# Identifying the exotic species for which possible changes may occur as a result of Climate Change induced temperature rise in the Delta

Anneke van den Brink

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Image on cover: Anneke van den Brink

P.O. Box 68
1970 AB IJmuiden
Phone: +31 (0)317 48 09 00
Fax: +31 (0)317 48 73 26
E-Mail: imares@wur.nl
www.imares.wur.nl

P.O. Box 77
4400 AB Yerseke
Phone: +31 (0)317 48 09 00
Fax: +31 (0)317 48 73 59
E-Mail: imares@wur.nl
www.imares.wur.nl

P.O. Box 57
1780 AB Den Helder
Phone: +31 (0)317 48 09 00
Fax: +31 (0)223 63 06 87
E-Mail: imares@wur.nl
www.imares.wur.nl

P.O. Box 167
1790 AD Den Burg Texel
Phone: +31 (0)317 48 09 00
Fax: +31 (0)317 48 73 62
E-Mail: imares@wur.nl
www.imares.wur.nl

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**Summary**

One of the effects of climate change to the marine waters in the Southwestern part of the Netherlands is the increase in sea water temperature. As part of the Knowledge for Climate (Kennis voor Klimaat) Southwestern Delta research programme, the effect of an increase in temperature of 2°C on present and potentially arriving exotic species in the Delta area of the Netherlands was investigated. The arrival and establishment, or population growth and spread of some exotic species in the area may pose a threat to native wildlife conservation and cause financial strain on the fisheries industry.

For a selection of the exotic species currently present in the Delta area, a literature and website investigation was carried out to find temperature ranges and tolerances for each species. Of the 25 investigated species, maximum survival temperatures were found for only five species, while for the others only optimal temperature ranges were found. Of these five, a predicted 2°C temperature increase in 50 years due to climate changes exceeded the maximum survival temperature of only the brown alga *Undaria pinnatifida*, and then only for a few weeks during the year. It is expected that this species will decline with an increase in temperature of 2°C.

Predictions of potential new exotic species to arrive in the Netherlands (not present exotics) were also made using the current distribution maps provided by the DAISIE website for 15 species currently not recorded in, or north of the Netherlands, but present in more southern regions of Europe (thus potentially limited by temperature). Of these, only the Kuruma prawn, *Marsupenaeus japonicus*, is classified on the DAISIE list of top 100 of the worst invaders. The prawn's optimal temperature of 28 – 30°C may be a current limiting factor to its distribution as far north as the Netherlands. Even with the predicted temperature increases due to climate change it is not likely that this species will establish permanently in the Dutch marine waters.

While this report highlights some exotic species for which an increase in temperature may result in changes in population growth and/or distribution, it also emphasises the limits of the use of literature information to make realistic predictions.

# 1 Introduction

### 1.1 Klowledge for Climate

The Dutch Knowledge for Climate (Kennis voor Klimaat) Research Programme is focussed on the development of knowledge to better assess investments for spatial planning and infrastructure over the coming twenty years in terms of their resistance to climate change (Knowledge for Climate website, 2011).

The present study is part of the Knowledge for Climate project “Climate change effects on restoration of estuarine dynamics within the Delta region”, which is part of the Hotspot “South-West Netherlands Delta”. The aim of this project is to develop a tool to predict the effects of climate change on natural values within the Delta area. The Pacific oyster (*Crassostrea gigas*) has been chosen as a model species. As part of this project, changes in environmental conditions have been calculated with a hydrodynamic and water quality model (Martini and Wesenbeeck, 2012) and used as input to the habitat model of Pacific oysters (Schellekens et al., 2012). NIOZ-Yerseke has conducted field experiments on the conditions that influence the settlement of Pacific oysters (IJzerloo and Bouma, 2012). The present report, finally, focusses on the effect of temperature increase on the existing marine exotic species in the Southwestern Delta and the invasive species that might invade the Delta area in the future as a result of the sea water temperature increase.

### 1.2 Effects of climate change in the Delta waters

Climate change is a complicated and multi-faceted concept. Although we know that it is occurring, we cannot precisely understand or predict what effects it will have on the natural marine environment. Numerous different factors can all be affected in different ways and their interactions can vary resulting in a vast number of different scenarios. The concept of climate change in the marine environment includes factors such as sea level rise, temperature increase, acidification, rainfall, storm frequency and intensity and changes in population dynamics of resident species.

The marine environment of the Delta waters in the Netherlands is a dynamic system that changes constantly. Species that are presently considered of importance for nature conservation may have been reduced drastically in 50 years despite the best efforts to preserve them. This may be due to climate change or natural dynamics of the system.

In the delta waters of the Netherlands, future aquaculture or infrastructure activities may also influence the marine environment in ways that we can currently not predict. For example, a new or different storm surge barrier may greatly alter the environment as the current one in the Oosterschelde did in the past.

The seawater temperature in the North Sea has increased in the past 30 years due to climate change (Hiddink & ter Hofstede, 2008), and it is expected that this increase will continue in the future. The consequences, however, are not yet completely understood. Considering the vast variability in effects caused by all factors resulting from climate change, we focus here simply on one important factor of climate change, the increase in average sea water temperature.

