Risk analysis on the import of seed mussels from Norway into the Wadden Sea

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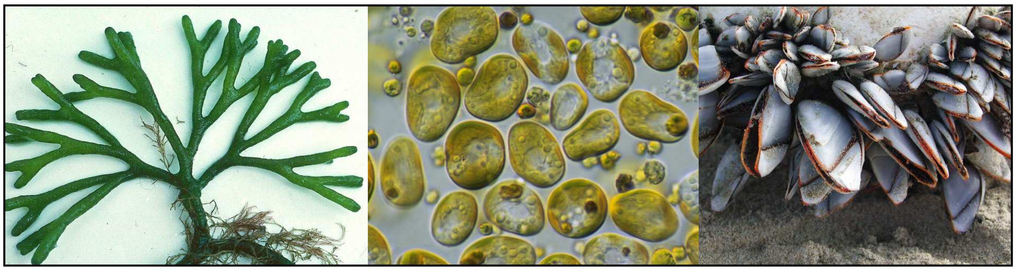

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Contents

i. Summary

This report is the result of a risk analysis on the introduction of exotic non-indigenous species with the import of rope culture mussels from Norway into the Wadden Sea. Based on available literature data and expert judgement, the target species are identified and the risks of these species are assessed semi-quantatively. Based on the risk analysis it is concluded that the risk of introducing exotic non-indigenous species into the Dutch part of the Wadden Sea with the import of mussels from Norway is low, but not totally absent.

At present, 37 exotic non-indigenous species are known for the Dutch part of the Wadden Sea. Many of these species were either not able to establish permanently or had insignificant effect to the ecosystem. Five species have established well and have or might become an important component of the Wadden Sea ecosystem. In total 51 exotic non-indigenous species are known for the Norwegian coastal waters. Fourteen of these species are new for the Dutch coastal waters and can be regarded as target species, which could potentially be introduced into the Wadden Sea with the import of mussels from Norway.

For all 14 target species the chance of successful introduction and the expected impact to the ecosystem after successful introduction has been evaluated using literature data and the judgment of an international team of 10 experts. Species with highest chance of successful introduction are the algal species *Aglaothamnion halliae, C. fragile* ssp *scandinavicum, Verrucophora farcimen, Karlodinium micrum* and *Olisthodiscus luteus*, the polychaete *Scolelepsis korsuni* (due to the lack of information on this species and the precautionary principle that is used in this study) and the goose barnacle (*Lepas anatifera*). Species with the highest potential impact once introduced are the algal species *Verrucophora farcimen* and *Olisthodiscus luteus*, the American lobster (*Homarus americanus*), the king crab (*Paralithodes camtschaticus*) and the Manila clam (*Ruditapes philippinarum*). Due to the lack of information also the polychate *Scolelepis korsuni* is scored as a species with potential high impact (precautionary principle).

The risk assessment indicates the following species as the species with the highest risk: The polychate *Scolelepis korsuni*, the algae *Verrucophora farcimen, Codium fragile* ssp *scandinavicum* and *Olisthodiscus luteus*, the American lobster (*Homarus americanus*) and the Manila clam (*Ruditapes philippinarum*). The risks of the American lobsters and the Manila clam are largely depending on the transport method. With transport by boat, larvae of these species could be effectively introduced into the Wadden Sea. However, both species are not expected to reproduce in Norwegian waters and transport of adults from rope culture mussels is unlikely. The literature information of the polychaete *Scolelepis korsuni* is very limited. This is by itself an indication that this species has not lead to any problems yet. *Verrucophora farcimen* is probably already present in the Dutch coastal waters. *Olisthodiscus luteus* (synonym for *Heterosigma akashiwo*) was first found in the Wadden Sea in 1992. At present the distribution of the *Codium fragile* complex in Norway is north of sector 20 (Tromsø and further to the north)

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 kunnen vissen vanwege de vermeende negatieve effecten op de natuurwaarden. Om toch aan de constante vraag vanuit de markt naar mosselen te kunnen voldoen worden er regelmatig mosselen geïmporteerd uit het buitenland. Geïmporteerde consumptie mosselen worden verhandeld aan de veiling en na een verwaterperiode getransporteerd naar de klanten. Niet alleen consumptie mosselen, maar ook mosselzaad wordt naar 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 naar de Oosterschelde, om daar op de kweekpercelen uit te kunnen groeien tot consumptie mosselen.

Op dit moment is er de wens bij de vereniging van schelpdier importeurs om ook mosselzaad te importeren uit Noorwegen en Zweden, waar regelmatig een overschot aan mosselzaad beschikbaar is. De kwekers willen dit mosselzaad op de percelen in de Waddenzee uitzaaien. Er is geen belangstelling om het mosselzaad uit te zaaien op de percelen in de Oosterschelde omdat men vindt dat het rendement vanwege de slechte groei daar te laag is. Met de insleep van de mosselen naar de Waddenzee bestaat het risico dat er ongewenste exoten worden geïntroduceerd die kunnen leiden tot (schadelijke) beïnvloeding voor het ecosysteem. Dit rapport beschrijft de resultaten van een risico inventarisatie naar de introductie van exoten in de Waddenzee met de import van mosselzaad uit Noorwegen. De resultaten van deze studie zullen door de vereniging van schelpdier 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 Waddenzee dient er een onderscheid te worden gemaakt tussen soorten die endemisch zijn voor de Noordoost Atlantische kustregio en exoten. De eerste groep komt van oorsprong voor ergens binnen in 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. Het kan dan ook worden aangenomen dat deze soorten in het verleden (lees in de afgelopen 1000 jaar) wel eens in de Waddenzee terecht zijn gekomen. Het feit dat ze zich niet hebben weten te vestigen is een indicatie dat de omgevingscondities niet geschikt zijn/waren voor deze soorten. De introductie van dergelijke soorten levert doorgaans dan ook weinig risico. Opgemerkt moet worden dat het als gevolg van veranderende omgevingscondities mogelijk is dat soorten die zich voorheen niet hebben weten te vestigen nu wel in staat zijn zich te vestigen. Een voorbeeld hiervan is het oprukken van de Zuidelijke soorten met de opwarming van het water als gevolg van het broeikas effect. Veelal leiden deze soorten niet tot grote impact omdat ze vaak aan de grens van hun tolerantie zitten en pathogenen en parasieten vaak mee worden getransporteerd.

De risico’s van de introductie van exoten zijn doorgaans groter. Exoten zijn soorten die van oorsprong niet voorkomen in de Noordoost Atlantische kustregio. 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 Noorwegen of Zweden) in de Waddenzee worden geïntroduceerd (secundaire introductie). Het risico van dergelijke introducties is veel groter omdat de kans bestaat dat de omgevingscondities in de Waddenzee overeen kunnen 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 Waddenzee. Daarnaast zijn er specifieke exoten die bekend zijn vanwege hun invasieve karakter.

In deze studie zijn de risico's van de introductie van exoten in de Waddenzee met de import van mosselen uit Noorwegen in kaart gebracht. Allereerst is er een overzicht gemaakt van de exoten die zijn waargenomen in de Waddenzee op basis van een overzichtsstudie van Wolff in 2005. In totaal zijn er 37 exoten aangetroffen in het Nederlandse deel van de Waddenzee. Veel van deze soorten worden sporadisch aangetroffen en hebben weinig tot geen effect op het functioneren van het ecosysteem. Sommige exoten in de Waddenzee zoals het Japans bessenwier, *Marenzellaria*, de Amerikaanse zwaardschede, het muiltje en de Japanse oester hebben de potentie om zich te kunnen ontwikkelen, of hebben zich reeds ontwikkeld, tot biomassa's die het functioneren van het ecosysteem kunnen beïnvloeden. Voor de Noorse mariene- en kustwateren is in het kader van deze studie ook een overzicht gemaakt van de exoten. In totaal zijn er 51 exoten bekend voor de Noorse mariene- en kustwateren. Deze studie richt zich op de 14 doelsoorten, die zich hebben gevestigd in de Noorse wateren, maar die nog niet zijn aangetroffen in de Nederlandse wateren. Deze doelsoorten kunnen in potentie worden geïntroduceerd met de mosseltransporten naar de Waddenzee.

Het risico van de introductie van een doelsoort kan worden gekwantificeerd uit 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 waarschijnlijkheid dat een soort mee kan liften met de hangcultuur mosselen vanuit Noorwegen, de kans dat deze het transport overleeft en of de omgevingscondities in de Waddenzee geschikt zijn voor de soort om zich er permanent te vestigen. Het effect van een soort na succesvolle introductie is ondermeer afhankelijk van in hoeverre de omgevingscondities in de Waddenzee optimaal zijn voor de soort, of de soort invasief kan worden soort en de invloed van de soort 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 8 experts. Hierbij is uitgegaan van het voorzorgsprincipe waarbij de kans op succesvolle introductie van soorten waar weinig kennis/informatie is te vinden maximaal wordt gegeven. De soorten die de meeste kans maken op succesvolle introductie als gevolg van het mosseltransport zijn de algen *Aglaothamnion halliae, Codium fragile* ssp *scandinavicum, Verrucophora farcimen Karlodinium micrum* en *Olisthodiscus luteus*, de borstelworm (*Scolelepsis korsuni*) (vanwege de beperkte informatie) en de eendenmossel (*Lepas anatifera*). Kijkend naar de potentiële impact die de soorten kunnen hebben op het ecosysteem zijn de algen *Verrucophora farcimen* en *Olisthodiscus luteus*, de Amerikaanse kreeft (*Homarus americanus*), de koningskrab (*Paralithodes camtschaticus*) en de Japanse tapijtschelp (*Ruditapes philippinarum*) als soorten aangemerkt die mogelijk impact kunnen hebben op het functioneren van het ecosysteem van de Waddenzee. Vanwege de beperkte informatie is uit voorzorg ook de borstelworm *Scolelepis korsuni* hiertoe gerekend.

Uit de studie blijkt dat de soorten *Scolelepis korsuni*, de algen *Verrucophora farcimen, Codium fragile* ssp *scandinavicum* en *Olisthodiscus luteus*, de Amerikaanse kreeft (*Homarus americanus*) en de Japanse tapijtschelp (*Ruditapes philippinarum*) de meeste risico's te geven. De risico's van de Amerikaanse kreeft en de Japanse tapijtschelp zijn sterk afhankelijk van de wijze van transport. In deze studie is uit voorzorg uitgegaan van het meest risicovolle transport namelijk transport per boot waarbij het water continu ververst wordt. De pelagische larven van beide soorten worden in staat geacht deze vorm van transport te kunnen overleven. Echter het is veel minder aannemelijk dat ze gevangen worden in de hangcultuur en vervolgens het transport in big-bags per vrachtwagen of vliegtuig zullen overleven. Daarbij is het onzeker of de Amerikaanse kreeften die zijn waargenomen in Noorwegen in staat zijn zich voort te planten. Hetzelfde geld voor de Japanse tapuitschelp. Deze soort is eind jaren tachtig op zes locaties in Noorwegen geïntroduceerd en op drie van de locaties zijn er 6 jaar later nog levende volwassen exemplaren teruggevonden. Juveniele exemplaren zijn niet meer teruggevonden. De kans dat volwassen exemplaren van zowel de Amerikaanse kreeften als de Japanse tapuitschelp worden gevangen met de hangcultuur mosselen is zeer onwaarschijnlijk. In het kader van deze studie is geen relevante informatie gevonden van de borstelworm *Scolelepis korsuni*. Dit is de reden waarom deze soort als grootste risico soort is aangemerkt. Het feit echter dat er in de literatuur weinig informatie over deze soort is te vinden is een indicatie dat deze soort elders in de wereld nog niet tot problemen heeft geleidt. *Verrucophora farcimen* komt zeer waarschijnlijk al voor in de Nederlandse kustwateren. In april 2006 werd ten N. van Terschelling een omvangrijke bloei ($>10^7$ cellen/l) van een alg vastgesteld die hiermee zeer veel overeenkwam of identiek was (pers. comm. R.P.T. Koeman). *Olisthodiscus luteus* (synoniem voor de alg *Heterosigma akashiwo* is een soort die in 1992 voor het eerst in de Waddenzee is aangetroffen. Het huidige verspreidingsgebied van *Codium fragile* in Noorwegen is voornamelijk in de meest Noordelijke delen, boven Tromsø.

De algemene conclusie van deze risico studie is dat het risico van de introductie van exoten met de import van mosselen uit Noorwegen 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 omdat er onzekerheden zitten in de analyses en uitspraken. Zo is het bijvoorbeeld mogelijk dat er exoten in de Noorse wateren over het hoofd zijn gezien of dat een geïntroduceerde exoot het beter blijkt te doen dan op dit moment is ingeschat.

1 Introduction

1.1 Motive of this research

The production of mussels in the Wadden Sea and the Oosterschelde fluctuates due to varying recruitment and survival rates. The demand of mussels however is relatively constant and even increasing. In order to fulfil the demand of mussels and 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 (2006). These mussels are transported to the Netherlands and sold at the auction in Yerseke (consumption mussels), or relayed at the culture plots (juvenile mussels).

1.2 Research problem

With the import of mussels into the Dutch waters, there is a risk of introducing exotic organisms 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 and 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, in a permit was given to the corporation of shellfish importers to import 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.

At present the mussel importers would like to import juvenile mussels from rope cultures in Norway to be re-layed on the culture plots in the Dutch part of the Wadden Sea. Norway was not part of the PRIMUS study that was carried out in 2006. Moreover, the study of 2006 (Wijsman and Smaal, 2006) was focussed on the Oosterschelde as the receiving water while this time the importers want bring the mussels to the culture plots in the Dutch part of the Wadden Sea. At present, the amount of exotic species in the Wadden Sea is much lower than in the Oosterschelde. In order to apply for a permit, Holstein consultancy, has requested Wageningen IMARES on behalf of the corporation of shellfish importers, to conduct a risk analysis for the introduction of exotic species into the Wadden Sea with the import of mussel seed from Norway (PRIMUS-Norway). In this report the results of this study are presented. This study was carried-out parallel to a comparable study (PRIMUS-Sweden) on the import of mussels from Sweden (Wijsman *et al.*, 2007b). The results of both studies will be used by the client for the proper assessment that is needed for the application of the permits.

1.3 Study approach

The approach of the present study is largely based on the PRIMUS study of 2006 (Wijsman and Smaal, 2006). In a risk assessment, the risk of introducing an non-indigenous species can be evaluated as the product of the chance of successful introduction of a 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 Norway into the Wadden Sea is made based on literature data and expert judgement.

Chapter 2 gives a definition on 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 Dutch part of the Wadden Sea is presented. This overview is largely based on the study of Wolff (2005). Chapter 4 gives an overview of the exotic non-indigenous species in the Norwegian marine waters. Also an overview of the practice of mussel farming in Norway and the health conditions in the production areas is given as well as the marine flora and fauna, in particular the flora en fauna that is associated with the rope culture. This chapter is a contribution of Vivian Husa and Øivind Strand from the Institute of Marine Research in Norway and is purely based on available literature data. The semi-quantitative risk assessment presented in chapter 5 is based on the judgement of 10 international experts. For the exotic non-indigenous species that could potentially be introduced into the Dutch part of the Wadden Sea 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 6.

Although this study is based on the PRIMUS study of 2006, some adaptations are made. Whereas in 2006, samples were taken both from the culture plots in Ireland/UK and the trucks arriving in Yerseke, the present study is solely based on available literature data. Also the risk of introducing *M. galloprovincialis* and / or *M. trossulus* is not specifically addressed in this study. With respect to the risk assessment, more experts were consulted in the present study compared to the 2006 study. Finally, while the 2006 report was audited by an external expert, Prof. Wim Wolff, the present report is reviewed according to the IMARES quality standards by Norbert Dankers.

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 Vivian Husa and Øivind Strand (Institute of Marine Research Norway), Louis Peperzak (NIOZ), Wim Wolff and Deniz Haydar (University of Groningen), Herre Stegenga (Leiden University), Rob Leewis (Naturalis), Reinoud Koeman (Koeman en Bijkerk), Johan Craeymeersch and Jan van Dalfsen (IMARES) are thanked for their judgements on the risks. Vivian Husa and Øivind Strand from the Institute of Marine Research in Norway gave a clear overview on the mussel practice and the exotic non-indigenous species in Norwegian waters. Norbert Dankers 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 ecological barriers. Recently, the species could have been introduced into the ecosystem due to the removal of the natural 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 somewhere for the Northeast Atlantic shelf region. Northeast Atlantic non-indigenous species may have been imported into the Dutch coastal waters in the past and thrive for a number of years, but ultimately, they (have) disappear(ed) again because 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 been changed permanently.

