Risk analysis on the import of mussels from the Limfjord and the Isefjord (Denmark) to the Oosterschelde

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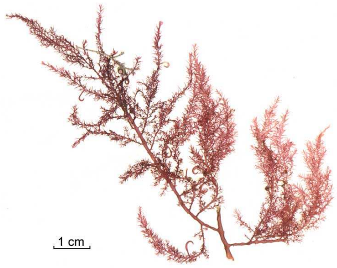


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Contents

i Summary

This report is the result of a risk analysis on the introduction of exotic non-indigenous species – species that have their origin outside the North Atlantic Continental Shelf region – with the import of bottom culture mussels from the Isefjord and the Limfjord (Denmark) into the Oosterschelde. Based on available literature data and expert judgement, the target species are identified and the risks of these species are assessed semi-quantitively. It is concluded that the risk of introducing exotic non-indigenous species into the Oosterschelde with the import of mussels from the Isefjord and the Limfjord is low.

The Oosterschelde is rich in indigenous and (exotic) non-indigenous species. At present, 77 exotic non-indigenous species are known for the Oosterschelde. Many of these species were either not able to establish permanently or have had insignificant effect to the ecosystem. However, some of the exotic species have influenced the functioning of the ecosystem. In the past, the slipper limpet (*Crepidula fornicata*) was extremely abundant and mussel and oyster farmers fished on this species to reduce the nuisance. At present another exotic species, the Pacific oyster (*Crassostrea gigas*) is a dominant shellfish that covers large areas of the intertidal flats and dike pitchings and competes with the indigenous shellfish for food and space.

In the coastal waters of Denmark, 40 exotic non-indigenous species are present of which 25 species are known for the Isefjord and/or the Limfjord. Additionally 29 exotic species in the Danish coastal waters are not established, cryptogenic or there is still debate whether the species can be regarded as exotic. Twelve of these species are known for the Isefjord and/or Limfjord. Six species are regarded as target species. These species are defined as exotic non-indigenous species that could potentially be introduced into the Oosterschelde with the import of mussels from the Isefjord and / or the Limfjord.

For all 6 target species the chance of successful introduction and the expected impact on the ecosystem after successful introduction has been evaluated using literature data and the judgment of an international team of 11 experts. Species with highest chance of successful introduction are the macro algal species *Codium fragile* ssp *scandinavicum* and *Bonnemaisonia hamifera*. The effect of *Codium fragile* might be fouling on shellfish beds and clogging the dredges of the fishermen. The impact of *Bonnemaisonia hamifera* is expected to be smaller however, this fast growing opportunistic species has few consumers and is able to overgrow other macro algae. For both species it is not unlikely that they have already been introduced in the Oosterschelde, but did not manage to settle. The amphipod *Platorchestia platensis* lives among algae that have been washed up on the beach. It is often regarded as a semi-terrestrial or semi-aquatic. Hence, unless mussels are mixed with seaweeds from the shore (or temporarily stored on the shore) there is little chance for its introduction. The species might compete with native species.

Other target species are the ectoproct species *Bowerbankia gracilis* and *Bowerbankia imbricata* and the gastropod *Potamopyrgus antipodarum*. These species are not expected to give any risks. *Potamopyrgus antipodarum* is a freshwater species that is tolerant to low salinity conditions.

ii Uitgebreide samenvatting

De Nederlandse mosselsector heeft te maken met een onregelmatige zaadval in de Waddenzee en de Oosterschelde. Daarnaast blijkt het ieder jaar weer moeilijk om het gevallen zaad op te vissen vanwege de vermeende negatieve effecten op de natuurwaarden. Om toch aan de vraag naar mosselen vanuit de markt te kunnen voldoen worden er regelmatig mosselen geïmporteerd uit het buitenland. Geïmporteerde consumptie mosselen worden na een verwaterperiode verwerkt en getransporteerd naar de klanten. Niet alleen consumptie mosselen, maar ook mosselzaad wordt in Nederland geïmporteerd. In 2006 is er door het ministerie van LNV een NB wet vergunning afgegeven om mosselzaad vanuit 12 gebieden in Ierland en het Verenigd Koninkrijk te importeren en uit te zaaien in de Oosterschelde, om daar op de kweekpercelen uit te kunnen groeien tot consumptie mosselen of op de verwaterpercelen te kunnen worden opgeslagen.

Consumptiemosselen vanuit de Deense en Duitse Waddenzee mogen in Yerseke worden verwaterd in containers op de wal en op verwaterpercelen. Het spoelwater van de containers en de tarra die overblijft na de verwerking mag worden geloosd in de Oosterschelde. De Deense mosselproductiegebieden het Limfjord en het Isefjord horen niet tot de Deense Waddenzee. De mosselen uit deze gebieden moeten worden verwerkt in een quarantaine station. Het spoel- en proceswater mag niet vrij in de Oosterschelde worden geloosd, maar moet eerst worden behandeld om eventuele schadelijke organismen te verwijderen. Hierdoor wordt het risico op introductie van ziekten en exoten sterk verminderd. De tarra moet worden afgevoerd.

Het gebruik van quarantainesystemen leidt echter tot extra kosten voor de mosselhandel. Daarom is door een aantal mosselhandelaren de vraag gesteld wat de risico's zijn als mosselen van het Isefjord en het Limfjord dezelfde behandeling zouden krijgen als de mosselen van het Deense wad, m.a.w. als deze mosselen tijdelijk op de verwaterpercelen in de Oosterschelde worden bewaard en in de normale verwater containers worden naverwaterd. Met de risico's is hierbij bedoeld de risico's dat exoten worden geïntroduceerd en dat deze een impact hebben op het functioneren van het Oosterschelde ecosysteem. Dit rapport beschrijft de resultaten van een risico inventarisatie naar de introductie van exoten in de Oosterschelde door de import van consumptiemosselen uit het Isefjord en het Limfjord. De resultaten van deze studie zullen door de mossel importeurs worden gebruikt bij het schrijven van een passende beoordeling ten behoeve van de NB-wet vergunningaanvraag.

Bij de introductie van nieuwe soorten in de Oosterschelde dient er een onderscheid te worden gemaakt tussen soorten die endemisch zijn voor de Noordoost Atlantische kustregio en exoten. De eerste groep kent zijn oorsprong binnen de biogeografische zone 'Noordoost Atlantisch continentaal plat'. Deze regio strekt zich ruwweg uit van de Noordelijke kust van Spanje tot aan Noorwegen en behelst ook de wateren rond Ierland, het Verenigd Koninkrijk en de Baltische zee. Omdat er geen duidelijke fysieke barrière bestaat binnen deze regio kunnen deze soorten zich "vrij" bewegen binnen dit gebied. Er kan worden aangenomen dat deze soorten in het verleden (lees in de afgelopen 1000 jaar) wel eens in de Oosterschelde terecht zijn gekomen, maar zich niet konden vestigen. Het feit dat ze zich niet hebben weten te vestigen is een indicatie dat de omgevingscondities niet geschikt zijn/waren voor deze soorten. Er wordt aangenomen dat de introductie van dergelijke soorten doorgaans dan ook weinig risico oplevert.

Exoten zijn soorten die van oorsprong niet voorkomen in de Noordoost Atlantische kustregio. De risico's van de introductie van exoten zijn doorgaans groter. Door de aanwezigheid van fysieke barrières zoals oceanen en continenten zijn ze niet in staat geweest de regio op natuurlijke wijze te bereiken. Door menselijk handelen (e.g. scheepvaart, schelpdiertransport) zijn ze uiteindelijk wel in de Noordoost Atlantische kustregio terecht gekomen en hebben zich weten te vestigen (primaire introductie). Door natuurlijk transport (e.g. waterbeweging, zwemmen) of menselijk handelen (e.g. scheepvaart, schelpdiertransport) kunnen ze vanuit de primaire vestigingsplaats in de Noordoost Atlantische kustregio (bijvoorbeeld het Isefjord en het Limfjord) in de Oosterschelde worden geïntroduceerd (secundaire introductie). Het risico van dergelijke introducties is veel groter omdat de kans bestaat dat de omgevingscondities in de Oosterschelde overeen komen met de omgevingscondities in het gebied van oorsprong van deze soort (bijvoorbeeld Noord-Amerika, Japan) en specifieke natuurlijke vijanden en/of ziektes afwezig of slecht ontwikkeld zijn in de Oosterschelde. Daarnaast zijn er specifieke exoten die bekend zijn vanwege hun invasieve karakter.

In deze studie zijn de risico's op introductie van exoten in de Oosterschelde met de import van mosselen uit het Isefjord en het Limfjord in kaart gebracht. Allereerst is er een overzicht gemaakt van de exoten die zijn waargenomen in de Oosterschelde op basis van een overzichtsstudie van Wolff in 2005 en de PRIMUS studie van Wijsman en Smaal in 2006. Deze lijst is aangevuld met recente waarnemingen. In totaal zijn er 77 exoten aangetroffen in de Oosterschelde. Veel van deze soorten worden sporadisch aangetroffen en hebben weinig tot geen effect op het functioneren van het ecosysteem. Voor de Deense kustwateren is in het kader van deze studie ook een overzicht gemaakt van de exoten. In totaal zijn er 40 exoten bekend voor de Deense mariene- en kustwateren, waarvan er 25 soorten zijn aangetroffen in het Isefjord en/of het Limfjord. Daarnaast zijn er nog 29 soorten gevonden die zich niet permanent hebben weten te vestigen, cryptogeen zijn of waarvan niet duidelijk is of ze exoot zijn. Twaalf van deze soorten zijn ook aangetroffen in het Limfjord en/of het Isefjord.

Deze studie richt zich voornamelijk op de risico's verbonden aan de introductie van de 6 doelsoorten, die zich hebben gevestigd in het Limfjord en/of het Isefjord, maar die nog niet zijn aangetroffen in de Oosterschelde. Deze doelsoorten kunnen in potentie worden geïntroduceerd met de mosseltransporten naar de Oosterschelde.

Het risico op introductie van een doelsoort kan worden ingeschat op basis van de kans op succesvolle introductie en het effect van de soort op het ecosysteem na succesvolle introductie. De kans op succesvolle introductie is ondermeer afhankelijk van de waarschijnlijkheid dat een soort mee kan liften met mosselen (voornamelijk bodemcultuur) vanuit het Limfjord en het Isefjord, de kans dat deze het transport overleeft en / of de leefomstandigheden in de Oosterschelde. Het effect van een soort na succesvolle introductie is ondermeer afhankelijk van de ontwikkeling van de soort als deze zich eenmaal heeft gevestigd. Vooral invasieve en schadelijke soorten hebben meer invloed op andere soorten en het functioneren van het ecosysteem.

Voor de doelsoorten is de kans op succesvolle introductie en het effect semi-kwantitatief geschat op basis van literatuurgegevens en de beoordeling door een internationaal team van 11 experts. Hierbij is uitgegaan van het voorzorgsprincipe waarbij de kans op succesvolle introductie van soorten waar weinig kennis/informatie is te vinden als maximaal wordt gegeven. De soorten die de meeste kans maken op succesvolle introductie als gevolg van de import naar de Oosterschelde zijn de macroalgen *Codium fragile* ssp *scandinavicum* en *Bonnemaisonia hamifera*. De mogelijke impact van de *Codium fragile* is dat deze mosselbanken kan overgroeien en dat overmatige groei de netten van de vissers kan verstoppen. Ook kan het massaal aanspoelen en afsterven van deze macroalg leiden tot stankoverlast. Het roodwier *Bonnemaisonia hamifera* kan in potentie ook tot problemen leiden. Deze snelgroeiende opportunist heeft slechts weinig vijanden en kan andere macroalgen overgroeien Het is echter de vraag of de ecologische omstandigheden in de Oosterschelde geschikt zijn voor een massale groei en expansie van deze soorten. Er zijn aanwijzingen dat ze reeds eerder in de Oosterschelde zijn geïntroduceerd. Ze hebben zich echter nog niet permanent weten te vestigen. De amfipode *Platorchestia platensis* komt voornamelijk voor op de stranden tussen aangespoelde macroalgen. De soort wordt vaak gezien als semi-aquatisch/semi-terrestrisch. Het is niet aanmemelijk dat de soort zal worden meegenomen met de mosseltransporten mits de mosselen niet worden gemengd met aangespoelde macroalgen van de stranden. Als de soort wordt geintroduceerd kan het mogelijk concurreren met de inheemse strandvlooien langs de Oosterschelde

De andere doelsoorten, de mosdiertjes *Bowerbankia gracilis* en *Bowerbankia imbricata* en het slakje *Potamopyrgus antipodarum* vormen vrijwel geen risico. Het slakje *Potamopyrgus antipodarum* is een zoetwatersoort en de Oosterschelde is veel te zout om te overleven.

De algemene conclusie van deze risico studie is dat het risico van de introductie van exoten met de import van mosselen uit het Limfjord en het Isefjord klein is maar niet afwezig. Het risico is klein omdat de kans en/of de verwachte effecten van de geïdentificeerde doelsoorten beperkt is, maar niet afwezig. De analyse is opgesteld aan de hand van meest up-to-date informatie en input van experts. Er kunnen echter steeds nieuwe exoten de fjorden binnendringen die niet in deze analyse zijn meegomen. Het is daarom zaak dat er een vinger aan de pols wordt gehouden.

1 Introduction

1.1 Motivation of this research

The production of mussels in the Wadden Sea and the Oosterschelde fluctuates due to varying recruitment and survival rates. The demand for mussels, however, is relatively constant and even increasing. In order to fulfil the demand for mussels and to exploit the existing production capacity, mussels (juveniles as well as consumption mussels) are imported from various European estuaries and coastal waters, particularly from Germany, UK and Ireland (Wijsman & Smaal 2006). These mussels are transported to the Netherlands and sold (as consumption mussels), or seeded at the culture plots (as juvenile mussels).

With the import of shellfish there is a risk of introducing exotic species that might become invasive and could have a negative impact on the functioning of the ecosystem. In 2006, a risk analysis was carried out within the PRIMUS (Project RIsk analysis of MUSsels transfer) project by Wageningen IMARES (Wijsman & Smaal 2006) on the introduction of exotic species into the Oosterschelde with the import of mussels from the Irish and Celtic seas. Based on the results of this study, a permit was given to the Association of shellfish importers to import and relay mussels and oysters from 12 production areas in Ireland and the UK into the Oosterschelde. The imports of consumption mussels from these areas are monitored on the presence of exotic species by means of regular sampling upon arrival in Yerseke.

1.2 Research problem

At present, it is allowed to transfer mussels from the Danish Wadden Sea directly into the Oosterschelde. Two important mussel production areas in Denmark, the Limfjord and the Isefjord, are not part of the Danish Wadden Sea, and therefore the mussels from these areas cannot be imported and relayed into the Oosterschelde uless a permit is given. The imported consumption mussels from these areas should be kept in special quarantine containers at the waterside in Yerseke. In order to prevent exotic organisms to escape from the containers, the discharge water is treated before it is discharged into the Oosterschelde. Also the tare that results from the processing of the mussels could not be dumped into Oosterschelde. Since there are extra costs involved with the quarantine containers compared to the “normal” containers that discharge freely into the Oosterschelde, the mussel industry prefers to use the “normal” containers for processing mussels from the Isefjord and the Limfjord, as in the case for the mussels from the Danish Wadden Sea. Moreover, it is desirable for them that it is allowed to store the mussels at the natural re-watering plots in the Oosterschelde.

In order to apply for a permit to import mussels from the Limfjord and the Isefjord into the Oosterschelde, the Association of shellfish importers in the Netherlands has requested Wageningen IMARES to study the risks of introducing exotic species with this import. The results of this study will be used by the client for the proper assessment that is needed for the application of the permit.

1.3 Study approach

The approach of the present study is largely based on the PRIMUS study of 2006 (Wijsman & Smaal 2006), and is equivalent to the risk studies for the import of mussels from Norway (Wijsman et al. 2007b) and Sweden (Wijsman et al. 2007c) into the Dutch part of the Wadden Sea. In a risk assessment, the risk of introducing a non-indigenous species can be evaluated as the product of the chance of successful introduction of certain species and the impact of the species to the local ecosystem after introduction. In this study, a semi-quantitative risk assessment on the introduction of non-indigenous species with the mussel import from the Isefjord and the Limfjord (DK) into the Oosterschelde is made based on literature data and expert judgement.

Chapter 2 gives a definition of non-indigenous species. The difference between exotic non-indigenous and Northeast Atlantic non-indigenous species is described and it is explained why the risk of the introduction of exotic non-indigenous species is generally larger than the introduction of Northeast Atlantic non-indigenous species. In chapter 3, an overview of exotic non-indigenous species in the Oosterschelde is presented. This overview is largely based on the study of Wolff (2005) and Wijsman & Smaal (2006) and is updated with the most recent literature information. Chapter 4 gives an overview of the mussel culture and sanitary control in the Limfjord and the Isefjord. This chapter is a contribution of H.T. Christensen from the National Institute of Aquatic resources at the Technical University of Denmark (DTU, Aqua), K.R. Jensen from the Zoological Museum in Copenhagen and P. Wiladsen from the Association of Danish Fish Processing Industries and Exporters. Chapter 5 gives an overview of the flora and fauna that is present in the Limfjord and the Isefjord. Exotic species are identified. Also an overview is given of all the exotic species that are known for the Danish marine waters. The chapter is a contribution of K.R. Jensen from the Zoological Museum in Copenhagen. The semi-quantitative risk assessment presented in chapter 6 is based on the judgement of 11 international experts. For the exotic non-indigenous species that could potentially be introduced into the Dutch part of the Oosterschelde with the import of mussels the experts were asked to score the chance and expected impact. Finally, the conclusions of this study are enumerated in chapter 7

The authors would like to thank Wim Wolff for providing his database on non-indigenous marine and estuarine species in the Netherlands. The members of the international expert panel, consisting of Kathe Rose Jensen (Zoological Museum Copenhagen), Vivian Husa (Institute of Marine Research Norway), Stephan Gollasch (GeoConsult), Francis Kerckhof (BMM), Louis Peperzak (NIOZ), Deniz Haydar (University of Groningen), Herre Stegenga (Leiden University), Reinoud Koeman (Koeman en Bijkerk), Arjan Gittenberger (GiMaRIS), Godfried van Moorsel (EcoSub) and Johan Craeymeersch (IMARES) are thanked for their judgements on the risks. Helle Torp Christensen and Per Dolmer (DTU Aqua) and P. Wiladsen are thanked for their clear overview on the mussel culture in the Isefjord and the Limfjord and the food safety control. Kathe Rose Jensen is thanked for giving an up-to-date overview of exotic marine species from Denmark. Reinier Hille Ris Lambers is thanked for critically reviewing the report.

2 Introduction of non-indigenous species

2.1 Non-indigenous species

Non-indigenous species are defined as species that did not exist in a particular ecosystem in historical times[1]. Environmental conditions in that particular ecosystem were not suitable for the species, or the species could not reach the area due to the presence of physical and/or ecological barriers. Recently, the species could have been introduced into the ecosystem due to the removal of the barriers (e.g. through transport by human activities) or due to a change in the environmental conditions within the receiving ecosystem, for example as a result of global warming.

For the Dutch coastal zone, Wolff (2005) makes a distinction between Northeast Atlantic non-indigenous species and exotic non-indigenous species.

- **Northeast Atlantic non-indigenous species** are non-indigenous for the Dutch coastal zone and originate from the Northeast Atlantic shelf region. It is assumed that Northeast Atlantic non-indigenous species have arrived in the Dutch coastal waters a couple of times in the past by natural transport, but that they were unable to establish themselves, as the environmental conditions were not suitable for these species. Northeast Atlantic non-indigenous species can only settle permanently in the Dutch coastal waters if the environmental conditions have changed permanently.

- **Exotic non-indigenous species** are non-indigenous species for the Dutch coastal zone that originate from other parts of the world than the Northeast Atlantic shelf region. Altough they might (have) be(en) able to live here, they could not reach The Netherlands by natural transport because of ecological and/or physical barriers. They are exotic species for all Northeast Atlantic shelf waters. If the environmental conditions in the Dutch waters are suitable for the species, they might establish themselves permanently after introduction (Wolff 2005). Most of these exotic non-indigenous species that have settled in The Netherlands originate from temperate areas (NW-Atlantic and NW-Pacific) where the climate matches the climate in The Netherlands.

