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Risk Analysis of Mussels Transfer

J.W.M. Wijsman and A.C. Smaal

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Risk Analysis of Mussels Transfer

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ii. Summary and conclusions

Conclusion: The risk that the transfer of mussels from the Irish and Celtic Sea to the Oosterschelde will lead to substantial ecological impact as a result of importing exotic non-indigenous species is small, but not totally absent.

In Irish and UK marine waters, 74 exotic species are present, of which 22 are not found in the Oosterschelde. None of these 22 exotic non-indigenous species were either found on the mussel plots in Ireland and Wales, nor in the transport samples. This, however, does not completely exclude the possibility of their transport. From literature data and expert judgment we assessed that 14 out of these 22 species there is a *chance* to survive transport, and establish populations in the Oosterschelde.

With respect to the *effect*, out of the 22 exotic non-indigenous species the possible negative impact is considered high for three species. These are the algae *Alexandrium tamarense* and *Gyrodinium* cf. *aureolum* and the gastropod *Urosalpinx cinerea* (American oyster drill). The algae can lead to toxic blooms and the American oyster drill predates oyster spat and can have a devastating effect on oyster beds. The algae species already occur in and along the North Sea, and could be able to find their own way to the Oosterschelde. The American oyster drill It has been found locally on the Essex and Kent coasts at the East coast of the UK, and precautions are taken to prevent dispersal to the mussel production areas.

This study showed that the *chance* of introducing exotic species by means of mussel transports is realistic for a number of species. The *effects* are considered limited, given the characteristics of the exotic species and the fact that mussel imports have been going on for over 30 years, and no observations on adverse effects have been reported.

Summary
The Oosterschelde is known for the relatively high number of exotic species (Wolff, 2005). The import of mussels from various areas like the Irish and Celtic Sea already takes place for at least 35 years, and may have played a role (Wolff, 2005). Apart from import of shellfish, specific environmental characteristics of the Oosterschelde are important. The system has an open connection with the North Sea and a large variety of habitats. Especially the rocky shores that are manmade to provide protection of the dikes form a habitat for an extensive community of hard substrate flora and fauna, resulting in a very high biodiversity, partly of exotic origin. Partly due to these characteristics, the system is designated as a nature conservation area of national and international importance (Geurts van Kessel, 2004).

Due to the growing intensity of transport by ships, the transfer of shellfish and the construction of shipping canals, the introduction of exotic species in European waters has increased over the last decades. Also the dispersion rate of exotic species within the North East Atlantic shelf has increased due to human activities. Whether an introduced species can establish itself in a receiving ecosystem depends on the local environmental conditions and the habitat requirements of the introduced species. In most cases, a successful introduction of an exotic species will result in an increase in biodiversity and the impact on the other organisms is negligible or low. However, in some exceptional cases an introduction can have a significant effect on the functioning of the ecosystem.

Although other transport vectors also play a role in the introduction of exotic species in Dutch waters (Wolff, 2005), the present risk analysis focused on the role of mussel import, and no quantitative information on the other vectors is taken into account.

This study focused on species exotic to the North East Atlantic which are at the same time non-indigenous to the Oosterschelde. According to Wolff (2005) it is not likely that native species

from the Northeast Atlantic region, but not indigenous to the Oosterschelde will be able to settle permanently after introduction. As the Oosterschelde is part of the same region they would have settled here already if the habitat was suitable.

The risk analysis specifically focused on the import of mussels from the Irish and Celtic Sea, as these are main source areas. The study focused on the risk of introducing species for the environment. Human health aspects are subject to existing EU legislation concerning pathogenic microorganisms and biotoxins in shellfish. Import from areas that do not meet the sanitary standards or have risk for biotoxins (including the occurrence of cysts of harmful algae) is not allowed, hence are not part of this study.

Together with the mussels large amount of other materials are imported into the Oosterschelde. The risk of introducing exotic non-indigenous species through shellfish import is related to the amount of mussels that are transported, the species composition of the organisms that come with the mussel transport and the local environmental conditions in the Oosterschelde. The Dutch mussel industry becomes more and more dependent on the import of mussels. It is estimated that in the season '05/'06 a total amount of about 26 784 ton (27 million kg) of mussels are imported to the Netherlands from the Irish and Celtic Sea. The relative amount of tare was 23 %. About 5 360 ton are juvenile mussels which are re-laid directly on the mussel culture plots in the Oosterschelde. From the 21 424 ton consumption mussels, part is stored at the rewatering plots in the Oosterschelde, while the rest is kept in containers on land. It is not known how many of the consumption mussels are stored on the re-watering plots. A total amount of 6 246 ton of tare is discharged into the Oosterschelde, either directly (on culture plots and re-watering plots) of indirectly at the slipperplaat after storage in a container.

This study describes a framework for applying a semi-quantitative risk assessment, using the import of mussels from the Irish and Celtic Sea as a case study. Data on mussel transports from Ireland and the UK to the Netherlands has been collected. Species composition of the associated flora and fauna was described, both at the mussel plots in Ireland and Wales as well as amongst the transported mussels at arrival in the Netherlands. An overview is given on the presence of exotic species in the Oosterschelde.

In the Irish and the British marine waters 74 exotic non-indigenous species have been recorded (Minchin & Eno, 2002). Of these species 69 species have been recorded in UK waters and 35 species have been found in the Irish waters. Not all of these species will be able to be transported with the mussel transfer to the Oosterschelde. For species with a very local distribution, far from the mussel production locations, it is very unlikely that they will be introduced into the Oosterschelde with the mussels. However, for species with a more dispersed distribution or species that are associated with the mussel beds the risk of introduction through mussel transfer is higher. Three exotic non-indigenous species were found on the mussel beds in Wales (the crustaceans *Eliminus modestus* and *Balanus improvisus* and the gastropod *Crepidula fornicata*). In Ireland, one exotic species was recorded on the mussel beds (*Aphelochaeta marioni*). In the samples from the import, four exotic non-indigenous species were observed (the bivalve *Mya arenaria* and the crustacean *Balanus improvisus* and *Elminius modestus*). All these exotic species are already present for a long time in the Oosterschelde.

In total 22 target species, i.e. exotic non-indigenous species that are present in UK and Irish waters and are unknown for the Oosterschelde are selected. These species could potentially be introduced with the mussel import. None of these exotic species however, are observed at the mussel plots in Wales and Ireland, nor have they been recorded in the transports.

It seems likely that 14 of the 22 target species could establish permanent populations in the Oosterschelde. They will be able to survive the transport and the local environmental conditions are regarded suitable. The fact that these species are not observed in the Oosterschelde yet could be that they are not associated with the mussel beds in Ireland and the UK. The actual chance of introduction depends on the possibility that the species are caught with the mussel fishery in the Irish and Celtic Sea, the survival during the transport to the Netherlands, the habitat requirements of the species and the environmental conditions in the Oosterschelde. The chance that each of the target species can be introduced in the Oosterschelde has been evaluated by expert judgment.

Out of the 22 target species, three species are known as potential pest species. The algae *Alexandrium tamarense* and *Gyrodinium* cf*. aureolum* and the gastropod *Urosalpinx cinerea* (American oyster drill). These species already occur in and along the North Sea, hence transfer of mussels from the Irish Sea has no direct relation with the fate of these species. In addition, the algae may induce potential harmful blooms and biotoxins. It can be discussed what ecological impacts might be involved. It is noticed that human health effects of potential harmful algae are under control by phytoplankton and biotoxin monitoring programmes.

Recommendation
It is recommended to develop a risk management programme provided with accurate information by a sound monitoring programme. The monitoring programme should provide information on:

- Detailed registration of origin, amount and composition of imports
- Species composition and seasonal fluctuation at source areas and tare of imported mussels
- Monitoring of the development and new introductions of exotic species in Ireland and the UK
- Specific information of risk species *Alexandrium tamarense, Gyrodinium* cf*. aureolum* and *Urosalpinx cinerea*

1 Introduction

Mussels are imported into the Netherlands for a long time. Since the 1970's records show that mussels are imported from other European countries (including Ireland and the UK) to fill the shortage in mussel stocks in the Netherlands. Mussels are either imported as consumption mussels (>4.5 cm), which are directly used for processing or re-laid at the storage plots of the wholesalers in the Oosterschelde, or as juveniles (< 4.5 cm), which are spread at the production sites in the Oosterschelde. With the import of the mussels and re-laying in the Oosterschelde, there is a risk of importing exotic plants, animals and micro-organisms that might become invasive and could have a negative impact on (parts of) the ecosystem of the Oosterschelde. Depending on the extent of the ecological effect and the species concerned, the introduction of exotic species could result in harmful effects to various user functions of the system, including the shellfish industry. In order to identify and manage possible risks Wageningen IMARES was asked to collect data and conduct a risk analysis of mussel transfer on the introduction of exotic non-indigenous species (PRIMUS). The Dutch Ministry of Agriculture, Nature and Food Quality, and the Mussel Importers Association requested this study. The study was co-financed by the province of Zeeland. This report is the result of this risk analysis.

1.1 Introduction of exotic species

A species is considered to be an exotic species to a certain area when it originally never occurred in that area. Natural barriers prevented the settlement of the exotic species by natural dispersion. Only when human activities (e.g., shipping, shellfish transfers, digging canals etc.) transport such species across these natural barriers, they may establish themselves in new areas. In these new areas, these species are called exotics. Many exotic species are transported across natural barriers, but only a minority (10%) establishes itself in the newly reached region. Of the established exotic species most remain uncommon, but again a minority shows strong population development. And of the strongly developing exotic species a few appear to be harmful to the receiving ecosystem and to functions of this ecosystem (Williamson, 1996).

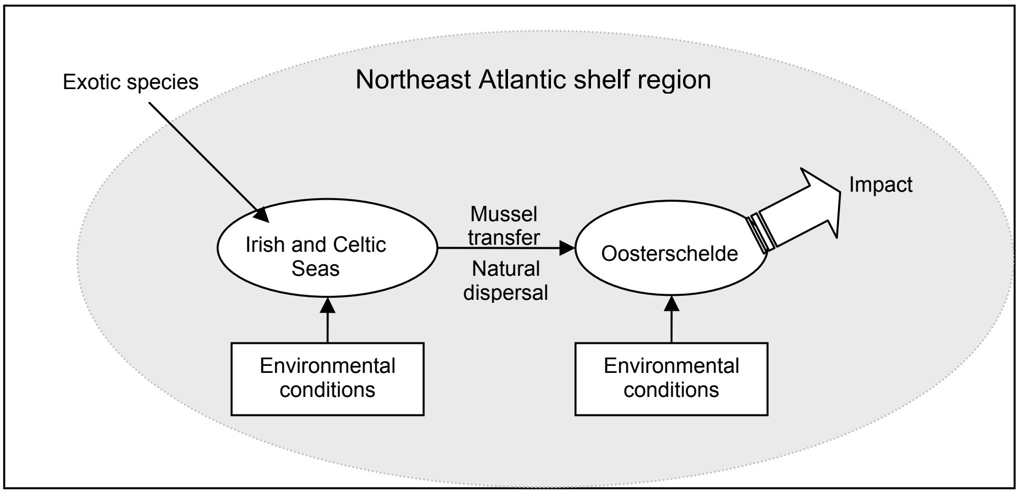

Figure 1: Schematic overview of the process of the introduction of exotic species into the Oosterschelde with the import of mussels from the Irish and Celtic seas.

Both the Irish and Celtic Seas as the Oosterschelde are part of the Northeast Atlantic shelf region (Figure 1). Exotic species, i.e. species that do not belong to this region originally, could have been imported in the past from other regions by means of ballast water, ship hull's, shellfish transport, etc. When the local environmental conditions are suitable for this species, it will be able to settle in the region. Once established the exotic species become subject to transport processes. Depending on the characteristics of the species and the pattern of water movements they will disperse slowly or rapidly over the other Northeast Atlantic shelf waters. Areas over longer distances generally require more time to be colonized.

The Irish en Celtic Seas are relatively isolated from the Oosterschelde. However, (exotic) species are able to migrate over these distances by natural dispersion processes. Depending on the dispersal rate of the organism (Shanks *et al.*, 2003), it might take years to centuries for exotic species to migrate from the Irish and Celtic Sea to the Oosterschelde by means of natural dispersion. Human activities, such as the transport of mussels might decrease this time significantly (Wolff, 2005). However, whether introduced exotic species from the Irish and Celtic Sea will also be able to settle in the Oosterschelde and cause any ecological impact will depend on the environmental conditions in the Oosterschelde and the habitat requirements of the particular species.

1.2 History and legislation of mussel imports

Transplantation of shellfish seems to be a traditional activity in shellfish culture. The Oosterschelde trade of oysters in historic times included regular import and export. Also mussels have been transported intensively. Figure 2 shows the locations in Western Europe from where mussels have been transported to Yerseke and the Oosterschelde, and Figure 3 shows that indeed extensive import and export is a usual practice. As it was realized that adverse effects could be induced by unlimited shellfish transport policy was formulated during the 1980's.

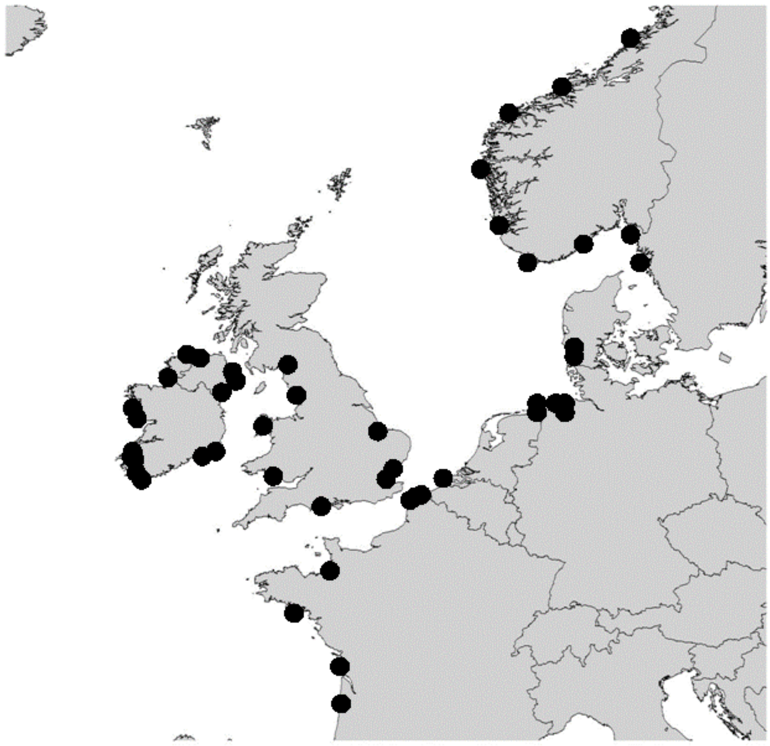

Figure 2: Locations in the Western European waters that are known as source of mussels that were imported alive to the Netherlands in the last decades (Fish Board)

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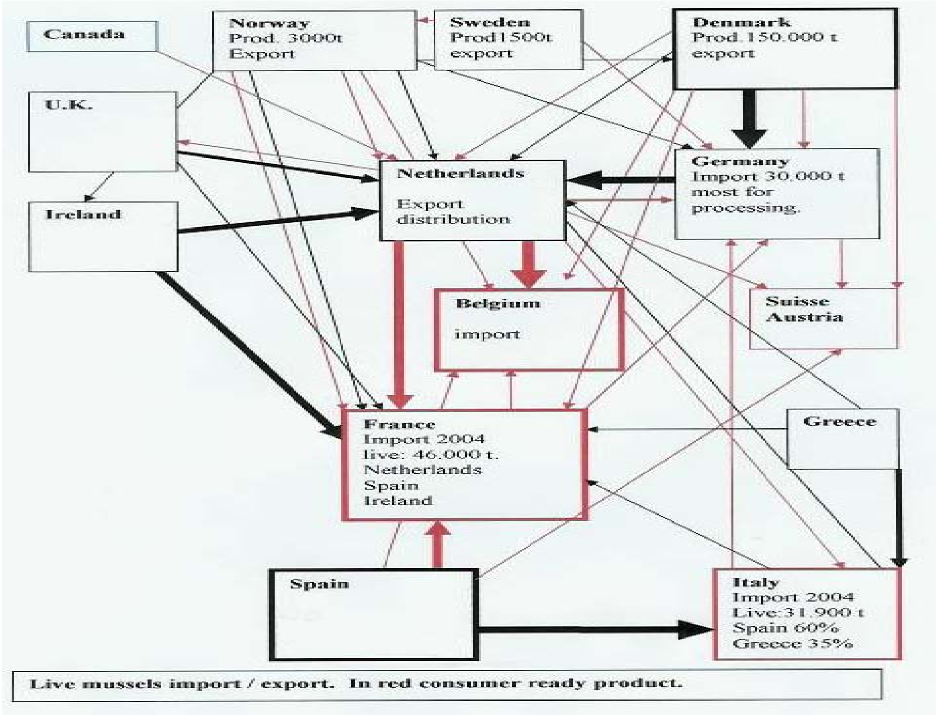

Figure 3: Live mussel import and export though the Netherlands (Dutch Mussel Importers Organization)

From the early 1990's, a permit was needed for each production location for the import of mussels. The approval of the permits was tested against the occurrence of Diarrheic Shellfish Poisoning (DSP) and Paralytic Shellfish Poisoning (PSP), Amnesic Shellfish Poisoning (ASP) and Neurotoxic Shellfish Poisoning (NSP) in the areas of origin, as well as the sanitary status (A, B or C area or prohibited area). For mussels, the first exemption on import legislation is registered in the year 1993 (Morecambe Bay, UK, data commodity board of fish), which was followed by other exemptions rapidly. During this period the Regulation on Introduction of Exotic Dinoflagellates (commodity board of fish) and the Policy Decision Transfer of Shellfish (ministry of LNV, 1997) was designed.

However, it was recognized that knowledge was lacking on the risk of introducing exotic species with the import of mussels. As a result, a new line of policy concerning the displacement of shellfish came into effect in 1997. Displacement of mussels from the Irish and Celtic Sea into the Oosterschelde was not permitted. Also the process water and the tare from the consumption mussels originating outside the boreal waters needed to be purified before being discharged into the Oosterschelde (Snijdelaar *et al.*, 2004).

In 2003, the Raad van State (Highest Court in the Netherlands) withdrew the ban for import on mussels from the Irish and Celtic Sea. It was brought forward that the ban was conflicting with the EC guidelines for freedom of trade. Also it was substantiated that the precaution principle was formulated too general (Snijdelaar *et al.*, 2004). From that period, the Dutch Ministry of Agriculture, Nature and Food Quality, issued permits for the displacement of mussels from the Irish and Celtic Sea into the Oosterschelde. However, the applicant had to prove that mussels originated from a particular production area in the Irish Sea, or have been in that production area for at least one year.

In March 2006, the Raad van State decided that the existing permits were not valid. The Oosterschelde is part of the Natura 2000 network based on both the Bird (79/409/EEC) and the Habitat (92/43/EEC) directives. Any plan or project in the area likely to have a significant effect thereon shall be subject to an appropriate assessment of its implications for the site in view of the site's conservation objectives. For the existing permits, no such assessment was carried out and therefore all permits for importing mussels from the Irish and Celtic Sea were withdrawn.

For a new application for permits, an appropriate assessment should be made. This appropriate assessment should be based on existing knowledge. In 2004, a risk analysis was made on the import of shellfish (Snijdelaar *et al.*, 2004) based on an internet discussions and a workshop with experts. It was concluded that risks are difficult to exclude and therefore allowing import implies possible risks. However, no further quantification of the risks were made. They advised either to regulate or to prohibit the imports of mussels from risk areas.

1.3 Study approach

The risk of introduction of exotic species is the product of the chance of a successful introduction and the effect of the introduction. In this study, data are gathered in order to make a more quantitative assessment of the risks, based on estimating both the chances and effects of the introduction of exotic species into the Oosterschelde with the import of mussels from the Celtic and Irish Sea. The study was carried out under the responsibility of Wageningen IMARES.

As an introduction to the problem, an overview is given on the introduction and the development of non-indigenous species in Northeast Atlantic shelf, and in particular the Dutch coastal waters (chapter 2). In chapter 3 an overview is given on the mussel practice in the Netherlands, Ireland and Wales (contribution of School of Ocean Sciences, University of Wales, Bangor). Also an estimation of the quantities of mussels that are transported from the Irish and Celtic Sea to the Netherlands is made based on data of consumption mussels from the Commodity board of fish (data provided by R. van Aert) and information on the imports of juvenile mussels from Ireland and UK was given by mussel importers and mussel farmers (Delisea, Barbé, Delta, De Ronde and Padmos).

In chapter 4 an overview is given on exotic non-indigenous species in the Irish and British marine waters. Additionally an overview is given on species associated with commercial mussel beds in Wales (contribution of School of Ocean Sciences, University of Wales, Bangor) and Ireland (contribution of Marine Institute, Galway, Ireland). Exotic non-indigenous species can hitch with the mussels to the Oosterschelde. Trucks from Ireland and the UK are sampled and analyzed for the species composition of the tare (E. Brummelhuis, Wageningen IMARES). The results are presented in chapter 5.

Many exotic species are already known for the Oosterschelde. In chapter 6, an overview is given of the exotic species based on literature research and existing databases. This chapter is a contribution of AquaSense (M.J. De Kluijver).

The mussel import into the Oosterschelde creates a possibility to introduce the Mediterranean mussel (*Mytilus galloprovincialis*). This species is able to hybridize with the native common mussel (*Mytilus edulis*). Chapter 7 deals with the occurrence of *M. galloprovincialis*, both in the Oosterschelde and the imports from Ireland and the UK. In the framework of this project new data were collected and analyzed by a team coordinated by NIOO-CEME. The analysis will be finalized during the coming months, and are not yet available for this report.

Based on the collected information and input from an expert panel, a risk analysis is made by TNO IMARES, Den Helder on the risk of introducing exotic species with the import of mussels from the Irish and Celtic Seas into the Oosterschelde (chapter 8).

The conclusions of this research are enumerated in the beginning of theis report (chapter ii).

Prof. Dr. W.J. Wolff acted as an independent external auditor to this report. His comments and remarks are formulated in the audit report which is included in Appendix C of this report.

1.4 Limitations of this study

This study presents a risk assessment on the introduction of exotic species with the mussel transfer from the Irish and Celtic Sea into the Oosterschelde. This study is partly based on expert knowledge, literature review and additional field observations. In this paragraph an overview is given on the limitations of this study. We identified the most important limitations as follows:

- This study is focused on the introduction of **exotic** species, i.e. species that are non-indigenous for the whole northeast Atlantic shelf region. It is assumed that NE Atlantic shelf species which are non-indigenous for the Oosterschelde will not be able to permanently establish itself in the Oosterschelde. The reason for this is that if the environmental conditions in the Oosterschelde are suitable for this species, it would have been established already in the past. However, the Oosterschelde is a dynamic and changing system. Environmental conditions have been changed recently due to the Delta works and global warming. As a result NE Atlantic shelf species could be introduced and settle permanently.
- The list of exotic species from Ireland and the UK dates from 2002 (Minchin & Eno, 2002). In the meanwhile new exotic species might have been introduced.
- The actual establishment of an exotic species and the development to a nuisance is depending on a series of coincidences that are often difficult to predict. This requires a detailed knowledge on the habitat requirements of the species involved and the environmental conditions of the receiving system. Also for experts the risks are therefore difficult to assess.
- Data on amount and origin of the import are not systematically collected and controlled. This study was based on data given by the importers and data from the fish board. These data might be incomplete.
- The import parties were sampled from the top of the big-bags. Especially the smaller organisms might have been washed to the bottom of the big bags.
- Trucks were only sampled in February/March. Due to seasonal dynamics in species composition, some species that are present later in the season could be missed. This is especially the case for macro algae which might have not been developed this early in the season.
- In the short period of sampling, trucks only arrived from a limited number of production grounds. As a result, no observations were available for the other production grounds.
- The samples from the import were sieved over a 1 mm sieve. This 1 mm sieve is often used as a measure for macrofauna organisms. All smaller organisms, such as cysts of potentially harmful algae, were not caught. Also incubation of spores on shell material was not done within the framework of this project.
- Not all individuals sampled from the trucks could be identified to species level, because they were damaged in such a way that essential deterministic characters were missing.
- The samples from the culture plots in Ireland and Wales were only checked on macro-invertebrates. Other species like macro- and micro algae were not recorded. The observations in the mussel plots in Ireland covered only a few areas and a limited part of the season (May 2006).
- The occurrence of *M. galloprovincialis* in the Oosterschelde and the Irish and Celtic Sea was based on literature study. Selective sampling has been done within the framework of this project, however the data were not ready to be included within this concept report.
- Transfer of mussels involves not only the risk of introducing exotic species, but could also lead to problems concerning sanitary quality and biotoxins. From areas that do not meet the sanitary standards (EU, 1991), no export is allowed. Hence this report is focused on the ecological risks of shellfish import. Risks for human health are considered to be effectively covered by the existing management rules and are not part of the present study.

2 Introduction of non-indigenous species

2.1 Non-indigenous species

Non-indigenous species are species that did not exist in an 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 province. 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 are sub-optimal 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.

The Oosterschelde is part of the Northeast Atlantic shelf province (Figure 4). Longhurst (1998) has defined this area as one ecological and biogeographical union for the pelagic ecosystem. It comprises the continental shelf of Western Europe, from northern Spain to Denmark. The Baltic Sea and the Irish and UK marine waters are also part of this province. The area was based on observed distribution patterns of marine organisms. Note that the northern boundary of the Province is not clear from Longhurst (1998). The text shows that the edge of the deep Faeroe-Shetland Channel and the Norwegian trench forms the northern boundary of the province. This means that the Norwegian coast is not part of this Province. Figure 4 is based on the map presented in the book which shows that the Norwegian coast is part of this Province. However for the present study the location of this northern boundary is of minor importance.

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

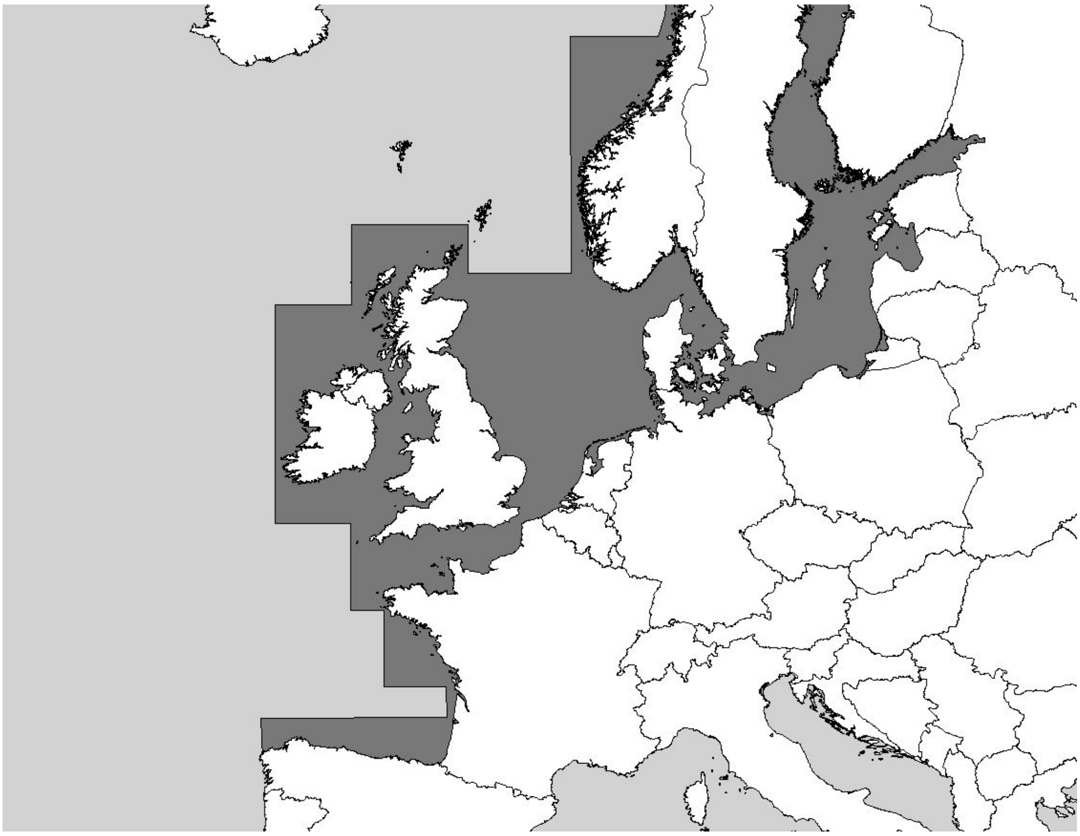

Figure 4: Map indicating the Northeast Atlantic shelf province (dark grey). Figure is adapted from (Longhurst, 1998).

2.2 *Introduction and transport vectors*

Two types of introduction of exotic non-indigenous species can be identified, primary and secondary introduction (Minchin & Gollasch, 2002). Primary introduction is the first introduction of a species in a biogeographic region from another, separated biogeographic region.

Once established in the Northeast Atlantic shelf region, the exotic species will be dispersed by natural transport processes and could establish in other locations within the biogeographic region (secondary introduction). Wolff (2005) has constructed a map indicating the area from which marine organisms can reach the Dutch coastal waters by natural transport processes. This map was based on wind and current patterns. The area ranges from the Bay of Biscay, the waters around the British Isles, the North Sea and the Baltic (Figure 5). Human activities, however, might increase the dispersal rate of the introduced exotic species within the Northeast Atlantic region significantly.

Figure 5: Map indicating the area from which marine organisms may reach Dutch coastal waters by natural transport processes (dark grey). The southern boundary might even extend along the Portuguese coast (indicated by question marks) (adapted from Wolff, 2005).

Various transport vectors can be responsible for the introduction of exotic species (e.g. Minchin, 2006; Wolff, 2005)

- Natural transport by currents of floating and pelagic stages of organisms (secondary introductions)
- Hull fouling on ships
- Dry ballast such as sand, gravel and rocks from the shore
- Ballast water
- Shellfish transport
- Shipping canals
- Intentional introductions
- Other ways such as through aquaria

Shipping (ballast water and hull fouling) is by far the most important vector responsible for the primary introductions of exotic species into European waters (Minchin & Gollasch, 2002; Wolff, 2005). The vectors for secondary introduction are more diverse. For the Dutch coastal waters natural expansion, hull fouling and shellfish transport are likely the most important vectors for the primary and secondary introduction of the exotic non-indigenous species (Wolff, 2005). There has been a change in importance of the different vectors over time. Hull fouling used to be very important until the advent of modern anti-fouling coatings, dry ballast is not used any longer, ballast water is very important nowadays but regulations are being developed by IMO and national governments to minimize the importance of ballast water, shellfish transports and opening of new canals are still important.

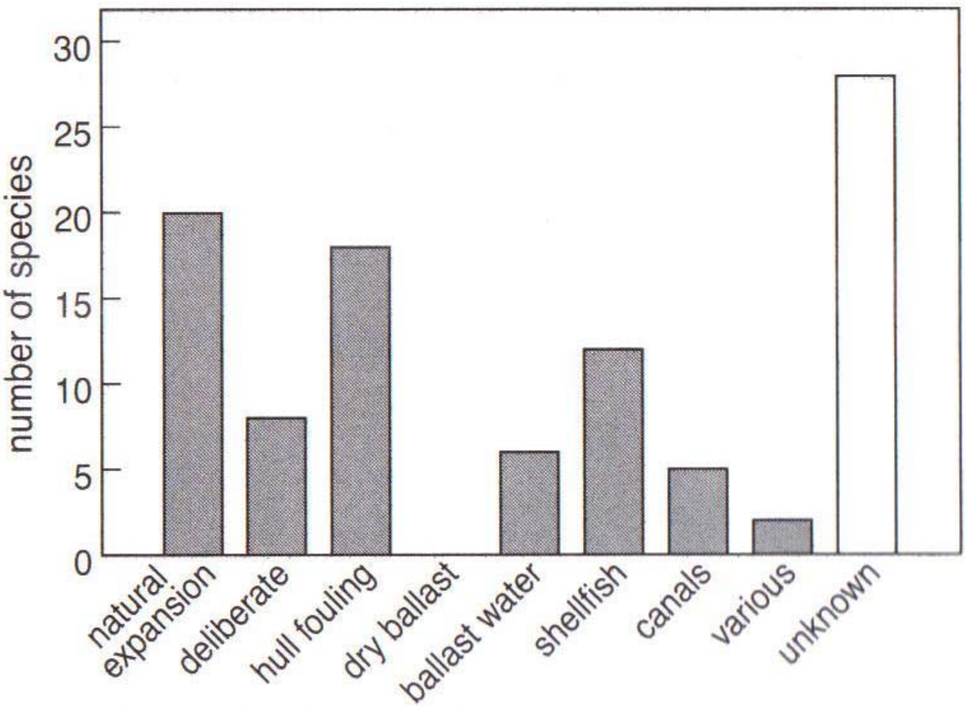

Figure 6: Most likely transport vectors for the primary and secondary introduction of exotic non-indigenous species into the Dutch coastal waters. From Wolff (2005).

