species

Table 7.4: Criteria for assessment of the importance of Fehmarnbelt as a nursery area for fry/juvenile stages of the species.

Importance	Criteria for assessment of the importance of Fehmarnbelt as a nursery area for fry/juvenile stages of the species.	Species/group
Very high	The main nursery area of the species/stock is in Fehmarnbelt.	
High	The nursery area is of regional importance.	Sea stickleback
Medium	The nursery area is of local importance.	Atlantic cod, flatfish, shallow water species
Minor	The nursery area is either insignificant, unspecified or has a large regional distribution.	herring, whiting, European sprat, European eel

Table 7.5: Criteria for assessment of the importance of Fehmarnbelt as a feeding area for adult individuals of the fish species/group.

Importance	Criteria for assessment of the importance of Fehmarnbelt as a feeding area for adult individuals of the species/group.	Species/group
Very high	The main feeding area of the species/stock is in Fehmarnbelt.	
High	The feeding area of the species is of regional importance.	Sea stickleback
Medium	The feeding area of the species/group in Fehmarnbelt is of local importance.	Atlantic cod, flatfish, shallow water species
Minor	The feeding area is either insignificant, unspecified or has a large regional distribution.	herring, European sprat, European eel

Table 7.6: Criteria for assessment of the importance of Fehmarnbelt as a migration area for the species or group of fish.

Importance	Criteria for assessment of the importance of Fehmarnbelt as a migration area for the species or group of fish	Species/group
Very high	Fehmarnbelt is essential for the exchange between different isolated regional stocks or for the migration between isolated regional spawn-	European eel

	ing or feeding areas.	
High	Fehmarnbelt constitutes an important link between regional stocks or for the migration between regional spawning and feeding areas.	Atlantic cod, herring
Medium	Fehmarnbelt is important for the exchange between local stocks or for the migration between local spawning and feeding areas.	whiting, European sprat, Atlantic salmon, sea trout, river lamprey
Minor	Fehmarnbelt constitutes a more or less continuous habitat for the species with overlapping spawning and feeding areas.	flatfish

Table 7.7: Overall assessment of the importance of fish species/groups in relation to protection and ecological importance.

Importance	Overall assessment of the importance of fish species/groups in relation to protection and ecological importance	Species/groups
Very high	The species is protected by international Conventions, e.g. Natura 2000, Annex II or Annex IV species with reference to the Habitats Directive. The significance of Fehmarnbelt for the species is of wider/transnational ecological importance	European river lamprey, European eel, twaite shad, European sturgeon (European eel)
High	The species is protected under National legislation and/or included in the Red List of threatened species in Denmark or Germany. The significance of Fehmarnbelt for the species/group is of regional ecological importance	snakeblenny, sea stickleback, corkwing wrasse, ballan wrasse, sea trout, Atlantic salmon, greater weever, painted goby, autumn spawning herring Atlantic cod, spring spawning herring
Medium	The significance of Fehmarnbelt for the specific species/group is of local ecological importance	European sprat, flatfish, shallow water species,
Minor	The significance of Fehmarnbelt for the species/group has minor ecological importance	remaining species according to the species list

8. References

Alheit J (1988). Reproductive biology of Sprat (*Sprattus sprattus*) factors determining annual egg production. J. cons. Int. Explor. Mer., 44: 162-168.

Alheit J and Hagen E (1997). Long-term climate forcing of European herring and sardine populations. Fisheries Oceanography, 6(2): 130-139.

Alheit J, Möllmann C, Dütz J, Kornilovs G, Loewe P, Mohrholz V and Wasmund N (2005). Synchronous ecological regime shifts in the central Baltic and the North Sea in the late 1980s. ICES Journal of Marine Science, 62, 1205-1215.

Amezcua F and Nash RDM (2001). Distribution of the order Pleuronectiformers in relation to the sediment type in the North Irish Sea. Journal of Sea Research, 45, 293-301.

Amstrong MJ, Connolly P, Nash RDM, Pawson MG, Alesworth E, Coulahan PJ, Dickey-Collas M, Milligan SP, O'Neill MF, Witthames PR and Woolner L (2001). An application of the annual egg production method to estimate the spawning biomass of cod (*Gadus morhua* L.), plaice (*Pleuronectes platessa* L.) and sole (*Solea solea* L.) in the Irish Sea. ICES Journal of Marine Science, 58, 183-203.

Andersen SM, Teilmann J, Harders PB, Hansen EH and Hjoellund D (2007). Diet of harbour seals and great cormorants in Limfjord, Denmark: interspecific competition and interaction with fishery. ICES Journal of Marine Science, 64, 1235-1245.

Andriashev AP (1986). Agonidae. p. 1265-1268. In Whitehead PJP, Bauchot M-L, Hureau J-C, Nielsen J and Tortonese E (eds.). Fishes of the North-eastern Atlantic and the Mediterranean. UNESCO, Paris. Vol. 3.

Aneer G (1985). Some speculations about the baltic herring (*clupea harengus membras*) in connection with the eutrophication of the baltic sea. Canadian journal of fisheries and aquatic sciences 42: 83-90.

Aneer G (1989). Herring (*Clupea harengus* L.) Spawning and Spawning Ground Characteristics in the Baltic Sea Fisheries Research, 8, 169-195.

Aro E (1989). A review of fish migration patterns in the Baltic. Rapp.P.-V. Renu.-Cons. Int. Explor. Mer. 190, 72-96.

Aro E (2000). The spatial and temporal distribution patterns of cod (*Gadus morhua callaria* L.) in the Baltic Sea and their dependence on environmental variability – implications for fishery management. PhD-thesis, Finnish Game and Fisheries Research Institute, Helsinki.

Arrhenius F and Hansson S (1993). Food consumption of larval, young and adult herring and sprat in the Baltic Sea. Marine Ecology Progress Series 96: 125−137.

Atkinson CJL, Bergman M and Kaiser MJ (2004). Habitat selection in whiting. Journal of Fish Biology, 64, 788-793.

Axenrot T and Hansson S (2003). Predicting herring recruitment from young-of-the year densities spawning stock biomass, and climate. Limnology and Oceanography, 48, 1716-1720.

BACC (2007). Assessment of climate change for the Baltic Sea Basin – the BACC project. International Conference, Gothenburg, Sweden, 22-23 May, 2006. IKSS, Geestacht, Germany. http://www.gkss.de(baltex/BACC/Climate_change_report_07.pdf

BACC (2008). BACC Author Team: Assessment of Climate Change for the Baltic Sea Basin; Springer: New York, 474 pp

Bagge O (1969). Preliminary results of the cod tagging experiments in the Western Baltic. ICES CM 1969/F:29, 7.

Bagge O and Steffensen E (1989). Stock identification of demersal fish in the Baltic. Rapp. P.-v. Réun. Cons. Int. Explor. Mer., 190, 3-16.

Bagge O and Thurow F (1993). The Baltic cod stocks, fluctuations and possible causes. ICES, Cod and Climate Symposium, 14, 20pp.

Bagge O and Thurow F (1994). The Baltic cod stock, fluctuations and the possible causes. ICES Mar. Sci. Symp., 198, 254-268.

Bagge O, Thurow F, Steffensen E and Bray J (1994). The Baltic cod. Dana 10: 1−28

Barros P, Tirasin M and Toresen R (1998). Relevance of cod (*Gadus morhua* L.) predation for inter-cohort variability in mortality of juvenile Norwegian spring-spawning herring (*Clupea harengus* L.) ICES J. Mar. Sci., 55(3), 454-466.

Bauer R, Stepputtis D, Storr-Paulsen M, Weigelt R and Hammer C (2010). Estimating abundances of 0-group western Baltic cod by using pound net fisheries. Inf. Fischereiforsch. 57, 1-11.

Baumann H, Peck MA, and Herrmann JP (2005). Short-term decoupling of otolith and somatic growth induced by food level changes in postlarval Baltic sprat, *Sprattus sprattus*. Marine and Freshwater research, 56, 539-547.

Baumann H, Hinrichsen H-H, Möllmann C, Köster FW, Malzahn AM and Temming A (2006a). Recruitment variability in Baltic Sea sprat (*Sprattus sprattus*) is tightly coupled to temperature and transport patterns affecting the larval and early juvenil stages. Canadian Journal of Fisheries and Aquaric Sciences, 63, 2191-2201.

Baumann H, Gröhsler T, Kornilovs G, Makarchouk A, Feldman V and Temming A (2006b). Temperature-induced regional and temporal growth differences in Baltic young-of-the-year sprat, Sprattus sprattus. Marine Ecology Progress Series 317: 225-236.

Baumann H, Hinrichsen HH, Voss R, Stepputtis D, Grygiel W, Clausen LW and Temming A (2006c). Linking growth to environmental histories in the central Baltic young-of-the-year sprat, Sprattus sprattus: an approach based on otolith microstructure analysis and hydrodynamic modelling. Fisheries Oceanography 15: 465−476

Beaugrand G, Brander KM, Lindley JA, Souissi S and Reid PC (2003). Plankton effect on cod recruitment in the North Sea. Nature 426:661-664

Beaugrand G and Kirby RR 2010. Climate, plankton and cod. Global Change Biology 16(4): 1268-80.

Behrenfeld MJ, O'Malley RT, Siegel DA, McClain CR, Sarmiento JL, Feldman GC, Milligan AJ, Falkowski PG, Letelier RM and Boss ES (2006). Climate-driven trends in contemporary ocean productivity. Nature 444: 752-755

Bekkevold D, André C, Dahlgren TG, Clausen LAW, Torstensen E, Mosegaard H, Cavalho GR, Christensen TB, Norlinder, E and Ruzzante DE (2005). Environmental correlates of population differentiation in Atlantic herring. Evolution, 59(12), 2656-2668.

Bekkevold D, Clausen LAW, Mariani S, André C, Christensen TB and Mosegaard H (2007). Divergent origins of sympatric herring population components determined using genetic mixture analysis. Mar Ecol Prog Ser, 337, 187–196.

Bekkevold D (2010). Preliminary results for genetic analyses of herring samples provided by FeBEC. Memo to FeBEC.

Berner M (1967). Results of cod tagging in the Western and Central Baltic in the period 1962-1965. ICES CM 1967/F:05, 10.

Berner M (1971a). Ergebnisse der Dorschmarkierungen des Jahres 1968 in der Bornholm- und Arkonasee. Fischerei-Forschung Wissenschaftliche Schriftenreihe 9(1), 15-20.

Berner M (1971b) Ergebnisse der Dorschmarkierungen des Jahres 1969 in der Mecklenburger Bucht und Arkonasee. Fischerei-Forschung Wissenschaftliche Schriftenreihe 9(1), 21-27.

Berner M (1974). Some results of the cod tagging experiments of the GDR in the Baltic 1968-1971. ICES CM

Berner M (1980a). Ergebnisse der dorschmarkierungen der jahre 1972 und 1973 in der arkonasee. Fischerei-Forschung, 18(2), 25-29.

Berner M (1980b). Ergebnisse der dorschmarkierungen des jahres 1975 in der bornholmsee (sd 25) einschliesslich einiger mortalitätsrechnungen und eignungsvergleiche unterschiedlicher marken- und schiffstypen. Fischerei-Forschung, 18(2), 51-57.

Berner M (1985) Die periodischen Veränderungen der Gonadenmasse under der Laichzyklus des "Ostsse-" und "Beltseedorsches" (*G. morhua callarias*/*G. morhua morhua*) in verschiedenen Regionen der Ostsee. Fischerei-Forschung Wissenschaftliche Schriftenreihe 23(4), 49-57.

Biester E (1989). The distribution of spring-spawning herring larvae in coastal waters of the German Democratic Republic. Rapp. P.-v. Réun. Cons. Int. Explor. Mer., 190, 109–112.

Biester E (1979). Der Frühjahrshering Rügens – seine Rolle in der Fischerei der Ostsee und in den Übergangsgebieten zur Nordsee. Rostock, Wilh.-Pieck-Univ., Dissertation B, unpublished.

Biester E (1989). The distribution of spring spawning herring larvae in coastal waters of the German Democratic Republic. Rapp. P.v. Reun, 190, 109-112.

Bjornsson B and Steinarson A (2002). The food-unlimited growth rate of Atlantic cod (*Gadus morhua*). Canadian Journal of Fisheries and Aquatic Sciences 59: 492-502

Blaxter J (1969). Development: Eggs and larvae. In: Hoar WS and Randall DJ (eds.). Fish Physiology. Vol. III, 177-252. Acad. Press New York.

Blaxter JHS and Hempel G (1963). The influence of egg size on herring larvae (*Clupea harengus* L.). J. Cons. Perm. Int. Explor. Mer., 28, 211-240.

Blaxter JHS and Hunter JR (1982). The biology of clupeoid fishes. Academic Press, New York.

Bleil M and Oeberst R (2000). Reproduction areas of the cod in the western Baltic Sea. International Council for the Exploration of the Sea. C.M. 2000/N:02.