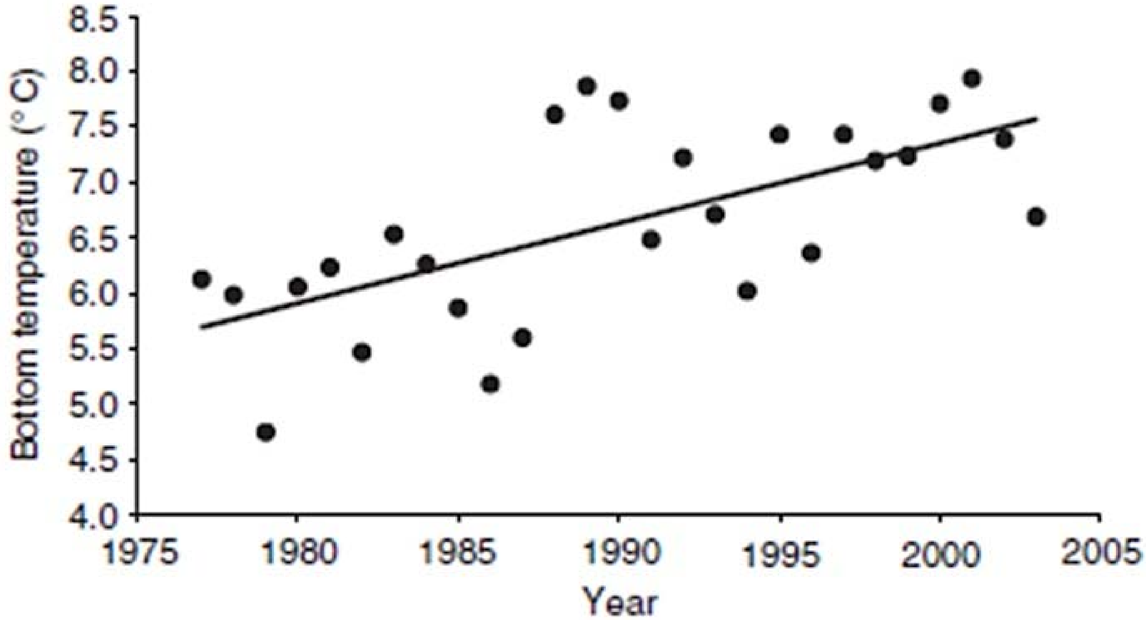


Figure 1. Average winter temperature in the North sea over about 30 years (from Hiddink & ter Hofstede, 2008). This figure suggests a temperature increase of about 2°C over the last 30 years.

### 1.3 Approach

This study is a first approach to develop an impression of the potential effects of an average rise of 2°C in sea water temperature in the Delta. We approached the study in two ways:

1. We investigate the information available in the literature on temperature tolerances of exotic species already present in the Delta and attempt to identify species for which possible changes in populations with a 2 °C increase in water temperature might occur.

2. We compile a list of exotic species currently not present in the Delta, but which have the potential of being introduced with a 2 °C increase in water temperature. These species are present in locations south of the Netherlands and therefore are potentially able to spread north to the Dutch waters.

We focus here only on temperature rise as an effect of climate change due to the unpredictability of the cumulative effects of climate change in general (see 1.2 Effects of climate change, above).

The conclusions presented here are somewhat speculative due to the nature of the available information on each species. Therefore, this report should only be considered as a first attempt to identify exotic species for which the presence in the Delta area might change due to temperature increase.

### 1.4 Exotic species

Exotic species are non-indigenous species that have been introduced via human driven vectors into geographic areas where they could not have naturally spread. Many exotic species present in the Delta waters have been introduced via vectors such as ship ballast water, hull fouling, or through shellfish transport for the aquaculture industry (Wolff, 2005).

In this study we consider both ‘present exotic’ species and ‘not present exotic species’:

- **Present exotics**: exotic species already present in the Netherlands
- **Not present exotics**: exotic species not (yet) present in the Netherlands but are present further south (Belgium, France). Assuming these species are limited by temperature, an increase in temperature may result in their distribution limits moving north and they may then be able to establish in the Dutch waters.

Both present exotics and not present exotics originate outside the Northeast Atlantic shelf region. Longhurst (1998) defined the NE Atlantic shelf region as ‘one ecological and biogeographical union for the pelagic ecosystem’. It comprises the continental shelf of Western Europe, from northern Spain to Denmark and includes the Baltic Sea and the Irish and UK marine waters (Figure 2). Not present exotics are already present within the shelf region to the south of the Netherlands, but they are not native there.

Species native to areas of the NE Atlantic but not present in the Dutch waters, for example due to low temperatures are not classed as exotic. It is assumed that these species could have reached the Dutch waters by natural dispersion in the past. The fact that they are not present indicates that the environmental conditions in the Dutch waters are not suitable. If the limiting factor is temperature, an increase in sea water temperature due to climate change could increase the potential for these species. Wijsman & Smaal (2006), however, suggest that since these species are already at the northern limits of their distribution and tolerance ranges a slight increase in sea water temperature might only lead to sub-optimal conditions, and the species will therefore not be very successful.

There has been an increase in present exotic species in the Dutch delta waters in recent years (Figure 3). This is most likely to be due to increased shipping and aquaculture activity in the area, along with more intensive investigations and observations.