2.3 Development of invasions

Not every introduction of a non-indigenous species into an ecosystem is successful. In contrast, most introductions fail sooner or later because the environmental conditions are not suitable. 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)

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 7). 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.

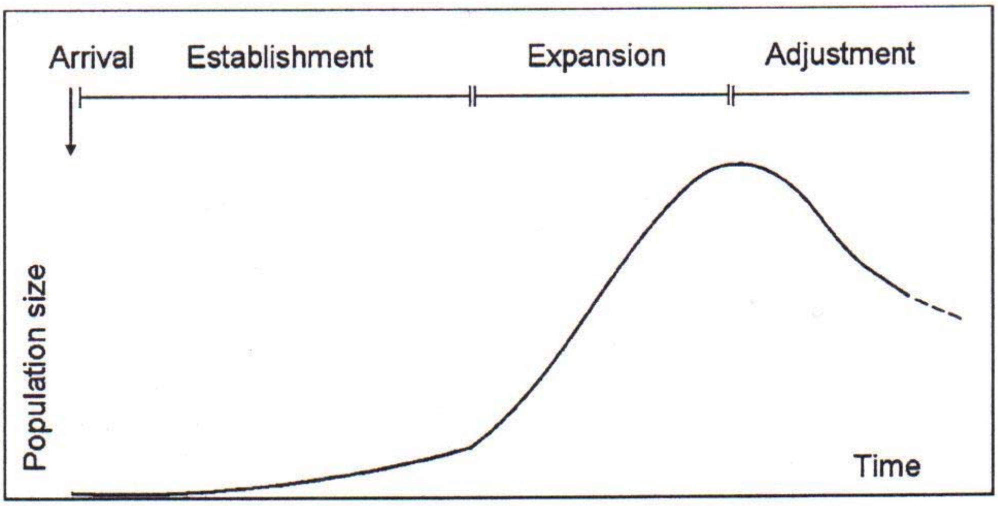

Figure 7: Phases of invasion during the introduction of invasive species. From Reise *et al.* (2006).

2.4 Exotic non-indigenous species in Northeast Atlantic shelf waters

The European waters are known both as an important source and an important recipient region for other biogeographical regions. This is mainly caused by the success of migrating Europeans all over the world (Leppäkoski *et al.*, 2002). Compared with the northern Pacific, European coastal waters have fewer species. The invasiveness of the European waters is high because of the low species richness combined with strong anthropogenic changes (Reise *et al.*, 2006)

A bibliographical studies of exotic species has revealed that more than 800 exotic marine species have been introduced in European coastal waters (Gollasch, 2006; Streftaris *et al.*, 2005). The majority of these species (615) are found in the Mediterranean while 133 are found in the Atlantic waters and 141 in the North Sea area (including coastal waters) (Streftaris *et al.*, 2005).

The North Sea is not severely impacted by invaders and the invaders here are more additive without major consequences to the ecosystem (Reise *et al.*, 1999, 2002). In the British waters 30 animal species and 21 plant species were defined as non-native in 1997 (Eno *et al.*, 1997). In 2002 74 exotic species were recorded in the British and Irish waters (Minichin & Eno, 2002). In the Atlantic and Channel coast of France, 104 exotic non-indigenous species have been recorded (Goulletquer *et al.*, 2002). There, the introduction of the exotic non-indigenous Pacific Oyster (*Crassostrea gigas*) is considered to be successful since it sustains a large industry producing yearly 150 000 ton of oysters with a total value of 300 million Euros (Goulletquer *et al.*, 2002). The introduction rate in France peaked in the 1970's with 20 species per decade and gradually decreases to 14 species per decade in the 1990's.

Wolff (2005) lists 99 exotic non-indigenous and 13 Northeast Atlantic non-indigenous species that have been introduced in the Dutch coastal zone. Of the exotic non-indigenous species 55% have been found in the Oosterschelde and 14% are exclusively found in the Oosterschelde. In the Wadden Sea, only 30% of the exotic non-indigenous species are found. The higher number of exotic non-indigenous species in the Oosterschelde is ascribed to the importation of foreign shellfish in the estuary (Wolff, 2005), but could also be related to the large diversity of habitats in the estuary and the relatively clear waters, supporting a high biodiversity.

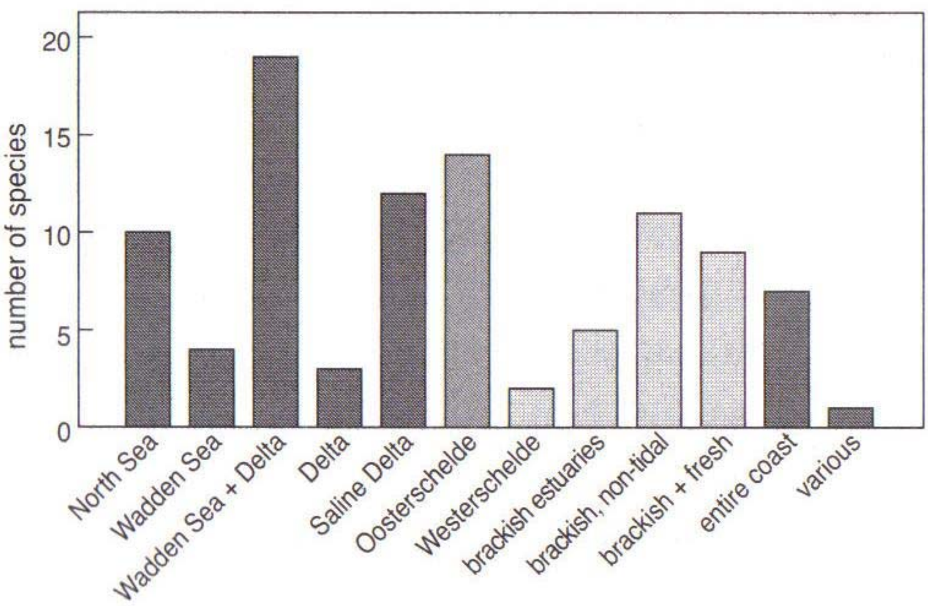

Figure 8: Distribution of exotic non-indigenous species in the Netherlands in 2004. Each column represents the number of species occurring in that particular area only. From Wolff (2005).

3 Practice of mussel culture

3.1 Mussel culture in the Netherlands

The culture of mussels in the Netherlands is carried out mainly as bottom cultures at leased sites in the Oosterschelde and the Wadden Sea. Mussel spat is collected from wild stocks in sub tidal parts in the Wadden Sea and, sometimes, in the Oosterschelde. After a culture cycle of 2-3 years, the mussels reach consumption size (> 45 mm) and 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 (Figure 9) before being transported to the customers (Smaal & Lucas, 2000).

The production capacity of the (processing industry) of mussels in the Netherlands is about 100 000 metric ton. The national production has decreased since the 1980 and amounts on average 70.000 ton over the last 15 years. The production of mussels in the Oosterschelde and Wadden Sea fluctuates due to varying recruitment and survival rates. New measures have been taken to close mussel seed fishing for nature conservation purposes. The demand for mussels, however, is relatively constant and even increasing. In order to fulfill the demand of mussels and exploit the existing production capacity, mussels are imported from various European estuaries and coastal waters particularly from UK and Ireland. Also mussels from the German Wadden Sea are an important resource, and additionally mussel from Denmark and Norway are imported for processing These mussels are transported to the Netherlands and sold at the auction. Since scarcity of mussel seed from the Wadden Sea juvenile mussels are imported and spread on culture sites in the Oosterschelde (Figure 9) where they grow until they reach a marketable size.

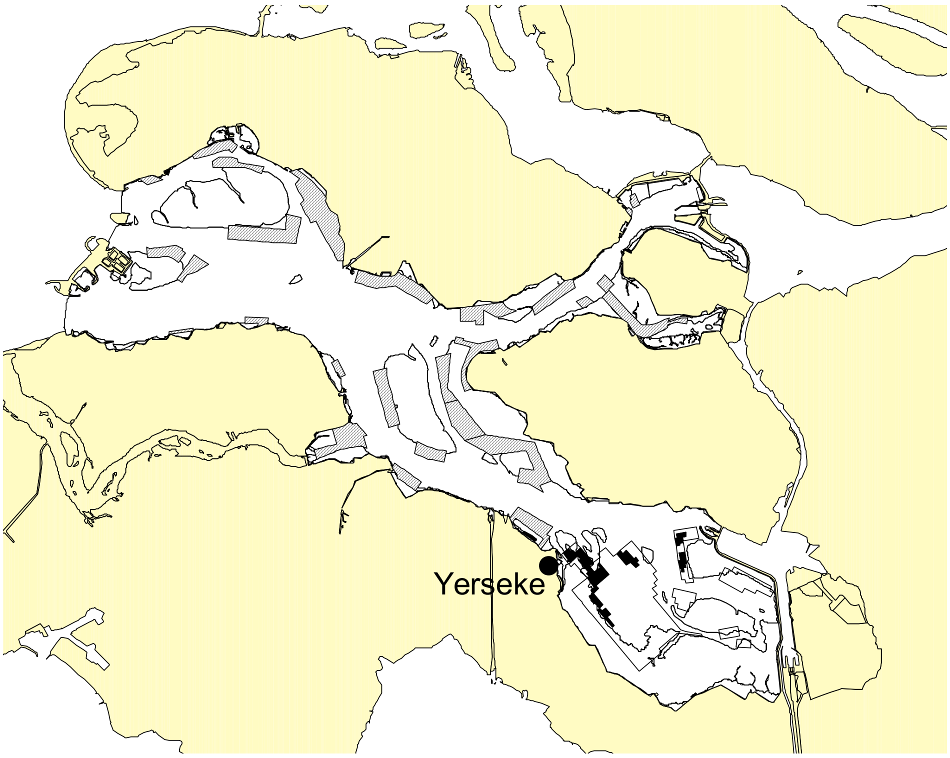

Figure 9: Map of the Oosterschelde with the location of the natural watering sites (solid black) and the locations of the culture plots (hatched).

The Irish and Celtic sea are important areas for mussel import into the Netherlands. In Figure 10, the most important production locations for the import of mussels to the Netherlands are presented. The sanitary and toxicity conditions within these production areas are monitored regularly (Ó'Cinneide, 2005).

The microbiological classification code of the production areas is recorded according to the following criteria (EU, 1991; Masterson, 2005).

- Category A: Either <230 E. coli or <300 feacal coliforms per 100 g of flesh. Mussels from these areas can be collected for direct human consumption.
- Category B: 90% compliance with 230-4600 E. coli or 300-6000 feacal coliforms per 100 g flesh. Mussels from these areas must undergo purification for at least 48 hours.
- Category C: 6000 - 60 000 feacal coliforms per 100 g flesh. Relaying of the mussels is required for at least two months in a clean sea.
- Prohibited areas: more than 60 000 feacal coliforms per 100 g flesh.

Upon arrival in the Netherlands, Category A mussels are treated as category B, which means that they have to be purified before being sold to the market. Juvenile mussels do not have to be purified, and can be distributed directly on the culture plots in the Oosterschelde.

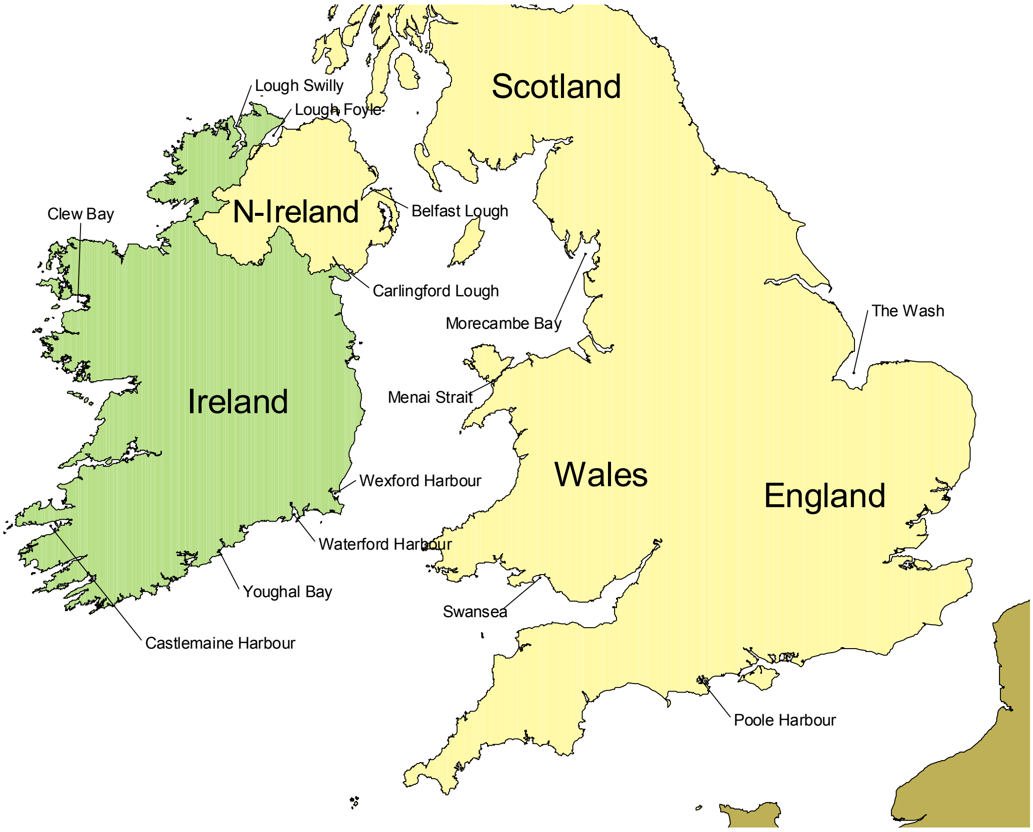

Figure 10: Map of Ireland and the UK with the most important bottom culture sites indicated.

3.2 Mussel culture in Ireland

In Ireland and the UK, mussels are cultured both in rope and bottom cultures. At the West coast of Ireland, rope cultures are more important while in the Loughs on the east coast, bottom cultures dominate. The annual production of bottom culture accounts for 30 000 ton in 2003 and 2004 while rope culture accounted for about 9 000 ton (Parsons, 2005; Parsons *et al.*, 2004). The production of mussels is solely dependent on natural seed resources (Bendezu *et al.*, 2005). Mussel seed for the bottom culture is mainly collected from the East coast in the Irish Sea.

Starting from 30th June, fishermen are allowed to fish for mussel seed. The occurrence of seed beds can vary significantly both spatially and temporally from one year to the next (Bendezu *et al.*, 2005). The mussels are transferred to culture plots in the Loughs where they grow to market size (Figure 10). This takes about 1.5 to 2.5 year.

Nearly 90% of the bottom mussel production was exported in live bulk format in 2004. About 54% of the exported mussels were exported to the Netherlands and 45% was exported to France (Parsons, 2005). The original culture plot of each transport of mussels is registered.

3.3 Mussel culture in Wales

Contribution of R. Seed, J. Bussell and L. Oliver (School of Ocean Sciences, University of Wales Bangor). A more detailed overview of the mussel culture in Wales is given in Appendix A

All mussel production in Wales is in the form of bottom culture. Bottom culture is based on transferring young mussel seed (spat) from areas where they have settled in great abundance, to culture plots. At the culture sites mussels are re-laid at lower densities and moved intermittently between different tidal heights. This management regime allows the mussels to obtain improved growth and fattening, and facilitates control of predation (Dare, 1980), which results in higher productivity.

The largest mussel fishery in North Wales can be found at the eastern end of the Menai Strait. The annual production within this area is about 10 000 to 15 000 ton per year. In the Conwy estuary, mussels are harvested in a traditional way with long handled rakes and open boats. The extensive Conwy fishery produces approximately 300 ton of mussels each year, which are exclusively for the home market. Also in the southern part of Wales (Swansea Bay) mussels are cultured (Figure 11).

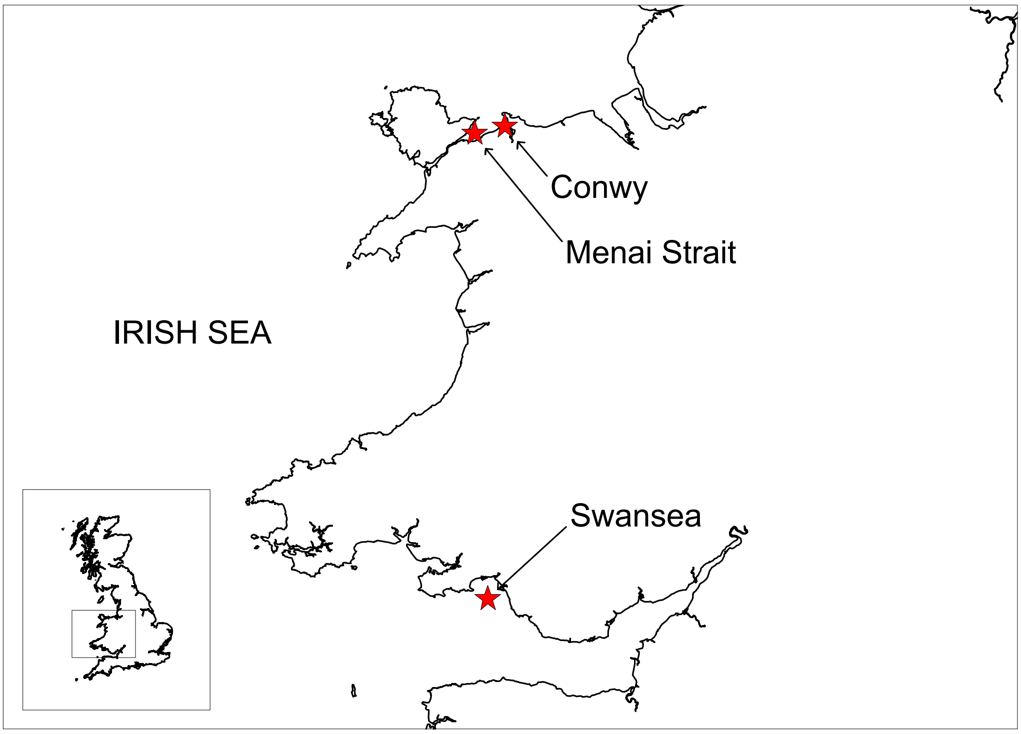

Figure 11: Map of Wales showing location of the main mussel growing areas.

Mussel cultivation in the Menai Strait started around 1958. In the Menai Strait-based industry, seed mussels (~6mm shell length) are collected by dredging seed beds elsewhere (e.g. Morecambe Bay, Caernarfon Bay). These are re-laid on the muddy substrata, at a density of ~

50 – 60 ton per hectare, for on-growing. Once the mussels reach a marketable size (>45 mm), dredges are used to harvest the mussels between September and April.

The Wales mussel industry collects seed by dredging natural seed beds. The mussel culture industry in the Menai Strait harvests seed from three main areas (Figure 12): Caernarfon Bay, Morecambe Bay and South Wales. Seed beds have also developed periodically in Conwy Bay (Saurel *et al.*, 2004). The main seed fishing grounds in South Wales are located at St Ishmael, Whitford and Caldey Island. Within the UK, the transports of mussels onto registered shellfish farms are recorded in a Shellfish Movement Record book. The UK operates a system of approved zones in respect of *Bonamia* and *Marteilia*. Mussels from the east coast of England (e.g. The Wash) however, might originate from the production grounds in Wales (e.g. Menai Strait).

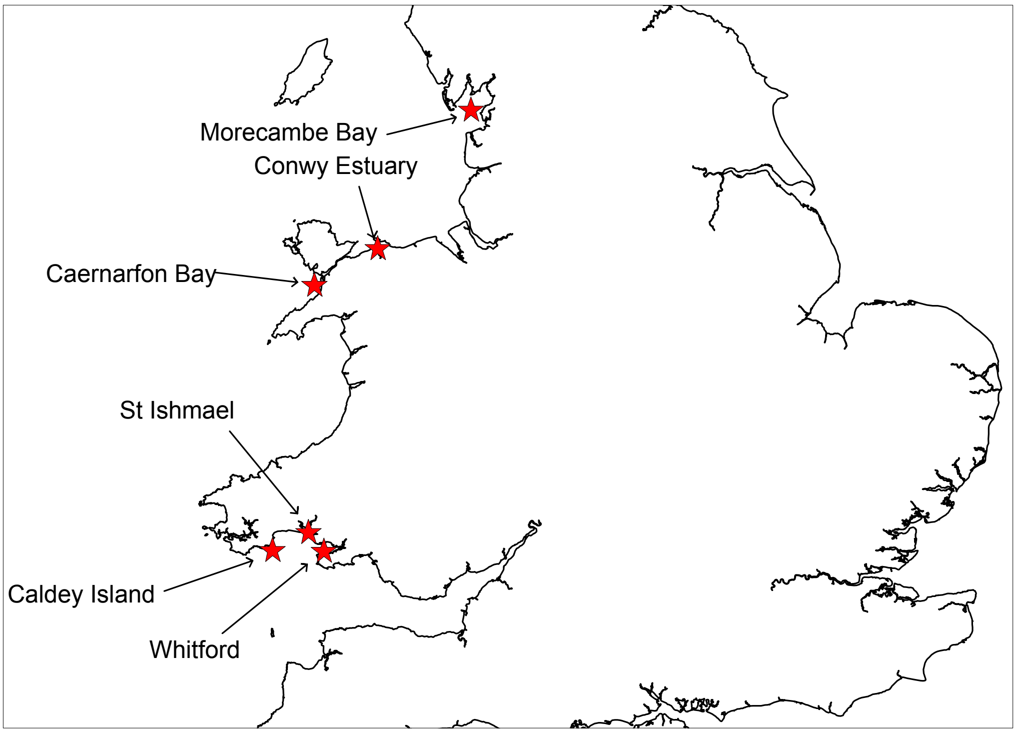

Figure 12: Map of showing locations of the main seed mussel fishing grounds used by Welsh mussel fisheries.

Table 1 shows the mussel landings (in ton) for the North and South Wales fisheries from 1997 to 2004. Almost all mussels produced in the Menai Strait are exported to Holland. The fishery in north Wales is obviously the most substantial, accounting for 98% of the mussels cultured in 2004.

Table 1 Welsh mussel landings in ton gross weight from 1997 – 2004 (Source: SWSFC and NW&NWSFC)

Fishery	1997	1998	1999	2000	2001	2002	2003	2004
S. Wales	30	60	31	30	52	200	11.5	287
N. Wales	-	-	-	-	8 478	10 577	15 120	14 527

3.4 Quantification of mussel transports

For the import of mussels from Ireland and the UK to the Netherlands, three types of mussel transport can be distinguished:

1. Consumption mussels from Ireland and the UK that are kept in watering containers in Yerseke before the transport to the customers. These mussels are not re-laid in the Oosterschelde. The tare, however, is collected in containers and discharged at the dump location "Slipperplaat" in de Oosterschelde, also the effluent water from the containers is discharged in the Oosterschelde. It is a usual practice not to distinguish discharge material from different origin, hence native tare is mixed with imported tare.
2. Consumption mussels from Ireland and the UK that are re-laid on the watering plots in the Oosterschelde. After a couple of weeks, they are fished from the watering plots and distributed to the customers.
3. Juvenile mussels from Ireland and the UK. These mussels are transferred directly (without purification in watering containers) into the Oosterschelde at the culture sites.

Mussels are transported in big-bags placed on pallets in temperature conditioned trucks. Each truck carries about 25 000 kg of mussels. There is no central registration covering all transports of mussels from the Irish and Celtic Sea into the Oosterschelde.

In order to quantify the amount of mussels that are transported from the Irish and Celtic Sea into the Oosterschelde, data from various sources have been gathered and analyzed.

3.4.1 Data sources

Consumption mussels
Consumption mussels imported from the Irish and Celtic Seas are treated as originating from category B areas (Parsons, 2005). This means that the mussels must undergo purification in containers for at least 48 hours. The consumption mussels will then either be rewatered in containers in Yerseke or at the natural watering sites in the Oosterschelde, depending on the demand and supply for mussels.

The commodity board of fish has a record of the imports that have been offered to the office for analysis. The database contains information of the origin of the mussels for each transport, total weight and for most, but not all, information of the quality of the mussels (e.g. % tare, length of the mussels) within the shipment. These data are used by the traders to set the price of the transport. The commodity board of fish has no records of the juvenile mussels that are brought into the Oosterschelde nor have they information on the destination of the consumption mussels (rewatering sites in the Oosterschelde or quarantine containers).

The import data of the consumption mussels covers a period, starting in July 2002 and ending in March 2006. The data have been grouped based on the location of origin in Ireland, N-Ireland, Wales and England. Imports from England are subdivided in the east coast (the Wash) and the west/south coast (Irish and Celtic Sea).

Juvenile mussels
The juvenile mussels are directly re-laid on the mussel growing plots in the Oosterschelde. Since they are not used for consumption directly they don't have to be tested on sanitary conditions (e.g. *E. coli* and salmonella). The mussels are re-laid as soon as possible on the culture plots in the Oosterschelde without any treatment. Mussels from Ireland are 25 - 50 hours out of the water for the transport.

There is no central registration of the amount of juvenile mussels imported into the Oosterschelde. In order to get an idea of the flows, the importers and farmers have been asked to give an overview of their imports of juvenile mussels from Ireland and the UK during the season 2005-2006. These companies, from which the data were received, cover about 95% percent of the total import of juvenile mussels into the Oosterschelde.

3.4.2 Flows of consumption mussels

The mussel producers organization aims to produce 100 000 ton mussels per year (Smaal & Lucas, 2000). Due to the relatively low and fluctuating production in the Dutch waters, mussels have to be imported from other European countries. On average the import of mussels since 1980 accounts for 22% of the total mussel production (Figure 13). In the seasons '84/'85, '91/'92 and '03/'04, the import of mussels accounted for more than 40% of the total mussel production.

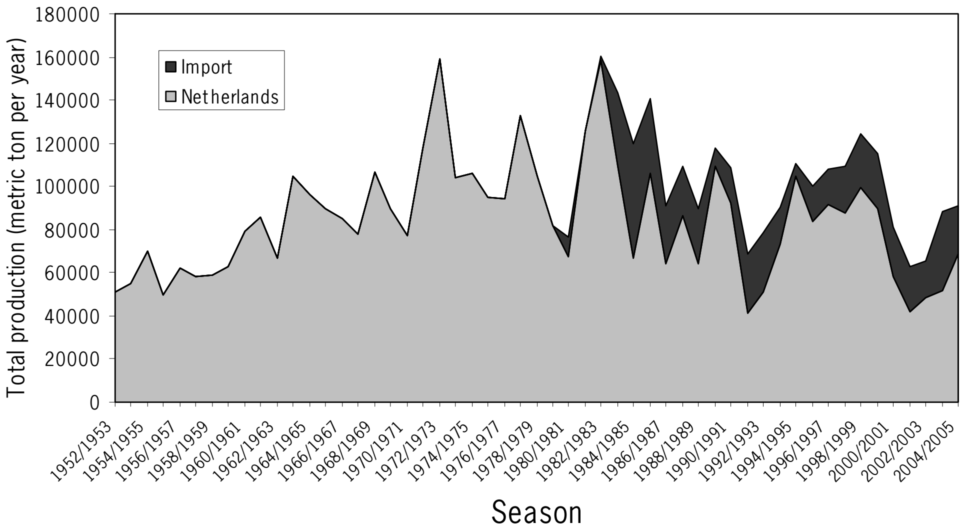

Figure 13: Total production in the Netherlands and the import of consumption mussels (metric ton). Data from the commodity board of fish

In the seasons '02/'03 to '05/'06, the total annual import of mussels was 24 500 ton. The majority of the import came from German Wadden Sea (39% of the total import). The import from the Irish and Celtic Sea accounted for 57% of the total import of consumption mussels (Figure 14).

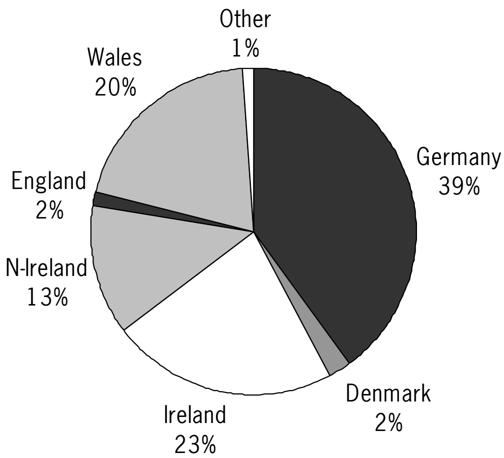

Figure 14: Relative contribution of various European countries in the import of mussels to the Netherlands from July 2002 - March 2006. The average yearly import was 24 500 ton. Others include the import from the countries France, Greece, Italy, Norway and Scotland.

On average the total annual import of consumption mussels from the Irish and Celtic Sea to the Netherlands is 13 800 (stdev = 2 800) metric ton (Figure 15). Important seasons for the import of mussels were '03/'04 and '05/'06. The season of the import from the Irish and Celtic Sea starts in August and ends in April (Figure 16). The peak is in November, when on average 2 800 ton of mussels are imported.

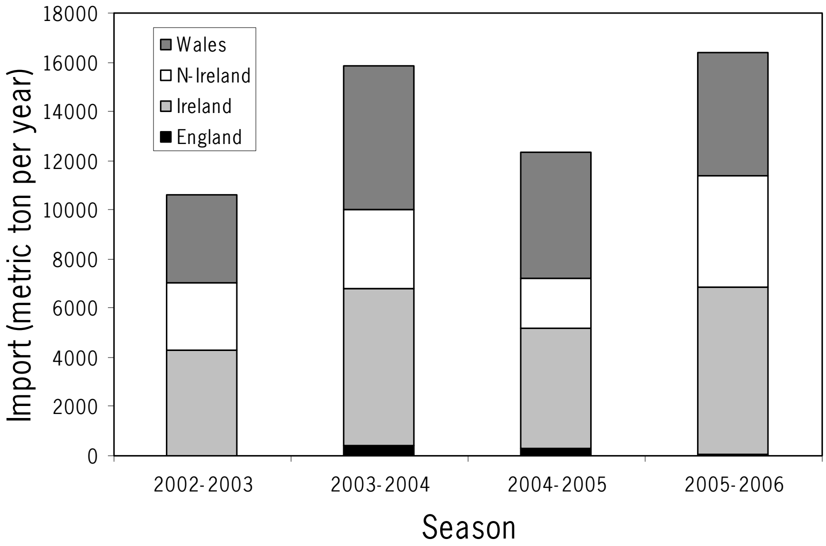

Figure 15: Yearly import of consumption mussels from the Irish and Celtic Seas (net metric ton). Data from the commodity board of fish.

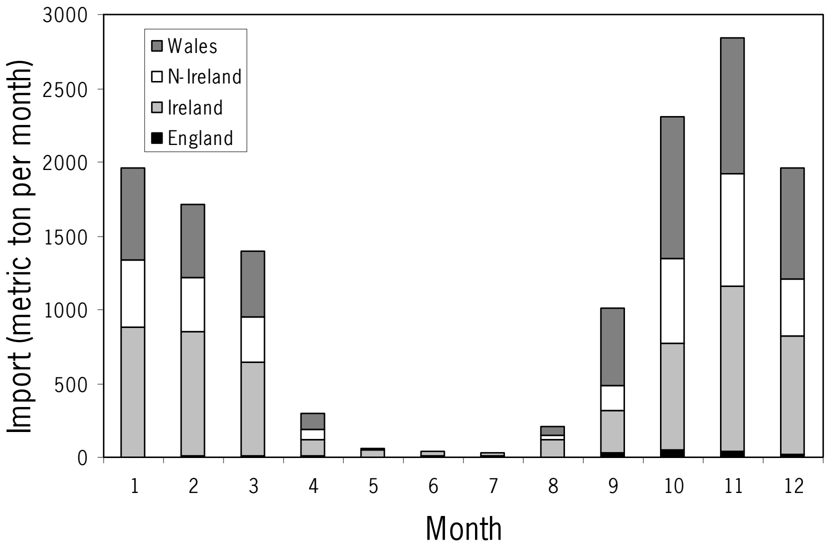

Figure 16: Average monthly import of consumption mussels from the Irish and Celtic Seas (net metric ton) from 2002-2005. Data from the commodity board of fish.