From a biogeographical point of view, the marine world can be divided into different climatic zones: From north to south: arctic, boreal, northern temperate, tropical, southern temperate, antiboreal and Antarctic. Moreover, the shelves of each zone can be isolated from each other by geographical barriers like the continents, and the wide and deep oceans that predominantly run north to south on the globe. As a result the marine waters of the world can be divided in twenty isolated areas (regions) within the seven climatic zones (Brattegard & Holthe 1997). The Dutch coastal waters, including the Oosterschelde, are part of the Northeast Atlantic shelf region (Figure 1, left hand side). Longhurst (1998) has defined this area as one ecological and biogeographical region for the pelagic ecosystem, based on observed distribution patterns of marine organisms within the region. It comprises the continental shelf of Western Europe, from northern Spain to Norway and includes the Baltic Sea. Brattegard and Holthe (1997) also present a comparable map of the same region called Eastern North Atlantic Boreal (Figure 1, right hand side). Within a region, there are no large physical barriers and depending on the mobility of the (life stages of the) species they are able to migrate within the region. Within a region the flora and fauna could vary according to topography, substrate exposure, temperature and hydrogeographical conditions. For example, the species composition along the northern coast of Spain differs largely from the species composition in the Norwegian Fjords. Although both areas belong to the same biogeographical region (Northeast Atlantic shelf), the prevailing temperature conditions result in other species.

The Limfjord and the Isefjord fall within the same biogeographic region (Northeast Atlantic shelf region) as the Oosterschelde. According to the definitions given in this report, species that are exotic non-indigenous to the Isefjord and the Limfjord are also exotic non-indigenous to the Oosterschelde. Species that are indigenous to the Isefjord and the Limfjord and non-indigenous to the Oosterschelde are called Northeast Atlantic non-indigenous species for the Oosterschelde.

[1] "In historical times" is taken as being since 1000 years before present Petersen et al. 1992).

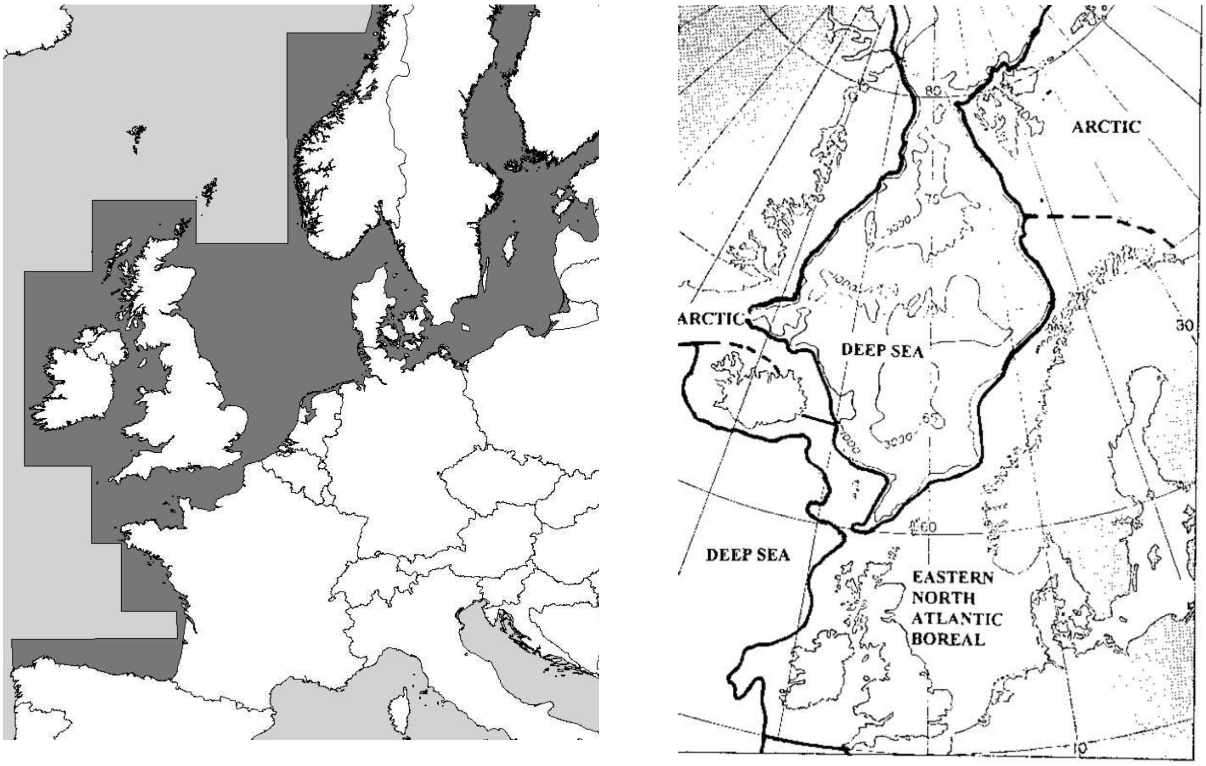


Figure 1: Left hand side: Map indicating Northeast Atlantic Shelf region (dark gray). Figure adapted from Longhurst (1998). Right hand side: Map from Brattegard and Holthe (1997) indicating the Eastern North Atlantic boreal region.

2.2 Introduction and expansion

As a result of globalization, natural barriers for the dispersal of organisms are becoming more and more weakened. New species can be introduced into environments they cannot reach through natural transport mechanisms. Many of these introduced species will not survive because the environmental conditions are not suitable. Also, most of the introduced species do not spread widely, nor do they cause substantial environmental change within the invaded region (Ricciardi & Cohen 2007). As a rule of thumb, the "Tens Rule" of Williamson (1996) can be used as a proxy for the success of an introduction. Of all species that are transported by humans, about 10% are able to establish themselves. Only 10% of these establishments are permanent, and of this group 10% will become an ecological and/or an economical nuisance (Van Der Weijden et al. 2005). This means that only 0.1% of the introduced exotic species will become a problem. However, newly established species can adapt and become better at exploiting available resources, strengthening its position in relation to competitors and predators over time (e.g. Leppäkoski et al. 2002).

The development of a successful invasion generally starts with one or more incidences of arrival during which the species is able to establish itself, followed by an expansion phase caused by a group of successfully reproducing individuals (Figure 2). The rate of expansion and the duration of the establishment phase depends on the life history characteristics of the species (dispersion rate and reproduction rate) but also on the environmental conditions of the system (Van Der Weijden et al. 2005, Van Der Weijden et al. 2007). The expansion phase sooner or later comes to an end and is followed by a phase of adjustment. In this adjustment phase, the species might remain dominant, but most often a regression takes place and the species stabilizes at a lower density

(Van Der Weijden et al. 2005, Reise et al. 2006, Van Der Weijden et al. 2007). Possible causes of these regressions are (Van Der Weijden et al. 2007)

- depletion of food and/or other resources
- increase of infection pressure
- native parasites, and development of diseases or predators attack the new host
- the invader is followed by parasites, pathogens or predators from its native area.

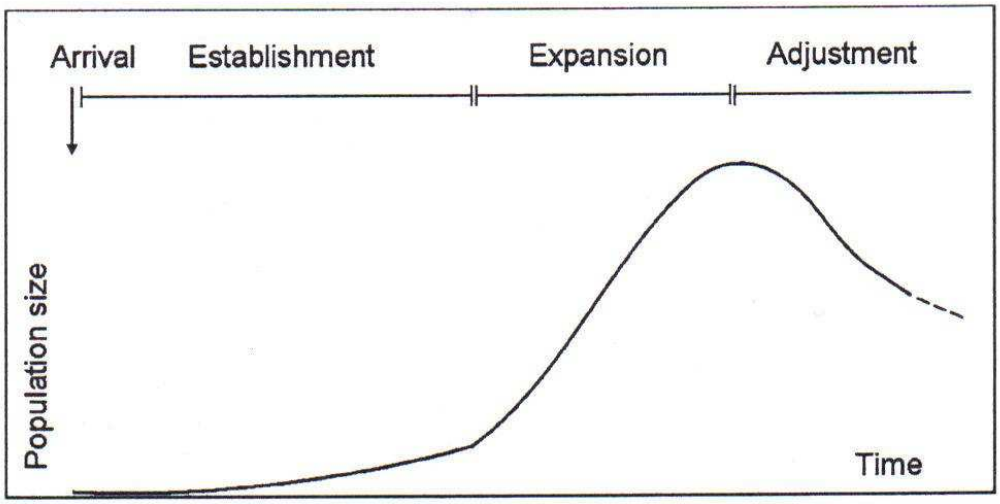


Figure 2: Phases of invasion during the introduction of invasive species. From Reise et al. (2006).

The invasive ability of exotic species differs greatly between species. While taxonomy might give an indication of this ability, it this is not sound: An invasive species is often the only one in its family, and only small taxonomic differences can result in large ecological effects (Van Der Weijden et al. 2007). Usefull predictors for invasivity (Williamson 1996, Ricciardi & Rasmussen 1998, Van Der Weijden et al. 2007) are if the species

- fits into one of the present habitats
- is known as invasive species in another region
- is able to exert significant propagule pressure
- has the ability to "hitch-hike" with a specific transport
- is able to withstand the stresses of transportation

In general small organisms have more chances to become invasive as they are able to hitch-hike with a transport without being noticed. Usually they are numerous, and they have higher chance of breeding with partners following arrival and have lower chance of being completely wiped out by predators, parasites, pathogens, competitors or humans. In addition, since they are often introduced in higher numbers, they have more genetic variation and thereby more opportunities to adapt. Finally, they often reproduce more rapidly and therefore need less time to develop a viable population. However, in the subsequent phase of maintaining and spreading, the larger organisms might have an advantage (Van Der Weijden et al. 2007).

3 Mussel culture and non-indigenous species in the Oosterschelde

3.1 Mussel culture in the Netherlands

The mussel culture in the Netherlands is mainly based on bottom culture at leased sites. The main areas for mussel culture are the Wadden Sea in the North and the Oosterschelde in the south-west. Reproduction of the mussels in the Dutch waters takes place during May and June. Mussel spat is collected twice a year from wild stocks, predominantly in the sub tidal parts of the Wadden Sea. The seed mussels, with a shell length of 10-30 mm (Kamermans & Smaal 2002) are seeded at culture plots in the in the western part of the Wadden Sea (Figure 3) and Oosterschelde where they are left to grow to market size (>4.5 cm). Depending on the environmental conditions, market size is reached in 1-3 year. All mussels are sold at the mussel auction in Yerseke. The sold mussels are temporarily stored for cleansing and re-watering at natural re-watering sites in the eastern part of the Oosterschelde (Smaal & Lucas 2000).

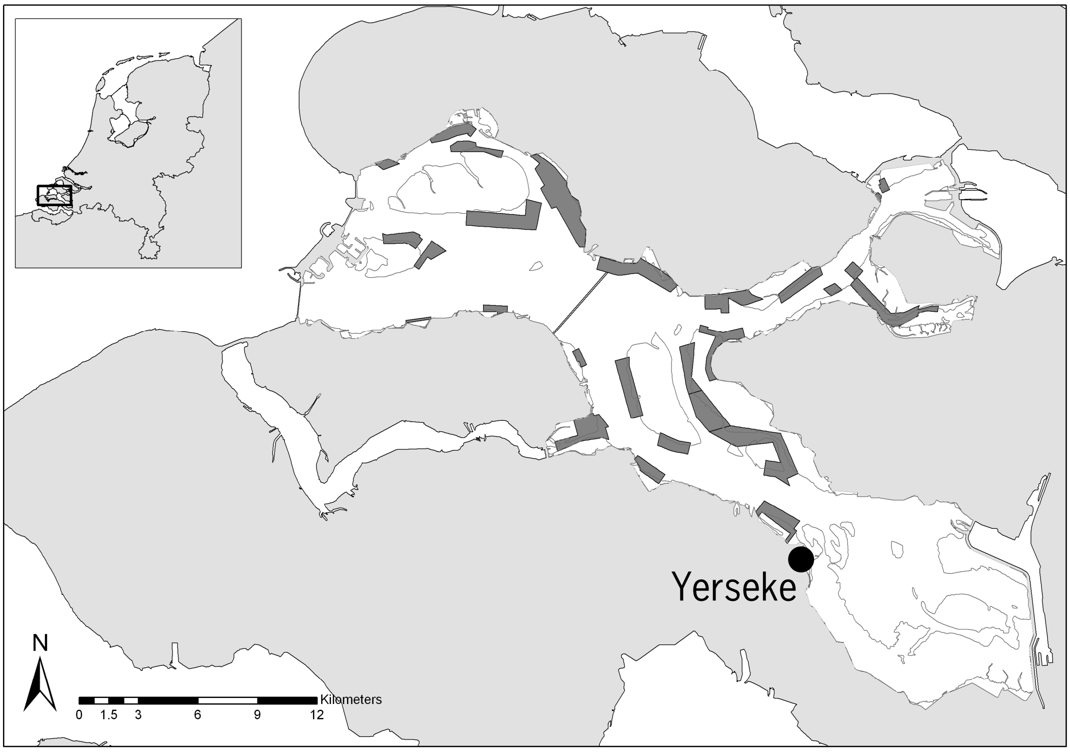


Figure 3: Location of the culture plots (dark grey) in the Oosterschelde, south-western part of The Netherlands.

During the culture cycle, the mussels are regularly transported by the farmers to other plots in order to optimize production. During the winter period, sheltered areas are preferred where the losses due to storms are reduced. In spring and summer, the mussels are often transferred to more exposed locations where the mussels have a better access to food and growth is better. The Dutch legislation allows mussels from the (more productive) Wadden Sea to be transported to the (more sheltered) culture plots in the Oosterschelde on the condition that 85% of the seed mussel stock fished in spring (minus the autumn fishery) remains in the Wadden Sea during winter (LNV 2004). This is to allocate food for eider ducks. Transport from the Oosterschelde to the Wadden Sea is not allowed.

The production capacity of (processing industry of) mussels in the Netherlands is about 100×10^6 kg. Experience of mussel growers shows that a catch of about 65×10^6 kg seed mussels is needed to sustain a total production of 100×10^6 kg (Kamermans & Smaal 2002). The total production of mussels of the Dutch mussel sector fluctuates due to varying recruitment and survival rates. Also the recurring conflicts with nature conservation goals lead to larger uncertainties for the sector to obtain sufficient mussel seed. In order to fulfil the demand for mussels and exploit the existing production capacity, consumption mussels are imported from various European countries (e.g. Germany, Ireland and UK) (Wijsman & Smaal 2006). Additionally seed mussels are imported from Ireland and UK and spread on culture plots in the Oosterschelde where they grow to market size. The mussels are usually imported with big-bags in conditioned trucks. Transport usually takes less than one day.

Besides the import of mussels from other countries, also innovative experiments with mussel seed capture devices are being carried out in the Oosterschelde, Voordelta and Wadden Sea (Scholten et al. 2007). With these devices, mussel seed is collected with ropes and nets in the water column during spat fall. At the end of the summer (August), when mussels are about 0.5 – 3.5 cm they are harvested and transferred to culture plots in the Oosterschelde or Wadden Sea.

3.2 Exotic non-indigenous species in the Oosterschelde

With the import of consumption size mussels from the Isefjord and the Limfjord to Yerseke there is a risk of introducing exotic species into the Oosterschelde, either with discharge water from the containers or discharge of the tare litter at the Slipperplaat in the Oosterschelde. Also the whole party of mussels might be stored at the re-watering plots in the Oosterschelde leading to a release of exotic species.

Species-rich regions like the Oosterschelde often provide more invasive species than species-poor regions. The most obvious explanation for this is that the Oosterschelde has a high diversity of different habitat types that results in a high biodiversity. Also exotic species could profit from the variety in habitat types (Van Der Weijden et al. 2007).

In total 77 exotic non-indigenous species are present in the Oosterschelde (Table 1). This table is based on the publication of Wolff (2005) updated with recent observations. The red algae *Gracilaria vermiculophylla* was found in The Netherlands in the late 1990s in the brackish lake Oostvoorne. In the early 2000s, *G vermiculophylla* spread to several countries along the North Sea coast (Rueness 2005, ICES 2006). At the moment it is very abundant in the German Wadden Sea and apparently spreading into the Dutch part of the Wadden Sea (personal communication H. Stegenga, Wijsman et al. 2007c). The macro alga *Mastocarpus stellatus* is an exotic species that was recently recorded in the Oosterschelde (personal communication H. Stegenga and D. Haydar). The same accounts for the dinoflagellate *Prorocentrum minimum* (personal communication R. Koeman). It has also been recorded in the coastal area of the North Sea (Peperzak 2003). The brown macro alga *Dictyota dichotoma* is present in the Oosterschelde as well (personal communication H. Stegenga and R. Koeman). The sponge *Celtodoryx girardae* has been described for the Oosterschelde (e.g. Van Soest et al. 2007). Live specimens, as well as the egg capsules of the American oyster drill (*Urosalpinx cinerea*) have recently been found in the Oosterschelde (Faasse & Ligthart 2007). *Bugula neritina* is an erect, arborescent bryozoan whose colonies form brown or reddish tufts on whatever substratum they encounter. It is a common and abundant member of the fouling community. In the summer of 2007 the species has been recorded near Burghsluis in the Oosterschelde (Faasse 2007). *Smittoidea prolifica* is also a bryozoan species that has been described for the Oosterschelde (De Blauwe & Faasse 2004). The Pacific crab (*Hemigrapsus penicillatus*) resembles another exotic crab species (*Hemigrapsus sanguineus*) and is described for the delta region and the Oosterschelde (Breton et al. 2002, Wijsman & Smaal 2006, Kerckhof et al. 2007). Since 2006, the comb jelly, *Mnemiopsis leidyi* has been identified at various locations in the delta area, including the Oosterschelde (Faasse & Bayha 2006, De Mesel 2007). The tunicate species *Didemunum* sp. was first recorded along the Dutch coast in 1991. From 1996 onwards the species expanded rapidly in the Oosterschelde. It is now the most common colonial ascidian in the Oosterschelde and is able to overgrow rocks and stones, but also other plants and animals (Gittenberger 2007, Minchin 2007). The first observations in the Oosterschelde of another ascidian species *Perophora japonica* date from 2004 (Faasse 2004). Several populations were recorded in the Oosterschelde again in 2005 (Gittenberger 2007).

Table 1: Exotic non-indigenous species in the Oosterschelde. The table is based on Wolff (2005) and updated with new observations (see text).

Taxon	Species	Synonym
RHODOPHYTA		
	Acrochaetium densum	*Chromastrum densum*
	Agardhiella subulata	
	Anothrichium furcellatum	*Griffithsia furcellata*
	Antithamnionella spirographidis	
	Antithamnionella ternifolia	*Antithamnionella sarniensis*
	Colaconema dasyae	*Acrochaetium dasyae*
	Dasya baillouviana	*Dasya pedicellata*
	Gracilaria vermiculophylla	
	Grateloupia turuturu	*Grateloupia doryphora*
	Heterosiphonia japonica	*Dasysiphonia sp.*
	Mastocarpus stellatus	
	Polysiphonia harveyi	*Neosiphonia harveyi*
	Polysiphonia senticulosa	
DINOPHYTA		
	Alexandrium tamarense	
	Prorocentrum minimum	
PHAEOPHYCEAE		
	Colpomenia peregrina	*Colpomenia sinuosa*
	Dictyota dichotoma	
	Elachista sp	
	Leathesia verruculiformis	
	Sargassum muticum	
	Undaria pinnatifida	
RAPHIDOPHYCEAE		
	Chattonella antiqua	
	Chattonella marina	
	Fibrocapsa japonica	
CHLOROPHYTA		
	Codium fragile	
	Ulva pertusa	
TRACHEOPHYTA		
	Spartina maritima	
PROTISTA		
	Bonamia ostreae	
	Haplosporidium armoricanum	*Minchinia armoricana*
	Marteilia refrigens	
PORIFERA		
	Celtodoryx girardae	
	Haliclona loosanoffi	*Acervochalina loosanoffi*
	Haliclona xena	*Haliclona cf. simplex*
	Hymeniacidon perlevis	
	Mycale micracanthoxea	
	Scypha scaldiensis	
ANTHOZOA		
	Diadumene cincta	
	Haliplanella lineata	*Diadumene luciae*
HYDROZOA		
	Gonionemus vertens	
	Bimeria franciscana	*Perigonimus megas*
	Nemopsis bachei	
	Thieliana navis	

Taxon	Species	Synonym
CNIDARIA		
	Mnemiopsis leidyi	
ANNELIDS		
POLYCHAETA		
	Aphelochaeta marioni	*Tharyx marioni*
	Nereis virens	
	Proceraea cornuta	*Autolytus cornutus*
MOLLUSCA		
GASTROPODS		
	Ocenebra erinacea	
	Urosalpinx cinerea	
BIVALVIA		
	Crassostrea gigas	
	Ensis directus	*Ensis americanus*
	Mercenaria mercenaria	
	Mya arenaria	
	Petricola pholadiformis	
	Psiloteredo megotara	
	Teredo navalis	
BRYOZOAN		
	Bugula neritina	
	Smittoidea prolifica	
	Tricellaria inopinata	
	Walkeria uva	
CRUSTACEA		
CIRRIPEDIA		
	Balanus improvisus	
	Elminius modestus	
ISOPODS		
	Limnoria lignorum	
DECAPODS		
	Callinectes sapidus	
	Hemigrapsus penicillatus	*Hemigrapsus takanoi*
	Hemigrapsus sanguineus	
AMPHIPODS		
	Caprella mutica	*Caprella macho*
COPEPODS		
	Mytilicola intestinalis	
	Mytilicola orientalis	
	Mytilicola ostreae	*Myicola ostreae*
UROCHORDATA		
ASCIDIACEA		
	Styela clava	
	Botrylloides violaceus	
	Molgula manhattensis	
	Corella eumyota	
	Didemunum sp	
	Perophora japonica	
NEMATODA		
	Anguillicola crassus	
PISCES		
	Oncorhynchus mykiss	*Salmo gairdneri*

3.3 Specific introduced non-indigenous species in the Oosterschelde

The larger part of the 77 exotic non-indigenous species in the Oosterschelde remain insignificant additions to the native biota and are occasionally observed. Five of the introduced species, which are listed below, might have stronger effects on habitat properties and native biota in the Oosterschelde.