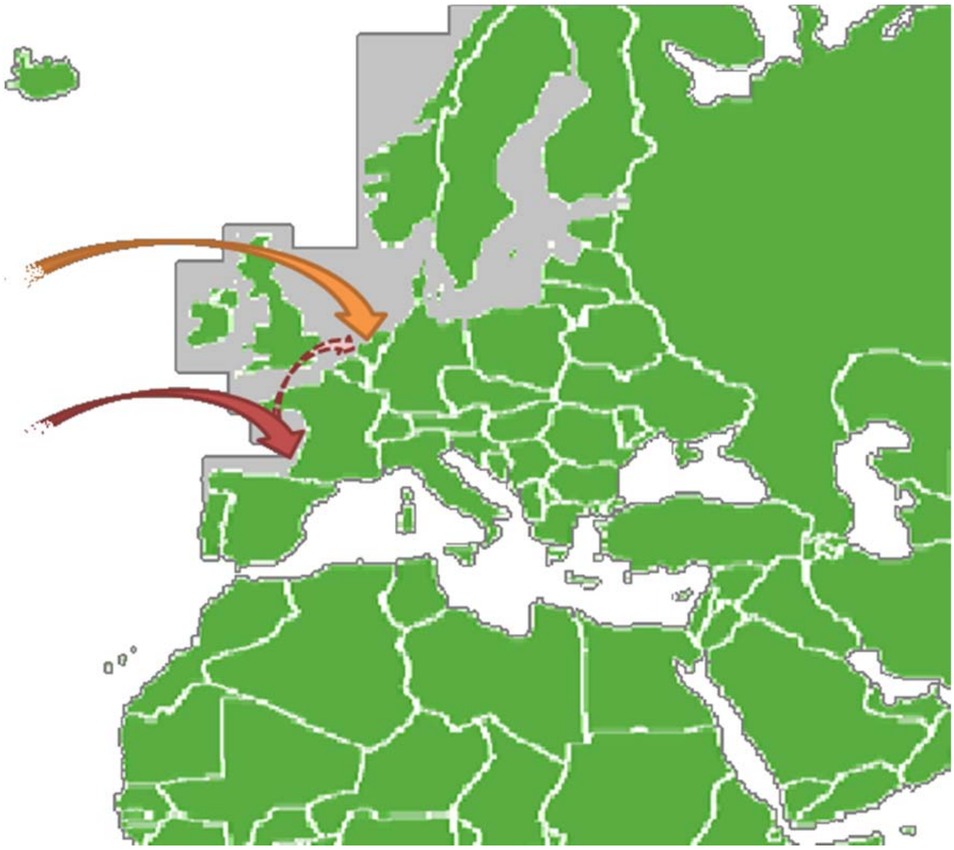

Figure 2**.** Map indicating an example of the movement of exotic species. Exotic species originate from outside the Northeast Atlantic shelf province (grey area). ‘Present exotics’ (orange arrow) are now present in the Netherlands. ‘Not present exotics’ (red arrow) are present south of the Netherlands. If the ‘not present exotic’ species are limited by temperature, an increase in temperature may result in their moving north to the Netherlands (broken arrow). Figure is adapted from Wijsman and Smaal (2006).

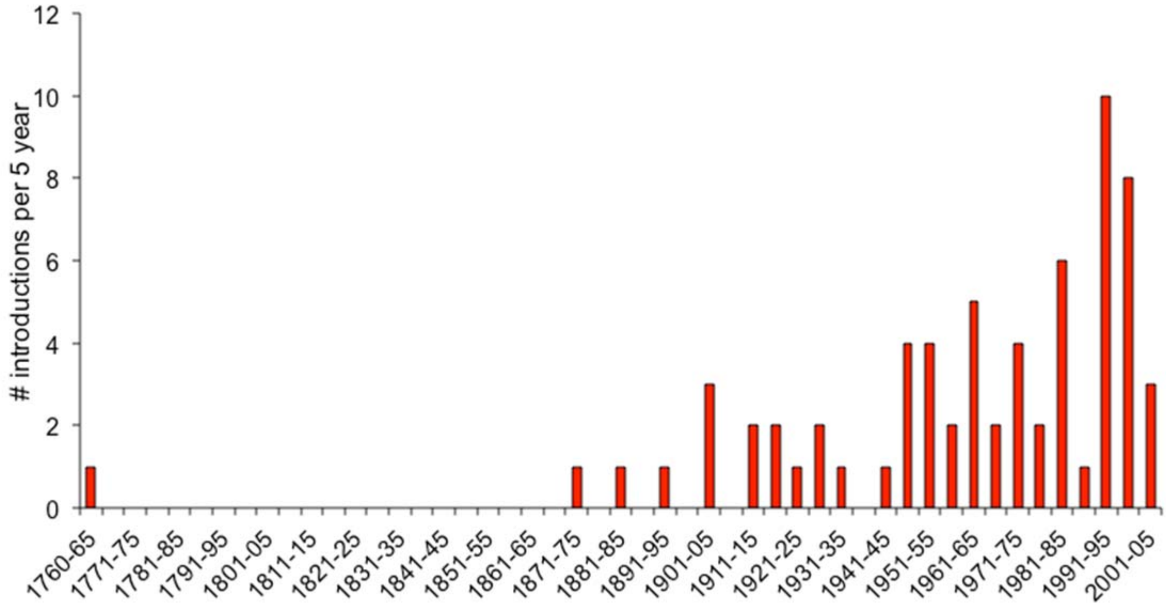


Figure 3 Number of present exotic species reported in the Dutch delta waters (from Wijsman & Smaal, 2006).

The effect of the introduction of new exotic species into an environment may be positive or negative. Some exotic species have the potential to alter local environments, influence the food web and potentially disrupt fisheries activities. New exotic species can alter native environments through competition with, predation on, or the removal of food sources of native species, while others may increase biodiversity and aid in protection from erosion. Some may present a financial strain to aquaculture by increasing the cost of fisheries activities as a result of reducing the available catch, increasing maintenance costs by clogging equipment and smothering cultured shellfish, while others may become a new commercially useful species.