Bleil M and Oeberst R (2002). Spawning areas of the cod stock in the western Baltic Sea and minimum length at maturity. Archive of Fisheries and Marine Research, 49, 243-258.

Bleil M and Oeberst R (2005). The potential fecundity of cod in the Baltic Sea from 1993 to 1999. Journal of applied ichthyology 21: 19-27.

Bleil M and Oeberst R (2007). Ostseefisherei – Laichgebeite des Dorschs in der westlichen Ostsee. Inf. Fischwirtsch. Fischereiforsch., 47(4).

Bleil M, Oeberst R and Urrutia P (2009). Seasonal maturity development of Baltic cod in different spawning areas: importance of the Arkona Sea for the summer spawning stock. Journal of Applied Ichthyology, 25, 10-17.

Bolle LJ, Rijnsdorp AD and Veer van der HW (2001). Recruitment variability in dab (*Limanda limanda*) in the southeastern North Sea. Journal of Sea Research, 45, 255-270.

Bombace GB (2001). Influence of climatic changes on stocks, fish species and marine ecosystems in the Mediterranean Sea. Archives in Oceanography Limnology 22: 67-72

Bonnet DD (1939). Mortality of the cod egg in relation to temperature. Biological Bulletin, 76, 428-441.

Bos AR (1999). Tidal transport of flounder larvae (*Pleuronectes flesus*) in the Elbe River, Germany. Archive of Fishery Marine Research, 47(1), 47-60.

Brander K (2005) Cod recruitment is strongly affected by climate when stock biomass is low. ICES Journal of Marine Science 62(3): 339-43

Brander KM (2010a) Impacts of climate change on fisheries. Journal of Marine Systems 79:389–402

Brander KM (2010b). Cod *Gadus morhua* and climate change: processes, productivity and prediction. Journal of Fish Biology 77: 1899-1911.

Breder CM and Rosen DE (1966). Modes of reproduction in Fishes. THF Publications, Jersey City, 941 pp.

Brophy D, Danilowicz BS and King PA (2006). Spawning season fidelity in sympatric populations of Atlantic herring (*Clupea harengus*). Can J Fish Aquat Sci, 63, 607–616.

BSH (2007). Standard. Undtersuchung der Auswirkungen von die Meeresumwelt (StUK 3), Bundesamt für Seeschifffahrt und Hydrographie. 1-58.

Bucholtz RH, Tomkiewicz J and Dalskov J (2008). Manual to determine gonadal maturity of herring (*Clupea harengus* L.). DTU Aqua-report 197-08, Charlottenlund: National Institute of Aquatic Resources. 45 pp.

Buckley L, Caldarone EM and Ong T-L (1999). RNA-DNA ratio and other nucleic acid-based indicators for growth and condition of marine fishes, Hydrobiologia, 401, 265-277.

Bunn NA, Fox CJ and Webb T 2000. A literature review of studies on egg mortality: Implications for the estimation of spawning stock biomass by the annual egg production method. Science Series Technical Report no. 111, Centre for Environment, Fisheries and Aquaculture Services. Lowestoft 2000.

Caldarone EM, Clemmesen CM, Berdalet E, Miller TJ, Folkvord A, Holt GJ, Olivar MP, Suthers IM (2006): Intercalibration of four spectrofluorometric methods for measuring RNA/DNA ratios in larval and juvenile fish. Limnology and Oceanography: Methods, 4, 153-163.

Cardinale M, Möllmann C, Bartolino V, Casini M, Kornilovs G, Raiid T, Margonski P, Grzyb A, Raitaniemi J, Gröhsler T and Klinkman J (2009). Effect of environmental variability and spawner characteristics on the recruitment of Baltic herring *Clupea harengus* populations. Marine Ecology Progress Series 388: 221-234

Cardinale MC, Casini, M, Arrhenuis, F and Håkansson, N (2003). Diel spatial distribution and feeding activity of herring (*clupea harengus*) and sprat (sprattus sprattus) in the Baltic Sea.

Carl H, Nielsen JG and Møller PR (2004). En kommenteret og revideret oversigt overdanske fisk. Flora og Fauna 110(2): 29–39.

Casini M, Cardinale M and Arrhenius F (2004). Feeding preferences of herring (*Clupea harengus*) and sprat (*Sprattus sprattus*) in the southern Baltic Sea. ICES Journal of Marine Science, 61, 1267-1277.

Casini M, Cardinale M and Hjelm J (2006). Inter-annual variation in herring, *Clupea harengus*, and sprat, *Sprattus sprattus*, condition in the central Baltic Sea: what gives the tune? Oikos, 112(3), 638 – 650.

Casini M, Lövgren J, Hjelm J, Cardinale M, Molinero J-C and Kornilovs G (2008). Multi-level trophic cascades in a heavily exploited open marine ecosystem. Proc. R. Soc. B,275, 1793-1801.

Casini M, Bartolino V, Molinero JC and Kornilovs G (2010). Linking fisheries, trophic interactions and climate: Threshold dynamics drive herring *Clupea harengus* growth in the central Baltic Sea. Marine Ecology Progress Series 413: 241-252.

Chenoweth HF, McGladdery SE, Sindermann CJ, Sawyer TK, Bier JW (1986). An Investigation into the Usefulness of Parasites as Tags for Herring (*Clupea harengus*) Stocks in the Western North Atlantic, with Emphasis on Use of the Larval Nematode Anisakis simplex. J. Northw. Atl. Fish. Sci. 7: 25-33.

Chicharo MA and Chicharo L (2008). RNA:DNA ratio and other nucleic acid derived indices in marine ecology. International Journal of Molecular Sciences, 9(8), 1453-1471.

Chicharo MA, Esteves E, Santos AMP, dos Santos A, Peliz A and Re P (2003). Are sardine larvae caught off northern Portugal in winter starving? An approach examining nutritional conditions. Marine Ecology Progress Series, 257, 303-309.

Christensen JH, Christensen OB, Lopez P, Van Meljgaard E and Botzet M (1996). The HIR-HAM4 regional atmospheric climate model, Scientific Report 96-4, 51 pp, Danish Meteorological Institute, Copenhagen.

Christensen OB and Christensen JH (2004). Intensification of extreme European summer precipitation in a warmer climate. Global and Planetary Change, 44, 107–117.

Clarke KR and Warvick RM (2001). Change in marine communities: An approach to statistical analysis and interpretation, 2'nd edition. PRIMER_E: Plymouth .

Clausager Rasmussen P (2003). Stamsild i Randers Fjord, 2003. The County of Aarhus 2004, ISBN 87-7906-288-1.

Clausen LAW, Horsten MB and Hoffmann E (2002). Gyde- og opvækstpladser for kommercielle fiskearter i Norsøen, Skagerrak og Kattegat. DFU-rapport nr. 118-02.

Clausen LAW, Bekkevold D, Hatifield EMC and Mosegard H (2007). Application and validation of otolith microstructure as a stock identification method in mixed Atlantic herring (*Clupea harengus*) stocks in the North Sea and western Baltic – ICES Journal of Marine Science, 64.

Clausen LAW 2010. Otolith microstructure analysis of individual herring caught near-site Fehmarn Belt. Memo to FeBEC.

Clemmesen C (1993). Improvements in the fluorometric determination of the RNA and DNA content of individual marine fish larvae. Marine Ecology Progress Series, 100, 177-183.

Clemmesen C (1994). The effect of food availability, age or size on the RNA/DNA ratio of individually measured herring larvae: laboratory calibration. Marine Biology,118, 377-382.

Clemmesen C, Potrykus A, Schmidt JO (2007). Climate change and European fisheries. Study for the European Parliament's Committee on Fisheries. 133 pp.

Collins, KJ, Jensen, AC and Mallinson, JJ (1996). Observations of wrasse on an artificial reef. Fishing News Books, Oxford (UK).

Coombs SH (1981). A density-gradient column for determining the specific gravity of fish eggs, with particular reference to eggs of mackerel Scomber scombrus. Mar Biol 63:101-106.

Council Regulation (EC) No 1100/2007 of 18 September 2007

Council Regulation (EC) No 2187/2005 of 21 December 2005

COWI (1996). Biological Monitoring. Herring Spawning April/May 1996. Great Belt Monitoring programme. COWI/VKI Document 96/005/3.1.

Cushing DH (1990). Plankton production and year-class strength in fish populations: An update of the match/mismatch hypothesis. Advances in Marine Biology 26: 249-294

Crean SR, Dick JTA, Evans DW, Rosell RS and Elwood RW (2005). Survival of juvenile European eels (*Anguilla anguilla*), transferred among salinities, and developmental shifts in their salinity preference. Journal of Zoology, 266(1), 11-14.

Cunningham JT (1880 and 1886). in: Russell, FS (1976). The egg and Planktonic Stages of British Marine Fishes. Academic press. ISBN: 0-12 604050-8.

Dahl J (1961). Sabelkarpe (*Pelecus cultratus* (L.)) første gang i Danmark. – Flora og Fauna 67: 163-164

Damalas D, Maravelias CD, Katsanevakis S, Karageorgis AP and Papaconstantinou C (2010). Seasonal abundance of non-commercial demersal fish in the eastern Mediterranean Sea in relation to hydrographic and sediment characteristics. Estuarine, Coastal and shelf Science, 89,(1), 107-118.

Dannevig H (1895). Embryonic development of five species of gadoid fishes in Icelandic waters." Rit Fiskideidar, 5(6), 1-68.

Dickmann M, Möllmann C and Voss R (2007). Feeding ecology of Central Baltic sprat (*Sprattus sprattus* L.) larvae in relation to zooplankton dynamics - implications for survival. Marine Ecology Progress Series 342: 277−289

Dickson RR, Kelly PM, Colebrook JM, Wooster WS and Cushing DH (1988). North winds and production in the eastern North Atlantic. Journal of Plankton Research, 10:151–169.

Dietrich R (2004). Untersuchungen zur Biologie der Flunder (*Platichthys flesus* Linnaeus, 1758) in der Unterwarnow, einem Ästuar der südwestlichen Ostsee. Verhandlungen der Gesellschaft für Ichthyologie, 4, 7-24.

Dippner JW, Kornilovs G and Sidrevics L (2000). Long-term variability of mesozooplankton in the Central Baltic Sea. Journal of Marine Systems 25: 23-31.

DMU, 2010. Den danske rødliste. http://www2.dmu.dk/1_om_dmu/2_tvaer-funk/3_fdc_bio/projekter/redlist/gpdata2.asp?ID=12

Doney SC, Fabry VJ, Feely RA and Kleypas JA (2009). Ocean Acidification: The Other CO2 Problem. Annual Review of Marine Science 1:169-192.

Donner M (2006). Wachstum und Kondition von Heringslarven (*Clupea harengus* L.) in der Kieler Förde und im Nord-Ostsee-Kanal. Diploma thesis Kiel University.

Dorow M and Ubl C (2011). Bestandssituation des Europäischen Aals – Gefährdungsursachen und Monitoringarbeiten im Bereich des Landes Mecklenburg-Vorpommern – Teil 1. Fischerei & Fischmarkt in Mecklenburg-Vorpommern, 1/2011, 27-31.

Döscher R, Willen U, Jones C, Rutgersson A, Meier H and Hansson U (2002). The development of the coupled ocean-atmosphere model RCAO. Boreal Environmental Research, 7:183-192.

Döscher R and Meier HEM (2004). Simulated sea surface temperature and heat fluxes in different climates of the Baltic Sea. Ambio, 33, 242-248.

Drinkwater KF (2005). The response of Atlantic cod (*Gadus morhua*) to future climate change. ICES Journal of Marine Science 62(7): 1327-1337.

Drinkwater KF (2009). Comparison of the response of Atlantic cod (*Gadus morhua*) in the high-latitude regions of the North Atlantic during the warm periods of the 1920s-1960s and the 1990s-2000s. Deep Sea Research (II) 56(21-22): 2087-96.

Dulcic J, Grbec B, Lipej L (1999). Information on the Adriatic ichthyofauna - effect of water warming? Acta Adriatica 40(2): 33-43.

Durif CMF and Elie P (2008). Prediction of downstream migration of silver eels in a large river catchment based on commercial fishery data. Fisheries Management and Ecology, 15, 127-137.

Durif CMF, Gjøsæter J and Vøllestad LA (2010). Influence of oceanic factors on *Anguilla anguilla* (L.) over the twentieth century in coastal habitats of the Skagerrak, Southern Norway. Proceedings of the Royal Society B. online first doi:10:1098/rspb.2010.1547.

Dynesen C and Zilling L (2006). A Fixed Link across the Fehmarnbelt and the Environment. Environmental Consultation Report 2006. Federal Ministry of Transport, Building and Urban Affairs, Germany. Ministry of Transport and Energy, Denmark. January 2006. ISBN 87-90917-25-1.

