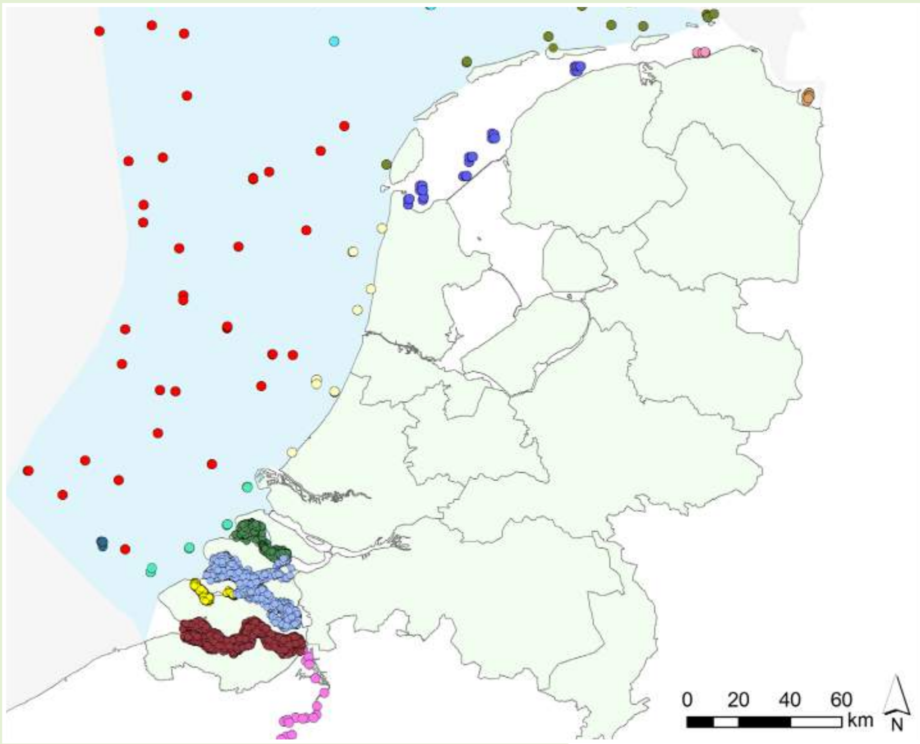
# Analysis of the potential to detect alien species in marine MWTL monitoring

## Review of efficiency and possible improvements




K. Didderen
T.M. van der Have
M. Dorenbosch

Bureau Waardenburg bv
Ecology & landscape

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K. Didderen
T.M. van der Have
M. Dorenbosch

Bureau Waardenburg bv
Consultants for environment & ecology

P.O. Box 365  4100 AJ Culemborg, The Netherlands
Tel. +31 345 51 27 10   Fax +31 345 51 98 49
info@buwa.nl   www.buwa.nl

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| Authors: | K. Didderen M. Sc.<br>T. M. van der Have D. Phil.<br>M. Dorenbosch D. Phil. |
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**Bureau Waardenburg bv**
Consultants for environment & ecology

P.O. Box 365 4100 AJ Culemborg, The Netherlands
Tel. +31 345 51 27 10 Fax +31 345 51 98 49
info@buwa.nl www.buwa.nl

# Preface

The MWTL (Monitoring Waterstaatkundige Toestand des Lands) program is a long-term monitoring program on the water quality and biology of the Dutch waters. Part of this program monitors the macrozoobenthos in the soft sediment communities in the Dutch North Sea, the Delta area and the Wadden Sea. Occasionally during the monitoring alien species are found.

The commissioner Drs. A.A.J. Smolders of the Office for Risk Assessment and Research (BuRo) Team Invasive Alien Species (Ministry of Economic Affairs, Netherlands Food and Consumer Product Safety Authority) commissioned Bureau Waardenburg bv to analyse the current monitoring program with regard to the potential to detect (newly introduced) invasive alien species (IAS). The question is whether the current monitoring program is able to detect adequately newly introduced IAS, whether the current fixed monitoring locations are suitable to detect newly introduces AIS, and which other options and improvements are available.

