Risk analysis on the import of seed mussels from the west coast of Sweden into the Wadden Sea

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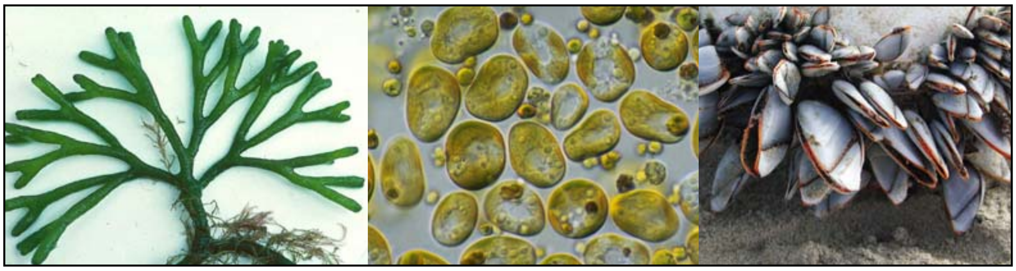

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Contents

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 Sweden 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 Sweden 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 41 exotic non-indigenous species are known for the Swedish coastal waters. Ten 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 Sweden.

For all 10 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 *Verrucophora farcimen* and *Aglaothamnion halliae* and the crustacean *Pilumnus spinifer.* Species with the highest potential impact once introduced are the algal species *Verrucophora farcimen, Oxytoxum criophilum, Pleurosira laevis Codium fragile* and the trematode *Pseudobacciger harengulae.*

The risk assessment indicates the following species as the species with the highest risk: The algae *Dissodinium pseudocalani, Oxytoxum criophilum, Pleurosira laevis, Verrucophora farcimen* and *Codium fragile* and the trematode *Pseudobacciger harengulae*. The dinoflagellate *Dissodinium pseudocalani* is an ectoparasite on copepod eggs. The dinoflagellate *Oxytoxum* can form mucilaginous macroagregates during blooms. *Verrucophora farcimen* is a well known red-tide phytoplankton that is probably already present in the Dutch coastal waters and therefore it is unlikely that it will be successfully introduced by the shellfish transfer. The trematode *Pseudobacciger harengulae* is an parasite on several herring species. It is very likely that this species is also introduced before into the Wadden Sea by the migration of herring.

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 Zweden. 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 Zweden 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 mariene- en kustwateren aan de westkust van Zweden is in het kader van deze studie ook een overzicht gemaakt van de exoten. In totaal zijn er 41 exoten bekend voor de Zweedse mariene- en kustwateren. Deze studie richt zich op de 10 doelsoorten, die zich hebben gevestigd in de Zweedse 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 Zweden, 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 10 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 *Verrucophora farcimen* en *Aglaothamnion halliae* en de krab *Pilumnus spinifer*. Kijkend naar de potentiële impact die de soorten kunnen hebben op het ecosysteem zijn de algen *Verrucophora farcimen, Oxytoxum criophilum, Pleurosira laevis Codium fragile* en de trematode *Pseudobacciger harengulae.* als soorten aangemerkt die mogelijk impact kunnen hebben op het functioneren van het ecosysteem van de Waddenzee.

Uit de studie blijkt dat de algen *Dissodinium pseudocalani, Oxytoxum criophilum, Pleurosira laevis, Verrucophora farcimen* en *Codium fragile* en de trematode *Pseudobacciger harengulae* de meeste risico's te geven. *Dissodinium pseudocalani* is een dinoflagellaat die kan parasiteren op de eieren van copepoden. Tot op heden zijn er geen voorbeelden gevonden in de literatuur waarin drastische effecten van de soort zijn beschreven. De dinoflagellaat *Oxytoxum criophilum* kan bij optimale condities tot massale aggregaties van algen leiden die locaal tot verstikking kunnen leiden. *Verrucophora farcimen* komt zeer waarschijnlijk al voor in de Nederlandse kustwateren. In april 2006 werd ten Noorden 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). De trematode *Pseudobacciger harengulae* is een parasiet van diverse haringsoorten. Deze soort kan zich eenvoudig verspreiden met zijn gastheer. Her is dan ook aannemelijk dat deze soort reeds eerder in de Waddenzee terecht is gekomen met de migratie van de haring. Het feit dat de soort zich niet heeft weten te vestigen is een aanwijzing dat de omgevingscondities in de Waddenzee niet geschikt zijn.

De algemene conclusie van deze risico studie is dat het risico van de introductie van exoten met de import van mosselen uit Zweden 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 Zweedse 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 Sweden to be re-layed on the culture plots in the Dutch part of the Wadden Sea. Sweden 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 Sweden (PRIMUS-Sweden). In this report the results of this study are presented. This study was carried-out parallel to a comparable study (PRIMUS-Norway) on the import of mussels from Norway (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 Sweden 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 along the West coast of Sweden. Also an overview of the practice of mussel farming in Sweden 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 Erik Norin from the Tjärnö Marine Biological Laboratory of the Göteborg University 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) and Johan Craeymeersch and Jan van Dalfsen (IMARES) are thanked for their judgements on the risks. Erik Norin Tjärnö Marine Biological Laboratory of the Göteborg University, gave a clear overview on the mussel practice and the exotic non-indigenous species in along the West coast of Sweden. 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 Swedish coastal waters. 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 west coast of Sweden 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 Swedish coastal waters are also exotic non-indigenous to the Wadden sea. Species that are indigenous to the Swedish coastal waters and non-indigenous to the Wadden sea are called Northeast Atlantic non-indigenous species for the Wadden Sea.

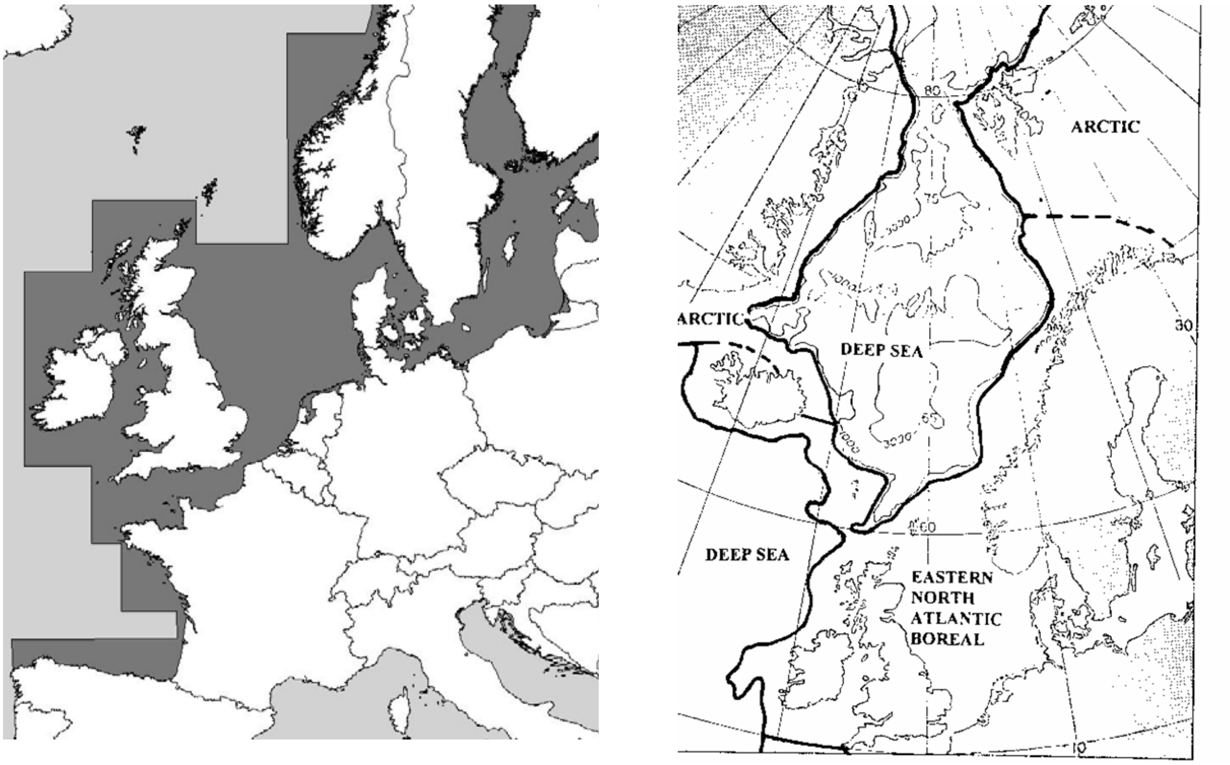

Figure 1: Left hand side: Map indicating Northeast Atlantic Shelf region (dark gray). Figure adapted from Longhurst (1998). Right hand side: Map from Brattegaard and Holthe (1997) indicating the Eastern North Atlantic boreal region.