Edeline E, Dudour S and Elie P (2009). Proximate and Ultimate Control of Eel Continental Dispersal. In Spawning Migration of the European Eel. Chapter 18, 433-462. Editors Thillart van den G, Dufour S. and Rankin J.C. Fish and Fisheries 30. Springer.

Eero M, MacKenzie BR, Köster FW and Gislason H (2011). Multi-decadal responses of a cod (*Gadus morhua*) population to human-induced trophic changes, fishing, and climate. Ecological Applications 21, 214-226.

Edwards M, Richardson AJ (2004). Impact of climate change on marine pelagic phenology and trophic mismatch. Nature 430(7002): 881-884.

Ehrenbaum E (1905-1909). Nordisches Plankton. Eier und larven von Fischen, andere Eier und Cysten. Verlag von Lipsius and Tischer.

Elmgren R (1989). Man's impact on the ecosystems of the Baltic Sea: energy flows today and at the turn of the century. Ambio, 18, 326–332.

Engelhard GH and Heino M (2006). Climate change and condition of herring (*Clupea harengus*) explain long-term trends in extent of skipped reproduction. Oecologia 149(4): 593-603.

Engell-Sørensen K (1999). Nordvestjydsk Fritidsfiskerforening, skrubbeopdræt 1996-1998, samlerapport. Bio/Consult as, Aabyhøj, DK.

Engell-Sørensen K, Andersen P and Holmstrup M (2009). Preservation of the invasive ctenophore Mnemiopsis leidyi using acidic Lugol's solution. Journal of Plankton Research, advance access, published May 25, 2009.

Engell-Sørensen K, Holmstrup M and Leonhard S.B (2012). Acidic Lugol's solution as an effective fixative for flounder eggs. Journal of Applied Ichthyology 28(2), pp. 261-263.

Enin U and Gröger J (2004). An assessment of the biomass production theory in the Baltic Sea using fish landings data. Journal of Applied Ichthyology, 20, 362–368.

EU-FP5 (2009). EU- project HERGEN (EU project QLRT 200-01370), final report www.hull.ac.uk/hergen

European Commission. Proposal for Regulation (EU) No …/…of the European parliament and of the Council. Brussels, 22.6.2010, COM (2010) 325 final, 2010/0175 (COD)

Evans S (1983). Production, predation and food niche segregation in a marine shallow soft-bottom community. Marine Ecology – Progress Series, 10, 147-157.

FAO/ICES (2009). Report of the EIFAC/ICES Working Group on Eels, Göteborg (Sweden), 7–12 September 2009.

FeBEC (2009a). Migrating silver eel 2008. Technical Report. Prepared for Femern A/S, Doc. No. E4-TR-011, 48 pp.

FeBEC (2009b). Migrating silver eel 2008. Survey Report. Prepared for Femern A/S, Doc. No. E4-TR-005.

FeBEC (2009c). Data report RNA/DNA measurements FeBEC – April 2009 sampling campaign. Data Report, Prepared for Femern A/S, Doc. No. E4-TR-043, 17pp.

FeBEC (2010a). Spring spawning herring 2009. Adult herring and spawning activity. Technical report. Prepared for Femern A/S, Doc. No. E4-TR-014, 39pp.

FeBEC, (2010b). Sediment Dose Response Study. Technical Report. Prepared for Femern A/S, Doc. No. E4-TR-036. 147pp.

FeBEC (2010c). Fish Communities and Nursery Grounds in Fehmarnbelt. Technical Report. Prepared for Femern A/S, Doc. No. E4-TR-044, 173pp.

FeBEC (2010d). Migrating silver eel 2009. Technical report. Prepared for Femern A/S, Doc. No. E4-TR-016, 42pp.

FeBEC (2011a). Distribution of pelagic fish in Fehmarnbelt, estimated from hydro-acoustic surveys. Technical Report. Prepared for Femern A/S, Doc. No. E4-TR-046.

FeBEC (2011b). Egg and Larvae in the Fehmarnbelt 2008-2010. Technical report. Prepared for Femern A/S, Doc. No. E4-TR-045.

FeBEC (2013). Commercial fisheries in the Fehmarnbelt area. Baseline report. Prepared for Femern A/S, Doc. No. E4-TR-035, 268pp.

FeBEC (2011d). Autumn spawning herring 2009. Data Report. Prepared for Femern A/S, Doc. No. E4-TR-047.

FeBEC (2011e). Migrating silver eel 2009. Technical Report. Prepared for Femern A/S, Doc. No. E4-TR-048.

FeBEC (2011f). Density measurements of flatfish eggs. Data Report. Prepared for Femern A/S, Doc. No. E4-TR-049.

FeBEC (2011g). Cod migration 2010. Technical Report. Prepared for Femern A/S, Doc. No. E4-TR-050.

Feistel R, Nausch G and Wasmund N (2008). State and Evolution of the Baltic Sea, 1952-2005: A Detailed 50-Year Survey of Meteorology and Climate, Physics, Chemistry, Biology, and Marine Environment. John Wiley & Sons, Inc., Hoboken, New Jersey.

FEMA (2010). Fehmarnbelt Fixed Link. Marine Biology Service. Plankton of flora and fauna of the Greater Fehmarnbelt. Baseline Survey – Phase I. Femern A/S, Doc. No. E2-TR-0013.

Fishbase (2011). http://www.fishbase.org

Florin A-B (2005). Flatfishes in the Baltic Sea. -a review of biology and fishery with a focus on Swedish conditions. Fiskeriverket Informerar, 14, 56 pp.

Florin A-B and Höglund J (2008). Population structure of flounder (*Platichthys flesus*) in the Baltic Sea: differences among demersal and pelagic spawners. Heredity 101, 27-38.

Francour P, Boudouresque CF, Harmelin JG, Harmelin-Vivien ML, Quignard JP (1994) Are the Mediterranean waters becoming warmer? Information from biological indicators. Marine Pollution Bulletin 28(9): 523-526

Folkvord A, Rukan K, Johannessen A and Moksness E 1997. Early life history of herring larvae in contrasting feeding environments determined by otolith microstructure analysis. Journal of Fish Biology, 51 (Supplement A): 250-263.

Fox CJ, Geffen AJ, Blyth R and Nash RDM (2003). Temperature-dependent development rates of plaice (*Pleuronectes platessa* L.) eggs from the Irish Sea. Journal Of Plankton Research, 25(11), 1319–1329.

Fox CJ, Taylor M, Dickey-Collas M, Fossum P, Kraus G, Rohlf N, Munk P, van Damme CJG, Bolle LJ, Maxwell DL and Wright PJ (2008). Mapping the spawning grounds of North Sea cod (*Gadus morhua*) by direct and indirect means. Proc. R. Soc. B, 275, 1543–1548

Fricke R, Berghahn R, Rechlin O, Neudecker T, Winkler HM, Bast H-D and Hahlbeck E (1998). Rote Liste der in Küstengewässern lebenden Rundmäuler und Fische (Cyclostomata and Pisces). In: Binot M, Bless R, Boye P, Gruttke H and Pretscher P (Hrsg.) Rote Liste gefährdeter Tiere Deutschlands. Schr.-R. f. Landschaftspfl. u. Natursch., H.55, 60-64.

Fricke R, Rechlin O, Winkler HM, Bast H-D and Hahlbeck E (1996). Rote Liste und Artenliste der Rundmäuler und Meeresfische des deutschen Meeres- und Küstenbereichs der Ostsee. In: Merck, T. and Nordheim Hv (Hrsg.) Rote Listen und Artenlisten der Tiere und Pflanzen des Deutschen Meeres- und Küstenbereichs der Ostsee. Schr.-R. f. Landschaftspfl. u. Natursch., H.48, 83-90.

Friedland KD, Miller MJ and Knights B (2007). Oceanic changes in the Sargasso Sea and declines in recruitment of the European eel. ICES J. Mar. Sci., 64, 519–530.

Frieß CC (1987). Ergebnisse und Bewertung von Grundfischsurveys des FFS „Eisbär“ in der Arkonasee und Mecklenburger Bucht in den Winterhalbjahren 1981-86 für Flunder, Scholle, Steinbutt und Kliesche. Fischerei-Forschung, Rostock, 25, 55-62.

Frieß CC (2005). Jungfischsurvey in der Arkonasee und Mecklenburger Bucht (ICES 22+24). BFA für Fischerei Hamburg, Institut für Ostseefischerei Rostock, 6 pp.

Ganias K (2009). Linking sardine spawning dynamics to environmental variability. Estuarine, Coastal and Shelf Science 84: 402-408.

Gerritsen HD, Armstrong MJ, Allen M, McCurdy WJ and Peel JAD (2003). Variability in maturity and groth in a heavily exploited stock: whiting (*Merlangius merlangus* L.) in the Irish Sea. Journal of Sea Research, 49, 69-82.

Gibson RN and Robb L (1992). The relationship between body size, sediment grain size and the burying ability of juvenile plaice, Pleuronectes platessa L. Journal of Fish Biology, 40. 771-778.

Gibson RN (1994). Impact of habitat quality and quantity on the recruitmentof juvenile flatfishes. Netherlands Journal of Sea Research, 32(2). 191-206.

Gordon C, Cooper C, Senior CA, Banks H, Gregory JM, Johns TC, Mitchell JFB and Wood RA (2000). The simulation of SST, sea ice extents and ocean heat transports in a version of the Hadley Centre coupled model without flux adjustments. Climate Dynamics, 16:147–166.

Gordon JDM and Duncan JAR (1979). Some notes on the biology of the snakeblenny, *Lumpenus lampretaeformis* on the west coast of Scotland. J. Mar. Biol. Assoc. U.K. 59(2), 413-419.

Goren M and Galil BS (2005). A review of changes in the fish assemblages of Levantine inland and marine ecosystems following the introduction of non-native fishes. Journal of Applied Ichthyology 21(4): 364-370.

Graham C and Harrod C (2009). Implications of climate change for the fishes of the British Isles. Journal of Fish Biology 74(6): 1143-205.

Grauman GB and Yula E (1989). The importance of 440 abiotic and biotic factors in the early ontogenesis of cod and sprat. Rapports et Proces.

Grimm SK and Herra T (1984). Spawning cycles of southern Baltic fishes based on surveys of eggs and larvae. ICES CM 1984/J:30.

Grønkjær P and Wieland K (1997). Ontogenetic and environmental effects on vertical distribution of cod larvae in the Bornholm Basin, Baltic Sea. Marine Ecology Progress Series 154: 91-105.

Günther C (2008). Untersuchungen zum Sommerwachstum juveniler Sprotten (*Sprattus sprattus*) in der westlichen Ostsee. Diploma thesis, University of Hamburg, 89 pp

Hajdu S, Edler L, Olenina I, Witek B (2000). Spreading and establishment of the potential toxic dinoflagellate *Prorocentrum minimum* in the Baltic Sea. In: International Review of Hydrobiology, 85: 561-575.

Hall-Spencer JM, Rodolfo-Metalpa R, Martin S, Ransome E, Fine M, (2008). Volcanic carbon dioxide vents show ecosystem effects of ocean acidification. Nature 454:96–99.

Hammer C and Zimmermann C (2004). The Role of Stock Identification in Formulating Fishery Management Advice. IN: Stock Identification Methods. Cadrin SX, Friedland KD and Waldman JR (eds.), Elsevier Publishers, New York, pp. 631-657.

Hammer C, Oeberst R, and Ernst P (2007). Experimental Scientific Programme to the Pilot-Project "Aquaculture Based Cod management in the western Baltic Sea" as Part of the COBALT-Network (International Cooperation in Rebuilding Cod Stocks in the Baltic), unpublished.

Hammer C, Dorrien Cv, Ernst P, Gröhsler T, Köster F, Mackenzie B, Möllmann C, Wegner G and Zimmermann C (2008). Fish Stock Development under Hydrographic and Hydrochemical Aspects, the History of Baltic Sea fisheries and Its Management. In State and Evolution of the Baltic Sea, 1952-2005, eds. Feistel, R.; Nausch, G. and Wasmund, N.: Cpt. 18, 543-581.

Hansen MM, Fraser DJ, Als TD, Mensberg KLD (2008). Reproductive isolation, evolutionary distinctiveness and setting conservation priorities: The case of European lake whitefish and the endangered North Sea houting (Coregonus spp.). Evolutionary Biology 8:137.

Hansson HG (2006). Ctenophores of the Baltic and adjacent Seas – the invader Mnemiopsis is here! Aquatic Invasions 1(4), 295-298.

Hansson D, Eriksson C, Omstedt A and Chen D (2010). Reconstruction of river runoff to the Baltic Sea, AD 1500-1995. International Journal of Climatology doi: 10.1002/joc.2097.

Harley CDG, Hughes AR, Hultgren KM, Miner BG, Sorte CJB, Thornber CS, Rodriguez LF, Tomanek L, Williams SL (2006). The impacts of climate change in coastal marine systems. Ecological Letters 9(2): 228-241.