Most important production areas in the Irish and Celtic Sea are Wexford, Carlingford Lough, Castlemaine Harbour and Belfast Lough in Ireland and N-Ireland and Menai strait in Wales (Table 2). The average amount of tare in the transport of consumption mussels is 23.2% (stdev = 10.9%). Especially the import mussels from Wales have a low tare content (18.6%, stdev 7.6%). With a total import of 13 800 net metric ton per year, a total amount of 4 170 ton of tare is imported each year (Table 2).

Table 2 Overview of the average yearly import of consumption mussels (net metric ton), the percentage of the total import and the total amount of tare from the various locations in the Irish and Celtic Sea. Data from the commodity board of fish.

Location	**Net import of mussels (ton yr^{-1})**	**(% of total)**	**Tare (ton yr^{-1})**
Clew Bay (Ireland)	5	0.0%	5
Wexford (Ireland)	2 583	18.7%	834
Bantry Bay (Ireland)	81	0.6%	14
Carlingford (Ireland)	1 255	9.1%	324
Castlemaine (Ireland)	1 254	9.1%	516
Waterford (Ireland)	420	3.0%	119
Unknown (Ireland)	5	0.0%	1
Carlingford (N-Ireland)	811	5.9%	262
Belfast Lough (N-Ireland)	1 786	12.9%	818
Lough Foule (N-Ireland)	390	2.8%	146
Lough Swilley (N-Ireland)	112	0.8%	33
Unknown (N-Ireland)	28	0.2%	9
Menai Strait (Wales)	4 816	34.9%	1 097
Swansea (Wales)	67	0.5%	21
Morecamb (England)	178	1.3%	80
Liverpool (England)	12	0.1%	4
Total	13 805	100.0%	4 170

3.4.3 Flows of juvenile mussels

Juvenile mussels are imported from the UK and Ireland to be re-laid on the culture plots in the Oosterschelde. From September 2005 until March 2007, a total amount of 9 471 ton (gross weight) of juvenile mussels were imported. 44% of these mussels (4 111 ton) were imported from the Wash and the Thames, at the east coast of England and Poole Harbour at the south coast, and therefore did not originate from the Irish and Celtic Sea (Figure 17). Lough Foyle and Swansea were important fishing grounds in the Irish and Celtic Sea for the juvenile mussels in '05/'06. No juvenile mussels were imported from Carlingford and Menai strait, which are important production areas for consumption mussels (Table 2).

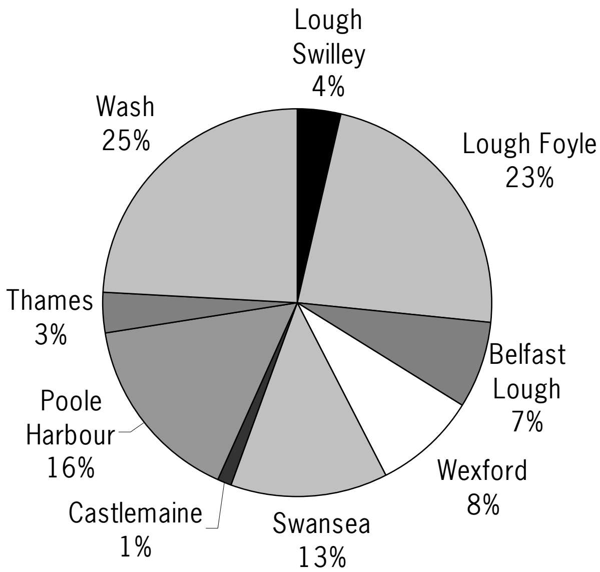

Figure 17: Origin of the juvenile import mussels that are planted in the Oosterschelde in the season '05/'06. The total amount of juvenile import mussels from the UK and Ireland was 9 471 ton.

The juvenile mussels are recorded in gross weight (including tare). Two of the importers recorded both the net as the gross weight of the mussels. 4 354 ton gross weight was equivalent to 3 322 ton net weight. This results in a tare percentage of 23.7%. Applying this figure to the total import of juvenile mussels from the Irish and Celtic Seas, an amount of 4 090 ton (net weight) of juvenile mussels and 1 270 ton of tare is imported with the juvenile mussels.

The mussels (and the tare) are re-laid on the mussel culture plots in the Oosterschelde where they will grow to the size of consumption mussels (>4.5 cm). The mussels are then fished and sold at the auction in Yerseke as mussels originating from the Oosterschelde.

The total import of mussels (consumption and juveniles) from the Irish and Celtic Sea in the season 2005/2006 was 26 784 ton (Table 3). With the import of mussels, a total amount of almost 6 300 ton of tare is imported. At least 1 300 ton of this tare is discharged directly on the culture plots of the Oosterschelde with the juvenile mussels. The other 5 000 ton, which is imported with the consumption mussels is either spread out with the mussels on the watering plots in the Oosterschelde or is discharged as waste material from cleaning the mussels in the processing factories at the dump location the slipperplaat in the Oosterschelde. This waste material is kept in containers on shore. When these containers are full they are brought to the dump location. It is not known how much of the consumption mussels are brought to the watering plots and how much is kept in the containers on land.

Table 3 Overview of the total import of mussels (in ton gross and net weight) and the amount of tare (ton) that was imported from the Irish and Celtic Seas during the season '05/'06.

	Gross weight (ton)	**Net weight (ton)**	**Tare (ton)**
Consumption	21 424	16 411	5 013
Juveniles	5 360	4 090	1 270
Total	26 784	20 501	6 283

4 Profile of harvesting sites Irish and Celtic Sea

4.1 Exotic species in Irish and UK waters

Minchin and Eno (2002) give an overview of the Exotic non-indigenous species in coastal and inland waters of Ireland and Britain. The British Isles lie off the North European continent and the Channel that separates them acts as a barrier for the spread of some exotic species. Due to the extensive trading network and proximity to the European continent, Britain has a larger number of exotic non-indigenous species than Ireland. In total 74 exotic non-indigenous species have been reported for Britain and Ireland (Minchin & Eno, 2002). Five species are present in Ireland and unknown in Britain whereas 39 species are found in Britain and are not recorded in Ireland (Table 4).

Table 4 Exotic non-indigenous estuarine and marine species that are established in Ireland and Britain. Cryptogenic species are species that are neither clearly native nor exotic (Minchin & Eno, 2002).

Taxon	Species	Cryptogenic	Ireland	Britain
Algae	*Agardhiella subulata*			x
	Alexandrium tamarense	x	x	x
	Anotrichium furcellatum			x
	Antithamnion densum		x	x
	Antithamnionella ternifolia			x
	Antithamnionella spirographidis		x	x
	Asparagopsis armata		x	x
	Bonnemaisonia hamifera		x	x
	Codium fragile ssp. atlanticum		x	x
	Codium fragile ssp. tomentosoides		x	x
	Colpomenia peregrina		x	x
	Coscinodiscus wailesii			x
	Cryptonemia hibernica		x	
	Grateloupia doryphora			x
	Grateloupia filicina var. luxurians			x
	Gyrodinium c.f. aureolum		x	x
	Heterosigma akashiwo	x	x	x
	Odontella sinensis			x
	Pikea californica			x
	Polysiphonia harveyi		x	x
	Sargassum muticum		x	x
	Scytosiphon dotyi	x		x
	Soliera chordalis			x
	Thalassiosira tealata			x
	Thalassiosira punctigera			x
	Undaria pinnatifida			x
Angiosperma	*Spartina alterniflora hybrids*		x	x
Porifera	*Suberites massa*			x
Coelentrata	*Clavopsella navis*			x
	Gonionemus vertens			x
	Haliplanella lineata			x
Nematoda	*Anguillicola crassus*		x	x
Annelida	*Ficopomatus enigmaticus*		x	x
	Hydroides dianthus			x
	Hydroides elegans			x
	Hydroides ezoensis			x
	Janua brasiliensis			x
	Marenzellaria cf. wireni			x
	Pileolaria rosepigmentata			x
Pycnopoda	*Ammothea hilgendorfi*			x
Mollusca	*Calyptraea chinensis*	x	x	x
	Crassostrea gigas		x	x
	Crepidula fornicata			x
	Dreissena polymorpha		x	x
	Ensis americanus			x

Taxon	Species	Cryptogenic	Ireland	Britain
	Mercenaria mercenaria			x
	Mya arenaria		x	x
	Mytilopsis leucophaeta			x
	Petricola pholadiformis			x
	Potamopyrgus antipodarum		x	x
	Teredo navalis		x	x
	Tiostrea lutaria			x
	Urosalpinx cinerea			x
Crustacea	*Balanus amphitrite*		x	x
	Balanus improvisus		x	x
	Corophium sextonae		x	x
	Elminius modestus		x	x
	Eriochier sinensis			x
	Eusarsiella zostericola			x
	Herrmannella duggani	x	x	
	Limnoria tripunctata		x	x
	Myicola ostreae		x	
	Mytilicola intestinalis		x	x
	Mytilicola orientalis		x	
	Pilumnus perlatus			x
	Porcellidium ovatum	x	x	
	Rithropanopeus harrisii			x
Bryozoa	*Bowerbankia gracilis*			x
	Bugula stolonifera			x
	Tricellaria inopinata			x
Tunicata	*Perophora japonica*			x
	Phallusia mammilata		x	x
	Styela clava		x	x
Teleostei	*Oncorhynchus mykiss*		x	x

Table 4 lists the exotic non-indigenous species that could potentially be transferred with the mussel transfer from the Irish and Celtic sea to the Oosterschelde. However, some of these species have very local distribution (often near ports) while others have a more general distribution within the region. For an exotic species with a very restricted area of distribution (for example recorded only in one estuary at the east coast of Britain), it is very unlikely that it will be introduced with the mussel transfer to the Oosterschelde. For exotic species that are found on the mussel cultivation plots, it is more likely that they will be introduced into the Oosterschelde with the mussel transports. *Dreissena polymorpha* and *Potamopyrgus atipodarum* are essentially salt-tolerant freshwater species. For these species it is very unlikely that they will be successfully introduced in the Oosterschelde. Therefore, data have been collected specifically on organisms that are associated with the commercial mussel plots. In paragraph 4.2 an overview is given on the species associated with commercial mussel beds in Ireland (Wexford and Cromane). In paragraph 1.1 an overview is given on the macroinvertebrates that were associated with commercial mussel beds in Wales (Menai strait, Swansea Bay and Conwy estuary).

4.2 Species associated with mussel beds in Ireland

Contribution of F. O'Beirn (Marine Institute Galway Ireland)

In May 2006 mussel culture plots have been sampled and analyzed on macroinvertebrate species composition. In total 15 samples have been taken from Wexford Harbour and 15 samples from Cromane (Near Castlemaine Harbour) (Figure 18).

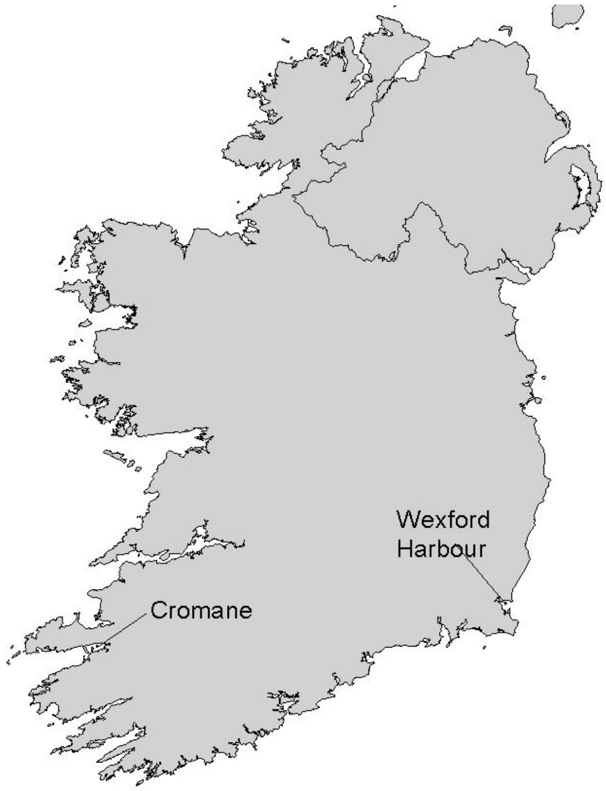

Figure 18: Locations of the sampling for species composition associated with commercial mussel beds in Ireland.

In total 42 macorinvertebrate species were observed in Wexford and 47 species in Cromane (Table 5). In the samples one exotic non-indigenous species was recorded. The polychaete *Aphelochaeta marioni* was found at a culture plot in Wexford. This species is also present in the Oosterschelde (Wolff, 2005).

Table 5 Macroinvertebrate species observed at the commercial mussel beds in Wexford (left) and Cromane (right). Exotic species are highlighted.

Wexford

Taxa	Species
Annelida	*Aonides oxycephala*
	Aphelochaeta marioni
	Autolytus prolifera
	Capitomastus minimus
	Chaetozone setosa
	Eumida bahusiensis
	Glycera tridactyla
	Kefersteinia cirrata
	Lepidonotus squamatus
	Melinna palmata
	Nephtys hombergii
	Nereis longissima
	Nereis virens
	Nicolea venustula
	Notomastus latericeus
	Pholoe synophthalmica
	Phyllodoce mucosa
	Platynereis dumerilii
	Polydora sp.
	Pomatoceros lamarckii
	Scoloplos armiger
	Spio sp.
	Sthenelais boa
	Tubificoides benedii
	Tubificoides pseudogaster
	Tubificoides sp.
Bryozoa	*Membranipora membranacea*
Cnidaria	*Actina sp.*
	Actinia sp.
Crustacea	*Cancer pagurus*
	Carcinus maenas
	Coleoptera larva
	Gammarus zaddachi
	Melita palmata
	Pagurus bernhardus
	Pinnotheres pisum
	Pisidia longicornis
	Semibalanus balanoides
Echinodermata	*Amphipholis squamata*
	Asterias rubens
Mollusca	*Abra alba*
	Cerastoderma edule

Cromane

Taxa	Species
Annelida	*Anaitides mucosa*
	Aonides oxycephala
	Capitella capitata
	Capitomastus minimus
	Chaetozone setosa
	Eulalia viridis
	Eumida bahusiensis
	Glycera tridactyla
	Kefersteinia cirrata
	Lanice conchilega
	Lepidonotus squamatus
	Malacoceros fuliginosus
	Melinna palmata
	Nemertea sp.
	Nephtys hombergii
	Nereis longissima
	Nicolea venustula
	Perinereis cultrifera
	Pholoe synophthalmica
	Phyllodoce mucosa
	Platynereis dumerilii
	Polydora sp.
	Polyophthalmus pictus
	Pomatoceros lamarckii
	Pomatoceros triqueter
	Scoloplos armiger
	Tubificoides benedii
	Tubificoides pseudogaster
Bryozoa	*Membranipora membranacea*
Cnidaria	*Actina sp.*
	Actinia sp.
Crustacea	*Cancer pagurus*
	Carcinus juvenile
	Carcinus maenas
	Chaetogammarus marinus
	Gammarus insensibilis
	Jaera albifrons
	Melita palmata
	Pinnotheres pisum
	Pisidia longicornis
	Semibalanus balanoides
Echinodermata	*Amphipholis squamata*
	Asterias rubens
Mollusca	*Cerastoderma edule*
	Leptochitona cinereus
	Littorina littorea
Vertebrata	*Nerophis lumbriciformis*

4.3 Species associated with mussel beds in Wales

Contribution of R. Seed, J. Bussell and L. Oliver (School of Ocean Sciences, University of Wales Bangor)

In this report, an overview is given of macroinvertebrate species that are associated with commercial mussel beds in Wales. Table 6 results from three separate studies of the commercial mussel beds in the Menai Strait (N. Wales). The second table (Table 7) represents the data from a study of a commercial mussel bed in Swansea Bay (S. Wales) and the third table (Table 8) gives an overview of the species associated with mussels beds located in and around the Conwy Estuary (N. Wales). These studies were all concerned with the macroinvertebrate diversity of mussel beds and were not designed specifically to investigate the presence of exotic species.

Exotic species have been highlighted in the tables. The barnacles *Elminius modestus* and *Balanus improvisus* are both exotic species (Minchin & Eno, 2002) but not a direct threat to mussel fisheries. The exotic mollusc *Crepidula fornicata* or American slipper limpet can reach such densities that it will completely carpet the seabed and so is undesirable both from a fisheries and conservation point of view (Eno *et al.*1997). This species has been found in south Wales but not in north Wales or the Menai Strait. The polychaete *Polydora ciliata* is not an exotic species but does burrow into the shell of infected mussels causing weakness that renders the animals more susceptible to predation (Ambariyanto & Seed, 1991; Lauckner, 1983).

In terms of algae, there are two species of concern. *Sargassum muticum* is an exotic macro algal species that causes the displacement of native species through overgrowing and shading and is also a fouling organism in oyster beds (Eno *et al.*, 1997). Current records show that *Sargassum* has only been found at the Caernarfon end of the Strait where there are no commercial mussel beds. *Coscinodiscus wailesii* is a non-native centric diatom of unusually large size which has come to dominate the plankton in Red Wharf Bay / Conwy Bay in the autumn – winter period. This diatom can reach high numbers and produce copious amounts of mucilage that accumulates insoluble skeletons of plankton and mineral particles thereby increasing its volume and density and blanket the seabed (Eno *et al.*, 1997).

Table 6 Macroinvertebrate species observed at intertidal areas of the commercial mussel beds in the Menai Strait, N. Wales. The list is a compilation of three different studies. These surveys all took place between 2000 and 2006. Some of the data have been published in Beadman *et al.* (2004), and some data are taken from ongoing research projects being conducted at the School of Ocean Sciences. Exotic species are highlighted.

Taxa	Species
Annelida	*Ampharete acutifrons*
	Amphicteis gunneri
	Arenicola marina juv
	Capitella capitata
	Cirratulus cirratus
	Cirratulus filiformis
	Hediste diversicolor
	Lanice conchilega
	Malacoceros fuliginosus
	Nephtys hombergii
	Nereimyra punctata
	Notomastus latericeus
	Pholoe assimilis
	Pholoe inornata
	Polydora ciliata
	Pseudomystides limbata
	Pygospio elegans
	Scolelepsis squamata
	Scoloplos armiger
	Sphaerodoridium claperedii
	Sthenelais boa
	Tubificoides benedii
Crustacea	*Amphithoe rubricata*
	Balanus crenatus
	Carcinus maenas
	Chaetogammarus spp.
	Corophium arenarium
	Elminius modestus
	Gammarus locusta
	Hyale nilssoni
	Jaera albifrons
	Melita palmate

Taxa	Species
	Pinnotheres pisum
	Pisidia longicornis
	Semibalanus balanoides
Echinodermata	*Amphipholis chiajei*
	Amphipholis squamata
	Asterias rubens
Mollusca	*Buccinum juv.*
	Cerastoderma juvenile
	Gibbula umbilicalis
	Leptochitona cinereus
	Littorina littorea
	Littorina obtusata
	Macoma balthica
	Modiolula phaseolina
	Mysella bidentata
	Mytilus edulis
	Nucella lapillus
	Patella vulgata
	Potamopyrgus antipodarum

Table 7 Macroinvertebrate species observed at a subtidal commercial mussel bed located in Swansea Bay (S. Wales) the details of which can be found in Smith & Shankley (2004). Exotic species are highlighted.

Taxa	*Species*
Annelida	*Ampharete acutifrons*
	Eumida sanguinea
	Lanice conchilega
	Nephtys hombergii
	Owenia fusiformis
	Phyllodoce groenlandica
Crustacea	*Abludomelita obtusata*
	Acanthomysis longicornis
	Ampelisca brevicornis
	Atylus swammerdami
	Carcinus maenas
	Pagurus pubescens
	Pisidia longicornis
	Semibalanus balanoides
Echinodermata	*Amphiura chiajei*
Mollusca	*Crepidula fornicata*
	Modiolula phaseolina
	Mytilus edulis
	Spisula subtruncata
Pycnogonida	*Nymphon gracile*

Table 8 Macroinvertebrate species observed on intertidal_mussel beds located in and around the Conwy Estuary (N. Wales). There is a small mussel fishery in the Conwy estuary, but harvesting is done only by hand and the mussels are not exported. However, seed mussels are occasionally taken from the mouth of the estuary and re-laid in the Menai Strait. Data from an ongoing PhD project University of Wales, Bangor. Exotic species are highlighted.

Taxa	*Species*
Annelida	*Ampharete acutifrons*
	Capitella capitata
	Cirratulus cirratus
	Cirratulus filiformis
	Eteone picta
	Eulalia bilineata
	Eulalia viridis
	Hediste diversicolor
	Heteromastus filiformis
	Oligochaete indet.
	Pholoe inornata
	Phyllodoce maculata
	Scoloplos armiger
	Sphaerosyllis bulbosa

Taxa	*Species*
	Aphelochaeta marioni
	Tubificoides benedii
Chelicerata	*Mite (Astigmata)*
	Mite (Cryptostigmata)
	Mite (Mesostigmata)
Crustacea	*Anthura gracilis*
	Balanus balanoides
	Balanus improvisus
	Carcinus maenus
	Chaetogammarus marinus
	Chaetogammarus stoerensis
	Corophium arenarium
	Elminius modestus
	Eulimnogammarus obtusata
	Gammarus finmarchicus
	Gammarus salinus
	Hyale nilssoni
	Idotea pelagica
	Jaera albifrons
	Jaera nordmanni
	Melita palmata
	Pinnotheres pisum
	Semibalanus balanoides
	Sphaeroma serratum
Hexapoda	*Anurida maritima*
	Chironomid larvae
	Diptera larvae
Mollusca	*Hydrobia neglecta*
	Juvenile Littorinids <10mm
	Lepidochiton cinereus
	Littorina littorea
	Macoma balthica
	Mytilus edulis
	Nucellus lapillus
Nemertea	*Emplectonema gracile*
	Lineus bilineata
	Lineus ruber
	Lineus viridis
	Nemertopsis flavida
Sipuncula	*Sipunculan indet.*

5 Samples from imported mussels

5.1 Approach

The mussel imports from Ireland and the UK arrive in Yerseke in big-bags that are placed in temperature conditioned trucks. The mussels are not stripped, but are transported with the tare and all organisms that were part of the tare. In order to get an idea of the species that come with the tare, samples are taken directly from the top of the big-bags in the trucks.

In total 61 trucks were sampled in the period 17 February 2006 until 30 March 2006. The average weight of the samples was 5.5 kg (stdev 1.1 kg). The average amount of tare was 21 % (1.2 kg), which corresponds to the average tare percentage of the import consumption mussels at the auction (23.2%). During the relative short period, trucks arrived from 6 production areas (Table 9). Of the major production areas, only Belfast Lough was not sampled.

Table 9 Number of trucks sampled for species determination per production area.

Location	#samples
Lough Foyle	12
Carlingford Lough	4
Wexford	19
Castlemaine Harbour	4
Menai Strait	21
Poole Harbour	1
Total	61

In the lab, the tare was separated from the mussels and sieved over a 1 mm sieve. Samples were stored in formaldehyde (40%) until analysis. Within each sample, the organisms were determined to species level as much as possible. It is also recorded whether the species was alive when it was caught or whether it was already dead (remains of shells). The dead species might give an indication of the species that are present at the production grounds (or the fishing grounds for the juvenile mussels) and could potentially be transported alive with the mussel transfer.

5.2 Results

In total 52 species could be identified in the samples that have been taken from the trucks (Table 10). Organisms that could not be identified to species level (e.g. organisms that were damaged) are excluded from the list. In total 4 algal species were identified. The algal species were all recorded as living, but may have been damaged. A total of 9 worm species and 3 echinoderms were identified. For the Mollusks 25 species were identified, of which only 10 species were living. From the other 15 species only shell remains were found. Finally 10 crustaceans and one bryozoan (*Flustra foliocea*) was found.

Table 10 Species recorded in the transport trucks from the Irish and Celtic Sea. L = alive when caught and D = dead when caught. Exotic species are highlighted.

Group	**Species**	**Lough Foyle**		**Carlingford Lough**		**Wexford**		**Castlemaine Harbour**		**Menai Strait**		**Poole Harbour**	
		L	D	L	D	L	D	L	D	L	D	L	D
Algae	*Ascophyllulum nodosum*			X				X		X			
	Fucus serratus	X		X				X		X			
	Fucus vesiculosus			X		X		X		X			
	Laminaria saccharina	X		X									
Annelida	*Anaitides maculate*									X			
	Cirratulus filiformis			X									
	Harmothoe imbricate									X			
	Harmothoe impar	X											
	Lepidonotus squamatus					X							
	Nereis longissima			X		X		X		X			
	Pomatoceros lamarcki	X				X		X		X			
	Pomatoceros triqueter	X				X				X			
	Streblospio shrubsolii					X							
Echinodermata	*Asterias rubens*	X		X				X		X			
	Ophiotrix fragilis	X		X		X				X			
	Psammechinus miliaris					X							
Mollusca	*Bittium reticulatum*		X				X						
	Buccinum undatum		X		X		X	X	X	X	X		
	Cerastoderma edulis	X	X		X	X	X		X		X	X	
	Corbula gibba						X				X		
	Diodora apertura						X						
	Diodora graeca						X						
	Donax vittatus						X						
	Echinacardium echinata												X
	Gibbula cineraria	X											
	Littorina littorea		X		X		X	X		X	X		
	Macoma baltica		X				X	X					
	Musculus costulatus			X									
	Mya arenaria						X						
	Mytilus edulis	X		X		X		X		X			
	Nassarius pigmaeus		X										
	Nucula nitidosa		X										
	Nucula nucleus	X											
	Nucula sulcata						X						
	Paphia rhomboides		X				X						
	Pavicardium exiguum		X				X						
	Spisula subtruncata		X										
	Tapes philippinarum						X						
	Turritella communis		X		X								
	Venerupis senegalensis	X	X			X	X				X		
	Venus verrucosa	X	X				X						
Crustacea	*Balanus crenatus*	X		X		X		X		X			
	Balanus improvisus	X				X		X				X	
	Cancer pagurus					X							
	Carsinus maenas	X		X		X	X	X		X	X		
	Elminius modestus	X		X		X		X		X			
	Gammarus locusta	X											
	Pagurus bernardus	X								X			
	Pagurus pubescens	X		X		X				X			
	Pinnotheres pisum			X			X			X			
	Pisidia longicornis	X				X	X			X			
Bryozoa	*Flustra foliacea*	X								X			

5.3 Evaluation of the results

In total 73 kg of tare was examined from the import. In the samples 4 species were recorded that are characterized as exotic non-indigenous species. From two species: *Mya arenaria* and *Tapes philippinarium* only the shell remains are found. *Mya arenaria* has established in Ireland and the UK (Minchin & Eno, 2002) and is quite common in the Netherlands. The Manila clam (*Tapes philippinarium*) is not established in Ireland and the UK and the shell is probably a remain of the intensive clam industry in Ireland (Parsons, 2005; Parsons *et al.*, 2004). Two exotic crustaceans were found alive in the samples, the acorn barnacle (*Balanus improvisus*) and the modest barnacle (*Elminius modestus*). *Balanus improvisus* is possibly a cryptogenic species and present for a long time in the Oosterschelde (Wolff, 2005). *Elminius modestus* is an exotic species originating from New Zealand and southern Australia (Wolff, 2005) that is present in the Oosterschelde since the 1950s (Den Hartog 1953 cited in Wolff, 2005).

It has to be emphasized that not all individuals could be identified to species level since they were too much damaged and essential deterministic characteristics were missing. This was especially the case for some of the worms. In the table we have only included those species that could be identified to species level.

Some species could also be introduced into the Oosterschelde with the mussels as eggs or juvenile organisms attached to the mussel shells. By cultivation the shell material in the lab organisms can be identified. In this study, no cultivation of shell material could be realized in the frame work of this project and therefore organisms that are transported as juveniles or eggs, attached to the shells might be missed.

6 Exotic species in the Oosterschelde

Contribution of M. J. De Kluijver (AquaSense)

6.1 Introduced species in the Oosterschelde

One of the most pervasive and ecologically damaging effects of human activities in the marine environment is the widespread movement of species beyond their natural range (Ricciardi & Rasmassen, 1998). In most countries, 10^2-10^4 non-indigenous species have been documented (Lodge, 1993), and these numbers will increase as expanding global trade increases. Besides natural dispersal processes, there are several physical means (introduction vectors) by which species are transported from one geographic region to another. These introduction vectors can be grouped into a number of categories:

- Ships, moveable structures and other craft.
  - Ballast water (since the 1870s), solid ballasts and ballast sediments.
  - Hull fouling.
- Aquaculture activities.
  - Intentional release and stock movements and spread of associated species.
  - Accidental release, incl. the associated species.
  - Gear movements.
  - Discharge of feeds.
- Fisheries.
  - Intentional release of species (e.g. the red king-crab, American lobster, pink salmon).
  - Gear movements (e.g. *Caulerpa taxifolia* within the Mediterranean).
  - Release of packing material for living crustaceans and molluscs.
  - Discharge of frozen foods (e.g. white-spot syndrome virus in prawns).
- Aquarium industry and public aquaria.
  - Intentional releases of traded species (e.g. *Limulus polyphemus*).
- Marine leisure tourism.
  - Transport of bait worms for anglers.
  - Movements through fishing and diving gear.
- Research and education.
  - Releases of study objects (e.g. *Mastocarpus stellatus*).
  - Transplantation experiments between different areas.
- Others.
  - Opening of new waterways.
  - Floating objects in the sea.

Once an exotic non-indigenous species has reached a recipient area, secondary vectors or natural dispersal processes might cause a further expansion towards other areas. In general ship movements (hull fouling and ballast water) are the most important primary vectors for the introduction of exotic non-indigenous species. As a secondary vector of transport to the Dutch waters, natural expansion and shellfish transport become more important (Wolff, 2005).

In this study, a distinction is made between exotic non-indigenous and NE Atlantic non-indigenous species. The area of origin of exotic species is located outside the NE Atlantic shelf and for these species a distinction between the possible vectors is made. For most species indigenous for the NE Atlantic, that recently entered the Oosterschelde estuary, the distinction between the possible vectors is more difficult. An extension of the natural range of a species, caused by climatic changes, can be facilitated by anthropogenic influences, like stock movements.

The Oosterschelde estuary is a tidal inlet of the North Sea with unique characteristics, which enable introduced species to establish themselves. Through the construction of the Delta works in 1986, an environment was created with decreased current velocities, high temperatures during summer and a constant salinity. The former estuary provides different types of habitats. The bottom of the tide-ways are sandy and towards the eastern part of the estuary the texture of the sediment is finer and the mud content increases. Especially in the eastern part peat banks protrude through the sediments. Most of the tide-ways are protected with hard substrata of different nature. Limestone and various kinds of non-erosive blocks form 'a natural rocky coast'. The estuary is connected through sluices with brackish waters. Through this diversity in habitats it is relatively easy for an introduced species to establish itself.

6.2 Results

In Table 11, the exotic non-indigenous species in the Oosterschelde and adjacent waters are listed. Although it is not always possible to identify the primary vector, it was recorded for the exotic non-indigenous species. If known, also the secondary transport vector for the introduction in the Dutch coastal waters is given. For each of the species the area of origin is listed as well as the location where it was first found in Europe. In Appendix B.1 a more detailed overview is given for these species.