3.3.1 Crassostrea gigas

The Pacific oyster was deliberately introduced by oyster growers. *C. gigas* originates from Japan and South East Asia (Wolff 2005). In the Oosterschelde, Pacific oysters were introduced in 1964 to support the oyster sector after mass mortality of flat oysters during the severe winter of 1962/1963 (Wijsman et al. 2007a, Wijsman et al. 2008). It was believed that the Pacific oyster could not reproduce in the relative cold waters of the Oosterschelde. Moreover, at that time it was planned to change the Oosterschelde into a freshwater lake. However, the Oosterschelde remained salt and the oysters were able to reproduce. In 1976, the first reproduction was observed in the Oosterschelde, and since then the Pacific oysters have exponentially increased in the Oosterschelde. At present about 700 ha of the intertidal area within the Oosterschelde is covered with Pacific oyster reefs and the same amount is present in the sub tidal areas. Most of the dike pitchings are covered with oysters (De Kluijver & Dubbeldam 2003). The Pacific oysters compete with the endemic shellfish species (blue mussel and cockles) for space and food. The solid reefs formed by the oysters are a completely new biogenic structure in the Oosterschelde and could form a habitat for many species like lobsters, tunicates and seaweed, such as Japanese seaweed (*Sargassum muticum*). Since predation of *C. gigas* is lower than on native bivalves and parasites are less effective on *C. gigas*, it is expected that *C. gigas* will continue to expand in the Oosterschelde region. The Pacific oyster is listed as one of the 100 worst marine invaders (DAISIE database, www.europe-aliens.org).

3.3.2 Sargassum muticum

This Japanese seaweed originates from the Pacific Ocean. The first records of plants washed ashore at Dutch beaches date from 1977 (Wolff 2005). The first attached plants were found in 1980, near Texel (Wolff 2005). In the Oosterschelde it occurs mainly attached to oysters and mussels in a zone close to the low tide line. It is unlikely that the species will displace resident macro algae (Reise et al. 2002). The complex thalli of the algae offer a habitat for epigrowth and motile fauna and thus the species can have a positive effect on biodiversity.

3.3.3 Crepidula fornicata

The America slipper limpet was probably introduced in Europe with American oysters and was first observed in 1872 (Wolff 2005). In the Netherlands, the first specimens were found in 1929 in the eastern part of the Oosterschelde. At present the species is common, especially in the SW Delta area (Wijsman & Smaal 2006). Slipper limpets are considered as a pest on commercial oyster and mussel beds. The slipper limpet forms dense assemblages at oyster and mussel beds. In the beginning of the 20^{Th} century the slipper limpets were fished massively in the Oosterschelde since it was believed that they competed with the commercial shellfish species for food and they fed on oyster and mussel larvae. Also in waters of high concentrations of suspended material they encourage deposition of mud due to the accumulation of faeces and pseudo faeces. At present the population of slipper limpets in the Oosterschelde has decreased and the species is not regarded as an important nuisance species. The slipper limpet is listed in as one of the 100 worst marine invaders (DAISIE database, www.europe-aliens.org).

3.3.4 Undaria pinnatifida

Undaria pinnatifida is a brown seaweed that can reach an overall length of 1-3 metres. *U. pinnatifida* is an opportunistic alga that has the ability to rapidly colonise disturbed or new surfaces, often growing on man-made structures such as marina pontoon. It is found mostly on sheltered reef areas which are subject to oceanic influence, rarely in highly exposed areas. The seaweed grows in the intertidal zone down to the sub tidal zone, to a depth of 15-20 metres. In its native habitat, it occurs in dense stands, forming a thick canopy on a wide range of shores from low tide level down to 15 m in clear waters. In 1999 the first attached plants were found in the Oosterschelde on shells in former oyster ponds (Wolff 2005). The species also flourishes on rope cultures of mussels in the Oosterschelde. *U. pinnatifida* is listed in the 100 of the world's worst invasive alien species (Global invasive species database, www.issg.org).

3.3.5 Didemnum sp.

The first sighting of *Didemnum* sp. in the Oosterschelde dates from 1991. In 1998-1999, *Didemnum* sp. suddenly became very common in the Grevelingen and Oosterschelde, covering much of the available hard substratum. Most of the colonies die in winter (December and January), and therefore other organisms (ascidians, sponges, sea anemones, among others) are able to settle in early spring, before the didemnids begin to expand their colonies. The colonies grow over all hard substratum (rocks, mussels, oysters) and also over other organisms (hydroids, tunicates) that are normally not overgrown by other species (Gittenberger 2007). The species have negative effect on the success of the mussel seed capture devices that are deployed in the Oosterschelde. When the substrates are covered with *Didemnum* sp., mussel seed has no opportunities to settle. Colonies of Didemnium sp. die when water temperature becomes lower than 5°C. Colonies rapidly grow at water temperatures between 14 °C and 18 °C (Leewis & Gittenberger 2007).

4 Mussel culture in the Limfjord and the Isefjord

Contribution of H.T. Christensen (National Institute of Aquatic Resources, Technical University of Denmark, DTU Aqua), K.R. Jensen (Zoological Museum, Copenhagen) and P. Willadsen (Association of Danish Fish Processing Industries and Exporters).

4.1 General overview

4.1.1 The Limfjord

The Limfjord is a 1,500 km^2 shallow water estuary with an open connection to the North Sea in the west and to Kattegat in the east (Figure 4). With a volume of about 7.1 km^3 (Wiles et al. 2006), the Limfjord is the largest estuary in Denmark. In the western part the Limfjord is dominated by large broads and small inlets with a water depth of 5-8 meters connected by channels of 18-22 meters (Limfjord 2007). The eastern part is almost entirely a deep channel.

Figure 4: Map showing locations of the Limfjord and the Isefjord, Denmark.

Historically the Limfjord was only connected to Kattegat in the eastern end and salinity decreased from east to west. In 1825 a storm surge formed an opening in the western end and, because the opening was unstable, a permanent canal was established in 1875. After this, salinity changed so that the highest salinity now is found in the western part, decreasing towards the east (Hylleberg 1992; Limfjord 2007). The fauna changed completely from a brackish to a marine fauna (Hylleberg 1992).

Salinity ranges from 24 psu in the eastern part to 32 psu in the western part and the area is highly eutrophic caused by nutrient rich run off from a 7,500 km^2 catchment area (Dolmer et al. 1999). Smaller and larger freshwater streams run into the Limfjord. Skive-Karup stream, Skals stream and Ry stream are the three streams with the largest catchment area (Basisanalyse). For the Limfjord the yearly freshwater input is about 84 m^3 s^{-1} (Limfjordsovervaagningen 2005). Mixing is basically wind-driven, and stratification occurs during periods with low wind velocities or intrusion of high saline bottom water from the North Sea. Extended periods with stratified water may cause oxygen depletion near the bottom (Christiansen et al. 2006). Water residence times in the Limfjord are about 1-1.5 months during winter months, when the river input is high, and 2-3 months in the summer (Limfjord 2007). The tidal range is low (~ 0.2 m) (Dolmer and Frandsen 2002).

A high primary production (1 g C m^{-2} d^{-1}) sustains a high growth rate of blue mussels compared to other north European fjords and estuaries (Dolmer 1998; Frandsen and Dolmer 2002). In the inner western areas of the fjord, bottom water stagnates for up to several weeks in summer, which result in a high risk of oxygen depletion (Jørgensen 1980). Figure 5 shows areas with high risk of oxygen depletion (indicated in red) the last ten years.

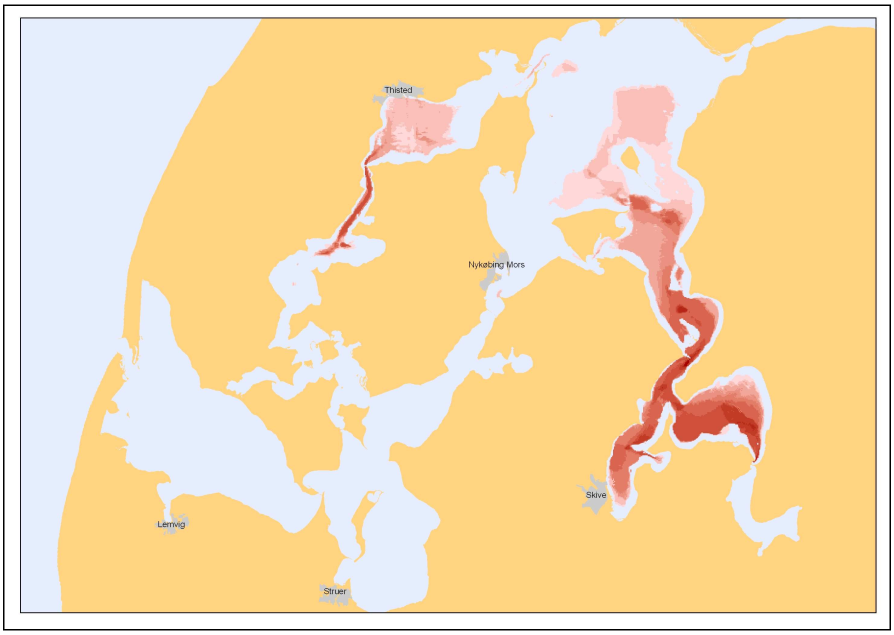


Figure 5: Red colour indicates areas in the Limfjord with high risk of oxygen depletion. Light red indicates areas with least years with oxygen depletion, while dark red indicate areas with the highest risk of oxygen depletion (www.aqua.dtu.dk).

4.1.2 The Isefjord

The Isefjord is characterized as a threshold fjord with a central basin and a number of small secondary fjords (Figure 4). The Isefjord covers an area of 307 km^2 (Larsen et al. 2007), has a length of 36 km and a width of four to 13 km. The fjord is connected to Kattegat by a four km wide opening (Figure 6).

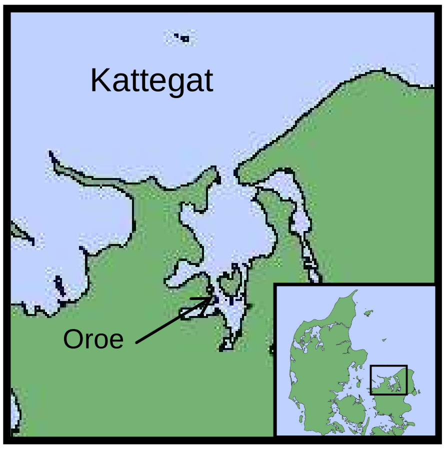


Figure 6: The Isefjord

The average water depth at the mouth is 3 m, but there are natural channels at the eastern (depth 11 m) and western (depth 15 m) edges and a dredged navigation channel (depth about 7 m) in the middle (Rasmussen 1973). North of the island Oroe (Figure 6) is the 17 km long and 13 km wide Outer Broad, and south of Oroe the 7 km long and 4 km wide Inner Broad. Inner Broad and the Outer Broad of the Isefjord are connected through the two deep channels on each side of the island Oroe (Rasmussen 1973).

The average water depth is 5-7 m. Maximum depth, 17 m, is found in the channel west of Oroe (Larsen et al. 2007). Water exchange with Kattegat is relatively small because of the shallow mouth. Exchange of water in the system is dependent of the wind and therefore season. It is greatest in winter, when there are regular breakthroughs of water from Kattegat (Novana 2004).

Water temperature is driven by solar radiation and air temperature and is therefore highest in August and September. The water temperature normally varies from 0 to 22°C. Due to shallow water depths and the intensive wind-induced mixing, stratification does not occur and water temperature at top and bottom is the same. The water in the Isefjord is brackish and varies between 18-26 psu in winter and 16-20 psu in summer. Because the area is a semi-enclosed system, the level of nutrients is normally higher than in open waters. The concentration of nutrients is highest in the inner parts of the estuary and it decreases gradually, when moving closer to Kattegat (Novana 2004).

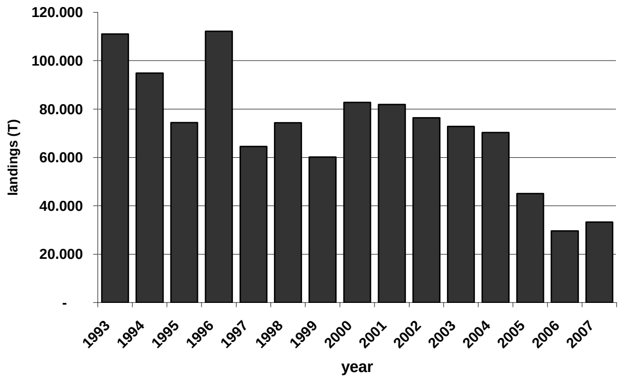
Oxygen depletion in the Isefjord is rare because of the relatively shallow water depths and high rate of wind mixing of the water column. Occasions of oxygen depletion only happens in short periods of time and mostly in the deeper waters in the Outer Broad. The fauna of the Isefjord has in general a high diversity. In Rasmussen (1973) 477 animal species were described and new species are successively identified in the area.

4.2 Mussel fishery and culture

4.2.1 The Limfjord

Fishery on natural mussel beds

In Denmark, the Limfjord is the most important area for both fisheries on wild stocks and off bottom cultivation of blue mussels (*Mytilus edulis*). Blue mussel fishery rose dramatically during World War II, but collapsed after a few years due to reasons not described (Dyekjær et al. 1995). Demands for blue mussels slowly increased during the 1970s (Dyekjær et al. 1995). In the beginning of the 1990s the yearly landings were around 100,000 metric tonnes. Since 2005 fishermen voluntarily reduced their weekly quotas and landings have since been stabilized around 40,000 tonnes per year (Figure 7). More than 90% of the total landings are exported (Danish Veterinary and Food Administration 2006).



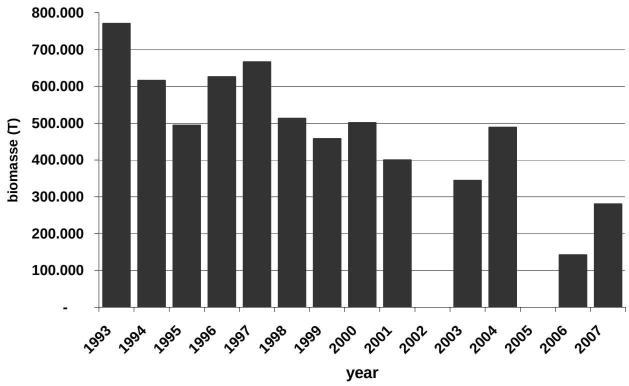


Figure 7: Left hand side: Present landings of blue mussels from the Limfjord from 1993-2007. Right hand side: Biomass of blue mussels in the Limfjord in the same period. No monitoring of blue mussels was conducted in 2002 and 2005 which explains the missing data.

Blue mussel fishery is an important economic income in the communities around the Limfjord. Technical University of Denmark (DTU Aqua) has monitored the stock almost annually since 1993 (Hoffmann 1993; Kristensen and Hoffmann 2002; Kristensen and Hoffmann 2004) (Figure *7*). Biomass of blue mussels in the Limfjord has been declining in that period due to frequent occasions of oxygen depletion, change in algae production and abundance of predators. A change in sampling strategy in 1999-2000, may also explain a part of the decrease in stock sizes. In 2005 fishermen voluntarily reduced their quota with 50 % in response to the decline in biomass. The reduced quota is still in action and therefore the fishery is assessed as being sustainable (DFU 2006).

Table 2: Landings of blue mussels from the Limfjord in 2003 to 2007 (The Danish Directorate of Fisheries).

Year	Landing (tonnes)
2003	73,045
2004	70,336
2005	45,043
2006	29,630
2007	33,286

Blue mussel fishery in the Limfjord today makes up 50 % of the total blue mussel fishery on natural blue mussel beds in Denmark. 51 vessels have permit for fishery of blue mussels in the Limfjord. Harvesting normally takes place from around September till the end of June depending on water temperature.

Fishery on natural mussel beds is not the only way the resource is exploited. Today exploitation of the species takes place in three ways – fishery on the wild stock, on bottom culture beds and harvesting of cultures on long lines.

Bottom culture of mussels

Bottom culturing of blue mussels has during the last years increased in the Limfjord. Mussels below minimum legal size (4.5 cm) are discarded from the grading process at the mussel industries and transplanted to bottom plots. Landings from these plots are included in the total landings from the Limfjord (Kristensen and Lassen 1997).

During the last five years the fishery has transplanted blue mussel seed from natural mussel beds in areas with high mortality, due to oxygen depletion, to culture plots in areas with good growth conditions. This means that biomass and nutrients that during summer can be expected to be released into the environment if the mussels die during oxygen depletion, are removed from high risk areas. The biomass is transplanted to areas where a high growth rate ensures an efficient removal of nutrients incorporated in mussel biomass. Furthermore the good growth conditions support a high quality product. In 2007-2008, 5,000-10,000 tonnes of seed are transplanted. Investigations in 2007 indicated a doubling in biomass from relay in May to October. It can be expected that the production of mussels for fresh consumption in bottom cultures will increase the next decade.

Off bottom long line culture

Around the year 2000 the first producers of off bottom cultures became established in the Limfjord and today 56 licenses are given in all in Denmark. However, it should be noted that not all licenses are in use. Of the 56 given licenses around 45 are given for production in the Limfjord (Figure *8*). Off bottom culture in the Limfjord and the rest of Denmark is predicted to have a large commercial potential. In the first phase of the establishment, farmers have struggled with local adjustments of production concepts. Today, only a small production amount is recorded, but the amount is increasing.

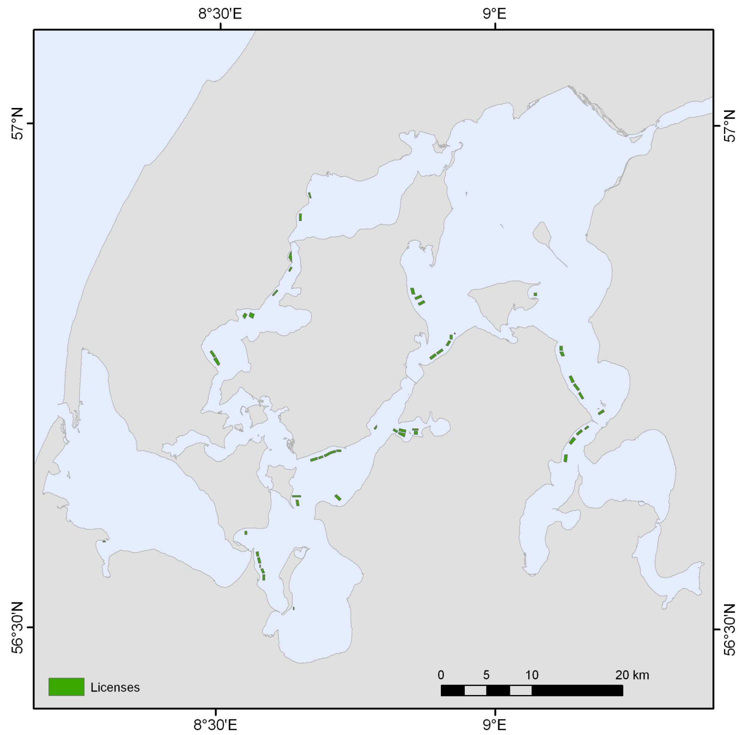


Figure 8: Map shows where the licences for long line mussel farms are located in the Limfjord.

Table 3 shows production (metric tonnes) of long line blue mussels from the Limfjord and a single culture located south of the island of Funen (see Figure 4). The goal of the mussel farmers is to produce 20,000 tonnes long line mussels in 2013. Due to a reduced environmental impact of mussel farming in contrast to mussel dredging, there is a strong political pressure to substitute a part of the mussel fishery with mussel farming.

Table 3: Production (gross) of blue mussels on long line culture in the Limfjord in year 2003 to 2007 (The Danish Directorate of Fisheries).

Year	Production (tonnes)
2003	11
2004	55
2005	235
2006	406
2007	964

Production cycle

The production cycle of long line mussels in the Limfjord is relatively short. In general the production cycle is one year but due to local conditions and different production methods the production cycle can span from 10 to 24 months. Longer cycles are caused by e.g. delayed seed collection, delay in stocking, secondary settling of larvae on the seed collectors or bio fouling. The latter can especially become a problem if the mussels are not harvested until June/July and later, but it varies from year to year.