Hays GC, Richardson AJ, Robinson C (2005). Climate change and marine plankton. Trends in Ecology and Evolution. 20(6):337-344.

Härkönen T, Bäcklin B, Barrett T, Bergman A, Corteyn M, Dietz R, Harding K, Malmsten J, Roos A and Teilmann J (2008). Mass mortality in harbour seals and harbour porpoises caused by an unknown pathogen. Veterinary Record 2008, 162, 555-556.

Heinen A (1911). Die planktonischen Fisheier und Larven der Ostsee. Aus dem Laboratorium für internationale Meeresforschung in Kiel. Biologischer Abteilung. Nr. 23.

Helcom (2004). Minutes of the sixth meeting of nature protection and biodiversity group (HELCOM HABITAT 6/2004). Paragraphs 5.1-5.4. 12 pp and Annexes. http://sea.helcom.fi/dps/docs/documents/Nature%20Protection%20and%20Biodiversity%20Group%20(HABITAT)/HABITAT%206,%202004/FINAL%20MINUTES.pdf

HELCOM (2005). Coastal fish monitoring Workshop 2/2005; List of threatened and declining fish species in the Baltic Sea. Second Meeting Helsinki, Finland, 31 January - 3 February 2005.

Helcom (2007). Helcom Red list of threatened and declining species of lampreys and fishes of the Baltic Sea. Baltic Sea Environment Proceedings, No. 189. 40 pp.

HELCOM (2009). Eutrophication in the Baltic Sea – An integrated thematic assessment of the effects of nutrient enrichment and eutrophication in the Baltic Sea region: Executive Summary. Baltic Sea Environment Proc. No. 115A.

HELCOM (2011a). http://www.helcom.fi/environment2/biodiv/fish/species_communities/en_GB/communities/:

HELCOM (2011b). http://www.helcom.fi/environment2/biodiv/alien/en_GB/alienspecies. Accessed 21.03.2011.

Helmuth B, Mieszkowska N, Moore P, Hawkins SJ (2006). Living on the Edge of Two Changing Worlds: Forecasting the Responses of Rocky Intertidal Ecosystems to Climate Change. Annual Review of Ecology, Evolution and Systematics 37: 373-404.

Hermansen T and VisualSoft (1998). Almanac Version 1.0b. http://intra.nakskov-gym.dk/vs/almaopd.htm.

Hilge V (2004): Dem Aal steht das Wasser bis zum Hals, Bundesforschungsanstalt für Fischerei; Institut für Fischereiökologie – Arbeitsschwerpunkte 2005, 34.

Hinrichsen HH, Böttcher U, Oeberst R, Voss R and Lehmann A (2001a). The potential for advective exchange of the early life stages between the western and eastern Baltic cod (*Gadus morhua* L.) stocks. Fisheries Oceanography, 10, 249-258.

Hinrichsen HH, John MS., Aro E, Grønkjaer P and Voss R (2001b). Testing the larval drift hypothesis in the Baltic Sea: retention versus dispersion caused by wind-driven circulation. ICES Journal of Marine Science, 58, 973-94.

Hinrichsen HH, Möllmann C, Voss R, Köster FW and Kornilovs G (2002). Biophsical modelling of larval Baltic cod (*Gadus morhua* L) growth and survival. Canadian Journal of Fisheries and Aquatic Sciences 59: 1858-1873.

Hinrichsen HH, Kraus G, Voss R, Stepputtis D and Baumann H, (2005). The general distribution pattern and mixing probability of Baltic Sprat juvenile population. Journal of Marine Systems, 58, 52-66.

Hinrichsen HH, Lehmann A, Petereit C and Schmidt JO (2007). Correlation analyses of Baltic Sea winter water mass formation and its impact on secondary and tertiary production. Oceanologia 49(3): 381−395.

Hinrichsen HH, Kraus G, Böttcher U and Köster F (2009). Identifying eastern Baltic cod nursery grounds using hydrodynamic modelling: knowledge for the design of Marine Protected Areas. ICES Journal of Marine Science, 66: 101-108.

Hirzel A, Hausser J, Chessel D and Perrin N (2002). Ecological-niche factor analysis: How to compute habitat-suitability maps without absence data?, Ecology, 83, 2027–2036.

Hirzel A, Le Lay G, Helfer V, Randin C and Guisan A (2006). Evaluating the ability of habitat suitability models to predict species presences, Ecol. Model., 199, 142–152.

Höök TO, Gorokhova E and Hansson S (2008). RNA:DNA ratios of Baltic herring larvae and copepods in embayment and open sea habitats. Estuarine, Coastal and Shelf Science, 76, 29-35.

Hjalmarsson S, Wesslander K, Anderson LG, Omstedt A, Perttilä M and Mintrop L (2008). Distribution, long-term development and mass balance calculation of total alkalinity in the Baltic Sea. Continental Shelf Research, 28:593–601.

Hjort J (1914). Fluctuations in the great fisheries of Northern Europe – viewed in the light of biological research. Rapports et Proces-Verbaux des Reunions, Conseil International pour l'Éxploration de la Mer 20: 1-288.

Hoepffner N, Dowell MD, Edwards M, Fonda-Umani S, Green DR, Greenaway B, Hansen B, Heinze C, Leppänen J-M, Lipiatou E, Özsoy E, Philippart K, Salomons W, Sanchez-Arcilla A, Schrimpf W, Schrum C, Theocharis A, Tsimplis M, Gomes FV, Wakenhut F, Zaldivar JM (2006). Marine and coastal dimension of climate change in Europe. A report to the Europena Water Directors. 1-100.

Hurrel JW and van Loon H (1997). Decadal variations in climate associated with the North Atlantic Oscillation. Climate Change, 36:301–326.

Huwer, B (2004). Larval growth of *Sardina pilchardus* and *Sprattus sprattus* in relation to frontal systems in the German Bight. Diploma Thesis, Kiel University, 108 pp.

Hvidt, CB, Klaustrup, M, Leonhard SB, (2005). Monitoring Programme – Final Report 2004. Fish at the cable trace. Nysted Offshore Wind Farm at Rødsand. Bio/consult. Commissioned by ENERGI E2: 1-51.

Hvidt CB, Klaustrup M, Leonard SB and Pedersen J (2006). Fish at the cable trace Nysted offshore wind farm. Final report 2004. Prepared for ENERGI E2 A/S.

Ibbotson I, Smith J, Scarlett P and Aprahamian MW (2002). Colonisation of freshwater habitats by the European eel *Anguilla anguilla*. Freshwater Biology, 47, 1696–1706.

ICES (2005). Report of the ICES Advisory Committee on Fishery Management, Advisory Committee on the Marine Environment and Advisory Committee on Ecosystems, 2005. ICES Advice. Volumes 1 - 11. 1,418 pp.

ICES (2007a). WKHRPB Report of the ICES/BSRP Workshop on Recruitment of Baltic Sea herring stocks (WKHRPB). Workshop: 27 February – 2 March 2007. Hamburg, Germany

ICES (2007b). Report of the ICES Advisory Committee on Fishery Management, Advisory Committee on the Marine Environment and Advisory Committee on Ecosystems, 2007. ICES Advice. Book 8, 147 pp.

ICES (2007c). Manual for the Baltic International Trawl Surveys (BITS), March 2007 Rostock Germany.

ICES (2007d) Report of the ICES Advisory Committee on Fishery Management, Advisory Committee on Marine Environment and Advisory Committee on Ecosystems, 2007. ICES Advice. Books 1-10(6), 310 pp

ICES (2007e). Report of the Working Group on the Application of Genetics in Fisheries and Mariculture WGAGFM. ICES CM 2007/MCC:03.

ICES (2008a). Report of the Working Group for International Pelagic Surveys (PGHARS), ICES CM 2008/SSGESST:03.

ICES (2008b). Report of the Herring Assessment Working Group for the South of 62o N. Quality Handbook ANNEX: HAWG.herring WBSS

ICES (2008c). Report of the ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea (WGIAB). ICES CM 2008/BCC:04.

ICES (2008d). Report of the ICES Advisory Committee on Fishery Management, Advisory Committee on the Marine Environment and Advisory Committee on Ecosystems. ICES Advice. North Sea. Book 6.

ICES (2008e) Report on developing and testing environmentally-sensitive stock-recruitment relationships of Baltic herring and sprat stocks. ICES CM 2008/BCC:05

ICES/EIFAC (2008). Report of the 2008 session of the Joint EIFAC/ICES Working Group on Eels. ICES CM 2008/ACOME:15, EIFAC Occasional Paper No. 43.

ICES (2009a). Report of the Working Group for International Pelagic Surveys (WGIPS), ICES CM 2009/SSGESST:03.

ICES (2009b) Report of the Baltic Fisheries Assessment Working Group (WGBFAS) 22-28 April 2009 ICES Headquarters, Copenhagen. ICES CM 2009/ACOM:07, 626 pp.

ICES (2009c). Report of the Workshop on Combining Climatic Scenarios and Medium- Term Predictions for Baltic Herring and Sprat stocks (WKCSMPB), 13–16 October 2009, Ponza, Italy. ICES CM 2009/BCC:03, 50 pp.

ICES (2010a). Report of the Working Group for International Pelagic Surveys (WGIPS), ICES CM 2010/SSGESST:03.

ICES (2010b). Cooperative Research Report, No. 305, September 2010. Cod and future climate changes.

ICES (2010c) Report of the Baltic Fisheries Assessment Working Group (WGBFAS). ICES CM 2010/ACOM:10

ICES (2010d). Report of the Herring Assessment Working Group for the Area South of 62° N (HAWG), 15-23 March 2010, ICES Headquarters, Copenhagen, Denmark. 688pp. 3. Herring in Division IIIa and Subdivisions 22–24.

ICES (2010e). Review service: Evaluation of the Eel management plans. Report of the ICES secretariat.

ICES (2010f) Workshop on Including Socio-Economic considerations into the Climate-recruitment framework developed for clupeids in the Baltic Sea (WKSECRET), Ponza, Italy, 5-8 October 2010

Iles TD (1964). The Duration of Maturation Stages in Herring. ICES J. Mar. Sci., 29, 166-188.

IPCC (2000) IPCC special report emission scenarios, summary for policymakers. 27 pp

IPCC (2007) Climate change 2007: impacts, adaptation and vulnerability, summary for policy-makers 21 pp

IUCN (2010). http://www.iucnredlist.org/

Jaspers C, Titelman J, Hansson LJ, Haraldsson M and Ditlefsen CR (2010). The invasive ctenophore *Mnemiopsis leidyi* poses no direct threat to Baltic cod eggs and larvae. Limnol. Oceanogr. 56(2), 431-439.

Javidpour J, Sommer U, Shiganova TA (2006). First record of *Mnemiopsis leidyi* A. Agassiz 1865 in the Baltic Sea. Aquatic Invasions 1:299–302.

Jensen AJ (2003). Atlantic salmon (Salmo salar) in the regulated River Alta: Effects of altered water temperature on parr growth. River Research Applied 19(7): 733-747.

Jobling M (1997) Temperature and growth: Modulation of growth rate via temperature change. In: Global Warming: Implications For Freshwater And Marine Fish: 225-253

Johansson JM, Davis JL, Scherneck H-G, Milne GA, Vermeer M, Mitrovica JX, Bennett RA, Jonsson B, Elgered G, Elósegui, Koivula H, Poutanen M, Rönnäng BO and Shapiro II (2002). Continuous GPS measurements of postglacial adjustment in Fennoscandia 1. Geodetic results. Journal of Geophysical Research 107(B8) 2157, 10.1029/2001JB000400.

Johansen JE, Pinhassi J, Blackburn N, Zweifel UL and Hagström Å (2002). Viability in motility characteristics among marine bacteria. Aquatic Microbial Ecology, 28, 229-237.

Jönsson N and Scabell J (1986). Verbreitung und Wanderverhalten des Rügenschen Frühjahrsherings. 1. Fischereibiologische Herbsttagung vom 20.-21. November 1986 in Rostock. Published by „Der Rektor“ Wilhelm Pieck Universität Rostock, Sektion Biologie, 13-26.

Kääriä J, Rajasilta M, Kurkilahti M and Soikkeli M (1997). Spawning bed selection by the Baltic herring (*Clupea harengus membras*) in the Archipelago of SW Finland. ICES Journal of Marine Science, 54, 917-923.

Kaiser MJ, Gibson RN and Hughes RN (1992). The effect of prey type on the predatory behaviour of the fifteen-spined stickleback, *Spinachia spinachia* (L.). Animal Behaviour, 43(1), 147-156.

Karasiova E (2002). The variability of sprat peak spawning and larvae appearance timing in the southeastern Baltic Sea during the past six decades. Bulletin of the Sea Fisheries Institute, Gdynia 156: 57-68.