Table 11 Exotic non-indigenous species in the Oosterschelde and adjacent waters, primary and secondary transport vector (AQ = aquaculture, SH = Ships Hull, B = ballast water and dry ballast, H = Host, D = deliberate, T = trade, N= Natural transport ? = unknown) and year of introduction in NL. For a more detailed description of the species: see Appendix B.1

Taxon	Species	Prim vector	Sec Vector	Year NL
Algae	*Acrochaetium densum*	?	?	1967
	Agardhiella subulata	AQ	?	1998
	Alexandrium leei	?	?	1991
	Anotrichium furcellatum	AQ	?	1950
	Antithamnionella spirographidis	SH	AQ	1974
	Antithamnionella ternifolia	SH	AQ	1951
	Botrytella sp	?	?	1919
	Codium fragile ssp tomentosoides	SH	AQ	1904
	Colaconema dasyae	AQ	H	ca. 1960s
	Colpomenia peregrina	AQ	?	1986
	Dasya baillouviana	AQ	?	1950
	Dasysiphonia sp	AQ	?	1994
	Elachista sp	?	H	1993
	Grateloupia turuturu	AQ	?	1993
	Leathesia verruculiformis	?	H	1994
	Lomentaria hakodatensis	AQ	?	2004
	Myriactula sp	?	H	1983
	Odontella sinensis	B	?	1905
	Polysiphonia harveyi	?	?	1960
	Polysiphonia senticulosa	?	?	1993
	Sargassum muticum	AQ	N	1980
	Ulva pertusa	?	?	1993
	Undaria pinnatifida	AQ	D	1999
Protista	*Bonamia ostreae*	AQ	AQ	1980
	Haplosporidium armoricanum	AQ	AQ	1974
	Marteilia refringens	AQ	AQ	1974
Porifera	*Acervochalina loosanoffi*	AQ	?	1880s
	Celtodoryx girardae	AQ	?	2002
	Haliclona xena	AQ	?	1982
	Mycale micracanthoxea	?	?	19th c.
	Scypha scaldiense	?	?	1951
Cnidaria	*Garveia franciscana*	?	?	1920
	Gonionemus vertens	?	?	1960
	Haliplanella lineata	SH	AQ	1912
	Nemopsis bachei	SH	?	1990s
	Thieliana navis	?	?	1964
Platyhelminthes	*Stylochus flevensis*	?	?	1921
Annelida	*Ficopomatus enigmaticus*	SH	?	1968

Taxon	Species	Prim vector	Sec Vector	Year NL
	Janua brasiliensis	SH	H	1985
	Marenzelleria wireni	B	?	1983
	Nereis virens	?	?	1915
	Proceraea cornuta	SH	AQ	1941
Nematoda	*Anguillicola crassus*	AQ	?	1985
Crustacea	*Balanus eburneus*	SH	?	1890s
	Callinectes sapidus	B	?	1932
	Caprella mutica	?	?	1993
	Elminius modestus	SH	?	1946
	Eriocheir sinensis	B	?	1929
	Eurytemora americana	?	?	1963
	Hemigrapsus penicillatus	SH	?	2000
	Hemigrapsus sanguineus	B	?	1999
	Monocorophium sextonae[1]	SH	?	1952
	Mytilicola intestinalis	AQ	?	1949
	Mytilicola orientalis	AQ	AQ	unknown
	Mytilicola ostreae	AQ	AQ	1992
	Palaemon macrodactylus	?	?	1999
	Rhithropanopeus harrisii	?	?	1874
Mollusca	*Crassostrea gigas*	AQ	AQ	1964
	Crepidula fornicata	AQ	?	1929
	Ensis directus	B	N	1981
	Mercenaria mercenaria	AQ	AQ	1950s
	Mya arenaria	SH	N	1765
	Petricola pholadiformis	AQ	?	1905
Bryozoa	*Smittoidea prolifica*	AQ	?	1999
	Tricellaria inopinata	SH	?	2000
Urochordata	*Botrylloides violaceus*	SH	?	2000
	Pterophora japonica	?	?	2004
	Styela clava	SH	AQ	1974
Vertebrata	*Oncorhynchus mykiss*	T	?	1960s

In order to identify recent non-indigenous species in the Oosterschelde estuary, the inventory of 1979 is used as a base-line (Elgershuizen *et al.*, 1979). In 2000, Stegenga (2002) reported the changes in the algal composition and more recently, Wolff (2005) published a comprehensive article concerning the non-indigenous species in the marine and estuarine environment. In Table 12, a chronological overview is given of the introduction of NE Atlantic non-indigenous species in the Oosterschelde. A more detailed description of NE Atlantic non-indigenous species is presented in Appendix B.2 of this report. It should be noted that NE Atlantic species, as defined in this report could also be introduced into the Oosterschelde by natural transport processes. This definition is wider than the definition of Wolff (2005) where NE Atlantic species could only be introduced by means of human activities.

Table 12 NE Atlantic non-indigenous species that recently entered the Oosterschelde

Species	Year	Vector	Where
Palinurus elephas	1769	SH	eastern part
Leptochiton cancellatus	1897	AQ	eastern part
Elysia viridis	1899	N	
Sabellaria spinulosa	1938	AQ	eastern part
Calyptraea chinensis	1940	AQ	eastern part
Polydora hoplura	1940	AQ	eastern part
Syllis gracilis	1940	AQ	eastern part
Syllidia armata	1943	AQ	eastern part
Goniodoris castanea	1949	?	
Hymeniacidon perlevis	1951	AQ	eastern part
Tritonia plebeia	1952	?	
Palaemon adspersus	1953	?	Ouwerkerk
Goniodoris nodosa	1956	?	
Prorocentrum triestinum	1961	?	
Microphtalmus similis	1962	?	
Gobius niger	1964	?	Veerse Meer

[1] The crustacean *Monocorophium sextonae* is often indicated as an exotic species. However this species is actually a cryptogenic species (Wolff, 2005)

Species	Year	Vector	Where
Branchiomma bombyx	1973	?	Kanaal
Calliostoma zizyphinum	1976	AQ	eastern part
Haliclona rosea	1976	AQ	eastern part
Aplidium glabrum	1977	?	eastern part
Dendronotus frondosus	1977	N	
Diplosoma listerianum	1977	N	western part
Gibbula cineraria	1980	?	eastern part
Idmidronea atlantica	1985	N	central part
Thecacera pennigera	1985	?	
Bugula stolonifera	1986	SH	
Alexandrium tamarense	1989	?	
Gymnodinium mikimotoi	1989	?	
Hermaea bifida	1989	?	central part
Inachus phalangium	1989	?	western part
Leuckartiara octona	1989	?	western part
Lomentaria clavellosa	1989	?	eastern part
Plocamium cartilagineum	1989	?	western part
Schizomavella linearis	1989	?	western part
Balanus balanus	1990	AQ	eastern part
Phycodrys rubens	1991	?	eastern part
Facelina auriculata	1992	?	
Placida dendritica	1992	?	central part
Athanas nitiscens	1994	N	
Suberites massa	1994	?	western part
Limacia clavigera	1995	N	western part
Bowerbankia citrina	1997	?	
Polycera quadrilineata	1997	?	western part
Janolus hyalinus	1998	N	central part
Jorunna tomentosa	1998	N	
Parablennius gattorugine	1998	N	western part
Acanthocardia echinata	1999	?	central part
Chilionema foecundum	1999	?	western part
Flabellina pedata	1999	?	
Geitodoris planata	1999	N	
Molgula complanata	1999	?	western part
Myriotrichia clavaoformis	1999	?	Grevelingen
Onoba semicostata	1999	?	western part
Porphyrostromium boryanum	1999	?	western part
Ulva tenera	1999	?	western part
Bugula simplex	2000	SH	eastern part
Janiropsis breviremis	2000	?	western part
Amphiporus lactifloreus	2001	?	eastern part
Bimeria vestita	2001	?	central part
Carcinonemertes carcinophila	2001	?	western part
Emplectonema gracile	2001	?	western part
Flabellina lineata	2001	?	
Lineus sanguineus	2001	?	western part
Nemertopsis flavida	2001	?	western part
Nephasoma minuta	2001	?	eastern part
Nolella pusilla	2001	?	eastern part
Tetrastemma ambiguum	2001	?	western part
Tetrastemma coronatum	2001	?	eastern part
Tetrastemma robertianae	2001	AQ	eastern part
Trivia arctica	2001	?	
Fenestrulina malussii	2002	N	eastern part
Petalonia filiformis	2002	?	western part
Polysiphonia brodiaei	2002	?	western part
Prosorhochmus claparedii	2002	?	western part
Trinchesia rubescens	2002	?	
Eubranchus farrani	2003	?	central part
Gobius paganellus	2003	N	
Griffithsia corallinoides	2003	?	eastern part
Halecium lankesteri	2003	?	western part
Liocarcinus pusillus	2003	?	central part
Sertularella ellisii	2003	?	western part
Balistes carolinensis	2004	N	central part
Cutleria multifida	2004	?	western part
Gobiusculus flavescens	2004	N	eastern part

Species	Year	Vector	Where
Amphiura brachiata	2005	?	
Corymorpha nutans	2005	?	western part
Haliclona cinerea	2005	AQ	construction pit
Halisarca dujardini	2005	?	western part
Oscarella lobularis	2006	?	western part

6.3 Discussion

In total 158 non-indigenous species have been found in the SW Delta area: 69 with an exotic origin and 89 with a NE Atlantic distribution. 32% of the exotic species were introduced primarily by shipping and 36% by aquaculture. The remaining 32% were brought into the area by trade or its vectors are unknown. The total of 69 exotic species is less than the 80 estimated species for the whole North Sea in 1998 (Reise *et al.*, 1999).

Table 13 Area of origin and vectors for the exotic species in the Oosterschelde estuary.

Vector/origin	Pac.	NW Atl.	Ind.Oc./trop	Med/Ponto	Unkn.	total
Ships	12.5	7	1.5	0	1	22
Aquaculture	12	7.5	0	2.5	3	25
Trade	1	0	0	0	0	1
Unknown	11.5	3.5	1	1	4	21
total	37	18	2.5	3.5	8	69

The number of introductions from the Pacific is larger than the number from the NW Atlantic and most species were brought into the NE Atlantic by aquaculture (Table 13). The vectors favored different taxonomic groups. Shipping was most successful for crustaceans (32% of the introductions), followed by polychaetes (18%), and algae (14%). Sponges were not introduced by this vector. Aquaculture favored algae (40%), followed by sponges and crustaceans (each 12%). Polychaetes were not introduced by this vector.

The number of NE Atlantic species entering the Oosterschelde estuary is slightly larger than the number of exotic species. 50% of the exotic species were brought into the area since 1971, while the introduction of NE Atlantic species in the Oosterschelde estuary happened more recently. 50% of the species entered the estuary after 1996 (Figure 19). This might partly be a temporary effect related to the mild winters. It might be suspected that many of these species will disappear again in case of a severe winter.

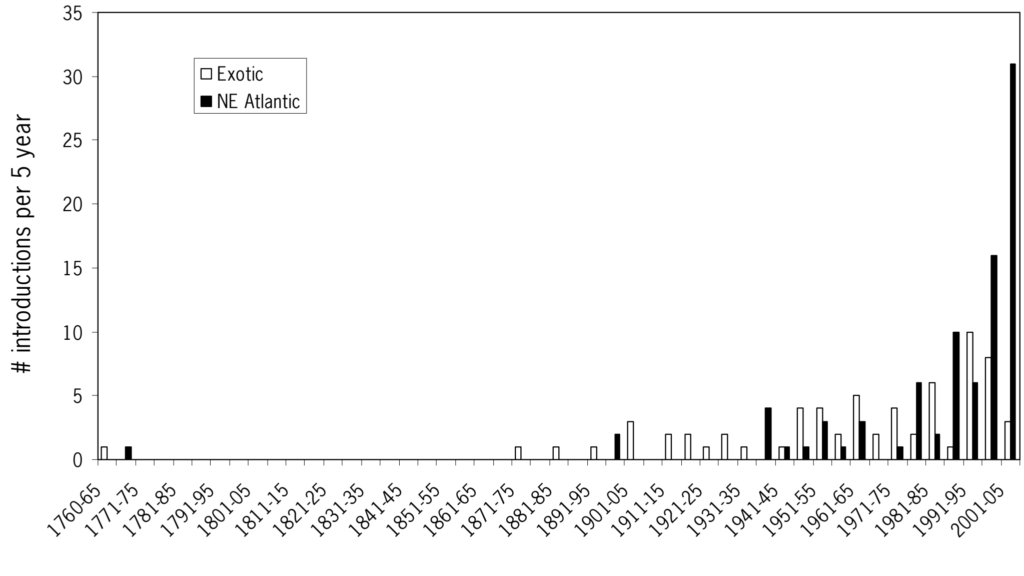

Figure 19: Number of introductions (first observations) of exotic and NE Atlantic non-indigenous species in the Oosterschelde and adjacent waters per 5 years.

There might be several reasons for the increased introductions of NE Atlantic species after 1996.

- Climatic changes, the winters of 1995/96 and 1996/97 were the last severe ones. As the temperature in the Oosterschelde estuary is lower during winter than in the North Sea, mild winters favor NE Atlantic species to establish themselves.
- An increase in the number of underwater observations and the accessibility of the results. The number of observations strongly increased with the popularity of diving in combination with photography and the results can be accessed through the internet, for example through 'Stichting Anemoon'.
- Increased introductions due to increased transport related to human activities.

But it is most likely that all three factors are involved:

- 21% of the species belongs to the nudibranchs, a group of species that is known to be sensitive for changes in temperature. This might partly be a temporary effect. It might be suspected that many of these species will disappear again in case of a severe winter.
- 12% of the species belonged to nemertins, a group of species that might have been overlooked in the past.
- 10% of the species belonged to algae, 9% to sponges and 8% to crustaceans, a contribution that is more similar with the introduction of exotic species through aquaculture than shipping.

Once an introduction is successful, the introduced species might influence the biodiversity of the communities in the recipient area. In most cases, a successful introduction of an exotic species will result in an increase in biodiversity and the impact on the other organisms is negligible or low. However in some exceptional cases an introduction can have a significant effect on the functioning of the ecosystem. An example for this is the introduction of *Crassostrea gigas* in the Oosterschelde. During a monitoring program of sublittoral communities in the Oosterschelde a significant decrease in biodiversity (Figure 20) was found by an increasing percentage cover of the introduced exotic *Crassostrea gigas* (Kluijver & Dubbeldam, in prep).

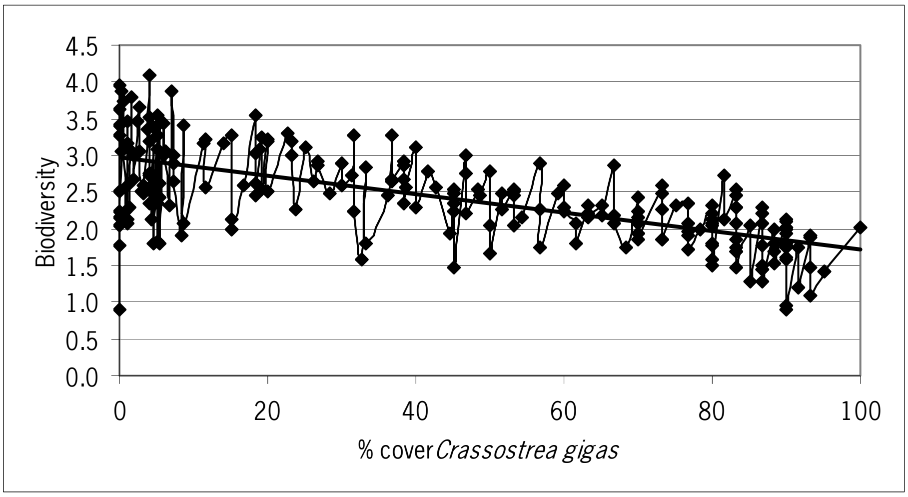

Figure 20: Relation between the percentage cover of *Crassostrea gigas* and the biodiversity of the original communities in the Oosterschelde estuary (n=230, P<5%) (Kluijver & Dubbeldam, in prep).

A similar effect was found for the introduced tunicate *Didemnum lahillei*. Although its area of origin is uncertain at this moment, it might be possible that it is a NE Atlantic species. Its distribution pattern in the Oosterschelde suggest that it has been introduced with oyster imports.

7 Genotype of mussels from the Oosterschelde and Ireland

With the import of mussels from the Irish and Celtic Sea, there is a chance of introducing the non-indigenous *Mytilus galloprovincialis* into the Oosterschelde. The risk of introducing *M. galloprovincialis* is the product of chance and effect. *M galloprovincialis* can probably interfere with the endemic *M. edulis* in the Oosterschelde. The risk of introducing *M. galloprovincialis* from the Irish and Celtic Sea is depending on the presence of *M. galloprovincialis* in Ireland and the Oosterschelde. It can be assumed that *M. galloprovincialis* has no problem to survive the transport in the trucks. If *M. galloprovincialis* is not present in the Irish and Celtic waters, there is no chance of introducing *M. galloprovincialis* into the Oosterschelde. On the other hand, if *M. galloprovincialis* is already present in the Oosterschelde, the effect of this introduction was apparently low.

In this study, which is based on literature, an overview is given on the distribution of M. galloprovincialis within Europe. Within the framework of this project also samples have been taken from Ireland, UK and the Oosterschelde which are at this moment analyzed by the Marine Biotechnology Institute of Oceanology in Poland. The results could not be included in this concept report, but will be included in the final report.

7.1 Mytilus spp. in European waters

The blue mussel (*Mytilus* spp.) is composed of three different species which are all present in the European coastal waters: *Mytilus edulis, Mytilus galloprovincialis* and *Mytilus trossulus* (Braby & Somero, 2006). In general, *M. galloprovincialis* is a temperate warm-water mussel, occurring in more exposed locations which do not experience pronounced salinity variations. In Europe, *M. galloprovincialis* occurs originally in the Mediterranean Sea and the Black Sea. *M. edulis* is a temperate cold-water mussel which can occur in brackish water. It is the native species for the Northeastern Atlantic coast, including the Oosterschelde and the Irish and Celtic Sea. *M. trossulus* is a cold-water mussel that is apparently able to withstand very low salinities (Gardner, 1996). *M. trossulus* is the endemic species of the Baltic Sea.

It is difficult to distinguish between *M. galloprovincialis* and *M. edulis* on morphological parameters (IJzerman, 1994). It is believed that *M. galloprovincialis* has a broader and angular shell then *M. edulis*, but in the field, it is difficult to differentiate due to morphological adaptations to environmental conditions and interbreeding between the species. Molecular techniques, such as enzyme electrophoresis and DNA sequencing (Bendezu *et al.*, 2005; Gardner, 1996; Toro, 1998), are often used to differentiate between the different *Mytilus* species. For the identification of the mussels, in general, several different markers are used, after which multivariate techniques are used to make a distinction between the species.

The three *Mytilus* species show large similarities in their genetic material. As a result they are able to interbreed with each other. When two distinct species co-occur and interbreed, a hybrid zone can result. If the genetic incompatibilities between the two taxa are not too great, fertile F1 hybrids and backcrosses can be formed (Gardner, 1996). One of the most evident effects of hybridization is the formation of individuals which are morphologically, physiologically, or behaviorally intermediate between the parental types (Gardner, 1996). The zone of hybridization between *Mytilus edulis* and *Mytilus galloprovincialis* in the Northeast Atlantic waters extends from the coasts of Scotland to the Basque Country (Daguin *et al.*, 2001). The hybrid zones for *Mytilus* spp. are often characterized by a mosaic of populations, which are either pure *M. edulis* or *M. galloprovincialis* or hybrids between *M galloprovincialis* and *M edulis* (Daguin *et al.*, 2001; Gardner, 1996; Hilbisch *et al.*, 2002). However, at some locations, hybridization and gene introgression is so extensive that no individuals of pure *M. edulis* or pure *M. galloprovincialis* can be found (Riginos & Cunningham, 2005).

In Figure 21, the distribution of *M. galloprovincialis*, *M. edulis* and their hybrids is presented (Daguin *et al.*, 2001). The analysis was based on DNA extraction and PCR techniques followed by correspondence analysis. From the figure it can be seen that *M. galloprovincialis* dominates in the Mediterranean and Black Sea and along the west coast of Spain and Portugal. *M. edulis* dominates in Scandinavia and in the Channel. Along the west coast of France (Brittany and Vendée) but also at the west coast of England (Cornwall), a zone of hybridization occurs where *M. edulis* and *M galloprovincialis* are present as well as the hybrid form.

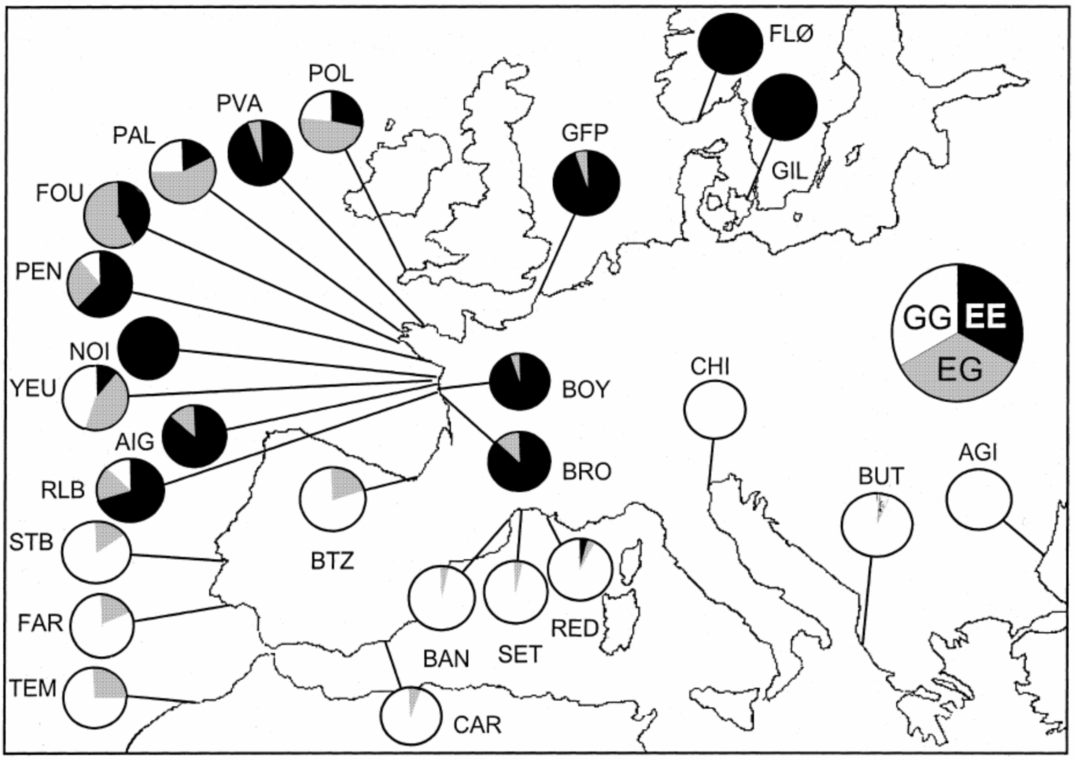

Figure 21: Genotypic composition of *Mytilus* spp., subdivided in pure *M. galloprovincialis* (GG; white), Pure *M. edulis* (EE, black) and hybrids between *M. galloprovincialis* and *M. edulis* (grey, EG) at various locations in Europe. Figure from (Daguin *et al.*, 2001)

In Figure 22, the distribution of *M. galloprovincialis*, *M. edulis* and *M. trossulus* in the European waters is presented together with the hybrid forms. The analysis are based on DNA extractions, followed by a specific DNA marker (*Me15/16*) and PCR amplification (Śmietanka *et al.*, 2004). The figure shows a similar pattern as Figure 21, with a dominance of *M. galloprovincialis* in the Mediterranean, Sea of Azov and at the Portuguese coast. *M. edulis* is highly dominant in the northern part (Iceland the White Sea). *M. trossulus* is present in the Baltic Sea, where it hybridizes with *M. edulis*. In Ireland (Galway) and North Ireland (Giants Causeway), *M. galloprovincialis* dominates the mussel population. Some *M. edulis* are present and hybridization between the two species takes place. In Ireland and the UK, *M. galloprovincialis* occurs in exposed areas, intermixed with *M. edulis*, whereas *M. edulis* predominates in sheltered areas. This spatial segregation in hybrid zones can be explained by differential settlement of larvae and selection at adult size. In exposed, rocky intertidal habitats, the mortality rate of *M. edulis* is higher than *M. galloprovincialis*. This is partly because *M. edulis* migrates actively to exterior parts of the mussel beds, where the probability of dislodgment is highest (Schneider *et al.*, 2005). Along the Atlantic coast of Ireland, the mussel population is dominated by *M. galloprovincialis* (Śmietanka *et al.*, 2004). It can be assumed that in the more sheltered locations in the Irish Sea, where the mussel seed is fished, *M. edulis* is more abundant, however, it is not likely that *M. galloprovincialis* is absent there. Additional field observations will give the definitive answer on this.

In the figure, also some data is presented from a location in the Oosterschelde (Yerseke). The mussels (50 individuals) at this location were sampled by hand from the shore in May 1995.

About 70% of the mussels were characterized as *M. edulis*. Also *M. trossulus* was found at this location (5%) as well as hybrids of these two (23%). From the figure it can be seen that also hybridization occurs between *M. galloprovincialis* and *M. edulis* in the Oosterschelde. No pure *M. galloprovincialis* were found, but the presence of hybrids is an indication that *M. galloprovincialis* were already present in the Oosterschelde in 1995. The total allele frequency for the Me15/16 nuclear marker for *M. galloprovincialis* in the Oosterschelde was 1% (Śmietanka *et al.*, 2004).

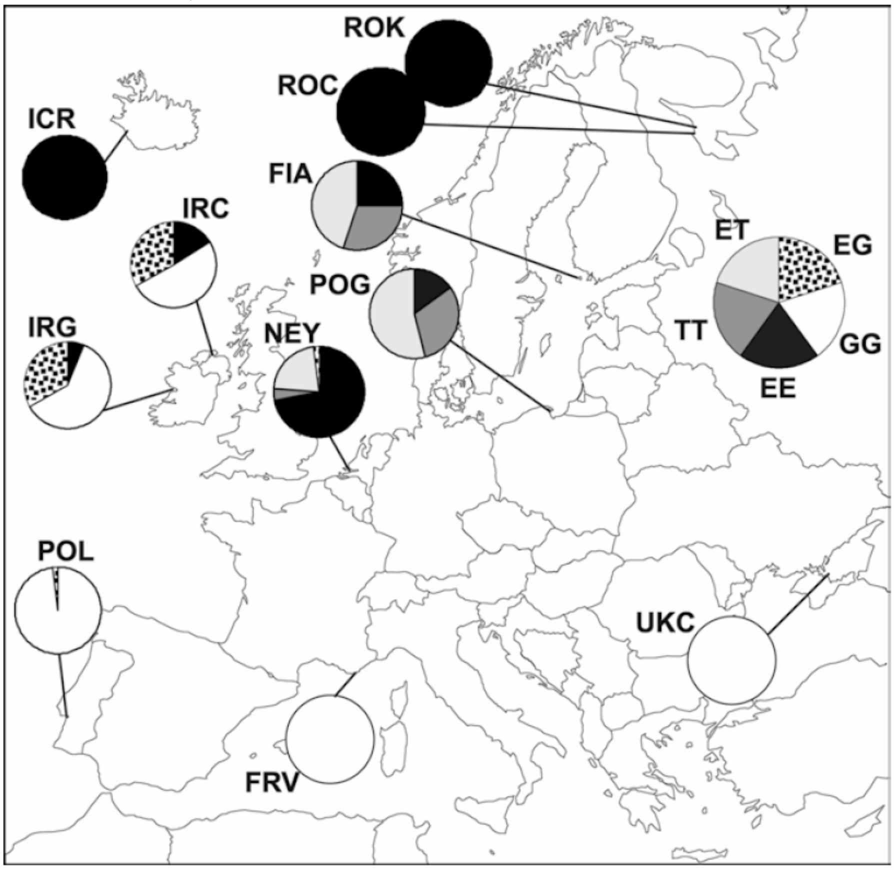

Figure 22: Distribution of *M. edulis*, *M. galloprovincialis*, *M. trossulus* and their hybrids along the European coast. From (Śmietanka *et al.*, 2004).

In another study with mussels sampled from the rope culture at Neeltje Jans (Oosterschelde) in 1994, IJzerman (1994; 1995) analyzed the genetic composition by means of iso-enzyme electrophoresis. From this study he concluded that *M. galloprovincialis* was present in the Oosterschelde. In the Wadden Sea, indications are found that *M. galloprovincialis* is also present there. In a study of 321 mussels, collected at 14 sites in 2001, two percent of the mussels were hybrids of *M. galloprovincialis* and *M. edulis*, while the remainder of the analyzed mussels were pure *M. edulis* (Luttikhuizen *et al.*, 2002)

7.2 Sampling for genetic composition of Mussels in Oosterschelde and import

Although there are indications that *M. galloprovincialis* is present both in the Irish and Celtic Sea as in the Oosterschelde, additional field sampling has been done within this study. The results of these analyses will be ready in August, and therefore it was not possible to include them in this concept report. In the final report, which will be ready in September the results of the genetic characterization will be included. In this concept report information on the presence of *M. galloprovincialis* in the Irish and Celtic Sea and the Oosterschelde is derived from literature.

As part of this study, mussels have been sampled directly from the imports (from the Irish and Celtic seas) (Table 14) as well as from various locations in the Oosterschelde (Figure 23). [1] mussels were sampled from the slopes of the dikes, in the intertidal area (11. locations, 11 samples). These mussels are recruited in the Oosterschelde. [2] Mussels from the rope culture in Bruinisse (1 location, 4 samples). These mussels are recruited in the Oosterschelde and are caught with the seed collection ropes in near Bruinisse. [3] mussels from the bottom culture plots in the Oosterschelde with Oosterschelde mussels (6 locations, 18 samples). These mussels are from the seed fishing in the Oosterschelde and are recruited in the Oosterschelde and [4] mussels from the bottom culture plots in the Oosterschelde with mussels from the Wadden Sea (2 locations, 6 samples). Each sample consists of 50 mussels. The mussels are preserved on ethanol (70%) and sent for analysis. They will be analyzed on 3 different nuclear DNA markers to look for the presence of *M. galloprovincialis*. For the samples with an unclear pattern, two additional analyses will be made.

Table 14 Production areas in the Irish and Celtic Sea from which mussels were sampled for genetic characterization. Mussels were sampled from the trucks upon arrival in Yerseke.

Location	# samples
Wexford	3
Poole Harbour	1
Carlingford	1
Lough Foyle	3
Menai Strait	2
Castlemaine Harbour	1
Total	11

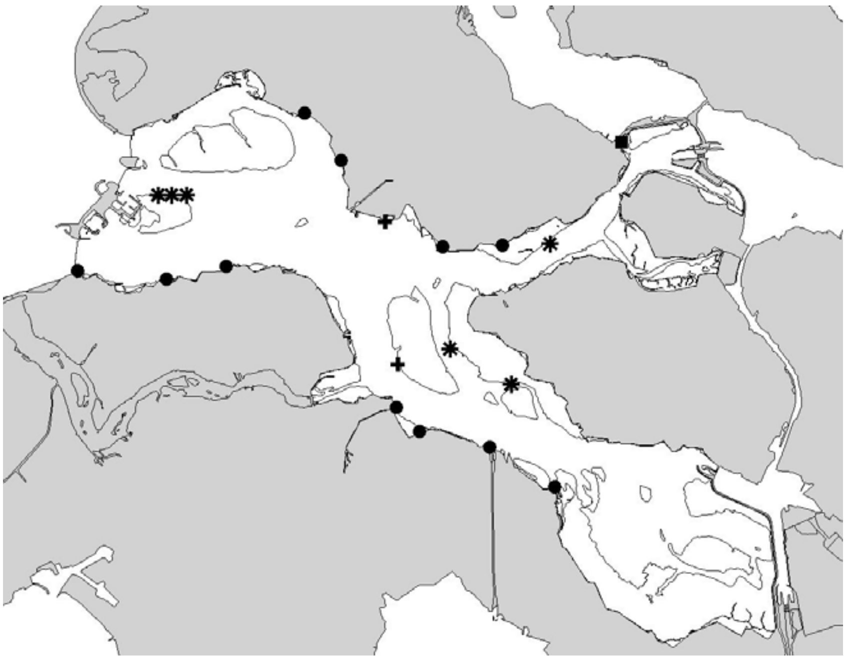

Figure 23: Sampling locations in the Oosterschelde for the genetic composition. ● = slopes of the dikes; ■ = rope culture Bruinisse; * mussel plots with Oosterschelde mussels + = mussel plots with Wadden Sea mussels.

7.3 Risks of introducing M. galloprovincialis in Oosterschelde

The Mediterranean mussel (*M. galloprovincialis*) is regarded as an invasive species. It is able to alter the physical conditions of a system by forming dense beds and fouling on hard structures.

The characteristics of *M. galloprovincialis* are largely comparable with *M. edulis*. However, *M. galloprovincialis* is assumed to be a faster grower and they have more byssus threads which makes them do better under exposed conditions and probably also in rope cultures. *M. edulis* is more adapted to colder and brackish waters.

It has invaded the shores of South Africa in the mid-1970's. From that invasion, the spreading rate was estimated at about 115 km yr^{-1} (Branch & Steffani, 2004). It is known that *M. galloprovincialis* is able to out compete and displace native mussels and become the dominant mussel species in certain localities. This is because *M. galloprovincialis* may grow faster than native mussels, be more tolerant to air exposure and have a reproductive output of between 20% and 200% greater than that of indigenous species (Branch & Steffani, 2004). It is also said that *M. galloprovincialis* has more and stronger byssus threads and therefore is better able to attach itself to the substrate in exposed conditions. *M. edulis* tends to occupy more sheltered habitats than *M. galloprovincialis* (Daguin *et al.*, 2001).