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.

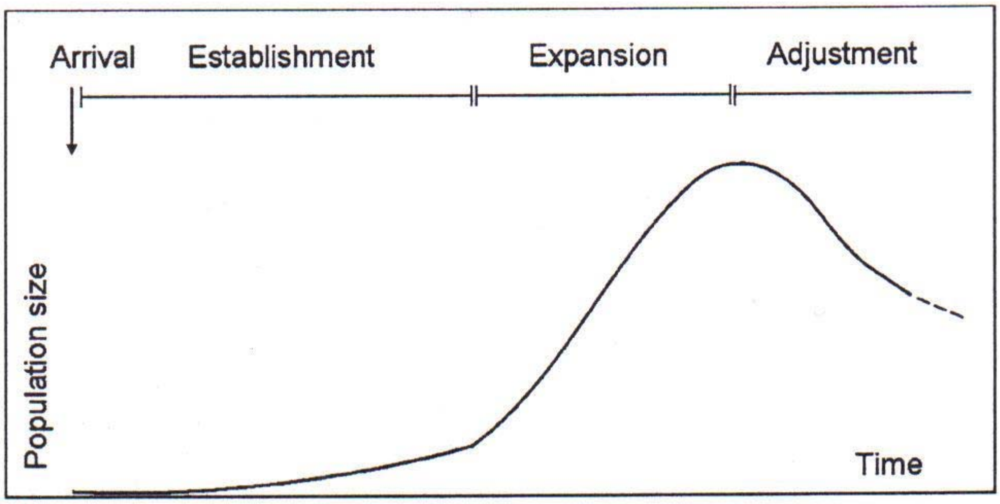

Figure 2: Phases of invasion during the introduction of invasive species. From Reise et al. (2006).

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 subtidal 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).

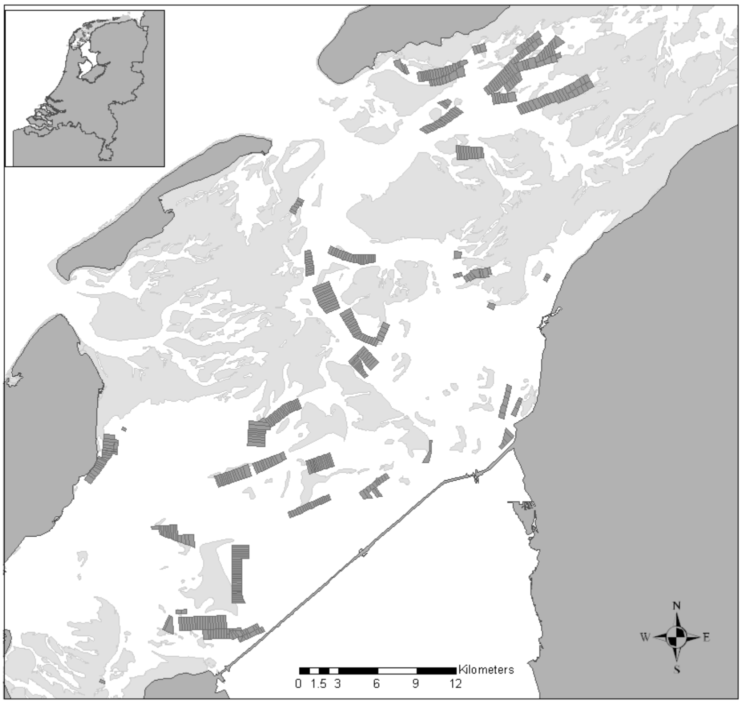

Figure 3: Location of culture plots in the western part of the Dutch part of the Wadden Sea

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 Sweden, as well as Norway, there is often an over production of mussel seed during the summer and autumn (see section 4.2), when the captured mussel seed is graded and sorted in socks. 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 Sweden 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 Sweden to the Dutch part of the Wadden Sea will take approximately one-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 Sweden 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.) at the west coast of Sweden

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4.1 Background

Cultivation of blue mussels is an expansive business at the West Coast of Sweden. Settling of the mussels is extensive. While the settling in the Dutch waters is unpredictable and in many years to low to fulfill the demand, there is interest in importing juvenile mussels from long line cultivations in Sweden and cultivate them on the bottom culture plots in the Wadden Sea. Although transferring of species might result in introducing unwanted associated species into the Wadden Sea. This study ordered by Wageningen IMARES, Dutch Institute for Marine Resources and Ecosystem Studies, list *M. edulis* associated flora and fauna at the West Coast of Sweden, with special interest to the exotic non-indigenous species.

4.2 The mussel industry in Sweden

Today mussel cultivation is by far the most important shellfish cultivation. In fact no other species of shellfish are commercially cultivated. Efforts have been performed on an experimental basis to cultivate lobsters and oysters. An oyster hatchery is now under development at the island of Koster.

Cultivation of blue mussels, *M. edulis* occurs in Sweden since the 1970's. In 1987 the production reached 2500 tonnes. During the end of the 80's DST producing micro algae became a big problem for the industry and many of the smaller production sites were forced to close (Nordlander, 2006). Today the production have recovered and reached 2500-3000 tonnes (Kollberg, personal communication, Aug 2007). Long-line is by far the dominant method of cultivation although harvest of wild mussels also occurs in Sweden (Nordlander, 2006). Harvest of wild mussels is a small business that only a couple fishermen with hand tools perform (Loo, personal communication, Sept 2007). There are permits to cultivate more than 10 000 tonnes within the Västra Götalandsregionen, West Coast of Sweden.

Long-line cultivation is an extensive form of cultivation, where no additional food has to be added. Long-lines are placed in the water prior to settling of the pelagic larvae that usually occurs in the middle of June. A typical cultivation site occupies an area of 0,4 ha and can produce 50 tonnes of consumption mussels year^{-1} (Kollberg, 1999).

The larvae attach to the lines, no relocation of the mussels have to be done during the cultivation cycle. After 14-16 months the mussels have reached a size of 50-60 mm and are ready to harvest (Loo and Rosenberg, 1983). Figure 4 shows a growth curve of mussels in a long-line cultivation. Generally the mussels are not graded and sized, all the mussels on the lines are harvested. The main part of the production is exported; fresh mussels from Swedish cultivations are exported to the Netherlands, Norway, Denmark and France (Syverssen, personal communication, Sept 2007; Kollberg, 1999).

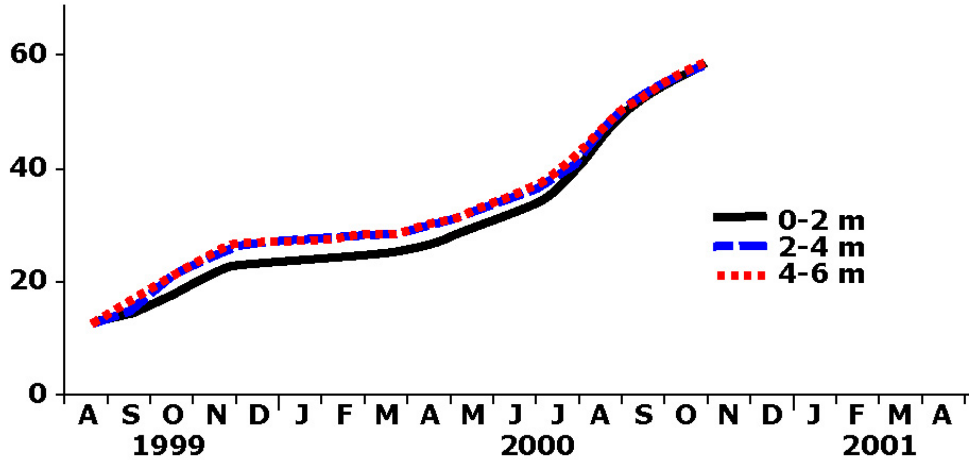

Figure 4: Average shell length (mm) at different depths (0-2 m; 2-4 m and 4-6 m) in a cultivation site at Lysekil between 1999 and 2000 (Petersen and Loo, In prep).