This study used data analysis of existing MWTL monitoring data, a literature review and several interviews with stakeholders to answer the above questions. Research was carried out by Karin Didderen, Martijn Dorenbosch, Tom van der Have and Jie Zhang. Dr. W. Lengkeek was responsible for the quality control.

Experts that contributed to this report are Arie Naber (RWS CIV), Suzanne Stuijfzand (RWS WVL), Rob Dekker (Royal NIOZ) Godfried van Moorsel (Ecosub), Edwin Verduijn (Grontmij), Marjolijn Christianen (RUG).
The authors thank everyone who has contributed to this report.

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# Summary

Detection of new alien species in the monitoring area can strengthen management strategies and are useful for analysing the effectiveness of prevention and control measures. A practical early detection strategy requires achieving balance between efficient sampling and taxonomy methods that minimize early detection costs such as time and effort with the risk associated with non-detection.

This report evaluates the current MWTL (Monitoring Waterstaatkundige Toestand des Lands) program with respect to the possibilities of detection of (new) marine invasive alien species. The MWTL program is a long-term monitoring program on the water quality and biology of the Dutch waters. Part of this program monitors the macrozoobenthos in the soft sediment communities in the Dutch North Sea, the Delta area and the Wadden Sea. Marine alien species are found occasionally during the monitoring.

The question is whether the current monitoring program is able to detect alien species adequately, whether the current fixed monitoring stations are positioned strategically in relation to known introduction sites in order to detect new alien species, if macro-algae can be incorporated in the program and which other options (e.g. monitoring data) and improvements are available.
This study carried out a quantitative and spatial analyses of available MWTL monitoring data, a literature review of all reported alien species in the Netherlands and interviews with the experts involved to answer the above questions.

*What is the effectiveness of the MWTL-program with respect to detection rate, detection time lag and detection probability of alien species?*
A total of 24 marine alien species were detected in the MWTL program in the period 1990 – around 2010. More alien species were detected in areas with more vectors present (Eastern Scheldt and western Wadden Sea). The detection time lag is two years on average. The MWTL program detects alien species with both low densities and high densities.

Only a small part of all marine alien species (12%) present in Dutch coastal and marine ecosystems were included in MWTL monitoring. Of these 21 species were already established for several years of even several decades before the start of the program. Only three soft sediment species were introduced and detected in the Netherlands during the MWTL program.
The time lag between the first observation and MWTL detection is 5 years for the Asian shore crab and one year for the Manila clam. The MWTL program detected the large polychaete worm *Marphysa sanguinea* for the first time in the Netherlands. Since the MWTL program has recently been reduced to once every three years for most areas, time lag will be increasing threefold.

The detection rate of the MWTL program is only high for species typical for estuarine and marine soft sediments and 88% of alien species are not detected by the MWTL program (e.g. plankton, epifauna, mobile species and species typical for hard substrates). The MWTL program is therefore only adequate for monitoring alien species limited to estuarine and marine soft sediment and without annual monitoring the program can hardly be used for signalling purposes.

*Are MWTL sampling locations, in particular fixed locations and transects, situated at strategic locations in relation to the major entry points of alien species?*
The design of MWTL is not related to the distance to major entry points of alien species (harbours, aquaculture plots) but based on historically selected fixed sampling points (Wadden Sea, North Sea) or random sampling of all ecotypes (Delta area). Furthermore sampling locations only include soft-sediments, whereas hard substrate is excluded from sampling.
Although minimum distance varies, most harbours lay within 10 km distance to the nearest MWTL sample station and most shellfish culture plots lay within a 5 km distance range to a MWTL sample station. The closest MWTL stations to the Port of Rotterdam is at >10 km distance. Dispersal maps of alien species can be created based on MWTL data and relations with obvious vectors can be detected (i.e. *Marphysa sanguinea* in the vicinity of Yerseke, an important centre for aquaculture). However, dispersal maps based on MWTL are mostly useful for species that are abundant.

*Is it possible to include marine (benthic) macroflora in the MWTL-sampling?*
Since the method and taxonomic expertise deployed for the current MWTL program are specific for macrozoobenthos, macroalgae are not included at this point. An additional person could be added to the MWTL teams in order to perform a specific algae survey. In this way logistics needed for arriving at the numerous sampling stations are easily combined and additional costs will be lower then with a separate program. The limited number of experts with taxonomic knowledge on algae in the Netherlands is a point of concern.