In potential, the risk of introducing *M. galloprovincialis* with juvenile mussels is larger than the risk of introducing the species with the consumption mussels. If the consumption mussels are kept in containers and they are not in spawning condition, the chance of introducing the species with the imports of consumption mussels is very low.

It can be concluded that *M. galloprovincialis* is present in Ireland and the UK. However, the data presented are mainly from exposed areas, while the mussels that are imported to the Netherlands are mainly from sheltered areas in the Irish Sea. Although it is suggested that *M. galloprovincialis* is assumed to do better in exposed areas than in sheltered areas compared to *M. edulis*, it is possible that with the import of mussels also *M. galloprovincialis* will be imported. The results of the genetic characterization from the imported mussels will give clarity on this.

From literature, there is evidence that *M. galloprovincialis* is already present in the Oosterschelde (IJzerman, 1994, 1995; Śmietanka *et al.*, 2004) and also in the Wadden Sea (Luttikhuizen *et al.*, 2002). Therefore, the possible import of *M. galloprovincialis* from the Irish and Celtic Sea will not alter the situation in the Oosterschelde. Moreover, since in the Wadden Sea *M. galloprovincialis* is present too, the import of mussels from the Wadden Sea could also be regarded a source of *M. galloprovincialis* into the Oosterschelde. The effect of the presence of *M. galloprovincialis* to the ecosystem of the Oosterschelde is apparently not quite obvious given the observation that *M. galloprovincialis* was already present in 1994. The results of the new survey are required in order to estimate the extent of the occurrence of *M. galloprovincialis* in the Oosterschelde.

8 Risk assessment

Contribution of N.H.B.M. Kaag, C.C. Karman and E.M. Foekema (TNO Imares Den Helder)

8.1 Introduction

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

The significance of the effect that the establishment of exotic species may have on the local ecosystem depends on the life history of the species 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

In this study, a semi-quantitative risk assessment is made on the risk of introducing hazardous exotic, non-indigenous species into the Oosterschelde with the mussel imports from the Irish and Celtic Sea. Roughly this risk assessment is divided in tree steps (Figure 24)

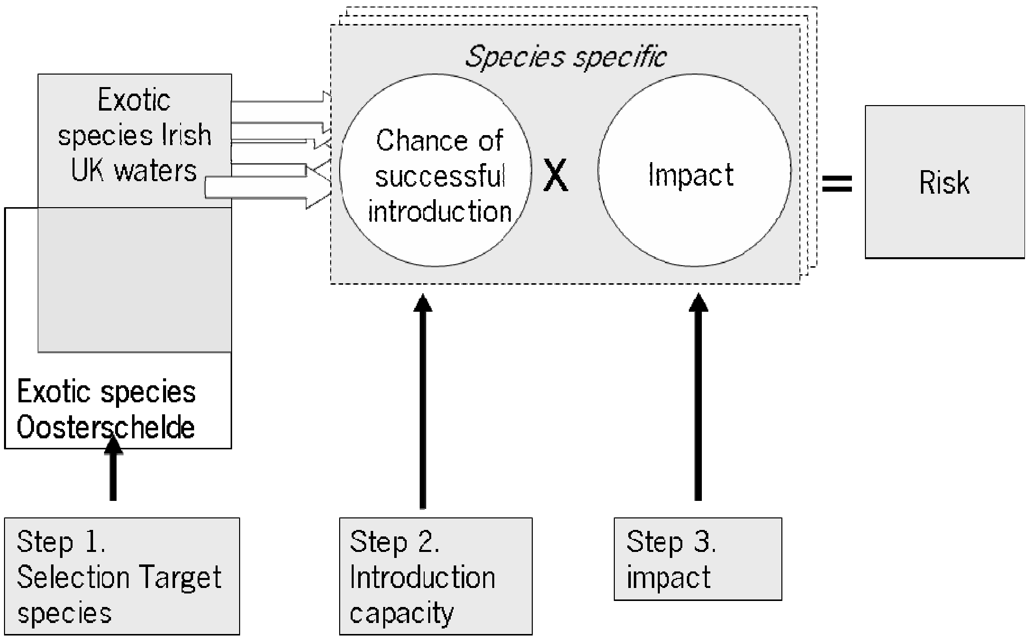

Figure 24: Overview of the set-up of the risk analysis.

In the first step, the target species are identified based on the exotic species occurring in the both starting with a list of exotic species (target species) that can be found in the Irish and Celtic Sea and are not known to be present in the Oosterschelde.

The second step is to quantify the chance that these target species may become established in the Oosterschelde due to the transfer of mussels. This assessment will be based on available information on ecological and physiological characteristics of the selected species. As far as available, also field observations (i.c. monitoring data) on the dispersion of the species and their influence upon ecosystems (pest characteristics) are considered here

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

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 combining expert judgment with field observations, a more balanced (semi-)quantitative risk analysis can be made. Moreover, by separately describing the risk of the two parts, the outcome of the second part will not be influenced by the results of the first part.

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. 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 as bacteria, viruses and parasites. A Dutch expert group concluded in 2004 that the current legislation is sufficient to prevent human safety risks due to microorganisms in consumed shellfish and that additional measures for the prevention of the introduction of microbial organisms due to transfers of shellfish are 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.

With the import of mussels also diseases and parasites of wild flora and fauna can be introduced. These type of introductions can have an important effect on the ecosystem (e.g. *Bonamia ostrea*) but these small organisms are not fully covered in this report.

8.2 Identification of target species

The 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, will be introduced into the Oosterschelde. Some of these species might settle for a couple of years, however eventually these species will disappear because the environmental conditions in the Oosterschelde are not suitable for this species to form a self-sustaining population (Wolff, 2005). If these species should be able to become established in the Oosterschelde, 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 Oosterschelde, the transport of mussels will advance the introduction. For these species the transfer of mussels forms an additional transport mechanism above the normal influences of water currents and other forms of natural transport.

All exotic non-indigenous species that are present in the source area (Irish and UK waters) and not in the Oosterschelde form the target species for this study. These target species will be 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 Oosterschelde (Table 15). There are records available of mussel transports from the Irish and Celtic Sea from the 1970's. Therefore, some of the existing exotic, non-indigenous species in the Oosterschelde might have been introduced from the Irish and Celtic Sea with the mussel transfer. For as yet, this has not resulted in severe ecological problems, but it cannot be ruled out that some of these species may cause ecological problems in the future. However, it is very difficult, if not impossible to remove these species from the system.

Table 15 Schematic presentation of the selection of the target species that could potentially be introduced in the Oosterschelde by mussel transfer from the Irish or Celtic Sea.

	Exotic non-indigenous species		
	A	B	C
Present in Irish/UK waters?	No	Yes	Yes
Present in Oosterschelde?	Not relevant	Yes	No
Target species?	**No**	**No**	**Yes**

Exotic species that are not reported as inhabitants in the Oosterschelde, 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 Oosterschelde area by natural ways from the surrounding waters, and therefore the influence of mussel transfer from Ireland or the UK is of little significance. It can also not be excluded that these species are already present in the Oosterschelde but have not yet been reported. This is the case for the algae *Alexandrium tamarense*, *Heterosigma akashiwo*, *Gyrodinium cf aureolum,* the Coelanterate *Clavopsella navis* and the mollusks *Mytilopsis leucophaeta* and *Potamopyrgus antipodarum* which have all become permanently established in the Netherlands (Wolff, 2005), although they are not yet reported as inhabitants of the Oosterschelde. According to Wolf (2005), the macro algal species *Asparagopsis armata* and *Bonnemaisonia hamifera* are regularly found washed ashore along the Dutch coasts, but as yet have not become established (Table 16).

Table 16 Exotic non-indigenous estuarine and marine species that have become established in Ireland and Britain and are not yet observed in the Oosterschelde, but that were not identified as target species for this study. For explanation see text.

Taxonomic group	**Species name**	**Establishment in the Netherlands (Wolff, 2005)**
Algae	*Alexandrium tamarense*	Permanently established
Algae	*Heterosigma akashiwo*	Permanently established
Algae	*Gyrodinium cf aureolum*	Permanently established
Coelenterata	*Clavopsella navis*	Permanently established
Mollusca	*Mytilopsis leucophaeta*	Permanently established
Mollusca	*Potamopyrgus antipodarum*	Permanent established
Algae	*Asparagopsis armata*	Not established
Algae	*Bonnemaisonia hamifera*	Not established

The final list of target species contains 22 species (Table 17). These are the exotic species that can be found in the Irish and/or UK waters, but are not yet reported to be present in the Netherlands.

It is good to realize, that this selection of the target species is based on reported observations made in the area's of interest, and that it is not unlikely that more species are present without being observed. Moreover, this list describes a snapshot of a situation that is continuously changing. New exotic species are discovered regularly in European waters. Clearly such species cannot be accounted for in the present risk analysis. For *Urosalpinx cinerea* and *Ammothea hilgendorfi* it should be noted that they are only observed at the South-East coast of England and not in the Irish and Celtic Sea. Strictly these species are exotic species for the UK, but they are not exotic species for the Irish and Celtic Sea.

Table 17 Selected target species: Exotic non-indigenous estuarine and marine species that have become established in Ireland and Britain and are not yet observed in the Oosterschelde. *Calyptraea chinensis* is regarded as a cryptogenic species. *Urosalpinx cinerea* and *Ammothea hilgendorfi* are exotic species for the UK, but they are not exotic species for the Irish and Celtic Sea.

Taxonomic group	Species name
Algae	*Antithamnion densum*
	Codium fragile ssp. atlanticum
	Cryptonemia hibernica
	Grateloupia filicina var. luxurians
	Pikea californica
	Scytosiphon dotyi
	Soliera chordalis
	Thalassiosira tealata
Angiosperma	*Spartina alterniflora hybrids*
Annelida	*Hydroides dianthus*
	Hydroides ezoensis
	Pileolaria rosepigmentata
Crustacea	*Eusarsiella zostericola*
	Herrmannella duggani
	Limnoria tripunctata
	Pilumnus perlatus
	Porcellidium ovatum
Mollusca	*Calyptraea chinensis*
	Tiostrea lutaria
	Urosalpinx cinerea
Pycnopoda	*Ammothea hilgendorfi*
Tunicata	*Phallusia mammilata*

8.3 Potential for establishment of self-sustaining populations

8.3.1 Potential for establishment of self-sustaining populations

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

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

8.3.2 The probability that target species are successfully transferred;

The probability that species are successfully transferred with mussels from the Irish/Celtic Sea to the Oosterschelde depends on the likelihood that the species are collected with the mussels at the production plots 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 beds. Most of the by-catch of larger organisms will consist of species that live in close connection with the mussels and the mussel beds. Planktonic species or life stages can easily be transported with the water attached to (or enclosed in) the mussels. The probability that species will be collected together with the mussels can be determined on bases of the ecological profiles.

To be successfully transported to the Oosterschelde these species must be capable to survive the conditions during transport to the Netherlands. During transportation the mussels are packed in large (1.5 m^3) big-bags without water. This situation lasts for about 25 - 50 hours. Therefore, in order to survive the transportation the species must be able to overcome this period under moist conditions, but out of the water. The assessment of this potential can be based on available knowledge about the physiology of the species involved and field observations on samples of imported mussels (Chapter 5) were used to validate this assessment where possible. As a precaution measure the field observations should only be used to correct false negative assumptions, thus in cases where living individuals of a species were found in the imported mussel samples, while this was not expected based on the species physiology. In the reverse situation (no surviving individuals in imported mussel samples although expected) the first assumption should not be changed.

The likelihood that a species is transferred to the Oosterschelde 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 was maintained.

When assessing the likelihood that a species can successfully be transferred with mussels to the Oosterschelde and can become established there, it became clear that for most of the species little ecological/physiological information is readily available. This resulted in a worst case score (5) for many species (Table 18). This was especially the case for the assessment of the likelihood of species being transferred successfully. 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. Exceptions to this 'worst-case' score were made for the wood boring isopod *Limnoria tripunctata* and the salt march species *Spartina alterniflora* (Smooth cordgrass) that are not expected to be collected together with the mussels as these species prefer a different habitat.
Urosalpinx cinerea (American oyster drill) and *Tiostrea lutaria* (New Zealand flat oyster) are given a lower score because these species are not widely spread in the source area and both species show an only slow natural dispersal (Eno *et al.*, 1997).

Although a lot of the target species are given a high score for the likelihood of being transferred with the imported mussels, none of the species was found either on the commercial mussel beds or in the transport trucks as reported in chapter 5 of this report.

8.3.3 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 Oosterschelde when the mussels are placed on the mussel beds, or with the tare that is disposed as waste in the area. 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 Oosterschelde 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 Oosterschelde 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.

The assessment of the likelihood that a transferred species is able to become established in the Oosterschelde (establishment score; Table 18) was also hampered by a lack of ready available ecological information for some species. In these cases again the worst-case assumption was made (score 5). For seven species it is thought to be unlikely (score 2) that they will be able to become established in the Oosterschelde. One of these is *Calyptraea chinensis*. According to Wolff (2005), this mollusk was reported to be living in the Netherlands in 1942, probably being imported with French oysters. However, this species was not able to maintain a self sustaining population and is assumed not to be present in the Dutch waters at this moment. Apparently the situation in the Oosterschelde does not suit this species needs. The other six species with score 2, prefer higher water temperatures then what can be expected in the Oosterschelde, and population development will thus most likely be inhibited by too low summer temperatures (Eno *et al.*, 1997) or winter mortality (*Tiostrea lutaria*; (Eno *et al.*, 1997).

Score 3 (likely) was given to the tube worm *Hydroides dianthus*, that should be able to survive the environmental conditions, but will probably suffer from low food availability. It is actually a species of eutrophic waters that are characterized by a high phytoplankton density (Eno et al., 1997). Moreover, this tubeworm is known to be a poor competitor (for food) and it is, therefore, thought that it will not be able to establish Itself amongst such efficient filter feeders as mussels. In this light, also the 'transfer score' of 5 that was applied for this species will be an overestimation. *Urosalpinx cinerea* (American oyster drill) was also given a transfer score 3. In the UK, this species is only found locally. This not only suggests a poor ability for the colonization of new area's, but also that transfer may easily be prevented when mussels for transport to the Oosterschelde are not collected in areas where this species occurs. The qualification 4, indicating that it is very likely that this species will become established after successful transfer is given to *Spartina alterniflora* (smooth cordgrass). If sufficient material (whole plants or stolons) reach a tidal mudflat in the Oosterschelde, it is likely that the plant will be able to successfully colonize this area.

Table 18 Score for the likelihood that target species are successfully transferred with mussels and become established in the Oosterschelde respectively. Score: 1 very unlikely/certainly not, 2 unlikely, 3 likely, 4: very likely, 5: certain. The ‘overall score’ is formed by the product of the ‘transfer’ and the establishment’ score.

Code	Species name	Transfer score	Establishment score
1	*Antithamnion densum*	5	5
2	*Codium fragile* ssp. *Atlanticum*	5	5
3	*Cryptonemia hibernica*	5	5
4	*Grateloupia filicina* var. *luxurians*	5	2
5	*Pikea californica*	5	2
6	*Scytosiphon dotyi*	5	5
7	*Soliera chordalis*	5	2
8	*Thalassiosira tealata*	5	5
9	*Spartina alterniflora* hybrids	2	4
10	*Hydroides dianthus*	5	3
11	*Hydroides ezoensis*	5	2
12	*Pileolaria rosepigmentata*	5	5
13	*Eusarsiella zostericola*	5	5
14	*Herrmannella duggani*	5	5
15	*Limnoria tripunctata*	2	2
16	*Pilumnus perlatus*	5	5
17	*Porcellidium ovatum*	5	5
18	*Calyptraea chinensis*	5	2
19	*Tiostrea lutaria*	2	2
20	*Urosalpinx cinerea*	3	3
21	*Ammothea hilgendorfi*	5	5

22	*Phallusia mammilata*	5	5

8.3.4 Overall score

When the individual scores for transfer and establishment are multiplied and divided by 5, an overall score for the likelihood that target species become established in the Oosterschelde due to mussel transfer, was calculated. On base of this list it seems (at least) likely 14 out of the 22 target species are able to become permanently established in the Oosterschelde due to mussel transfer (Table 19).

Table 19 Overall score for the likelihood that target species become established in the Oosterschelde due to mussel transfer. The 'overall score' is formed by the product of the 'transfer' and the establishment' score divided by 5 (Table 18). The species are sorted by the overall score, numbers in the 1st column refer to the positions in Table 18

Nr.	**Species name**	**Taxon. group**	**Overall score**	
1	*Antithamnion densum*	Algae	5.0	"certain"
2	*Codium fragile* ssp*. Atlanticum*	Algae	5.0	"
3	*Cryptonemia hibernica*	Algae	5.0	"
6	*Scytosiphon dotyi*	Algae	5.0	"
8	*Thalassiosira tealata*	Algae	5.0	"
12	*Pileolaria rosepigmentata*	Annelida	5.0	"
13	*Eusarsiella zostericola*	Crustacea	5.0	"
14	*Herrmannella duggani*	Crustacea	5.0	"
16	*Pilumnus perlatus*	Crustacea	5.0	"
17	*Porcellidium ovatum*	Crustacea	5.0	"
22	*Phallusia mammilata*	Tunicata	5.0	"
21	*Ammothea hilgendorfi*	Pycnopoda	4.0	"very likely"
10	*Hydroides dianthus*	Annelida	3.0	"likely"
4	*Grateloupia filicina* var*. luxurians*	Algae	2.0	"unlikely"
5	*Pikea californica*	Algae	2.0	"
7	*Soliera chordalis*	Algae	2.0	"
11	*Hydroides ezoensis*	Annelida	2.0	"
18	*Calyptraea chinensis*	Mollusca	2.0	"
20	*Urosalpinx cinerea*	Mollusca	1.8	"
9	*Spartina alterniflora* hybrids	Angiosperma	1.6	"
15	*Limnoria tripunctata*	Crustacea	0.8	"very unlikely"
19	*Tiostrea lutaria*	Mollusca	0.8	"

8.4 Potential for ecological impact

In general, it is very hard, if not impossible, to predict 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 Oosterschelde and its ability to survive and successfully reproduce considering the environmental conditions here. This is considered in the previous paragraphs.

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). Especially enclosed, relatively isolated water bodies may be susceptible. Since the closing of the storm-surge barrier, many new species have successfully colonized the

Oosterschelde, due to the fact that environmental conditions have changed. The Pacific oyster (*Crasostrea gigas*), which was introduced in the Oosterschelde in 1963 has recently developed exponentially and has lead to a nuisance. Many of the other introduced species just filled the empty niches that developed in the changing ecosystem of the Oosterschelde after the closure of the storm surge barrier. Also the relatively mild winters that have occurred recently can have played an important role in the successful introduction of new species.

In order to assess the probability that additional new exotic invaders will have a detrimental effect on the ecosystem of the Oosterschelde 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 Oosterschelde. The risk was scored from 1 (very unlikely) to 5 (very likely). However, due to the short time available, only two experts were able to fill in the list, while only one of them felt confident enough to judge the algae. The resulting scores, therefore, are provisional.

In general, the both experts consider the risk that the invertebrate species will cause ecological problem as low (score 1 or 2), but for three algal species a high risk is indicated: *Gyrodinium c.f. aureolum* , *Alexandrium tamarense* and *Heterosigma akashiwo.* These species, however, are already present in the Netherlands. *Gyrodinium* and *Alexandrium* are found in the North Sea and *Heterosigma akashiwo* is found in the Wadden Sea in 1992 (Wolff, 2005). For two species, an intermediate/possible risk (score 3) is indicated by one of the experts, viz. the marsh grass *Spartina alterniflora* and the mollusc *Calyptraea chinensis* (Chinese hat). The latter species has been found in the eastern parts of the Oosterschelde before 1990, but has disappeared again. (http://www.anemoon.org/anm/soorten/46300.htm).

Table 20 The assessment of two marine biology experts of the probability of target species having substantial ecological impact on the Oosterschelde system after successful introduction.

		Score	
Taxon. Group	**Target species**	**Expert 1**	**Expert 2**
Algae	*Antithamnion densum*	2	
	Codium fragile ssp. *Atlanticum*	2	
	Cryptonemia hibernica	2	
	Grateloupia filicina var. *luxurians*	2	
	Pikea californica	2	
	Scytosiphon dotyi	2	
	Soliera chordalis	2	
	Thalassiosira tealata	2	
Angiosperma	*Spartina alterniflora* hybrids	3	
Annelida	*Hydroides dianthus*	1	2
	Hydroides ezoensis	1	2
	Pileolaria rosepigmentata	1	2
	Eusarsiella zostericola	1	2
	Herrmannella duggani	1	2
	Limnoria tripunctata	2	1
	Pilumnus perlatus	1	2
	Porcellidium ovatum	1	1
Mollusca	*Calyptraea chinensis*	2	3
	Tiostrea lutaria	2	2
	Urosalpinx cinerea	2	2
Pycnopoda	*Ammothea hilgendorfi*	1	
Tunicata	*Phallusia mammilata*	2	1

Table 21 The assessment of two marine biology experts of the probability of exotic species that are already present in the Netherlands but not reported for the Oosterschelde having substantial ecological impact on the Oosterschelde system after successful introduction.

	Non Target species	**Expert 1**	**Expert 2**
Algae	*Alexandrium tamarense*	4	
	Asparagopsis armata	3	
	Bonnemaisonia hamifera	2	
	Gyrodinium c.f. aureolum	4	
	Heterosigma akashiwo	4	

Coelenterata	*Clavopsella navis*	1	2
Mollusca	*Mytilopsis leucophaeta*	2	1
	Potamopyrgus antipodarum	1	1

An additional approach to obtain an idea of the risk the target species may pose for the Oosterschelde ecosystem, is to assess whether the species are known as pest species. Welch & Lucas (2002) summarized known pest status for a number of exotic species. The algae *A. tamarense* and *Gyrodinium* cf. *aureolum* are considered a threat to ecosystems due to their capability to produce toxins. The latter species has caused shellfish poisoning in New Zealand and has developed into a large bloom in the English Channel in 1986.

The gastropod *Urosalpinx cinerea* (American oyster drill) is a predator of oysters and considered a pest species. It may develop into a severe pest of commercial oyster culture in the Oosterschelde. It could potentially also attack the reefs of the Pacific oysters now developing in Dutch waters and which are considered an ecological nuisance.

8.5 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 Oosterschelde after being transferred to the area with imported mussels. Among these species there are only a few that are identified as potential pest species and only three of these are at this moment not recorded as inhabitants of the Oosterschelde. These species are the micro algae *Alexandrium tamarense* and *Gyrodinium cf. aureolum* and the gastropod *Urosalpinx cinerea* (American oyster drill). The micro algae can be expected to be easily transported with the mussels in the attached or enclosed seawater. The gastropod can be introduced in the Oosterschelde as living animal or as egg cages attached to the imported mussels. However, the algae are already present in the North Sea in concentrations that has not resulted in harmful algal blooms as yet, and the American oyster drill is not known in the source area. Its distribution is described for the English east coast of Kent and Essex. It has been introduced to England over 100 years ago suggesting a limited ability of dispersal (personal communication Ian Laing). The species is covered under the control and deposit act, and movement of shellfish from these areas are stricktly controlled. The species was not found in any of the mussel sample that was investigated for this project.

8.6 Uncertainties

8.6.1 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 Ireland and the United Kingdom with that of the Oosterschelde. 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 Oosterschelde in which case the risk is under estimated. On the other hand it is possible that species that are assumed absent in the Oosterschelde 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.

8.6.2 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 many of the species, that could be found within the relative short timeframe of the project. Due to the precautional principle that a lack of information would result in a worst-case assessment, this has probably lead to an overestimation of the probability that introduced species will become permanently established in the Oosterschelde. This could explain the discrepancy between the risk assessment and the field observations: Target species that are considered to have a high potential to become established in the Oosterschelde are not yet found there Oosterschelde, despite the fact that mussels from Ireland and the UK have been introduced already for many years.

The observation that some exotic species that have become permanently established in the Dutch coastal waters are absent in the Oosterschelde can indicate that these species have problems settling in the Oosterschelde area.

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 & 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).

8.6.3 Potential for ecological impact

Predicting whether a certain species may become a pest in a new environment is very difficult. The only species that were considered a potential pest in this study were selected on bases of the fact that they caused problems in the past that were related to specific characteristics of the species involved: the algae can produce toxins and the American oyster drill is a known predator for the economically important oysters. However, history also 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 Oosterschelde could lead to substantial ecological impact may therefore be underestimated.

It is recommended to verify this probably 'worst-case' 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 Oosterschelde with Irish or British 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.

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Appendix A: Mussel culture in Wales

Contribution of R. Seed, J. Bussell and L. Oliver (School of Ocean Sciences, University of Wales Bangor)

A.1 Overview of the mussel culture

The seabed cultivation of mussels generates the greatest revenue of any molluscan shellfish cultivation in the UK. Production in 2004 was 26 611 ton, 14 814 ton of which came from Wales. In Wales, 98% of mussels came from lays in the Menai Strait (North West and North Wales Sea Fisheries Committees (NW&NWSFC)). The Welsh mussel fishery is thought to be worth between €3 and €4.5 million a year (Nautilus, 2000).

All mussel production in Wales is in the form of bottom culture. Bottom culture is based on transferring young mussel seed (spat), from areas where they have settled in great abundance, to culture plots. At the culture sites mussels are re-laid at lower densities and moved intermittently between different tidal heights. This management regime allows the mussels to obtain improved growth and fattening, and aids control of predation (Dare, 1980), which results in higher productivity.

The cultivation of mussels on the sea bed in Wales is covered by the Sea Fisheries (Shellfish) Act 1967. Through this Act, Several and Regulating Orders are granted by the Department for the Environment, Food and Rural Affairs (DEFRA) and the National Assembly for Wales. A Several Order provides the Grantees of the Order with exclusive rights to fish, dredge or take, within a defined area, shellfish of a description to which the Several Order applies (Section 2 Sea Fisheries (Shellfish) Act 1967). Regulating Orders grant the right to regulate the exploitation of the shellfishery, which may include the issue of licenses authorizing the dredging, fishing or taking of shellfish in a manner and extent defined by the Grantees. The Orders are subject to consent from the owner of the sea bed, or persons with rights on or over the area cultivated. In the main this is from the Crown Estate. Shellfish health and disease controls are implemented through the Fish Health Regulations 1997 and the Diseases of Fish (Control) regulations 1994. These regulations mainly deal with the control of the movement of shellfish in order to prevent spread of disease (Beadman, 2003).

There is a well-known propensity for shellfish re-laying operations to act as significant vectors for the introduction of non-native species to new areas. In the 1980's the UK had a statutory system to reduce the risks of the spread of such species to new areas (Molluscan Shellfish (Control of Deposit) Order). This statutory arrangement was solely to protect the industry, not for nature conservation reasons. It was later rescinded and such controls now only to apply to organisms brought in from outside the EU (Rees *et al.*, 2003).

North Wales
The largest mussel fishery in North Wales can be found at the eastern end of the Menai Strait. There is also a currently smaller Several Order Fishery, managed by a group of 20 fishermen, in the Conwy estuary. Mussels are harvested from the Conwy in a more traditional way with long handled rakes from open boats. The previously extensive Conwy fishery only produces approximately 300 ton of mussels each year, exclusively for the home market (NW&NWSFC).

Mussel cultivation in the Menai Strait started around 1958, when Severnside Oyster Co. began relaying and depuration at Siliwen. By early 1960s, operations extended to Bangor Flats and to the channel bottom between Bangor flats and Beaumaris-Gallows Point. Sublittoral cultivation attempts in the latter area were abandoned because of heavy starfish predation. From 1963 to 1972, annual production from intertidal lays averaged around 700 ton using seed taken from

Caernarfon Bay (sublittoral) and Morecambe Bay (intertidal), as well as larger mussels from various sources beyond the Menai Strait. Seed supply was intermittent and unpredictable, and consequently annual production very variable.

There were some early experiments involving rope cultivation of mussels in the Menai Strait but these proved unsuccessful due to the strong currents that are a feature of this area (Dare, 1980). From about 1971, Welsh Seafood's Ltd. took over operations and built a processing plant near Caernarfon, and installed modern Dutch machinery for making up-market mussel products. A large suction dredger collected and transported small seed mussels from Morecambe Bay and Caernarfon Bay to lays on Bangor Flats. In 1974, some 2,000t were re-laid from the latter source; unfortunately, this lay was washed away in January 1975 by an unusual combination of a severe NE gale during spring tides. The company never recovered, and had ceased operations by 1976. There was then a hiatus until the 1980s when Myti Mussels Ltd. took over and succeeded where the pioneers had failed (Rees *et al.*, 2003).

In the Menai Strait-based industry, seed mussels (~6mm shell length) are collected by dredging seed beds elsewhere (e.g. Morecambe Bay, Caernarfon Bay). These are re-laid on the muddy substrata, at a density of ~ 50 – 60 ton per hectare, for on-growing. Mussels are laid first in the intertidal zone for c. 18 months, until they grow large enough to reach a partial predation refuge (~ 30mm). The mussels are then moved into subtidal lays for a final period of rapid growth. Mussels are marketable when they reach a shell length >45 mm, a process that takes approximately 2½ years from the settlement of spat to the harvesting of marketable mussels (Saurel *et al.*, 2004).

Once the mussels reach a marketable size (>45 mm), dredges are used to harvest the mussels between September and April. Once on board of the dredger the mussels pass along a conveyor belt, where large animals such as the shore crab *Carcinus maenas* and the starfish *Asterias rubens* are removed by hand to a large extend. Mussels then go through a thorough washing process which removes part of the smaller animals that are not removed by hand pickers. Mussels are then bagged in sea water and taken back to shore for export (T. Jones, 'Extra Mussel', *pers comm*).

South Wales

There are currently four Several Order fishery areas located in Swansea Bay, South Wales which are administered by the South Wales Sea Fisheries Committee (SWSFC), at present only two of these are being fished. Mussels are laid and harvested as described above.

A.2 Location of the seed fishing grounds

The North Wales mussel industry collects seed by dredging natural seed beds. The Sea Fisheries Committee issue a license to the farmer for the collection of seed although there is no current legislative support for this management. The seed mussels are dredged once a layer of "mussel mud" has built-up under the mussel beds. This means that farmers can dredge the targeted bed and collect seed leaving the substratum relatively unaffected (Kaiser *et al.*, 1998).

In the Menai Strait one ton of unprotected seed mussels usually produces about 1 ton of marketable >45 mm mussels (2 – 2½ years), indicating a 85% mortality. The high rate of mortality is mainly due to shore crab (*Carcinus maenas*) predation (Saurel *et al.*, 2004).

The mussel culture industry in the Menai Strait harvests seed from three main areas (Figure 12): Caernarfon Bay, Morecambe Bay and South Wales. Seed beds have also developed periodically in Conwy Bay (Saurel *et al.*, 2004).

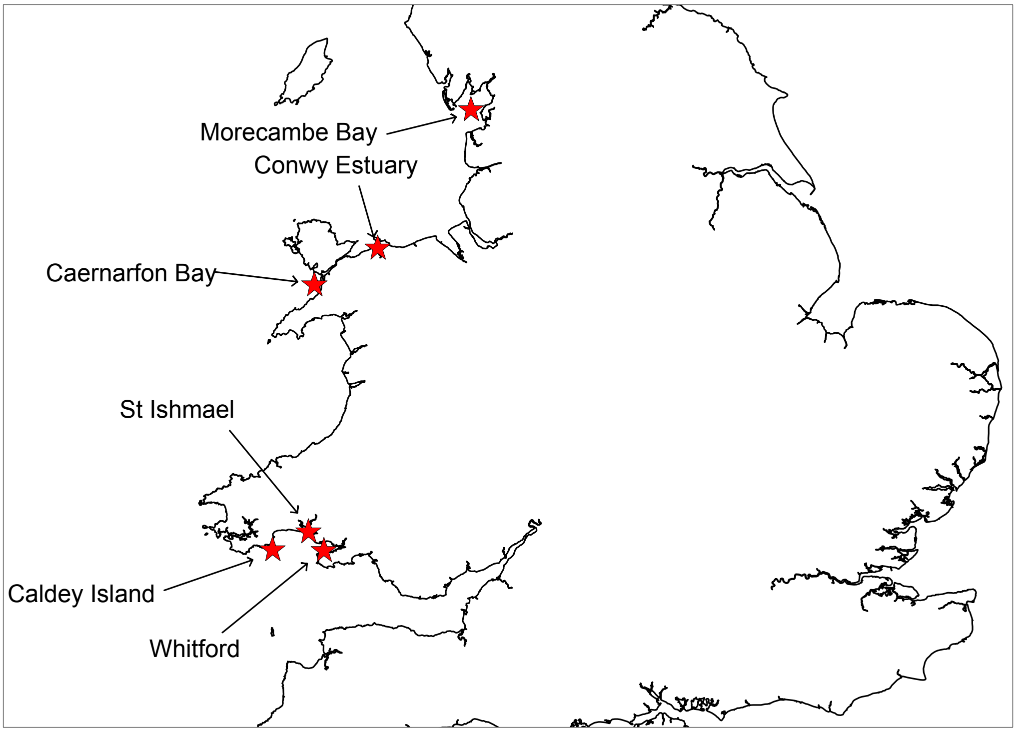

Figure 25: Map of showing locations of the main seed mussel fishing grounds used by Welsh mussel fisheries.