It is an advantage to the farmers when juvenile mussels can be exported before the age of one year. This would make it possible to reuse the rig with new ropes the next coming year. Mussel farmers have revealed a great interest in exporting juvenile mussels, at the moment the amount of juvenile mussels that can be produced and exported to the Netherlands depends on how much investments done for this purpose. There are possibilities to export at least 10 000 tonnes of juvenile mussels from Sweden (Loo, personal communication, Sept 2007). Large scale cultivation of mussels in Sweden has been discussed as a new and sustainable action of ecological food production for a long time. With cultivation of mussels no additional food is needed and by harvesting the mussels, nutrients recycles from sea to land while eutrophication decreases. The intervention plan against eutrophication within the Västra Götaland county administrative board states that the nitrogen load into the coast waters should decrease with 2750 tonnes year^{-1} at 2011. It has been calculated that 20% of this amount or 500 tonnes, can be displaced by cultivation of blue mussels with a yearly harvest of 50 000 tonnes. There has earlier been a lack in means of control and encouragement to the farmers, who have not got any compensation for their environmental work. Emission trade with nutrients has therefore been developed as a tool and a mean of control against eutrophication. The municipality of Lysekil is the first to have an agreement of nutrient emission with a cultivation company. Instead of upgrading their sewage plant for nitrogen treatment the cultivation company is paid to cultivate mussels. The cultivation of mussels corresponds to a nitrogen uptake of 100% of the emissions. This makes the effort in Lysekil unique though the requirement of sewage plant of this size is a nitrogen uptake of 70%. Additionally compensation cultivation is a cheaper solution (Lindahl, 2005). The cultivation industry in Sweden seems to be an expanding business but as the domestic market for mussel products is small, an expansion of the industry depends on successful exports (Lindahl et al., 2005).

4.2.1 Mussel production along the West Coast of Sweden.

Operators of mussel industry in Sweden are limited with only 16 companies or persons with licences to cultivate mussels, most of the licenses are unutilized. The industry is concentrated within the areas of Orust and Lysekil. Scanfjord AB and Nordic shell production are the two companies responsible for the most of the production. Other operators are; Orust Shellfish, Tjärnö Vattenbruk, e.g. Figure 5 shows a map of the present cultivation sites for mussels at the Swedish West Coast, some changes may have occurred since the map was made but in general it's correct.

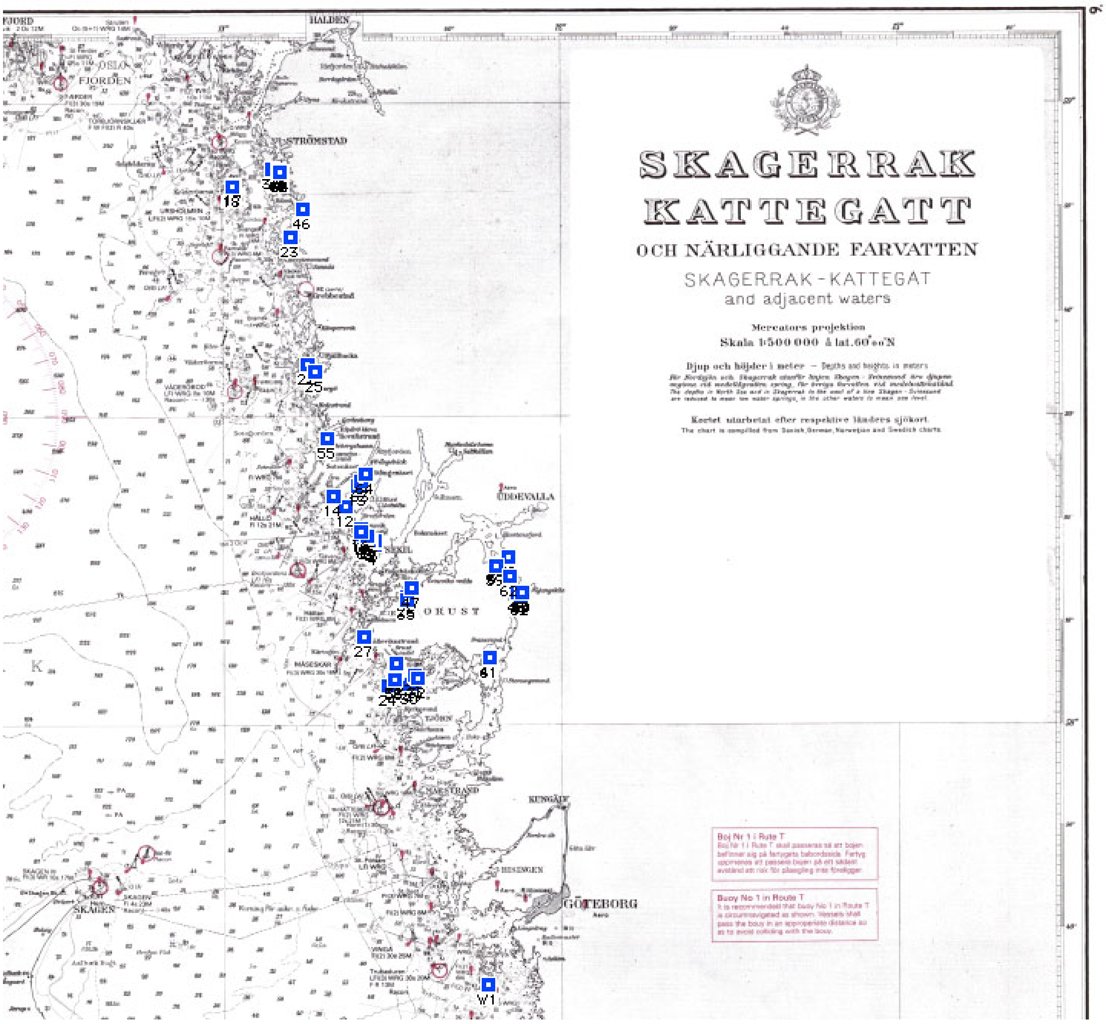

Figure 5: Map of the Swedish West Coast. Blue squares represent cultivation sites active between 2005 and 2007.

4.3 Flora and fauna associated with mussels

4.3.1 Habitats for mussels

There are three types of habitats where blue mussel are found at the Swedish West Coast, rocky habitats, blue mussel beds (shells on soft bottom), and cultivation sites. Mapping and inventory of the natural blue mussel beds are the focus of many studies (e.g. Haamer, 1999; Magnusson et al., 2003), but only few studies contains lists of associated species at the West Coast of Sweden. Associated flora and fauna have mostly been studied in blue mussel beds, because of their ecological importance. Associated flora and fauna of the cultivation ropes have rarely been investigated. And only few studies have been performed on rocky habitats. The data from mussel beds and rocky shore habitats are presented in section 4.3.2 and flora and fauna on cultivation ropes are presented in section 4.3.3.

4.3.2 Data on flora and fauna naturally occurring within the mussel production areas

Generally it is not allowed to fish mussels from the natural blue mussel beds in Sweden, although there is a possibility to apply for exemption at the Swedish board of fishery, the county administrative board also has to give its opinion. Scraping for mussels is a very small business compared to long-line cultivation in Sweden. Only a few fishermen with hand tools practise it (Loo, personal communication Sept 2007).

In the Internet based teaching media Aquascope (www.vattenkikaren.gu.se) the biodiversity associated with the natural blue mussel beds at the West Coast of Sweden are described. In Table 2, an overview is given on the flora and fauna that is associated to the blue mussel beds.

Table 2: Flora and fauna associated with natural mussel beds along the West coast of Sweden (www.vattenkikaren.gu.se). Exotic non-indigenous species are indicated by *

Macro algae

Clorophyta
- *Cladophora rupestris*
- *Codium fragile*
- *Enteromorpha intestinalis*
- *Monostroma grevillei*
- *Ulva lactuca*

Phaeophyta
- *Ascophyllum nodosum*
- *Chorda filum*
- *Desmarestia aculeata*
- *Fucus serratus*
- *Fucus spiralis*
- *Fucus vesiculosus*
- *Halidrys siliquosa*
- *Laminaria digitata*
- *Laminaria saccharina*

Rhodophyta
- *Ceramium rubrum*
- *Chondrus crispus*
- *Corallina officinalis*
- *Delesseria sanguinea*
- *Furcellaria lumbricalis*
- *Hildenbrandia rubra*
- *Lithothamnion glaciale*
- *Phymatolithon lenormandii*
- *Phymatolithon purpureum*
- *Polysiphonia* sp.