### 1.5 Effect of temperature increase on organisms

According to the predictions by the KNMI'06 Climate Scenario W, North Sea temperatures could increase by about 2 °C by 2050 (KNMI, 2011). An increase in sea water temperature in the Delta as a result of climate change is likely to result in a change in the current ecosystem.

If survival, growth and/or reproduction of a species are currently limited by low temperatures, an increase in temperature may lead to population growth and spread in these species. Conversely, species whose survival, growth and reproduction are dependent on colder water temperatures may experience population declines due to a warmer and less suitable environment. The appearance, disappearance, growth or decline of a species may have either a positive or negative effect on the ecosystem, some may require management while others may provide new opportunities for aquaculture.

Increased sea water temperatures may affect exotic organisms as well. Environments where an exotic species was originally excluded or limited due to temperature boundaries, may become more habitable with a temperature increase. This may lead to new invasions, or more successful spread or development of exotic species already present.

Species considered economically, ecologically or conservationally important may appear in new environments and spread, while others may decline or even disappear. Species with temperature tolerance ranges close to the extremes of the water temperature in the Delta may experience population changes as a result of those temperature extremes changing.

### 1.6 Implications for Nature protection

As a result of a temperature increase due to climate change, the ecosystem in the Delta will change from its current state. Species and communities we now consider important and worth protecting under the Natura 2000 framework may become less important for the Delta ecosystem in the future. New species may be introduced and may become ecologically valuable or problematic to the environment in the future. These changes are impossible to predict as they are dependent on the interaction of a vast range of influences.

The information presented in this report should be interpreted while taking the dynamic nature of the environment in the delta into consideration. This is especially important for policy makers developing new conservation approaches. The nature conservation goals are static on a short time scale. On a longer time scale the goals should take the dynamic behaviour of the ecosystem and the effects of climate change into account.

# 2 Materials and Methods

## 2.1 Present exotics

A list of 25 present exotic species in the Delta was selected from a combination of a list presented in Gittenberger (2009) and data collected during an epifauna sampling survey by Deltares (unpub. data). For these species, a literature study was conducted to compile information about their temperature ranges and tolerances.

This information was compiled from literature searches as well as various internet sources such as The Global Invasive Species Database (http://www.invasivespecies.net), The World Register of Marine Species (http://www.marinespecies.org) MarLIN: The Marine Life Information Network (http://www.marlin.ac.uk) and DAISIE: Delivering Alien Invasive Species Europe (http://www.europe-aliens.org/). The data collected from these sources were mostly based on field and lab studies.

From the gathered information we attempt to identify which of the present exotic species may be affected by an increase in water temperature.

## 2.2 Not present exotics

The selection of not present exotics for which potential introductions may occur with an increase in temperature was based on the methods of Gjershaug *et al.* (2009). The DAISIE database was used for this selection. Only exotic species that do not originate in the North East Atlantic Shelf province are included (see section 0).

A search was conducted using the DAISIE database for exotic marine species whose distribution appeared to be limited by climate and, as a result of climate change, may be able to spread to and establish in the Netherlands. The species selected were:

a) Present and established in locations in the Atlantic Ocean south of the Netherlands (from Spain to Belgium or southern UK), and
b) Not present in the Netherlands or north of the Netherlands

DAISIE has developed a public access online database of 11 000 exotic terrestrial and aquatic species in Europe with information on distributions for most, and full factsheets for 100 of the most widespread and invasive species. This database allows a search for species by species name, experts or by region.

Not present exotic species listed in the top 100 worst invaders according to the DAISIE website are considered to be a potentially major threat to the delta waters of the Netherlands. From this information we attempt to make predictions about the risk and impact of their introduction into the Dutch Delta area.

# 3 Results

## 3.1 Present exotics

At total of 25 species were found in common from both Gittenberger (2009) and the Deltares study. These were selected for further literature investigation (see Appendix 1). The exotic species comprised of decapods (five species), bivalves (four species), ascidians (three species), gastropods (two species), amphipods (two species), cirripeds (two species), phaeophycids (two species) and one chlorophyte, ctenophore, fish, polychaete and rhodophyte.

Information on optimal temperatures and tolerances were found in the literature for these species and roughly sorted by optimal temperature from cool to warm (Table 1). Information on maximum temperatures for survival was available for only five species. These were the brown alga *Undaria pinnatifida*, the green alga *Codium fragile,* the comb jelly *Mnemiopsis leidyi*, the red alga *Heterosiphonia japonica* and the Pacific Oyster *Crassostrea gigas.*

When the maximum temperature for survival of these five species is compared with the predicted temperature increase due to climate change, only *Undaria pinnatifida* may be negatively affected, as temperatures may exceed its maximum survivable temperature of 23°C, but only for one or two weeks in the year (Figure 4).

Most of the temperature information available concerned optimal temperatures rather than survival extremes because most studies focussed on aspects such as growth and reproduction rather than survival in extreme conditions. Consequently, information about the extreme temperatures at which these species can still grow and reproduce (although not optimally) was not found and the actual temperature boundaries for these species are not known.