The main seed fishing grounds in South Wales are located at St Ishmael, Whitford and Caldey Island. The latter is the subject of specific assessment in conjunction with the Countryside Council for Wales (CCW) as it lies within a Special Area of Conservation (SAC). Some seed from these areas is also re-laid in the Wash on the North Sea coast (South Wales Sea fisheries committee).

The mussel seed beds in Caernarfon Bay are mainly subtidal, and are the main source of seed for the lays in the Menai Straits. The distribution, growth rates and mortality of mussels at these sites are not well known, although they are known to be patchy in space and time. Video footage of these beds from June 2003 shows very dense settlement of small mussels in places (100% cover with several layers), and high densities of invertebrate predators (starfish, crabs, whelks) (Saurel *et al.*, 2004).

There is annual settlement on a permanent adult mussel bed in the Conwy estuary, and spat from the top of the bed is generally removed by the NW&NWSFC to lays in the low intertidal or subtidal. This site is very different to the other seed beds in the area because it is sheltered, with settlement on to live adult mussels. Settlement is much less patchy than in Caernarfon Bay, both within and between seasons. In 1997, subtidal mussel seed beds developed in Conwy Bay. Two were harvested and one left for monitoring purposes, but was subsequently decimated by starfish predation. Since then, subtidal spatfall has not been observed in Conwy Bay (Saurel *et al.*, 2004).

Morecambe Bay seed beds tend to form in fairly predictable areas, although the extent of settlement is highly variable from year to year. In recent years, settlement has been high around Morecambe, with a possible change in settlement patterns related to coastal defence works which have altered the flow regime. Monitoring work by NW&NWSFC in Morecambe Bay has concentrated on two intertidal seed beds; Heysham Flats, near Morecambe, and the so-called South America bed, which is 4-5 km offshore and only accessible by helicopter or small boat. Both beds have been harvested for the Menai Strait fisheries in the past (Saurel *et al.*, 2004).

A.3 Location of the growing plots

The main growing area for mussels in Wales is located at the north east end of the Menai Strait on Bangor flats (Figure 11) These mussel lays are worked by large companies with relatively large mussel dredging boats. There are several other, much smaller areas within the Menai Strait but these are either not worked, used for Oysters, or form the basis of small local operations. The mouth of the Conwy estuary also supports a population mussels that are harvested by hand raking from small boats.

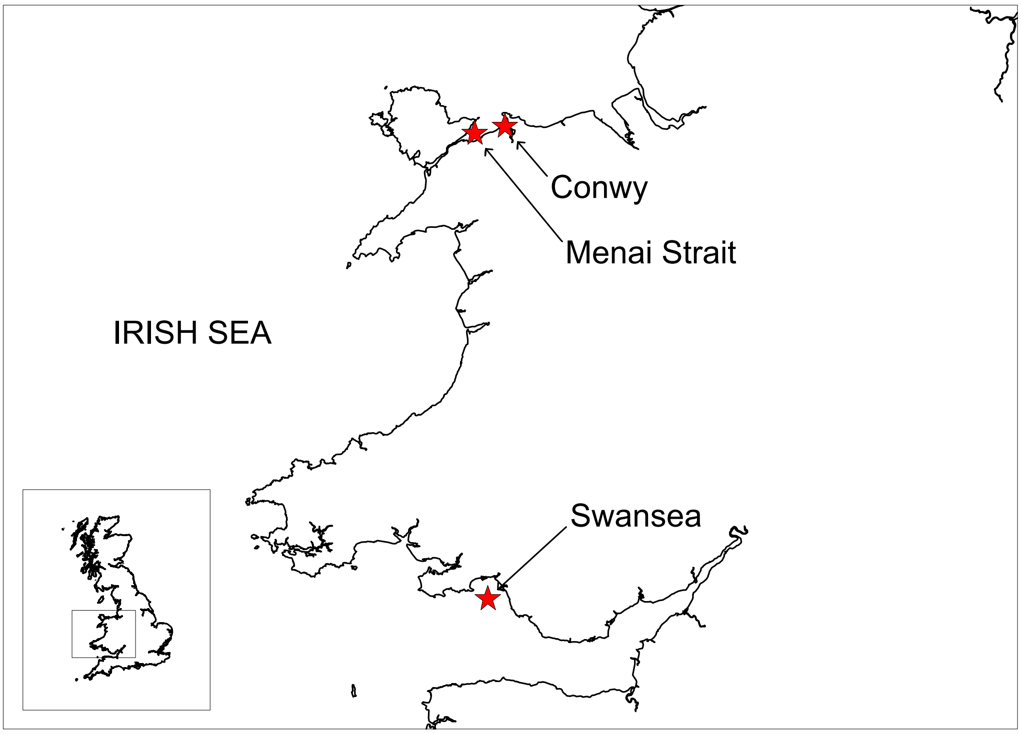

Figure 26: Map of Wales showing location of the main mussel growing areas.

A.4 Mussel production in Wales and export to the Netherlands

Table 1 shows the mussel landings (in ton) for the North and South Wales fisheries from 1997 to 2004. The fishery in north Wales is obviously the most substantial, accounting for 98% of the mussels cultured in 2004.

Table 22 Welsh mussel landings in ton from 1997 – 2004 (Source: SWSFC and NW&NWSFC)

Fishery	1997	1998	1999	2000	2001	2002	2003	2004
S. Wales	30	60	31	30	52	200	11.5	287
N. Wales	-	-	-	-	8478	10577	15120	14527

Appendix B: Non-indigenous species in the Oosterschelde

Contribution of M. J. De Kluijver (AquaSense)

In this appendix, an overview is given of the exotic species in the Oosterschelde In the first paragraph (B.1) an overview is given of the exotic non-indigenous species, in the second paragraph (B.2) an overview is given of Northeastern Atlantic non-indigenous species and in the third paragraph of this appendix (B.3) an overview is given of species with an uncertain origin. Another comprehensive overview of exotic non-indigenous marine and estuarine species in the Netherlands is presented by Wolff (2005).
The references for this appendix are listed in B.4.

B.1 Exotic non-indigenous species and adjacent areas

Rhodophyta
Acrochaetium densum (Drew) Papenfuss
(Syn. *Chromastrus densum* (Drew) Stegenga & Mulder)
The area of origin of this exotic non-indigenous species is in the Pacific, and the species is brought into Europe by an unknown vector.
The first record of this species in Atlantic Europe was in the Netherlands in 1967. Nowadays established in the Wadden Sea, the Oosterschelde estuary and in the Grevelingen Meer. As its gametophyte (*A. catenulatum*) was also recorded in 1996, the species seems to be permanently established in the Wadden Sea, Oosterschelde estuary and in the Grevelingen Meer.

Agardhiella subulata (C. Agardh) Kraft & Wynne
The area of origin of this exotic non-indigenous species is the Atlantic coast of North America from the tropics to Massachusetts or even Canada. Probably introduced with shellfish.
First observations in Atlantic Europe before 1973 in the Solent, UK. In the Netherlands the species was found in 1998 near Yerseke (Stegenga, 1999a). Nowadays it is common on hard-substrata in the eastern part of the estuary.

Anotrichium furcellatum (J. Agardh) Baldock
(Syn. *Griffithsia furcellata* J. Agardh)
The area of origin of this exotic non-indigenous species is the Mediterranean. Probably introduced with shellfish.
First observations in Atlantic Europe before 1922 in NW France. In the Netherlands the species was found in 1968 in the Oosterschelde estuary, but a specimen in the Rijksherbarium, Leiden, was collected in 1950 in the oyster ponds near Yerseke. It seems that the species was only temporarily established.

Antithamnionella spirographidis (Schiffner) Wollaston
The area of origin of this exotic non-indigenous species is in the North Pacific. Primary introduced in Europe by ships and secondary transported with shellfish.
The first European find was made in Plymouth in 1906, but the species was described in 1911 from the Mediterranean (Maggs & Stegenga, 1999). Observed in the Oosterschelde estuary around 1974 near Yerseke. From 1993 onwards rather common in the Oosterschelde estuary. It is permanently established, but still in its establishment phase.

Antithamnionella ternifolia (J.D. Hooker & Harvey) Lyle
(Syn. *Antithamnionella sarniensis* Lyle)

The area of origin of this exotic non-indigenous species is in the southern Hemisphere, perhaps Australia. Primary introduced in Europe by ships (Plymouth 1906) and secondary transported by residual currents or aquaculture.
First observed in Europe in 1906 in Plymouth. In 1911 it was recorded from the Mediterranean. In 1951 it was found in the Oosterschelde estuary near Yerseke (Maggs & Stegenga, 1999). Later observations are doubtful, as the species is easily confused with *A. spirographidis*. Apparently, it was only temporarily established.

Colaconema dasyae (Collins) Stegenga, Mol, Prud'homme van Reine & Lokhorst
(Syn. *Acrochaetium dasya* Collins)
The area of origin of this exotic non-indigenous species is the Atlantic coast of North America. Probably introduced with its host *Dasya baillouviana*, which is suspected to be introduced with shellfish.
First observations in Atlantic Europe in the Netherlands. The first observations were made in the non-tidal brackish Gat van Ouwerkerk. Nowadays, it is still in its establishment phase, found near Yerseke and in the Veerse Meer. It is not found in the Gat van Ouwerkerk and Kanaal door Zuid-Beveland anymore.

Dasya baillouviana (S.G. Gmelin) Montagne
(Syn. *Dasya elegans* (G. Martens), *Dasya pedicellata* (C. Agardh) C. Agardh))
The area of origin of this exotic non-indigenous species is the Mediterranean and the Atlantic coast of North America. The introduction vector is unknown, but the first record of the species was near an oyster pond.
The first Atlantic European and Dutch record was found washed ashore at Rockanje in 1948. In 1950 it was found in the Kanaal door Zuid-Beveland (Stegenga, 2003b). Nowadays it is established in the eastern part of the Oosterschelde estuary and in its expansion phase in the brackish Lake Veere.

Dasysiphonia sp.
(Syn. *Heterosiphonia japonica*)
The area of origin of this exotic non-indigenous species is NE Asia. Probably introduced with shellfish, both into Europe and the Netherlands.
First observations in Atlantic Europe in probably in France. An apparently identical alga was found in Galicia (Spain) in 1990. In the Netherlands the species was found in 1994 in former oyster pounds near Yerseke (Oosterschelde estuary). At present it is common in the Oosterschelde estuary and Grevelingen Meer.

Grateloupia turuturu Yamada
(Syn. *Grateloupia doryphora* (Mont.) M. Howe)
The area of origin of this exotic non-indigenous species is in the Pacific near Japan and Korea. Probably introduced with shellfish, both into Europe and the Netherlands.
First observations in Atlantic Europe in the Solent (England) in 1969. In the Netherlands the species was found in 1993 in oyster ponds near Yerseke. At present, it is established in the eastern part of the Oosterschelde estuary.
Remarks: *Grateloupia doryphora* is still a valid species found off the coast of South America, but the European material is more related to the Japanese species *Grateloupia turuturu* (Stegenga, 2004a).

Lomentaria hakodatensis Yendo
The area of origin of this exotic non-indigenous species is NE Asia (Japan). The introduction vector is unknown, but probably introduced with shellfish.
First observations in Europe in the Mediterranean (Thau Lagoon, Hérault, France) in 1979. Since 1984 reported from the coast of Brittany. In the Netherlands the species was found in 2004 in the construction pit in the Oosterschelde estuary (Stegenga, 2004b). As the species arrived recently in the Netherlands it is not expanded.

Polysiphonia harveyi Bailey

The area of origin of this exotic non-indigenous species is in Japan, and the species is brought into Europe by an unknown vector.
Introduction into Atlantic Europe in 1832 in Brittany (France) and in 1908 in Dorset (England) in 1908. In the Netherlands it was found in 1960 in the Kanaal door Zuid-Beveland. Nowadays it is very common in the Oosterschelde estuary and in the Grevelingen Meer. It is also found off Texel.

Polysiphonia senticulosa Harvey
The area of origin of this exotic non-indigenous species is in the North Pacific. The introduction vector is unknown, but its distribution suspects import with oysters.
Introduction into Atlantic Europe in 1993 at Gorishoek in the eastern part of the Oosterschelde estuary. Nowadays common in a large part of the Oosterschelde estuary and locally abundant in oyster ponds at Yerseke.
Description: Like *P. harveyi*, but 30 cm in length, dark-red and the branchlets ending in a sharp point (Jansen & Perk, 2000).

Bacillariophyceae
Odontella sinensis (Greville) Grunow
(Syn. *Biddulphia sinensis* Greville)
The precise area of origin of this exotic non-indigenous species is unknown, but probably in Chinese waters or in the Indian Ocean or the Red Sea. Introduced into Europe by ships, probably in ballast water.
First observation in Europe in 1889. In 1903 in the North Sea and in 1905 along the Dutch coast. The species is fairly common in the North Sea (Wolff, 2005).

Phaeophycea
Botrytella sp.
(Syn. *Sorocarpus micromorus* (Bory) Silva)
The material of this exotic non-indigenous species seems closely related to some Pacific species. The introduction vector is unknown.
Introduction into Atlantic Europe is unknown, but in 1919 the species was found in the harbour of Nieuwediep and identified as *Sorocarpus uvaeformis* (Lyngb.) Pringsh.)). In 1981 the species was found in the NIOZ harbour at Texel and in 1993 and 1995 on *Sargassum muticum* in the saline Lake Grevelingen.

Colpomenia peregrina (Sauvageau) Hamel
(Syn. *Colpomenia sinuosa* (Roth) Derb. & Sol.)
The area of origin of this exotic non-indigenous species is the Atlantic coast of North America. Probably introduced with juvenile American oysters.
First observations in Europe in the Mediterranean and Atlantic coast of Spain, and since 1906 along the French and English coasts. In the Netherlands the species was found in 1986 at Dreischor in the enclosed Grevelingen Meer.
Nowadays, common and sometimes abundant in the Grevelingen Meer, but also in tidal pools in the Oosterschelde estuary.

Elachista sp.
(Syn. *Elachista flaccida* (Dillw.) Aresch.)
The area of origin of this exotic non-indigenous species is probably in the NW Pacific. The introduction vector is unknown, but local dispersal through drifting with *Sargassum muticum*.
Introduction into Atlantic Europe in 1993 as an epiphyte of *Sargassum muticum* in the Grevelingen Meer. Nowadays common in Lake Grevelingen, in tidal pools in the construction pit in the Oosterschelde estuary and the Havenkanaal van Goes (Stegenga, 2000a).

Leathesia verruculiformis Y.P. Lee & I.K. Lee
The area of origin of this exotic non-indigenous species is probably in the NW Pacific. The introduction vector is unknown, but local dispersal through drifting with *Sargassum muticum*.

Introduction into Atlantic Europe in 1994 as an epiphyte of *Sargassum muticum* near Bruinisse in the Grevelingen Meer. Nowadays frequently found in the Grevelingen Meer, in tidal pools in the eastern part of the Oosterschelde estuary and near the storm-surge barrier.

Myriactula sp.
(Syn. *Myriactula rivulariae* (Suhr) Feldmann)
(Exotic non-indigenous species)
The area of origin and the introduction vector of this exotic non-indigenous species are unknown. Local dispersal through drifting with *Sargassum muticum*.
Introduction into Atlantic Europe in 1980 as an epiphyte of drifting *Sargassum muticum* in the Grevelingen Meer. In 1983 found on attached plants. Nowadays it is permanently established in the Grevelingen Meer, and is fairly common in some years.

Sargassum muticum (Yendo) Fensholt
The area of origin of this exotic non-indigenous species is the NW Pacific (Japan, Russia, Korea and China). Probably introduced with oysters, and a subsequent dispersal by currents.
First observations in Atlantic Europe in 1971 near Bembridge, Isle of Wight (UK), but probably introduced to the French side of the Channel in 1966. In the Netherlands attached plants were found in 1980 on Texel, in the Oosterschelde estuary and the Grevelingen Meer. At present, it is abundant on all suitable hard-substrata along the Dutch coast and in the SW Delta area.

Undaria pinnatifida (Harvey) Suringar
The area of origin of this exotic non-indigenous species is in the NW Pacific (China, Japan, Korea and SE Russia). Introduced with oysters, but also deliberately introduced.
First observed in Europe in Étang de Thau (Mediterranean, France) in 1971, introduced with the Pacific oyster. Deliberately introduced for cultivation purposes into Brittany in 1983. In 1987 it was found in Ouessant, in 1988 in northern Spain, in 1994 in southern England, in 1998 in the Strait of Dover and in 1999 on the Belgium coast (Stegenga, 1999b). In the Netherlands attached plants were found in 1999 near Yerseke in the Oosterschelde estuary. It is in its expansion phase and dominant in the eastern part and off the northern coast of the Oosterschelde estuary.

Dinophyta
Alexandrium leei (Balech) Balech
The area of origin of this exotic non-indigenous species is probably in the Pacific, near Korea, Gulf of Thailand and Philippines. The introduction vector is unknown, but local dispersal through tidal currents.
Introduction into Atlantic Europe in 1991 along the Dutch coast.

Chlorophyta
Codium fragile (Suringar) Harriot *ssp. tomentosoides* (van Goor) Silva
The area of origin of this exotic non-indigenous species is in the Pacific, around Japan. Primary introduced into Europe by ships, and secondary transported with shellfish.
The first European find was a specimen washed ashore at Huisduinen (the Netherlands) in 1900 (Chapman, 1999). In 1904 attached specimens were found near Den Helder. Nowadays, the species is common in the SW Delta area, along the Marsdiep and at West-Terschelling.

Ulva pertusa Kjellman
The area of origin of this exotic non-indigenous species is probably in the northern Pacific. The introduction vector is unknown.
Introduction into Atlantic Europe in 1993 in the SW Delta area (the Netherlands). At present, the species is one of the most common *Ulva* species in the Oosterschelde estuary and in the Grevelingen Meer. It is also present at Texel in the western Wadden Sea. The species is mainly epilithic, but may also be found on other algae, in the low intertidal and subtidal (Stegenga & Mol, 2002).

Protista

Bonamia ostreae Pichot, Comps, Tigé, Grizel & Rabouin, 1979
The area of origin of this exotic non-indigenous species is in the NE Pacific, California. It is a parasite and introduced with oysters.
First observed in Atlantic Europe in the late 1970s in Brittany. A second introduction took place in 1977 in Asturia (Spain). In the Netherlands, the species was introduced into the Oosterschelde estuary in 1980 with oysters from Brittany. In 1988 the species was also found in the Grevelingen Meer. It caused the nearly complete disappearance of the indigenous oyster *Ostrea edulis*.

Haplosporidium armoricanum (Van Banning, 1977)
(Syn. *Minchinia armoricana* Van Banning, 1977)
The area of origin of this exotic non-indigenous species is unknown. It is a parasite and is probably introduced with oysters.
This parasite was found in 1974 in the Oosterschelde estuary in flat oysters (*Ostrea edulis*), which had been imported from Brittany (France). After the removal of all infected oysters, the parasite was not observed after 1978 anymore.

Marteilia refringens Grizel, Comps, Bonami, Cousserans, Duthoit & Le Pennec, 1974
The area of origin of this exotic non-indigenous species is unknown. It is a parasite and is probably introduced with oysters.
First observed in Atlantic Europe in 1968 in Brittany, where it caused the 'Aber' disease in the flat oyster *Ostrea edulis.* The parasite was found in 1974 in the Oosterschelde estuary, but exclusively in oysters imported recently from France. After the removal of all infected oysters, the parasite was not observed after 1978 anymore.

Porifera
Acervochalina loosanoffi (Hartman, 1958)
(Syn. *Haliclona loosanoffi* Hartman, 1958)
The area of origin of this exotic non-indigenous species is the Atlantic coast of North America. It is probably introduced with oysters.
First observed in Atlantic Europe in the 1880s in the eastern part of the Oosterschelde estuary near oyster ponds (Soest, 1976). The only other European record was made in 1977 in Lough Ine (Ireland). Nowadays the species is rare, but still present.

Celtodoryx girardae sp. nov.
The area of origin of this exotic non-indigenous species is unknown. It is probably introduced with oysters.
First observed in Atlantic Europe in the western basin of the Gulf of Morbihan (Brittany, France) in 1996. Collected and positively identified in the eastern part of the Oosterschelde estuary in 2005, but photographs indicate that the species might have been present already in December 2002. Although the species is recently established, it shows a rapid growth and expansion.
Description: The sponge is thickly encrusting to massive, with a mean thickness of 8-10 cm and up to 50 cm. In France, specimens of ca 1 m^3 have been observed. Its colour in life is pale yellow to yellow. The surface is punctuated, rather regularly microlobate with round lobes underwater (2-2.5 cm x 1-1.5 cm), with more irregular lobes after collection. Its consistency is soft. Oscules are located at the top of small chimneys. No special pore area and no fistule are observed. Very abundant mucus is produced upon collection.

Haliclona xena De Weerdt, 1986
The area of origin of this exotic non-indigenous species is unknown, but the NW Pacific is suspected. It is probably introduced with oysters.
First observed in Atlantic Europe in 1982 in the eastern part of the Oosterschelde estuary near oyster ponds. Nowadays it is common in the Oosterschelde estuary, Grevelingen Meer and Veerse Meer.

Mycale micracanthoxea Buizer & Van Soest, 1977

The area of origin of this exotic non-indigenous species and its introduction vector are unknown. It was already collected in the Oosterschelde estuary in the 19th century and identified as *Mycale contareni*. Buizer and Van Soest (1977) compared the Dutch specimens with live French specimens and found specific differences. The species is also known from Algecirras (SW Spain).
Nowadays, the species is common in the Oosterschelde estuary and in the Grevelingen Meer.

Sycon scaldiense (Koolwijk, 1982)
(Syn. *Scypha scaldiensis* Koolwijk, 1982)
The area of origin of this exotic non-indigenous species and its introduction vector are unknown. It was already collected in the Oosterschelde estuary in 1951 and identified as *Sycon villosum* (Koolwijk, 1982). It was a rare species in the 1950s and 60s, but was common in the 1970s. Nowadays is very rare,

<u>Hydrozoa</u>
Garveia franciscana (Torrey, 1902)
(Syn. *Perigonimus megas* Kinne, 1956)
The area of origin of this exotic non-indigenous species is unclear, but probably it is native to the northern Indian Ocean estuaries. The introduction vector is unknown.
Introduction into Atlantic Europe in 1920 in the southeastern Zuiderzee. The species was recognised as *Bougainvillia ramosa* (Wright). Nowadays, the species is present in the Oosterschelde estuary and in the brackish part of the Westerschelde estuary.

Gonionemus vertens A. Agassiz, 1862
The area of origin of this exotic non-indigenous species is the Atlantic and Pacific coasts of North America and SE Asia. The introduction vector is unknown, but ships' hulls, ballast water and aquaculture are mentioned.
Introduction into Atlantic Europe in the 19th century in Portugal, in 1913 in NE England and in 1921 in the Oslofjord. In the Netherlands the species was found in the Kreek Rammekenshoek in 1960, the Oosterschelde estuary in 1963 and in the Grevelingen Meer in the period 1976-82. In 1995-2000, the species was found in the Goesse Meer.

Nemopsis bachei (L. Agassiz, 1849)
The area of origin of this exotic non-indigenous species is at the Atlantic coast of North America. Probably transported into Atlantic Europe as polyps on ships' hulls.
The first European find was made at the Hebrides in 1879, and in 1879 it occurred in Norway. It was common in the former Zuiderzee, and in the 1990s its polyps were recorded from the Oosterschelde estuary (Faasse & Ates, 1998) and in 2000 medusae were found in the Wadden Sea (Tulp, 2002).

Thieliana navis (Millard, 1959)
This exotic non-indigenous species is found in South Africa, the Baltic, England and the Netherlands. The species described from the Black Sea as *Cordylophora inkermanica* Marfenin, 1983 might be the same species. The introduction vector is unknown.
Introduction into Atlantic Europe in 1960 in the mouth of the Nordsee-Ostsee Kanal in the Kieler Förde (Germany). In the Netherlands the species was found in 1964 in the non-tidal Gat van Ouwerkerk near the Oosterschelde estuary. Recent records come from the Goesse Meer and the Westkapelse Kreek (Faasse & Vervoort, 2001).

<u>Anthozoa</u>
Haliplanella lineata (Verrill, 1869)
(Syn. *Diadumene luciae* (Verrill, 1898))
The area of origin of this exotic non-indigenous species is in the NW Pacific. Probably transported into Atlantic Europe on ships' hulls, but secondary transports with shellfish movements are likely.
First observed in Atlantic Europe in 1896 near Plymouth. In the Netherlands the species was found in 1912-13 near Den Helder. Since the 1970s, the species is reported from the

Oosterschelde estuary (Braber & Borghouts, 1977; Dekker, 1987; Faasse, 1996c; Faasse, 1997b). Nowadays, the species is known from several localities in the Wadden area and SW Delta area.

Platyhelminthes

Stylochus flevensis (Hofker, 1930)
The area of origin and the introduction vector of this exotic non-indigenous species are unknown.
Introduction into Atlantic Europe in the brackish Zuiderzee, where it was observed from 1921 till 1932. Although the species is restricted to the Netherlands, it is unlikely that it is an indigenous species. Recent records from the brackish Veerse Meer and Noordzeekanaal (Faasse, 2003c) and in the harbour of Lauwersoog (Tulp, 2005).

Polychaeta

Ficopomatus enigmaticus (Fauvel, 1923)
(Syn. *Mercierella enigmatica* Fauvel, 1923)
The area of origin of this exotic non-indigenous species is in the SW Pacific. Transported into Atlantic Europe on ships' hulls or in ballast water.
First observed in Atlantic Europe in 1921 in the harbour canal of Caen, France. In the Netherlands the species was found in 1968 in the brackish Veerse Meer and the Kanaal door Walcheren (Hove & Lucas, 1996; Velde et al., 1993). Nowadays, the species is locally very abundant in the Veerse Meer, Kanaal door Walcheren and Noordzeekanaal near Velzen, rear in the Oosterschelde.

Janua brasiliensis (Grube, 1872)
This exotic non-indigenous species is found in tropical seas, including Brazil.
Probably transported into Atlantic Europe on ships' hulls, but secondary transport with drifting *Sargassum muticum* or leisure crafts are likely.
First observed in Atlantic Europe in 1974 in Portsmouth Harbour, UK. In the Netherlands the species was found in 1985 in the Havenkanaal van Goes. Nowadays, the species is found in the Havenkanaal van Goes, the Kanaal door Zuid-Beveland and the Grevelingen Meer. Rare in the Oosterschelde estuary.

Marenzelleria wireni Augener, 1913
(Syn. *Marenzelleria viridis* auct.)
The area of origin of this exotic non-indigenous species is the eastern coast of North America, and perhaps arctic waters. Transported into Atlantic Europe in ballast water.
First observed in Atlantic Europe in the late 1970s in the Tay estuary, Scotland. In the Netherlands the species was found in 1983 in the Ems estuary (Essink, 1999). Nowadays, the species is found along the whole Dutch coast and in the Oosterschelde estuary.

Nereis virens Sars, 1835
The area of origin of this exotic non-indigenous species is in the North Atlantic or North Pacific. Its introduction vector is unknown.
Introduction into Atlantic Europe in Norway, where the species was described in 1835. Observations in the German Wadden Sea started in 1923-26. In the Netherlands the species was found near Den Helder in 1915 and nowadays it is a common species.

Proceraea cornuta (A. Agassiz, 1862)
(Syn. *Autolytus cornutus* A. Agassiz, 1862)
Probably this is an exotic non-indigenous species with its area of origin in North America, brought into Europe on ships' hulls, probably with a secondary dispersal through oysters.
Introduction into Atlantic Europe in 1929 near Plymouth (UK). In the Netherlands the species was found on oysters in the Oosterschelde estuary in 1941 (Wolff, 2005). It is an uncommon species with only a few observations.

Nematoda

Anguillicola crassus Kuwahara, Niimi & Itagaki, 1974
The area of origin of this exotic non-indigenous species is Japan. This parasitic nematode, living in the swim-bladder of eels, was imported in Europe with infected Japanese eels *Anguilla japonica*.
First observed in Europe in 1982 in Italy and Germany. In the Netherlands the parasite was first observed in 1985 in the indigenous eel *Anguilla anguilla*. In 1986 it was found at almost all locations sampled between the Veerse Meer and Lauwersmeer. Although after 1989 the prevalence of the parasite declined, it is still present in the swim-bladders of eels and also in smelt (*Osmerus eperlanus*).

Cirripedia
Balanus eburneus Gould, 1841
The area of origin of this exotic non-indigenous species is the Atlantic coast of America from Boston to Rio de Janeiro. Transported into Atlantic Europe on ships' hulls.
First observations in Atlantic Europe in Spain, France, in the Mediterranean and in the Black Sea. In the Netherlands the species was collected in the 1890s. In 1914 it was collected from ferries in the Oosterschelde estuary (Wolff, 2005). There are no recent finds in Dutch waters.

Elminius modestus Darwin, 1854
The area of origin of this exotic non-indigenous species is New Zealand and southern Australia. Transported into Atlantic Europe on ships' hulls and dispersed in Europe by hull fouling and marine currents.
First observed in Atlantic Europe in 1945 in Chichester harbour in West Sussex, England. In the Netherlands the species was found in 1946 in the area of Hoek van Holland. In 1951 the species had already colonised almost the entire Dutch coast, and at present it is a very common species.

Copepoda
Eurytemora americana Wiliams, 1906
The area of origin of this exotic non-indigenous species is at the east coast of North America. Its introduction vector is unknown.
Introduction into Atlantic Europe in the UK. In the early 1930s the species was recorded from the Channel near Plymouth, brackish ponds in Sussex and on the isle of Wight. In the Netherlands the species was found in 1963 in the Veerse Meer. Recent observation, until 1988, came from the Veerse Meer and Grevelingen Meer.

Mytilicola ostreae Hoshina & Sugiura, 1953
The area of origin of this exotic non-indigenous species is Japanese and Korean waters. It was introduced with Pacific oysters.
First observed in Atlantic Europe in 1972 in oysters at Marennes-Oléron (France). In the Netherlands the species was first observed in 1992 in the Oosterschelde estuary in *Crassostrea gigas*.

Mytilicola intestinalis Steuer, 1902
This exotic non-indigenous species was described from the Mediterranean, near Trieste, in 1902. It was introduced with mussels (*Mytilus edulis*), probably growing on ships' hull, but was later dispersed with seed mussels.
First observed in Atlantic Europe in 1938 near Cuxhaven and in Ostfriesland (Germany). In the Netherlands the species was first observed in 1949 in the SW Delta area. In 1950 it was found in the eastern Wadden Sea and in 1952 its range expanded to the west. Nowadays, it is a common species in *Mytilus edulis* in the Oosterschelde estuary. In the first years after its introduction, *M intestinalis* was considered as a serious pest for the mussel culture, but at present it is relatively harmless.

Mytilicola orientalis Mori, 1935

The area of origin of this exotic non-indigenous species is in the NW Pacific. The species was introduced with Pacific oysters, either originating direct from Japan or through introductions from British Colombia (Canada).
First observed in Atlantic Europe in 1977 in the Bassin d'Arcachon (France) in *Crassostrea gigas*. In the Netherlands the species was observed in 1992 in the Oosterschelde estuary in *Crassostrea gigas*, *Ostrea edulis* and *Mytilus edulis*. Nowadays, it is a common species in the Oosterschelde estuary.

Amphipoda
Caprella mutica Schurin, 1935
(Syn. *Caprella macho* Platvoet, De Bruyne & Gmelich Meyling, 1995)
The area of origin of this exotic non-indigenous species is in east Asia in the Sea of Japan. Its introduction vector is unknown.
Introduction into Atlantic Europe in the Netherlands in 1993 as *Caprella macho* (Platvoet et al., 1995). More recently the species was recorded from West Norway and Helgoland. Nowadays the species is recorded from several localities in the Oosterschelde estuary, and Borssele in the Westerschelde estuary.