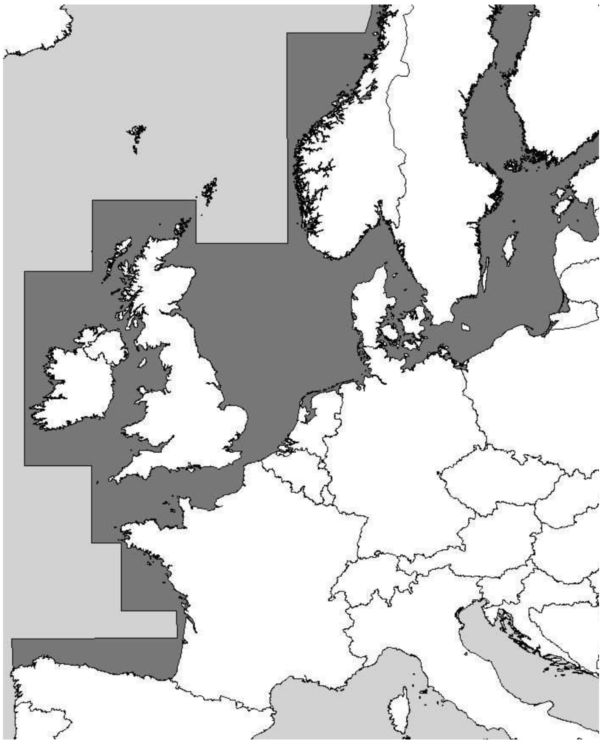
- **Exotic non-indigenous species** are non indigenous species for the Dutch coastal zone that originate from other parts of the world. They are exotic species for all Northeast Atlantic shelf waters. If the environmental conditions in the Dutch waters are suitable for the species, they might establish 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 (Brattegaart and Holte, 1997). 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 occurring temperatures result in other species.

The Dutch coastal waters, including the Wadden Sea, are part of the Northeast Atlantic shelf region (Figure 1, left hand side). Longhurst (1998) has defined this area as one ecological and biogeographical union 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. Brattegaard and

[1] "In historical times" is taken as being since 1000 years before present Petersen, K.S., Rasmussen, K.L., Heinemelers, J. and Rudd, N. (1992). Clams before Columbus? Nature, 359: 679.

Holthe (1997) also present a comparable map of the same region called Eastern North Atlantic Boreal (Figure 1, right hand side). According to both maps, the Norwegian coast as well as the Skagerrak and Kattegat fall within the same biogeographic region (Northeast Atlantic shelf region) as the Wadden Sea. According to the definitions given in this report, species that are exotic non-indigenous to the Norwegian coastal waters are also exotic non-indigenous to the Wadden sea. Species that are indigenous to the Norwegian coastal waters and non-indigenous to the Wadden sea are called Northeast Atlantic non-indigenous species for the Wadden Sea.



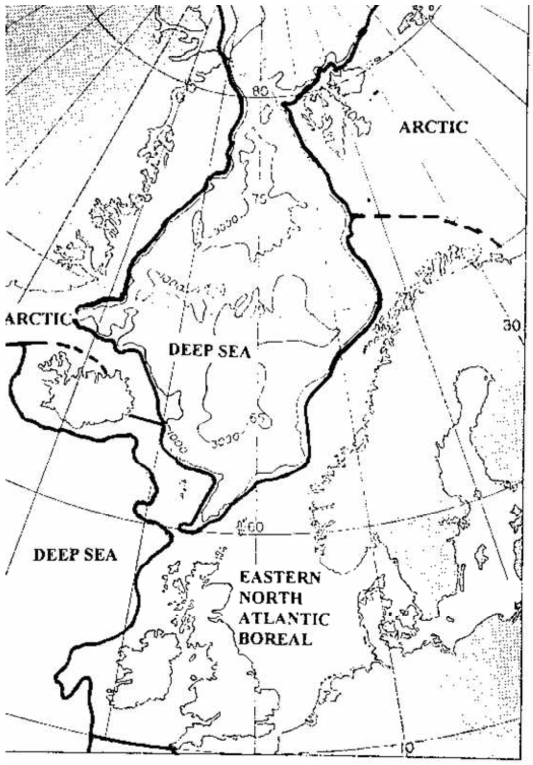


Figure 1: Left hand side: Map indicating Northeast Atlantic Shelf region (dark gray). Figure adapted from Longhurst (1998). Right hand side: Map from Brattegaard and Holthe (1997) indicating the Eastern North Atlantic boreal region.

2.2 Introduction and expansion

As a result of the globalization, the natural barriers for the dispersal of organisms are becoming more and more weakened. New species can be introduced into environments where they did not have the chance to develop before. Many of these introduced species will not survive because the environmental conditions are not suitable. However, some of the species could establish themselves and might become a nuisance to the ecosystem. Newly established species can adapt and become better at exploiting available resources and strengthening its position in relation to competitors and predators over time (Leppäkoski *et al.*, 2002).

As a rule of thumb, the "Tens Rule" of Williamson (1996) can be used for the success of an introduction. Of all species that are transported by human, about 10% are able to establish themselves. Only 10% of these establishments are permanently, 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.

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 time of the establishment phase depends on the characteristics of the species (dispersion rate and reproduction rate) but also on the environmental conditions of the system (Van Der Weijden *et al.*, 2005). The expansion phase sooner or later comes to an end followed by a phase of adjustment. In this adjustment phase, the species might remain dominant, but mostly a regression takes place and the species stabilizes at a lower densities (Reise *et al.*, 2006; Van Der Weijden *et al.*, 2005). Possible causes of these regressions are depletion of food and/or other resources and development of diseases or predators.

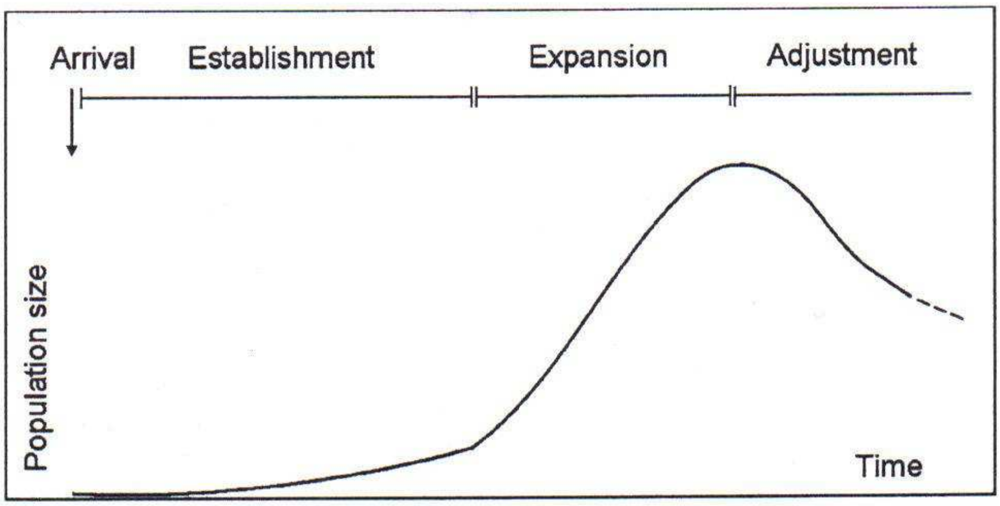


Figure 2: Phases of invasion during the introduction of invasive species. From Reise et al. (2006).

3 Mussel culture and non-indigenous species in the Wadden Sea

3.1 Mussel culture in the Wadden Sea

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. 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 and Smaal, 2002) are re-layed 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 re-laid for cleansing and rewatering at natural rewatering sites in the eastern part of the Oosterschelde (Smaal and Lucas, 2000).

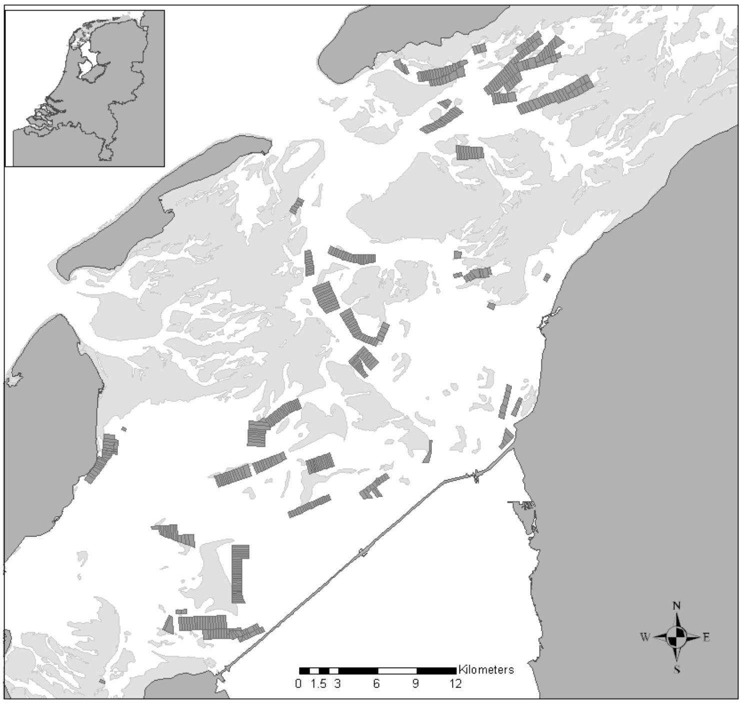


Figure 3: Location of culture plots in the western part of the Dutch part of the Wadden Sea

During the culture cycle, the mussels are regularly transported by the farmers to other plots in order to optimize the 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 the more exposed locations where the mussels have a better access to the 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) remain in the Wadden Sea during the winter (LNV, 2004). This is to allocate food for the eider ducks. Transport from the Oosterschelde to the Wadden Sea is not allowed.

The production capacity of the (processing industry of) mussels in the Netherlands is about 100×10^6 kg mussels. Experience of mussel growers shows that a catch of about 65×10^6 kg seed mussels is needed to sustain the total production of 100×10^6 kg (Kamermans and 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 the 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) and sold at the auction in Yerseke (Wijsman and Smaal, 2006). Additionally seed mussels are imported from Ireland and UK and spread on culture plots in the Oosterschelde where they grow until market size.

The sector is looking for new sources of mussel seed. In Norway there is often an over production of mussel seed during the summer and autumn (see sections 4.1 and 4.2), when the captured mussel seed is graded and sorted in socks. In general, due to the temperatures the period of grading is later in the season going along the Norwegian coast to the north. Re-stocking and relocation of the mussels takes place from August to October with mussel sizes ranging from 10-30 mm. In general the Dutch farmers see opportunities in buying the mussel seed in Norway and transport it to the culture plots in the Wadden Sea. Transport can be done within big-bags on conditioned trucks or within boats where fresh seawater can be circulated. A truck can carry 25 000 kg of mussels in big-bags and transport from Bergen to the Dutch part of the Wadden Sea will take approximately two full days. The preferred size ranges from 15 mm ("stukstal": 2 000 mussels per 880 ml) to 25 mm ("stukstal": 400 mussels per 880 ml), but even mussels of 8 mm ("stukstal": 10 000 mussels per 880 ml) could potentially be used. In general the smaller the mussels, the higher the losses during transport, predation and storms. There is no interest to bring the seed mussels to the culture plots in the more sheltered Oosterschelde because of the low growth potential in this area.

3.2 Exotic non-indigenous species in the Dutch part of the Wadden Sea

With the import of mussels from Norway to the Wadden Sea there is a risk of introducing exotic non-indigenous species that could become a nuisance to the ecosystem. At present 99 exotic non-indigenous species have been recorded for the Dutch coastal zone area (Wolff, 2005). About 30% of these species are found in the Dutch part of the Wadden Sea. For the whole Wadden Sea, a total of 52 non-indigenous species have been introduced (Essink *et al.*, 2005). Many of these species remain insignificant additions to the native biota but some species have lead to local displacements (Reise *et al.*, 2002).

From the publication of Wollf (2005), we have compiled a list of exotic non-indigenous species that have been recorded in the Wadden Sea (Table 1). The ctenophore *Mnemiopsis leidyi*, that was observed in the Wadden Sea in 2006 (Faasse and Bayha, 2006). The total list includes 37 species, which is less than the 69 species that are known for the Oosterschelde (Wijsman and Smaal, 2006). For some of these species, there is no firm evidence that they have been introduced and they might be endemic species. These species are indicated as cryptogenic species. Some of the species listed in the table have been recorded in the Wadden Sea for only a few occasions and they were either not able to establish permanently or had insignificant effect for the ecosystem. Five of the species (see paragraph 3.3) have established very well and have become a dominant species and lead to strong effects on the native biota in the Wadden Sea (Reise *et al.*, 2002).

Table 1: Exotic non-indigenous species recorded in the Dutch part of the Wadden Sea. Table is based on (Wolff, 2005).

Taxon	Species	Year in NL	Comments
Algae	*Acrochaetium densum*	1967	
	Botrytella sp	1919	
	Chattonella antiqua	1991	Cryptogenic?
	Codium fragile	1904	
	Fibrocapsa japonica	1991?	Cryptogenic?
	Heterosiga akashiwo	1992	Cryptogenic?
	Polysiphonia harveyi	1960	
	Sargassum muticum	1980	
	Ulva pertusa	1993	
Tracheophyta	*Cotula coronopifolia*	1846	
Cnidaria	*Diadumene cincta*	1925	
	Haliplanella lineata	1912	
	Nemopsis bachei	1990s	
Ctenophora	*Mnemiopsis leidyi*	2006	(Faasse and Bayha, 2006)
Annelida	*Marenzelleria cf. wireni*	1983	
	Nereis virens	1915	
Mollusca	*Corambe obscura*	1879	
	Crassostrea gigas	1964	
	Crepidula fornicata	1929	
	Ensis directus	1981	
	Mya arenaria	1765	
	Mytilopsis leucophaeata	1895	
	Petricola pholadiformis	1905	
	Teredo navalis	1730	
Bryozoa	*Bugula stolonifera*	1993	
Crustacea	*Balanus improvisus*	1870s	Cryptogenic?
	Callinectes sapidus	1932	
	Elminius modestus	1946	
	Eriocheir sinensis	1929	
	Gammarus trigrinus	1960	
	Limnoria lignorum	1834	Cryptogenic?
	Mytilicola intestinalis	1949	
	Platorchestia platensis	1950	
	Rhithropanopeus harrisii	1874	
Urochordata	*Styela clava*	1974	
Nematoda	*Anguillicola crassus*	1985	
Vertebrata	*Trinectes maculatus*	1984	

3.3 Specific introduced non-indigenous species in the Wadden Sea

The larger part of the 37 introduced exotic non-indigenous species in the Dutch part of the Wadden Sea 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 Wadden Sea. However non of these species has caused immediate harm to human health and economy, nor do they offer a great benefit yet, except for Pacific oysters in culture (Essink *et al.*, 2005).

Sargasum muticum
This Japanese seaweed originates from the Pacific ocean. The first recording is from 1980, near Texel (Wolff, 2005). In the Wadden Sea 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 the resident macroalgae (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 the biodiversity.

Marenzelleria cf. *wireni*
This polychaete species originates from the eastern coast of North America. The first occurrence in the Wadden Sea dates from 1983 in the Dollard (Wolff, 2005). After an exponential increase the abundance of the species has levelled off. From the Ems, other areas within the Wadden Sea were invaded. There is no clear evidence of competitive interaction with other (native) polychaetes (Reise *et al.*, 2002).

Ensis directus
The razor clams (*Ensis directus*) originates at the Atlantic coast of North America from Labrador to North Carolina (Wolff, 2005). It has been introduced into Europe with ballast water and was first observed in Europe in the German Bight in 1979 (Dörjes, 1992). In 1981 the species was found in the Bocht van Wattum in the Dutch part of the Wadden Sea (Essink, 1985). At present the *Ensis directus* is the most dominant razor clam in the Dutch coastal waters (Wijsman *et al.*, 2006). One of the factors enabling the rapid dispersal of the species is the long pelagic larval phase (2-4 weeks, Armonies and Reise, 1999; Muir, 2003). Larvae can therefore be transported over long distances (Essink, 1984). Successful recruitment is irregular in the Wadden Sea. Significant interactions with native suspension feeders have not been noted so far although *Ensis directus* may be the most abundant large bivalve in the shallow subtidal (Essink *et al.*, 2005).

Crepidula fornicata
The America slipper limpet was probably introduced in Europe with American oysters and was first observed in 1872 (Wolff, 2005). In the Wadden Sea, the densities are still low but locally increasing. The slipper limpets in the Wadden Sea changed their habitat from oyster to mussel beds (Essink *et al.*, 2005). The main limiting factor for the population growth in the Wadden Sea is apparently winter mortality. When the slipper limpets reach high abundances they can compete with other filter-feeding invertebrates for food and space. Also in waters of high concentrations of suspended material they encourage deposition of mud owing to the accumulation of faeces and pseudofaeces. Slipper limpets are considered as a pest on commercial oyster and mussel beds.