Table 1. Species with known temperature information roughly sorted from cool to warm optimal temperatures and the type of information from which these data came (see Appendix A for references).

| Taxon | Species | Optimal temperature | Maximum temperature for survival (°C) | Information type |
|---|---|---|---|---|
| PHAEOPHYCEAE | *Undaria pinnatifada* | 12 | 23 | Factsheet |
| PISCES | *Oncorhynchus mykiss* | 12 | | Field study |
| PHAEOPHYCEAE | *Sargassum muticum* | >8 | | Field study |
| ASCIDIACEA | *Styela clava* | >15 | | Histology study |
| POLYCHAETA | *Ficopomatus enigmaticus* | 18 | | Field study |
| BIVALVIA | *Dreissena polymorpha* | 12-20 | | Field study |
| BIVALVIA | *Mytilopsis leucophaeata* | 18-20 | | Factsheet |
| BIVALVIA | *Mercenaria mercenaria* | 20 | | Field study |
| CHLOROPHYTA | *Codium fragile* | 24 | 33 | Field study |
| ASCIDIACEA | *Didemnum vexillum* | -2-24 | | Field study |
| CIRRIPEDIA | *Elminius modestus* | 6-24 | | Field study |
| AMPHIPODA | *Caprella mutica* | -2-25 | | Lab study |
| DECAPODA | *Rhithropanopeus harrisii* | 20-25 | | Field study |
| GASTROPODA | *Urosalpinx cinerea* | >20 | | Field study |
| CTENOPHORA | *Mnemiopsis leidyi* | >21 | 30 | Field study |
| ASCIDIACEA | *Botrylloides violaceus* | 8-25 | | Lab study |
| DECAPODA | *Hemigrapsus sanguineus* | 15-25 | | Field study |
| DECAPODA | *Hemigrapsus takanoi* | 15-28 | | Factsheet |
| RHODOPHYTA | *Heterosiphonia japonica* | 19-25 | 30 | Factsheet |
| CIRRIPEDIA | *Balanus improvisus* | 0-30 | | Field study |
| DECAPODA | *Eriocheir sinensis* | 15-30 | | Field study |
| GASTROPODA | *Crepidula fornicata* | 15-30 | | Factsheet |
| DECAPODA | *Callinectes sapidus* | 15-30 | | Factsheet |
| AMPHIPODA | *Melita nitida* | <32 | | Lab study |
| BIVALVIA | *Crassostrea gigas* | 4-35 | 30 | Field study |

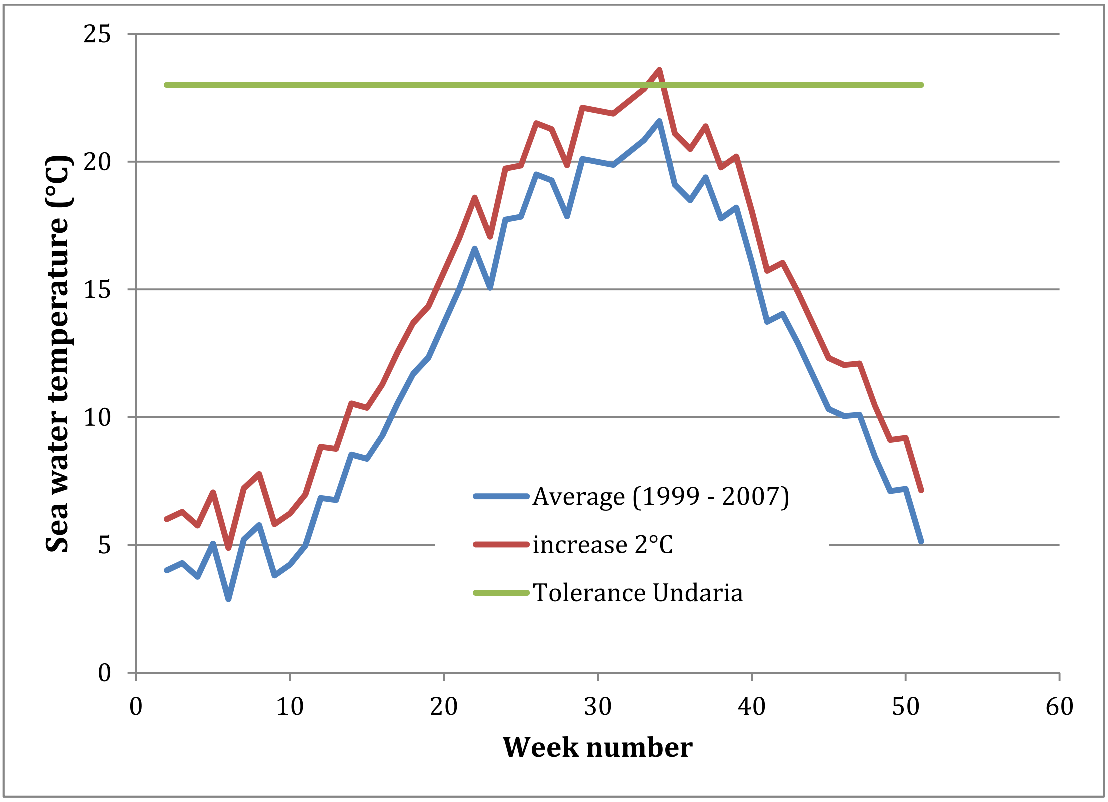


Figure 4. Seasonal fluctuations of the average seawater temperature in the Oosterschelde (1999 – 2007, blue lines) The solid red line indicates the possible mean temperatures after the predicted 2 °C increase. The green line indicates the maximum temperature for survival of *Undaria pinnatifida.*

### 3.2 Not present exotics

From the DAISIE website, 15 species were found to be present and established in locations south of the Netherlands but not within, or north of the Netherlands. These species included algae (four species), Annelids (three species), Crustaceans (two species), gastropod molluscs (two species), one bivalve mollusc, one dinoflagellate, one bryozoan and one plant (see Appendix B).