Macro fauna

Porifera
- *Clionidae*
- *Halichondria panicea*

Cnidaria
- *Anthomedusae*
- *Aurelia aurita*
- *Chrysaora hysoscella*
- *Clava multicornis*
- *Cyanea capillata*
- *Cyanea lamarckii*
- *Dynamena pumila*
- *Leptomedusae*
- *Metridium senile*
- *Rhizostoma octopus*
- *Sagartiogeton viduatus*
- *Tubularia larynx*
- *Urticina felina*

Ctenophora
- *Beroe* sp.
- *Pleurobrachia pileus*

Polychaeta
- *Hediste diversicolor*
- *Pomatoceros triqueter*
- *Spirorbis spirorbis*

Mollusca
- *Aeolidiella sp.*
- *Cerastoderma edule*
- *Cerastoderma lamarcki*
- *Gibbula cineraria*
- *Hiatella* sp.
- *Littorina fabalis*
- *Littorina littorea*
- *Littorina obtusata*
- *Littorina saxatilis*
- *Mya arenaria*
- *Nucella lapillus*
- *Ostrea edulis*

Polyplacophora
- *Testudinalia testudinalis*

Crustacea
- *Balanus crenatus*
- *Balanus improvisus*
- *Carcinus maenas*
- *Gammarus locusta*
- *Idotea baltica*
- *Idotea granulosa*
- *Mysidacida* sp.
- *Pagurus bernhardus*
- *Palaemon adspersus*
- *Palaemon elegans*
- *Semibalanus balanoides*
- *Ammodytidae* sp.

Bryozoa
- *Membranipora membranacea*
- *Electra pilosa*

Echinodermata
- *Asterias rubens*
- *Psammechinus miliaris*

Chordata
- *Clavelina lepadiformis*
- *Ciona intestinalis*
- *Dendrodoa grossularia*

Vertebrata
- *Ctenolabrus rupestris*
- *Gasterosteus aculeatus*
- *Syngnathus typhle*

In order to separate the effects of structure and biology of *M. edulis* on associated fauna a manipulative field experiment was performed at Vanarna, close to Tjärnö (Pettersson, 2006). Shells of *M. edulis* were compared with cleaned mussels. After three months of colonisation both "Shells" and "Cleaned" had similar numbers of associated species, although the species composition of the two groups differed (Pettersson, 2006).
Table 3 shows all the macro algae and macro fauna species found associated to *M. edulis* in the study. The dominating groups in all patches were Crustacea, Gastropoda and Polychaeta. Although no *Fucus evanescens** was found in the study it often grow attached to the shells of blue mussels (Wikström, 2004).

Table 3: Flora and fauna associated with the natural mussel bed vanarna, close to Tjärnö (Pettersson, 2006). Exotic non-indigenous species are indicated by *

Macro algae	**Gastropoda**
Clorophyta	*Bittium reticulatum*
Cladophora rupestris	*Nassarius reticulatus*
Ulva intestinalis	*Hydrobia sp.*
Ulva sp.	*Littorina littorea*
Phaeophyta	*Lepidochitona cinerea*
Chorda filum	*Rissoa* sp.
Ectocarpus siliculosus	**Bivalvia**
Elachista fucicola	*Cerastoderma edulis*
Fucus vesiculosus	*Modiolus modiolus*
Fucus juv.	*Mya arenaria* *
Saragassum muticum *	**Crustacea**
Spermatochnus paradoxus	*Athhanas nitescens*
Sphacelaria cirrosa	*Balanus improvisus* *
Pilayella littoralis	*Carcinus maenas*
Ralfsia sp.	*Corophium volutator*
Rhodophyta	*Crangon crangon*
Osmundea truncata	*Microdeutopus gryllotalpa*
Polysiphonia fucoides	*Amphipoda* juv.
Ceramium nodulosum	*Palaemon elegans*
Ceramium tenuicorne	*Callipius rathein*
Chondrus crispus	**Bryozoa**
Corallina officinalis	*Cryptosula pallasiana*
Hildenbrandia sp.	**Echinodermata**
Phymatolithon lenormandii	*Asterioidae*
Macro fauna	*Psammechinus miliaris*
Cnidaria	**Chordata**
Metridium senile	*Ascidia conchilega*
Oligochaeta	**Vertebrata**
Tubificoides sp.	*Pomatoschistus minutes*
Polychaeta	**Insecta**
Eualia viridis	*Chironomide* sp.
Phyllodocidae	*Insecta* sp.
Nereimyra punctata	
Nereidae	
Hamothoe imbricata	
Polydora ciliata	
Spirobis spirobis	
Polychaeta sp.	

Kostylev (1996) studied mussel community structure on three islands in Swedish rocky shore habitats close to Tjärnö. The variation in associated fauna in different mussel patches within the same island, in comparison to differences in communities inhabiting different islands was investigated. The associated fauna of the pooled sites found in this study are shown in Table 4.

Table 4: *M. edulis* associated fauna from rocky shore habitats at islands close to Tjärnö (Kostylev, 1996). No exotic non-indigenous species were found.

Hyale pontica	*Echinoogammarus stoerensis*
Semibalanus balanoides	*Rissoa* sp.
Odostomia scalaris	*Nucella lapillus*
Rissoa parva	*Phyllodoce* sp.
Littorina saxatilis	*Asterias rubens*
Oligochaeta sp.	*Hydrobia ulvae*
Nematoda sp.	*Lacuna parva*
Parajassa pelagica	*Onoba semicostata*
Jaera albifrons	*Eualia viridis*
Idotea viridis	*Idotea grannulosa*
Hiatella sp.	*Leptochiton asellus*
Nereis pelagica	*Littorina littorea*
Bittium reticulatum	*Sipunculidae* sp.
Emplectonema gracile	*Veneride* sp.

4.3.3 Data on flora and fauna associated with the mussel seeds on the ropes

The settling of *M. edulis* at the west coast of Sweden usually occurs in the middle of June but varies with temperature. Other animals with similar growth and reproduction compete with the mussel for a place to attach to on the ropes. As a result, the success of settling varies from year to year.
This differences in settling and fouling can be caused by different amount of pelagic larvae and competition, but also by predation by common eider and sea stars (Kollberg, 1999). During the first year there is almost no fouling of mussel shells by animals and algae due to the mussel's ability to use their foot for cleaning their own shell. When this ability decreases as the mussels grow larger barnacles and polychaetes can establish on the shells, but they are probably no effective competitors to the mussels. Fouling in the cultivations is expected to increase with the age of the mussels and fouling in older cultivation sites is thereby more abundant (Rosenberg, 1983).

The cluster of mussels constitutes an ecosystem on its own, an artificial hard bottom habitat. Except mussels amphipods, tunicates, sponges and barnacles have been observed in cultivations (Haamer, 1977).
Loo and Rosenberg (1983) described abundance, biomass, growth and production in a long-line cultivation site at Tjärnö, Sweden. The abundance of associated species increased with time. The age of the cultivation site was 17 months when the last samples were taken. The dominating species excluding *M. edulis* were *Ciona intestinalis* (L), *Balanus improvisus* (Darwin), *Pomatoceros triqueter* (L) and *Microdeutopus* spp. *Balanus* was most abundant at 0-2 meters depth, *Ciona* was most abundant at 2-4m the first year of the study and 4-6m at the second year. *Pomatoceros* had its highest density at 4-6m.

A more recent study, which deals with associated flora and fauna in cultivation sites, was performed as a Master thesis project at Kristineberg Marine Research Station, near Lysekil (Müller, 2007). The aim of this study was to compare a sheltered long-line cultivation with a more exposed in the aspect of the nutritional value in associated fauna. The mussels in the cultivation sites had grown for 15 months. The associated species found on the ropes these two studies are presented in Table 5.

Table 5: Flora and fauna associated with rope culture in Tjärnö and Lysekil, Sweden. Data from Loo and Rosenberg (1983) and Müller (2007), Exotic non-indigenous species are indicated by *.

Bryozoa	**Crustacea**
Bryozoa in det.	*Amphipoda-Gammaridea sp.*
Cryptosula pallasiana	*Amphipoda-Jassidae*
Cnidaria	*Athamas nitescens*
Electra pilosa	*Balanus improvisus**
Hexacorralina	*Caprellidae*
Hydroida, in det *Anomia* sp.	*Carcinus maenas*
Metridium senile	*Corophium insidiosum*
Sagartiidae	*Dexamine spinosa*
Echinodermata	*Ericthonius*
Asteroidea-Asteria rubens	*Eucardia-Carcinus maens*
Echinoida, in det.	*Gammarus locusta*
Echinoidea-Psammechinus militaris	*Macropodia rostrata*
Psammechinus miliaris	*Microdeutopus* sp.
Polychaeta	*Ostracoda,* in det.
Cryptocelides loveni	*Palaemon elegans*
Hesionidae	**Rhodophyta**
Nereidae	*Polysiphonia* sp.
Platyhelmintes,Turbellaria	**Chordata**
Polychaeta, in det.	*Ascidiacea*
Polynoidae	*Ascidiella aspersa*
Pomatoceros triqueter	*Ascidiella scabra*
Mollusca	*Ascidiella* sp.
Aplysidae-Aplysia punctata	*Ciona intestinalis*
Bittium reticulatum	*Corella parallelogramma*
Cardium sp.	**Insecta**
Hiathella artica	*Dipteria* larvae, in det.
Musculus discors	
Nucula nitidosa	
Nucula sp.	
Rissoa sp.	