Karlsson L, Bartel R and Tesch FW (1988). Migration and orientation of tagged silver eels released in the southeastern Baltic. ICES C.M., 1988/M:17, pp. 1-6.

Kauppila P, Meeuwig JJ and Pitkanen H (2003). Predicting oxygen in small estuaries of the Baltic Sea: a comparative approach. Estuarine, Coastal and Shelf Science, 57: 1115–1126.

Kempf A, Floeter J and Temming A (2009). Recruitment of north sea cod (*Gadus morhua*) and norway pout (*Trisopterus esmarkii*) between 1992 and 2006: The interplay between climate influence and predation. Canadian Journal of Fisheries and Aquatic Sciences 66(4): 633-48

Kjesbu OS (1989). The spawning activity of cod, Gadus morhua L. Journal of Fish Biology 34: 195-206.

Kjesbu OS, Solemdal P, Bratland P and Fonn M (1996). Variation in annual egg production in individual captive Atlantic cod (*Gadus morhua*). Canadian Journal of Fisheries and Aquatic Sciences, 53, 610-620.

Kjesbu OS, Righton D, Krueger-Johnsen M, Thorsen A, Michalsen K, Fonn M and Witthames PR (2010). Thermal dynamics of ovarian maturation in atlantic cod (*Gadus morhua*). Canadian Journal of Fisheries and Aquatic Sciences 67(4): 605-25

Kjørsvik E, Stene A, and Lønning S (1984). Morphological, physiological and genetical studies of egg quality in cod (*Gadus morhua* L). In: The propagation of cod *Gadus morhua* L. Dahl, E., Danielssend, D.S., Moksness, E., Solemdal, P., (Eds). Flødevigen Rapportserie, 1, 67-86.

Klinkhardt M (1996). Der Herring. Magdeburg, Westarp-Wiss, Heidelberg. Spektrum Akad. Verl.:1-203.

Klinkhardt M and Reschke B (1980). Bestandszusammensetzung und Bestandsverbreitung des Herings südlich und westlich Rügens. Diplomarbeit Universität Rostock, Sektion Biologie, pp.159.

Kloppmann MHF, Böttcher U, Damm U, Ehrich S, Mieske B, Schultz N, Zumholz K (2003). Erfassung von FFH-Anhang II-Fischarten in der deutschen AWZ der Nord- und Ostsee. Abschlussbericht der Bundesforschungsanstalt für Fischerei über die Ergebnisse der naturschutzorientierten AWZ Forschung zum Schutzgut Fische. F+E-Vorhaben FKZ: 802 85 200, 82p.

Knudsen F, Hawkins A, McAllen R and Sand O (2009). Diel interactions between sprat and mackerel in a marine lough and their effects upon acoustic measurements of fish abundance. Fisheries Research 100:140-147.

Kornilovs G, Sidrevics L and Dippner JW (2001). Fish and zooplankton interaction in the Central Baltic Sea. ICES Journal of Marine Science 58: 579−588.

Kosior M and Strzyzewska K (1979). Fecundity of Baltic cod. ICES CM 1979/J:10.

Köster FW and Möllmann C (1997). Predation by sprat and herring on early life stages of cod and sprat in the central Baltic. In: Proceedings of the Symposium on Forage Fishes in Marine Ecosystems, Alaska Sea Grant College Program, AK-SG-97-01:41-69.

Köster FW, Möllmann C, Neuenfeldt S, Vinther M, StJohn MA, Tomkiewicz J, Voss R, Hinrichsen HH, Kraus G and Schnack D (2003a) Fish stock development in the central Baltic Sea (1976-2000) in relation to variability in the environment. ICES Marine Science Symposia 219: 294−306

Köster FW, Hinrichsen HH, Schnack D, StJohn MA, MacKenzie BR, Tomkiewicz J, Möllmann C, Kraus G, Plikshs M, Makarchouk A and Aro E (2003b) Recruitment of Baltic cod and sprat stocks: identification of critical life stages and incorporation of environmental variability into stock-recruitment relationships. Scientia Marina 67(1): 129−154

Köster FW, Möllmann C, Hinrichsen H-H, Tomkiewicz J, Wieland K, Kraus G, Voss R, MacKenzie BR, Schnack D, Makarchouk A, Plikshs M and Beyer JE (2005). Baltic cod recruitment – the impact of climate variability on key processes. ICES Journal of Marine Science, 62, 1408-1425.

Kotta J, Kotta I, Simm M and Pollupuu M (2009). Separate and interactive effects of eutrophication and climate variables on the ecosystem elements of the Gulf of Riga. Estuarine, Coastal and Shelf Science 84(4): 509-18.

Kottelat M and Freyhof J(2007). Handbook of European freshwater fishes. Berlin

Krappe M (2007). Erhaltungszustand von Neunaugenpopulationen in Mecklenburg-Vorpommern, Teil 2: Aktuelle Vorkommen und ihre Bewertung im Rahmen der FFH-Richtlinie. Naturschutzarbeit in Mecklenburg- Vorpommern 50 (1): 3-17.

Kraus G (1997). Fruchbarkeitsuntersuchungen an Dorschen in der zentralen Ostsee. MSc Thesis. Institut für Meereskunde, Universität Kiel.

Kraus G, Tomkiewicz J and Köster FW (2002). Egg production of Baltic cod in relation to variable sex ratio, maturity and fecundity. Canadian Journal of Fisheries and Aquatic Sciences 59: 1908-1920.

Kraus G, Pelletier D, Dubreuil J, Möllmann C, Hinrichsen H-H, Bastardie F, Vermard Y and Mahévas S (2009). A model-based evaluation of Marine Protected Areas: the example of eastern Baltic cod (Gadus morhua callarias). ICES Journal of Marine Science, 66, 109-121.

Kube J (2000). Naturschutzrelevante Untersuchungen zur Offshore-Windenergienutzung. Bundesamt für Naturschutz und Bundesministerium für Umwelt und Reaktorsicherheit, unveröffentlicht, 21 pp.

Kube S, Postel L, Honnef C and Augustin CB (2007). In the Baltic Sea – distribution and overwintering between autumn 2006 and spring 2007. *Mnemiopsis leidyi*. Aquatic Invasions, 2(2), 137-145.

Kändler R (1944). Untersuchungen über den Ostseedorsch während der Forschungsfahrten mit dem R.F.D. Poseidon in den Jahren 1925-1938. Berichte der deutschen wissenschaftlichen Kommission der Meeresforschung 11: 137-245.

LANU (1998). Umweltmonitoring in Schleswig-Holstein. Kleinfische der Ostseeküste. Monitoring-Bericht 1998, Kiel, 82 pp.

Lasne E and Laffaille P (2008). Analysis of distribution patterns of yellow European eels in the Loire catchment using logistic models based on presence–absence of different size-classes. Ecology of freshwater Fish 2008, 17, 30–37.

Last JM (1978). The food of three species of gadoid larvae in the eastern english channel and southern north sea. Marine Biology, 48, 377-286.

Le Pape O, Baulier L, Cloarec A, Martin J, Le Loc`h F and Desaunay Y (2007). Habitat suitability for juvenile common sole (*Solea solea*, L.) in the Bay of Biscay (France): A quantitative description using indicators based on epibenthic fauna. Journal of Sea Research, 57, 126-136.

Lee O, Danilowicz BS and Collas MD (2006). Temporal variability in growth and condition of dab (*Limanda limanda*) and sprat (*Sprattus sprattus*) larvae in the Irish Sea. Fisheries Oceanography, 15, 490-507.

Lee O, Danilowicz BS and Nash RDM (2007). Small-scale variability in growth and condition of dab Limanda limanda (L.) larvae in relation to an Irish Sea tidal-mixing front off the west coast of the Isle of Man. Journal of Fish Biology, 71, 1056-1068.

Lelek A (1987). Threatened Fishes of Europe. The Freswater Fishes of Europe vol 9. AULA *Wiesbaden: 1-343

Limburg KE, Wickström H, Svedäng H, Elfman M and Kristiansson P (2003). Do Stocked Freshwater Eels Migrate? Evidence from the Baltic Suggests “Yes”. American Fisheries Society Symposium, 33, 275–284.

Lindegren M, Diekmann R and Möllmann C (2010a). Regime shifts, resilience and recovery of a cod stock. Marine Ecology Progress Series 402: 239-53.

Lindegren M, Möllmann C, Nielsen A, Brander K, MacKenzie BR and Stenseth NC (2010b). Ecological forecasting under climate change: the case of Baltic cod. Proceedings of the Royal Society B 277: 2121-2130.

Lindegren M, Möllmann C, Nielsen A and Stenseth NC (2009). Preventing the collapse of the Baltic cod stock through an ecosystem-based management approach. Proceedings of the National Academy of Sciences of the United States of America 106: 14722-14727.

Loeng H and Drinkwater K (2007). An overview of the ecosystems of the Barents and Norwegian seas and their response to climate variability. Deep Sea Res (II) 54(23-26): 2478-500.

Loots C, Vaz S, Planck B and Koubbi P (2010). Spawning distribution of North Sea plaice and whiting from 1980 to 2007. Journal of Oceanography, Research and Data 3: 77 – 95.

Lozan JL and Kausch H (2007). Angewandte Statistik fur Naturwissenschaftler. 4. Aufl. Wissenschaftliche Auswertungen, Hamburg. 1-301.

Luksenburg JA, Pedersen T and Falk-Petersen I-B (2004). Reproduction of the shorthorn sculpin Myoxocephalus scorpius in northern Norway. Journal of Sea Research, 51(2), 157-166.

MacKenzie BR, Hinrichsen HH, Plikshs M, Wieland K and Zezera AS (2000). Quantifying environmental heterogeneity: habitat size necessary for successful development of cod Gadus morhua eggs in the Baltic Sea. Marine Ecology Progress Series 193: 143-156.

MacKenzie BR and Schiedek D (2007a). Daily ocean monitoring since the 1860s shows unprecedented warming of northern European Seas. Global Change Biology, 13, 1335-1347.

MacKenzie BR and Schiedek D (2007b). Long-term sea surface temperatures baselines – time series, spatial covariation and implications for biological processes. Journal of marine Systems, 68, 405-420.

MacKenzie BR, Alheit J, Conley DJ, Holm P and Kinze CC (2002). Ecological hypotheses for a historical reconstruction of upper trophic level biomass in t the Baltic Sea and Skagerrak. Can. J. Fish. Aquat. Sci., 59, 173-190.

MacKenzie BR and Köster FW (2004). Fish production and climate: sprat in the Baltic Sea. Ecology, 85, 784-794.

MacKenzie BR, St John MA, Plikshs M, Hinrichsen H-H and Wieland K (1996a). Oceanographic processes influencing seasonal and interannual variability in cod spawning habitat in the Eastern Baltic Sea. ICES CM 1996/C+J:4.

MacKenzie BR, St John MA and Wieland K (1996b). Eastern Baltic cod: perspectives from existing data on processes affecting growth and survival of eggs and larvae. Marine Ecology Progress Series, 134, 265-281.

MacKenzie DJ, Piccolella M, Dalle Valle AZ, Taylor EW, Bolis CL and Steffensen JF (2003). Tolerance of chronic hypercapnia by the European eel *Anguilla anguilla*. The Journal of Experimental Biology 206: 1717-1726.

MacLennan DN and Simmonds JE (eds.) (1992). "Fisheries acoustics" Chapman and Hall, ISBN 04123306010.

MacLennan DN and Fernandes P (2000). Definitions, units and symbols in fisheries acoustics. Appendix D. Report of the working group on fisheries acoustics science and technology. ICES CM 2000/B:04.

MacLennan DN, Fernandes PG and Dalen J (2002). A consistent approach to definitions and symbols in fisheries acoustics, ICES Journal of Marine Science. 59, 365–369.

Maitland PS and Hatton-Ellis TW (2003). Ecology of the Allis and Twaite shad. Conserving Natura 2000 Rivers Ecology Series No. 3.English Nature, Peterborough.

Malzahn AM, Clemmesen C, Wiltshire KH, Laakmann S and Boersma M (2007). Comparative nutritional condition of larval dab (*Limanda limanda*) and lesser sandeel (*Ammodytes marinus*) in a highly variable environment. Marine Ecology Progress Series, 334, 205-212.

Mantzouni I and MacKenzie BR (2010). Productivity responses of a widespread marine piscivore, *Gadus morhua*, to oceanic thermal extremes and trends. Proceedings of the Royal Society of London, Series B: Biological Sciences 277(1689): 1867-1874.

Maravelias CD, Reid DG (1995). Relationship between herring (*Clupea harengus*, L.) distribution and sea surface salinity and temperature in the northern North Sea. Scientia Marina 59(3-4): 327-343.

Margonski P, Hansson S, Tomczak MT and Grzebielec R (2010). Climate influence on Baltic cod, sprat, and herring stock-recruitment relationships. Progress in Oceanography 87(1-4): 277-88.