Production cycles vary between different locations in the Limfjord and are also determined by how well the farmers maintain the culture system. In the western part of the fjord the cycles tend to be longer compared to other parts of the fjord (Christensen et al. 2007).

4.2.2 The Isefjord

Another important area for blue mussel exploitation in Denmark is the Isefjord (Figure 4). Today the exploitation of the species is only taking place as fishery on the natural mussel beds (two permits), but in the future off bottom culture on long lines is expected to be established in the fjord. About 20-30 years ago long line production of blue mussels and Pacific oyster was located in the area (Kristensen 1989). Production was later stopped due to a cold winter where ice damaged the culture system and caused a high mortality of oysters.

Today licenses have been given for establishing long line production systems but none are in use yet. In the Isefjord there are two licences to fishery and the landings have in the later years been above 2,000 tonnes per year (see Table 4).

Table 4: Landings of blue mussels from the Isefjord in 2003 to 2007 (The Danish Directorate of Fisheries).

Year	Landing (tonnes)
2003	995
2004	1,115
2005	2,957
2006	2,600
2007	2,881

4.2.3 Market for Danish mussels

Market in general[2]

In 2007 Denmark exported blue mussels for 287 million DKK (≈ 38 million €). The market can roughly be divided in two parts, fresh and manufactured mussels. In 2007 the value of the fresh mussels exported from Denmark was 83 million DKK (≈ 11 million €), corresponding to about 26,000 tonnes mussels (meat and shell). The value of manufactured mussels (cooked, frozen etc.) for export was 204 million DKK (≈ 27 million €) which is equal to about 9,281 tonnes mussels (only meat).

A trend in the marked shows that the manufactured mussels to a larger degree, and with economically advantages, can be imported from e.g. Chile. An increasing part is imported through Denmark to the traditional market, but with time more and more is imported directly to the import countries.

The fresh market is not as threatened by the cheap farmed mussels from third countries as the manufactured market. So far it is not technically possible to reach the fresh market from countries outside Europe. Danish fresh mussels are mainly exported to Germany, 80 % of the total fresh exports are exported across the border to Germany. The Netherlands imports 15 % and United Kingdom and France import the rest.

For manufactured mussels, France (29%) is the largest import country in a Danish perspective, followed by Germany (21%), United Kingdom (12%), Sweden (11%), The Netherlands (11%) and Poland (5%).

As indicated the fresh market seems least threatened on short term since the fresh mussels can not be displaced by imports from overseas. However, the market for European manufactured mussels is on long term pressed by imports from Chile and in the future China, when the market opens for imports from the east.

There are different solutions to overcome the competition from outside Europe. The most obvious is to focus on producing live mussels for the fresh market, but this market is unfortunately also limited. Instead branding and certification of the Danish mussels is expected to be a sustainable goal. Focus on branding and certification will help maintain the Danish mussel fishery and thus the Danish mussel industry.

[2] This section is written by Peter Willadsen from The Association of Danish Fish Processing Industries and Exporters.

Market for long line mussels
The production of long line mussels in Denmark is still rather low, but is increasing every year (Table 3). With new licenses taken into use and established farmers better understanding of the production cycle it is expected that production will continue to increase to about 2,000 tonnes in 2008 and increase with another thousand tonnes in 2009 (pers. comm. Arne Baekgaard).

Danish long line mussels are mainly exported to The Netherlands (about 80 %). The rest is exported to France or sold on the Danish home market. The quality of the Danish long line mussels is very high with meat percentages around 30%. A high quality and better understanding of timing regarding harvest is expected to secure a Danish market share (pers. comm. Arne Baekgaard).

4.3 Food safety, monitoring and control

4.3.1 Toxic algae

Denmark has yearly occasions of algal blooms. On many occasions these blooms include toxic algae (Harmful Algae Bloom, HAB). The most commonly appearing group of algal toxins in Denmark is the lipophilic DSP-toxins (okadaic acid and esters of okadaic acid), causing diarrheic shellfish poisoning. DSP toxins are produced by *Dinophysis* species and *Prorocentrum lima*.

The PSP toxin group, which is causing paralytic shellfish poisoning, is produced by species of *Alexandrium*, *Gymnodinium* and *Pyrodinium.* Toxic species from the genera *Gymnodinium* and *Pyrodinium* have not been registered in Denmark. PSP toxins are rarely found in Danish bivalve molluscs.

The ASP toxin group, which is causing amnesic shellfish poisoning, is caused by species of *Pseudo-nitzschia*. The toxin is only occasionally found in Denmark.

DSP is found in Denmark almost every year causing closings of production areas and aquaculture establishments, for the mussel fishery in shorter periods. It should be noted that toxins from *Dinophysis acuta* might be retained for long periods, possibly several months (Danish Veterinary and Food Administration 2006). The last years HAB's have occurred in the Limfjord and affected the mussel fishery as well as the harvest from long line aquaculture establishments. In Table 5 toxic algae species and concentration thresholds for Danish waters are shown.

Table 5: Limits for toxic algae (Closing production areas and aquaculture establishments).

Type of Algae	Limits, Cells per litre	Type of poisoning
Dinoflagellates		
Dinophysis acuminata	*500*	*Diarrhoeic shellfish poisoning, DSP*
Dinophysis acuta	*100*	*Diarrhoeic shellfish poisoning, DSP DSP, Pectenotoxins*
Dinophysis dens	*100*	*Diarrhoeic shellfish poisoning, DSP*
Dinophysis norvegica	*1 000*	*Diarrhoeic shellfish poisoning, DSP*
Dinophysis rotundata	*1 000*	*Diarrhoeic shellfish poisoning, DSP*
Dinophysis spp.	*1 000*	*Diarrhoeic shellfish poisoning, DSP*
Protoceratium reticulatum	*Only if mice react*	*Yessotoxin poisoning*
Protoceratium spp.	*Only if mice react*	*Yessotoxin poisoning*
Lingulodinium polyedrum	*Only if mice react*	*Yessotoxin poisoning*
Lingulodinium spp.	*Only if mice react*	*Yessotoxin poisoning*
Prorocentrum lima	*500*	*Diarrhoeic shellfish poisoning, DSP*
Prorocentrum balticum	*Only if mice react*	*Potentiality toxic*
Prorocentrum micans	*Only if mice react*	*Potentiality toxic*
Prorocentrum minimum	*Only if mice react*	*Potentiality toxic*
Prorocentrum triestinum	*Only if mice react*	*Potentiality toxic*
Prorocentrum spp.	*Only if mice react*	*Potentiality toxic*
Alexandrium ostenfeldii	*500*	*Paralytic shellfish poisoning, PSP*
Alexandrium tamarense	*500*	*Paralytic shellfish poisoning, PSP*
Alexandrium pseudogonyaulax	*500*	*Paralytic shellfish poisoning, PSP*
Alexandrium minutum	*500*	*Paralytic shellfish poisoning, PSP*
Alexandrium spp.	*500*	*Paralytic shellfish poisoning, PSP*
Protoperidinium crassipes	*Only if mice react*	*Azaspirazid shellfish poisoning, AZP*[1)]
Protoperidinium curtipes	*Only if mice react*	*Azaspirazid shellfish poisoning, AZP*[1)]
Protoperidinium spp.	*Only if mice react*	*Azaspirazid shellfish poisoning, AZP*[1)]
Karenia mikimotoi	*Only if mice react*	*Neurotoxic shellfish poisoning, NSP*
Karenia spp.	*Only if mice react*	*Neurotoxic shellfish poisoning, NSP*
Diatoms		
Pseudo-nitzschia seriata	*200 000*	*Amnesic shellfish poisoning, ASP*
Pseudo-nitzschia spp.	*500 000*	*Amnesic shellfish poisoning, ASP*
Blue-green algae		
Nodularia spumigena[2)]	*100 000*	*Nodularin. Potentiality toxic. Skin irritation*
Anabaena spp.	*Only if mice react*	*Potentiality toxic. Skin irritation*

[1)] The *Protoperidinium spp.* are included for safety reasons, even though there now are doubts about them actually producing azaspirazid. Chemical screening is carried out.

[2)] Colonies per litre

4.3.2 Inspection and control

Legislation

Inspection and control of food safety regarding live bivalve molluscs, echinoderms, tunicates and marine gastropods in Denmark is very strict. Monitoring of toxic algae became mandatory in the fall of 1990, and in 1991 the European Union laid down rules regarding control and monitoring of toxic algae and algal toxins in live bivalve molluscs, echinoderms, tunicates and marine gastropods (EEC Council Directive 91/492/EEC). These rules were rescinded on the 1st of January 2006 by the set of new EC Food Hygiene and Control Regulations.

The regulations most relevant for establishments producing and placing on the markets of live bivalve molluscs, echinoderms, tunicates and marine gastropods, are now the following:

- REGULATION (EC) No 852/2004 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 29 April 2004 on the hygiene of foodstuffs (hygiejneforordningen[3])
- REGULATION (EC) No 853/2004 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL, of 29 April 2004 laying down specific hygiene rules for the hygiene of foodstuffs (hygiejneforordningen for animalske fødevarer[4])
- COMMISSION REGULATION (EC) No 2073/2005 of 15 November 2005 on microbiological criteria for foodstuffs (mikrobiologiforordningen[5])
- REGULATION (EC) No 854/2004 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 29 April 2004 laying down specific rules for the organisation of official controls on products of animal origin intended for human consumption (kontrolforordningen for animalske fødevarer[6])

To supplement the EC Food Hygiene and Control Regulations the Danish Veterinary and Food Administration, DVFO, has given the following order and guidance document:

- Order no. 840 of the 20th of July 2006 on the Production of Bivalve Molluscs etc.
- Guideline on Food Hygiene

It is only legal to harvest and produce live bivalve molluscs, echinoderms, tunicates and marine gastropods, from, production areas that the competent authority has designated. All production areas and aquaculture establishments are closed, unless actively opened by the Control and Enforcement Office Viborg, DVFO, according to the requirements given in the order no. 840.

A production area or an aquaculture establishment can only be opened for harvesting if the following two criteria are met:

1. The weekly results of analysis for algal toxins and toxic algae must be in accordance with the limits

And

2. The production area must have weekly preliminary microbiological classifications as A, B or C. The permanent classified production area must have verified permanent microbiological classifications as A, B or C.

Sample of mussels etc. and water must be taken and submitted for analysis one week before harvest can be permitted by the Control and Enforcement Office Viborg, DVFO. Sample of mussels and water must be taken from the same nautical positions.

The classification, A, B or C, of production areas and aquaculture establishments determines how the harvested mussels etc. can be used. Only mussels etc. from A-classified production areas and A-classified aquaculture establishments can be sold for fresh live consumption both inside and outside Denmark.

Intensive sampling of water and mussels

If the contamination of toxic algae in the water is high but still below limits and/or if algae toxins are present under the limits, intensive sampling can be introduced. Intensive sampling means, that each fisherman or aquaculture establishment must take samples every day of each lot of mussels harvested and landed. No landed lots are permitted for sale at the market before the results of the analysis are received and evaluated by the Control and Enforcement Office Viborg, DVFO, and found negative for algal toxins over the limits and the harvested lots then given free for sale.

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3 Europa-Parlamentets og Rådets forordning (EF) nr. 852/2004 af 29. april 2004 om fødevarehygiejne.

4 Europa-Parlamentets og Rådets forordning (EF) nr. 853/2004 af 29. april 2004 om særlige hygiejnebestemmelser for animalske fødevarer.

5 Kommissionens forordning (EF) nr. 2073/2005 af 15. november 2005 om mikrobiologiske kriterier for fødevarer

6 Europa-Parlamentets og Rådets forordning (EF) nr. 854/2004 af 29. april 2004 om særlige bestemmelser for tilrettelæggelsen af den offentlige kontrol af animalske produkter til konsum.

Closing production areas and aquaculture establishments
If the limits for toxic algae are exceeded, or if algal toxins are present over the limits, then the production areas and establishments concerned are closed.

Re-opening production areas and aquaculture establishments
If closing was due to exceeding limits for algal toxins: The levels of algal toxins in mussels and of toxic algae in the water must be below the limits in samples taken in two consecutive weeks, before the production areas and/or aquaculture establishments can be re-opened.
If closing was due to exceeding limits for toxic algae: The levels of toxic algae must be below the limits in two water samples taken no closer than 48 hours, and algal toxins must not be present in the mussels, before the production areas and/or aquaculture establishments can be re-opened.

Chemical contaminants
Mussel fishermen and aquaculture establishments must one time per year in each active production area and aquaculture establishment take one sample of mussels etc, and get it analysed for chemical contaminants for which limits are given.

Mussel fishermen and aquaculture establishments must take samples of mussels and water for control of food safety as a part of their own-check system. Therefore all primary producers of mussels must pass a training course in sampling of water and mussels. The course has to be repeated every second year.

Official control and verification programme
The Danish Veterinary and Food Administration has an official control and verification programme, which is established for the purpose of confirming the reliability of the samples taken by primary procedures and of the laboratories performing the analysis, that is:

- The sampling performed by the mussel fishermen and by the aquaculture establishments
- The analytical results of samples of mussels and of water

Information flow and access to information
The fishermen and aquaculture establishments are informed about the status – opening, closing or intensive sampling, of the production areas on the Danish Veterinary and Food Administration Homepage for the mussel monitoring and management programme:
http://www.foedevarestyrelsen.dk/Kontrol/Kontroltyper/Muslingeovervaagning/forside.htm

The general public will be notified through press release if collecting and consuming mussels etc. can be a health risk.

5 Exotic species in the Limfjord and the Isefjord

Contribution of K.R. Jensen (Zoological Museum, Copenhagen).

5.1 Mussel beds and associated fauna

5.1.1 Introduction

In Danish waters mussels mainly form beds on soft bottoms. The competent mussel larvae use empty shells, small stones or seaweed as a settling substrate, and later mussels settle on older mussels forming large beds that are substrate for a diverse associated fauna that use the beds for attachment or hiding space. Mussel beds trap sediment ("mussel mud"), including fecal pellets and pseudo feces with a high content of organic matter, which constitutes the food of many deposit-feeders. Thus, blue mussels are important habitat forming organisms.

Blue mussels, *Mytilus edulis*, occur from shallow water (<1 m) to about 10 m depth. At greater depth they are replaced by horse mussels, *Modiolus modiolus*. Considering the depths of both the Limfjord and the Isefjord, natural mussel beds can form over most of these waters and therefore the majority of the species recorded in these areas may be associated with *Mytilus edulis*. For the Isefjord Rasmussen (1973) published a comprehensive list of the fauna, listing 477 animal species, and additional species have been recorded since that (Rasmussen 1987, 1997) (Appendix B). Only a fraction of these have been recorded by the national monitoring program (NOVA 2003). The national monitoring program also comprises seagrasses and macro algae (NOVA 2003, NOVANA 2004) (Appendix A). For the Limfjord no comprehensive species list exists and the majority of species records are from the national monitoring program (Hedeselskabet 2003) (Appenidix D). This monitoring program use quantitative samples taken with rather small corers or grabs and hence larger and mobile fauna is not included. Also, epifauna is not included, unless it enters the grab/corer. For the Limfjord, DTU Aqua has collected some of these larger, mobile invertebrates in their test trawling (Hoffmann 2005). In recent years a few more species have been recorded, both introduced and naturally dispersed ones (Tendal et al. 2007; Jensen & Hoffman 2007; Møller & Riisgård 2007). These are listed separately in Appendix D. Information on the marine flora in the Limfjord (Appendix C) has been taken from Nielsen (2005) with the addition of the recently introduced species *Gracilaria vermiculophylla* (Thomsen et al. 2007b) (Appendix C).

Natural mussel beds are affected by oxygen depletions and mass death has been reported in several years. In the Limfjord, an estimated 350,000 tons died in 1997 and about 100,000 tons in 1999 (Kristensen & Hoffmann, 2004). The steady decrease in population has been attributed to changes in substrate caused by the dredging of mussels, which removes shell fragments and other "hard substrate" that juvenile mussels use to settle on (Kristensen & Hoffmann 2004) as well as oxygen depletions and failure of spat recruitment. However, large fluctuations in population of mussels have occurred ever since the opening of the Limfjord to the North Sea in 1825 (Hylleberg 1992).

5.1.2 Reproduction

Mytilus edulis in Danish waters spawn from May to late June/ early July. In the Isefjord there may be one sharply defined spawning in May, or spawning may be more prolonged, and larvae can be found in the plankton throughout the year (Rasmussen 1973). Three peaks of larval abundance were identified by Larsen et al. (2007). Settling occurs about 1 month after spawning (Rasmussen 1973).

5.1.3 Predators

Diving ducks, especially eiders, may be important predators of blue mussels. One eider duck can consume 2-3 kg blue mussels per day, and they are considered a serious threat to mussel production facilities (Dolmer & Petersen 2004). Calculations from the Limfjord have shown that diving ducks in Løgstør Broad exploit about 14% of the mussel stock and that fishery exploitation is about the same level (Dolmer, pers. comm.). Thus fishery does not interfere with the food resources of the diving ducks. Part of the area set off for commercial mussel fishery is protected through the EU Bird Directive as well as the Habitats Directive and fishery therefore takes place only at depths over 2 or 4 m (Dolmer & Hoffmann 2007) in the Limfjord and 4 m in the Isefjord, and the shallower mussel beds are left for the birds. The most common invertebrate predator, and possibly the one consuming the largest quantity of blue mussels, is the common sea star, *Asterias rubens*, but also neogastropods, such as the common whelk, *Buccinum undatum*, and various species of crabs, e.g. *Carcinus maenas* and *Cancer pagurus*, are important predators on mussels. Recently the European rough tingle, *Ocenebra erinacea*, has arrived in the Limfjord (Jensen & Hoffmann 2007). This predatory gastropod may also feed on mussels (Fretter & Graham 1985).

5.1.4 Identity of blue mussels in Danish waters

There has been some controversy whether Baltic mussels are a separate species, *Mytilus trossulus*, or whether allometric and allozyme differences are caused by low salinity (Theisen 1978). Based on allozyme frequencies, hybridization between Baltic mussels, identified as *M. trossulus* and North Sea mussels, identified as *M. edulis* occurs through the Danish Belt Sea (Väinölä & Hvilsom 1991). Although the picture has been further complicated by DNA studies of nuclear and mitochondrial genes (Kijewski et al. 2006), mussels from the Isefjord and the Limfjord are almost identical to those from the North Sea (Väinölä & Hvilsom 1991; Kijewski et al. 2006), and hence will be identified as *M. edulis* in this report.

5.1.5 Parasites and pathogens:

Blue mussels are hosts to a number of parasitic or commensal organisms and also some pathogenic microorganisms. Some species bore in the shell and may only affect the mussels at high infestation rates; others are true parasites and feed on the tissues and body fluids of the mussels. Below the parasitic species recorded from blue mussels in Danish waters are listed.

Cliona celata Grant, 1826 and *Cliona lobata* Hancock, 1849
These boring sponges may attack mollusk shells. They use shells from living as well as dead mussels (Rasmussen 1973; Køie et al. 2000). Bore holes made by *Cliona* spp. are very similar to holes caused by the lichen, *Arthopyrenia sublitoralis* (Leighton) Arnold, which is very common in shells of several mollusk species in the Isefjord (Rasmussen 1973).

Polydora ciliata (Johnston, 1838)
This polychaete occurs in two forms, one of which bores into the shell of mussels. They usually do not attack small-sized mussels, and when infection rate is high they weaken the shell to make the mussel more susceptible to predators, especially those that crush or break open the shell (Kent 1981). The worms also cause lower condition index because mussels spend energy trying to repair the damage caused (Ambaryanto & Seed 1991). In most Danish surveys only the non-boring form has been included due to the sampling protocols (not recording epifauna).

Pinnotheres pisum (Linnaeus)
The pea crab may be a commensal rather than a true parasite. It lives in the mantle cavity of bivalves and feeds on the plankton trapped on the gills of the bivalve. Adult crabs have been found in *Mytilus edulis* and *Modiolus modiolus* and juveniles in *Spisula subtruncata* (Christensen 1962). Larger size mussels are preferred as hosts, and the crabs apparently change hosts from *Spisula* spp. to *Mytilus edulis* or *Modiolus modiolus* when they reach the hard-shell stage (Christensen 1962).

Mytilicola intestinalis Steuer, 1902
This parasitic copepod is an exotic species. In Danish waters it occurs only in the Limfjord (Theisen 1964, 1966). In high numbers it causes decreased condition of mussels, and densities of more than 10 copepods per mussel render the mussels unmarketable due to low condition. It has a distinctive red color making it highly visible when opening an infected mussel. Apparently only mussels close to or on the bottom are infected (Theisen 1987). Hence long-line culture should not be affected, although low rates of infestation have been found in such cultures in German waters (Buck et al. 2005).