4.4 Exotic non-indigenous species along the West coast of Sweden

The website, www.frammandearter.se, is a joint information channel for the three regional information offices along the Swedish coast: the Skagerrak/Kattegat area on the Swedish West Coast, the Baltic Sea proper, and the Gulf of Bothnia. The site presents a list of exotic species in Sweden. This is the most extensive and updated list of alien species in Swedish waters today. The list includes scientific names as well as common names and risk species likely to spread to Swedish waters. Species already appearing at the West Coast from this list are presented in Table 6. Potentially, these species can be imported with the import of mussels into the Wadden Sea. However, the chance of introducing these species is depending on the abundance on the rope culture and the ability to survive the transport and local conditions in the Wadden Sea. The Pacific oyster *Crassostrea gigas* has newly been found in Sweden. It seems like it thrives at shallow blue mussel beds but no settling on the long-lines has been reported.

Table 6: Overview of exotic non-indigenous species along the Swedish west coast (www.frammandearter.se).

Phytoplankton	**Invertebrates**
Micro algae	**Cnidarians**
Dinoflagellates	*Cordylophora caspia*
Alexandrium angustitabulatum	*Gonionemus vertens*
Alexandrium minutum	**Crustaceans**
Dicroerisma psilonereiella	**Barnacles**
Dissodinium pseudocalani	*Balanus improvisus*
Gyrodinium corallinum	**Copepods**
Karenia mikimotoi	*Acartia tonsa*
Oxytoxum criophilum	**Crabs**
Prorocentrum minimum	*Eriocheir sinensis*
Diatoms and silicoiflagellates	*Pilumnus spinifer*
Coscinodiscus wailesii	**Ctenophora**
Odontella sinensis	*Mnemiopsis leidyi*
Thalassiosira punctigera	**Molluscs**
Verrucophora cf*. fascima*	**Bivalves**
Brown algae	*Crassostrea gigas*
Colpomenia peregrina	*Ensis directus*
Fucus evanescens	*Mya arenaria*
Sargassum muticum	*Petricola pholadiformis*
Green algae	*Teredo navalis*
Codium fragile ssp*. scandinavicum*	**Snails**
Codium fragile ssp*. tomentosoides*	*Crepidula fornicata*
Red algae	*Potamopyrgus antipodarum*
Aglaothamnion halliae	**Worms**
Bonnemaisonia hamifera	**Nematodes**
Dasya baillouviana	*Anguillicola crassus*
Gracilaria vermiculophylla	**Trematodes**
Heterosiphonia japonica	*Pseudobacciger harengulae*
Neosiphonia harveyi	**Fish**
	Oncorhynchus mykiss
	Mammals
	Mustela vison

4.5 Health conditions

4.5.1 Harmful algae

In Sweden, the annual occurrence of the diarrheic shellfish toxins, DST, in blue mussels *M. edulis*, is the largest impediment to a further development of the mussel industry (Kollberg, 1999). Farmers may have to stop deliveries for up to six months a year due to elevated levels of toxins accumulated in the mussels (Lindegarth, 1997).

Diarrheic shellfish toxins such as okadaic acid, OA, and Dinophysistoxin-1, DTX-1, have occurred regularly in blue mussels, *M. edulis*, at the Swedish west coast during the past years. The occurrence of *Dinophysis acuta* and *Dinophysis acuminata* has been linked to the toxic indices in the region. There are both seasonal and regional differences in DST concentrations. The concentration in mussel meat is generally high, >160µg kg^{-1} mussel meat, from October to December and low concentration, <160µg kg^{-1} mussel meat, from March to August. Peaks above the limit have however occurred in June and July (Karlsson et al., 2007). In Swedish waters several species of *Alexandrium* occur; *A. tamarense*, *A. minutum*, *A. pseudogonyaulax*, and *A. ostefeldii* (Karlsson et al., 2007).

Up to now, no cases of Paralytic Shellfish Poisoning (PSP) have occurred in Sweden, the occurrence of PST in Swedish mussels is however rarely investigated (Lindegarth, 2007). Only sporadic tests have been conducted in April to May which is generally the period when PST producing algae bloom in the area. Concentrations above the limit of sale have been detected at 5 times during 1988-2002 (Karlson and Rehnstam-Holm, 2002).

A recent project, between 2005 and 2007, which aimed to increase the knowledge of the occurrence of PST, showed Paralytic Shellfish Toxins (PST) occurs along the Swedish West Coast generally from February until June. The report from the project further states that this period should be considered as the risk period of PST. Overall *A. tamarense* was the species contributing most to the mussel toxicity even though *A. ostenfeldii* also contributed to the toxicity. There was a lack of correlation between toxin content in the mussels and the cells of *Alexandrium* in the water. Therefore a negative *Alexandrium* count should not be considered as a reliable test for stating the PST status of the mussels. There was a great variation between mussels in PST levels. Hence the numbers of mussels should in a PST test not be less than 15 (Lindegarth, 2007).

Cyst forming species

A study of the occurrence of dinoflagellates cysts in sediments at the West Coast of Sweden was performed by Persson et al. (2000). Nine of the species found had not been reported from Sweden before: *Diplopelta parva*, *D. symmetrica*, *Diplopsalopsis latipeltata*, *Diplopsalis lebourae*, *Protoperidinium americanum*, *P. avellana*, *P. divaricatum*, *P. nudum* and *P. stellatum*. All the species found are listed in Table 7.

Table 7: Cysts of dinoflagellates found in sediments at West coast of Sweden (Persson et al., 2000). Exotic non-indigenous species are indicated by *

Alexandrium minutum *	*Diplopsalis lebourae*
Alexandrium tamarense	*Diplopsalis lenticula*
Alexandrium spp.	*Diplopsalopsis latipeltata*
Gonyaulax digitale	*Diplopsalopsis orbicularis*
Gonyaulax scrippsae	*Zygabikodinium lenticulatum*
Gonyaulax spinifera	*Protoperidinium americanum*
Bitectatodinium tepikiense	*Protoperidinium avellana*
Spiniferites elongatus	*Protoperidinium claudicans*
Spiniferites membranaceus	*Protoperidinium conicoides*
Spiniferites mirabilis	*Protoperidinium conicum*
Spiniferites pachydermus	*Protoperidinium divaricatum*
Spiniferites ramosus	*Protoperidinium excentricum*
Spiniferites, unidentified	*Protoperidinium leonis*
Gonyaulax verior	*Protoperidinium minutum*
Lingulodinium polyedrum	*Protoperidinium nudum*
Protoceratium reticulatum	*Protoperidinium oblongum*
Pentapharsodinium dalei	*Protoperidinium pentagonum*
Scrippsiella trochoidea	*Brigantedinium majusculum*
Scrippsiella cf. *lachrymosa*	*Trinovantedinium capitatum*
Gymnodinium nolleri	*Protoperidinium punctulatum*
Polykrikos schwartzii	*Protoperidinium stellatum*
Diplopelta parva	*Protoperidinium subinerme*
Diplopelta symmetrica	

A larger part of the cysts found in the study remained unidentified when mounted on slides, since they could not be picked for germination experiments nor turned around to get the archeopyle in better position for identification.

4.5.2 Parasites

A common parasite of *M. edulis* in Swedish waters is the trematode *Renicola roscovita* (Granovitch and Johannesson, 2000). Svärdh and Thulin (1985) investigated the parasite fauna of blue mussels at the Swedish West Coast. Mussels from mussel farms at two locations were compared with two natural populations in the nearness to the farms. One of the farm locations were at Tjärnö and the other at the island of Vrångö, 180 km southward. The parasite fauna of the farmed mussels was identical between the populations. *Myticola intestinalis* was not found. *Modicola* sp. and small unidentified nematodes and cilliates were found in mussels from all localities. Both natural populations were infected by the trematod *Renicola roscovita* to the extent of 96 resp. 100%. Whereas 12 resp. 4% of the farmed mussels were infected. The differences are explained by the unfavorable habitat in the farm for the life cycle of the parasite.

To this day no occurrences of the oyster parasites *Bonamia* and *Marteilia* have been reported in Sweden. *Marteilia* is a parasite that can also infect blue mussels (OIE, 2003). There are ongoing discussions to start a control program for the two parasites, to declare that the Swedish waters are free of *Bonamia* and *Marteilia* (Valero, personal communication, Sept 2007).