Crasostrea 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 the mass mortality of the flat oysters during the severe winter of 1962/1963 (Wijsman *et al.*, 2007a). In the Oosterschelde the oysters have spread exponentially and have become a dominant species in the ecosystem. In 1983, *C. gigas* was first observed in the Dutch part of the Wadden Sea near Texel and in 2003 *C. gigas* has

achieved a continuous distribution throughout the entire Wadden Sea. The solid reefs that the oysters form are a completely new biogenic structure in the Wadden Sea and could give a habitat for many species. 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 take over in the Wadden Sea as well, both as an ecosystem engineer generating solid reefs and as competitive suspension feeder (Essink *et al.*, 2005).

4 Associated flora and fauna of *Mytilus edulis* (L.) in Norway

Contribution of Vivian Husa and Øivind Strand (Institute of Marine Research, Norway)

4.1 Practice of mussel farming in Norway

Mussels (*Mytilus edulis*) are farmed along the entire shores of the Norwegian coast. The total number of licenses for blue mussel farming (31.12. 2006) was 580 (Figure 4), but not all licenses represents active mussel farms. Since 2005 The Directorate of Fisheries has started to withdraw inactive licenses. The total annual harvest of blue Mussels in Norway is about 4000 metric tons. The annual harvest per county (Table 2) gives a representative picture of the activity on mussel farms in Norway. The major production areas are in the south and south west (Skagerrak, Rogaland, Hordaland and Sogn and Fjordane) and in the middle part (Nordland, Nord-Trøndelag and Sør-Trøndelag) of Norway. There is a general trend in the Norwegian blue mussel farming, that many small companies now are merged into larger companies with higher expertise and better equipment for maintenance, production and harvesting of the mussels.

Table 2: Distribution of the annual harvest of shellfish in 2006 over the Norwegian Counties (weight in metric ton) (Data from Directorate of Fisheries, Institute of Marine Research).

County	Mussel	Great scallop (wild harvest)	Flat and cupped oysters	Other shellfish species
Finnmark	0,1	0	0	13
Troms	0,3	0	0	0
Nordland	654	17	0	0.1
Nord-Trøndelag	734	69	0	0
Sør-Trøndelag	520	700	0	0
Møre og Romsdal	69	13	0.3	16
Sogn og Fjordane	99	0	0	0
Hordaland	382	4	0.3	1
Rogaland	513	0	0	0
Other Counties (Skagerrak)	733	0	0.7	0.1
Total	3705	803	1	30

Of the annual harvest of mussel in Norway, 60 - 90 % is exported. The export consists mainly of fresh mussels that are sold to countries in Europe. The major countries for export are France, Germany, Denmark, The Netherlands and Sweden. A minor part of the exported mussels goes to other European countries, Israel and Asia. The consumption of mussel in Norway is increasing, and mostly fresh shells are traded (80 %). The rest is sold as frozen or conserved products.

Figure 4: Left-hand side: Map of counties in Norway. Red dots indicate cities. Right-hand side: Distribution of licenses for mussel farming in Norway (Data from Directorate of Fisheries). Map: Arne Duinker (NiFES)

The mussel production in Norway is mainly based on long line systems where natural spat is collected and grows to harvestable size on the ropes. Originally, both collection and growth took place at the same substrate and location. Nowadays, production systems for relaying mussels in socks after sorting and grading, becomes more and more practice. Systems developed in Sweden, Canada and New Zealand have been adopted with varying success, while the concept of Smart Farm systems has been developed in Norway and is now applied in other countries. The Smart Farms (Figure 5) operate only at depths down to about 3 meters and are therefore used in areas where the spat settlement is restricted to the upper layers.

Some regions have developed farming strategies involving collection of spat with in areas with reliable spatfall and subsequent transfer to areas for ongrowing. In the Sognefjord and Nordfjord regions, the development of this strategy has been supported by regional funds and the Industry Development Strategy Plan of The County of Sogn and Fjordane. The mussel spatfall in the inner fjord area is more reliable and extends from the stratified surface layer down to 10-15 meters depth. However, toxic phytoplankton (*Dinophysis* spp.) within these areas has precluded development of mussel production for human consumption. The outer fjord areas are generally not severely affected by toxic phytoplankton but still demonstrate the sheltered advantage of fjord environment for mussel farming. By moving spat from collection sites in the fjord to outer areas the problems with toxic algae in the inner parts of the fjords are solved. Also in the County of South Trøndelag there are companies producing spat in the inner part of the fjord areas which are transferred for ongrowing to mussel farming sites located in the outer pars of the fjord.

Figure 5: Smart farm system in Høgsfjorden. Mussels are grown on 2 - 3 meters deep nets attached to long buoyancy lines. The maintenance and harvesting of mussels are done by specialized machines/scooters, which run along the nets. Photo: Øivind Strand

4.2 Areas and seasons suitable for mussel spat production

At present, there is no Norwegian company producing mussel-spat for export. However, initiated by the Dutch request for importing mussel seed a stronger interest has evolved, also in other regions of the coast where spat collection for transfer has not been practised.

In Norway the mussel mainly spawns from April to June, when the sea water temperature rises to 10 °C. It should be mentioned that time of spawning has varied considerable between years and in coastal areas (A. Duinker, pers.com), while time of spawning in the inner fjord-areas seem to be more regular. The larvae settle within about four weeks, and normally reaches a mean size of 10 - 30 mm during August - October. The settlement of larvae usually takes place during late May to early July, but larvae can be found in the water column (and settling) until the end of October. In the Sognefjord there may be a very dense settlement of spat in May/June, of about 10 - 20 000 spat per meter, but farmers experience is that slow growth due to high density makes it more favourable to collect spat in June when the density is lower (thousands spat per meter). This affects the farmers' strategy on maintenance of the cultures during autumn. Traditionally the farmers have thinned the cultures at this time, and the superfluous spat has not been used. In recent years stocking practice has become more common, also for grading and reducing density on collectors during the first autumn. As there is a considerable overproduction of spat in the fjord areas, only the largest sizes have been used when re-stocking and the rest has been thrown away. Re-stocking and relocation of cultures have successfully been performed with 10 - 30 mm mussels in August to October and with larger mussels in late winter (Hovgaard *et al.*, 2001; Hovgaard pers. comm.).

It is recognized that Norway has good conditions for natural spat production (Hovgaard *et al.*, 2001). The settlement of spat is particularly good in the inner parts of the fjord systems (Figure 6), where spat settles on ropes from the brackish surface layer and down to 10 - 20 meters depth. The highest densities are found from just below the pycnocline (below the brackish layer) at 1 - 3 meters depth and generally at decreasing densities with depth. At some sites spatfall density is relatively high and stable between years. In the largest fjords there is a general trend moving from the inner to the outer areas that the settlement depth interval increases, the upper settlement gets shallower and reliability of a successful spatfall generally decreases. This trend seem to be related to the vertical structure in salinity (strength of stratification), that changes as the brackish surface layer in the inner part mixes with coastal water and is reduced as it flows towards the outer part of the fjord. In the outer areas the settlement can also be high, but in general it is restricted to 0 - 2 meters depth. In these areas mussel and spat production is best maintained by use of the Smart farm systems or similar devices (Hovgaard *et al.*, 2001; Kleppe, 1986; J. Bonardelli pers. comm.).

Depending on the size demands of the Dutch farmer, the Norwegian farmers can provide spat for export in the period June to late autumn (and later if larger specimens are preferred). The mean size of the juveniles at the west coast is 10 - 12 mm in August and 15 - 20 mm in October. By next spring (April- May) the mussels have reached a size of 15 - 40 mm (Hovgaard *et al.*, 2001).

The time period the mussel spat will be remaining in Norwegian waters will depend on the size preferred. Normally 2 - 3 months would be sufficient to have large enough spat for harvesting. A shorter period may also be an option, if handling and relocation of spat of a smaller size may be successfully performed.

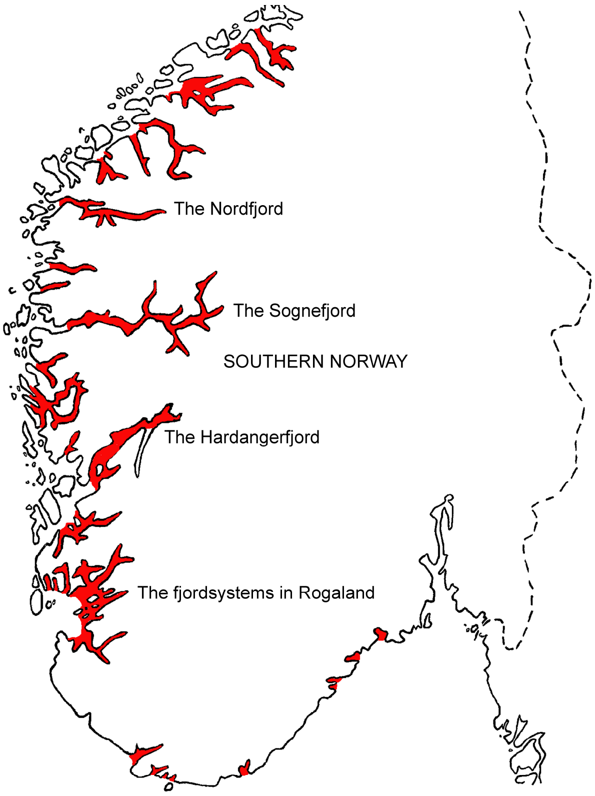


Figure 6: Map of Southern Norway, indicating in red the areas where spat settlement is considered to be particularly good. More to the north, on the coast of Trøndelag and Nordland, settlement of spat is presumably following the same pattern as further south, with the deepest and most stable settlement in the inner areas of fjord systems.

4.2.1 Genetic composition of Norwegian Blue mussels

Mytilus galloprovincialis has not been observed in Norwegian waters. Two studies carried out on mussels from the western coast shows high genetic variability in mussel populations in the area (Ridgway, 2001; Ridgway and Nævdal, 2004). The study of population from sites with high variability in salinity suggests that two species is present in this area; *M. edulis* in the outer coastal areas and *M. trossulus* in inner brackish fjord areas (Ridgway, 2001; Ridgway and Nævdal, 2004). However no morphological differences between specimens from inner and outer areas are obvious and the mussel farmers are not distinguishing between species when collecting spat for culture. Both the aquaculture authorities and the mussel industry recognise the Norwegian mussels to be *M. edulis*.

4.3 Health conditions in the production areas

4.3.1 Shellfish pathogens and parasites

The health-monitoring program of king scallops (*Pecten maximus*) and flat oysters (*Ostrea edulis*) show that Norwegian shells do not suffer from any serious diseases. *Bonamia* spp. and *Marteilia* spp. has never been recorded in Norwegian bivalves. Mussels are not included in the regular monitoring program, but no diseases in Mussels have so far been reported in Norway. The parasite *Myticola intestinalis* has not been recorded in Norwegian bivalves.

A *Vibrio*-strain related to *Vibrio tapetis*, causing Brown Ring Disease (BRD) in clams has been isolated from a constrained population of manila clams (*Ruditapes philippinarum*) in 2003, but studies show that the strain has a low virulence, and has apparently not been transferred to other organisms in this area (Berg and Mortensen, 2005). The manila clam, which was released at this location in the late 1980ies, is not reproducing at this site (see Introduced Species section). Another strain of *Vibrio tapetis* has additionally been isolated from the fish species *Symphodus melops* the Norwegian coast (Berg and Mortensen, 2005).

In 2001 picoeucaryot algae was observed infecting blue mussels near Kragerø in southern Norway. The algae are causing abnormal growth, mantle deformities and green spots in the mantle and adductor muscle. Studies show that the algae mainly infect old mussels with a shell longer than 60 mm. No effects of the algae were observed in small mussels (shell length < 30 mm) (Mortensen et al. 2005). There are relatively few previous reports on this kind of mussel infection, and we regard the phenomenon to be occurring occasionally in natural mussel populations (Mortensen pers. comm.).

4.3.2 Fish pathogens

Recently, there has been an increasing awareness of the possible transmission of fish pathogens through bivalves. Opportunistic pathogen bacteria may survive outside the host and can be accumulated in filter feeding organisms, such as bivalves. Robust viruses like IPNV (Infectious Pancreatic Necrosis Virus) and Nodaviruses may as well be transmitted through bivalves.

4.3.3 Pathogens of particular concern

Pathogenic bacteria
Aeromonas salmonicida subsp. *salmonicida*

Causing furunculosis mainly in salmonid fishes, but can also infect other fish species. Introduced through aquaculture to Norway in 1986. The bacterium is hydrophobic and relatively robust, and may thus survive on or inside bivalves. An experimental transmission was performed through contaminated king scallop juveniles, to susceptible Atlantic salmon. Potential transmission via mussels is presently under investigation (Mortensen pers. Comm.).

Piscirickettsia salmonis
Causing piscirickettsiosis (SRS), in salmonid fishes and sea bass.
The bacteria were first recognized in Norway in 1998 and are also present in Chile, Canada and Ireland. The bacteria can survive in seawater 10-15 days (Poppe, 1999), but no research on transmission via shellfish has been performed.

Viruses
ISAV- virus causing 'Infectious Salmon Anaemia' in salmonid fishes
Also present in East Canada and Scotland. This virus has been one of the greatest challenges to Norwegian salmon farming in the latest years. Studies have shown that the ISAV virus is rapidly inactivated both in water and in mussels. Mussels are not likely to be a reservoir host or vector of ISAV (Skår and Mortensen, 2007).

IPNV- virus casing 'Infectious Pancreatic Necrosis' in salmonid fishes and halibut.
Preliminary results show that the virus can survive in scallops, and that bivalves may be a possible carrier of the virus (Mortensen, 1993).

Nodaviruses- causing 'Viral Encephalopathy' and 'Retinopathy' in aquacultured halibut and cod – also present in wild fish species.
Nodaviruses are robust viruses and we still know very little about possible reservoir hosts of these viruses (Berg and Mortensen, 2005). Preliminary results from experimental challenge indicate that Nodaviruses may persist for 2 – 3 weeks in mussels after filtration (Mortensen pers. comm.).

The Institute of Marine Research in Norway is running several research projects focusing on the potential spreading of fish pathogens, and trying to gain information on this topic. Although viruses and pathogen bacteria are commonly found in wild fish populations, an outbreak of disease in fish farms could result in a concentration of pathogens and therefore could have more fatal consequences. Therefore it is recommended as a precautionary rule that mussel spat should not be harvested in areas where there is an outbreak of disease in fish farms in the vicinity.

4.3.4 Algal blooms and harmful algae

Major harmful algal blooms have occurred in the Norwegian waters in the last 20 years:

- 1988: *Chrysochromulina polylepsis* in Southern Norway
- 1989: *Prymnesium parvum* at the west coast
- 1991: *Chrysochromulina leadbeateri* in Northern Norway
- 1992: *Alexandrium tamarense* in Mid Norway
- 1998: *Verrucophora fascima* (*Chattonella* aff. *verruculosa*) first bloom at the southern coast
- *Chrysochromulina leadbeateri* in Northern Norway
- 2001: *Verrucophora fascima* in southern Norway

Since 1981, monitoring of harmful algae has been included in the coastal monitoring programme. Potentially harmful algae along the Norwegian are regularly monitored by a cooperation program between several institutions (Institute of Marine Research, The Norwegian Veterinary College, SINTEF, NIVA, Directorate of Fisheries and the Norwegian Food Safety Authority) which gives weekly public advice to shellfish and fish farmers. Both the abundance of harmful algal species and the levels of potential toxins in shellfish are regularly monitored.

Species with DSP- toxins:

Dinophysis species

The main algae group causing yearly problems for the shell farmers are the *Dinophysis* species. *Dinophysis* species produce toxins that accumulate in shellfish and could result into diarethic shellfish poisoning (DSP). Four species are present in Norwegian waters *D. acuta*, *D. acuminata*, *D. norwegica* and *D. rotundata*, among which *D. acuta* has the highest toxic potential. The three species are present along the entire coastline. In the recent years the abundance of *D. acuta* has been lower than usual in the southern part of the country, while in the northernmost part the problems with this species have increased (Dahl *et al.*, 2007). In the fjord systems the highest concentration of toxins are usually observed in the inner parts of the fjords.

Species with PSP toxins:

Alexandrium spp.