Monocorophium sextonae (Crawford, 1937)
The area of origin of this species is unknown. The species could be classified as a cryptogenic species (Wolff, 2005). In the Netherlands the species was found in 1952 at IJmuiden. In 2000, it seemed to be common on hard substrata in water with a high salinity in the SW Delta area (Grevelingen Meer, Oosterschelde estuary and entrance of the Westerschelde estuary (Faasse & Moorsel, 2000)).

Decapoda
Callinectes sapidus Rathbun, 1896
The area of origin of this exotic non-indigenous species is the Atlantic coast of North America from the Nova Scotia to the Uruguay. Transported into Atlantic Europe in ballast water.
First observations in Atlantic Europe in 1900 in the harbour of Rochefort (SW France). In the Netherlands the species was found in the Zaan (1932), Entropothaven, Amsterdam (1934), Vlissingen (1950), Nauerna (1951) and Schiermonnikoog (1967). In 1996 the species was caught near Zierikzee in the Oosterschelde estuary (Craeymeersch & Kamermans, 1996). Nowadays the species is permanently established in the Westerschelde estuary and Noordzeekanaal, and isolated populations occurred in the Oosterschelde estuary and the Wadden Sea.

Eriocheir sinensis H. Milne Edwards, 1854
The area of origin of this exotic non-indigenous species is East Asia, from the Street of Taiwan north to Korea. Transported into Atlantic Europe in ballast water and subsequent dispersal through walking over river bottoms and transport of larvae by tidal currents.
First observations in Atlantic Europe in 1912 in Aller (Weser, Germany). In the Netherlands the species was found in the Ems-Dollard estuary in 1929 and 1930. In 1932 the western part of Friesland was colonised and in 1935 the species occupied almost all suitable parts of the Netherlands. Nowadays it is an abundant species, especially in coastal areas.

Hemigrapsus penicillatus (De Haan, 1835)
The area of origin of this exotic non-indigenous species is in the northwestern Pacific from Sakhalin to Taiwan. Transported into Atlantic Europe in ballast water or hull fouling (Nijland, 2001) and subsequent dispersal in Europe by oyster imports.
First observations in Atlantic Europe in 1993 in Bremerhaven (Germany). In the Netherlands the species was found in the eastern part of the Oosterschelde estuary in 2000 (Nijland & Beekman, 2000; Nijland, 2000). In 2001, the species spread westwards (Faasse et al., 2002) and at present, the species is known from the central and eastern part of the Oosterschelde estuary and the Westerschelde estuary.

Hemigrapsus sanguineus (De Haan, 1835)

The area of origin of this exotic non-indigenous species is in the northwestern Pacific from Sakhalin to Taiwan. Probably transported into Atlantic Europe in ballast water.
First observations in Atlantic Europe in 1999 in Le Havre (France) and at Schelphoek, Oosterschelde estuary (Udekem d'Acoz & Faasse, 2002). Nowadays the species is only known from isolated populations at Schelphoek, the Dutch coast and the Wadden Sea (Faasse, 2004a; Nijland & Faasse, 2005).

Palaemon macrodactylus Rathbun, 1902
The area of origin of this exotic non-indigenous species is in Asia. Its introduction vector is unknown. In the 1950s it was recorded from the USA.
Introduction into Atlantic Europe in 1999 in Spain and the Netherlands. Recent observations in the Westerschelde estuary, the Nieuwe waterweg, the Noordzeekanaal, the Oosterschelde estuary, Veerse Meer, Grevelingen Meer and in the Eemshaven (Faasse, 2005).

Rhithropanopeus harrisii (Gould, 1841)
(Syn. *Pilumnus tridentatus* Maitland, 1874)
The area of origin of this exotic non-indigenous species is at the Atlantic coast of America from New Brunswick to NE Brazil. Its introduction vector is unknown, but ballast water is unlikely as its introduction dates from the early 1870s.
Introduction into Atlantic Europe in the Zuiderzee, were it was described in 1874 as *Pilumnus tridentatus*. Nowadays it occurs in the Westerschelde estuary, Veerse Meer, Noordzeekanaal and in fresh water rivers up to Germany.

Gastropoda
Crepidula fornicata (Linnaeus, 1758)
The area of origin of this exotic non-indigenous species is the Atlantic coast of North America from Nova Scotia to the Gulf of Mexico. The species was introduced with oysters, but a secondary dispersal in the recipient area might have occurred with drifting material.
First observed in Atlantic Europe in 1872 in Liverpool Bay (UK), but this population died out. Later introductions took place into Essex (UK) between 1887 and 1890. Molecular genetic data showed that the French population, which was established after 1940, originated from several populations, either in Europe or in North America. In the Netherlands the first living specimen was observed in 1929 in the eastern part of the Oosterschelde estuary. At present, the species is common, especially in the SW Delta area.

Bivalvia
Crassostrea gigas (Thunberg, 1793)
The area of origin of this exotic non-indigenous species is SE Asia. The species was deliberately introduced (Drinkwaard, 1999), but introduction through ship hulls occurred as well.
First observed in Atlantic Europe already in 1819 in Portugal and described as *Crassostrea angulata* (Lamarck, 1819). This species was probably introduced on ships' hulls from Taiwan. Other European countries deliberately introduced this species from Portugal for cultivation. In the Netherlands the species did not established itself and the species was imported with French *Ostrea edulis* (1936), from Brittany (1947) and directly from Portugal (1961-62). Oysters from the Pacific coast of the USA and Canada as well as from Japan directly were deliberately introduced into the Netherlands (1964), the UK (1965) and France (1966) as *Crassostrea gigas*. It was expected that the oysters could not reproduce themselves at the latitude of the Dutch waters. However, during the warm summers of 1975 and 1976 spat settlement was observed and in 1977 new imports from Japan and the USA stopped. However, imports of marketable oysters from France and Belgium continued. In 1987 settlement of the oyster was observed in the Grevelingen Meer, and in the Oosterschelde estuary, strong expansions occurred in the period 1989-1993. In the Wadden Sea, in 1976 experiments with *C. gigas* were carried out in a shellfish institute. In 1982 the first specimens were found in the Wadden Sea and a rapid expansion toward the east took place. Nowadays the oyster covers most of the hard-substrata in the low intertidal and sublittoral in the Oosterschelde estuary, is

increasing in the Westerschelde estuary, Veerse Meer and Grevelingen Meer and starts to built reefs in the Wadden Sea.

Ensis directus (Conrad, 1843)
(Syn. *Ensis americanus* (Gould in Binney, 1870)
The area of origin of this exotic non-indigenous species is the Atlantic coast of North America from Labrador to North Carolina. Probably transported into Atlantic Europe in ballast water, and further transport of larvae through tidal currents.
First observations in Atlantic Europe in 1979 in the German Bight (Armonies & Reisse, 1999). In the Netherlands the species was found in 1981 in the Wadden Sea. In 1984 the first live specimen was found in the North Sea off Texel. Nowadays the species is common along the whole Dutch coast and in the estuaries (Verkuil, 2004).

Mercenaria mercenaria (Linnaeus, 1758)
The area of origin of this exotic non-indigenous species is the Atlantic coast of North America from Nova Scotia to Yucatan. The species was deliberately introduced.
First imported in Atlantic Europe in 1861 in the Bassin d'Arcachon (France) for human consumption. In 1864, it was found in the Humber (UK). In the Netherlands it was introduced with French oysters. In the 1950s it was introduced in the Oosterschelde estuary and for culture experiments is was deliberately introduced in the Veerse Gat (Wolff, 2005). At present, the species is uncommon in the SW Delta area.

Mya arenaria (Linnaeus, 1758)
The area of origin of this exotic non-indigenous species is the Atlantic coast of North America and northernmost parts of the Pacific. Probably transported into Atlantic Europe with Viking vessels, and further transport of larvae through tidal currents.
First observations in Atlantic Europe before 1245-1295. In the Netherlands the oldest record is in 1765, but it probably was introduced earlier. Common.

Petricola pholadiformis Lamarck, 1818
The area of origin of this exotic non-indigenous species is the Atlantic coast of North America from the Gulf of St Lawrence to the Gulf of Mexico. The species is probably introduced with oysters.
First imported in Atlantic Europe with North American oysters before 1890, and found in Essex (UK). In the Netherlands the species was observed in 1905 off the Dutch coast. Although it was common in the 1940s along the whole coast, nowadays it is scarce.

Bryozoa
Smittoidea prolifica Osburn, 1952.
The area of origin of this exotic non-indigenous species is in the Pacific. The species is probably introduced with oysters.
The only records of this species in Atlantic Europe are in the SW Delta area (the Netherlands). All positively identified specimens were collected since 1999 (Blauwe & Faasse, 2004). At present, the species is not uncommon.

Tricellaria inopinata d'Hondt & Occhipinti Ambrogi, 1985
The area of origin of this exotic non-indigenous species is probably in the Pacific. Transported into Atlantic Europe on ships' hull.
First observations in Europe in 1982 in the lagoon of Venice (Blauwe, 2002). The first Atlantic observation was in 1996 in Galicia (Spain). In the Netherlands the species was found in 2000 in the SW Delta area and identified as *Scrupocellaria reptans* (Otten, 2001a; Otten, 2001b). Nowadays it is from the Oosterschelde and Westerschelde estuary, the Grevelingen Meer and Goesse Meer.

Urochordata
Botrylloides violaceus Oka, 1927

The area of origin of this exotic non-indigenous species is probably Japan, but the species was later found on the Pacific (1970) and Atlantic coasts of North America (1972-73) and in Italy (Faasse & Blauwe, 2002). Probably transported into Atlantic Europe on ships' hull, but a further dispersal by oysters is possible.
First observations in Atlantic Europe in 2000 near Breskens in the Westerschelde estuary. Nowadays common in the eastern part of the Oosterschelde estuary.

Pterophora japonica Oka, 1927
The area of origin of this exotic non-indigenous species is in the Pacific. Its introduction vector is unknown.
Introduction into Atlantic Europe in 1982 in the Channel. In the Netherlands the first colonies were found in the Oosterschelde estuary (the Netherlands) in 2004 (Faasse, 2004b).
Description: Colonies consist of large numbers of small transparent zooids connected by basal stolons.

Styela clava Herdman, 1882
The area of origin of this exotic non-indigenous species is probably the Sea of Okhotsh, the Sea of Japan and the coasts of Japan, Korea and northern China as far south as Shanghai. Probably transported into Atlantic Europe on ships' hull, but a further dispersal by oysters is possible.
First observations in Atlantic Europe in 1952 in Plymouth, UK (Lützen, 1999). In the Netherlands the species was found in 1974 in the harbour of Den Helder. Some months later it was found in the ferry harbour of Texel and again a few months later in the Oosterschelde estuary.
Nowadays it is common on hard-substrata along the coast and in the SW Delta area.

Pisces
Oncorhynchus mykiss (Waldbaum, 1792)
(Syn. *Salmo gairdneri* Richardson, 1836)
The area of origin of this exotic non-indigenous species is the Pacific coasts of Asia and North America. The species was deliberately introduced for angling purposes.
First deliberate introductions into France in 1882. Since 1898, the fish was cultivated in Germany and releases into Dutch waters took place. From the middle of the 1960s fish was released in the brackish Veerse Meer, Grevelingen Meer and Oostvoornse Meer. The species is caught in the Oosterschelde estuary and near the Haringvliet sluices, but reproduction takes only place in the brackish lakes.

B.2 Northeastern Atlantic non-indigenous species in the Oosterschelde and adjacent areas

This paragraph lists the Northeastern Atlantic non-indigenous species in the Oosterschelde and adjacent areas. This list enumerates species which for some reason (natural expansion or human introduction) extended their range by natural means. The list probably also contains species which have been overlooked before (e.g., various Nemertini).

Rhodophyta
Griffithsia corallinoides (Linnaeus) Trevisan, 1845
This species is widely distributed along the NE Atlantic coast. In 2003, the species was found in the eastern part of the Oosterschelde estuary (Stegenga, 2004a).

Lomentaria clavellosa (Turner) Gaillon, 1828
This species is widely distributed in the NE Atlantic from the Faeroes, down to the Mediterranean. In the 'Flora van de Nederlandse zeewieren' (Stegenga & Mol, 1983) the species is only known from drift material. Since 1989 the species is common, especially in the eastern part of the Oosterschelde estuary (Kluijver, 1997).

Phycodrys rubens (Linnaeus) Batters, 1902

This species is widely distributed in the NE Atlantic from the E Greenland, down to the S Spain. In the 'Flora van de Nederlandse zeewieren' (Stegenga & Mol, 1983) the species is not described for the Netherlands. In 1991 the species was found attached in the Oosterschelde estuary at the location Wemeldinge (Kluijver, 1997). There are no recent records.

Plocamium cartilagineum (Linnaeus), P.S. Dixon, 1967
This species is widely distributed in the NE Atlantic from the Faeroes, down to the Morocco. In the 'Flora van de Nederlandse zeewieren' (Stegenga & Mol, 1983) the species is only known from drift material. In 1989 the species was found attached in the western part of the Oosterschelde estuary (Kluijver, 1997). There are no recent records.

Polysiphonia brodiaei (Dillwyn) Sprengel, 1827
This species is widely distributed in the NE Atlantic from the Faeroes, down to the Mediterranean. Before 2002, the species was only recorded from the Netherlands from drift material. In 2002, the species was found at a pontoon near the sluice in the Oosterschelde estuary (Stegenga, 2003a).

Porphyrostromium boryanum (Montagne) Trevisan
This species is distributed in the Mediterranean and temperate coasts of Atlantic Europe. In 1999 the species was found in the western part of the Oosterschelde estuary (Stegenga, 2000b).

Phaeophyceae
Chilionema foecundum (Strömfelt) R.L. Fletcher, 1987
This species is distributed in the NE Atlantic from E Greenland to N France. In 1999, the first Dutch record was made in a tide pool just outside the Oosterschelde estuary (Stegenga, 2000c).

Cutleria multifida (Turner) Greville
This species is common along the NE Atlantic coast and the Mediterranean. In 2004 female gametophytes were collected in the western part of the Oosterschelde estuary (Stegenga, 2005).

Myriotrichia clavaeformis Harvey
This species is widely distributed along the NE Atlantic coasts of Europe and N America. In 1999 it was found growing epiphytic on *Scytosiphon lomentaria* in the Grevelingen Meer (Stegenga, 1999c). It is expected that the species will colonise other areas in the SW Delta area and other substrata.

Petalonia filiformis (Batters) Kuntze
This species is distributed in the NE Atlantic (Iceland, Helgoland, Britain and Ireland). In 2002, the species was found in the upper intertidal in the western part of the Oosterschelde estuary (Stegenga & Sloof, 2003).

Dinophyta
Alexandrium tamarense (Lebour) Balech
This species was described as a new species from the Tamar estuary (UK) in 1925, but the PSP intoxication, which is a characteristic effect of this species, had been described already in 1827. Although the species occurred al long in NE Atlantic waters, the first observations in Dutch waters lasted till 1989.

Gymnodinium mikimotoi Miyake & Kominami ex Oda
(Syn. *Gyrodinium aureolum* Hulburt)
Caused by taxonomic confusion between the populations in the different seas, it is hard to identify the area of origin of this species. *Gymnodinium mikimotoi* is described from Japanese waters, while the material in the NE Atlantic is considered to belong to *Gyrodinium aureolum*. The last species has a wide distribution in the NE Atlantic.

In Atlantic Europe the species was recorded in 1966 off the SW coast of Norway. In 1989 the species was found for the first time in Dutch waters, and nowadays it is found in the entire Dutch sector of the North Sea. Highest concentrations were found in the pycnocline at the Oyster Grounds.

Prorocentrum triestinum Schiller
(Syn. *Prorocentrum redfieldii* Bursa)
This species has been described from the Atlantic coast of North America, but might have a worldwide distribution. Since 1961 the species is found as bloom forming in the Dutch coastal waters.

Chlorophyta
Ulva tenera Kornmann & Sahling
This species was recently described as new for Helgoland (Kornmann & Sahling, 1994). Since 1999 the species is found at exposed localities in the Oosterschelde and Westerschelde estuary. The species grows epilithic in the upper intertidal (Stegenga & Mol, 2002).

Porifera
Haliclona cinerea (Grant, 1826)
This species is distributed in the NE Atlantic from the Shetlands, along the west coasts of the British Isles, south into the Mediterranean. Although there are some observation at the British North Sea coast, it was not recorded from the continental coast of the North Sea. In 2005, the species was found in the Oosterschelde estuary.

Haliclona rosea (Bowerbank, 1866)
This species is distributed in the NE Atlantic from the east coast of Greenland to France. In 1976, is was found at Wemeldinge in the Oosterschelde estuary. It is suspected that the species is imported with oysters as it was found abundantly in oyster ponds near Yerseke (Buizer, 1989).

Halisarca dujardini Johnston, 1842
This species is distributed along the Atlantic coast of Europe. In the North Sea, the species in known from Helgoland. In 2005, the species was found in the western part of the Oosterschelde estuary (Bragt, unpublished data).

Hymeniacidon perlevis (Montagu, 1812)
This species is distributed along the Atlantic coast of Europe. First collected in the Netherlands in 1951 near Wemeldinge and later in 1989 in oyster ponds at the Yerseke Bank. In recent years, the species is still present in the Oosterschelde estuary, but also in the Grevelingen Meer and Veerse Meer (Kluijver, 1997).

Oscarella lobularis (Schmidt, 1862)
This species is distributed along the Atlantic coast of Europe. In the North Sea, the species in known from Helgoland. In 2006, the species was found for the first time in the mouth of the Oosterschelde estuary (Faasse, unpublished data).

Suberites massa Nardo
The distribution area of this species is unknown. It is reported from brackish water zones of some southern estuaries in the UK. In 1994 it was recorded from the western part of the Oosterschelde estuary (Kluijver, 1997). Nowadays, the species is rare.

Hydrozoa
Bimeria vestita Wright, 1859
This is a rare species, only known from some localities in the Celtic Sea, along the Belgium coast and in the Mediterranean. In 2001 the species was found in the central part of the Oosterschelde estuary (Faasse, 2003a).

Corymorpha nutans M. Sars, 1835
This species is distributed from Norway, down to the Mediterranean. In 1966 the species was found off the coast of the Delta area by Wolff (1973) In 1988 it was found off the coast in the southern Delta area (Kluijver, 1997). In 2005, the species was found in the western part of the Oosterschelde estuary (Bragt & Faasse, 2006).

Halecium lankesteri (Bourne, 1890)
This species has a southern distribution area, from West Africa to Norfolk (UK). The species was recorded from the western Oosterschelde estuary for the first time in 2003 (Faasse, 2003d).

Leuckartiara octona (Fleming, 1823)
(Syn. *Perigonimus repens*)
This species is common around the British Isles and in north-west Europe. The species was recorded from the Dutch coast, but was not known for the southern Delta area. In 1989 the species was found in the western part of the Oosterschelde estuary (Kluijver, 1997). In 2001 is was also reported by Faasse (2003a).

Sertularella ellisii (Deshayes & Milne-Edwards, 1836)
The area of distribution of this species is tropical waters and temperate zones of the NE Atlantic. In 2003 the species was found in the western part of the Oosterschelde estuary (Faasse, 2003d).

Sipuncula

Nephasoma minuta (Keferstein, 1862)
Although this species is widely distributed in the North Sea (Shetland, Sweden down to Brittany) it was not recorded from inshore waters. In 2001, 11 specimen were collected in the eastern part of the Oosterschelde estuary (Faasse, 2002). In the same article, the author is doubtful about the identity of *Onchnesoma steenstrupi* Koren & Danielssen, 1876 as collected in the Westerschelde (Stock, 1966).

Polychaeta

Branchiomma bombyx (Dalyell, 1853)
This species is distributed in the NE Atlantic to the Gulf of Guinea, the Mediterranean and in the North Sea to Öresund. In 1973, the species was collected in the Kanaal door Walcheren in a thermally polluted area (Wolff, 1974).

Microphtalmus similis Bobretzky, 1870
The species is distributed in the Black Sea, Mediterranean and North Sea. As the first NW European records dates from 1962 near Neuwerk (Germany), it might originate from the Mediterranean or Black Sea. In the Netherlands it was collected in 1962 or 63 in the Brouwershavense Gat and in 1966 in the North Sea off the Delta area (Wolff, 1969, 1973).

Polydora hoplura Claparède, 1870
The species is distributed in the southern North Sea, Channel, NE Atlantic, Mediterranean, Australia and New Zealand. The species has been repeatedly been imported with oysters from Brittany. In 1950, oyster growers attempted to control the species because of its abundance (Wolff, 2005). Nowadays, records of the species are scarce.

Sabellaria spinulosa Leuckart, 1849
The species is distributed from the NE Atlantic to the Gulf of Guinea, and in the Black Sea. The species has been repeatedly been imported with oysters from Arcachon and Brittany. Records are known from the period between 1938 and 1950 (Wolff, 2005). In 1991, the species was found at the artificial reefs of Noordwijk (Moorsel, 1993), and later records are from the SW Delta area (1992-2001).

Syllidia armata Quatrefages, 1865

The species is distributed in the Atlantic from the Hebrides to South Africa, and in the Mediterranean. The species has been imported with oysters from Brittany. The only record is from 1943 in the Oosterschelde estuary.

Syllis gracilis Grube, 1840
The species is distributed in the Channel and southern North Sea up to Helgoland. The species has been imported with oysters from Brittany. The only record is from 1940 in the Oosterschelde estuary.

Nemertina
Amphiporus lactifloreus (Johnston, 1827-28)
This species is distributed from the Mediterranean and northern coasts of Europe to the Atlantic and Arctic coast of N America. In 2001 the first Dutch finds were made in the eastern part of the Oosterschelde estuary (Faasse, 2003b).

Carcinonemertes carcinophila (Kölliker, 1845)
Found on galatheid, portunid and xanthid crabs from Europe to the Atlantic coast of N America. In 2001, the first Dutch records were made in the Oosterschelde and Westerschelde estuary (Faasse, 2003b).

Emplectonema gracile (Johnston, 1837)
This species has a wide geographic range, including the west coast of N America and the northern coasts of Europe. In 2001, the first Dutch records were made in the Oosterschelde and Westerschelde estuary and the Grevelingen Meer (Faasse, 2003b).

Lineus sanguineus (Ratke, 1799)
(Syn. *Ramphogordius sanguineus* (Ratke, 1799))
The geographic range of this species extends from the British Isles to the coasts of Sweden, Belgium and France. In 2001, the first Dutch records were made in the Oosterschelde and Westerschelde estuary (Faasse, 2003b).

Nemertopsis flavida (McIntosh, 1873-74)
This species is distributed from Denmark to the Mediterranean, although it is also recorded (as *Nemertopsis tenuis*) from South Africa. In 2001, the first Dutch records were made in the Oosterschelde and Westerschelde estuary (Faasse, 2003b).

Prosorhochmus claparedii Keferstein, 1862
This species is distributed from Britain, down to Spain into the Mediterranean. It lives under stones and in rock crevices, at upper and lower shore and in the subtidal. In 2002, the first Dutch records were made in the Oosterschelde and Westerschelde estuary (Faasse, 2003b).

Tetrastemma ambiguum Riches, 1893
This species was only known from Plymouth (UK), were it lives in the sublittoral. In 2001, the first Dutch records were made in the Oosterschelde and Westerschelde estuary (Faasse, 2003b).

Tetrastemma coronatum (Quatrefages, 1846)
This species is distributed is known from Britain and Scandinavian, and the Mediterranean and Black Sea. In 2001, the first Dutch records were made in the Goesse Meer and Oosterschelde estuary (Faasse, 2003b).

Tetrastemma robertianae McIntosh, 1873-74
The distribution range of this species extends from Scandinavia to the British Isles. In 2001, the first Dutch record was made near Yerseke in the Oosterschelde estuary (Faasse, 2003b).

Cirripedia
Balanus balanus (Linnaeus, 1758)

The species has a northern distribution from the Arctic to the northern North Sea and Celtic Sea. The first record from the Netherlands dates from 1990 in the Westerschelde. Specimens found in the Oosterschelde estuary occurred on illegally imported mussels in 1993.

Isopoda
Janiropsis breviremis Sars, 1899
This species is sporadically reported from the north-east, south and west coasts of the British Isles. In 2000, the first Dutch record was made at a pontoon just outside the Oosterschelde estuary (Faasse, 2001a).

Decapoda
Athanas nitiscens (Leach, 1814)
This species is found off the south and west coasts of the British Isles, and is scarce in the north-east. In the 1994 the species was recorded from the Oosterschelde estuary (Faasse, 1994), During the next year, the species became more common 1996a). After the cold winter of 1995-96 the number of species strongly decreased (Faasse, 1997a).

Inachus phalangium (Fabricius)
This species is distributed from Norway to West Africa, Cape Verde and Mediterranean. In the Netherlands, the species was recorded in 1989 from the Westerschelde. In 1994 the species was found in the Oosterschelde estuary (Faasse, 1994). During the next year, the species became more common (Faasse, 1996b).

Liocarcinus pusillus (Leach, 1815)
This species is distributed from Norway down to NW Africa, but is scarce in the southern North Sea. In 2001 a specimen was washed ashore at Texel (Cadée & Kooten, 2001) and in 2003, a live specimen was found in the central Oosterschelde estuary (Ligthart & Faasse, 2004).

Palaemon adspersus Rathke, 1837
This species is distributed from Sweden down into the Mediterranean. In the Netherlands, the species was recorded from the Gat van Ouwerkerk in 1953. In 1982 the species was found in the Grevelingen Meer and recently the species also occurs in the Oosterschelde estuary (Boois, 2000).

Palinurus elephas (Fabricius, 1787)
This species is distributed from the south and west coasts of the British Isles to the Azores and Mediterranean. The first record of the Netherlands dates from before 1769 when a large decapod (which may have been *P. elephas*) was brought in on a ships' hull. Around 1907, two specimens from France were deliberately released in the Oosterschelde estuary. In 1927 one specimen was caught (Heerebout, 2001). There are no other records of this species.

Polyplacophora
Leptochiton cancellatus (Sowerby G.B. II, 1840)
(Syn. *Lepidopleurus cancellatus*)
It is an European species, mainly restricted to the coasts of the British Isles, but also dredged in the southern North Sea. The only record from the Netherlands is near Yerseke in the Oosterschelde estuary in 1897. The location of import suggests an introduction with oysters.

Gastropoda
Calliostoma zizyphinum (Linnaeus, 1758)
This species is distributed from Norway, down to the Mediterranean, Canaries and Azores. The first observation in the Netherlands was near Yerseke in 1976. In 2003 the species was recorded again (Gittenberger, 2004a). As most records are near oyster ponds an introduction with oysters is suggested.

Calyptraea chinensis (Linnaeus, 1758)

This species is distributed from West Scotland, down to NW Africa and Mediterranean. This species is probably a cryptogenic species. In the North Sea it is restricted to the southern part. In the Netherlands the species was introduced with oysters in the 1940s. There are no recent observations.

Dendronotus frondosus (Ascanius, 1774)
This species has a Boreo-arctic distribution. First Dutch record in 1877 near Vlissingen in the Westerschelde estuary. It was a fairly common species in the Oosterschelde in the period 1965-1975 (Wolff, unpublished observations). After 1977 the species has been found in varying numbers along the Dutch coast and in the Oosterschelde estuary (Bragt, 2004).

Elysia viridis (Montagu, 1804)
This species is distributed from Norway, down to the Mediterranean and N Africa. The first observation in the Netherlands dates back to 1899. It disappeared locally after 1938, but was found again in 1989. The population disappeared after the cold winter of 1995/96 and 1996/97. In November 1998 it was observed again in the Oosterschelde and in 2001 in was found in the Grevelingen Meer. At present it is one of the most common sea slugs in the estuary (Bragt, 2004).

Eubranchus farrani (Alder & Hancock, 1844)
This species is distributed from Norway down to the Mediterranean. In 2003 the species was found in the Grevelingen Meer and Oosterschelde estuary (Bragt, 2004).

Facelina auriculata (Müller, 1776)
Distributed from Norway to the Mediterranean. First Dutch record in 1992 in the Oosterschelde estuary. Nowadays, not common but established (Bragt, 2004).

Flabellina lineata (Lovén, 1846)
Distributed from Norway to the Mediterranean. In 1954 a single specimen was found washed ashore near Den Helder. In 2001 the species was found in the western part of the Oosterschelde estuary near Burghsluis. There are no recent records (Bragt, 2004).

Flabellina pedata (Montagu, 1815)
Distributed from Norway to the Mediterranean. In 1999 two specimens were found in the western part of the Oosterschelde estuary. Other specimens were found in 2002 and 2003 (Bragt, 2004).

Gibbula cineraria (Linnaeus, 1758)
This species is distributed from Norway and Iceland, down to Gibraltar. First written record in the Oosterschelde estuary in 1994 (Wolff, 2000), but found already alive in the 1983 (Gittenberger, 2004b). Since 1998, the species is found on a regular base in the Oosterschelde estuary. As the first finds are all in and near oyster ponds, introduction with oysters is suggested.

Geitodoris planata (Alder & Hancock, 1846)
(Syn. *Discodoris planata*)
This species is distributed from Norway, along the British west coast down to the Mediterranean, but no records exist for the North Sea coasts. In 1999, the species entered the Oosterschelde estuary (Bragt, 2004). Nowadays, it is one of the most common dorids in the estuary Faasse, 2001b). In 2002 the species was also found in the Südhafen at Helgoland.

Goniodoris castanea (Alder & Hancock, 1845)
The species is distributed in the NE Atlantic at the European coast and in the Mediterranean. First observed in the Netherlands in 1949. In 2000 and 2001 the species was common in the SW Delta area (Grevelingen Meer, Oosterschelde estuary and Westerschelde estuary). At present found in limited numbers (Bragt, 2004).

Goniodoris nodosa (Montagu, 1808)
This species is distributed in the NE Atlantic from Norway to N Spain. It was first observed in 1956 in the Oosterschelde estuary near Zierikzee. No observations after 1959 (Bragt, 2004).

Hermaea bifida (Montagu, 1815)
The species is known from all around the British Isles to the Mediterranean. In the period 1989-92 a few animals were found per year in the Oosterschelde estuary. Last record from 2003 (Bragt, 2004).

Janolus hyalinus (Alder & Hancock, 1854)
This species is distributed from Normandy and the British west and south coasts down to the Mediterranean. In 1990 and 1993, two specimens were found in the Grevelingen Meer. In 1998 the species was found in the Oosterschelde estuary (Zeelandbrug). The species seems to be established, but occurs in low numbers (Bragt, 2004).

Jorunna tomentosa (Cuvier, 1804)
This species is distributed from Norway to the Mediterranean and Morocco. The species was recorded from 1992 to 1996 along the Dutch coast. From 1998 on, the species became common in the Oosterschelde estuary (Bragt, 2004).

Limacia clavigera (Müller O.F., 1776)
This species is distributed from Norway, along the British west coast down to the Mediterranean and along the North African coast. In the North Sea it is known from the British east coast and the German Bight. In 1995 the species was found in the western part of the Oosterschelde estuary. Since 1999, a small population has been observed each year near Burghsluis in the Oosterschelde estuary (Bragt, 2004).

Onoba semicostata (Montagu, 1803)
This species is distributed from Norway to the Mediterranean. In 1999, live specimens were found at two localities in the western part of the Oosterschelde estuary (Faasse, 2000, 2004c).

Placida dendritica (Alder & Hancock, 1843)
This is a widespread species, known from Norway to the Mediterranean. It might even be cosmopolitan. First record in the Oosterschelde estuary in 1992. The species is established, but occur in low numbers only (Bragt, 2004).

Polycera quadrilineata (Müller O.F., 1776)
This species is distributed from Greenland and Iceland, along the British west coast down to the Mediterranean. In the North Sea it is known from the British east coast and German Bight. In 1997 it was found in the Oosterschelde estuary. There are no recent observations (Bragt, 2004).

Thecacera pennigera (Montagu, 1815)
This is a cosmopolitan species. In 1954 it was found near Vlissingen in the Westerschelde estuary. In 1985 the species was found in the Oosterschelde estuary. The last record date back to 2001 (Bragt, 2004).

Trinchesia rubescens (Picton & Brown, 1978)
This species was only known from the Trondheim fjord (Norway) and 40 locations along the west coasts along the British Isles. In 2002 the species was found in the Oosterschelde estuary (Bragt, 2004).

Tritonia plebeia Johnston, 1828
This species is distributed from arctic Norway to the western Mediterranean. The initial Dutch records, from 1877 to 1952, are all from the North Sea. From 1952 to 1994 the species was recorded from the Westerschelde, Oosterschelde and the North Sea. In 2003, adults and spawn were recorded from the Oosterschelde estuary (Bragt, 2004).