4.5.3 Bacteria and viruses

Escherichia coli, which often is used as an indicator for fecal contamination, is common in mussels, few strains are pathogenic to humans but they are probably very unusual in mussels (Nordlander, 2006).
Rehnstam-Holm and Hernroth (2005), describes public health associated to shellfish consumption in Sweden. Bacterial infections associated to shellfish consumption listed were: *Salmonella typhimurium*, *Vibrio parahaemolyticus*, *Vibrio vulnificus*, *Vibrio cholera* and viral infections listed were: Hepatitis A, Norovirus, also referred to as calcivirus or Norwalk-like viruses, and Adenovirus, the serotypes 40 and 41.

In Sweden annually around 400-100 salmonella infections are reported, the transmission associated to bivalve consumption has the potential to increase, virulent strains of *S. typhimurium* could multiply in the blood circulation system of mussels at favorable temperatures. *Vibrio* generally occurs in warmer waters, *V. cholera* also exists at southern part of Sweden were temperature and salinity fits its demand. *V. parahaemolyticus* intoxications are rare and only two outbreaks have been reported in Sweden, one associated to imported crayfish and the other of unknown origin. *V. vulnificus* exist in low levels in Scandinavian seawater, marine sediment and, shellfish and wild fish (Nordlander, 2006; Rehnstam-Holm and Hernroth, 2005). Hepatitis A, HAV viruses is the most serious virus infection linked to consumption of bivalves. In 1955, 629 cases of HAV infections were linked to consumption of raw oysters in Sweden. HAV is nowadays not endemic to Sweden and was not found in a study of cultivated mussel during 18 months, Norovirus were frequently found in all sampling sites. Infections of Noroviruses seem to occur more frequent in the winter and are thus called "The winter vomiting disease" (Hernroth et al., 2002). Adenoviruses, mostly affects children and outbreaks associated to shellfish consumption are therefore unusual.

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 Sweden. Roughly this risk assessment is divided in tree steps (Figure 6).

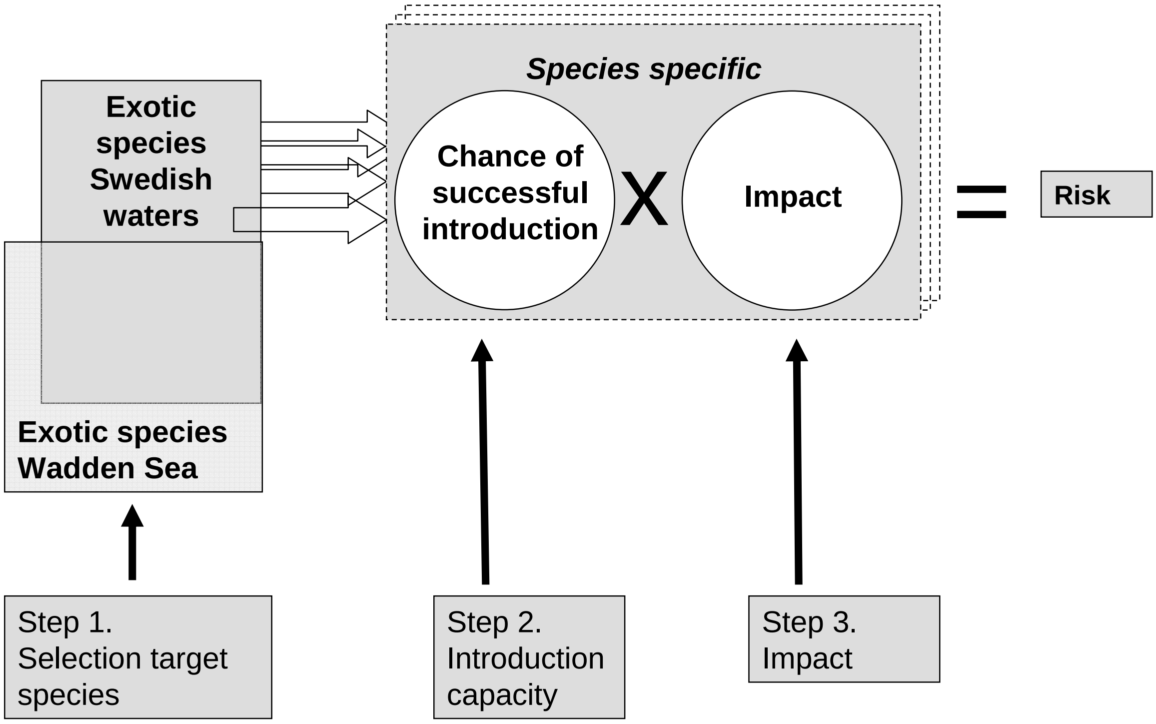

Figure 6: Overview of the set-up of the risk analysis.

In the first step, the target species are identified. Target species are exotic species that can be found in the Swedish 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 Sweden 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 Sweden 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. 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.

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 (Swedish 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 8).

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

	Exotic non-indigenous species		
	A	B	C
Present in Swedish 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 Sweden is of little significance. This is the case for the algae *Heterosigma japonica*, which have become permanently established in the Netherlands (Wolff, 2005), although they are not yet reported as inhabitants of the Wadden Sea. It can also not be excluded that these species are already present in the Wadden Sea but have not yet been reported. 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

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

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 Faasse & Bayha (2006). The crustacean *Acartia tonsa* is already established in brackish waters of the Netherlands and can be expected to be present in the Wadden Sea by now (pers. comm. Prof. W.J. Wolff). *Undaria pinnatifida*, a brown algae, is present in the Dutch estuary 'Oosterschelde' (Wolff, 2005). The red macroalgae *Gracilaria vermiculophylla* was first recorded in Sweden during August-September 2003. *Gracilaria vermiculophylla* was found in the Netherlands in the late 1990s in the Brackish lake Oostvoorne. In the early 2000s *G. vermiculophylla* spread to several countries on the North Sea coast (ICES, 2006). At the moment it is very abundant in the German Wadden Sea and apparently spreading into the Dutch Wadden Sea (pers. comm.. H. Stegenga). According to ICES (2006) and the Swedish factsheet (source: http://www.frammandearter.se/) it is already present in the Netherlands.

The exotic species list from Sweden contains two *Alexandrium* species: *A. minutum* and *A. angustitabulatum*. However, these planktonic algae species are possibly conspecific (pers. comm. R. Leewis). According to Gómez (2005) the correct name of the species is *Alexandrium minutum.* Four species are assigned to the *Alexandrium minutum* group: *A. minutum, A. lusitanicum, A. angustitabulatum* and *A. andersonii*. Lilly *et al*. (2005) studied the species boundaries within the *Alexandrium minutum* group. They found that the morphospecies *A. angustitabulatum* was not morphologically recoverable. DNA analyses also fail to recognize these species. It was recommended that all isolates previously designated as *A. angustitabulatum* be redesignated as *A. minutum*. Therefore, only *Alexandrium minutum* is selected for this risk assessment. In Europe, *A. minutum* is slowly spread from France through Ireland, England, and Denmark. Wallentinus (2002) and FAO (2004) report that *A. minutum* is already present in the Netherlands. The planktonic algae *A. minutum* is already present in the southern part of the North Sea and could easily reach the Wadden Sea by natural transport. The chance of introducing *A. minutum* by natural transport is considered higher than by mussel transfer (pers. comm. L. Peperzak, NIOZ). It has been suggested that human transport, natural current patterns, nutrient loading from coastal eutrophication and aquaculture contribute to the apparent expansion in bloom frequency and toxicity (Lilly *et al.*, 2005).

Dicroerisma psilonereiella has been found in Sweden since 1997 and is known from Kamchatka and British Columbia. It is a relatively rare species, but quite easy to recognize with the internal skeleton (ICES, 2006). *Dicroerisma psilonereiella* has also been observed in the North Sea in March and December 2004, around the Island of Terschelling (Brochard *et al.*, 2006).

Table 9: Exotic non-indigenous estuarine and marine species that have become established in Sweden 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	*Bonnemaisonia hamifera*	Not established, only found washed ashore in The Netherlands [1]
	Heterosiphonia japonica	Present in The Netherlands but not established in the Wadden Sea [1]
	Dasysiphonia sp.	
	Prorocentrum minimum	Present in the Netherlands [2]
	Gracilaria vermiculophylla	Present in the Netherlands [4]
	Alexandrium minutum	Present in the Netherlands [5]
	Dicroerisma psilonereiella	Present in the Netherlands [6]
Crustacean	*Acartia tonsa*	Present in the Netherlands [1]
Ctenophora	*Mnemiopsis leidyi*	Present in The Netherlands [3]

1 Wolff (2005); 2 Peperzak (2003); 3 Faasse & Bayha (2006); 4 ICES (2006); 5 Wallentinus (2002) and FAO (2004); 6 Brochard *et al.* (2006)

The final list of target species contains 10 species (Table 10). These are the exotic species that can be found in the Swedish 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 can not be excluded 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.