Three species from the genus *Alexandrium* are present at the Norwegian coast, *A. tamarense, A. minutum* and *A. ostenfeldii.* The three species are a part of the plankton community during the whole summer season along the entire coast. The most important species is *A. tamarense* is forming blooms in the spring/summer. Alexandrium species could lead to Paralytic Shellfish Poisoning (PSP). The algae are forming resting cysts, which 'germinate' the next spring. The main season for blooms of these species is April- June in southern Norway and a bit later in the north (May- August). The toxicity of the species is highly variable between sites, season and even between cells. Although *Alexandrium* species are present yearly in Norwegian waters, leading to shorter periods when bivalves are not consumable, there have been no large blooms of these species observed in the recent years (Dahl *et al.*, 2004; Dahl *et al.*, 2007).

Species that potentially can produce ASP toxins:

Pseudo-nitzschia spp.

Pseudo-nitzschia spp. contains Domoic acid, which can accumulate in shellfish and lead to Amnesic Shellfish Poisoning (ASP). Several species are common for the Norwegian coast. There is a great variance in the toxicity within these species. While the species are causing annually problems in Scottish waters, there have only been a few episodes in restricted areas with slightly too high levels of ASP toxins in Norwegian waters (Dahl *et al.*, 2004; Dahl *et al.*, 2007).

Species with causing fish mortality (ichthyotoxic)

In the last decade there has been few problems with species producing ichthyotoxins, with the exception of the bloom of *C. leadbeateri* in north of Norway 2003.

Chrysochromulina species

Two species have been causing harmful blooms in Norwegian waters: *Chrysochromulina polylepsis* and *C. leadbeateri*. The two species is a natural component of the algal community, but are only forming blooms and becoming highly toxic under certain conditions. The extensive *C. polylepsis* bloom in 1988 in the Skagerrak area caused fish mortality and had a strong impact on benthic flora and fauna in the uppermost 10- 20 meters. Unusual hydrographical conditions, with a strong low saline surface layer, accompanied by high phosphate/nitrate ratio, were the must likely reasons for the species becoming so abundant and highly toxic (Dahl *et al.*, 2005 and references therein). *C. leadbeateri* were forming smaller blooms associated with fish mortality in 1991 and 2003 in the counties of Troms and Nordland (northern Norway) (Figure 7).

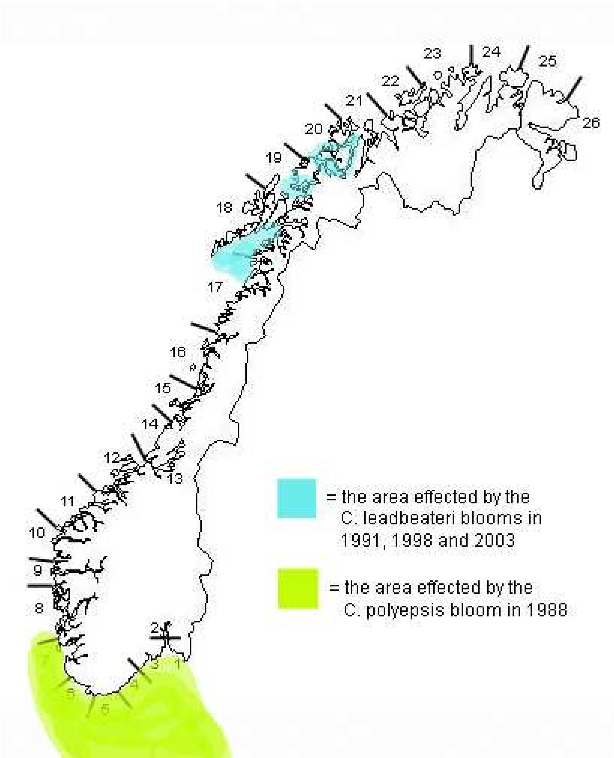


Figure 7: Map indicating the area effected by *C. polylepsis* bloom in 1988 (green) and *C. leadbeateri* in 1991, 1998 and 2003 (blue)

Karenia mikimotoi

Synonyms: *Gyrodinium auroleum, Gymnodinium mikimotoi, Gymnodinium nagasakiense*

This is an introduced species, originating from the Pacific. It can cause fish mortality when the algae are present in large quantities. The species was first observed in Europe in 1966 when a major bloom occurred in the Skagerrak area (Tangen, 1977). During the following decades periodically blooms of this species lead to mortality in cultured salmon and cod, most extensively in 1989. The species is naturally occurring in the coastal water and is occasionally forming localized blooms. This species has had the most severe economic impact on Norwegian fish aquaculture, but the last decade there have been relatively few problems with this species (Dahl *et al.*, 2004). The blooming season is from August to October.

Prymnesium species

Two species are found at the Norwegian coast, *Prymnesium parvum* and *Prymnesium patteliferum*. Prymnesium has caused fish mortality in the fjord systems in Rogaland on several occasions, first time in 1989. The species are closely related to the genus *Chrysochromulina* and can, like these, be highly variable in its toxicity. There have been fewer problems with these species in the last decade than in the 1980's (Dahl *et al.*, 2004).

Verrucophora fascima
Synonym: *Chattonella* aff. *verruculosa*
This exotic species has caused the largest problems at the Norwegian coast in the latest decade, forming blooms in 1998 and 2001. See: introduced species section for more information on this species.

Heterosigma akashiwo
Often appearing in high abundances associated with *Verrucophora* blooms. The mechanism behind the toxicity in species is not well understood, but it seems that high abundances could result in clogging of the fish gills.

Prorocentrum minimum
An introduced dino-flagellate with wide tolerance limits. The first registration of this species was in Northern Europe in 1979, when a massive bloom occurred in the outer Oslofjord. At the Norwegian coast it is most abundant in southern Østfold (sector 1) where it blooms in the summer and colours the sea yellow brown and reduced transparency. The toxicity of the species is still uncertain, but no major problems have been reported during blooms of this species.

In addition to species mentioned here the abundance of species that potentially can produce Yesso toxins (YTX toxins), Pecteno toxins (PTX toxins), Azarspiracider (AZA toxins), Spirolids and the level of these toxins in shellfish regularly monitored by the national program.

A complete checklist of phytoplankton species in the Skagerrak area is available at:
http://www.smhi.se/oceanografi/oce_info_data/plankton_checklist/ssshome.htm

4.4 Marine flora and fauna

4.4.1 Distribution of marine flora and fauna along the Norwegian coastline

Approximately 4000 benthic species have been recorded along the Norwegian coast. The majority of these species are present along the North Sea shores. Some of the species are coldwater species with a southern temperature limit at the Norwegian coast. These are species that most likely will not be able to establish further south in Europe.

For pragmatic reasons, the Norwegian coastline can be divided into 26 marine sectors (Figure 8). For each sector, the marine diversity is compiled from old and new registration of species on the behalf on the Norwegian Directory of Nature in 1997 (Brattegaart and Holte, 1997). Since then, the lists have been updated several times. Note that there has been no recent survey of species in the fjord areas such as The Sognefjord (in sector 9) and The Hardangerfjord (in sector 8) since the 1960's. A general trend in the distribution pattern of benthic species in fjord areas is that the number of species decreases with decreased salinity towards the inner parts of the fjords. Considering the distribution of *Paralithodes camtschaticus* (Red King Crab) in the two northernmost counties of Norway, we found it natural to keep a buffer zone against the main distribution area (pink) of this invasive species. We therefore included distribution data only for sectors 1-18, which is a potential area for mussel export (indicated with light blue on the map) (Figure 8). A detailed overview on the occurrence of marine flora and fauna in these Norwegian sectors are given in the report of the Norwegian Directory for Nature Management. The complete and updated list (fauna updated in 2001 and flora updated in 2004) of marine benthic species (including coastal fish species) can be found at: http://www.dirnat.no/content.ap?thisId=1005138&language=0. We have only included phyla /groups that are commonly associated with mussels (according to Bjørnseth and Didiriksen, 2005; Iversen *et al.*, 2004; Kleppe, 1986; Wennberg *et al.*, 1981; Wijsman and Smaal, 2006).

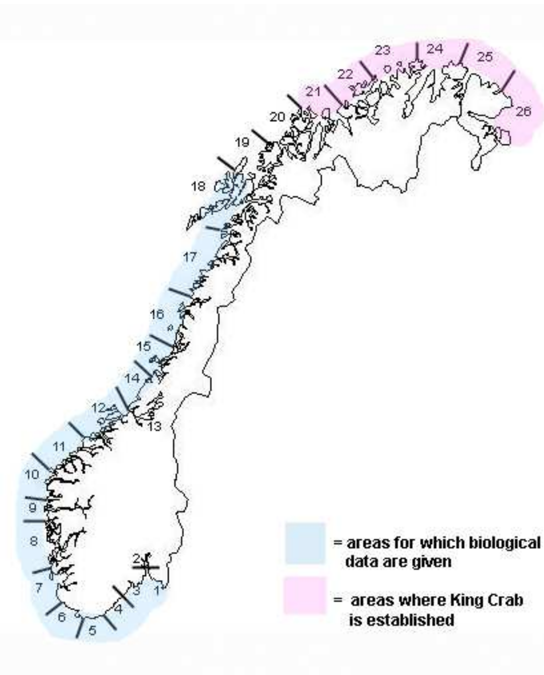


Figure 8: Location of the Marine Sectors 1-26 along the Norwegian coast. Data on flora and fauna for sectors 1 – 18 (indicated in blue) are presented in this report.

4.4.2 Flora and fauna associated with rope culture

There are, to our knowledge, not many species-specific studies on epibiota and associated species related to mussels in Norway. In studies of Iversen et al. (2004), Kleppe (1986) and Wennberg (1981), the organisms are only identified to higher taxonomic levels. Kleppe (1986) reports macro algae, ascidians, calcareous worms, hydroids, bryozoans and sea stars from Hordaland and Rogaland. Wennberg (1981) reports the same groups of organisms from mussels in the Sognefjord. Iversen et al. (2004) made observations of sea stars, ascidians (*Ciona intestinalis*) and the calcareous worm *Pomaterus triqueter* on mussels in Nordland County. A recent study in the Sognefjord (Bjørnseth and Didiriksen, 2005) has recorded algae, *Balanus* sp, bivalves, gastropods, *Pomaterus triqueter, Anomia* sp. hydroids, bryozoans, caprellids, crabs, mysids and other crustaceans associated with mussels in the area. (Polychaetes have also been frequently observed associated with mussels on ropes (Strand pers. obs.).

4.5 Exotic non-indigenous species in Norwegian marine waters

At present, 51 exotic non-indigenous marine species are recorded in Norwegian marine waters (Data from: Directorate for Nature management and The Norwegian Biodiversity Information Centre). Of these species 16 species are not recorded from the Netherlands according to Wolff (2005), Faase & Bayha (2006) and Peperzak (2003).

Table 3: Exotic non-indigenous species recorded in Norwegian marine waters. * indicate not recorded in the Netherlands

Scientific name		In NL	Note	Origin	Year of first observation	Distribution in Norway Sector nr.
Algae						
	Aglaothamnion halliae	*		West Atlantic	1980	1-3
	Alexandrium tamarense		Cryptogenic	?	?	1
	Bonnemaisonia hamifera		Only found drifting in The Netherlands	Japan	1902	1-12
	Verrucophora fascima (SYNONYM: *Chattonella* aff *verruculosa*)	*	Cryptogenic	?	1998	3-9
	Codium fragile subsp *atlanticum*	*		Indo- Pacific Japan	1895	8-12
	Codium fragile subsp *scandinavicum*	*		Indo- Pacific Japan	1929	3-21
	Codium fragile subsp *tomentosoides*			Indo- Pacific Japan	1946	3-11
	Colpomenia peregrina			Pacific	1933	1-15
	Coscinodiscus wailesii			Pacific	1979	2,3,13-15
	Dasya baillouviana			Mediterranean- NV- Atlantic	1966	3, 8
	Heterosiphonia japonica *Dasysiphonia* sp.		Present in The Netherlands but not established in the Wadden Sea	NE Pacific	1996	2-13
	Fucus evanescens	*		North Atlantic/Pacific	1900	Presumably all sectors
	Heterosigma akashiwo			Pacific and Atlantic	1964	2-19
	Karenia mikimotoi		As: Gymnodinium mikimotoi	Japan, North Atlantic	1966	3-14
	Karlodinium micrum	*				
	Neosiphonia harveyi			Pacific	1985	2-9
	Odontella sinensis			Indian Ocean, Red Sea?	1903	All
	Olisthodiscus luteus	*		Japan & Europe	1999	?
	Prorocentrum minimum		Present in the Netherlands according to Peperzak (2003)	Cold temperate- tropical	1979	1,2, 16-23
	Sphaerococcus coronopifolius				1994	2
	Sargassum muticum			Japan	1984/1988	1-10
	Thalassiosira punctigera			Unknown	1979	2, 16-23
	Thalassiosira tealata			Japan, England	1968	2
Polychaeta						
	Scolelepsis korsuni	*		?	1995	8-19

Scientific name	In NL	Note	Origin	Year of first observation	Distribution in Norway Sector nr.
Alkmaria rominji	*		?	?	1
Marenzelleria cf *wireni*			NV Atlantic/Artic	?	9, 10
Amphipoda					
Caprella mutica			Japan	1999	8-18
Cirrepedia					
Balanus improvisus			Australia	1900	1-8, 17
Lepas anatifera	*	Only found drifting in Norway	South Atlantic	<1900	Occasional west coast
Malacostraca					
Monocorophium sextonae			New Zealand /Mediterranean	1985	4-6
Eriocheir sinensis			East Asia	1976	1, 2
Homarus americanus	*		North east America	1999	2, 5, 6
Paralithodes camtschaticus	*		Released in Russia	1985	15-26
Chinocetes opilio	*		North West Atlantic	2003	23 (Båtsfjord)
Hydrozoa					
Cordylophora caspia			The Caspian Sea	1985	1-8
Gonionemus vertens			North Pacific West Atlantic	1921	2-13
Ctenophora					
Mnemiopsis leidyi		Present in The Netherlands according to Faase & Bayha (2006)	West Atlantic North America	2005	3, 8
Bivalva					
Crassostrea gigas			Pacific	1979	8-18
Ensis directus Synonym: *Ensis americanus*			North Atlantic America	1989	1-5
Mya arenaria			North America	Approx. 1000-1200	All sectors
Petricola pholadiformis		Synonym *Petricolaria pholadiformis*	Atlantic North America	1955	1-6
Ruditapes philippinarum	*		South East Asia	1987	8-15
Teredo navalis			?	1700	1-15
Gastropoda					
Crepidula fornicata			North West Atlantic	Approx. 1700	7-13
Potamopyrgus antipodarum			New Zealand	1952	1-7

Scientific name		In NL	Note	Origin	Year of first observation	Distribution in Norway Sector nr.
Ascidiacea						
	Molgula manhattensis			America?	?	1, 8, 13
Pisces						
	Oncorhynchus mykiss			North Pacific	1902	2-21
Nematoda						
	Anguillicola crassus			Japan	1994	1-6
Platyhelminthes						
	Pseudodactylogyrus anguillae	*		?	1990	1-6
	Pseudodactylogyrus bini	*		?	1990	1-6
Bacteria						
	Aeromonas salmonicida subsp. *salmonicida*			?	1986	All sectors
Parasites						
	Gyrodactylus salaris		Restricted to fresh water, but can live for a short while (18 hours) in brackish water	The Baltic Sea	1970-1980	1-20

In the following section a short description is given on the exotic non-indigenous species in the marine Norwegian waters that are not recorded in the Netherlands yet.

Macro Algae:

Fucus evanescens
First registration in Norway: ca. 1900
Distribution in Norway: Cold water species presumably distributed in all sectors.
Distribution in Europe: Baltic Sea, Britain, Denmark, Faroer, Iceland and Sweden.
Brown algae (10 –40 cm tall) with artic origin. Can make dense populations in area where there has been a disturbance in natural communities, like harbour areas and in nutrient rich waters like the Oslofjord.

Codium fragile ssp *scandinavicum*
Codium fragile ssp *atlanticum*
There exists no systematic information on the distribution of the subspecies of *Codium fragile* in Norway. The *Codium fragile* complex is distributed north to sector 20.

Sphaerococcus coronopifolius
Only occasionally recorded from the Oslofjord (sector 2) since 1994. This red alga is present in most of Europe including France and The British Isles.

Aglaothamnion halliae
First registration in Norway: 1980.
Distribution in Norway: In the Oslofjord and sector 2 and 3 (Figure 9). Small species with a restricted distribution in the Oslofjord area, the species is not recorded from any other sites in the east Atlantic. The species is however difficult to distinguish from other species in the *Aglaothamnion* genus, and might thus be underreported.