The five algae species (*Caulacanthus ustulatus, Goniotrichiopsis sublittoralis, Laurencia brongniartii, Pleurosigma planctonicum* and *Alexandrium taylori*) all showed the same distribution; along the French Atlantic coast and ending at the border of Belgium. According to the website www.algaebase.org *C. ustulatus* is very prevalent in Spain with 41 records (not shown on the DAISIE map), but less prevalent in France with five records, while no known records place it in Belgium or the Netherlands. The only European records of *Goniotrichiopsis sublittoralis* are from France according to both DAISIE and www.algaebase.org, with no records of it in Belgium or the Netherlands. *Laurencia brongniartii* has also not been recorded further north than France (with two records according to www.algaebase.org). *Alexandrium taylori* was recorded on the French Atlantic coast in Archachon Bay in 1994. Since then there has been no known further recordings of it in the area. Whether it is still present in France is currently unknown.

Three annelid species, *Boccardia semibranchiata*, *Hydroides dianthus* and *H. ezoensis* were also shown with a northern most distribution in Europe of the French coast. According to DAISIE, there are records of *B. semibranchiata* as far north as St-Vaast, Normandy. *Hydroides dianthus* has a much more widespread distribution compared with the other two annelid species and is present in both the Mediterranean and Atlantic coasts of Europe while *H. ezoensis* has records (in DAISIE) only from France. Both species are recorded as far north as the English channel in the North Sea.

Two crustaceans are also included in the list, the copepod *Pseudomyicola spinosus* and the shrimp *Marsupenaeus japonicas*. DAISIE has only one record of *Pseudomyicola spinosus* in France at Arcachon Bay (SE Biscay Bay), which indicates that it may have been a coincidental sighting and that the species did not establish in the area. While *M. japonicas* has not yet been recorded as established in the Atlantic or North Sea, it has been recorded on the Atlantic coast of Portugal and in the southern waters of Great Britain. The prawn is established in the eastern Mediterranean, around Egypt and Turkey.

The Bryozoan *Watersipora aterrima* was recorded in Archachon Bay, France and although there are few other records of it, it is known to be present in Atlantic Europe (www.marinespecies.org), but not as far north as the North Sea.

The saltmedow grass, *Spartina patens* has spread throughout Spain and it present along the Atlantic coast of France in the Bay of Arcachon.

The two gastropods, *Gibbula albida* and *Truncolariopsis trunculus* are both recorded as far north as the Bay of Arcachon in France. Other sources report their presence in the general 'European waters' (www.marinespecies.org), but are not more specific. *Gibbula albida* is also present on the Atlantic coast of Spain, while there are no known records of *T. trunculus* distributed so widely.

If these species are restricted to their current distributions in Europe due to temperature, an increase in temperature may allow them to spread further north and enter the Dutch delta waters.

Only one of the not present exotic species, the Kuruma prawn, *Marsupenaeus japonicus,* is identified on the DAISIE list of top 100 of the worst invaders due to it outcompeting and causing the local extinction of a native prawn species.

# 4 Discussion

From the limited information available in the literature, it does not appear that an increase in sea water temperature of 2°C in the delta waters of the Netherlands present a great risk of potential increased invasive success of either present exotic species or not present exotic species.

## 4.1 Present exotics

Most of the optimal temperatures for the present exotic species found in the literature lay well within the temperature regime experienced by the Delta waters in the Netherlands, and an increase of 2°C will not greatly alter that regime. Furthermore, with acclimatisation some species can adapt to temperatures outside their stated range or extremes (for example, *Crassostrea gigas* was stated in the literature to have an optimal temperature range of 4-35°C (Nehring 2006) while it was stated elsewhere in the literature to have an upper limit for survival of 30°C (Strand et al. 2011)). Temperature boundaries may also vary for different life stages of the same species; larvae are often more sensitive to temperature changes than adults.

The only species for which data was available, and whose maximum survival temperature would be exceeded with the predicted temperature increase is the brown alga, *Undaria pinitifida*, and this temperature may only be exceeded for approximately two or three weeks in the given year. *Undaria pinitifida* prefers artificial substrates and as a fouling species, frequent cleaning of aquaculture equipment and boats is required. In the Netherlands it grows mainly on the Pacific oyster, *Crassostrea gigas*, but also on mussels. It is slippery, and therefore can cause problems for fishermen harvesting oysters and may impair aquaculture harvests (Global-Invasive-Species-Database, 2009). Therefore, if an increase in temperature results in a decrease of *U. pinitifida* (and possibly other species) in the Delta, there may be a positive impact on the environment.

It is possible that some of the present exotic species for which no lethal temperature was found in the literature, but which had lower optimal temperature ranges such as the fish *Oncorhynchus mykiss*, the alga *Laminaria saccharina* and the brittle star *Acrocnida brachiate*, may be adversely affected by a rise in water temperature. However, given the restricted information used in this study, this can only be speculated upon.

The expected average temperatures in Figure 4 may not be totally representative of the temperatures experienced in the Delta waters. Also in future situations there will be year-to-year variation in sea water temperatures. Furthermore, these average temperatures are an average for the whole Oosterschelde and do not include micro-habitat differences, such as localised shallow areas where water temperatures are generally more extreme compared to the deeper gullies.