Table 10: Selected target species: Exotic non-indigenous estuarine and marine species that have become established in Sweden and are not yet observed in the Wadden Sea.

Taxonomic group	Species name
Algae	
Dinoflagellates	*Dissodinium pseudocalani*
	Gyrodinium corallinum
	Oxytoxum criophilum
Diatoms and silicoflagellates	*Pleurosira laevis f. polymorpha*
	Verrucophora cf. fascima
Brown algae	*Fucus evanescens*
Green algae	*Codium fragile* ssp. *scandinavicum*
Red algae	*Aglaothamnion halliae*
Crustaceans	
Crabs	*Pilumnus spinifer*
Worms	
Trematodes	*Pseudobacciger harengulae*

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 Sweden 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 mussel 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 of 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 continuously fresh water.

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 11).

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 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 11: 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**
Dissodinium pseudocalani	5	5	5
Gyrodinium corallinum	5	5	5
Oxytoxum criophilum	5	5	5
Pleurosira laevis f. polymorpha	5	2	2
Verrucophora cf. fascima	5	5	5
Fucus evanescens	5	2	2
Codium fragile ssp. *scandinavicum*	5	5	5
Aglaothamnion halliae	5	5	5
Pilumnus spinifer	5	5	5
Pseudobacciger harengulae	5	5	5

Dissodinium pseudocalani

The flagellate species *Dissodinium pseudocalani* feeds upon the eggs of the copepod *Pseudocalanus elongatus* of which it is an ectoparasite. Besides an invasive species of the Swedish seas, it is found in the German Bay of the North Sea and in the North of Scotland (Hansson, 1997). *D. pseudocalani* is probably also present in the Dutch part of the North Sea (pers. comm. R. Koeman). It is therefore considered ‘certain’ that this species will establish in the Wadden Sea (score 5).

Gyrodinium corallinum
Within Europe, *G. corallinum* is only found established in Sweden since 1997 and has probably been introduced by ballast water. *G. corallinum* is a relatively large dinoflagellate species and is known from California. Whether it was a new introduction in Sweden, or previously has been overlooked, was not known (ICES, 2006). However, Wallentinus (2002) describes *G. corallinum* as a quite distinct species and thus easy to recognize. The author notes that *G. corallinum* could be a native species of Sweden. *Gyrodinium* spp. have been observed grazing on diatoms in coastal Antarctic waters and the northern Gulf of Mexico. In addition, the heterotrophic dinoflagellates were also found to be important grazers of the phytoplankton in nearshore waters of the southern North Sea (Stelfox-Widdicombea *et al.*, 2004). It is therefore considered 'certain' that this species will establish in the Wadden Sea (score 5).

Oxytoxum criophilum
Oxytoxum criophilum is identified as one of the dominant phytoplankton species of the sub-antarctic seas around Kerguelen Islands (Pruvost *et al.*, 2005). Since this species is also observed in the northern Adriatic Sea for example (Totti *et al.*, 2005), it has a wide range of occurrence. The genus *Oxytoxum* has been observed in the Dutch coastal waters but no species was identified (Brochard *et al.*, 2006; Koeman *et al.*, 2003). It is therefore considered 'certain' that this species will establish in the Wadden Sea (score 5).

Pleurosira laevis f. polymorpha
The accepted name of *Pleurosira laevis f. polymorpha* is *Pleurosira laevis* (www.marinespecies.org, accessed on 24 October 2007). The colonial diatom *Pleurosira laevis* is a brackish water alga. It originates from subtropical regions and is first found in Sweden in 1995 in cooling water of power plants. Abrahamsson *et al.* (2003) describe, that in the area studied, *P. laevis* only occurs in flowing heated water in autumn in up to 0.5 m high colonies. *P. laevis* did not occur in water of 12 °C. Because *P. laevis* is a 'warm water' species, it is considered unlikely that this species 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 Dutch coastal waters. In April 2006 a large algal bloom north of the island Terschelling, was found to be resembling or identical to *V. farcimen* .This indicates that this species has already been introduced (pers. comm. L. Peperzak; pers. comm. R. Koeman). 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.*, 2007). Preliminary experiments indicate that the species will form resting stages (cysts) under certain conditions (Naustvoll, 2006). Considering its wide occurrence along the European coasts it is considered 'certain' that this species will establish in the Wadden Sea (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).

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 Sweden 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, *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 considered as certain (score 5).

Pilumnus spinifer

The red hairy crab *Pilumnus spinifer* is a small crab with a carapace width of at most 25 mm. It is thought to originate from Europe. There is one observation of this species in a harbour in Sweden. It occurs from the Bay of Biscay (France/Spain) to Mauritania, the Azores, the Canary Islands and Madeira and throughout the Mediterranean. Although not common, the closely related species *Pilumnus hirtellus* is found established in the Netherlands. *Pilumnus spinifer* is found on various types of bottom, from shallow inshore areas with water just a metre deep to depths of almost 180 m (Factsheet *Pilumnus spinifer* and *Pilumnus hirtellus,* Updated version December 2006, source: http://www.frammandearter.se/). Based on the available information it is considered ‘certain’ that this species will establish in the Wadden Sea (score 5).

Pseudobacciger harengulae

The parasitic species *Pseudobacciger harengulae* has possibly been introduced in Sweden by ballast water. It is therefore likely that this species could also be distributed by mussel transfer, by being present in the water surrounding or within the mussels. Several herring species are known hosts of this parasite (Dimitrov *et al.*, 1999). It is therefore considered ‘certain’ that this species will establish in the Wadden Sea (score 5).

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 10 target species are able to become permanently established in the Wadden Sea due to mussel transfer (Table 12).

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). Ten experts participated in the assessment (Table 13). The experts scored 11 target species (at least) likely to become established in the Wadden Sea due to mussel transfer.

Table 12: 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 11). 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 ssp. *scandinavicum*	Algae	5	"
Dissodinium pseudocalani	Algae	5	"
Gyrodinium corallinum	Algae	5	"
Oxytoxum criophilum	Algae	5	"
Verrucophora cf. fascima	Algae	5	"
Pilumnus spinifer	Crustaceans	5	"
Pseudobacciger harengulae	Trematodes	5	"
Fucus evanescens	Algae	2	"unlikely"
Pleurosira laevis f. polymorpha	Algae	2	"

Table 13: 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. Presented are average and range of the scores and (between parenthesis) the number of experts that indicated a score for this species.

		Score	
Taxon. Group	**Target species**	**Average**	**Range (n)**
Algae	*Dissodinium pseudocalani*	3.0	- (1)
	Gyrodinium corallinum	2.0	- (1)
	Oxytoxum criophilum	2.0	- (1)
	Pleurosira laevis f. polymorpha	3.0	- (1)
	Verrucophora cf. fascima	3.5	2 – 5 (4)
	Fucus evanescens	3.4	2 – 4 (5)
	Codium fragile ssp. *scandinavicum*	3.5	2 – 5 (4)
	Aglaothamnion halliae	3.8	2 – 5 (4)
Crustacea	*Pilumnus spinifer*	4.0	3 – 5 (3)
Trematodes	*Pseudobacciger harengulae*	3.0	- (1)

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 15. The results of the expert judgment are presented in Table 16.

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 Sweden, 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, 2002b). 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 harbor 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
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 (2002a) 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).

Dissodinium pseudocalani
The genus *Dissodinium* contains two described species, both of which are ectoparasitic on copepod eggs. While all of the parasitic dinoflagellate forms can castrate their hosts, the severity of the effect appears dependent upon the invasiveness of the parasitic species (Shields, 1994). However, since there is no evidence found in available literature that this species has caused severe problems in areas of introduction, it is not considered certain that this species can have a substantial effect on the ecosystem. The probability of a substantial effect is therefore assessed as likely (score 3).

Gyrodinium corallinum
Large dinoflagellates such as *Gyrodinium* spp., may compete with copepods for the larger diatoms. Large dinoflagellates are often associated with blooms of diatoms (Stelfox-Widdicombea *et al.*, 2004). It can not be excluded that successful introduction of this species will affect the phytoplankton and zooplankton communities of the Waddden Sea ecosystem. However, the species is reported as not harmful by Wallentius (2002) and no indications were found in literature that this species has caused problems in areas of introduction. Therefore, it is considered unlikely that this species can have a substantial effect on the ecosystem (score 2).