Figure 9: Distribution of *Aglaothamnion Halliae* along the Norwegian coast

Heterosiphonia japonica, Dasysiphonia sp.
Red algae with Pacific origin (Japan, Korea)
We include information on this species distribution in Norway, even though it is present in the Netherlands, because it may be optional to restrict the species distribution, as it may be a nuisance epibiont on bivalves. The species is present in the Oosterschelde (1994), Grevelingenmeer (1995), Veerse Meer and Westerschelde estuary (2005) (pers. comm. H. Stegenga, University of Leiden), but to our knowledge the species is not recorded from the Wadden Sea. The species is also recorded from the Danish Limfjorden in 2005. *H. japonica* was first observed in Norway in 1996 and has spread rapidly along most of the southern and south western coast (Husa *et al.*, 2004) (Figure 10). *H. japonica* is an abundant epiphyte on king scallops in Norway (pers. obs.) and on oysters in Spain (Peña and Bárbara, 2006) and in the Oosterschelde (pers. comm. Deniz Haydar, University of Groningen). The species reproduces by fragmenting of small branches, which settles and develops to new plants within weeks (Husa and Sjøtun, 2006).
We do not have any information on whether the species is present in the fjord areas in Norway, nor if it grows on blue mussels in these areas. Records of the species in a fjord near Kristiansund indicate that the species may thrive in fjord areas.

Figure 10: Distribution of Heterosiphonia japonica along the Norwegian coast

Microalgae:

Karlodinium micrum

Synonyms: *Karlodinium veneficum, Woloszynskia micra, Gymnodinium micrum, Gymnodinium galatheanum* (Source Algae base)

Origin: Northwest Pacific

Distribution in Europe: Britain, Norway, Spain and Corsica. Dinoflagellate producing ichthyotoxins and often associated with rapid fish mortality in Spain (Garcés *et al.*, 2006) and USA (Goshorn *et al.*, 2004). The first algal bloom of this species was recorded in the Oslofjord in the 1970's and it is present along the coast to Hordaland (Sector 8). No major blooms causing fish mortality has been observed in Norway.

Olisthodiscus luteus

Toxic algae first observed in Norwegian waters in 1999. Little information exists on the distribution of this species, but no harmful blooms have been reported in Norwegian waters.

Verrucophora fascima

Synonym: *Chattonella aff. verruculosa*

This toxic alga was first observed in Norway during a large bloom in 1998 and again in 2001.

The species has until recently been called *Chattonella* aff. *verruculosa*, but recent genetic and morphologic analysis concludes that the species is not belonging to the *Chattonella* genus and the new name is suggested to be *Verrucophora fascima* by Edvardsen et al. (Submitted). The origin of the species is uncertain and it might have been previously present without being recognized at the Scandinavian coasts (Naustvoll, 2006). The large blooms in 1998 and 2001 resulted in mortality in farmed salmon along the southern coast of Norway. In 2004 there were two smaller blooms of this species at the Danish and Swedish coast, none of them reaching Norway.

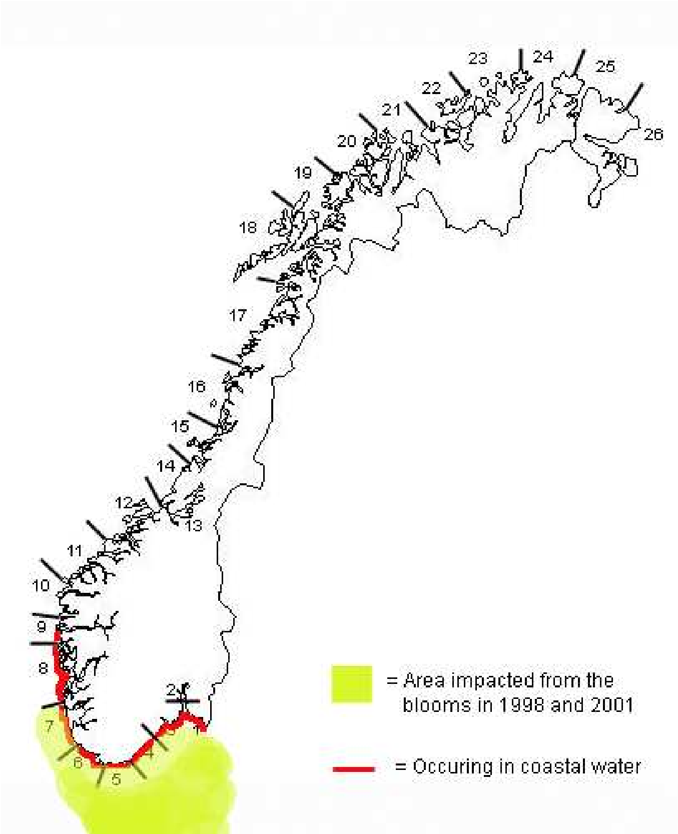


Figure 11: Distribution of *Verrucophora fascima* along the Norwegian coast (red). The areas impacted from the blooms in 1998 and 2001 are indicated in green.

Currently the species has been observed from the German coast (North Sea coast of Schlesvig-Holstein), Danish coast (North Sea coast and Skagerrak), the Swedish west coast and the Norwegian coast. Even though the main problems with the species have been in the Skagerrak area, the species is common in the coastal waters from Hvaler to the Sognefjord (sector 1-9) (Dahl *et al.*, 2007) (Figure 11). Since 2004, major blooms of this species have not occurred in the North Sea area or Skagerrak. Preliminary experiments indicate that the species will form resting stages (cysts) under certain conditions. The mechanisms behind fish mortality are still unknown (Naustvoll, 2006).

Polychaeta:

Scolelepsis korsuni

The first registration of this alien polychaete was at the west coast (sector 8) in 1995 and the species is considered to have a limited distribution in Norway (Hopkins, 2001).

Alkmaria rominji

Species has only been recorded in Østfold (sector 1) and may be considered a cryptogenic species in Norway.

Bivalva:

Ruditapes philippinarum - Manila clam

The manila clam was intentionally introduced to Norway in 1987 from a Scottish hatchery for seed production in two land-based hatcheries. The seed was exported mainly to Ireland and Spain. During the period 1988-1990

R. philippinarum was released at least six sites in Norway for cultivation. A throughout survey of the release areas in 1995/1996 showed that only a few clams were still present at three of the sites at this time. Only the originally released shells were present and no juveniles were detected, whereas it was concluded that the species most likely are not able to reproduce in nature in Norwegian waters (Mortensen and Strand, 2000). The sites where *R. philippinarum* are still present in Norway are marked in Figure 12.

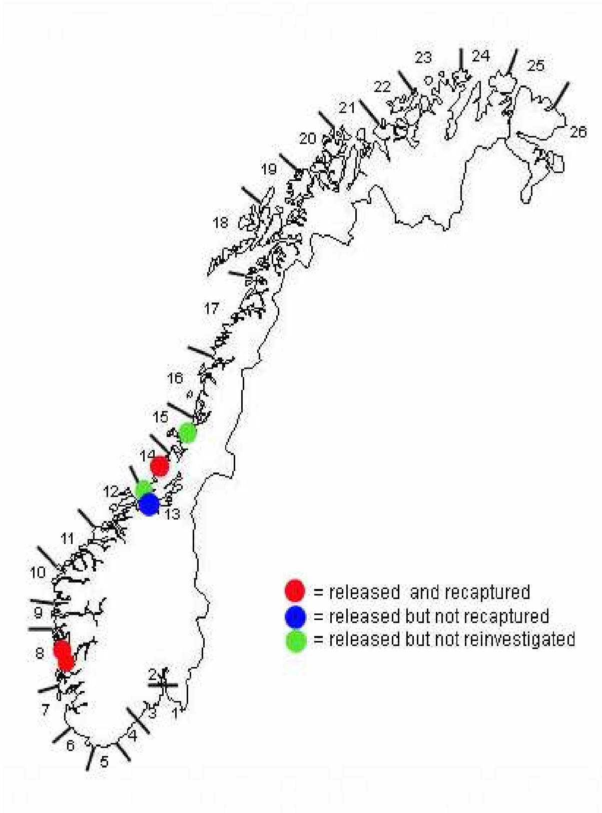


Figure 12: Map indication release sites of the Manilla clam (*Ruditapes philippinarum*) along the Norwegian coastline.

Cirrepedia:

Lepas anatifera

This species has regularly been found on drifting items at the Norwegian coast since 1900. It has never been observed established, and it is not regarded likely that *L. anatifera* is able to reproduce at our relatively cold coast.

Crustacea:

Paralithodes camtschaticus Red King Crab

Origin: North Pacific

Intentionally introduced to Barents region by the Russians for exclusive fisheries and successfully established in 1960. The first record from Norwegian waters was in 1977. The crab has since than established rapidly growing populations in the northernmost counties of Norway and dispersed as far west as Sørøya in Troms County (Figure 13). In the 2004 and 2005 single adult crabs have been caught at locations in Vesterålen (sector 18) and as far south as North Trøndelag County (sector 15). Norwegian scientists regard these records to be a result of fishermen illegally releasing crabs (pers. comm. Jan Sundet, IMR). Some of the crabs were carrying eggs, and it is still not known if any potential offspring have been able to establish populations in these areas. Monitoring of the *P. camtschaticus* distribution is mainly based on reports from fishermen.

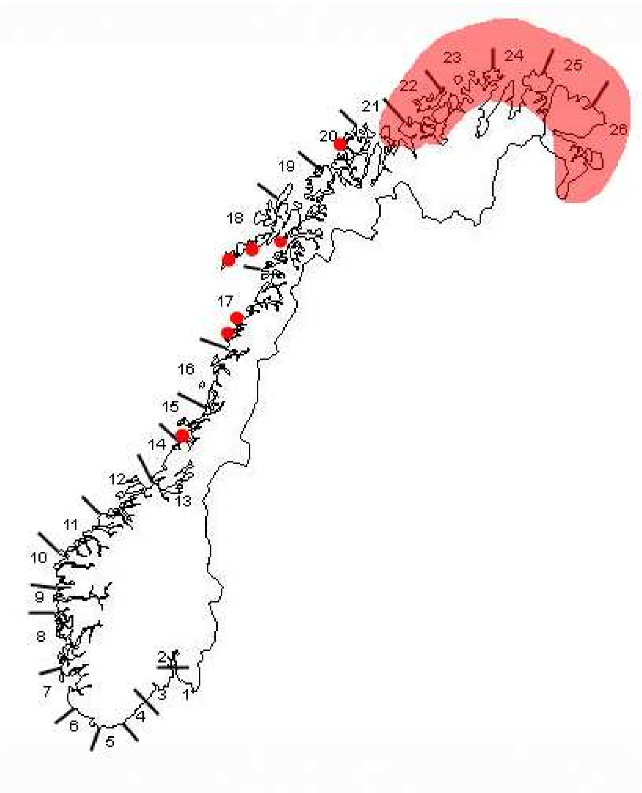


Figure 13: Map indicating the distribution of the Red King Crab (*Paralithodes camtschaticus*). Red dots indicate locations where single adult crabs have been caught.

In its native range the crabs are distributed south to Korea and tolerate temperatures from –1,7 to 11ºC, indicating a southern limit at sector 19-20 (pers. comm) at the Norwegian coast, thus it may be difficult to predict the crab's southern limits in Europe. Adult *P. camtschaticus* living in deep waters perform a shoreward migration to shallow water (10-30 m) for mating and moulting in late winter/spring. In its native range hatching of planctonic larvae takes place in May-June. The larvae settle on macroalgae, sponges bryozoans etc. in the shallow waters (10-20 m depth) and after two years the juveniles migrate to deeper waters (Jørgensen *et al.*, 2005).

Homarus americanus American lobster

Origin: Northeastern America, Labrador, Newfoundland and Canada

The first two specimens of *H. americanus* were observed in the Oslofjord in 1999. These were adult female specimens of which one was carrying eggs. In the following years several (16) adult lobsters have been identified as *H. americanus* along the southern and western coast of Norway with the northernmost record from Ålesund (sector 11, Figure 14). In 2005 five adult lobsters were identified in Hordaland County, of which two was carrying fertilized eggs. This lead to a throughout investigation in the area nearby, but no more lobsters were found (Jørstad *et al.*, 2006).

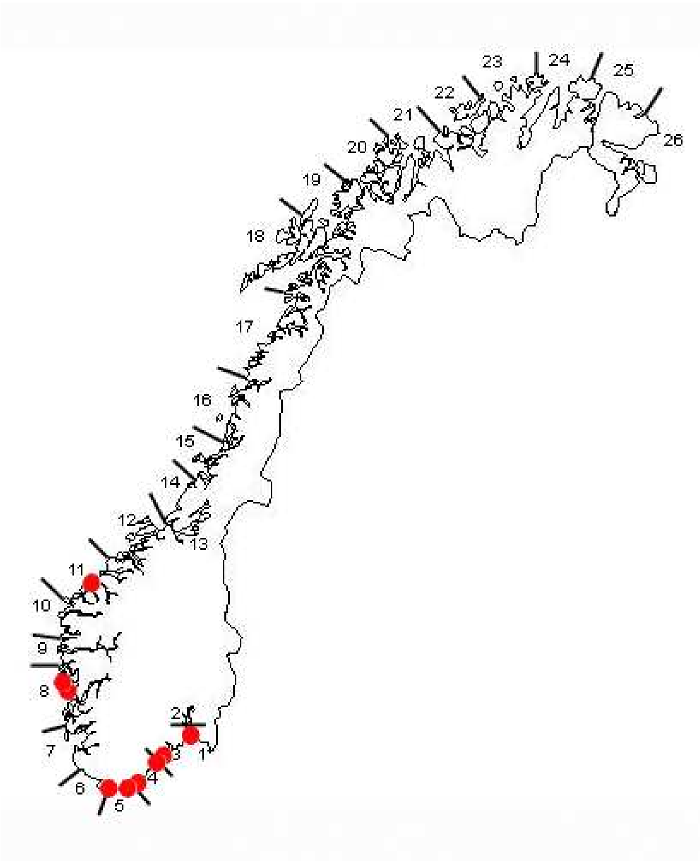


Figure 14: Map indicating recordings of American Lobsters (*Homarus americanus*)

All the American lobsters found in Norway have been adult specimens and often with elastic clips or marks from clips. Juvenile lobsters have not been observed in Norway and to our knowledge the species has not been able to reproduce successfully here. American lobster are frequently imported for consume or sale, and all the records in Norway have been close to either sales facilities, harbours with cruise traffic or near international airports (Van Der Meeren *et al.*, 2006). Based on the distribution pattern Norwegian scientists regard the records of American lobster to be separate introductions of lobsters either thrown at sea, escaped from sea storage cages or illegal deliberate releases (pers.comm Ann Lisbeth Agnalt, IMR).

The findings outside Bergen in 2005 of egg carrying females is the one that causes most concern, and this site will be followed up in regular monitoring as to see if any offspring has successfully established.
In its native range the American lobster spawns planctonic larvae, which settles into substrate or shelter within 22-103 days (2-4 weeks) where they develop to juvenile lobsters. The distribution range of larvae is not considered to be very wide (Van Der Meeren *et al.*, 2006).

H. americanus may be carriers of the bacteria *Aerococcus viridans* causing gaffkemia, a blood disease with high mortality in lobsters. The American lobsters have in many cases developed resistance to the bacteria and there is a high risk that such carriers will transfer the virus to native lobster, which suffers 100 % mortality (Hopkins, 2001). The American lobster closely resembles the European lobster, and genetic analysis seems to be the only secure way to identify the alien species(Jørstad *et al.*, 2006).

Chionoecetes opilio – Snow crab
Origin: North Pacific from Japan to the Bering Strait, North Atlantic from Cape Cod to Western Greenland
The Russians made the first registrations of *C. opilio* in The Barents Sea in 1996. Norwegian scientists have registered several snow crabs from offshore bancs in the Barents region and in 2003 one was found 2-3 nautical miles north of Båtsfjord (sector 25, Figure 15). The snow crab thrives best at temperatures below 3 °C, and there is little risk that this species will spread to more southern areas of Norway.

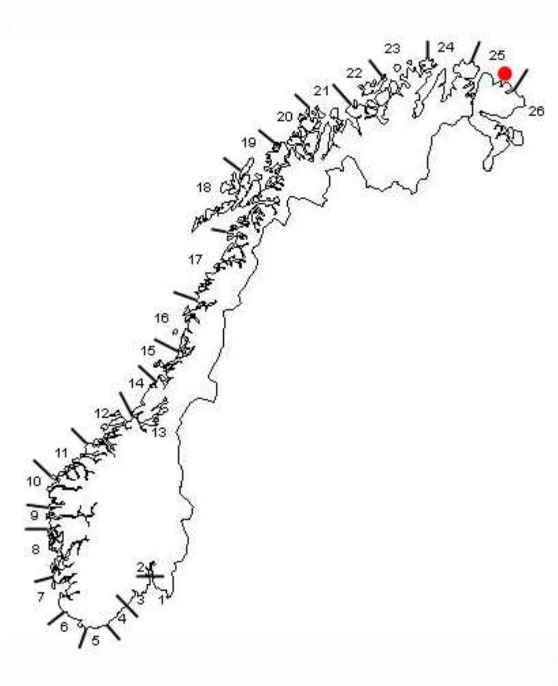


Figure 15: Map indicating recordings of the Snow crab (*Chionoecetes opilio*) along the Norwegian coast.