Trematodes: Several species of digenic trematodes have been recorded from *Mytilus edulis*. Most Danish records are from the Wadden Sea, but a few are from the Isefjord. In general, intertidal populations seem to have the highest rates of infection (Buck et al. 2005), and since tides in the Limfjord are negligible (<0.5 m) and absent in the Isefjord, this may not be a big problem. Three species of *Himasthla, H. elongata, H. continua* and *H. interrupta,* which all have birds as final hosts, use *M. edulis* as second intermediate host (Thieltges et al. 2006). *Renicola roscovita*, also having birds as final host, has been found in mussels from the Isefjord (Svärdh 1999) as well as from the Wadden Sea. This is probably the most common trematode parasite in blue mussels in Danish waters (Svärdh 1999; Buck et al. 2005; Thieltges 2006). It causes decreased growth rates in the host mussel (Thieltges 2006). All of the above species use snails, mostly *Littorina* spp. and *Hydrobia* spp. as first intermediate hosts (Buck et al. 2005). *Prosorhynchus squamatus* uses mussels as first intermediate host and sculpins (fish) as the final host (Køie 1984). The host mussels can become sterile from infection (Coustau et al. 1993).

Bacteria and virus: Only a few studies have examined pathogenic bacteria and virus from *Mytilus edulis* in Danish waters (Rasmussen 1986; Svärdh 1999), so there is not enough information to determine how important this problem is.

Other parasites: It should be mentioned that until now oysters (*Ostrea edule*) from Danish waters have been declared free from *Bonamia ostreae* (Haplosporidia) as well as *Marteilia refringens* (Paramyxea) (ICES 2005).

5.2 Exotic species in Danish waters

5.2.1 Introduction

Exotic species in Danish waters were summarized in 1999 (Knudsen 2001) and comprehensive lists of exotic benthic invertebrates (Jensen & Knudsen 2005) and macro algae (Thomsen et al. 2007) have also been published. A few phytoplankton algae and parasitic microorganisms are also suspected to be non-native, as is the rainbow trout, *Onorhynchus mykiss*, originally escaped from aquaculture, but now apparently established as an exotic species (Table 6). A few species have been established after the above-mentioned publications, and also new criteria for identifying exotic species have indicated that species hitherto not considered exotic are now included, either as cryptogenic or with uncertain status as exotics (Nehring & Leuchs 1999; Wolff 2005; Gollasch & Nehring 2006). Such species are included in Table 7 of non-established, cryptogenic and uncertain species. In the following section comments on certain species that might be problematic for mussel production are presented.

Table 6: Established exotic species in coastal waters in Denmark. Species recorded in the Limfjord and/or the Isefjord are marked grey.

Diatoms	**Nematoda**
Odontella sinensis	*Anguillicola crassa*
Dinoflagellates	**Polychaeta**
Alexandrium tamarense	*Ficopomatus enigmatica*
Gymnodinium mikimotoi	*Marenzelleria viridis*
Porocentrum triestinum	**Gastropoda**
Prorocentrum minimum	*Crepidula fornicata*
Rhodophyta	*Potamopyrgus antipodarum*[1]
Bonnemaisonia hamifera	**Bivalvia**
Dasya baillouviana	*Crassostrea gigas*
Heterosiphonia japonica	*Dreissena polymorpha*
Neosiphonia harveyi	*Ensis americanus*
Gracilaria vermiculophylla	*Mya arenaria*
Phaeophyta	*Petricola pholadiformis*
Colpomenia peregrina	*Teredo navalis*
Dictyota dichotoma	**Cirripedia**
Fucus evanescens	*Balanus improvisus*
Mastocarpus stellatus	*Elminius modestus*
Sargassum muticum	**Copepoda**
Chlorophyta	*Acartia tonsa*
Codium fragile ssp. *tomentosoides*	*Mytilicola intestinalis*
Codium fragile ssp. *scandinavicum*	**Amphipoda**
Flowering plants	*Platorchestia platensis*
Spartina anglica	**Ascidiacea**
Cnidaria	*Styela clava*
Cordylophora caspia	**Pisces**
Ctenophora	*Oncorhynchus mykiss*
Mnemiopsis leidyi	
Platyhelminthes	
Pseudodactylogyra anguillae	
Pseudodactylogyra bini	

[1] *Potamopyrgus antipodarum* is a freshwaterspecies that tolerates low salinity conditions.

Table 7: Exotic species that are not established (a), cryptogenic (b) or established but unknown whether the species is exotic (c). Species recorded in the Limfjord and/or the Isefjord are marked grey.

Phytoplankton	**Isopoda**
Coscinodiscus wailesii (a)	*Limnoria lignorum* (c)
Chattonella aff. *verruculosa* (b, c)	**Amphipoda**
Heterosigma carterae (a)	*Caprella mutica* (a**)
Porocentrum minimum (a)	**Decapoda**
Cnidaria	*Callinectes sapidus* (a)
Bougainvillea rugosa (a)	*Eriocheir sinensis* (a†)
Gonionemus vertens (a)	*Rhithropanopeus harrisii* (a)
Polychaeta	**Insecta**
Aphelochaete mariona (c)	*Telmatogeton japonicus* (a*)
Caulleriella killariensis (c)	Xiphosura
Neanthes succinea (b)	*Limulus polyphemus* (a)
Neanthes virens (c)	**Bryozoa**
Procereae cornuta (c)	*Bowerbankia gracilis* (a?, c)
Syllidia armata (c)	*Bowerbankia imbricata* (a?, c)
Gastropoda	**Ascidiacea**
Gibbula cinerea (c)	*Molgula manhattensis* (b)
Ocenebra erinacea (c)	**Pisces**
Bivalvia	*Aristichthys nobilis* (a)
Crassostrea virginica (a)	*Salvelinus fontinalis* (a)
Psiloteredo megotara (c)	*Salvelinus namaycush* (a)

* First record in 2003. ** First record in 2005. † Many records, but no reproducing population. a? Only a few records exist.

5.2.2 Microalgae

Coscinodiscus wailesii Gran & Angst, 1931
This is considered an alien species in the Netherlands (Wolff 2005) and Germany (Gollasch & Nehring 2006), but it has so far not been recorded in Denmark (NOBANIS).
http://www.nobanis.org/speciesInfo.asp?taxaID=2967

Chattonella aff. v*erruculosa*
Synonym: *Verrucophora farcimen* Eikrem, Edvardsen et Throndsen, 2007
The genus *Chattonella* is apparently very difficult to identify. Gollasch & Nehring (2006) list two species, *C. antiqua* and *C. marina* as alien, and these species are also listed by Wolff (2005) for the Netherlands. However, the species that for several years was identified as *Chattonella* aff. *verruculosa* in Norway and Denmark has recently been described as a new species, so far recorded only from Scandinavian waters. It is certainly a nuisance species, but at the present time not listed as alien (Edvardsen et al. 2007). Whereas the two species of *Chattonella* belong to the Raphidophyceae, *Verrucophora farcimen* (and the original *C. verruculosa*, which has also been transferred to *Verrucophora*) belong to the Dictyochophyceae (Edvardsen et al. 2007). For the Isefjord only *Chattonella* spp. (unidentified) have been recorded (NOVA 2001). Most blooms of *Chattonella* spp. have been in the North Sea and Skagerrak, but it has also been found in Kattegat (Mellergaard et al. 2002).

Heterosigma carterae
Synonyms: This is a synonym of *Heterosigma akashiwo* (Hada) Hada
It is doubtful whether this species is actually an alien. It occurs in the Netherlands (Wolff 2005) and Norway as established alien. It has been recorded from Denmark, but appears not to be established (NOBANIS).
http://www.nobanis.org/speciesInfo.asp?taxaID=2515

Prorocentrum minimum (Pavillard, 1916) Schiller, 1931
This species is easily misidentified as the native *Prorocentrum balticum*. It is not established in Denmark, but has been observed in the Isefjord (NOVA 2003). It is common in the Baltic Sea (NOBANIS). In Germany it is a different species, *P. redfieldii* that is listed as alien (Gollasch & Nehring 2006).
http://www.nobanis.org/speciesInfo.asp?taxaID=1629

5.2.3 Macroalgae

Dictyota dichotoma and *Fucus evanescens* (Phaeophyta) have been included among the exotic seaweeds in Danish waters, although they may have spread by natural means (Thomsen et al. 2007a). Thomsen et al. (2007a) excluded *Mastocarpus stellatus* because it has been established for more than 100 years. However, it has been included here. The only green algal invasive species, *Codium fragile* apparently occurs in two subspecies in Danish waters, *C. fragile* ssp. *tomentosoides* and *C. fragile* ssp. *scandinavicum*, but the regular monitoring programs have made no distinction between the two.

Two species deserve special mention because they appear to have some ecosystem impacts. *Sargassum muticum* was first found in the Limfjord in 1984 and rapidly proliferated throughout the fjord and into Kattegat and is now the dominating macro algal species in the Limfjord (Stæhr et al. 2000). It has caused a decrease in native large brown algae, especially *Halidrys siliquosa* (Pedersen et al. 2005). *Gracillaria vermiculophyllum* first occurred in Danish waters in 2003 and now is spreading. It occurs in the Limfjord but not yet in the Isefjord (Thomsen et al. 2007b). It has been shown to interfere with the byssus of mussels (Thomsen et al. 2007b).

Charophyta
Chara connivens Salzmann ex A. Braun.
We have not been able to find any confirmed records of this species in Danish waters. It is listed as rare in Sweden (Främmande arter 2006). The record listed on the NOBANIS website is most likely a mistake. The record was made by a Danish person, but the location was given as Riga Bay, which is either Estonia or Latvia, not Denmark.

5.2.4 Flowering plants

Spartina anglica C.E. Hubbard (cord grass)
This is a fertile species resulting from the chromosome doubling of an infertile hybrid between the North American *Spartina alterniflora*, which may have been introduced to Europe with ballast water, and *S. maritima*, which may be native to western Europe or may have dispersed naturally or been introduced from Africa (Nehring & Adsersen 2006). It is not quite clear whether the plants that were originally introduced for planting in the Danish Wadden Sea in the 1930s were the infertile hybrid, referred to as *Spartina x townsendii* or the fertile *S. anglica*, but at the present time *S. anglica* is found in several places in Denmark (Randløv 2007). However, it does not occur in the Limfjord. The only transplantation to the Limfjord was unsuccessful. It has not been recorded from the Isefjord either. It has a low and unstable seed production and the seeds do not have long-time viability in the field. Although *Spartina* does not grow in the same habitats as blue mussels, it is still possible that seeds or rhizome fragments may be carried by currents to places where mussels are cultured, and that they could be accidentally spread by the transfer of mussels. *S. anglica*, like *Mnemiopsis leidyi* and *Eriocheir sinensis*, has been listed as one of the 100 worst invasive species (Lowe et al. 2000). It binds sediment at very high rates – which is why it was originally introduced – and this modifies the habitat for a number of invertebrates that are important for ecosystem function.

5.2.5 Benthic invertebrates

Cordylophora caspia (Pallas, 1771)
This hydroid occurs mainly in very low salinity waters and hence is not associated with commercial mussel fishery or culture.

Opercularella lacerata (Johnston, 1847)
Synonyms: *Campanulina lacerata* (Johnston)

This hydroid is considered native in Europe, but invasive, although cryptogenic, in the NW Atlantic (Pederson et al. 2005), hence obviously a nuisance species. It occurs in the Isefjord (Rasmussen 1973).

Mnemiopsis leidyi A. Agassiz, 1865
This highly invasive ctenophore made its first appearance in Danish waters in 2005, although it was not correctly identified. In 2006 it was also found, though not identified, in a few places. In 2007, however, it spread rapidly throughout Danish waters (Tendal et al. 2007) and into the Baltic (Lehtiniemi et al. 2007). It occurs both in the Limfjord and the Isefjord (Tendal et al. 2007).

Aphelochaeta marioni (Saint-Joseph, 1894) (fam. Cirratulidae)
Synonyms: *Tharyx marioni*
This polychaete species is considered a cryptogenic exotic species in Germany (Gollasch & Nehring 2006) and the Netherlands (Wolff 2005), but not in other European countries (Rayment 2007). It occurs in the Limfjord (Hedeselskabet 2003), but nothing is known about its first appearance. This species is known to be associated with long-line mussel culture in Ireland (Chamberlain et al. 2001). There is a chance that this and the following species have been mixed up in Danish studies (Jensen 1992), as the systematics of this family seems rather confused.

Caulleriella killariensis (Southern, 1914) (fam. Cirratulidae)
Synonyms: *Tharyx killariensis*
This species is also considered non-native in Germany (Gollasch & Nehring 2006), but not in other European countries (Fauchal 2007). An unidentified species of *Caulleriella* has been recorded from the Limfjord (Hedeselskabet 2003). It occurs also in the Danish Wadden Sea, although it was unknown prior to the 1980s (Jensen 1992).

Ficopomatus enigmaticus (Fauvel, 1923)
This polychaete occurs only in the southern harbor of Copenhagen (Jensen & Knudsen 2005).

Marenzelleria viridis (Verrill, 1873)
Synonyms: *Marenzelleria* cf. *wireni* (auctt., see Sikorski & Bick 2004)
This polychaete was first found in Ringkøbing Fjord in 1990 and presently forms dense populations in a few localities (Jensen & Knudsen 2005), but has not been found in the Limfjord or the Isefjord.

Microphthalmus similis Bobretzky, 1870
This polychaete is regarded as a possibly exotic species in Germany (Gollasch & Nehring 2006). It has not been recorded in Danish waters, but two other species of the genus have, namely *M. aberrans* (Webster & Benedict, 1887) from the Isefjord (Rasmussen 1973) and *M. sczelkowi* Metschnikow, 1865 from the Limfjord (Hedeselskabet 2003). Since these species are very small and difficult to identify, it is possible that species have been confused.

Neanthes succinea (Frey & Leuckart, 1847)
Synonyms: *Nereis succinea, Alitta succinea*
In Danish waters this species is considered a cryptogenic species. It was first recorded in 1940 in Kattegat (Jensen & Knudsen 2005). In the Isefjord it was first recorded in 1953 and is now abundant (Rasmussen 1973; NOVA 2003). It is also one of the most common invertebrates in the Limfjord (Hedeselskabet 2003). It seems to have spread over most of the world and is considered a nuisance species in many countries (NIMPIS 2002a). It is not directly associated with *Mytilus edulis*, but may occur in sediment with natural mussel beds.

Neanthes virens (Sars, 1835)
Synonyms: *Nereis virens, Alitta virens*
This is not considered an exotic species in Danish waters, but has been considered exotic in the Netherlands, where it was first found in 1915 (Wolff 2005). However, it was described from Norway in 1835 and could fairly easily have dispersed by its own means. The population in the Isefjord has been considered a distinct species *N. southerni* Abdel-Moez & Humphries, 1955, but this is presently not recognized (Rasmussen 1973; Fauchald 2007). In the Isefjord the species only became common in the late 1940s (Rasmussen 1973).

Polydora cornuta Bosc, 1802
Synonym: *Polydora ligni* Webster, 1880
This species occurs in the Limfjord, often in high densities (Hedeselskabet 2003) and in the Isefjord as *P. ligni* (Rasmussen 1973). Rasmussen (1973) considered *P. ligni* a "form" of *P. ciliata*, which also occurs in the Isefjord. The synonymy of *P. cornuta* and *P. ligni* is now accepted by most specialists (Radashevsky 2005; Worsaae 2001). It is not considered an exotic species in Danish waters, but is in the Mediterranean (Çinar et al. 2005), the west coast of North America and in Australia (Hayes et al. 2005), but possibly there are still taxonomic problems to be solved.

Proceraea cornuta (A. Agassiz, 1862)
This is considered a possible exotic species in the Netherlands (Wolff 2005). It has been found a few times in the Limfjord (Hedeselskabet, 2003) and the Isefjord (Rasmussen, 1973).

Syllidia armata Quatrefages, 1866
This species is considered exotic, but not established in the Netherlands. Its native distribution appears to be slightly to the south of the Netherlands, in Brittany, and the single record is supposed to have been introduced with an oyster (Wolff 2005). It seems to be fairly common in the Limfjord (Hedeselskabet 2003) and in the Isefjord (Rasmussen 1973), and has not been considered an introduced species in Danish waters.

Crepidula fornicata (Linnaeus, 1758)
This species occurs in the Limfjord but not in the Isefjord (Jensen & Knudsen 2005). It was first recorded from the Limfjord in 1934, the same year it was discovered in the Danish Wadden Sea. Its present distribution includes the Wadden Sea, North Sea, Skagerrak, Northern Kattegat and the Limfjord (Jensen & Knudsen 2005). In soft bottom stations it occurs in low densities (about 30 ind/m^2), but occasionally up to 160 ind/m^2, e.g. in Løgstør Bredning in 1998 (Hedeselskabet 2003). The density of *Mytilus edulis* in these stations was not particularly high (<400 ind/m^2, and in most cases <100 ind/^{2}). *Crepidula fornicata* is known to cause increased sedimentation when it occurs in high densities (Ehrhold et al. 1998). Because *C. fornicata* is a suspension feeder, competition with oysters, both *Ostrea edule* and *Crassostrea gigas*, has been suggested to be a major impact. However, more recent studies have failed to identify food competition as a major effect (de Montaudouin et al. 1999; Thieltges et al. 2003). In fact, it has been shown that *C. fornicata* and *Crassostrea gigas* utilize particles of different sizes (Beninger et al. 2007). When *C. fornicata* uses *Mytilus edulis* as a substrate, predation by starfish is reduced (Thieltges 2005a), but also the attachment of *C. fornicata* increases the amount of energy spent by the mussel on producing byssus for attachment (Thieltges & Buschbaum 2007). Also, attachment of *C. fornicata* on mussels increased mortality and decreased growth rate, but this seems to be attributable to hydrodynamic effects rather than competition for food (Thieltges 2005b).

Potamopyrgus antipodarum (Gray, 1843)
This species occurs in parts of the Limfjord with very low salinity (Hylleberg 1979), but has not been found in the Isefjord (Rasmussen 1973).

Gibbula cineraria (Linnaeus, 1758)
This species is considered introduced and recently established in the Netherlands (Wolff 2005). It is not considered exotic in Danish waters and occurs in the Limfjord (Hedeselskabet 2003).

Ocenebra erinacea (Linnaeus, 1758)
This muricid gastropod has been introduced with oysters to the Limfjord a couple of times, but not established (Jensen & Knudsen 2005). It was found again in 2006 with egg capsules, and thus it seems to be established, though this time it has probably extended its natural distribution due to higher temperatures and presence of food (Jensen & Hoffmann 2007).

Crassostrea gigas (Thunberg, 1793)
This species was first recorded in the Danish Wadden Sea in 1999 (Diederich et al. 2005). However, this was interpreted as escapees from nearby culture areas at the German island Sylt. In the following years it became increasingly abundant and since 2004 or 2005 it has been reproducing in the Danish Wadden Sea. A separate population occurs in the Limfjord (Christensen & Elmedal 2007), and recently also a very small population has been identified in the Isefjord (Wang et al. 2007). Both these localities have been used for culture of imported

Crassostrea gigas in the 1980s, and apparently some escapees have been able to breed and form local populations. Recently a few small specimens have been found at two localities between the Wadden Sea and the Limfjord (Jane Groos, pers. comm.), but whether the larvae have come from one or the other populations is unknown. *C. gigas* impacts *Mytilus edulis* by settling on the mussels. In some parts of the Wadden Sea mussel beds seem to be replaced by oyster reefs (Kristensen & Pihl 2008). *C. gigas* occurs at shallower water than the native oyster, *Ostrea edule* (Christensen & Elmedal 2007), so the two species do not compete for space.

Crassostrea virginica (Gmelin, 1791)
This species was introduced for culture in the 1880s, but it was never successful (Jensen & Knudsen 2005).

Dreissena polymorpha
This species occurs only in freshwater habitats in Denmark (Jensen & Knudsen 2005)

Ensis americanus (Gould in Binney, 1870)
Synonyms: *Ensis directus* auctt. (Non Conrad, 1843)
This species was first recorded from the Danish Wadden Sea in 1981. The first record from the Limfjord was from 1984 (Knudsen 1989). It has only been found as empty shells at the mouth of the Isefjord (Rasmussen, 1996; Knudsen 1997), but larvae have been identified in the plankton (Larsen et al. 2007). This species is very difficult to collect alive because it retracts deeply into the sediment when disturbed. However, the amounts of shells that are washed up on the Danish shores indicate that the species is very abundant both in the North Sea, Kattegat and the Limfjord (Jensen & Knudsen 2005).

Mya arenaria Linnaeus, 1758
This species was apparently introduced to Europe by Vikings (Petersen et al. 1992) and is now considered completely naturalized. However, its spread in the Limfjord in the years after 1978 bears resemblance to an invasion. Prior to 1952 it was rare in most places except the brackish Lovns Bredning, but after 1978 (sampling was interrupted between 1952 and 1978) it was common in many places, and in the following years it spread to most of the Limfjord. During the same period (1910-1952), the congeneric, native *Mya truncata* decreased and has been very rare after 1978 (Christiansen et al. 2006).