Oxytoxum criophilum
The dinoflagellate *Oxytoxum* spp. appeared to be characteristic of mucilage periods (Totti *et al.*, 2005). Large mucilaginous macroaggregates (the dirty sea phenomenon) represent the last stage of aggregation of organic matter (i.e. DOM). The relative importance of the extracellular production of dinoflagellates is unknown (Totti *et al.*, 2005). A study of algal blooms in Chesapeake Bay, the largest estuary in the United States lying off the Atlantic Ocean, showed that at a certain stage *Oxytoxum* sp. was dominant within many of the dense patches (Loftus *et al.*, 1972). These blooms occurred in brackish (salinity of 9 - 12 ‰) and relatively warm (temperature of 25 - 30 °C) waters, compared to the conditions of the Wadden Sea. Predation, especially by the rotifers and tintinnids, and lowered nutrient levels reduced the net rate of reproduction of *Oxytoxum*. Based on the bloom - and mucilage forming capacities of *Oxytoxum* spp. the probability that *Oxytoxum criophilum* can have a substantial effect on the ecosystem is considered to be certain (score 5).

Pleurosira laevis f. polymorpha
The diatom *P. laevis* was found to be a stable large producer of the toxic compound $CHCl_3$ (Abrahamsson *et al.*, 2003). Kociolek *et al.* (1983) reported that *Biddulphia laevis,* a synonym for *P. laevis*, is a relatively large, chain forming centric diatom. Some filaments of *B. laevis* were observed to contain 50 cells, connected by pads of mucilage. It is therefore considered certain that this species can have a substantial effect on the ecosystem (score 5).

Pilumnus spinifer
No information has been found on the potential impact of *Pilumnus spinifer*. Once established, it is expected to compete with the closely related species *Pilumnus hirtellus* which is (rarely) found in the Dutch and Belgium

coastal waters. In south Portugal, both *P. hirtellus* and *P. spinifer* have been found side by side in the same sample, without intermediates. Intermediates of these species have been recorded (Factsheet *Pilumnus spinifer* and *Pilumnus hirtellus,* Updated version December 2006, source: http://www.frammandearter.se/). Based on the available information found, there are no indications of this species posing a threat to the ecosystem. The probability that these species can have a substantial effect on the ecosystem of the Wadden Sea is therefore considered as unlikely (score 2).

Pseudobacciger harengulae

Pseudobacciger harengulae is not known as a pest species in available literature. However, because several herring species are known hosts of this parasite, (Dimitrov *et al.*, 1999), it is considered very likely that this species can have a substantial effect on the ecosystem of the Wadden Sea (score 4).

Table 14: 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	*Dissodinium pseudocalani*	3	"likely"
	Gyrodinium corallinum	2	"unlikely"
	Oxytoxum criophilum	5	"certain"
	Pleurosira laevis f. polymorpha	5	"
	Verrucophora cf. fascima	4	"very likely"
	Fucus evanescens	2	"unlikely"
	Codium fragile ssp. *scandinavicum*	3	"likely"
	Aglaothamnion halliae	2	"unlikely"
Crustacea	*Pilumnus spinifer*	2	"unlikely"
Trematodes	*Pseudobacciger harengulae*	4	"very likely"

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). Ten experts participated in the assessment.

Table 15: 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. Presented are average and range of the scores and (between parenthesis) the number of experts that indicated a score for this species The consulted experts were not able to score the algae *Pleurosira laevis f. Polymorpha.*

		Score	
Taxon. Group	**Target species**	**Average**	**Range (n)**
Algae	*Dissodinium pseudocalani*	3.0	- (1)
	Gyrodinium corallinum	2.0	- (1)
	Oxytoxum criophilum	2.0	- (1)
	Pleurosira laevis f. polymorpha	-	- (0)
	Verrucophora cf. fascima	4.3	3 - 5 (4)
	Fucus evanescens	3.3	2 - 5 (3)
	Codium fragile ssp. *scandinavicum*	3.5	2 - 5 (2)
	Aglaothamnion halliae	2.5	1 - 5 (4)
Crustacea	*Pilumnus spinifer*	2.3	2 - 3 (3)
Trematodes	*Pseudobacciger harengulae*	4.0	- (1)

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 16 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 dinoflagellate *Oxytoxum criophilum* is identified as a species with a high overall risk. This is due to its bloom - and mucilage forming capabilities, as described in literature. The expert panel however, considers the risk for this species as very unlikely. Another species with a maximum overall risk score is *Pleurosira laevis*. This is a chain forming species and found to be a stable large producer of the toxic compound $CHCl_3$. Both the literature assessment as the expert panel indicates the probability of this species to have a substantial impact on the Wadden Sea as certain.

The trematode *Pseudobacciger harengulae* is a parasite of several herring species and therefore considered a risk for the Wadden Sea ecosystem. However, the expert panel considers the probability of a substantial risk unlikely. The algal species *Verrucophora farcimen* and *Codium fragile* ssp *scandinavicum* are also 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 Sweden. It is therefore recommended to verify these observations. *Dissodinium pseudocalani* is ectoparasitic on copepod eggs and is can therefore form a potential risk for the Wadden Sea ecosystem.

Table 16: Overall assessment of the risk that non-indigenous species that are introduced with the mussel imports from Sweden 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	*Dissodinium pseudocalani*	3.0	1.8	3.0
	Gyrodinium corallinum	2.0	0.8	2.0
	Oxytoxum criophilum	5.0	0.8	5.0
	Pleurosira laevis f. polymorpha	5.0	5.0	5.0
	Verrucophora cf. fascima	4.0	3.0	4.0
	Fucus evanescens	0.8	2.3	2.3
	Codium fragile ssp. *scandinavicum*	3.0	2.5	3.0
	Aglaothamnion halliae	2.0	1.9	2.0
Crustacea	*Pilumnus spinifer*	2.0	1.9	2.0
Trematodes	*Pseudobacciger harengulae*	4.0	2.4	4.0

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 Sweden 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 Sweden 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. *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 Swedish 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 Sweden into the Wadden Sea is evaluated based on literature data and expert judgment. In total 10 target species (exotic species present in Swedish coastal waters and not observed yet in the Netherlands) have been identified. Most of the target species are algae.

Four 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 Sweden 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 dinoflagellate *Oxytoxum criophilum* is considered as a risk species due to its bloom and mucilage forming capabilities as described in literature. The expert panel however, considers the risk for this species as very unlikely. Therefore the uncertainty of the result of the risk assessment for this species is large, and we advise to conduct a more thorough investigation on the potential effects of this species to the ecosystem. The diatom *Pleurosira laevis* is a toxic algae that could produce the toxic compound $CHCl_3$. At high concentrations this could have effect to the ecosystem and therefore this species is considered as a risk species. The parasitic dinoflagellate *Dissodinium pseudocalani* is an ectoperasite on the eggs of copepods. In literature no severe problems of this species have been reported. *Dissodinium pseudocalani* is probably already present in the Dutch part of the North Sea (pers. comm. R. Koeman).

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.

The impact of the other target algal species addressed in this study are assessed to be low. The algae *Aglaothamnion halliae, Fucus evanescens* and *Gyrodinium corallinum* are not assumed not to be able to establish and/or lead to substantial effects within the Wadden Sea.

The red hairy crab (*Pilumnus spinifer*) is found only once in a harbour of Sweden. It is not known whether it has established itself. The species can be found in the Mediterranean and can also be found in the southern part of the Northeast continental shelf region (Bay of Biscay). Although not common, the closely related species *Pilmnus hirtellus* is found established in the Netherlands.

The trematode *Pseudobacciger harengulae* is an parasite on several herring species and is present in Swedish waters. The parasite could be transported to the Wadden Sea with the transfer of mussels from Sweden. However, it is more likely that this species will be, or is already introduced into the Wadden Sea by infected herring. If it is already introduced before and is not observed it could be that the environmental conditions

The target species defined in this study are the exotic species that are present in the marine waters at the West coast of Sweden 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 Swedish marine waters is based on the web site on alien species in Swedish seas and archipelago areas (www.frammandaerter.se). Since new species will be introduced into the coastal waters of Sweden, 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 the Swedish waters 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 Swedish waters will be a risk for the ecosystem of the Wadden Sea.

The imported mussels will come from rope culture in Sweden, 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 Sweden was not part of the present study. At this moment consumption mussels from the rope culture in Sweden 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 because in case of doubt, the worst-case is supposed. We advise to perform 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 4.5, also many (non-exotic) pathogens and harmful algae are present in Swedish 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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