Pseudodactylogyrus anguillae and *P. bini*
Monogenean gill parasites in European eel, which has been present along the southern coast (sector 1-6) since 1990.

5 Risk assessment

5.1 Introduction

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 and 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 involved and a chain of events and coincidences within the system. It is not feasible to get a complete knowledge of this system and to forecast the future development.

From expert judgment the potential risks can be identified qualitatively. This has been tried in a previous study on the import of exotic species due to mussel transport (Snijdelaar *et al.*, 2004). In this study the experts agreed that it is hard to predict the impact of a species on forehand due to the fact that in most of the cases the knowledge about the (aut)ecology of the species is very limited at that stage.

The disadvantage of a qualitative approach is that often low probability/high consequence events tend to be overestimated, while high probability/low consequence events tend to be underestimated (Haugom *et al.*, 2002). By separately describing the risk of the two parts (i.e. probability and consequence), the outcome of the second part will not be influenced by the results of the first part. This approach will be used for our assessment.

In this study, a semi-quantitative risk assessment is made on the risk of introducing hazardous exotic, non-indigenous species into the Wadden Sea with the mussel imports from Norway. Roughly this risk assessment is divided in tree steps (
Figure 16).

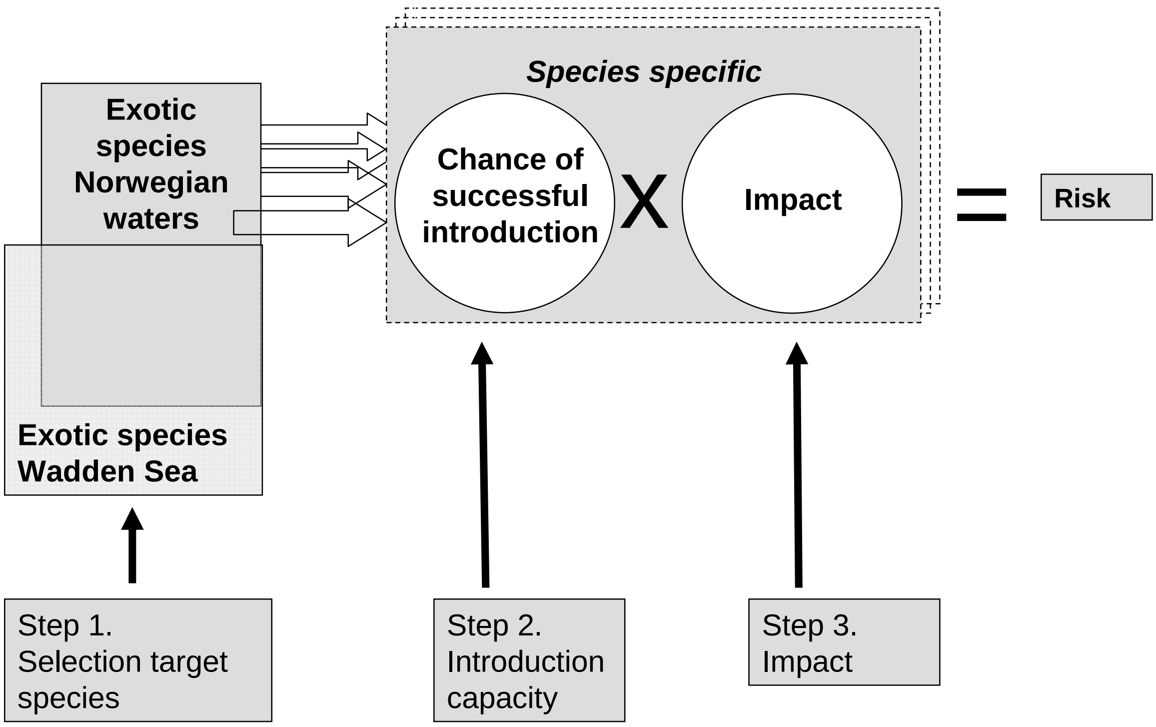


Figure 16: Overview of the set-up of the risk analysis.

In the first step, the target species are identified. Target species are exotic species that can be found in the Norwegian waters and are not known to be present in the Wadden Sea.

The second step is to quantify the chance of introduction of these target species from Norway into the Wadden Sea with the transfer of mussels and the possibility that they will become permanently established in the Wadden Sea. 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 Wadden Sea conditions. In addition, a group of experts has assessed the chance of successful introduction of exotic species by transporting mussels from Norway to the Wadden Sea.

The third step is to identify the impact that a target species will have on the ecosystem in the Wadden Sea, assuming successful introduction and is based on the judgment of a group of experts and literature on impact of invasive species.

Besides an ecological impact upon which this study is focused, the introduction of exotic species can also have economical, social and safety related impacts (Haugom *et al.*, 2002). Substantial ecological impact will in many cases also affect the other aspects. 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 there are circumstances possible where economical impact can occur without a substantial change of the ecosystem. This is for instance the case when exotic fouling organisms are clogging cooling water pipes. The economical consequences of introduction of exotic species situations are not explicitly covered by this study.

Also not covered is the risk of microorganisms, such as bacteria and viruses. A Dutch expert group concluded in 2004 that the current legislation is sufficient to prevent human safety risks due to microorganisms in consumed shellfish. Additional measures for the prevention of the introduction of microbial organisms due to transfers of shellfish are considered not necessary (Snijdelaar *et al.*, 2004). In the same report it is recommended to give more attention to (transfer of) mussels with respect to the monitoring of shellfish diseases. This effort now is more emphasized on oysters by CIDC (Central Institute for Animal Disease Control).

With the import of mussels also bacteria and viruses can be introduced causing diseases of wild flora and fauna. These type of introductions can have an important effect on the ecosystem but these small organisms are not covered in this report. For example, the American lobster *H. americanus* may be the carrier of the bacteria *Aerococcus viridans* causing gaffkemia, a blood disease that could lead to high mortality rates in lobsters. The American lobsters have in many cases developed resistance to the bacteria and there is a high risk that such carriers will transfer the virus to native lobster, which suffers 100 % mortality (Hopkins, 2001). The American lobster closely resembles the European lobster, and genetic analysis seems to be the only secure way to identify the alien species (Jørstad *et al.*, 2006).

Parasites can also cause diseases of wild flora and fauna. Parasitic species are included in this study, but it is possible that the list of parasites is not complete. Two parasite species (*Pseudodactylogyrus* spp.) in European eel have been found in Norway. These species are therefore included in this assessment.

5.2 Identification of target species

The present analysis is focused on exotic, non-indigenous species. With the transfer of mussels, also Northeast Atlantic non-indigenous species, that are native species for the Northeast Atlantic shelf waters, could be introduced into the Wadden Sea. Some of these species might settle for a couple of years. However, eventually they will disappear because the environmental conditions in the Wadden Sea are not suitable to form a self-sustaining population (Wolff, 2005). If these species should be able to become established in the Wadden Sea, they would have been able to colonize the area in the past without the 'help' of mussel transfer. For the exotic non-indigenous species that are able to settle in the Wadden Sea, the transport of mussels will advance the introduction. In this case, the transfer of mussels forms an additional transport mechanism besides the natural transport mechanisms such as water currents.

All exotic non-indigenous species that are present in the source area (Norwegian waters) and not in the Wadden Sea form the target species for this study. These target species were identified by comparison of a list of species that live in the source area and a list of species that can be found in the Wadden Sea (Table 4).

Table 4: 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 Norwegian waters?	No	Yes	Yes
Present in Wadden Sea/Dutch coastal waters?	Not relevant	Yes	No
Target species?	**No**	**No**	**Yes**

Similar to the previous study[2], exotic species that are not reported as inhabitants in the Wadden Sea, but are known to be present in the Dutch coastal waters, were not identified as target species for this study. These species will be able to reach the Wadden Sea area by natural ways from the surrounding waters, and therefore the influence of mussel transfer from Norway is of little significance. It can also not be excluded that these species are already present in the Wadden Sea but have not yet been reported. This is the case for the algae *Alexandrium tamarense* and *Heterosigma japonica*, which have become permanently established in the Netherlands (Wolff, 2005), although they are not yet reported as inhabitants of the Wadden Sea. According to Wolf (2005), the macro algal species *Bonnemaisonia hamifera* are regularly found washed ashore along the Dutch coasts, but as yet has not become established. The algae *Prorocentrum minimum* is present in the Netherlands according to Peperzak (2003). The ctenophore (comb jellies) *Mnemiopsis leidyi* is also present in the Netherlands according to Faase & Bayha (2006). The tentacled lagoon worm *Alkmaria rominji* has already been established in the Netherlands, and is regarded a native species (pers. comm. Prof. W.J. Wolff). Petersen *et al.* (1997) reported the status of *Alkmaria rominji* in the Wadden Sea as being critical. In the Dutch part of the Wadden Sea the species is extinct. Regarding its status in the area, this species is not selected as a target species.

Table 5: Exotic non-indigenous estuarine and marine species that have become established in Norway and are not yet observed in the Wadden Sea, but that were not identified as target species for this study. For explanation see text.

Taxonomic group	**Species name**	**Establishment in the Netherlands**
Algae	*Alexandrium tamarense*	Permanently established (Cryptogenic) *
Algae	*Bonnemaisonia hamifera*	Not established, only found washed ashore in The Netherlands *
Algae	*Heterosiphonia japonica* *Dasysiphonia sp.*	Present in The Netherlands but not established in the Wadden Sea *
Algae	*Prorocentrum minimum*	Present in the Netherlands **
Ctenophora	*Mnemiopsis leidyi*	Present in The Netherlands ***
Platyhelminthes	*Pseudodactylogyrus anguillae*	Present in The Netherlands ****

* (Wolff, 2005); ** (Peperzak, 2003); *** (Faasse and Bayha, 2006); **** (Borgsteede *et al.*, 1999)

The final list of target species contains 14 species (Table 6). These are the exotic species that can be found in the Norwegian waters, but are not yet reported to be present in the Netherlands.

It is good to realize, that this selection of the target species is based on reported observations made in the area's 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. Clearly such species cannot be accounted for in the present risk analysis.

[2] Wijsman *et al.* (2006): Project Risk Analysis of Mussels Transfer (PRIMUS)

Table 6: Selected target species: Exotic non-indigenous estuarine and marine species that have become established in Norway and are not yet observed in the Wadden Sea.

Taxonomic group	Species name
Algae	*Aglaothamnion halliae*
	Codium fragile subsp *atlanticum*
	Codium fragile subsp *scandinavicum*
	Fucus evanescens
	Verrucophora farcimen (SYNONYM: *Chattonella aff verruculosa*)
	Karlodinium micrum
	Olisthodiscus luteus
Polychaeta	*Scolelepis korsuni*
Cirrepedia	*Lepas anatifera*
Malacostraca	*Homarus americanus*
	Paralithodes camtschaticus
	Chionoecetes opilio
Bivalva	*Ruditapes philippinarum*
Platyhelminthes	*Pseudodactylogyrus bini*

5.3 Potential for establishment of self-sustaining populations

5.3.1 Potential for establishment of self-sustaining populations

The likelihood that a certain exotic species can become established in the Wadden Sea due to the transfer of mussels, is the resultant of two processes, both with a different 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.

The assessment of these probabilities is based on available knowledge about the physiology and ecology of the species involved. Furthermore, an expert panel has assessed the chance of successful introduction of the target species in the Wadden Sea.

5.3.2 The probability that target species are successfully transferred

The probability that species are successfully transferred with mussels from Norway to the Dutch Wadden Sea 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 is primarily dependent on the presence of the species on the rope culture sites. Most of the by-catch of larger organisms will consist of species that live in close connection with the mussels within the rope culture. 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 Wadden Sea these species must be capable to survive the conditions during transport to the Netherlands. There are several options for transport:

- By truck. During this type of transportation the mussels are packed in large (1.5 m^3) big-bags without water. This situation lasts for about 2 to 3 days, depending on the source location. Therefore, in order to survive the transportation the species must be able to overcome this period under moist conditions, but out of the water.

- By airplane. The mussels are packed and transported under conditions that are similar to transport by truck. Transport by plane will take a lot less time so changes of survival will increase.
- By coaster. With this type of transport the mussels can be kept in water, which could be continuously refreshed. The transport will take longer, but the conditions allow higher chances of target species survival.

Because the means of transport has not yet been decided on, we assume the worst case scenario for this risk assessment, thus the one that gives the maximum change that the target species will survive: transport by coaster with a continuous circulation of fresh seawater.

The likelihood that a species is transferred to the Wadden Sea with imported mussels was scored as a range between 1 (very unlikely) and 5 (certain). The starting point for this qualification was a score of '5' (i.e. 'worst case') for each target species. Based on available knowledge this score could be lowered. In these cases where insufficient knowledge was available the high score (worst case) was maintained (Table 7).

As a rule of thumb it was decided that all planktonic species and species with a clear planktonic life stage have a high potency of being transported with the water that is attached to, or enclosed in the transported mussels. Therefore, the likelihood that these species will be transferred was scored as 'certain' (score 5). This was also the case with fouling organisms that are assumed to be transported as biofouling on the shells of the mussels. Based on the available information of the species and the criteria above (planktonic and/or fouling organisms are scored 5) the chance of being transported is assessed as ‘certain’ (score 5) for all target species.

5.3.3 The probability that transferred species are able to become established

Those species that are supposed to be able to survive the transport can be introduced in the Wadden Sea when the mussels are placed on the mussel beds. 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 probability for a species to establish a self-sustaining population in the Wadden Sea was determined by expert-judgment based on its ecological profile.

The probability that a species is able to establish a self-sustaining population in the Wadden Sea was scored as a range between 1 (very unlikely) and 5 (certain), in the same way as was the probability that a species was transferred. Again, the starting point was a score of '5' (i.e. 'worst case') for each species. Based on available knowledge this score could be lowered. In these cases where insufficient knowledge was available the high score was maintained. This was the case for *Aglaothamnion halliae*. This species is difficult to distinguish from other species in the *Aglaothamnion* genus, and might thus be underreported. Also no relevant information could be found on the worm *Scolelepis korsuni* and the macro algae *Codium fragile* ssp *scandinavicum.* A short summary of relevant information that has been found on other species is provided in this paragraph.

Table 7: Score based on literature for the probability that target species are successfully transferred with mussels and become established in the Wadden Sea respectively. Score: 1 very unlikely/certainly not; 2 unlikely; 3 likely; 4 very likely; 5 certain.

Species name	**Transfer score**	**Establishment score**	**Probability**
Aglaothamnion halliae	5	5	5
Codium fragile subsp scandinavicum	5	5	5
Fucus evanescens	5	2	2
Verrucophora farcimen	5	5	5
Karlodinium micrum	5	4	4
Olisthodiscus luteus	5	5	5
Scolelepis korsuni	5	5	5
Lepas anatifera	5	2	2
Homarus americanus	5	4	4
Paralithodes camtschaticus	5	1	1
Chionoecetes opilio	5	1	1
Ruditapes philippinarum	5	4	4
Pseudodactylogyrus bini	5	1	1

Codium fragile
This macro-algal species 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). It is therefore likely that the transport of mussels from Norway to the Dutch Wadden Sea could introduce this species to the Dutch waters. According to Kerkum *et al.* (2004), three subspecies of *Codium fragile* (spp. *atlanticum, scandinavicum* and *tomentosoides*) are already present in the marine waters of the Netherlands. ICES (2006) reports only two *C. fragile* subspecies to be present in the Netherlands (spp. *atlanticum* and *tomentosoides*). Therefore only *Codium fragile* spp. *scandinavicum* is considered a target species for this study. The probability that this species is able to establish a self-sustaining population is therefore considered as certain (score 5).

Fucus evanescens
Fucus evanescens is a macro-algae of arctic origin. It normally occurs at water temperatures between -1 and 18°C (Coleman and Brawley, 2005). Considering its arctic origin it is unlikely that it will establish in the Wadden Sea (score 2).

Verrucophora farcimen (Synonym: *Chattonella aff. verruculosa*)
The dinoflagellate species *Verrucophora farcimen* has been observed along the German coast, Danish coast, the Swedish west coast and the Norwegian coast. There are recent observations (unpublished) of the algae *Verrucophora farcimen* in the Wadden Sea. This indicates that this species has already been introduced (pers. comm. L. Peperzak, NIOZ). It is uncertain whether some of the earlier observations of *Chattonella* species in Dutch coastal waters, French coastal waters and central North Sea also could include observations of *Chattonella aff. verruculosa*. It has formed extensive blooms in the North Sea and the Skagerak. All blooms have occurred when the water temperature was below 10°C. It can tolerate temperatures up to 15°C (Edvardsen *et al.*, Submitted). Preliminary experiments indicate that the species will form resting stages (cysts) under certain conditions (Naustvoll, 2006).