*Are alternative sampling programs of soft sediment sediments available, which are better suited for alien species detection than the MWTL program?*
Several long-term monitoring programs and project monitoring include macrozoobenthos sampling of soft sediments, for example, the NIOZ monitoring of the Balgzand. Several programs contain more locations thereby covering large areas in higher densities and closer to main entry points. However, the current sampling protocol leads to exclusion of smaller species or certain taxonomic groups (e.g. SIBES in the Wadden Sea, WOT shellfish survey in the coastal zone). Without adjustments of these monitoring programs (i.e. including all taxonomic groups and program extention for e.g. plankton, epifauna), these programs are not clearly better equipped for detecting alien species than the MWTL program.

Providing open access data is an important aspect that will enable the use of alternative monitoring programs and project monitoring for alien species detection.

*Which adjustments are needed to improve alien species detection by MWTL?*
The MWTL sampling, or soft-sediment sampling in general, cannot easily be used for early warning or signalling since densities are low and surface area sampled small. Increasing the number of samples will not easily improve detectability (or detection probability) of rare species, including alien species at early stages of invasion, in soft sediments. Furthermore, only a small fraction of marine alien species is sampled, since the majority of species, like plankton, epifauna and species typical for hard substrate are missed.

The MWTL database can be improved by adding a field with the status alien or native. In order to label species as “alien” or “invasive alien” either a definition of “invasive marine alien” or a standard marine alien species list should be assembled and made publicly available.
Adding stations near major points of entry (e.g. the port of Rotterdam) could lead to earlier detection. However, most alien species originating from the port are hard-substrate species that are therefore not detected in soft-sediment MWTL sampling.
Restoring the sampling frequency from once every three years to annually will improve the detection probability of rare species, including marine alien species and a possible threefold decrease in time lag from invasion to detection.

In conclusion, in spite of the effectiveness of MWTL in detecting the majority of soft-sediment species, the monitoring program is only suitable for detecting a minority of the total list of marine alien species. Both hard-substrate monitoring, mobile species monitoring and pelagic monitoring will add to a more complete set of habitats targeting hard-substrate species, algae, plankton and fish. Aggregating existing monitoring programs for this purpose aids cost minimization.

# Nederlandse samenvatting

Signalering van exoten draagt bij aan beheersmaatregelen en draagt bij aan het evalueren van preventieve maatregelen. Bij een efficiënte signalering van exoten wordt de balans gezocht tussen minimale monitoringsinspanning en de risico op het niet detecteren van soorten.

Dit rapport betreft de evaluatie van de mogelijkheden om het MWTL programma (Monitoring Waterstaatkundige Toestand des Lands) te gebruiken voor de signalering van mariene exoten. Het MWTL programma is een lange termijn monitoringsprogramma van de waterkwaliteit van Nederlandse wateren. Een gedeelte van dit programma betreft de bemonstering van macrozoobenthos in het zacht substraat van de zoute wateren in de Noordzee, Waddenzee en Delta. Exoten worden soms in deze bemonstering aangetroffen.

Deze studie betreft een analyse van het MWTL programma met betrekking tot de potentie voor detectie en signaleren van (nieuwe) exoten.
De hoofdvragen zijn of de MWTL monitoring geschikt is om recentelijk geïntroduceerde soorten te ontdekken, of de bemonsteringslocaties strategisch liggen ten opzichte van bronlocaties, of macro algen in het meetnet zouden kunnen worden opgenomen, of er nog andere monitoringsprogramma's zijn die gebruikt kunnen worden en welke verbeteringen en mogelijk zijn om exoten detectie te optimaliseren.

Voor het onderzoek is gebruikt gemaakt van een data-analyse en ruimtelijke analyse van monitoringsdata van MWTL. Daarnaast zijn een literatuurstudie en interviews met experts onderdeel van de studie.