Trivia arctica (Montagu, 1803)
Distributed from Norway to the Mediterranean. The species was found in 2001 in the eastern part of the Oosterschelde estuary. The species is scarce, but reported every year (Holsteijn, 2004).

Bivalvia
Acanthocardia echinata (Linnaeus, 1758)
This species is distributed from Iceland and Norway to the Canary Islands, the Atlantic coast of Morocco, into the Mediterranean. In 1999 the species was found in the Oosterschelde estuary. At this moment, it occurs only in low number (Goud, 2004).

Echinodermata
Amphiura brachiata (Montagu, 1804)
(Syn. *Acrocnida brachiata*)
In the North Sea the species is distributed on the east coast of the British Isles, down to the Dogger Bank. The species was found in 2005 in the Oosterschelde estuary (Bragt & Faasse, 2005) and in 2006 in the Grevelingen Meer (pers. observation).

Bryozoa
Bowerbankia citrina (Hincks, 1877)
This species has a southern distribution and is known from the south coast of the British Isles and Brittany. In 1997 it was recorded from the Oosterschelde estuary (Faasse, 1997c).

Bugula simplex Hincks, 1886
This species is known the NW Atlantic, NE Atlantic, Australia and New Zealand. In 2000, the species was observed in the harbour near Sas van Goes (Blauwe & Faasse, 2001). There are no other records in the Netherlands. As nearly all European records are from harbours, its vector is most likely ships' hulls.

Bugula stolonifera Ryland, 1960
This species is distributed on both sides of the Atlantic and in the Mediterranean. Due to the limited number of observations of this species and taxonomic confusion with *Bugula avicularia*, the status of this species is unclear (see Faasse, 1998a). In 1986, the species was found at the seaside of the Brouwersdam in the Springersdiep (Kluijver, 1997), in 1993 in the NIOZ harbour at Texel, and in the period 1990-98 at various other places in the SW Delta area (Faasse, 1998a). As most records are from harbours, its vector is most likely ships' hulls.

Fenestrulina malussii (Audouin, 1826)
This characteristic species is widespread around the British Isles, but was not recorded for the southern North Sea. In 2002 the species in the eastern part of the Oosterschelde estuary at the location Wemeldinge. In 2004, the species was also found off Helgoland (pers. observation).

Idmidronea atlantica (Forbes in Johnston, 1847)
The species is distributed from Norway and Shetland, down to the Mediterranean, Angola and the Azores. In the Netherlands, the only record is in the Oosterschelde estuary near Zierikzee in 1985 (Kaandorp, unpublished data). There are no recent observations.

Nolella pusilla (Hincks, 1880)
This inconspicuous species has been recorded from the UK., Helgoland and Sylt (Germany). In 2001 the species was found at Sas van Goes (Oosterschelde estuary) and in the Kreek van Westkapelle (Blauwe, 2003).

Schizomavella linearis Hassall, 1841
This species is widely distributed in the NE Atlantic, from Norway down to the Mediterranean. It is common in the western part of the Oosterschelde estuary, where it was found in 1989 for

the first time (Kluijver, 1997). As it forms small crusts on stones, it is probably overlooked in previous surveys.

Urochordata
Aplidium glabrum (Verrill, 1871)
This species has an Arctic-Boreal distribution. In 1977 it was found at Yerseke in the eastern part of the Oosterschelde estuary (Buizer, 1983). Nowadays, it is common in the eastern part of the Oosterschelde estuary and also found in the Grevelingen Meer and the Havenkanaal Goes.

Diplosoma listerianum (Milne-Edwards, 1841)
This species is widely distributed, but through confusion with *Diplosoma singulare* and *Diplosoma spongiforme*, its precise area is unknown. Found in the Oosterschelde estuary in 1977 (Buizer, 1983). Nowadays it is common in the Oosterschelde estuary and Grevelingen Meer, but its distribution pattern does not follow the expansion of oysters. Most likely it is a case of natural range extension, as it increased off Helgoland as well (pers. observation).

Molgula complanata Alder & Hancock, 1870
This species is distributed from the Arctic to Brittany. Recorded from the western part of the Oosterschelde estuary in 2005 (Faasse, 2006), but a *Molgula*-like species was already found in 1999 (Dubbeldam, pers. comm).

Pisces
Balistes carolinensis (Gmelin, 1789)
This species is distributed in the Atlantic. In the North Sea the fish occurs only in summer and autumn. Since 1970, 20 specimen were caught along the Dutch coast (Nijssen & Groot, 1987). In 2004, two specimens were caught in the western part of the Oosterschelde estuary.

Gobius niger Linnaeus, 1758
Common in the NE Atlantic, North Sea and Baltic. Recognised in 1964 in the Veerse Meer. Nowadays common in the Oosterschelde estuary, the Grevelingen Meer and Veerse Meer.

Gobius paganellus Linnaeus, 1758
This species is distributed from W Scotland, down to Mauritania. The species is known from the Channel, but was not reported from the North Sea. In 2003, a dead specimen was found in the Oosterschelde estuary (Moorsel & Zwart, 2005).

Gobiusculus flavescens (Fabricius, 1779)
This species is distributed from Norway, down to S Portugal. The species is not reported from the SE North Sea. In 2004, the species was found in the Oosterschelde estuary at the localities Zoetersbout and Zeelandbrug.

Parablennius gattorugine (Linnaeus, 1758)
(Syn. *Blennius gattorugine*)
Common in the NE Atlantic, but scarce along the Dutch coast (Nijssen & Groot, 1987). Since the late 1990s common in the Oosterschelde estuary (Holsteijn & Ates, 1999).

B.3 Species with an uncertain origin

Anthozoa
Diadumene cincta Stephenson, 1925
The distribution of this species is not precise known through confusion with small specimens of *Metridium senile*. It is recorded from the British Isles, the Netherlands, Helgoland and the south-west coast of Europe, down to N Spain. Through the confusion with *Metridium senile*, its origin is uncertain. It was described from Plymouth in 1925, but Ates (2006) arguments that the species was already present in 1890. The specimens of Helgoland have been imported with

mussels from the Netherlands. As it seems that the distribution of the species is restricted to Europe, Ates suggests that it is a European species with a limited distribution. In that case, the species has recently become very abundant, as it is now the most common anemone in the Netherlands.

Polychaeta

Aphelochaeta marioni (Saint-Joseph, 1894)
In Europe, the species is distributed in the North Sea and the Channel. Elsewhere it is recorded from the Indian Ocean, Australia, Chile and the Antarctic. As it was recorded in France in 1894, in Germany in 1960 and absent in the Netherlands in the early 1900s, it might be an exotic species.

Polydora ligerica (Ferronière, 1898)
(Syn. *Boccardia ligerica* Ferronière, 1898, *Polydora redeki* Horst, 1920)
In Europe the species is restricted to brackish waters in the North Sea, Baltic and N France. Elsewhere it is recorded from the N and S Atlantic and N Pacific. It was described in 1898 and 1920 for Europe, but it might be an exotic species.

Wood boring Isopoda and Bivalvia

The problem of wood boring organisms is that dispersal took place in early history by wooden ships or driftwood and thus obscuring the area of origin.
The isopod *Limnoria lignorum* (Rathke, 1799) was described from Scandinavia in 1799, observed in the British Isles in 1811 and in France in 1868. The first observations in the Netherlands date from 1885-86, but it is likely that the species had been overlooked and that was already in 1834 in Dutch waters. Nowadays, the species is nearly cosmopolitan.
Limnoria quadripunctata Holthuis, 1949 was described from driftwood on the Dutch coast in 1949, but seems not to be established in the Netherlands. Elsewhere it is recorded from New Zealand, South Africa and the Californian coast of N America.
The bivalve *Psiloteredo megotara* (Hanley in Forbes & Hanley, 1848) is widely distributed in the North Atlantic and has been found in driftwood in the Arctic. It was found in wooden vessels from Scheveningen in the early 1910s and is now recorded in wood along the entire Dutch coast.
Teredo navalis (Linnaeus, 1758) is nowadays widespread around the world. The species was described on Dutch material collected in 1730-32, but it remains uncertain whether the species has a NE Atlantic origin.

Bivalvia

Lamellaria sp.
In 2001 two specimen of an unknown *Lamellaria* species were collected in the Oosterschelde estuary at Zierikzee and the Tetjes (Goud & Gittenberger, 2004). As the identity of this species is unknown, its area of origin is unknown as well.

Bryozoa

Wolff (2005), considered some bryozoan species as possible exotic. As this species do not occur in the list of non-native species in the North Sea (Reise et al., 1999) the area of status of these species is uncertain.
Bowerbankia imbricata (Adams, 1798) is distributed in the NE Atlantic from the Barents Sea to the Meditteranean and in the Black Sea and in the W Atlantic from Greenland to Brasil. Is is common in the SW Delta area in the Netherlands.
Bowerbankia gracilis Leidy, 1855 is distributed in the NE Atlantic from the Arctic to the Meditteranean and in the Black Sea and in the W Atlantic from Greenland to Brasil. Is is common in the SW Delta are in the Netherlands, but frequently confused with *B. imbricata*.
Victorella pavida Kent, 1870 has a cosmopolitan distribution. It is common in non-tidal brackish waters in the SW Delta area (Heerebout, 1969).
Walkeria uva (Linnaeus, 1758) is distributed in the NE Atlantic from the Barents Sea to the Mediterranean and in the NW Atlantic. It was common in the SW Delta area (Heerebout, 1969), but there are no records of the species from the last years.

Urochordata
Didemnum lahillei Hartmeyer, 1909
This species is known from Plymouth and Brittany, with its northernmost record in Wimereux (N France). In 1991, it was recorded in the construction pit in the Oosterschelde estuary and identified as *Didemnum maculosum* (Kluijver, 1997). It became dominant in the eastern part of the estuary, associated with the Pacific oyster, and was identified by Dr F. Monniot as *Didemnum lahillei* (Ates, 1998). Recently this identification is doubted and a Pacific introduction with oysters is suspected. Moreover, the species is invading the Atlantic and Pacific coasts of N America too.

Molgula manhattensis (De Kay, 1843)
The area of origin of this species is unclear. Drawings from 1762, showing a specimen collected in the Oosterschelde estuary do not reveal enough information to identify the species. The N American species *M. manhattensis* (De Kay, 1843) was thought to differ from the European species *M. tubifera* Oersted, 1844, but recent studies by Monniot showed no difference. Nowadays, the species is common in the Veerse Meer, but less abundant in the Oosterschelde estuary.

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Appendix C: Audit report on the report Risk Analysis of Mussel Transfer

by

Prof.dr. Wim J. Wolff

on the report PROJECT RISK ANALYSIS OF MUSSEL TRANSFER (PRIMUS)
(The reactions of the authors are in bold)

General

Trying to quantify the risk of mussel transports is similar to measuring the dimensions of a structure which is only partly visible. One can measure the visible parts very carefully, but the dimensions of the invisible part can only be guessed at. Similarly, the quantification of the risks of mussel transfer can be done with utmost care for the exotic species we are aware of, but at the same time we know that an unknown number of exotic species must be present we have not yet discovered (e.g., very small life stages, microscopic algae, internal parasites). In addition, the quantification of the risk of transfer of known exotic species is difficult as well, mainly because we know so little about the characteristics of most exotic species. The report of the Project Risk Analysis of Mussel Transfers is testimony to that.

On the other hand, we know that exotic species cause problems. The examples of rabbits competing with live-stock and kangaroos in Australia and water hyacinths clogging lakes and rivers all over the world are sufficiently known. The introduction of the shipworm in the 18th century caused a disaster for the Dutch sea defenses. The oyster disease Bonamia nearly completely wiped out the Dutch flat oyster industry and the replacing Pacific oyster is likely to change the functioning of the Oosterschelde and the Wadden Sea.

We also know that marine introductions are very hard to remove again once they have established. So far, there is only one clearly documented case of removal available next to many failures. The only defense we have in most cases is prevention. Prevention of primary introductions of exotics from other parts of the world, and prevention of secondary spread (or rather slowing down secondary spread) of exotics which have managed to settle. Prevention of primary introductions nowadays receives ample attention, for example from the International Maritime Organization (IMO) of the United Nations and from the International Council for the Exploration of the Sea (ICES). Secondary introductions, however, receive less attention although they usually concern the same set of species.

The study Project Risk Analysis of Mussel Transfers makes a bold attempt to quantify the risks of secondary introductions for one particular transport route: from the Irish and Celtic Seas to the Oosterschelde estuary. The study has brought together a large amount of information from very different sources in a short time. The authors are to be congratulated with this comprehensive approach. The authors have carefully documented all steps they have taken in the scientific process and they have clearly expressed the shortcomings of their approaches. On the other hand the short period available has resulted in several data to be of lower quality than could have been wished.

In this audit no attention has been paid to errors in language or grammar; typing errors have been corrected only in case of errors in scientific names.

Chapter 1.

The Introduction to the PRIMUS report (Chapter 1) describes the problem connected to the import of mussels from Irish waters into the Oosterschelde estuary. It is stated that with the import of mussels exotic plants, animals, and micro-organisms might be imported which might become invasive and could have a negative impact on (parts of) the ecosystem of the Oosterschelde. The auditor wants to point out that also exotic species harmful to the shellfish cultures in the Oosterschelde estuary could be imported.

The Authors agree with the auditor. Depending on the extend of the ecological effect and the species concerned, the ecological impact could lead to "economical impact" for various user functions (including shellfish culture). Already at present exotic species are present in the Oosterschelde that have (had) negative impact to the shellfish culture in the Oosterschelde. Examples are *Sargassum muticum*, *Undaria pinnatifida*, *Crepidula fornicata* and *Crassostrea gigas*, which has recently been fished in the wild within an experiment by mussel farmers in order to control the population within the Oosterschelde. We have specified this potential consequence of introduction of exotic species in the text.

Section 1.1.

Remarkable enough, the Introduction to the report does not define what exotic species are and why they might cause problems. Exotic species (also known as alien species or non-indigenous species) are species occurring originally in other parts of the world and kept there because natural barriers prevent expansion to other areas. Only if human activities (e.g., shipping, shellfish transfers, digging canals etc.) transport such species across these natural barriers, they may establish themselves in new areas. In such new areas, these species are called exotics. Many exotic species are transported across natural barriers, but only a minority (10%) establishes itself in the newly reached region. Of the established exotic species most remain uncommon, but again a minority shows strong population development. And of the strongly developing exotic species a few appear to be harmful to the receiving ecosystem and to functions of this ecosystem for human society. Unfortunately, we cannot predict very well which species may become harmful. For that reason worldwide the first line of defense against harmful exotics is prevention of introduction into new areas of all exotics. The next line of defense is slowing down their subsequent spread in the new region. Finally, when a harmful exotic species has reached an area where it causes harm, directed measures may be taken. In general, however, such measures appear to be not very successful in the marine environment. So, our remaining options are prevention of introductions altogether and slowing down the dispersal of exotic species which did arrive in a new area.

Exotic species can establish themselves anywhere in NW-European waters. Once established they become subject to natural transport processes. Depending on the characteristics of the species and the pattern of water movements they will disperse slowly or rapidly over the other NW-European waters. But it will be clear that larger distances require a longer time to colonize new areas. This also holds for the Irish and Celtic Seas. Both distance and hydrographical pattern cause that natural expansion to the Oosterschelde estuary for most species will take years, if not centuries. This also holds for harmful exotic species occurring in the Irish and Celtic Seas.

A definition of exotic species was not included in the introduction since the second chapter was attributed to this topic. However, the authors agree that a definition of exotic species already in the introduction is informative to the reader. Therefore we have added a paragraph in the introduction, dealing with exotic species. In this paragraph a definition of exotic species is presented as well as the dispersion within the region and the influence of human activities on this dispersion.

Section 1.3.

Elsewhere in the Introduction it is stated that the Ministry of Agriculture, Nature and Food Quality and the Association of Mussel Importers in the Netherlands have requested Wageningen IMARES to make a quantitative risk assessment for the introduction of exotic non-indigenous species from the Irish and Celtic Seas. It is not explained, however, how this risk assessment will be performed. The next paragraph describes the results of the project, but also does not explain the reasoning behind the risk assessment. Although the auditor can understand the logic of most steps of the project described in this paragraph, he fails to understand why *Mytilus galloprovincialis* is being studied.

In paragraph 1.3 (study approach) we have now explained why is chosen for a risk assessment and how it is implemented in this study. It is recognized that the relevant ecological properties of invasive aquatic species are not fully understood, and interaction between both species and species and their physical environment are numerous and complex and therefore difficult to predict. Moreover, the actual establishment is depending on a series of coincidences that are often difficult to predict. With a risk analysis, it is possible to assess the risks, even without fully understanding the processes and the system. Moreover, the risk analysis allows a prioritization of the factors that require further assessment and/or monitoring.

The authors agree with the auditor that the chapter on *M. galloprovincialis* is somewhat out of the scope of the study. However, deliberate translocations of animals outside its natural range and area of its dispersal within the European Union are subject to specific EU legislation. In the chapter on *M. galloprovincialis* we study whether the Oosterschelde is outside the natural range of distribution.

Chapter 2, section 2.1.

In the chapter on Introduction of non-indigenous species Wolff (2005) is cited on the distinction between exotic non-indigenous species and Northeast Atlantic non-indigenous species. Erroneously, the latter category is stated to derive from the Northeast Atlantic shelf province. This is not right: the NE Atlantic shelf province is based on a biogeographic subdivision proposed by Longhurst (1998); it is not identical to the area shown in Fig. 7 of Wolff's paper (= Fig. 5) which indicates the area from which marine species may reach the Netherlands by natural processes. Moreover, Fig. 4 in the report shows that the Northeast Atlantic Shelf Province extends along the Norwegian coast. This might be mistaken since the text of the original publication mentions another area than the map in the book shows.

This was indeed a misinterpretation of figure 7 from Wolff (2005). We have made a new figure bases on Longhurst (1998) indicating the location of the NE Atlantic shelf. The text and subscript of the figure indicating the area from which marine species may reach the Neterlands by natural transport is adapted. The figure in the book of Longhurst (1998) is not very clear. In the text it is stated that the "edge of the deep Faeroe-Shetland Channel and the Norwegian Trench" forms the northern boundary of the Province. This means that the Norwegian coast is not part of the Province. We have addressed this misunderstanding in the text.

At the same page a footnote defines historical times as the past 5000 years. This long period is based on Eno et al. (1997) who give this period without explanation. Maybe it is an error because American literature uses 500 years (since the discovery of America). The oldest reference to an introduced marine species is less than 1000 years (Petersen et al., 1992). It is advised to use a shorter period, for example 1000 years.

The time path of 5000 years seems indeed arbitrary chosen. What is important for the reader is to know that the period is indeed on a geological scale in the order of

decades or eras. We have based this period on the reference of Eno et al. 1997: "Non-native marine species in British waters: a review and directory". The reference is added to the footnote. We have changed the period to 1000 years with reference to Petersen et al. (1992).

Section 2.1.

In the sub-chapter on Introduction and transport vectors an overview is given of the importance of the different transport vectors. It may improve understanding to indicate the importance of the different vectors over time (hull fouling used to be very important until the advent of modern anti-fouling coatings, dry ballast is not used any longer, ballast water is very important nowadays but regulations are being developed by IMO and national governments to minimize the importance of ballast water, shellfish transports and opening of new canals are still important). In the list of transport vectors in the third paragraph "(secondary introductions)" should be added after "Natural transport etc."

The authors agree that there has been a change in importance of the vectors due to various international legislative measures. We have added a sentence indicating this change in importance over time. In the list with the transport vectors an extension is given that natural transport of exotic species is by definition always a secondary introduction.

In the fourth paragraph Minchin & Gollasch, 2002 are cited. Citing Wolff, 2005, who found the same result, may reinforce the conclusion.

Wolff (2005) is also cited now.

Section 3.4.1.

In the third paragraph the observation period is given as July 2002 – March 2006. This period differs from the one in the legend of Fig. 14.

The legend of figure 14 contained an error. The data from the commodity board of fish that are presented in this figure range from July 2002 – March 2006. The error is corrected

Section 3.4.3; Fig. 17.

Fig. 17 shows mussels originating from Poole Harbour on the Channel. This is outside the area of interest (Irish and Celtic Seas). The data should either be removed or explained.

Poole Harbour is not part of the Irish and Celtic Sea. However, the figure gives an overview of the total import of juvenile mussels into the Oosterschelde from Ireland and the UK. In the text Poole Harbour was, incorrectly, not excluded from the Irish and Celtic Sea. This error is corrected now.

Section 4.1.

Table 4 gives a list of non-indigenous estuarine and marine species in Britain and Ireland. It is advised to place the species per main taxon in alphabetical order and to correct the following typing errors: *Odontella, Myicola ostreae, Bowerbankia, Bugula*. Further it may be questioned whether *Dreissena* and *Potamopyrgus* should be included in the list. These species are essentially salt-tolerant freshwater species and very unlikely to be ever found in the Oosterschelde (or in the British and Irish mussel production areas).

The table is re-arranged and the typing errors are corrected. The species *Dreissena* and *Potamopyrgus* are left in the table. Salinity at the production grounds in the Loughs can be very low in periods of high freshwater discharge. The chance that these species will be able to survive in the Oosterschelde however will be very low.

Section 4.2.

In the first paragraph samples are mentioned to have been taken from musselbeds in Wexford Harbour and near Cromane. This was only done once in May 2006. This is insufficient to provide a firm answer to the question if non-indigenous species did occur; sampling should have been done year-round and preferably with larger numbers of samples.
In the results the species *Aphelochaeta marioni* is listed; this species has been suggested to be a non-indigenous species (see Wolff, 2005 for explanation). Spelling errors in scientific names comprise *Tubificoides benedenii* (after the Belgian scientist Van Beneden). *Carcinus maenas* and *Chaetogammarus marinus* are listed twice due to spelling errors.

The sampling on the musselbeds in Ireland (Cromane and Wexford) have only been done in the framework of this project in May 2006. The authors agree that this will give only limited information on the species composition. Species that are only present in on the musselbeds in Summer or Autumn will not have been recorded. In paragraph 1.4 this limitation of this approach is addressed.
***Aphelochaeta marioni* is added as an exotic non-indigenous species and spelling errors are corrected.**

Section 4.3.

Third paragraph*: Coscinodiscus wailesii*
Table 6*: Polydora ciliata, Amphipholis chiajei, Potamopyrgus jenkinsi* is identical to *P. antipodarum* elsewhere in the report.
Table 8: Tharyx marioni is identical to *Aphelochaeta marioni* elsewhere in the report.

Spelling errors are corrected.

Chapter 5

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In the chapter Samples from imported mussels it is described how mussel imports are screened for additional species. Apparently, no substrate material was cultivated to study transport of microscopic stages of species; this should be recorded in the text.
In Table 10 the following names should be corrected: *Ascophyllum nodosum, Turritella communis, Venerupis senegalensis, Venus verrucosa, Pagurus pubescens, Flustra foliacea.*
In Table 10 *Tapes philippinarum* is a non-indigenous species.

We have indicated in the text that no cultivation of shell material was done. We discuss the consequences of this approach for the interpretation of the results. Spelling errors are corrected and *Tapes philippinarum* is indicated as an exotic species.

Chapter 6, section 6.2.

The legend of Table 11 should be made clearer: SH apparently means ship's hulls, B = ballast water (and dry ballast?), H = Host (unclear what this means), D = deliberate, T = trade (unclear what this means). What means N?
In the Table *Monocorophium sextonae* is mentioned as a non-indigenous species. This is doubted by Wolff (2005) (with arguments); it might be better designed as a cryptogenic species.

In the first paragraph it is said that the non-indigenous species in the Oosterschelde are listed. A number of species, however, occur either offshore or in brackish waters adjacent to the Oosterschelde, so it might be better to speak of “the Oosterschelde and adjacent waters”.
Table 12 is based on Appendix B.1; see for comments this Appendix.

The legend is corrected. N indicates introduction through natural transport. Natural transport is not a primary transport vector but only a secondary transport vector. Furthermore, it is stated in the text that the table represents the exotic species in the Oosterschelde and adjacent waters. A footnote is added to the table indicating that *Monocorrophium sextonae* might be a cryptogenic species with a reference to Wolff (2005)

Section 6.3.

In the first paragraph (as well as in Table 12) NE Atlantic non-indigenous species are mentioned. It should be made clear that this category in this report is wider than that used by Wolff (2005). The latter author only include species brought to the Oosterschelde by human activities, the present report also includes natural range extensions. This is not wrong but it should be made clear to prevent misunderstanding.
Fig. 19 is unclear; the data should be represented in a different way.
In the legend of Fig. 20 the source should be recorded.

In the text the definition of NE Atlantic species is repeated in paragraph 6.2. NE Atlantic species, as defined in this report could also have been introduced into the Oosterschelde by natural transport. This definition is wider than used in Wolff (2005), where it only includes species introduced by human activities.
A new figure 19 is included in the report. The data are grouped into only two groups: Exotic species and NE Atlantic non-indigenous species. No subdivision is made in transport vectors for exotic species.
The data presented in figure 20 are from Kluijver and Dubbeldam in prep. The source is given now in the legend of the figure.

Chapter 7.

In this chapter the term “risk” is used frequently. It should be made clear what the risk is, or the word risk should be replaced by “chance”.
In the sub-chapter *7.3.* on the Risks of introducing *M. galloprovincialis* in Oosterschelde no statement is made about the information in the legend of Fig. 14 where it is said that small quantities of mussels have been imported from France, Italy and Greece. Especially the shipments from the latter two countries should have contained (100%?) *M. galloprovincialis*.

Risk is the product of chance of introduction and the effect of the introduction. The document has been scanned on the use of the terms risk and chance. Figure 14 gives an overview of the import of consumption mussels to the Yerseke. The authors agree that the mussels from Italy, Greece and probably also France are most probably *M. galloprovincialis*. However, it is not allowed to introduce mussels from countries like Greece, Italy and France into the Oosterschelde. These consumption mussels are therefore most probably not brought into the Oosterschelde, but are directly marketed.

Chapter 8, Section 8.1.

The approach to the Risk Assessment is basically correct, but it has to be stressed that one of the problems with non-indigenous species is that all non-indigenous species present at a certain locality will never be known, resulting in an underestimate of the risk when considering the source area. On the other hand the same applies to the recipient area and in this case an over-estimate might be the result.

The authors agree with the referee. Not all exotic species are known, both in the Irish and Celtic Sea as in the Oosterschelde. Moreover, the data on exotic species in the UK and Irish waters date from 2002. New exotic species probably have entered in the meanwhile. The effect of this incompleteness in the data on the estimation of the risk is addressed in paragraph 8.6.1. of the report where the uncertainties of the risk assessment are addressed.

In the last paragraph the risk of introductions of diseases and parasites of wild fauna and flora should be mentioned as well.

With the import of mussels also diseases and parasites of wild flora and fauna can be introduced. These type of introductions can have an important effect on the ecosystem (e.g. *Bonamia ostrea*) but these small organisms are not fully covered in this report.

Section 8.2, Table 17.

Calyptraea is at most a cryptogenic species; this should be added.
Urosalpinx and *Ammothea* do not occur in the Irish and Celtic Seas, but instead in SE England and midway the Channel. For consistency they should not be include in the Table.

In the heading of the table it is indicated that *Calyptraea* is regarded as a cryptogenic species. For *Urosalpinx cinerea* and *Ammothea hilgendorfi* it should be noted that they are only observed at the South-East coast of England and not in the Irish and Celtic Sea. Stricktly these species are exotic species for the UK, but they are not exotic species for the Irish and Celtic Sea. These species are kept in the table, but this remark has been added.

Section 8.4.

In the 2nd paragraph the accelerated introduction of new species into the Oosterschelde is mainly explained by construction of the storm surge barrier. This may play a role but the sequence of very mild winters in the period considered should be taken into account as well.

A sentence is added to the paragraph indicating the role of mild winters on the (successful) introduction of new species. It is well possible that some of these recent introductions will disappear again after a series of severe winters.

In the 4th paragraph the occurrence of *Heterosigma* in the Westerschelde is mentioned and Wolff (2005) is cited as a source. Wolff, however, mentions the species from the Wadden Sea

The text is adapted into *Heterosigma akashiwo* is found in the Wadden Sea in 1992

Chapter 9, section 9.1. (Note that chapter 9 (conclusions) is moved to chapter ii, summary and conclusions

First paragraph, 4th line: " … it is likely that **native** species from the …"

Text is corrected

Conclusion 9. It is concluded that "the risk that the transfer of mussels will lead to substantial ecological impact in the Oosterschelde estuary due to imported exotic non-indigenous species seems limited." This conclusion mirrors the 'Rule of tens' formulated by Williamson (1996). This is a rule of thumb stating that of every thousands introductions on average only one will have a serious ecological impact. But it should be remembered that risk is the product of chance and impact. The risk of a yet unknown species may seem small because of a very small chance of introduction, but the impact may be devastating. History has taught that lesson many times all over the world.

The authors agree with the auditor. In general, even a successful introduction of an exotic species will have no (visual) impact on the ecosystem. In many cases it will be able to find its niche in the ecosystem and other native species will have to share (part of) their niche with this exotic species. In this study we have identified the exotic species that could potentially be transferred with the mussel imports into the Oosterschelde. From these species, the chance of being introduced into the Oosterschelde is either very low (e.g. *Urosalpinx cinerea*) or the impact after successful introduction is expected to be very low. However, there is a theoretical chance that one of these latter species, which is expected to be a species causing low/no impact (based on observations in the past), could lead to devastating impacts in the Oosterschelde because the environmental conditions (and timing of the introduction) in the Oosterschelde are perfect. Also yet unknown exotic species might be introduced with the mussel imports, but again this chance is expected to be very low. We have moved this conclusion to the beginning of the chapter.

Section 9.2.

These recommendations are certainly valuable, but the reader expects recommendations on the continuation of mussel imports from Ireland.

The purpose of this study was to make an assessment on the risks of introducing exotic species that are involved with the import of mussels from the Irish and Celtic Sea to the Oosterschelde. It is the task of the authorized authority to decide how to manage the risks. The recommendations are therefore focused on the research questions that are identified in order to support the risk management.

Appendix B

This comprehensive list of non-indigenous species in the Oosterschelde estuary consists of three parts: B.1. Exotic non-indigenous species, B.2. NE Atlantic non-indigenous species, and B.3. Species with an uncertain origin.

List B.1 leads to two main comments:

- clearly the list has been derived from Wolff (2005). It would have been easier for the reader of the present report if this had been stated at the beginning of the list. Cases with additional information or with conflicting viewpoints then could have been identified by specific literature references.
- the list has an unclear sequence; species belonging to the same taxonomic group (e.g., *Rhodophyta*) are found at different places in the list.

In the beginning of the appendix a reference to Wolff 2005 is given. The sequence of the species has been re-aranged.

Further comments on list B.1. concern:

- *Monocorophium sextonae*: according to Wolff (2005) a species with uncertain origin (cryptogenic species);
- *Mytilicola orientalis*: stated to have been a serious pest for the shellfish culture. A literature reference is needed because this has not been published before.
- *Mercenaria mercenaria*: stated to have been introduced in Veerse Meer. According to Wolff (2005) this was the tidal Veerse gat.

***Monocorophium sextonae* is now presented as a cryptogenic species. The sentence "In the first years after its introduction, *M orientalis* was considered as a serious pest for the shellfish culture, but at present it is relatively harmless" has been removed. Veerse Meer is changed to Veerse Gat.**

List B.2. enumerates the NE Atlantic non-indigenous species in the Oosterschelde estuary. This appears to be a mixture of species introduced by human activities (NE Atlantic non-indigenous species sensu Wolff (2005)), species which for some reason extended their range by natural means, and probably also species which have been overlooked before (e.g., various *Nemertini*). This information should be added at the beginning of the list.

In the beginning of the list the following sentence is added This paragraph lists the Northeastern Atlantic non-indigenous species in the Oosterschelde and adjacent areas. This list enumerates species which for some reason (natural expansion or human introduction) extended their range by natural means. The list probably also contains species which have been overlooked before (e.g., various *Nemertini*).

Further comments on List B.2. concern:

- *Corymorpha nutans* was found already in 1966 off the coast of the Delta area by Wolff (1973);
- *Calyptraea chinensis* is considered an exotic non-indigenous species in Table 17 of the present report;
- *Dendronotus frondosus* was a fairly common species in the Oosterschelde in the period 1965-1975 (Wolff, unpublished observations).

The observation of Wolff that *Corymorpha nutans* was found in 1966 off the coast of the Delta is added to the table. It is now stated in the text that *Calyptraea chinensis* is probably a cryptogenic species. The observations of Wolff on *Dendronotus frondosus* is added to the text.

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Signature:

Date: 15 June 2006