Petricola pholadiformis Lamarck, 1818
Synonym: *Petricolaria pholadiformis*
This species occurs in the Limfjord where substrate and salinity are suitable (Jensen & Knudsen 2005; Hedeselskabet 2003). It was first recorded in Denmark in 1905 and in the Limfjord in 1934. It should be mentioned that the native piddock, *Barnea candida*, has not been recorded in recent studies, although it was recorded as common in previous times (Collin 1884).

Teredo navalis Linnaeus, 1758
The origin of this species is uncertain, and also whether it has arrived through natural dispersal on driftwood or by human interference (in ships' timber) is unknown. Until recently it was not considered exotic in Danish waters, but after Baltic scientists noticed it spreading eastwards and also reproducing east of the Darsser Ort - Gedser threshold (Sordyl et al. 1998), it has been included in lists of exotic species (Jensen & Knudsen 2005). Although competent larvae were probably brought with an inflow of saltwater shortly before 1993, the larvae would not have been able to settle without man-made substrates in the form of groynes and marinas, and it appears that the Baltic population is now able to reproduce, which has not been the case with previous invasions (Sordyl et al. 1998). *T. navalis* is the only wood-boring species that can tolerate lower salinity. The other species of teredinids, *Psiloteredo megotara* (Hanley in Forbes & Hanley, 1848) and *Nototeredo norvagica* (Spengler, 1792) only occur in the North Sea and Skagerrak. Viking sagas from Iceland mention boring organisms in their ships, but it is not possible to determine whether these were shipworms or the boring isopod *Limnoria lignorum* (Rathke, 1799). Wood that has been preserved in the Zoological Museum in Copenhagen from a Dutch dike that was broken around 1730 contains bore-holes that have definitely been identified as those of *T. navalis*, but this is the earliest certain identification.

Balanus improvisus Darwin, 1854
This species was first recorded from the harbor of Copenhagen in 1880 (Jensen & Knudsen 2005). It is common in all Danish waters, and has been recorded both in the Limfjord (Hedeselskabet 2003) and the Isefjord (Rasmussen 1973).

Elminius modestus Darwin, 1854
The first record of this species is from 1978, when it was found in the Wadden Sea on *Mytilus edulis* and stones (Theisen 1980). The population has been wiped out during cold winters, but seems to be permanently established at the present time (Jensen & Knudsen 2005). In the summer of 2007 it was found at the eastern entrance to the Limfjord for the first time (B.F. Theisen, pers. comm.).

Caprella mutica Schurin, 1935
A few specimens identified as this species were recorded in 2005 during the monitoring program for the offshore windmill farm at Horns Rev in the North Sea (DONG Energy 2006). So far this is the only record from Danish waters.

Platorchestia platensis (Krøyer, 1845)
Synonym: *Orchestia platensis*
This species has been overlooked as an exotic species by previous authors (Knudsen 2001; Jensen & Knudsen 2005), probably because it is "terrestrial" rather than marine. It was originally described from La Plata, Argentina (Wolff 2005) and may have been introduced to the Sound (Øresund), Denmark directly from there. It is abundant in the Isefjord (Rasmussen 1973), but has not been recorded from the Limfjord.

Callinectes sapidus Rathbun, 1896
The blue swimming crab from the east coast of the USA has been found only two times in Danish waters (Tendal & Flintegaard 2007).

Eriocheir sinensis Milne-Edwards, 1854
The Chinese mitten crab is regularly found in most Danish waters, but very few egg-bearing females have been seen, and most had partly decomposed eggs, so it is unlikely that it is reproducing in Danish waters (Rasmussen 1987).

Rhithropanopeus harrisii (Gould, 1841)
This tiny crab that has been established as an exotic in most countries surrounding Denmark, has only been found once in 1953 in the harbor of Copenhagen (Jensen & Knudsen 2005).

Limulus polyphemus (Linnaeus, 1758)
The American horseshoe crab has been found on several occasions in Danish waters, but only as single specimens, probably released from passing vessels or from aquaria (Jensen & Knudsen 2005).

Telmatogeton japonicus Tokunaga, 1933
This giant Japanese chironomid was first found in 2003 in connection with the monitoring of the offshore wind farm at Horns Rev in the North Sea (DONG Energy 2006).

Bowerbankia imbricata (Adams, 1798) and *Bowerbankia gracilis* (Leidy, 1855)
Wolff (2005) discusses the status of these two species of the Bryozoan genus *Bowerbankia*. They are at best cryptogenic, but possibly not exotic at all. Both have been recorded a few times from the Isefjord (Rasmussen 1973), but it is uncertain whether they are established.

Botryllus schlosseri (Pallas, 1766)
This appears to be a native species in Danish waters, but is considered invasive in the USA and Australia (NIMPIS 2002b). It was first recorded from the Isefjord in 1984 and has been collected several times since though on the same locality (Rasmussen 1997).

Molgula manhattensis (De Kay)
There is some discussion about the identity of this species. Some authors consider it a synonym of *Molgula tubifera* (Ørsted) (Rasmussen, 1973), whereas others consider them different (Hayward & Ryland 1995). This species has been recorded from both the Isefjord (Rasmussen, 1973) and the Limfjord (Hedeselskabet, 2003).

Styela clava Herdman, 1882
This species was first recorded from the Limfjord in 1978, but may have arrived there a few years earlier (Jensen & Knudsen 2005). It occurs throughout the Limfjord and also in the Wadden Sea. It is a fouling species, forming dense growths on mussels, seaweeds and stationary fishing gear, including mussel culture facilities (Jensen & Knudsen 2005).

5.2.6 Pisces (Fish)

(see: http://fish.mongabay.com/data/Denmark.htm)

Aristichthys nobilis (Bighead carp)
This species has been introduced to Denmark and has been caught in the wild a few times. It occurs in brackish water, but is not established in Denmark.

Salvelinus fontinalis (Brook trout or brook char)
This is a freshwater species, intentionally introduced to Denmark for aquaculture. It is now an established alien species, but only found in a few streams. It may migrate to saltwater and has been caught for instance in Ringkøbing Fjord (on the North Sea coast of Denmark).

Salvelinus namaycush (Lake trout, Great Lakes trout, a.o.)
This is exclusively a freshwater species living in lakes. It is not established in Denmark.

6 Risk assessment

6.1 Introduction

In this study, a semi-quantitative risk assessment is made on the risk of introducing hazardous exotic, non-indigenous species into the Oosterschelde with the mussel imports from the Isefjord and the Limfjord.

Within the European Union (EU), risk assessment is defined as: "*A process of evaluation including the identification of the attendant uncertainties, of the likelihood and severity of (an) adverse effect(s)/event(s) occurring to man or the environment following exposure under defined conditions to (a) risk source(s)*". Based on this definition the risk assessment of invasive species should include a quantification of the likelihood and severity of biological effects.

The impact of invasive species on an ecosystem is difficult to predict. The likelihood of an introduced organism becoming established in the new environment depends on the characteristics of the species (its intrinsic properties) and the environment (the circumstances) into which it is introduced. The more similarity exists between the native and the new environment, the more likely it is that a species will be able to become established there. However, species can survive under a wide range of circumstances as long as these are within the species specific environmental tolerances (Hewitt & Hayes 2002).

The significance of the effect that the establishment of exotic species may have on the local ecosystem depends on the life history of the species and the prevailing environmental conditions in the system. The sensitivity of the system is also an important factor, as some ecosystems are more resilient to new invaders than others. It is not feasible to obtain a complete knowledge of the Oosterschelde and to forecast the future development. Most of the introduced species do not spread widely within the invaded region (Williamson 1996).

The potential risks can be identified qualitatively, using expert judgement. This has been done in a previous study on the import of exotic species with mussel transport (Snijdelaar et al. 2004). In this study the experts agreed that it is hard to predict the impact of an alien species in advance due to the fact that (in most cases) knowledge of the (aut)ecology of the species is very limited at that stage.

The disadvantage of a qualitative approach is that low probability/high consequence events often tend to be overestimated, while high probability/low consequence events tend to be underestimated (Haugom et al. 2002). In our assessment we separately describe the risk of the two components of risk (i.e. probability and consequence), so that the outcome of the second part will not be influenced by the results of the first part.

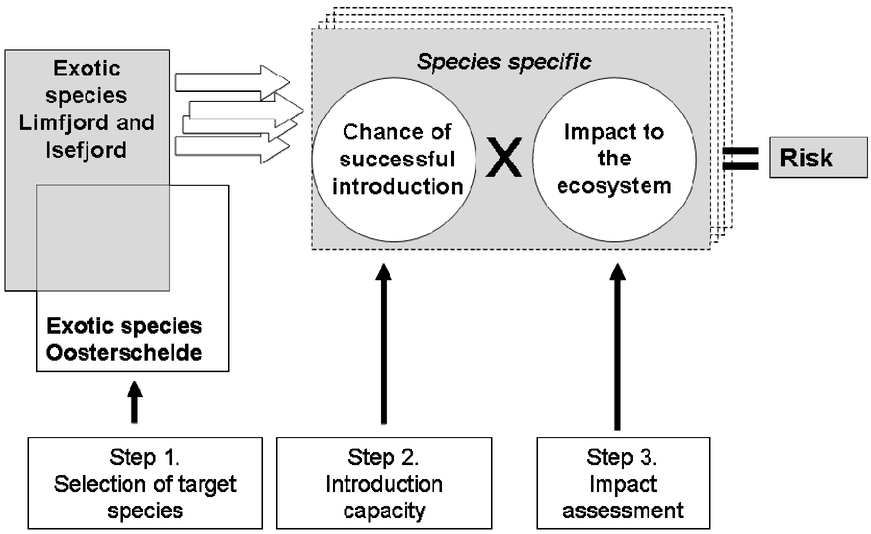

Figure 9: Overview of the set-up of the risk analysis.

Roughly, our risk assessment is divided into three steps (Figure 9): In the first step, the target species are identified. Target species are exotic species that are found in the Isefjord and the Limfjord but are not present in the Oosterschelde.

The second step is to quantify the chance of introduction of these target species into the Oosterschelde with the import and relay of the mussels from the Limfjord and the Isefjord, and the possibility that they will become permanently established in the Oosterschelde. This assessment is based on available information on ecological and physiological characteristics of the selected species. The available information is compared with the transport and environmental conditions in the Oosterschelde. An international group of 11 experts (see chapter 1.3) has assessed the chance of successful introduction of exotic species by transporting mussels from the Isefjord and the Limfjord to the Oosterschelde.

The third step is to identify the impact of a target species on the ecosystem of the Oosterschelde, assuming successful introduction. This is based on the judgment of a group of experts and literature on impact of invasive species.

Besides an ecological impact, which is the focus of this study, the introduction of exotic species can also have economical, social and safety related impacts (Haugom et al. 2002). Often these effects are inter-related. Reduction of the fishery/aquaculture production or tourist attraction will, for instance, have economical and social impact. Safety could be at risk when, for instance, toxic algal blooms occur in areas that are used for swimming or shellfish production. On the other hand in some cases economical impact can occur without a substantial change of the ecosystem when e.g. exotic fouling organisms are clogging cooling water pipes. The economical consequences of introduction of exotic species situations are not explicitly covered by this study.

6.2 Identification of target species

All exotic non-indigenous species that are present in the source area (the Limfjord and the Isefjord, Appendix A to D) and not in the Oosterschelde (Table 1) form the target species for this study (Table 8). It is good to realize, that the selection of the target species (Table 9) is based on reported observations made in the areas of interest, and that it is not unlikely that more species are present without being observed. Moreover, this list describes a snapshot of a situation that is continuously changing. New exotic species are discovered regularly in European waters. Therefore the list of target species is dynamic and should be updated regularly in order to account for recordings of new exotic species.

Table 8: Schematic presentation of the selection of the target species that could potentially be introduced in the Wadden Sea by mussel transfer from Norway.

	Exotic non-indigenous species		
	A	B	C
Present in the Limfjord and/or the Isefjord?	No	Yes	Yes
Present in the Oosterschelde?	Not relevant	Yes	No
Target species?	**No**	**No**	**Yes**

Table 9: Target species: Exotic non-indigenous estuarine and marine species that have been recorded for the Limfjord and/or the Isefjord and are unknown for the Oosterschelde

Taxon	**Species**
Rhodophyta	*Bonnemaisonia hamifera*
Chlorophyta	*Codium fragile scandinavicum*
Molusca	*Potamopyrgus antipodarum*
Amphipoda	*Platorchestia platensis*
Bryozoa	*Bowerbankia gracilis*
	Bowerbankia imbricata

6.3 Potential for establishment of self-sustaining populations

The likelihood that a certain exotic species can become established in the Oosterschelde due to the transfer of mussels, is the resultant of two processes, both with a separate probability:

1. the probability that target species are successfully caught and transferred with the mussel transport;
2. the probability that transferred species are able to become established permanently.

The assessment of these probabilities is based on available knowledge about the physiology and ecology of the species involved. The probability that species are successfully transferred with mussels from the Isefjord and the Limfjord to the Oosterschelde depends on the likelihood that the species are collected with the mussels at the production sites and subsequently survive transportation.

The first question to be answered is: which of the target species may be collected and transported together with the mussels? This primarily depends on the presence of the species on the mussel beds. Most of the by-catch of larger organisms will consist of species that live in close connection with the mussels and the mussel beds. Planktonic species or life stages can easily be transported with the water attached to (or enclosed in) the mussels. The probability that species will be collected together with the mussels can be determined on bases of the ecological profiles.

To be successfully transported to the Oosterschelde these species must be capable of surviving their transport to the Netherlands. For transport, the mussels are packed in large (1.5 m^3) big-bags without water. This situation lasts for about 24 hours. Therefore, in order to survive the transportation the species must be able to overcome this period under moist conditions, but out of the water. The assessment of this potential can be based on available knowledge about the physiology of the species involved, and observations of species associated with the mussels in the Limfjord and the Isefjord. Also the storage in the containers at the waterside in Yerseke can impact the chance of survival. Those species that are able to survive the transport can be introduced in the Oosterschelde, either with the discharge water from the containers or with the tare when this is dumped in the Oosterschelde.

In order to invade a new species must establish itself permanently after introduction. Many newcomers do not survive because the environmental conditions are not suitable. Even if they manage to reproduce, they might become extinct after a few generations: for example during an irregularly occurring harsh winter or fresh water event. Each species has its own needs and tolerance for physical characteristics of the seawater (salinity, dissolved oxygen concentration, water temperature, etc.) and structural characteristics of the target area (substrate type, currents, etc). The combination of these characteristics determines the suitability of the environment for a specific species and thus the possibility for the introduced organisms to establish a self-sustaining population.

The group of international experts was asked to score the chance of successful introduction with the mussel transports. The scores are therefore a combination of the chance of surviving the transport and the chance of successful establishment. The experts were asked to score the chance on a scale between 1 and 5. The results of these scores are given in Table 10

1. very unlikely / certainly not
2. unlikely
3. likely
4. very likely
5. certain

Table 10: The assessment of marine biology experts on the chance of successful introduction of target species. (Presented are the average scores as well as the range of scores. The last column indicates the number of experts that have given their score for the particular species.

Species name	Average	Range	# experts
Potamopyrgus antipodarum	1.43	1 - 3	7
Codium fragile scandinavicum	3	2 - 4	5
Platorchestia platensis	1.30	1 - 2	3
Bowerbankia gracilis	2.25	1 - 3	4
Bowerbankia imbricata	2.00	1 - 3	4
Bonnemaisonia hamifera	3.25	2 - 5	4

6.4 Potential for ecological impact

An imported species can reach several stages of penetration (Van Der Weijden et al. 2007):

1. Import of the species into a closed-off environment (e.g. big-bags for the mussels)
2. Introduction of the species in the wild (escape or release)
3. Settlement: the species is able to maintain itself and reproduce
4. Development into a pest.

Not all exotic species that have been introduced into a new environment will have an impact to the ecosystem; roughly speaking, out of every 1000 imported species, 1 will develop into a pest (Williamson 1996). Many of the other successful introductions will result in new species, but these species will have apparently no large impact. The group of experts was asked to score the probability that the species will have substantial impact on the ecosystem, assuming a successful introduction.

The experts were asked to score the probability on a scale between 1 and 5. The results of these scores are given in Table 11

1. very unlikely/certainly not
2. unlikely
3. likely
4. very likely
5. certain

Table 11: The assessment of marine biology experts of the probability that the species will have substantial impact on the ecosystem, assuming successful introduction. The average is the average score of the experts. The range gives the range of scores and the column # experts indicates the number of experts that gave a score for the particular species.

Species name	Average	Range	# experts
Potamopyrgus antipodarum	1.67	1 – 3	6
Codium fragile scandinavicum	3	2 – 4	4
Platorchestia platensis	1.30	1 – 2	3
Bowerbankia gracilis	1.50	1 – 2	4
Bowerbankia imbricata	1.25	1 – 2	4
Bonnemaisonia hamifera	2.20	1 – 3	5

6.5 Overall risk assessment

The overall risk is calculated by multiplying the chance of successful introduction with the impact divided by 5. The calculated risks are presented in Table 12. Species with highest sores are *Codium fragile* spp. *scandinavicum* and *Bonnemaisonia hamifera*. For *Codium fragile* spp. *scandinavicum* the chance of successful introduction is scored as 3 (likely) and the chance of ecological impact was also scored 3 (likely). The chance of successful introduction of *Bonnemaisonia hamifera* was slightly higher (3.25) but the impact was scored lower (2.20). This means that it is more than likely that this species will be introduced with the imports of mussels from the Limfjord and the Isefjord, but the species will give less impact than *Codium fragile scandinavicum* if introduced successfully. For the bryozoan species *Bowerbankia*, the chance of successful introduction is unlikely and even if it will be introduced, the probability of impact will be very unlikely. For the mud snail that is mainly present in fresh water (*Potamopyrgus antipodarum*), it is obvious that the chance of successful introduction is very unlikely, but even if it is introduced, it is not expected that the species will have any impact on the ecosystem. The gastropod *Potamopyrgus antipodarum* is an exotic species that has been a successful colonizer of freshwater systems (rivers, canals, ditches). The species tolerates low salinity conditions. Since the species is a freshwater species, it is not likely that the species will survive in the salt water of the Oosterschelde. The calculated risk of introducing this species with the shellfish transfer is 0.3.

Table 12: Overall risk score of the 6 target risk species for the import from the Limfjord and the Isefjord into the Oosterschelde.

Species name	Average
Codium fragile spp. *scandinavicum*	1.80
Bonnemaisonia hamifera	1.43
Bowerbankia gracilis	0.68
Bowerbankia imbricata	0.50
Potamopyrgus antipodarum	0.48
Platorchestia platensis	0.30

6.5.1 Codium fragile spp. scandinavicum

Codium fragile (green sea fingers) is a peculiar green algae, that is spongy, leathery, elastic and weighty. As the plant grows, each branch splits into two new branches. The branches are 4-5 mm thick. The surface is densely covered with long colorless hair. It is a member of the green algal order caulerpales that has many members in tropical and sub-tropical waters, and also a few in colder regions. *Codium fragile* ssp. *scandinavicum* is considered to have its origin in the Pacific Ocean and was already found in Ireland about 1808 and in Scotland before 1840. It was unintentionally introduced with shellfish (Eno et al. 1997). Its holdfast is a broad, sponge-like cushion of tissue. The tips of segments are blunt and the surface is soft, so it is sometimes mistaken as a sponge. There are many sub species and morphological identication of the subspecies is extremely difficult. According to Kerkum et al. (2004), *Codium fragile* ssp. *atlanticum*, *Codium fragile* ssp. *scandinavicum* and *Codium fragile* ssp. *tomentosoides* are present in the Dutch waters. Wolff (2005) describes *Codium fragile* spp *tomentosoides* as the exotic *Codium fragile* species that is permanently established in The Netherlands. One of the target species for this study, *Codium fragile* ssp. *scandinavicum*, exhibits various modes of reproduction which is a common trait in many successful invaders. It can reproduce sexually, parthenogentically and vegetatively. Water currents can and will carry this species over long distances introducing it to new locations. The species is very tolerant to a variety of salinity and water temperature levels. The rapid growth of this species and its ability to regenerate from broken fragments assist it in outcompeting other seaweed species. This species gives the largest risk for introduction into the Oosterschelde with the shellfish transport. Also in the risk study for the import of mussels from Sweden to the Dutch part of the Wadden Sea (Wijsman et al. 2007c), this species was indicated as one of the risk species. The experts in that study scored the risk for this species 1.75, which is comparable to the estimated risk in the present study.