*Wat is de effectiviteit van het MWTL programma ?*
24 mariene exoten zijn opgepikt door MWTL in de periode 1990-2010. In deelgebieden met meer vectoren zijn grotere aantallen exoten aangetroffen (Oosterschelde en westelijke Waddenzee). De vertraging tussen de eerste waarneming en waarneming binnen MWTL (tijd tot detectie) bedroeg gemiddeld 2 jaar. Binnen het MWTL programma zijn mariene exoten met zowel lage als hoge dichtheden aangetroffen.
Slechts een klein deel (12%) van de mariene exoten in Nederlandse wateren is aangetroffen in het MWTL programma. 21 van de 24 mariene exoten waren al voor de aanvang van het programma gevestigd in Nederland. Slechts drie soorten van zacht sedimenten zijn geïntroduceerd binnen de monitoringsperiode van MWTL. De tijd tot detectie is 5 jaar voor de penseelkrab en een jaar voor de Filipijnse tapijtschelp. De eerste vondst van de worm *Marphysa sanguinea* werd gedaan *binnen* het MWTL programma . Omdat voor veel gebieden de monitoringsfrequentie recent is afgenomen naar een keer per drie jaar, zal op deze locaties de tijd tot detectie drievoudig toenemen.
Het MWTL programma is alleen geschikt om zacht substraat mariene exoten op te pikken en 88% van de totale soortenlijst (waaronder plankton, epifauna en hard substraat soorten) wordt gemist. Bovendien is de frequentie van een keer per drie jaar (in het merendeel van de gebieden) ongeschikt om het monitoringsprogramma te gebruiken voor exoten signalering.

*Liggen MWTL bemonsteringslocaties strategisch ten opzichte van bronlocaties (havens, aquacultuur)?*

De opzet van MWTL houdt geen rekening met de positie bronlocaties, maar is gebaseerd op historisch vastgelegde locaties (Waddenzee, Noordzee) of het random bemonsteren van ecotopen (Delta).

De minimum afstand tussen MWTL locaties en havens of aquacultuur wisselt sterk, maar het merendeel van de haven is binnen 10 kilometer van een MWTL punt gelegen en voor de aquacultuur percelen is dit ca. 5 km. Het dichtstbijzijnde MWTL punt nabij de haven van Rotterdam is >10 km. Het is mogelijk om met MWTL data verspreidings- en invasie kaarten te genereren van mariene exoten.

*Is het mogelijk om macroalgen mee te nemen binnen de MWTL monitoring?*

Zowel de methode als de taxonomische kennis die vereist is, verschilt van de huidige MWTL aanpak. Een mogelijkheid is om een aanvullende algen bemonstering uit te voeren op dezelfde locaties van MWTL. Op deze manier kunnen transport en logistiek gecombineerd worden tegen wellicht geringe meerkosten. De schaarste aan taxonomische kennis van algen binnen Nederland is een zorgpunt bij het opzetten van een dergelijke monitoring.

*Zijn er alternatieve monitoringsprogramma's aan te wijzen die meer geschikt zijn voor exoten monitoring?*

Er zijn verschillende monitoringsprogramma's die macrozoobenthos bemonsteren, zoals de NIOZ monitoring van het Balgzand en het SIBES programma. Het ontwerp van deze programma's is echter altijd specifiek gericht op een beleidsdoel of onderzoeksvraag. Geen enkel ander monitoring programma is daarom specifiek meer geschikt voor detectie van exoten dan het MWTL programma. Open access (openbaarheid van gegevens) draagt bij aan de mogelijkheid om alternatieve programma's te gebruiken voor de detective van exoten.

*Welke aanpassingen dragen bij aan exoten detectie binnen MWTL?*

In de eerste plaats door exoten als zodanig te labelen in het MWTL bestand. Om soorten te kunnen labellen als exoot of invasieve exoot is het nodig om een "standaard mariene exotenlijst" samen te stellen en openbaar beschikbaar te maken.

Door het geringe oppervlak dat wordt bemonsterd is het niet gemakkelijk om de detectiekans te laten toenemen door uitbreiding van het aantal monsters.

Het toevoegen van monsterpunten in de nabijheid van belangrijke bronlocaties (bv Haven van Rotterdam), zal wellicht leiden tot een eerdere waarneming van exoten. Echter het grootste deel van de exoten uit havens betreft hard substraat soorten die niet worden waargenomen bij zacht substraat bemonsteringen.