Marteinsdottir G and Thorarinsson K (1998). Improving the stock-recruitment relationship in Icelandic cod (*Gadus morhua*) by including age diversity of spawners. Canadian Journal of Fisheries and Aquatic Sciences, 55, 1372-1377.

Martteinsdottir, G. and Steinarsson, A. (1998). Materal influenceson the size and variability of Icelandic cod (*Gadus morhua*) eggs and larvae. Journal Fish Biology, 52, 1241-1258.

Matthäus W and Schinke H (1994). Mean atmospheric circulation patterns associated with major Baltic inflows. Deutsche Hydrographische Zeitschrift, 46, 321-339.

McGurk MD (1986). Natural mortality of marine, pelagic fish eggs and larvae – role of spatial patchiness. Mar. Ecol. Prog. Ser., 34, 227-242.

Meier HEM, Broman B and Kjellström E (2004). Simulated sea level in the past and future climates of the Baltic Sea. Climate Research, 27:59–75.

Meier HEM (2006). Baltic Sea climate in the late twenty-first century: a dynamical downscaling approach using two global models and two emission scenarios. Climate Dynamics, 27:39–68.

Meier HEM, Kjellström E and Graham LP (2006). Estimating uncertainties of projected Baltic Sea salinity in the late 21st century. Geophysical Research Letters, 33, CITE ID L15705, DOI 10.1029/2006GL026488.

Mendel B, Sonntag N, Wahl J, Schwemmer P, Dries H, Guse N, Müller S and Garthe S (2008). Artensteckbriefe von See- und Wasservögeln der deutschen Nord- und Ostsee. Verbreitung, Ökologie und Empfindlichkeiten gegenüber Eingriffen in ihren marinen Lebensraum. BfN, Naturschutz und Biologische Vielfalt, 59, 437 pp.

Ministry of Food, Agriculture and Fisheries (2008). Danish Eel management plan. In accordance with COUNCIL REGULATION (EC) No 1100/2007 of 18 September 2007.

Mieszkowska N, Genner MJ, Hawkins SJ and Sims DW (2009). Effects of climate change and commercial fishing on Atlantic cod Gadus morhua. Advances in Marine Biology 56: 213-273.

Misund OA, Vilhjalmsson H, Jakupsstovu SH, Rottingen I, Belikov S, Asthorsson O, Blindheim J, Jonsson J, Krysov A, Malmberg SA and Sveinbjornsson S (1998). Distribution, migration and abundance of Norwegian spring spawning herring in relation to the temperature and zooplankton biomass in the Norwegian Sea as recorded by coordinated surveys in Spring and Summer 1996. Sarsia 83(2): 117-127.

Moksness E (1992). Validation of daily increments in the otolith microstructure of Norwegian spring-spawning herring (*Clupea harengus* L.). ICES Journal of Marine Science, 49, 231-235.

Möller H (1984). Daten zur Biologie der Quallen und Jungfische in der Kieler Bucht. Möller, Kiel.

Möllmann C and Köster FW (2000). Food consumption by Clupeids in the Central Baltic: is there evidence for top-down control? ICES Journal of Marine Science, 56, 100-113.

Möllmann C, Kornilovs G and Sidrevics L (2000). Long-term dynamics of main mesozooplankton species in the Central Baltic Sea. Journal of Plankton Research 22: 2015−2038.

Möllmann C, Kornilovs G, Fetter M, Köster FW and Hinrichsen HH (2003). The marine copepod, *Pseudocalanus elongatus*, as a mediator between climate variability and fisheries in the Central Baltic Sea. Fisheries Oceanography 12(4-5): 360–368.

Möllman C, Kornilovs G, Fetter M and Köster FW (2004). Feeding ecology of central Baltic Sea herring and sprat. Journal of fish biology, 65, 1563-1581.

Möllmann C, Kornilovs G, Fetter M and Köster FW (2005). Climate, zooplankton, and pelagic fish growth in the central Baltic Sea ICES J. Mar. Sci., 62(7), 1270-1280.

Möllmann C, Diekmann R, Müller-Karulis B, Kornilovs G, Plikshs M and Axe P (2009). Reorganization of a large marine ecosystem due to atmospheric and anthropogenic pressure: a discontinuous regime shift in the Central Baltic Sea. Global Change Biology 15: 1377−1393.

Müller A (1988). Seasonal change of zooplankton in Kiel Bay: IV. Ichthyoplankton. Kieler Meeresforsch., Sonderh., 6, 323-330.

Müller JP and Jensen HJ (2000). Fiskeundersøgelser i fjorde og kystnære marine områder. Udredning 2000. Rapport udarbejdet til Ringkøbing Amt, Frederiksborg Amt og Skov- og Naturstyrelsen.

Munk P (1997). Prey size and prey availability of larval and small juvenile cod. Journal of fish biology 51:340-351.

Munk P and Nielsen J (2008). Eggs and larvae of the North Sea Fishes. ISBN: 9788791319242.

Muus BJ and Nielsen JG (1999). Die Meeresfische Europas in Nordsee, Ostsee und Atlantik. Franckh-Kosmos Verlag, Stuttgart.

Muus BJ, Nielsen JG, Dahlstrøm P and Nystrøm BO (1998). Havfisk og fiskeri I Nordvest Europa. ISBN 87-12-02996-3, Gads forlag København.

Muus BJ and Nielsen JG (1999). Sea fish. Scandinavian Fishing Year Book, Hedehusene, Denmark

Muus J and Nielsen JG (2006). Havfisk og fiskeri i Nordvesteuropa. Gyldendal 6th edition.

Nellen W and Thiel R (1996). Kap. 6.4.1 Fische. In: G. Rheinheimer (Hrsg.) Meereskunde der Ostssee. Springer-Verlag, Berlin, Heidelberg, 190-196.

Nehring S (2003). Alien species in the North Sea: invasion success and climate warming. Ocean Challenges 13(3):12-16.

Neuenfeldt S, Hinrichsen H-H, Nielsen A and Andersen KH (2007). Reconstructing migrations of individual cod (*Gadus morhua* L.) in the Baltic Sea by using electronic data storage tags. Fish. Oceanogr. 16(6), 526–535.

Nicholls RJ and Cazenave A (2010). Sea-level rise and its impact on coastal zones. Science 328 (5985):1517-1520.

Nielsen JR (1996). Acoustic monitoring of herring in the Sound related to the establishment of a fixed link across the Sound between Copenhagen and Malmo. Final report 1993-96.

Nielsen EE, Hansen MM, Ruzzante DE, Meldrup D and Grønkjær P (2003). Evidence of a hybrid-zone in Atlantic cod (*Gadus morhua*) in the Baltic and the Danish Belt Sea revealed by individual admixture analysis. Molecular Ecology, 12,1497-1508.

Nielsen J (1996). Acoustic monitoring of herring related to the establishment of a fixed link across the Sound between Copenhagen and Malmo. Final report 1993-1996 to Øresundskonsortiet.

Nielsen JR, Lundgren B, Jensen TF and Stæhr KJ (1999). Acoustic monitoring of herring in the Sound. Final report 1993-98.

Nielsen JR, Lundgren B, Jensen TF and Stæhr KJ (2001). Distribution, density and abundance of the western Baltic herring (*Clupea harengus*) in the Sound (ICES Subdivision 23) in relation to hydrographical features. Fisheries Research, 50(3), 235-258.

Nielsen R, Lundgren B, Jensen TF and Staehr KJ (1999). Acoustic monitoring of herring in the sound - final report 1993-98. DFU-Rapport no. 67-99.

Niemann H (1991). Die Fischbesiedlung im Flachwasser der Kieler Bucht. Ein Vergleich der Sommer 1976 und 1990. Diplomarbeit, math. naturwiss. Fak. Kiel.

Nissling A, Kryvi H, and Vallin L (1994). Variation in egg buoyancy of Baltic cod *Gadus morhua* and its implication for egg survival in prevailing conditions in the Baltic Sea. Marine Ecology Progress Series, 110, 67-74.

Nissling A and Westin L (1997). Salinity requirements for successful spawning of Baltic and Belt Sea cod and the potential for cod stock interactions in the Baltic Sea. MEPS, 152, 261-271.

Nissling A, Hinrichsen H-H, Müller A, Köster FW and Makarchouk A (2002). Vertical distribution and egg survival of baltic sprat in relation to temperature and oxygen conditions - implications for stock development. ICES CM(2002/O:08).

Nissling A, Müller A and Hinrichsen HH (2003). Specific gravity and vertical distribution of sprat (Sprattus sprattus) eggs in the Baltic Sea. Journal of Fish Biology 63: 280-299.

Nissling A (2004). Effects of temperature on egg and larval survival of cod (*Gadus morhua*) and sprat (*Sprattus sprattus*) in the Baltic Sea - implications for stock development. Hydrobiologia 514(1-3): 115−123.

Norddeutscher Klimaatlas (2011) http://www.norddeutscher-klimaatlas.de

Oeberst R (2001). The importance of the Belt Sea cod for the eastern Baltic cod stock. Archive of Fisheries and Marine Research, 49, 83-102.

Oeberst R (2008). Distribution pattern of cod and flounder in the Baltic Sea based on international coordinated trawl surveys. ICES CM 2008/J:09, 28 pp.

Ojaveer H, Lumberg A (1995). On the role of Cercopagis pengoi (Ostroumov) in Parnu Bay and the NE part of the Gulf of Riga ecosystem. Proceedings of the Estonian Academy of Sciences. Ecology, 5: 20-25.

Ojaveer E and Kalejs M (2010). Ecology and long-term forecasting of sprat (*Sprattus sprattus balticus*) stock in the Baltic Sea: a review. Reviews in Fish Biology and Fisheries, 20/2, 203-217.

Omstedt A and Axell LB (2003). Modeling the variations of salinity and temperature in the large Gulfs of the Baltic Sea. Continental Shelf Research, 23:265–294.

Omstedt A, Edman M, Anderson LG, Laudon H (2010). Factors influencing the acid–base (pH) balance in the Baltic Sea: a sensitivity analysis. Tellus (62B): 280-295.

OSF (2004). Bericht über die 528. Reise des FFS“Solea“ vom 1.07. bis 12.07.2004. Untersuchungen zur demersalen Fischfauna in den für den Naturschutz bedeutsamen Gebieten vor der deutschen Ostseeküste mittels Grundschlepnetz. 6 p

Ospar Commission (2010). Background document for European eel *Anguilla Anguilla*. Biodiversity Series.

Otterlind G (1984). The Rügen-herring in Swedish Waters with remarks on herring population problems. ICES CM, 1984/J:16.

Otterlind G (1985). Cod migration and transplantation experiments in the Baltic. Zeitschr. Angew. Ichthyol. 1(1), 3-16.

Ottersen G, Hjermann DØ and Stenseth NC (2006). Changes in spawning stock structure strengthen the link between climate and recruitment in a heavily fished cod (*Gadus morhua*) stock. Fisheries Oceanography 15: 230-243.

Paaver T (1991). Elektroforetisk undersökning av romproteiner hos laxfisk. Information från Sötvattenslaboratoriet, Drottingholm, 4, 49-62.

Parmanne R, Rechlin O and Sjöstrand B (1994). Status and future of herring and sprat stocks in the Baltic Sea. Dana 10: 29-59.

Pauli, D. and Pullin, R.S.V. (1988). Hatching time in spherical, pelagic, marine fish eggs in response to temparature and egg size. Env. Biol. Fish., 21(2), 261-271.

Peck MA and Möllmann C (2008). RECLAIM – Resolving CLimatic IMpacts on fish stocks. Specific Targeted Research Project on "Modernisation and sustainability of fisheries, including aquaculture-based production systems". 1.6 Report of WP1 – Chapter 15 – Sprat.

Pedersen SA, Fock H, Krause J, Pusch C, Sell AL and Böttcher U (2009). Natura 2000 sites and fisheries in german offshore waters. ICES Journal of Marine Science 66, 155-169.

Pepin P, Evans GT and Shears TH (1999). Patterns of RNA/DNA ratios in larval fish and their relationship to survival in the field. ICES Journal of Marine Science, 56, 697-706.

Pepin P, Orr DC, and Anderson JT (1997). Time to hatch and larval size in relation to temperature and egg size in Atlantic cod (*Gadus morhua*). Can. J. Fish. Aquat. Sci., 54(S1), 2–10.

Perry AL, Low PJ, Ellis JR, Reynolds JD (2005). Climate Change and Distribution Shifts in Marine Fishes. Science 308(5730): 1912-1915.

Peschutter JGR (2008). Ernährungszustand von Fischlarven in der Kieler Förde und im Nord-Ostsee-Kanal. Diploma thesis Kiel University.

Petereit C, Haslob H, Kraus G and Clemmesen C (2008). The influence of temperature on the development of Baltic Sea sprat (*Sprattus sprattus*) eggs and yolk sac larvae. Marine Biology 154: 295−306.