The Wadden Sea is much more turbulent than many Norwegian Fjords and this is a reason why a number of flagellate species are expected to grow less in this area. However, once a species has been successfully introduced, there will always be a certain chance for survival and reproduction, even if it originates from less turbid waters (pers. comm. L. Peperzak, NIOZ). Considering its wide occurrence along the European coasts it is considered 'certain' that this species will establish in the Wadden Sea (score 5).

Karlodinium micrum (Synonyms: *Karlodinium veneficum, Woloszynskia micra, Gymnodinium micrum, Gymnodinium galatheanum* (Source Algae base))
This is a planktonic species that occurs in temperate to subtropical estuaries. It can be confused with other small dinoflagellates. It is (slightly) toxic and has been associated with fish kills in finfish aquaculture ponds as well as in estuarine waters (Source: website 'alien species in Swedish seas', http://www.frammandearter.se/). It is considered likely that this species will establish in the Wadden Sea (score 4).

Olisthodiscus luteus
This flagellate species can develop algal blooms in coastal waters. The optimum temperature has been determined at 20°C, but the species can tolerate temperatures even below 5°C and above 30°C (Karentz and Smayda, 1984). It has a wide salinity tolerance (Mahoney and McLaughlin, 1979). *O. luteus* resembles *Heterosigma akashiwo* in its cell size, cell shape and habitual environment (Kim *et al.*, 1999) and is therefore easily mistaken for this species. *H. akashiwo* is already present in the Wadden Sea. Given its wide tolerance for temperature and salinity it must be considered as certain that *Olisthodiscus luteus* will establish in the Wadden Sea (score 5).

Lepas anatifera (Goose barnacle)
The goose barnacle is an oceanic, pelagic species. It is attached to hard floating objects, such as logs (driftwood). It is found in the Atlantic and western English Channel (Neal, 2007). It is occasionally found washed ashore on the Dutch coast, attached on driftwood or bottles. It is native to the more southern seas and generally occurs where sea temperatures exceed 18-20°C (Patel, 1959). Reproduction is possible between 19 and 25°C but not at or below 15°C (Patel, 1959). Although it has been found washed ashore, *Lepas antifera* has never been observed established in Norway or the Netherlands. It is therefore unlikely that this species will establish in the Wadden Sea (score 2).

Homarus americanus (American lobster)
As mentioned before in this report, the American lobster has probably not been able to reproduce successfully in Norway. The distribution range of larvae is not considered to be very wide, but as they are planktonic, they could be transferred with the import of mussels. However, it is not very likely that they will be caught in the rope cultures. Besides offshore populations living down to 200 m depth, they are also found in shallow waters on mud, cobble, bedrock, peat reefs, eelgrass beds and occasionally within sandy depressions. It can tolerate temperatures from -1 to 30.5 °C, but prefers temperature between 5 and 20 °C (Van Der Meeren *et al.*, 2006). Since 2001, *H. americanus* is imported for direct consumption from the American and Canadian east coast (ICES, 2006). This also poses a risk for introducing this species in the Netherlands. Based on its habitat description, the probability that this species is able to establish a self-sustaining population is considered as very likely (score 4).

Paralithodes camtschaticus (Red King Crab)
Adults of the Red King crab occur on sand and mud substrata (Jørgensen, 2006). It produces planktonic larvae and could thus be transferred with the import of mussels. Considering this species cannot tolerate temperatures above 11 °C, it is however very unlikely that this species will establish in the Wadden Sea (score 1).

Chionoecetes opilio (Snow crab)
The snow crab is a subarctic species that prefers temperatures below 3 °C. Therefore, there is little risk that this species will spread to more southern areas. It can, however, occur at temperatures as high as 10°C(Tremblay, 1997). The planktonic larvae of this species could be transferred with the import of mussels. Adults occur primarily on mud bottoms and thus the Wadden Sea forms a potential habitat. However, the relatively high temperatures will prevent this species from establishing (score 1).

Ruditapes philippinarum (Manila clam)
Because this species has a planktonic life stage, it could be transferred with the import of mussels, however it is not very likely that they will be caught successfully with the rope culture. *Ruditapes philippinarum* needs a water temperature of at least 12 °C for reproduction (Flye-Sainte-Marie *et al.*, 2007). Temperatures of the Wadden Sea will thus allow this species to reproduce. The probability that this species is able to establish a self-sustaining population is therefore considered as very likely (score 4).

Pseudodactylogyrus bini
The *Pseudodactylogyrus* spp. species are gill parasites in European eel. The optimum temperature for eel production (20-25°C) almost corresponds to the optimum temperature for the parasite (Mellergaard and Dalsgaard, 1987). *Pseudodactylogyrus* spp species occur on eel in freshwater systems. *P. anguillae* is more common than *P. bini*. This species may also dwell and reproduce in brackish water habitats. Its upper salinity tolerance limit is 20‰ (Sobecka and Pilecka-Rapacz, 2003). Since the distribution of *P. bini* seems to be limited to only freshwater, it is considered highly unlikely that this species will establish in the Wadden Sea (score 1).

5.3.4 Overall score

The individual scores for transfer and establishment were multiplied and divided by 5 in order to calculate the overall score for the likelihood that target species become established in the Wadden Sea due to mussel transfer. Based on this list, it seems (at least) likely that 8 out of the 13 target species are able to become permanently established in the Wadden Sea due to mussel transfer (Table 8).

In addition, an expert panel was requested to judge the list of target species and to indicate the chance of successful introduction in the Wadden Sea. The risk was again scored from 1 (very unlikely) to 5 (very likely). Nine experts were able to fill in the list (Table 9). The experts scored 10 target species (at least) likely to become established in the Wadden Sea due to mussel transfer.

Table 8: Overall score based on literature for the likelihood that target species become established in the Wadden Sea due to mussel transfer. The 'overall score' is formed by the product of the 'transfer' and the establishment' score divided by 5 (Table 7). The species are ranked according to the overall score. Score: 1 very unlikely/certainly not; 2 unlikely; 3 likely; 4 very likely; 5 certain.

Species name	**Taxon. group**	**Overall score**	
Aglaothamnion halliae	Algae	5	"certain"
Codium fragile subsp scandinavicum	Algae	5	"
Olisthodiscus luteus	Algae	5	"
Scolelepsis korsuni	Polychaeta	5	"
Verrucophora farcimen	Algae	5	"
Karlodinium micrum	Algae	4	"very likely"
Homarus americanus	Malacostraca	4	"
Ruditapes philippinarum	Bivalva	4	"
Fucus evanescens	Algae	2	"unlikely"
Lepas anatifera	Malacostraca	2	"
Pseudodactylogyrus bini	Malacostraca	1	"very unlikely"
Paralithodes camtschaticus	Platyhelminthes	1	"
Chionoecetes opilio	Cirrepedia	1	"

Table 9: The assessment of marine biology experts of the chance of successful introduction of target species. Score: 1 very unlikely/certainly not; 2 unlikely; 3 likely; 4 very likely; 5 certain.

		Score	
Taxon. Group	**Target species**	**Average**	**Range**
Algae	*Aglaothamnion halliae*	3.8	2 - 5
	Codium fragile ssp scandinavicum	3.5	2 - 5
	Fucus evanescens	3.4	2 - 5
	Verrucophora farcimen	4.0	2 - 5
	Karlodinium micrum	3.7	2 - 5
	Olisthodiscus luteus	4.0	2 - 5
Polychaeta	*Scolelepis korsuni*	5.0	-
Cirrepedia	*Lepas anatifera*	3.1	1 - 5
Malacostraca	*Homarus americanus*	2.6	1 - 4
	Paralithodes camtschaticus	1.6	1 - 2
	Chionoecetes opilio	1.6	1 - 2
Bivalva	*Ruditapes philippinarum*	3.3	2 - 5
Platyhelminthes	*Pseudodactylogyrus bini*	3	-

Expert judgment on the chance of an introduction of the American lobster (*H. americanus*) is presently considered to be unlikely. Up to now, the species has not been able to successfully establish in Norway. However, it is possible that registrations of *H. americanus* are underestimated since it seems that genetic analysis is required. This judgement may therefore change in a time frame of decades (pers. comm. Ø. Strand). The chance of an introduction of *Ruditapes philippinarum* is considered to be unlikely, since this bivalve species is most likely not able to reproduce in Norway (pers. comm. Ø. Strand).

5.4 Potential for ecological impact

As described in the introduction of this chapter, there are several steps in the prediction whether an exotic species will be able to develop into an ecological nuisance, *i.e.* a pest species. A basic requirement is that the species can successfully settle. This depends on its ability to arrive in the Wadden Sea and its ability to survive and successfully reproduce considering the local environmental conditions. This is considered in the previous paragraphs.

The next step, described in this paragraph, is to identify the impact that a target species can potentially have on the ecosystem in the Wadden Sea, assuming successful introduction. Once established, the species may develop into a nuisance, provided the environmental conditions are very favorable for the species concerned. In historical times, many species have expanded their range and colonized new ecosystems. Some of these colonization's were spontaneous, whereas others were closely linked to human activities. There are no indications that it has resulted in large scale (European) species-extinctions and impairment of ecosystem functioning, but locally this has resulted in disappearance of some native species (Reise *et al.*, 2006). The Pacific oyster (*Crasostrea gigas*), which was introduced in the Netherlands for aquaculture purposes in 1963 has recently developed exponentially and has lead to a nuisance in large areas including the Wadden Sea. The relatively mild winters that have occurred recently might have played an important role in the successful introduction of new species, especially from the South.

The impact assessment is based on literature on impact of invasive species and the judgment of a group of experts. A literature research was conducted to answer a few key questions for each species: whether the species are known as pest species; whether the species could (potentially) displace native species; distribution of the species, habitat and food preference and other relevant ecological factors. Based on the available knowledge the potential impact is assessed. The results are described below and summarized in Table 10. The results of the expert judgment are presented in Table 11.

Aglaothamnion halliae
This species is difficult to distinguish from other species in the *Aglaothamnion* genus, and might thus be underreported. It is expected to have a small ecological impact, since the plants are small and it seems mainly to be restricted to harbour areas (ICES, 2005). It is therefore considered unlikely that this species can have a substantial effect on the ecosystem of the Wadden Sea (score 2).

Codium fragile
In Europe, *C. fragile* ssp *atlanticum* is not only recorded in Norway, but it has also been successfully introduced in Britain, Shetland, Ireland and Scotland. In British waters, the lack of grazers has probably contributed to its success. It is an opportunist, exhibiting vegetative propagation and perennation (Eno *et al.*, 1997). Another subspecies of *C. fragile* (spp. *tomentosoides*) is known to have the following effects: fouling of shellfish beds, fishing nets, wharf pilings, jetties, ropes, and beaches; increasing sedimentation; and habitat disturbance of some large invertebrates and fish (Global Invasive Species Database). The subspecies *tomentosoides* is among the most invasive seaweeds in the world, with extensive trans-oceanic and inter-oceanic spread this century. There are six described subspecies of *C. fragile*, diagnosed mainly by size and shape of the utricles. Of the six subspecies of *C. fragile*, only ssp. *scandinavicum*, ssp. *atlanticum* and ssp. *tomentosoides* are considered invasive. *C. fragile* ssp. *atlanticum* and ssp. *tomentosoides* are known non-native marine species in UK waters but are not currently assigned pest status (Welch and Lucas, 2002). The probability that these species can have a substantial effect on the ecosystem of the Wadden Sea is therefore considered as likely (score 3).

Fucus evanescens
This arctic brown macro-algae can make dense populations in areas where there has been a disturbance in natural communities, like harbour areas and in nutrient rich waters. Worm & Chapman (1998) have studied the effects of grazing pressure (periwinkles and crustaceans) and competition (by Irish moss - *Chondrus crispus*) on the growth of *Fucus evanescens. F. evanescens* is physiologically competent to invade the lower shore of Nova Scotia on the NW Atlantic seaboard but is nevertheless absent or very rare. The results show that colonization may only occur where there are gaps in the *Chondrus* canopy. It is therefore unlikely that *C. crispus*, a native species in the Netherlands, will be displaced by *F. evanescens*. Furthermore, because *F. evanescens* grows on rocks or other hard substrate, it will not be able to establish in most parts of the Wadden Sea. It is therefore considered unlikely that this species can have a substantial effect on the ecosystem of the Wadden Sea (score 2).

Verrucophora farcimen (Synonym: *Chattonella aff. verruculosa*)
This dinoflagellate species is able to form massive blooms. It is a well-known toxic red tide phytoplankton, that causes severe damage to fish aquaculture (Kim *et al.*, 1999). Since 1998 it has formed recurrent extensive blooms in the North Sea and the Skagerrak, causing fish mortalities (Edvardsen *et al.*, 2007). All blooms have occurred when the water temperature was below 10°C (Naustvoll, 2006). Welch & Lucas (2002) summarized known pest status for a number of exotic species. *Chattonella* sp. is listed as a marine pest species that pose a threat to the UK. Based on the available information it is considered very likely that this species can have a substantial effect on the ecosystem of the Wadden Sea (score 4).

Karlodinium micrum
This dinoflagellates species is (slightly) toxic and has been associated with fish kills in finfish aquaculture ponds as well as in estuarine waters. The toxins of *K. micrum* are uncharacterized. Besides the observed fish kills, it is not known whether this species can cause fish or shellfish disease or affect other marine animals. It is able to form resting cysts (Source website 'alien species in Swedish seas'). Based on the limited available information it is considered likely that this species can have a substantial effect on the ecosystem of the Wadden Sea (score 3).

Olisthodiscus luteus
This flagellate species can develop red algal blooms in coastal waters. The optimum temperature has been determined at 20°C (Karentz and Smayda, 1984). Successful introduction of this species could therefore cause red algal blooms along the Dutch coasts in summer. Kim *et al.* (1999) studied the toxic potential of *O. luteus* and conclude that this species can cause harmful effects on surrounding living organisms. Based on the available information it is considered highly likely that this species can have a substantial effect on the ecosystem of the Wadden Sea (score 4).

Lepas anatifera (Goose barnacle)
The goose barnacle is an oceanic, pelagic species. It is attached to hard floating objects, such as ships and logs (driftwood). There are no indications found in literature that it has developed into an ecological nuisance. Based on the available information it is considered unlikely that this species can have a substantial effect on the ecosystem of the Wadden Sea (score 2).

Homarus americanus (American lobster)
The American lobster is a competitor to the native European lobster, by sharing the same habitat and food preferences. Additionally, they can carry various diseases and parasites (as referred to in the first paragraph of this chapter). Being large and long-lived predators, able to manipulate their environment by digging and shuffling substrate, they might have a long-term effect on the ecosystem. Cross–species mating has been achieved in laboratories, producing live, fast growing and vigorous offspring, sometimes being sterile (Van Der Meeren *et al.*,

2006). Based on the available information it is considered very likely that this species can have a substantial effect on the ecosystem of the Wadden Sea, although the European lobster is not present in this area (score 4).

Paralithodes camtschaticus (Red King Crab)
This species is among the world's largest arthropods, weighing over 10 kg and reaching 22 cm in carapace length. It is native to the Okhotsk and Japan Sea, Bering Sea and Northern Pacific Ocean. In the sixties, it was intentionally released in the east Barents Sea to create a fishing resource. Since then, it has spread both east and westwards. In 1992 the crab became abundant in Norwegian waters. In areas of the Barents Sea recently invaded by the crab, molluscs and echinoderms mostly make up the crabs diet. It is able to exploit considerable areas of sea bottom. As the crab abundance increase, the echinoderms in de diet decreases while polychaetes become more important. Small crabs feed on sea stars, kelp, clams, mussels, nudibranch egg masses and barnacles. Food availability would likely appear to be the most important factor in limiting its distribution in a new environment (Jørgensen, 2006). King crabs are expected to have a negative effect on the benthic community trough direct predation, but no significant impact on the pelagic community (Falk-Petersen, 2004). Based on the available information it is considered very likely that this species will have substantial effect on the ecosystem of the Wadden Sea if it can become established there (score 4).

Chionoecetes opilio (Snow crab)
The snow crab (*Chionoecetes opilio*) is one of the most valuable commercially exploited marine species in Atlantic Canada (Hardy *et al.*, 1994). The crab develops from soft-shelled to hard-shelled via a moulting process. The soft-shelled crabs are fragile and vulnerable to predation. Species from the Northwest Atlantic prey on polychaetes, crustaceans (shrimp, crabs and smaller crustaceans), infaunal clams and fish. Based on food mass, shrimp and fishes are their main food source (Squires and Dawe 2003). There are no cases known in available literature that this species has affected an ecosystem after successful introduction. However, considering its food source it could compete with native predators. It is therefore considered likely that this species can have a substantial effect on the ecosystem of the Wadden Sea (score 3).