## 4.2 Not present exotics

Of the not present exotic species only one, the Kuruma prawn, *Marsupenaeus japonicus* is on the DAISIE top 100 list of the worst invaders. The species is on this list due to its presence in the Mediterranean coast of Egypt and the Nile delta lagoons resulting in the local extinction of the native prawn, *Melicertus kerathurus*, which has almost disappeared and its habitat overrun. However, in Egypt, Turkey and Israel the invader has become of major commercial importance and is now a highly prized species considered a boon to the Levantine fisheries (Galil, 2006b). The optimal temperature of *M. japonicus* is 28 – 30°C (24 – 32°C for larvae) (Galil, 2006b). As current temperatures in the Delta are lower than this range, the species may be limited in distribution by temperature. Even with a 2°C rise in water temperature *M. japonicus* is unlikely to establish a significant population in the Delta to have any major effect.

The dinoflagellate *Alexandrium taylori* was included in Streftaris and Zenetos' (2006) list of the 100 worst invasive species in the Mediterranean. The dinoflagellate has been found to have high biomass blooms during summer in the Mediterranean, which have led to deterioration of water quality for recreational uses and to economic losses for the tourist industry Streftaris and Zenetos, 2006). Yet with optimal growth rates between 20 and 26°C, and inhibition of growth below 16°C (Cucchiari et al. 2008), it is also unlikely to be particularly successful in the Delta waters, even with a 2 °C rise in sea water temperature.

There was little evidence to suggest that the most of the other species identified as not present exotics present a major threat to the environment if they were to be introduced into the Dutch delta waters.

### 4.3 This study

It is unwise to dismiss the potential threat of temperature rise to the environment in the Delta based on the information currently available. While the data presented in this report gives a crude indication of which species may be affected by a rise in sea water temperature of 2 °C, the literature on which this study is based is far from applicable or complete. Most literature available deals with optimal temperatures, yet few discuss temperature extremes in which a species might occur. More up to date information on temperature tolerances of different species coupled with abiotic characteristics of localised habitats within the Dutch delta is required before more substantial predictions can be made.

This study is limited only to exotic species with origins outside the NE Atlantic shelf province. Species native to the province, but currently not present in the Netherlands due to temperature restrictions may spread to the Netherlands if water temperatures rise. While a small rise in water temperature may move these temperature boundaries north to include the Netherlands, these species, which are already at the temperature boundaries of their distribution, are unlikely to become particularly successful if the delta waters become their new distribution boundary.

Furthermore, to realistically attempt to predict the population dynamics of a species in nature, factors other than direct temperature changes should also be considered, such as:

- A temperature rise may indirectly influence other environmental factors such as nutrient dynamics as a result of faster processes of decomposition and primary production which influence the growth, survival and reproduction of an organism.

- As physiological processes are also influenced by temperature, a rise in temperature of only 2°C may result indirectly in increased reproduction rates in a species even within its 'optimal temperature range' which may result in population growth or decrease.
- That an exotic species is not present in the Delta may not be due to temperature boundaries, but simply because it that has never arrived, while it may thrive in the area if it does.
- That an exotic species is not listed as present may simply be due to it being currently undetected or not recorded.
- The dynamics of an exotic species in a new environment cannot be precisely predicted or compared to other locations due to the unique community structure and abiotic factors in each area.

Finally, it is important to consider the results presented here as a snapshot of a dynamic and changing system. The delta waters of the Netherlands are continuous changing both naturally and through aquaculture and infrastructure activities. Highly important species currently being protected may still naturally decline or move to other locations in the future. The Eurasian Oystercatcher (*Haematopus ostralegus*) is a highly protected bird in the Netherlands and is included as a nature conservation goal in the Natura 2000 framework, yet its numbers continue to decrease (Troost & Van Hulzen, 2009). Whether this bird will still be considered conservation-worthy in 50 years cannot be predicted. Policy makers should take the dynamic nature of the delta system into consideration when developing management policies. These should be updated regularly to accommodate the present statue of the delta as a natural environment.

## 5 Conclusions

A climate change driven 2 °C temperature rise may alter the environment of the Delta and consequently the species, size of populations and community structure of organisms within it. However, the literature available are not appropriate to make reliable predictions about what changes might occur.

It is possible that exotic species currently present in the Delta, whether problematic or beneficial to the ecosystem, may reduce in abundance and/or distribution while others may increase. Furthermore, if temperatures rise exotic species currently limited to warmer environments may find their way to the Delta and present a new threat or benefit to the area. Management of the Delta must accommodate the fact that the Delta ecosystem will change, and therefore policies and management options must also adapt to these changes.

The Knowledge for Climate project aims to predict the future effects of climate change so that steps can be taken to manage these changes. This study is a brief overview of the present and published knowledge of present exotic species in the Delta and not present exotics that may arrive.

However, the study emphasises the lack of applicable information currently available. To make realistic predictions of how the environment and the species therein will react to climate change induced temperature rise for the Knowledge for Climate project, models such as that for the Pacific oyster *Crassostrea gigas* in Schellekens *et al.* (2012) need to be made for each present exotic species and for the not present exotics. In order to produce such models specific information about each species such as temperature tolerances, habitat preferences, diet, reproductive biology and ecology, must be available. It is also important to fill current knowledge gaps, particularly in the identification of exotic species to maintain up to date information, which can be used to develop management techniques and policies. Websites and published resources should also be kept up to date as new information emerges. Only with more specific information can substantial predictions of the effect of climate change on exotic species in the Delta area of the Netherlands be made.

## Quality Assurance

IMARES utilises an ISO 9001:2008 certified quality management system (certificate number: 57846-2009-AQ-NLD-RvA). This certificate is valid until 15 December 2012. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Environmental Division has NEN-AND-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 27 March 2013 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation.