6.5.2 Bonnemaisonia hamifera

Bonnemaisonia hamifera is a red alga that has a heteromorphic life history in which a multiseriate, radially branched, dioecious gametophyte alternates with a uniseriate, alternately branched tetrasporophyte (Breeman et al. 1988). The bright pink /red gametophyte plants are characterized by its small hook-like appendages. With the hooks they hitch-hike with other algae species by becoming entangled. The tetrasporophyte is brownish red, and occurs much branched, filamentous, in dense cotton-wool-like tufts to 25 mm in diameter. The species originates from Japan. The species has been recorded in The Netherlands from material washed ashore on the beach. Most of this material belongs to the sporophytic generation of this species (Wolff 2005). In Danish waters only the tetrasporophyte occurs. Lack of grazers, rapid growth rate, and its opportunistic qualities have contributed to its success of this species as an invader.

6.5.3 Bowerbankia gracilis and Bowerbankia imbricata

Bryozoan colonies consist of replicated series of zooids, each budded asexually from a predecessor. They form crust-like colonies on various types of substrates like mollusk shells, macro algae, seagrasses, or various other substrata. Bryozoa are suspension feeders that filter their food with tentacles that can be extended into the water column. Wolff (2005) discusses the status of these two species of the Bryozoan genus *Bowerbankia*. They are at best cryptogenic, but possibly not exotic at all. The species are often regarded as cosmopolitic in shallow waters. In the late 1960’s both species have been described for the estuaries of the Delta area (Heerebout 1969).

6.5.4 Platorchestia platensis

It is believed that *Platorchestia platensis* arrived in NW Europe on Danish coasts in the 1860s (Spicer & Janas 2006). *Platorchestia platensis* is an amphipod that lives among algae that have been washed up on the beach. In various papers it is called semi-terrestrial or semi-aquatic. Hence, unless mussels are mixed with seaweeds from the shore (or temporarily stored on the shore) there is little chance for its introduction. The species might compete with native species, *P. platensis* has been seen to co-occur with, and in some cases has outcompeted another amphipod, *Orchestia gammarellus* (Spicer & Janas 2006). The species lack a pelatic stage in the life cycle and dispersal mainly takes place when they accidently get into the water together with floating wracks (Persson 2001).

6.5.5 Potamopyrgus antipodarum

The species with the lowest risk score is *Potamopyrgus antipodarum*. This small, aquatic snail may reach a maximal size very near 5mm. Like most snails, it is dextral (opening to the animal's right). A full-grown shell normally has 5 or 6 whorls. *Potamopyrgus antipodarum* has a wide range of tolerances and it can occur in rivers, reservoirs, lakes, and estuaries. Densities are usually highest in systems with high primary productivity, constant temperatures, and constant flow. In estuaries *P. antipodarum* can tolerate up to 17-24‰ salinity. Mud snails are able to withstand a variety of temperature regimes. They can reach very high densities in fresh water systems. The most important risk characteristic of the species is that is reproduces parthenogenetically, i.e. one specimen can start a new population. The species occurs in parts of the Limfjord with very low salinity. It has not been found in the Isefjord.

6.6 Veterinary and sanitary risks

In the Isefjord and the Limfjord, harmful algal blooms occur regularly. The most commonly occurring harmful algae are DSP producing algae, that are found every year in Denmark and cause the closing of the production areas. PSP toxins producing algae are found rarely in Danish bivalve mollusks and ASP producing algae are found occasionally.

With the import of mussels from the Isefjord and the Limfjord into the Oosterschelde, the harmful algae and the algal toxins could also be introduced. However, EU legislation requires that the consumption mussels that are transported are free from biotoxins (ASP, PSP and DSP). Sound monitoring (concentration of harmful algae, mice tests) should take place in the area of origin. If pre-defined critical limits are exceeded, the area is closed for a certain period.

As far as the harmful algae are exotic non-indigenous species (e.g. *Alexandrium tamarense*, *Gymnodinium mikimotoi*) they are included in the present report. However, most of the harmful algae are endemic species that also are present in the Dutch coastal waters. In The Netherlands these harmful algae rarely occur in such high densities that they cause sanitary problems.

The mussels in the Limfjord and the Isefjord are mainly from bottom cultures. Microscopic cysts of the harmful algae that are present in the bottom could hitch-hike with the mussels that are transported to the Oosterschelde. There is up till now no clear evidence that the cysts of the harmful algae could lead to a harmful algal bloom (Snijdelaar et al. 2004).

Other sanitary risks are caused by bacteria and viruses. Coliforms and salmonella could lead to health problems when the shellfish are consumed by humans. The production areas in the Limfjord and the Isefjord are monitored weekly and microbiologically classified as A, B or C. Only mussels from A-classified production areas can be sold for fresh live consumption. Mussels from B- or C-classified areas need to be purified.

The veterinary risks include the shellfish diseases that could be introduced with the mussels. The transport of shellfish is the most important vector for introduction of shellfish diseases. These diseases might be caused by exotic non-indigenous organisms (e.g. *Bonamia ostrea*), but also endemic species could lead to problems for the shellfish population.

6.7 Risks of introducing Northeast Atlantic non-endemic species

The present analysis is focused on the risks of introducing exotic, non-indigenous species into the Oosterschelde. With the transfer of mussels, also Northeast Atlantic non-indigenous species could be introduced. Since there are no impassable barriers for these organisms between their original area of distribution and the Oosterschelde, it can be assumed that they have already been introduced into the Oosterschelde by natural transport in the past but have not managed to settle permanently. Apparently the environmental conditions in the Oosterschelde were not suitable for permanent settlement.

These Northeast Atlantic non-indigenous species could be introduced again into the Oosterschelde by the shellfish imports from the Isefjord and the Limfjord. Most of these species will not survive because the environmental conditions in the Oosterschelde are not suitable. Some of these species might settle for a couple of years. However, eventually they will disappear because the long term environmental conditions in the Oosterschelde are not suitable to form a self-sustaining population (Wolff 2005).

The environmental conditions in the Oosterschelde are not constant. For example, due to the climate change, the water temperature is increasing. As a result of especially the milder winters, more and more Northeast Atlantic non-indigenous from the south become established the Oosterschelde (Wijsman & Smaal 2006). Since the species from the Isefjord and the Limfjord are in general adapted to lower temperatures compared to the temperatures in the Oosterschelde it is not likely that the environmental conditions in the Oosterschelde will improve for these species due to global warming. It is therefore not likely that the introduction of new Northeast Atlantic non-indigenous species from the Isefjord and the Limfjord will be a risk for the ecosystem of the Oosterschelde.

7 Discussion

The risk of introducing exotic, invasive species with the import of mussels from the Isefjord and the Limfjord into the Oosterschelde has been evaluated based on literature data and expert judgement. In total 6 target species (exotic species that are present in the Isefjord and the Limfjord, but are not present in the Oosterschelde) have been evaluated in detail. Based on the results of the risk assessment, the risk of introducing exotic non-indigenous organisms with the import from the Isefjord and the Limfjord is low.

The highest risk is formed by the green macro algae *Codium fragile* spp. *scandinavicum*. This species might become an invader due to its large reproductive capacity. The most detrimental effect of this species is the fouling of shellfish beds and clogging the dredges in the Oosterschelde. Furthermore, the accumulation of masses of *Codium fragile* rotting on beaches and dikes may produces a foul odor. However, the species is difficult to distinguish from another subspecies *Codium fragile* spp *tomentosoides*, that is already present in the Oosterschelde (Wolff 2005). According to Kerkum et al (2004), the three subspecies of *Codium fragile* (*atlanticum*, *scandinavicum* and *tomentosoides*) are present in The Netherlands.

The second target species is the red algae *Bonnemaisonia hamifera*. This is also an opportunistic, fast growing species that can overgrow other macroalgae. *B. hamifera* has a heteromorphic life history. In the gametophyte stage, the species is capable of hitch hiking with other organisms over large distances. Since the species is small, the expected impact of this species is less than for example *Codium fragile* spp. *scandinavicum*. The species has been recorded in The Netherlands, where it is washed ashore (Wolff 2005), but it is not established. Since the species is found on the beaches along the Dutch coast, it is likely that the species has also been introduced into the Oosterschelde with the water currents.

The risk of the other target species: The bryozoan (moss animals) species *Bowerbankia gracilis* and *Bowerbankia imbricata* and the mud snail *Potamopyrgus antipodarum* is very small to absent. The colonies of the Bryozoa might form a crust layer on various substrates like she shellfish shells. It is not clear whether they are exotic or cryptogenic (Wolff 2005). According to Heerebout (1969), both species are (fairly) common to the Dutch Delta area. The mud snail occurs mainly in freshwater systems, but tolerates salinity up to 17-24 ‰, and therefore it can be expected not to have any impact to the Oosterschelde.

This risk analysis was done with the best available knowledge. The lists of exotic species in the Limfjord and the Isefjord, as well as the list for the Oosterschelde have been updated with recent observations. However, it is possible that new exotic species, that are not in the lists that are used in this study, have (or will) be(en) introduced into the Limfjord or the Isefjord. Not all exotic non-indigenous species from Denmark are present in the Limfjord and the Isefjord (Table 6), but they might get introduced from the surrounding Danish coastal waters. These new exotic non-indigenous species in the Limfjord and the Isefjord should be evaluated on the risk of their introduction into the Oosterschelde.

The up-to-date list for exotic species in the Oosterschelde is largely based on the extensive overview of Wolff (2005), the list of Wijsman and Smaal (2006) and the recent observations. It is possible that some of these species have been observed in the past, but have disappeared from the Oosterschelde. These species might be re-introduced with the import of mussels from the Isefjord and the Limfjord.

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Justification

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The scientific quality of this report has been peer reviewed by the a colleague scientist and the head of the department of Wageningen IMARES.

Approved:	Dr. Ir. Reinier Hille Ris Lambers Scientist
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Appendix A. Marine flora of the Isefjord

Data from NOVA (2003), NOVANA (2004) and Rasmussen (1973). Exotic species are in grey indicated by an *

Flowering plants
- *Potamogeton pectinatus*
- *Ruppia maritima*
- *Ruppia spiralis*
- *Zannichellia palustris*
- *Zostera marina*
- *Zostera nana*

Rhodophyta
- *Acrochaetium sp.*
- *Ahnfeltia plicata*
- *Antithamnion cruciatum*
- *Callithamnion corymbosum*
- *Ceramium nodulosum*
- *Ceramium tenuicorne*
- *Chondrus crispus*
- *Coccotylus truncatus*
- *Corallina officinalis*
- *Cystoclonium purpureum*
- *Dasya baillouviana**
- *Delesseria sanguinea*
- *Furcellaria lumbricalis*
- *Laurencia pinnatifida*
- *Lithophyllum macrocarpum*
- *Nemalion multifidum*
- *Phyllophora pseudoceranoides*
- *Phyllophora sp.*
- *Polyides rotunda*
- *Polysiphonia elongata*
- *Polysiphonia fibrillosa*
- *Polysiphonia fucoides*
- *Polysiphonia stricta*
- *Polysiphonia urceolata*
- *Polysiphonia sp.*
- *Rhodomela confervoides*
- *Spermothamnion repens*

Dinophyta
- *Prorocentrum minimum**

Phaeophyta
- *Chorda filum*
- *Dictyosiphon foeniculaceus*
- *Ectocarpus siliculosus*
- *Fucus serratus*
- *Fucus spiralis*
- *Fucus vesiculosus*
- *Halidrys siliquosa*
- *Laminaria saccharina*
- *Petalonia fascia*
- *Pilayella littoralis*
- *Sphacelaria cirrosa*
- *Sphacelaria sp.*

Chlorophyta
- *Bryopsis plumosa*
- *Bryopsis hypnoides*
- *Chaetomorpha melagonium*
- *Chaetomorpha linum*
- *Cladophora glomerata*
- *Cladophora rupestris*
- *Cladophora sericea*
- *Cladophora sp.*
- *Codium fragile**
- *Enteromorpha intestinalis*
- *Enteromorpha ahlneriana*
- *Enteromorpha sp.*
- *Ulva lactuca*

Appendix B. Invertebrate fauna of the Isefjord.

Data mostly from Rasmussen (1973) with additional species records from Rasmussen (1987, 1996, 1997) and Tendal et al. (2007). Alien species are in grey and marked by an *

Porifera

Leucosolenia botryoides (Ellis & Solander, 1786)
Leucosolenia complicata (Montagu, 1818)
Cliona celata Grant, 1826
Cliona lobata Hancock, 1849
Halichondria panicea (Pallas, 1766)
Halichondria bowerbanki Burton, 1930
Haliclona oculata (Pallas, 1766)
Haliclona limbata (Montagu, 1818)
Haliclona permollis (Bowerbank, 1866)
Adocia cinerea (Bowerbank)
Halisarca dujardini Johnston, 1842

Cnidaria

Protohydra leuckarti Greef, 1870
Coryne pusilla (Gaertner, 1774)
Coryne sarsi (Lovén, 1835)
Cladonema radiatum Dujardin, 1843
Clava multicornis (Forsskål, 1775)
Corydendrium dispar Kramp, 1935
(Cordylophora lacustris (Allmann, 1844))
Hydractinia echinata (Fleming, 1823)
Hydractinia carnea M. Sars, 1846
Bougainvillia muscoides (M.Sars, 1846)
Bougainvillia ramosa (Van Beneden, 1844)
Campanularia johnstoni (Alder, 1856)
Laomedea dichotoma (Linnaeus, 1758)
Laomedea geniculata (Linnaeus, 1758)
Laomedea longissima (Pallas, 1766)
Laomedea loveni (Allman, 1859)
Laomedea hyalina (Hincks, 1866)
Laomedea neglecta Alder, 1856
Laomedea gelatinosa (Pallas, 1766)
Laomedea plicata (Hincks, 1868)
Laomedea flexuosa Hincks
Calycella syringa (Linnaeus, 1758)
Campanulina lacerata (Johnston)
Lafoea dumosa (Fleming, 1820)
Lafoea gracillima (Alder, 1856)
Dynamena pumila (Linnaeus, 1758)
Sertularella rugosa (Linnaeus, 1758)
Sertularia cupressina Linnaeus, 1758
Sertularia tenera G.O. Sars, 1874
Euphysa aurata Forbes, 1848
Sarsia gemmifera Forbes, 1848
Rathkea octopunctata (M. Sars, 1835)
Lizzia blondina Forbes, 1848
Halitholus cirratus Hartlaub, 1913
Eutonina indicans (Romanes, 1876)
Cyanea capillata (Linnaeus, 1758)
Cyanea lamarcki Peron & Lesueur, 1809
Aurelia aurita (Linnaeus, 1758)
Halcampa duodecimcirrata (M. Sars, 1851)
Tealia felina (Linnaeus, 1767)
Metridium senile (Linnaeus, 1767)
Sagartiogeton viduatus (O.F. Müller, 1776)
Sagartiogeton undatus (O.F. Müller, 1788)
Sagartiogeton laceratus (Dalyell, 1848)

Ctenophora

Pleurobrachia pileus (O.F. Müller, 1776)
Bolinopsis infundibulum (O.F. Müller, 1776)
*Mnemiopsis leidyi A. Agassiz, 1865**

Platyhelminthes

Aphanostoma diversicolor Ørsted, 1845
Alaurina compositae Metschnikoff
Promesostoma marmoratum (Schultze)
Proxenetes flabellifer Jensen
Phonorhynchus helgolandicus (Metschnikoff)
Notoplana atomata (O.F. Müller)
Cercaria & metacercaria (several spp. in Hydrobia spp.)

Nematoda

Enoplus communis Bastian
Pontonema vulgare (Bastian)

Nemertini

Carinina coei Hylbom
Lineus ruber (O.F. Müller)
Nemertopsis tenuis Bürger
Oerstedia dorsalis (Abildgaard)
Amphiporus cordiceps Jensen
Amphiporus lactifloreus (Johnston)

Polychaeta

Lepidonotus squamatus (Linnaeus)
Gattyana cirrosa (Pallas)
Antinoella sarsi (Malmgren)
Harmothoe imbricata (Linnaeus)
Harmothoe impar Johnston
Pholoe minuta (Fabricius)
Eteone longa (Fabricius)
Phyllodoce (Anaitides) maculata (Linnaeus)
Phyllodoce (Anaitides) mucosa Ørsted
Eulalia viridis (Linnaeus)
Eulalia bilineata (Johnston)
Eumida sanguinea (Ørsted)
Microphthalmus aberrans (Webster & Benedict)
Kefersteinia cirrata (Keferstein)
Nereimyra punctata (O.F. Müller)
Syllidia armata Quatrefages
Streptosyllis websteri Southern
Exogone gemmifera Pagenstecher
Autolytus edwarsi Saint-Joseph
Autolytus prolifer (O.F. Müller)
Autolytus rubropunctatus (Grube)
Proceraea aurantiaca Claparède
Proceraea cornuta (A. Agassiz, 1862)
Platynereis dumerili (Audouin & Milne-Edwards)

Platynereis massiliensis Moquin-Tandon
*Neanthes succinea (Frey & Leuckart, 1847)**
Nereis (Neanthes) virens Sars, 1835
Hediste diversicolor (O.F. Müller, 1776)
Nereis pelagica Linnaeus, 1758
Nephtys caeca (Fabricius, 1780)
Nephtys hombergi Audouin & Milne-Edwards
Nephtys longosetosa Ørsted, 1843
Ephesiella minuta (Webster & Benedict, 1887)
Protodorvillea kefersteini (McIntosh, 1869)
Scoloplos armiger (O.F. Müller, 1776)
Paraonis fulgens (Levinsen, 1884)
Malacoceros fuliginosus (Claparède, 1869)
Spio filicornis (O.F. Müller, 1776)
Spio martinensis Mesnil, 1896
Spio goniocephalus Thulin, 1957
Pygospio elegans Claparède, 1863
Polydora ciliata (Johnston, 1838)
Polydora ligni Webster, 1880
Polydora quadrilobata Jacobi, 1883
Polydora (Pseudopolydora) antennata Claparède, 1870
Poecilochaetus serpens Allen, 1904
Flabelligera affinis M. Sars, 1829
Ophelia borealis Quatrefages, 1866
Ophelia rathkei McIntosh, 1908
Capitella capitata (Fabricius, 1780)
Mediomastus fragilis Rasmussen, 1973
Arenicola marina (Linnaeus, 1758)
Pectinaria (Lagis) koreni (Malmgren, 1866)
Ampharete grubei Malmgren, 1866
Neoamphitrite figulus (Dalyell, 1853)
Nicolea zostericola (Ørsted, 1844)
Fabricia sabella (Ehrenberg, 1836)
Hydroides norvegicus Gunnerus, 1768
Pomatoceros triqueter (Linnaeus, 1767)
Dexiospira pagenstecheri (Quatrefages)
Spirorbis (Laeospira) borealis Daudin, 1800
Spirorbis (Laeospira) tridentatus Levinsen, 1883
Spirorbis (Laeospira) corallinae de Silva & Knight-Jones, 1962

Oligochaeta

Paranais litoralis (Müller, 1780)
Fridericia gracilis von Bülow, 1957
Enchytraeus albidus Henle, 1837
Enchytraeus buchholzi Vejdovsky, 1879
Lumbricillus rivalis (Levinsen, 1884)
Lumbricillus lineatus (O.F. Müller, 1774)
Lumbricillus cf. helgolandicus (Michaelsen, 1934)
Lumbricillus viridis Stephenson, 1911
Lumbricillus pagenstecheri (Ratzel, 1869)
Lumbricillus tuba Stephenson, 1911
Lumbricillus buelowi Nielsen & Christensen, 1959
Lumbricillus arenarius (Michaelsen, 1889)
Marionina southerni (Cernosvitov, 1937)
Marionina sjaelandica Nielsen & Christensen, 1961
Marionina spicula (Leuckart, 1847)
Peloscolex benedeni (Udekem, 1855)
Tubifex costatus (Claparède, 1863)

Crustacea (Branchiopoda)

Evadne nordmanni Lovén, 1836
Podon polyphemoides (Leuckart, 1859)

Crustacea (Ostracoda)

Cyprideis litoralis (G.S. Brady, 1868)
Cythere lutea O.F. Müller, 1785
Leptocythere castanea (G.O. Sars, 1866)
Hemicythere villosa (G.O. Sars, 1866)
Cytherura nigrescens (Baird, 1838)
Cytherura cellulosa (Norman)
Loxoconcha impressa (Baird, 1850)
Hirschmannia viridis (O.F. Müller, 1785)
Xestoleberis aurantia (Baird, 1838)
Cytherois fischeri (G.O. Sars, 1866)
Paradoxostoma variabile (Baird, 1835)

Crustacea (Copepoda)

Thalestris longimana Claus
Lichomolgus albens Thorell
Notodelphys allmani Thorell
Notodelphys coerulea Thorell
Notodelphys elegans Thorell
Ascidicola rosea Thorell
Splanchnotrophus brevipes Hancock & Norman

Crustacea (Cirripedia)

Verruca stroemi (O.F. Müller)
*Balanus improvisus Darwin**
Balanus crenatus Bruguière
Balanus balanus (Linnaeus)
Balanus balanoides (Linnaeus)
Sacculina carcini Thompson

Crustacea (Mysidacea)