Ruditapes philippinarum (Manila clam)
R. philippinarum is native to the Indian-Pacific region and was introduced into European Atlantic and Mediterranean coastal waters for commercial exploitation. In the early seventies, this species was introduced to France. Since 1988 natural populations have colonised most embayments along the French Atlantic coast, creating an important fishing resource. In these areas, *R. philippinarum* is often affected by high mortalities in late winter. These mortalities have been associated with unfavourable environmental factors (reduced food availability, low temperatures and salinity) and with a bacterial disease. The Manila clam is a near-bottom suspension feeding bivalve. It is hypothesised that in mudflats, microphytobenthos is an important food source. It is known to also ingest toxic and non-toxic dinoflagellates (Flye-Sainte-Marie *et al.*, 2007). Introduction of *R. philippinarum* in the Venice Lagoon in 1983 changed the macrobenthic community, in particular bivalve molluscs. Pranovi *et al.* (2006) describe a sharp reduction, both in terms of distribution area and density, of all other filter feeder bivalves. Moreover, the filtration capacity has more than doubled from 1990 to 1999. This has altered the functioning of the ecosystem, resulting in a stronger benthic–pelagic coupling. Based on the available information it is considered very likely that this species can have a substantial effect on the ecosystem of the Wadden Sea (score 4).

Pseudodactylogyrus bini
P. bini was introduced, together with *P. anguillae*, from Asia to North America and Europe with the importation of the Japanese eel (*Anguilla japonica*). Both species now infect wild populations of the native North American eel (*Anguilla rostrata*) and wild populations of the native European eel (*Anguilla Anguilla*). These gill parasites have

caused serious problems among captive eels. Both parasites only occur on eel. *P. anguillae* is known to overwinter on eels while they are buried in the substrate, which has been observed at infected European eels in Britain. A study on the occurrence of parasites among wild eels collected from freshwater locations showed that *P. anguillae* is able to spread rapidly from host to host (Barker and Cone, 2000). Borgsteede *et al.* (1999) reported that almost 30% of the eels caught at freshwater and brackish locations in the Netherlands were infected by *P. anguillae*. The parasite preferred the brackish location over the freshwater sites (57% and 20% infected, respectively). *P. bini* was not found on the collected eel. Based on the available information it is considered unlikely that this species can have a substantial effect on the ecosystem of the Wadden Sea (score 2).

Table 10: Literature based assessment of the probability of target species having substantial ecological impact on the Wadden Sea system after successful introduction.

Taxon. Group	**Target species**	**Score**	
Algae	*Aglaothamnion halliae*	2	"unlikely"
	Codium fragile ssp scandinavicum	3	"likely"
	Fucus evanescens	2	"unlikely"
	Verrucophora farcimen	4	"very likely"
	Karlodinium micrum	3	"likely"
	Olisthodiscus luteus	4	"very likely"
Polychaeta	*Scolelepis korsuni*	5	"certain" (worst case)
Cirrepedia	*Lepas anatifera*	2	"unlikely"
Malacostraca	*Homarus americanus*	4	"very likely"
	Paralithodes camtschaticus	4	"very likely"
	Chionoecetes opilio	3	"likely"
Bivalva	*Ruditapes philippinarum*	4	"very likely"
Platyhelminthes	*Pseudodactylogyrus bini*	2	"unlikely"

In order to assess the probability that additional new exotic invaders will have a detrimental effect on the ecosystem of the Wadden Sea as it is currently developing, an expert panel was requested to judge the list of target species and to indicate for each species that it lead to detrimental ecological effect once established in the Wadden Sea. The risk was scored from 1 (very unlikely/certainly not) to 5 (certain). Nine experts were able to fill in the list.

Table 11: The assessment of marine biology experts of the probability of target species having substantial ecological impact on the Wadden Sea system after successful introduction. Score: 1 very unlikely/certainly not; 2 unlikely; 3 likely; 4 very likely; 5 certain. The consulted experts were not able to score *Scolelepis korsuni*

		Score	
Taxon. Group	**Target species**	**Average**	**Range**
Algae	*Aglaothamnion halliae*	2.5	1 - 5
	Codium fragile ssp *scandinavicum*	3.5	2 - 5
	Fucus evanescens	3.3	2 - 5
	Verrucophora farcimen	4.3	3 - 5
	Karlodinium micrum	3.0	2 - 4
	Olisthodiscus luteus	3.0	2 - 4
Polychaeta	*Scolelepis korsuni*	2.0	-
Cirrepedia	*Lepas anatifera*	2.4	1 - 5
Malacostraca	*Homarus americanus*	3.3	2 - 5
	Paralithodes camtschaticus	4.3	2 - 5
	Chionoecetes opilio	3.5	2 - 5
Bivalva	*Ruditapes philippinarum*	3.8	2.5 - 5
Platyhelminthes	*Pseudodactylogyrus bini*	3.0	-

5.5 Overall risk assessment

The risk assessment, as presented in this chapter, indicates that it is very likely that a number of exotic non-indigenous species will be able to establish self sustaining populations in the Wadden Sea after being transferred to the area with imported mussels. Table 12 summarizes the assessments based on literature and expert judgment. Six species are (very) likely to be successfully introduced and pose a threat to the ecosystem of the Wadden Sea (sore 3 or higher).

The algal species *Codium fragile* ssp *scandinavicum* and *Verrucophora farcimen* are considered a risk for the Wadden Sea. However, there are indications that these species are already present in the Wadden Sea. In this case, there will be no additional risk by mussel imports from Norway. It is therefore recommended to verify these observations. Based on available literature, the algae *Olisthodiscus luteus* is considered very likely to be successfully introduced and pose a threat to the ecosystem of the Wadden Sea. Successful introduction of this species could lead to toxic algal blooms. The polychaeta *Scolelepis korsuni* is assessed with the highest score. Because there is very little known about this species, the literature assessment is a worst case assumption. The expert judgement is based on only one score of the chance of successful introduction of this species. The potential impact of this species on the Wadden Sea ecosystem is unknown. Although this results in a high score of the overall assessment, the lack of information could also indicate that this species poses no threat. The lobster *Homarus americanus* is considered likely to have a substantial impact on the Wadden Sea ecosystem, mainly because it is a long lived predator that could cause competition with native predators. The bivalve species *Ruditapes philippinarum* is also likely to cause competition, in this case with other filter feeders.

Table 12: Overall assessment of the risk that non-indigenous species that are introduced with the mussel imports from Norway into the Wadden Sea, will have substantial impact on the Wadden Sea ecosystem. The overall judgment is the maximum (worst case) of the independent score based on literature data and expert judgment. Score: 1 very unlikely/certainly not; 2 unlikely; 3 likely; 4 very likely; 5 certain.

Taxon. Group	**Target species**	**Literature assessment**	**Expert judgment**	**Overall assessment**
Algae	*Aglaothamnion halliae*	2.0	1.9	2.0
	C. fragile ssp *scandinavicum*	3.0	2.5	3.0
	Fucus evanescens	0.8	2.3	2.3
	Verrucophora farcimen	4.0	3.4	4.0
	Karlodinium micrum	2.4	2.2	2.4
	Olisthodiscus luteus	4.0	2.4	4.0
Polychaeta	*Scolelepis korsuni*	5.0	2.0	5.0
Cirrepedia	*Lepas anatifera*	0.8	1.5	1.5
Malacostraca	*Homarus americanus*	3.2	1.7	3.2
	Paralithodes camtschaticus	0.8	1.3	1.3
	Chionoecetes opilio	0.6	1.1	1.1
Bivalva	*Ruditapes philippinarum*	3.2	2.5	3.2
Platyhelminthes	*Pseudodactylogyrus bini*	0.4	1.8	1.8

5.6 Uncertainties

5.6.1 Identification of target species

The target species for this study were identified by comparison of the lists of reported exotic non-indigenous marine and brackish species from Norway with that of the Wadden Sea. It can not be excluded that more species are present at these locations without being observed. This could on one hand mean that more exotic species can be transferred with mussels to the Wadden Sea in which case the risk is under estimated. On the other hand it is possible that species that are assumed absent in the Wadden Sea are actually already there. This will lead to an over-estimation of the risk.

Moreover, it must be clear that the introduction of non-indigenous species is a dynamic non-stop process, while the species list describes only a snapshot of recent situation. New exotic species are discovered regularly in European waters, some even being new to science. On bases of this knowledge, (Streftaris *et al.*, 2005) conclude that the numbers of non indigenous species across European seas remains an underestimate.

As described in paragraph 5.2, exotic species that are not reported as inhabitants in the Wadden Sea, but are known to be present in the Dutch coastal waters, were not identified as target species for this study. For species already established in the Netherlands, the influence of mussel transfer from Norway is considered of little significance. If the Wadden Sea forms a suitable habitat for these species, it will just be a matter of time when this area will be colonized by the populations already present in the Netherlands. It can however not be excluded that this process will be accelerated due to mussel transfers.

5.6.2 Potential for establishment of self-sustaining populations

The assessment of the potential of the target species to establish a self-sustaining population was hampered by the lack of knowledge about the ecology and physiology of some of the species (i.e. *Scolelepis korsuni, Aglaothamnion halliae* and *Codium fragile ssp scandinavicum*). Due to the precautionary principle that a lack of information would result in a worst-case assessment, this has probably lead to an overestimation of the probability that the introduced species will become permanently established in the Wadden Sea.

Insight in the physiological and ecological characteristics of specific species can increase the certainty about the probability that a species will be able to invade a new environment. From that point of view life history based risk assessments are considered useful (Hewitt and Hayes, 2002). However, the number of factors that have to be taken into account to assess the probability of a species to be able to invade a region are enormous, and it is recognized that it is impossible to exactly predict which organism will survive and establish in new habitats (Gollasch, 2002).

5.6.3 Potential for ecological impact

History shows that not all problems that are caused by invasive species are that simple to predict. It has been estimated that ca. 10% of the introductions will lead to an invasion and that ca. 10% of these invasions will lead to a plague (Van Der Weijden *et al.*, 2005) and sometimes the plague comes as an surprise. The potential that the introduction of exotic species in the Wadden Sea could lead to substantial ecological impact may therefore be underestimated.

It is recommended to verify this assessment with some specific research for these species. With that knowledge it may be possible to take measures to reduce the risk for these species being imported to the Wadden Sea with Norwegian mussels. Of course these measures are only useful if also other potential vectors are restricted. Because the introduction of non-indigenous species in new areas is a continuous process, it will be necessary to monitor the presence of new exotic species in the source areas regularly in order to prevent the transportation of unknown species with mussels.

6 Discussion

The risk of introducing exotic non-invasive species with the import of mussels from rope culture in Norway into the Wadden Sea is evaluated based on literature data and expert judgment. In total 14 target species (exotic species present in Norwegian coastal waters and not observed yet in the Netherlands) have been identified. The species scored with the highest risk is the polychaete *Scolelepsis korsuni*. This species is first recorded near Hordaland and is considered to have a limited distribution in Norway. The reason for the high scores of this species is the limited amount of information that is available for this species. The approach followed in this study is that when information is lacking, worst-case situation is applied. The fact however that information about this species is limiting in literature is an indication that the species is not known as an invasive species and has not lead to problems in other areas. In order to get a more realistic assessment of the risk of this species it is recommended to make a more thorough investigation on the characteristics of this species

Also the American lobster (*Homarus americanus*) and the Manilla clam (*Ruditapes philippinarum*) are identified as potential risk species. The high score is based on the possibility of successful introduction of the larvae with the transport by boats. For both species, however, it is unlikely that they are able to reproduce in Norwegian waters. The observations of American lobsters in Norway were all adult specimens (see section 4.5), most probably escaped from sea storage cages or illegal deliberate releases. Manilla clams were released at six sites during the period 1988-1990. At three of the sites, adult specimens were still present in 1995/1996, but no juvenile specimens were found suggesting that this species is most likely not able to reproduce in Norwegian waters. It is not likely that adult specimens of both species will be introduced with the mussels from the rope culture into the Wadden Sea.

Two micro-algal species were indicated as risk species. The micro-algae can easily be transported with the water when the mussels are transported by from Norway to the Wadden Sea by boat. If the mussels are transported in big-bags they might be transported as cysts. In general the turbid conditions in the Wadden Sea are not very suitable for dinoflagellate species. However, during calm conditions they might be able to develop into blooms. The dinoflaggelate species *Verrucophora farcimen* is a toxic algal species. There are indications that this species is already observed in the Wadden Sea (pers. Comm.. L. Peperzak, NIOZ). In April 2006 a large algal bloom ($>10^7$ cells l^{-1}) was observed, probably *Verrucophora farcimen,* North of Terschelling (pers. comm. R.P.T. Koeman). The flagellate *Olisthodiscus luteus* (synonym *Heterosigma akashiwo*) can develop algal blooms in coastal waters. According to Wolff (2005), *Heterosigma akashiwo* was first found in the Wadden Sea in 1992

Codium fragile ssp *scandinavicum* (green sea fingers) is a green macroalgae that exhibits various modes of reproduction which is a common trait in many invaders It can reproduce sexually, parthenogentically, and vegetatively. Water currents can and will carry this species over long distances introducing it to new locations. *C. fragile* is also tolerant of a variety of salinity and water temperature levels. It also thrives in sheltered habitats, which facilitate human mediated dispersal. The most detrimental effect of *C. fragile* ssp. is the fouling of shellfish beds. At present the distribution of the *Codium fragile* complex in Norway is north of sector 20 (Tromsø and further to the north).

The impact of the other target species addressed in this study are assessed to be low. The algae *Aglaothamnion halliae, Fucus evanescens* and *Karlodinium micrum* are not assumed not to be able to establish and/or lead to substrantial effects within the Wadden Sea. From literature there are no indications that the Goose barnacle (*Lepas anatifera*) has developed into an ecological nuisance. The Red king crab (*Paralithodes camtschaticus*) is only present in the most northern part of Norway. Since it tolerates temperatures from -1.7 – 11 °C it is clear that it will not be able to survive in the relative warm waters of the Wadden Sea. The snow crab (*Chionoecetes opilio*) is also a cold water species. It thrives best at temperatures below 3°C. In Norway it has been observed 2-3 miles from Båtsfjord in the north. The flatworm *Pseudodactylogyrus bini* is a parasite that occurs in brackish and freshwater conditions and is considered not to survive the saline conditions in the Wadden Sea.

The target species defined in this study are the exotic species that are present in the Norwegian coastal waters and have not yet been found in the Netherlands. The list is based on the most up-to-date information available. The exotic species in the Wadden Sea is based on an extensive study of Wolff (2005). Since then new species, such as the ctenophore *Mnemiopsis leidyi*, have been introduced (Faasse and Bayha, 2006). The list of exotic non-indigenous species in Norwegian marine waters are based on the database of the Directorate for Nature management (Norway). Since new species will be introduced into the coastal waters of Norway, the list will be updated regularly and the risk assessment should be updated with the new species.

This study is focused on exotic non-indigenous species that could be introduced by the transfer of mussels into the Wadden Sea. It is assumed that Northeast Atlantic non-indigenous species will not be able to permanently establish themselves into the Wadden Sea. The reason for this is that if the environmental conditions in the Wadden Sea are suitable for theses species, they would have been established already in the past. Since the species from Norway are in general adapted to lower temperatures compared to the temperatures in the Wadden Sea it is not likely that the environmental conditions in the Wadden Sea will improve for these species due to global warming. It is therefore not likely that introduction of Northeast Atlantic non-indigenous species from Norwegian waters will be a risk for the ecosystem of the Wadden Sea.

The imported mussels will come from rope culture in Norway, and not from bottom culture. The species associated with rope culture differ from the species associated with mussel culture. Specific sampling of species associated with the mussel rope culture in Norway was not part of the present study. At this moment consumption mussels from the rope culture in Norway are already transported to Yerseke. We suggest to sample these mussels upon arrival in Yerseke and analyze the associated flora and fauna. At present, this is also done for the mussels from Ireland and UK and results in valuable information on the associated species.

Part of the risks that are identified in this study are caused by the lack of knowledge. This is especially the case for *Scolelepsis korsuni*. Additional detailed literature studies on the identified species is advised in order to reduce the assessed risks.

It should be noted that once introduced, it is apparently impossible to remove it from the system. In some cases the negative effects can be managed. For the proper assessment it is of importance to realize that this study is focused in the introduction of exotic species into the Wadden Sea. As can be seen in paragraph 4.3, also many (non-exotic) pathogens and harmful algae are present in Norwegian waters that could be introduced into the Wadden Sea with the shellfish import.

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8 Referees and Authors

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