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## Justification

Rapport number: C100/12
Project Number: 4301900902

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

Approved: J.W.M. Wijsman
Senior Scientist

Signature:

Date: 24-08-2012

Approved: B.D. Dauwe
Head department Delta

Signature:

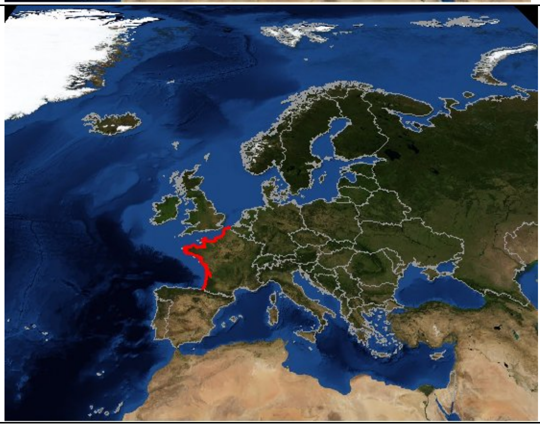
Date: 30-08-2012

**Appendix A. References used to compile temperature information for species in Table 1.**

| Taxon | Species | Reference |
|---|---|---|
| PHAEOPHYCEAE | *Undaria pinnatifada* | (Global-Invasive-Species-Database, 2009, Van den Brink, 2009) |
| PISCES | *Oncorhynchus mykiss* | (Global-Invasive-Species-Database, 2006b, Leidy et al., 2005) |
| PHAEOPHYCEAE | *Sargassum muticum* | (Josefsson & Jansson, 2006) |
| ASCIDIACEA | *Styela clava* | (Davis & Davis, 2007, Global-Invasive-Species-Database, 2006c, Minchin, 2008) |
| POLYCHAETA | *Ficopomatus enigmaticus* | (Cohen, 2005, Power et al., 2008) |
| BIVALVIA | *Dreissena polymorpha* | (Herbert et al., 1989, Zaiko & Olenin, 2006) |
| BIVALVIA | *Mytilopsis leucophaeata* | (Fransén, 2009) |
| BIVALVIA | *Mercenaria mercenaria* | (Gofas, 2009, Hill, 2004b) |
| CHLOROPHYTA | *Codium fragile* | (Galil, 2006a, Hanisak, 1979) |
| ASCIDIACEA | *Didemnum vexillum* | (Bullard & Whitlatch, 2007, Van den Brink, 2009) |
| CIRRIPEDIA | *Elminius modestus* | (EOL, 2009, Ewers, 2008, Harms, 1986) |
| AMPHIPODA | *Caprella mutica* | (Cook et al., 2007, MarLIN, 2009) |
| DECAPODA | *Rhithropanopeus harrisii* | (Bachelor et al., 2009, Forward Jr., 2009, Perry, 2009) |
| GASTROPODA | *Urosalpinx cinerea* | (Hancock, 1954, Van den Brink, 2009) |
| CTENOPHORA | *Mnemiopsis leidyi* | (Miller, 1974, Shiganova, 2009) |
| ASCIDIACEA | *Botrylloides violaceus* | (Van den Brink, 2009) |
| DECAPODA | *Hemigrapsus sanguineus* | (Dauvin et al., 2009, Gerard et al., 1999, Global-Invasive-Species-Database, 2006a) |
| DECAPODA | *Hemigrapsus takanoi* | (Brockerhoff & McLay, 2008, Mengedoht, 2009) |
| RHODOPHYTA | *Heterosiphonia japonica* | (Karlsson, 2006) |
| CIRRIPEDIA | *Balanus improvisus* | (Murina et al., 1995, Olenin, 2006) |
| DECAPODA | *Eriocheir sinensis* | (Crosier & Molloy, 2006, Global-Invasive-Species-Database, 2009, Gollasch, 2006, Rudnick et al., 2000) |
| GASTROPODA | *Crepidula fornicata* | (Zaiko, 2005) |
| DECAPODA | *Callinectes sapidus* | (Hill, 2004a, TPWD, 2009) |
| AMPHIPODA | *Melita nitida* | (Borowsky et al., 1996, Faase & Van Moorsel, 2003, Heiman et al., 2008, WoRMS, 2009) |

**Appendix B. Not present exotics; exotic species that may become introduced to the Netherlands in the future (from the DAISIE website).**

| Taxonomic Group | Species | Distribution (as found on DAISIE) |
|---|---|---|
| Algae | *Caulacanthus ustulatus* |  |
| Algae | *Goniotrichiopsis sublittoralis* |  |
| Algae | *Laurencia brongniartii* |  |

| Taxonomic Group | Species | Distribution (as found on DAISIE) |
|---|---|---|
| Algae (Dinoflagellate) | *Alexandrium taylori* |  |
| Annelida | *Boccardia semibranchiata* |  |
| Annelida | *Hydroides dianthus* |  |
| Annelida | *Hydroides ezoensis* |  |

| Taxonomic Group | Species | Distribution (as found on DAISIE) |
|---|---|---|
| Crustacea: Copepoda | *Pseudomyicola spinosus* |  |
| Crustacea: Malacostraca | *Marsupenaeus japonicus* |  |
| Bryozoan | *Watersipora aterrima* |  |
| Magnoliophyta (plant) | *Spartina patens* |  |

| Taxonomic Group | Species | Distribution (as found on DAISIE) |
|---|---|---|
| Mollusca: Gastropoda | *Gibbula albida* |  |
| Mollusca: Gastropoda | *Truncularia psis trunculus* |  |