Petereit C, Hinrichsen HH, Voss R, Kraus G, Freese M and Clemmesen C (2009). The influence of different salinity conditions on egg buoyancy, -development, -survival and morphometric traits of Baltic Sea sprat (*Sprattus sprattus balticus*) yolk sac larvae. Scientia Marina 73(1): 59−72.

Pielou EC (1966). Measurement of diversity in different types of biological collections. J. Theoret. Biol., 13, 131-144.

Power M, Attrill MJ and Thomas RM (2000). Environmental factors and interactions affecting the temporal abundance of juvenile flatfish in the Thames Estuary. Journal of Sea Research, 43, 135-149.

Purcell JE and Arai MN (2001). Interactions of pelagic cnidarians and ctenophores with fish: a review. Hydrobiologia, 451, 27–44.

Räisänen J, Hansson U, Ullerstig A, Döscher R, Graham LP, Jones C, Meier M, Samuelsson P and Willen U (2003). GCM driven simulations of recent and future climate with the Rossby Centre coupled atmosphere – Baltic Sea regional climate model RCAO. Reports Meteorology and Climatology 101, Swedish Meteorological and Hydrological Institute, Norrköping, Sweden, 61 pp.

Rannak LA (1958). Quantitative study of the Baltic herring eggs and larvae in the northern part of the Gulf of Riga and principle factor determining their survival. Trudy VNIRO, 34, 7-18.

Rasmussen J (2008). Pers. Com. Fisherman Lolland.

Rechlin O (1967). Heringsfischerei und Heringsbestand in der Ostsee während der Jahre 1961-1965. Fischereiforschung, 5(2), 23-31.

Rechlin O (1991). Tendencies in the Herring Population Development of the Baltic Sea. International Review of Hydrobiology, 76 (3) 405-412.

Rechlin O (2003). Zur Situation der kommerziell genutzten Fischbestände in der Ostsee. In: Fische und Fischerei in Nord- und Ostsee. Meer and Museum Bd.,17, 86-95.

Remane A and Schlieper C (1971). Biology of Brackish Water. Die Binnengewässer. Band XXV. Stuttgart, 1-372.

Riber HH and Raschke N (1999). Fehmarnbelt Feasibility Study Coast-to-Coast investigations, investigation of Environmental Impact. COWI-Lahmeyer, January, 1999.

Riecken U, Finck P, Raths U, Schröder E and Ssymank, A (2006). Rote Liste der gefährdeten Biotoptypen Deutschlands. Zweite fortgeschriebene Fassung. Bundesamt für Naturschutz Bonn – Bad Godesberg, Naturschutz und biologische Vielfalt, 34, 318 pp.

Rindorf A and Gislason H (2005). Functional and aggregative response of North Sea whiting. Journal of Experimental Marine Biology and Ecology, 324, 1–19.

Rogers SI (1992). Environmental factors affectimg the distribution of sole (*Solea solea* L.) within a nursery area. Netherlands Journal of Sea Research, 29(1-3), 153-161.

Roeckner E, Bengtsson L, Feichter L, Lelieveld J and Rodhe H (1999). Transient climate change simulations with a coupled atmosphere-ocean GCM including the tropospheric sulfur cycle. Journal of Climate, 12:3004–3032.

Rose GA (2005). On distributional responses of North Atlantic fish to climate change. ICES Journal of Marine Science, 62, 1360-1374.

Rose KA, Megrey BA, Hay D, Werner F and Schweigert J (2008). Climate Regime Effects on Pacific Herring Growth Using Coupled Nutrient–Phytoplankton–Zooplankton and Bioenergetics Models. Transactions of the American Fisheries Society, 137:278-297.

Rudstam LG, Aneer G and Hildén M (1994). Top-down control in the pelagic Baltic ecosystem. Dana 10: 105−129.

Rui Beja, P (1995). Structure and seasonal fluctuations of rocky littoral fish assemblages in south-western Portugal: Implications for otter prey availability. J. Mar. Biol. Assoc. U.K., 75(4), 833-847.

Russell FS (1976). The egg and Planktonic Stages of British Marine Fishes. Academic press, London. ISBN: 0-12 604050-8.

Sapota MR (2004). The round goby (*Neogobius melanostomus*) in the Gulf of Gdańsk – a species introduction into the Baltic Sea. Hydrobiologia Vol. 514, No. 1-3, 219-224.

Sarmiento JL, Slater R, Barber R, Bopp L, Doney SC, Hirst AC, Kleypas J, Matear R, Mikolajewicz U, Monfray P, Soldatov V, Spall SA and Stouffer R (2004). Response of ocean ecosystems to climate warming. Global Biogeochemical Cycles 18(3).

Scabell J (1988). Der Rügensche Frühjahrshering – Das Laichgeschehen. Dissertation, Universität Rostock: 117 pp.

Schaber M, Hinrichsen HH, Neuenfeldt S and Voss R (2009). Hydroacoustic resolution of small-scale vertical distribution in baltic cod *Gadus morhua* - habitat choice and limits during spawning. Marine Ecology Progress Series 377: 239-53.

Schinke H and Matthäus W (1998). On the causes of major Baltic inflows – an analysis of long time series. Continental Shelf Reports, 18, 67-97.

Schnack D (2003). Fische und Fischerei in Ost- und Nordsee. Meer und Museum 17:96-103.

Seber GAF (1973). The estimation of animal abundance and related parameters. London: Griffin.

Shannon C and Wiener N (1949). The mathematical theory of communication. University of Illinois Press, Champaign, 1-111.

Simon J (2011). Wenn Jäger zu Gejagten werden – Nahrungsuntersuchungen an Kormoranen in der Havel bei Potsdam. Angeln in Mecklenburg-Vorpommern, 1/2011, 12-16.

Sjöberg NB and Petersson E (2005). Blankålsmärkning – Till hjälp för att förstå blankålens migration i Östersjön. Fiskeriverket informerar, FINFO, 2005:3.

Sjöberg NB, Petersson E, Wickström H and Hansson S (2009). Effects of the swimbladder parasite *Anguillicola crassus* on the migration of European silver eels *Anguilla Anguilla* in the Baltic Sea. Journal of Fish Biology, 74, 2158–2170.

Skora KE (1997). *Neogobius melanostomus*. In: Baltic Sea alien species database. Olenin S, Leppakoski E and Daunys D (eds.).

Skóra KE and Stolarski J (1993). New fish species in the Gulf of Gdańsk *Neogobius sp.* [cf. *Neogobius melanostomus* (Pallas 1811)]. Bull. Sea Fisheries Inst., 1(128).

Skov- og Naturstyrelsen, 2010. http://www.skovognatur.dk/DyrOgPlanter/Artsleksikon/Fisk/

Smith PE and Richardson SL (1977). Standard Techniques for Pelagic Fish Egg and Larvae Surveys. Food and Agriculture Organization of the United Nations, Fisheries Technical Paper, 175, 100 p.

Sohlenius G, Emeis K-C, Andrén E, Andrén T and Kohly A. (2001). Development of anoxia during the Holocene fresh-brackish water transition in the Baltic Sea. Marine Geology, 177, 221-242.

Somarakis S, Ganias K, Tserpes G and Koutsikopoulos C (2004). Ovarian allometry and the use of the gonosomatic index: a case study in the Mediterranean sardine, Sardina pilchardus. Marine Biology 146: 181-189

Stepputtis D (2006). Distribution pattern of Baltic sprat (*Sprattus sprattus* L.) – causes and consequences. Dissertation zur Erlangung des Doktorgrades der Mathematisch-Naturwissenschaftlichen Fakultät der Christian-Albrecht-Universität zu Kiel. Vorgelegt von Daniel Stepputtis, Kiel 2006.

Stepputtis D, Hinrichsen HH, Böttcher U, Götze E and Mohrholz V (2011). An example of meso-scale hydrographic features in the central Baltic Sea and their influence on the distribution and vertical migration of sprat, *Sprattus sprattus balticus* (Schn.). Fisheries Oceanography 540 (20): 82-88.

Stenevik EK, Fossum P, Johannessen A and Folkvord A 1996. Identification of Norwegian spring spawning herring (*Clupea harengus* L.) larvae from spawning grounds off Western Norway applying otolith microstructure analysis. Sarsia, 80: 285-292.

Stevenson DK and Campana SE (1992). Otolith microstructure examination and analysis. Canadian Special Publication of Fisheries and Aquatic Sciences.

Stige LC, Ottersen G, Brander K, Chan K and Stenseth NC (2006). Cod and climate: Effect of the North Atlantic Oscillation on recruitment in the North Atlantic. Marine Ecology Progress Series 325: 227-41.

Stoltze M and Pihl S (1998). Gulliste over planter og dyr i Danmark. Miljø- og Energiministeriet.

Strand J (2006). Teknisk anvisning for marin overvågning. 6.1 Fiskeundersøgelser i kystnære marine områder. NOVANA. ver. 15-03-06. Danmarks Miljøundersøgelser. – Teknisk anvisning fra DMU's Marine Fagdatacenter 44 s. Modified from Teknikergruppen, 2002. Fiskeundersøgelser i kystnære marine områder. 1. udgave af teknisk vejledning, januar 2002. Ringkøbing Amt, Frederiksborg Amt og Århus Amt. ISBN 8-7781-222-0: 1-44.

Summers RW (1979). Life cycle and population ecology of the flounder *Platichthys flesus* (L.) in the Ythan Estuary, Scotland. Journal of Natural History, 13, 703-723.

Sundby S and Nakken O (2008). Spatial shifts in spawning habitats of Arcto-Norwegian cod related to multidecadal climate oscillations and climate change. ICES Journal of Marine Science 65(6): 953-62

Søgaard B, Skov F, Ejrnæs R, Nielsen KE, Pihl S, Clausen P, Laursen K, Bregnballe T, Madsen J, Baatrup-Pedersen A, Søndergaard M, Lauridsen TL, Møller PF, Riis-Nielsen T, Buttenschøn RM, Fredshavn J, Aude E & Nygaard B (2003). Kriterier for gunstig bevaringsstatus. Naturtyper og arter omfattet af EF-habitatdirektivet & fugle omfattet af EF-fuglebeskyttelsesdirektivet. 2. udgave. Danmarks Miljøundersøgelser. 462 s. - Fagligrapport fra DMU, nr. 457

Teilmann J, Carstensen J, Dietz, R, Edrén SME (2004). Effect on seals at Rødsand seal sanctuary from the construction of Nysted offshore wind farm based on aerial surveys. Technical report to Energy E2 A/S. National Environmental Research Institute, Roskilde.

Teschner E, Kraus G, Neuenfeldt S, Voss R, Hinrichsen HH and Köster F (2011). Impact of hypoxia on consumption of Baltic cod in a multispecies stock assessment context. Journal of Applied Ichthyology 26(6): 836-42.

Thiel R (2001). Spatial gradients of food consumption and production of juvenile fish in the lower river Elbe. Large Rivers 12 (2-4); Arch. Hydrobiol. Suppl., 135/2, 441-462

Thiel R and Backhausen I (2006). Survey of NATURA 2000 fish species in the German North and Baltic Seas. In Nordheim von H.; Boedeker, D. and Krause, J.C (Eds.) Progress in Marine -conservation in Europe. Natura 2000 Sites in German Offshore Waters. Springer. Cpt.9: 157-178

Thiel R and Winkler HM (2007). Erfassung von FFH-Anhang II-Fischarten in der deutschen AWZ von Nord- und Ostsee – (ANFIOS). Schlussbericht über das F+E-Vorhaben für das BfN (FKZ: 803 85 220). Stralsund und Rostock, Mai 2007, 108 pp.

Thiel R, Riel P, Neumann R, Winkler HM, Böttcher U and Gröhsler T (2008). Return of twaite shad alosa fallax (lacépède, 1803) to the southern baltic sea and the transitional area between the baltic and north seas. Hydrobiologia, 602(1),161-177.

Thiel R, Winkler HM and Urho L (1996). Zur Veränderung der Fischfauna. In: J.L. Lozán, R. Lampe, W. Matthäus, E. Rachor, H. Rumohr and H. v. Westernhagen (Hrsg.) Warnsignale aus der Ostsee – wissenschaftlich Fakten. Parey Verlag, Berlin, 181-188.

Thompson BM and Riley JD (1981). Egg and larval development studies in the North Sea cod (*Gadus morhua* L.). Rapp. P. Reun. Cons. Int. Explor. Mer., 178, 553-559.

Thurow F (1963). Dorschmarkieringen in der westlichen ostsee. Institut für Meerskunde d. Universität Kiel.

Thurow F (1970). Über die Fortpflanzung des Dorsches Gadus morhua (L.) in der Kieler Bucht. Berichte der Deutschen Wissenschaftlichen Kommission für Meeresforschung 21(1-4), 170-192.

Thurow, F. (1997). Estimation of the total fish biomass in the Baltic Sea during the 20th century. ICES J. Mar. Sci., 54, 444-461.