Gastrosaccus spinifer (Goes)
Schistomys ornata (G.O. Sars)
Praunus flexuosus (Müller)
Praunus neglectus (G.O. Sars)
Praunus inermis (Rathke)
Mesopodopsis slabberi (Van Beneden)
Neomysis integer (Leach)

Crustacea (Cumacea)

Bodotria scorpioides (Montagu)
Lamprops fasciata G.O. Sars
Diastylis rathkei (Krøyer)
Diastylis bradyi Norman

Crustacea (Isopoda)

Eurydice pulchra Leach
Limnoria lignorum (Rathke)
Spaeroma rugicauda Leach
Idotea baltica (Pallas)
Idotea emarginata (Fabricius)
Idotea granulosa Rathke
Idotea viridis (Slabber)
Jaera albifrons Leach
Portunion maenadis Giard & Bonnier, 1887

Crustacea (Amphipoda)

Ampelisca brevicosta (Costa)
Gitana sarsi Boeck
Ampithoe rubricata (Montagu)
Lembos longipes (Lilljeborg)
Microdeutopus gryllotalpa Costa
Atylus swammerdami (Milne-Edwards)

Apherusa bispinosa (Bate)
Calliopius rathkei (Zaddach)
Corophium volutator (Pallas)
Corophium crassicorne Bruzelius
Corophium bonelli G.O. Sars
Corophium insidiosum Crawford
Erichthonius hunteri (Spence Bate)
Erichthonius difformis Milne-Edwards
Dexamine spinosa (Montagu)
Cheirocratus sundevalli (Rathke)
Gammarus locusta (Linnaeus)
Gammarus oceanicus Segerstråle
Gammarus salinus Spooner
Gammarus zaddachi Sexton
Gammarus duebeni Lilljeborg
Melita palmata (Montagu)
Melita obtusata (Montagu)
Bathyporeia pelagica (Bate)
Bathyporeia pilosa Lindström
Bathyporeia sarsi Watkin
Haustorius arenarius (Slabber)
Pontoporeia femorata Krøyer
Gammaropsis melanops (G.O. Sars)
Megamphopus cornutus Norman
Microprotopus maculatus Norman
Pontocrates altamarinus (Bate & Westwood)
Phoxocephalus holboelli (Krøyer)
Metopa pusilla G.O. Sars
Metopa soelsbergi Schneider
Orchestia gammarellus (Pallas)
*Orchestia platensis Krøyer**
Talitrus saltator (Montagu)
Talorchestia deshayesei (Audouin)
Hyperia galba (Montagu)
Caprella linearis (Linnaeus)
Caprella septentrionalis Krøyer
Pariambus typicus (Krøyer)
Phtisica marina Slabber

Crustacea (Decapoda)

Eualus gaimardi (Milne-Edwards)
Athanas nitescens (Montagu)
Palaemon elegans Rathke
Palaemon squilla (Linnaeus)
Palaemonetes varians (Leach)
Crangon crangon (Linnaeus)
Homarus vulgaris Milne-Edwards
Eupagurus bernhardus (Linnaeus)
Carcinus maenas (Linnaeus)
Macropodia rostrata (Linnaeus)
*Eriocheir sinensis Milne-Edwards**

Pycnogonida

Nymphon rubrum Hodge
Nymphon brevirostre Hodge
Pallene brevirostris Johnston

Mollusca (Polyplacophora)

Lepidochiton cinereus (Linnaeus)
Tonicella rubra (Linnaeus)
Tonicella marmorea (Fabricius)

Mollusca (Gastropoda)

Acmaea virginea (O.F. Müller)
Acmaea tessulata (O.F. Müller)
Lacuna vincta (Montagu)
Lacuna parva (da Costa)
Lacuna pallidula (da Costa)
Littorina obtusata Linnaeus
Littorina littorea (Linnaeus)
Littorina saxatilis (Olivi)
Hydrobia ulvae (Pennant)
Hydrobia ventrosa (Montagu)
Hydrobia negelcta (Muus)
Cingula semicostata (Montagu)
Rissoa albella Lovén
Rissoa inconspicua Alder
Rissoa parva (da Costa)
Rissoa membranacea (Adams)
Skeneopsis planorbis (Fabricius)
Omalogyra atomus (Philippi)
Bittium reticulatum (da Costa)
Triphora perversa (Linnaeus)
Buccinum undatum Linnaeus
Nassarius reticulatus (Linnaeus)
Chrysallida obtusa (Brown)
Odostomia (Brachystomia) eulimoides Hanley
Odostomia (Brachystomia) scalaris Macgillivray
Odostomia (Odostomia) plicata (Montagu)
Eulimella nitidissima (Montagu)
Retusa truncatula (Bruguière)
Retusa obtusa (Montagu)
Philine aperta (Linnaeus)
Philine denticulata (Adams)
Akera bullata Müller
Stiliger bellulus (d'Orbigny)
Stiliger niger Lemche
Alderia modesta (Lovén)
Elysia viridis (Montagu)
Limapontia capitata (Müller)
Limapontia depressa Alder & Hancock
Polycera quadrilineata (Müller)
Palio dubia (M. Sars)
Acanthodoris pilosa (Müller)
Onchidoris muricata (Müller)
Adalaria proxima (alder & Hancock)
Dendronotus frondosus (Ascanius)
Coryphella gracilis (Alder & Hancock)
Amphorina rupium (Møller)
Embletonia pallida (Alder & Hancock)
Facelina curta (Alder & Hancock)
Favorinus branchialis (Müller)
Aeolidiella glauca (Alder & Hancock)

Mollusca (Bivalvia)

Modiolus adriaticus (Lamarck)
Musculus discors (Linnaeus)
Musculus marmoratus (Forbes)
Mytilus edulis Linnaeus
Astarte borealis (Chemnitz)
Arctica islandica (Linnaeus)
Mysella bidentata (Montagu)
Cardium ovale Sowerby

Cardium scabrum Philippi
Cardium exiguum Gmelin
Cardium edule Linnaeus
Cardium lamarcki Reeve
Venus striatula (da Costa)
Venerupis pullastra (Montagu)
Spisula elliptica (Brown)
Spisula subtruncata (da Costa)
Abra alba (Wood)
Scrobicularia plana (da Costa)
Macoma calcarea (Chemnitz)
Macoma balthica (Linnaeus)
Tellina fabula Gmelin
Tellina tenuis da Costa
Cultellus pellucidus (Pennant)
*Ensis americanus Gould, 1870**
Hiatella arctica (Linnaeus)
Corbula gibba (Olivi)
Mya truncata Linnaeus
*Mya arenaria Linnaeus**
Barnea candida (Linnaeus)
Zirfaea crispata (Linnaeus)
*Teredo navalis Linnaeus**
Thracia phaseolina (Lamarck)

Chaetognatha

Sagitta setosa J. Müller

Entoprocta

Pedicellina cernua (Pallas)
Barentsia gracilis (M. Sars)

Bryozoa

Crisia eburnea (Linnaeus)
Plagioecia patina (Lamarck)
Membranipora membranacea (Linnaeus)
Electra pilosa (Linnaeus)
Electra crustulenta (Pallas)
Callopora lineata (Linnaeus)
Callopora aurita (Hincks)
Cribrilina punctata (Hassall)
Alcyonidium gelatinosum (Linnaeus)
Alcyonidium polyoum (Hassall)
Alcyonidium hirsutum (Fleming)
Alcyonidium mamillatum Alder
Flustrellidra hispida (Fabricius)
Bowerbankia imbricata (Adams)
Bowerbankia gracilis (Leidy)
Walkeria uva (Linnaeus)

Echinodermata

Asterias rubens Linnaeus
Ophiopholis aculeata (O.F. Müller)
Ophiura texturata Lamarck
Ophiura albida Forbes
Psammechinus miliaris (Gmelin)
Echinocyamus pusilla (O.F. Müller)

Ascidiacea

Ciona intestinalis (Linnaeus)
Corella parallelogramma (O.F. Müller)
Dendrodoa (Styelopsis) grossularia (Van Beneden)
Molgula manhattensis (De Kay)
Molgula occulta Kupffer
Molgula citrina Alder & Hancock
Eugyra arenosa (Alder & Hancock)
Botryllus schlosseri (Pallas)

Larvacea

Oikopleura dioica Fol

Appendix C. Marine flora of the Limfjord.

Data from Nielsen (2005) with an addition from Thomsen et al. (2007b). Alien species are maked in grey and indicated with an *

Cyanophyta (=Cyanobacteria)

Anabaena torulosa
Beggiatoa alba
Beggiatoa leptomitiformis
Brachytrichia quoyi
Calothrix confervicola
Calothrix contarenii
Calothrix scopulorum
Chroococcus dimidiatus
Coelosphaerium kuetzingianum
Gloeocapsopsis crepidinum
Hyella balani
Hyella caespitosa
Leptolyngbya battersii
Leptolyngbya norvegica
Leptolyngbya terebrans
Lyngbya aestuarii
Lyngbya confervoides
Lyngbya lutea
Lyngbya majuscula
Mastogocoleus testarum
Merismopedia glauca
Microchaete grisea
Microcoleus acutirostris
Microcoleus chthonoplastes
Nodularia spumigena
Planktolyngbya contorta
Rivularia atra
Spirulina subsalsa
Symploca hydnoides

Rhodophyta

Acrochaetium hallandicum
Acrochaetium microscopicum
Acrochaetium secundatum
Aglaothamnion bipinnatum
Aglaothamnion hookeri
Aglaothamnion tenuissimum
Ahnfeltia plicata
Antithamnion cruciatum
Antithamnion villosum
Audouinella membranacea
Bangia atropurpurea
*Bonnemaisonia hamifera**
Brogniartella byssoides
Callithamnion corymbosum
Ceramium cimbricum
Ceramium diaphanum
Ceramium tenuicorne
Ceramium virgatum
Ceratocolax hartzii
Chondria dasyphylla
Chondrus crispus
Chroodactylon ornatum
Chylocladia verticillata
Coccotylus truncatus
Colaconema attenuatum
Coloconema daviesii
Coloconema nemalii
Coloconema savianum
Corallina officinalis
Cruoria pellita
Cruoriopsis danica
Cystoclonium purpureum
*Dasya baillouviana**
Delesseria sanguinea
Dilsea carnosa
Dumontia contorta
Erythrotrichia carnea
Erythrotrichia reflexa
Furcellaria lumbricalis
Gloiosiphonia capillaris
*Gracilaria vermiculophylla**
Griffithsia devoniensis
Haemescharia hennedyi
*Heterosiphonia japonica**
Hildenbrandia rubra
Jania rubens
Lithothamnion glaciale
Lithothamnion sonderi
Lomentaria clavellosa
*Mastocarpus stellatus**
Nemalion multifidum
*Neosiphonia harveyi**
Osmundea truncata
Peyssonelia dubyi
Phyllophora pseudoceranoides
Phymatolithon laevigatum
Phymatolithon lenormandii
Phymatolithon purpureum
Phymatolithon tenue
Pneophyllum caulerpae
Pneophyllum fragile
Pneophyllum limitatum
Polyides rotundus
Polysiphonia elongata
Polysiphonia fibrillosa
Polysiphonia fucoides
Polysiphonia nigra
Polysiphonia orthocarpa
Polysiphonia stricta

Porphyra leucosticta
Porphyra linearis
Porphyra purpurea
Porphyra umbilicalis
Porphyridium aerugineum
Porphyridium purpureum
Pterothamnion plumula
Rhodomela confervoides
Rhodophysema elegans
Rhodophysema georgii
Scagelothamnion pusillum
Seirospora interrupta
Spermothamnion repens
Stylonema alsidii
Titanoderma pustulatum

Xanthophyta

Vaucheria arcassonensis
Vaucheria compacta
Vaucheria coronata
Vaucheria dichotoma
Vaucheria erythrospora
Vaucheria intermedia
Vaucheria litorea
Vaucheria medusa
Vaucheria sescuplicaria
Vaucheria subsimplex
Vaucheria synandra
Vaucheria velutina

Phaeophyta

Acinetospora crinita
Acrothrix gracilis
Ascophyllum nodosum
Asperococcus bullosus
Asperococcus fistulosus
Botrytella micromora
Chilionema ocellatum
Chorda filum
Chordaria flagelliformis
Cladosiphon zosterae
Cladostephus spongiosus
*Colpomenia peregrina**
Desmarestia aculeata
Desmarestia viridis
Dictyosiphon chordaria
Dictyosiphon foeniculaceus
*Dictyota dichotoma**
Ectocarpus fasciculatus
Ectocarpus siliculosus
Elachista fucicola
Eudesme virescens
Feldmannia kjellmannii
Fucus serratus
Fucus spiralis
Fucus vesiculosus
Giraudia sphacelarioides
Gononema aecidioides
Halidrys siliquosa
Halopteris scoparia
Halosiphon tomentosus
Halothrix lumbricalis
Hincksia granulosa
Hincksia ovata
Hincksia sandriana
Laminaria digitata
Laminaria hyperborea
Laminaria saccharina
Leathesia difformis
Leptonematella fasciculata
Litosiphon laminariae
Mesogloia vermiculata
Microcoryne ocellata
Myriactula chordae
Myriactula rivulariae
Myrionema magnusii
Myrionema strangulans
Myriotrichia clavaeformis
Petalonia fascia
Petalonia zosterifolia
Pogotrichum filiforme
Punctaria plantaginea
Punctaria tenuissima
Pilayiella littoralis
Ralfsia verrucosa
*Sargassum muticum**
Scytosiphon lomentaria
Sphacelaria cirrosa
Sphacelaria plumigera
Sphacelaria plumosa
Sphacelaria rigidula
Sphaerotrichia divaricata
Spongonema tomentosum
Stictyosiphon soriferus
Stictyosiphon tortilis
Stilophora nodulosa
Stilopsis lejolisii
Stragularia clavata
Streblonema fasciculatum
Striaria attenuata
Trachynema mortensenii

Chlorophyta

Acrochaete inflata
Acrochaete leptochaete
Acrochaete operculata
Acrochaete polymorpha
Acrochaete repens
Acrochaete viridis
Acrochaete wittrockii
Acrosiphonia centralis
Acrosiphonia sonderi
Blastophysa rhizopus
Blidingia minima
Bolbocoleon piliferum

Bryopsis plumosa
Chaetomorpha ligustica
Chaetomorpha linum
Chaetomorpha melagonium
Chaetomorpha sutoria
Cladophora dalmatica
Cladophora flexuosa
Cladophora hamosa
Cladophora pygmaea
Cladophora rupestris
Cladophora sericea
Coccomyxa ophiurae
Codium fragile *
Derbesia marina
Epicladia heterotricha
Epicladia perforans
Epicladia phillipsii
Eugomontia sacculata
Gayralia oxysperma
Gomontia polyrhiza
Monostroma grevillei
Ochlochaete hystrix
Ostreobium quekettii
Percursaria percursa
Phaeophila dendroides
Planctonema lauterbornii
Prasiola stipitata
Pringsheimiella scutata
Pseudendoclonium fucicola
Pseudendoclonium submarina
Rhizoclonium implexum
Rhizoclonium riparium
Rosenvingiella polyrhiza
Spongomorpha aeruginosa
Ulothrix flacca
Ulothrix speciosa
Ulva clathrata
Ulva compressa
Ulva flexuosa
Ulva intestinalis
Ulva lactuca
Ulva linza
Ulva paradoxa

Charophyta

Chara aspera
Chara baltica
Chara canescens
Lamprothamnion papulosum
Tolypella nidifica

Appendix D. Benthic invertebrates of the Limfjord.

Species recorded by Hedeselskabet (2003). Exotic species are marked in grey and indicated by an *

Porifera
- *unidentified Porifera*

Cnidaria
- *unidentified hydroids*
- *Metridium senile*
- *unidentified Thenaria*
- *unidentified sea anemone*

Nematoda
- *Unidentified nematods*

Polychaeta
- *Ampharete baltica*
- *Arenicola marina*
- *Capitella sp.*
- *Capitomastus giardi*
- *Caulleriella sp.*
- *Cirratulus cirratus*
- *Dodecaceria concharum*
- *Eteone flava*
- *Eteone longa*
- *Eulalia bilineata*
- *Eulalia viridis*
- *Eumida sanguinea*
- *Exogone naidina*
- *Galathowenia oculata*
- *Gattyana cirrosa*
- *Harmothoe elisabethae*
- *Harmothoe imbricata*
- *Hediste diversicolor*
- *Heteromastus filiformis*
- *Kefersteinia cirrata*
- *Lanice conchilega*
- *Lepidonotus squamatus*
- *Malacoceros fuliginosus*
- *Mediomastus sp.*
- *Microphthalmus sczelkowi*
- *Neanthes succinea**
- *Neanthes virens*
- *Neoamphitrite figulus*
- *Nephtys caeca*
- *Nephtys hombergi*
- *Nereimyra punctata*
- *Pectinaria koreni*
- *Pherusa plumosa*
- *Pholoe baltica*
- *Pholoe inornata*
- *Phyllodoce maculata*
- *Phyllodoce mucosa*
- *Platynereis dumereli*
- *Polydora ciliata*
- *Polydora cornuta*
- *Polydora quadrilobata*
- *Pomatoceros triqueter*
- *Pseudopolydora pulchra*
- *Pygospio elegans*
- *Scoloplos armiger*
- *Spio cf. filicornis*
- *Spio martinensis*
- *Spiophanes bombyx*
- *Streblospio shrubsoli*
- *Syllidia armata*
- *Tharyx marioni*

Oligochaeta
- *Tubifex costatus*
- *Tubificoides benedeni*
- *unidentified oligochaetes*

Bryozoa
- *unidentified Bryozoa*

Mollusca (Bivalvia)
- *Abra alba*
- *Abra nitida*
- *Arctica islandica*
- *Cerastoderma edule*
- *Cerastoderma exiguum*
- *Cerastoderma glaucum*
- *Cerastoderma ovale*
- *Cerastoderma scabrum*
- *Chamelea gallina*
- *Chlamys varia*
- *Corbula gibba*
- *Ensis americanus**
- *Macoma balthica*
- *Musculus discors*
- *Musculus tumida*
- *Mya arenaria*
- *Mysella bidentata*
- *Mytilus edulis*
- *Ostrea edulis*
- *Petricola pholadiformis**
- *Phaxas pellucidus*
- *Spisula subtuncata*
- *Tellina fabula*
- *Tellina tenuis*
- *Venerupis pullastra*

Mollusca (Gastropoda)
- *Aporrhais pespelicani*
- *Buccinum undatum*
- *Crepidula fornicata**
- *Hinia reticulata*
- *Hydrobia sp.*
- *Littorina littorea*

Philine aperta
Retusa obtusa
Rissoa membranacea
Rissoa sarsii
Tectura testudinalis
Turritella communis
Mollusca (Polyplacophora)
Lepidochitona cinerea
Crustacea
Aegina echinata
Balanus crenatus
*Balanus improvisus**
Bathyporeia elegans
Carcinus maenas
Cheirocratus sundevalli
Corophium insidiosum/bonelli
Corophium volutator
Crangon crangon
Diastylis bradyi
Idotea baltica
Jassa falcata
Liocarcinus arcuatus
Macropodia rostrata
Microdeutopus anomalus
Microdeutopus danmoniensis
Microdeutopus gryllotalpa
unidentified Microdeutopus sp.
Pariambus typicus
Phthisica marina
Echinodermata
Asterias rubens
Ophiura albida
Ophiura texturata
Psammechinus miliaris
Ascidiacea
Ascidiella aspersa
Molgula manhattensis
*Styela clava**

Benthic invertebrates from the Limfjord caught in trawlsamples (Hoffmann 2005) and species not recorded by Hedeselskabet (2003) (Jensen & Hoffmann 2007; Knudsen 1997; Møller & Riisgård 2007; Rasmussen 1987; Tendal et al. 2007). Exotic species are marked in grey and indicated by an *.

Porifera
Halichondria panicea
Cnidaria
Metridium senile
Aurelia aurita
Cyanea capillata
Aequorea vitrina
Ctenophora
Pleurobrachia pileus
*Mnemiopsis leidyi**
Mollusca (Gastropoda)
*Crepidula fornicata**
Buccinum undatum
Ocenebra erinacea
Hinia reticulata
Philine aperta
Mollusca (Bivalvia)
Mytilus edulis
Modiolus modiolus
Ostrea edulis
*Crassostrea gigas**
Chlamys varia
Arctica islandica
Cerastoderma edule
*Mya arenaria**
*Ensis americanus**
Mollusca (Cephalopoda)
Loligo vulgaris
Alloteuthis subulata
Crustacea
Carcinus maenas
Cancer pagurus
Liocarcinus depurator
Hyas araneus
Macropodia rostrata
*Eriocheir sinensis**
Pagurus bernhardus
Crangon crangon
Leander adspersus
Palaemon elegans
Homarus gammarus
Galathea squamifera
Echinodermata
Asterias rubens
Ophiura albida
Strongylocentrotus droebachiensis
Ascidiacea
Ciona intestinalis
Ascidiella adspersa
*Styela clava**