Thompson BM, Milligan SP and Nichols JH (1981) The development rates of sprat (*Sprattus sprattus*) eggs over a range of temperatures. ICES CM 1981/H:15

Tomkiewicz J, Tybjerg L, Holm N, Hansen A, Broberg C and Hansen E (2002). Manual to determine gonadal maturity of Baltic cod. DFU rapport 116-02, Charlottenlund: Danish Institute for Fisheries Research, 49 p.

Tomkiewicz J, Støttrup J, Jacobsen C, Røjbek M and Köster FW (2009). Influenec of lipids and fatty acid composition in eastern Baltic cod (*Gadus morhus* L.) and its prey with emphasis on the timing of maturation and spawning. ICES CM 2009/C:10.

Toresen R and Oestvedt O (2000). Variation in abundance of Norwegian spring-spawning herring (*Clupea harengus*, clupeidae) throughout the 20th century and the influence of climatic fluctuations. Fish and Fisheries 1(3): 231-56.

Treasurer J and For L (2010). Assessment of egg quality and realised fecundity of whiting *Merlangius merlangus* L. in captivity. Journal of applied Ichthyology, 26(4), 554-560.

Trippel EA, Kraus G and Köster F (2005). Maternal and paternal influences on early life history traits and processes of Baltic cod, *Gadus morhua*. Marine Ecology Progress Series, 303, 259-267.

Vallin L, Nissling A, and Westin L (1999). Potential factors influencing reproductive success of Baltic cod *Gadus morhua*: a review. Ambio, 28, 92-99.

Vallin L, and Nissling A (2000). Maternal effects on eggs size and egg buoyancy of Baltic cod, *Gadus morhua*, Implications for stock structure effects on recruitment. Fisheries Research, 49, 21-37.

Varpe O, Fiksen O and Slotte A (2005). Meta-ecosystems and biological energy transport from ocean to coast: The ecological importance of herring migration. Oecologia 146(3): 443-51

Van Deurs M and Ramkær K (2007). Application of a tag parasite, anisakis sp., indicates a common feeding migration for some genetically distinct neighbouring populations of herring, *Clupea harengus*. Acta Ichthyologica et Piscatoria 37: 73-79

Van den Thillart G, Palstra G and Van Ginneken V (2007). Simulated migration of Europaen silver eel; swim capacity and cost of transport. Special Issue, pp. 1-16.

Van der Land MA (1991). Distribution of flatfish eggs in the 1989 egg surveys in the southeastern North Sea, and the mortality of plaice and sole eggs. Netherlands Journal of Sea Research, 27, 277-286.

Van Ginneken VJT, van den Thillart GEEJM (2000). Eel fat stores are enough to reach the Sargasso. Nature 403:156–157

Vinagre C, Franca S, Costa MJ and Cabral HN (2005). Niche overlap between juvenile flatfishes, Platichthys flesus and Solea solea, in a southern European estuary and adjacent coastal waters. Journal of Applied Ichthyology, 21, 114-120.

Vøllestad LA and Jonsson B (1988). A 13-Year Study of the Popultion Dynamics and Growth of the European Eel *Anguilla Anguilla* in a Norwegian River: Evidence for Density-Dependent Mortality, and Development of a Model for Predicting Yield. Journal of Animal Ecology, 57, 983-997.

Voss R, Schmidt JO, Schnack D (2007). Vertical distribution of Baltic sprat larvae: changes in patterns of diel migration? ICES Journal of Marine Science 64, 956-962.

Voss R (2002). Recruitment processes in the larval phase: the influence of varying transport on cod and sprat larval survival, Dissertation zur Erlangung des Doktorgrades der Mathematisch-Naturwissenschaftlichen Fakultät der Christian-Albrechts-Universität zu Kiel. Institut für Meereskunde an der Christian-Albrechts-Universität zu Kiel.

Voss R, Hinrichsen H-H and St John M (1999). Variations in the drift of larval cod (*Gadus morhua* L.) in the Baltic Sea: combining field observations and modelling. Fisheries Oceanography, 8, 199-211.

Voss R, Köster FW and Dickmann M (2003). Comparing the feeding habits of co-occurring sprat (*Sprattus sprattus*) and cod (*Gadus morhua*) larvae in the Bornholm Basin, Baltic Sea. Fisheries Research 63: 97-111

Walter U (1997). Fische, Fischerei und Garnelenfang in der Wismar-Bucht. Meer Museum, 13 pp. 53-61.

Warren MA, Gregory RS, Laurel BJ and Snelgrove PVR (2010). Increasing density of juvenile Atlantic (*Gadus morhua*) and Greenland cod (*G. ogac*) in association with spatial expansion and recovery of eelgrass (*Zostera marina*) in coastal nursery habitat. Journal of Experimental Marine Biology and Ecology, 394, 154-160.

Walkusz W, Paulic JE, Williams WJ, Kwasniewski S and Papst MH (2011). Distribution and diet of larval and juvenile arctic cod (*Boreogadus saida*) in the shallow Canadian Beaufort Sea. Journal of Marine Systems 84(3-4): 78-84.

Westerberg H, Lagenfelt I and Svedäng H (2007). Silver eel migration behaviour in the Baltic – ICES Journal of Marine Science, 64.

Westernhagen H von (1970). Erbütung der Eier von Dorsch (*Gadus morhua*), Flunder (*Pleuronectes flesus*) und Scholle (*Pleuronectes platessa*) unter kombinierten Temperatur- und Salzgehaltsbedingungen. Helgoländer Meeresuntersuchungen, 21, 21-102.

Westin L (1990). Orientation mechanisms in migrating European silver eel (*Anguilla anguilla*): temperature and olfaction. Mar Biol, 106, 175–179.

Westin L (1998). The spawning migration of European silver eel (*Anguilla anguilla* L.) with particular reference to stocked eel in the Baltic. Fisheries Research, 38, 257-270.

Westin L and Nissling A (1991). Effects of salinity and spermatozoa motility, percentage of fertilized eggs and egg development of Baltic cod *Gadus morhua*, and implications for cod stock fluctuations in the Baltic. Marine Biology 108, 5-9.

Wieland K, Waller U and Schnack D (1994). Development of Baltic cod eggs at different levels of temperature and oxygen content. Dana, 10, 163–177.

Wieland K and Jarre-Teichmann A (1997). Prediction of vertical distribution and ambient development temperature of Baltic cod (Gadus morhua L.) eggs. Fisheries Oceanography 6(3): 172-183.

Wieland K, Jarre-Teichmann A and Horbowa K (2000). Changes in timing of spawning of Baltic cod: possible causes and implications for recruitment. ICES Journal of Marine Science 57:542-464.

Winkler HM and Schröder H (2003). Die Fischfauna der Ostsee, Bodden und Haffe. Meer und museum, 17, 25-35.

Wlodarczyk E and Horbowa K (1997). Size-specific vertical distribution of Baltic cod (*Gadus morhua* L.) eggs in the Bornholm Basin in 1993 and 1994. ICES Journal of Marine Sciences, 54, 206-212.

WWF (2006). A Sustainable Future for Baltic Sea Cod and Cod Fisheries, Prepared by WWF Denmark October 2006 in corporation with WWF Baltic Ecoregion programme.

Table of figures

List of tables

Appendix

Appendix 1:

Total list of species registered during the investigations in 2008-2010 in the sub areas of Fehmarn (F), Fehmarnbelt (FB) and Lolland (L). Presence of the species in the fish community study and the Natura 2000 study is marked with X, whereas abundance in the herring and trawl studies is marked with XXX for abundant, XX for common and X for presence. In the egg and larvae surveys abundance is marked with E = found in low density (average density <0,01/m^3 in all surveys), EE = found in moderate density (average density more than 0.01/m^3 but less than 0.1/m^3 in at least one survey), EEE = abundant, average density > 0.1/m^3 in at least one survey. (E) Only found outside Fehmarnbelt. *Herring gill net has a very low affinity sampling smaller species, like sprat and gobies etc.

	Survey	**Fish communities**			**Herring ***		**Natura 2000**	**Trawl**	**Egg**	**Larvae**
Scientific name	**Common name**	**F**	**FB**	**L**	**F**	**L**	**L**	**FB**		
Agonus cataphractus	Hooknose	X	X	X	X	XX	X	X		EE
Ammodytes marinus	Lesser sandeel	X	X							E
Ammodytes tobianus	Small sandeel	X		X						EE
Anguilla anguilla	European eel	X		X			X			
Aphia minuta	Transparent goby			X				X		
Arnoglossus laterna	Mediterranean scaldfish	X	X					X		
Belone belone	Garfish	X		X	X	XX	X			
Callionymus lyra	Dragonet		X	X				X	(E)	
Callionymus reticulatus	Reticulated dragonet		X							
Ciliata mustela	Fivebeard rockling									E
Clupea harengus	Atlantic herring	X	X	X	XXX	XXX	X	XXX		EE
Ctenolabrus rupestris	Goldsinny wrasse	X		X	X	X	X	X	E	E
Cyclopterus lumpus	Lumpsucker	X	X	X			X	X		(E)
Enchelyopus cimbrius	Fourbeard rockling		X		X			X	EE	E
Engraulis encrasicolus	European anchovy		X					X		
Entelurus aequoreus	Snake pipefish	X						X		
Eutrigla gurnardus	Grey gurnard	X	X					X		
Gadus morhua	Atlantic cod	X	X	X	XXX	XX	X	XXX	EEE	EE
Gasterosteus aculeatus	Three-spined stickle-back	X		X			X			
Glyptocephalus cynoglossus	Witch flounder		X			X	X			E
Gobius niger	Black goby	X	X	X			X	X		EE
Gobiusculus flavescens	Two-spotted goby	X		X			X	X		
Gobiidae indet.	Unidentified gobies							X		EE
Hippoglossoides plates-soides	American plaice	X	X					XX		E
Hyperoplus lanceolatus	Great sandeel	X	X	X				X		E
Labrus bergylta	Ballan wrasse	X		X			X			(E)
Lampetra fluviatilis	River lamprey						X			
Limanda limanda	Common dab	X	X	X	XX	XX	X	XXX	EEE	EE
Liparis liparis	Striped seasnail									E
Liparis montagui	Montagus seasnail									E
Liza ramada	Thinlip grey mullet						X			
Lumpenus lampretaeformis	Snakeblenny		X					X		E
Merlangius merlangus	Whiting	X	X	X	XXX	XX	X	XXX		
Microstomus kitt	Lemon sole					X		X		
Mullus barbatus	Red mullet		X							

	Survey	**Fish communities**			**Herring ***		**Natura 2000**	**Trawl**	**Egg**	**Larvae**
Scientific name	**Common name**	**F**	**FB**	**L**	**F**	**L**	**L**	**FB**		
Mullus surmuletus	Surmullet		X			X		X		
Myoxocephalus scorpius	Shorthorn sculpin	X	X	X		X	X	X		E
Neogobius melanostomus	Round goby						X			
Nerophis lumbriciformis	Worm pipefish	X								
Nerophis ophidion	Straightnose pipefish	X		X						E
Perca fluviatilis	European perch			X		X	X			
Pholis gunellus	Rock gunnel	X		X						EE
Platichthys flesus	European flounder	X	X	X	X	X	X	XXX	EEE	EE
Pleuronectes platessa	European plaice	X	X	X	X	X	X	XXX	EEE	E
Pollachius virens	Saithe				X					
Pomatoschistus microps	Common goby	X		X						
Pomatoschistus minutus	Sand goby	X	X	X			X	X		EEE
Pomatoschistus pictus	Painted goby		X							
Psetta maxima	Turbot	X	X	X	X		X	XX	E	E
Pungitius pungitius	Ninespine stickleback	X		X						
Raniceps raninus	Tadpole fish				X					
Salmo salar	Atlantic salmon	X					X	X		
Salmo trutta	Sea trout	X		X	X	X	X			
Scomber scombrus	Atlantic mackerel	X		X	X	X				
Scophthalmus rhombus	Brill	X	X	X			X	X		
Solea solea	Common sole	X	X	X		X	X	XX	E	EE
Spinachia spinachia	Sea stickleback	X		X			X			
Sprattus sprattus	European sprat	X	X	X			X	XXX	EEE	EE
Symphodus melops	Corkwing wrasse	X		X	X		X			
Syngnathus typhle	Broadnosed pipefish	X	X	X			X	X		E
Syngnathus rostellatus	Nilsson's pipefish	X		X						E
Syngnathidae indet.	Unidentified pipefish									E
Taurulus bubalis	Longspined bullhead	X		X	X	XX	X	X		E
Trachinus draco	Greater weever	X	X							
Trachurus trachurus	Atlantic horse mackerel		X		X	X		XXX		
Trisopterus luscus	Pouting		X							
Trisopterus minutus	Poor cod				X					
Zoarces viviparus	Eelpout	X	X	X			X	X		
Total no. of species		43	35	38	19	19	33	36	10	32