Het uitbreiden van de meetfrequentie van 1 x per 3 jaar naar 1 x per jaar zal de kans vergroten dat zeldzame soorten, waaronder exoten, gevonden worden en de vertraging potentieel doen afnemen van 4 jaar naar 1 jaar.

Ondanks de effectiviteit van MWTL met betrekking tot het detecteren van mariene exoten van zachte substraten, kan geconcludeerd worden dat het huidige monitoringsprogramma slechts geschikt is voor het detecteren van een klein deel van de totale lijst van mariene exoten. Monitoring van zowel hard-substraat soorten, mobiele soorten en pelagische soorten draagt bij aan een meer complete set van habitats waarbij ook exoten binnen de groepen epifauna, algen, plankton en vis worden gedetecteerd. Het gebruik maken van diverse bestaande monitoringprogramma's voor dit doeleinde zal helpen bij kostenminimalisatie van de monitoring van mariene exoten.

# 1 Introduction

## 1.1 Marine invasive alien species in Dutch coastal waters

Invasive alien species (IAS) are species transported with the help of human activities to a new environment (e.g. the Netherlands) in which they are able to survive, reproduce and spread explosively (Mack *et al.* 2000; Beleidsnota Invasieve Exoten 2007). Although this phenomenon is not new, the number of invasions and species included has increased significantly in the past decades due to increased transport and trade (Castri 1989), and will increase with further globalization (McNeely 2006). Once invasive alien species are established in the new environment, they have the potential to change the ecological properties of the system, such as nutrient cycling or species interaction (Vitousek 1990), and therefore alter the ecosystem (Bax *et al.* 2003).

To become established, new immigrants need to survive the transport to, and the conditions of, the new environment. Only a fraction of the species survives this stage. The population of an established, newly introduced species often enters a lag phase first, during which the population remains small and is hard to detect. This results from several factors, including natural selection upon genotypes adapted to the new range of environmental factors (Mack *et al.* 2000). If a population can overcome the lag phase, it often proceeds in exponential growth. This growth will continue until the carrying capacity of an ecosystem is reached, or when population regulation occurs by predators, diseases or parasites, which is often absent during the exponential phase (Mack *et al.* 2000).

In the Dutch coastal waters, which consist of mainly soft sediments, numerous marine invaders are now present, in particular on hard substrates in or near harbours and aquaculture areas. Species can be introduced with dry ballast (until the 20$^{th}$ century), ballast water (1870 onwards), via ships hull fouling, by shellfish imports, or via freshwater shipping canals if the species is freshwater tolerant (e.g. the amphipod *Orchestia cavimana*) (Wolff, 2005). Alien species found in hull fouling and shellfish transports are often hard substrate species. Range expansion by secondary dispersal after an introduction and establishment somewhere else along the European coast is a also source for new invaders along the Dutch coast. The species that are able to expand swiftly usually have at least one planktonic life stage, as for instance the American comb jellyfish *Mnemiopsis leidyi* and the American jackknife clam *Ensis directus*.

## 1.2 Detecting invasive alien species

In marine habitats the prevention of introduction is generally considered the best, and only management option (Marine Strategy part 2). Consequently, evaluation of the efficiency of these measures is important. Early detection of introduced species is an essential component of this evaluation and can be implemented in current monitoring programs.

The entry points of alien species in our coastal waters are usually characterized by hard substrates and expected to be related with different pathways, such as large harbours (large ships as vectors for ballast water), marinas (small ships as vectors for biofouling) and aquaculture (shellfish transports as vectors). Alien species, which enter our waters by secondary dispersal, will be most likely transported by the major south – north (rest) currents. This pattern may be similar to invasions of cimate-induced range shifters, although these are generally considered t be a more natural phenomenon. The MWTL sampling, or soft-sediment sampling in general, cannot easily be used for early warning or signalling since densities are (too) low and surface area sampled small.

Detection of newly introduced alien species at low abundance, for example during the lag phase, in the monitoring area can strengthen current management strategies including alien species management and eradication. Early detection in both soft sediments and hard substrates is, therefore, necessary and useful, since if a new alien species is detected before it becomes established and will spread, the costs of eradication and control are generally low (Mehta *et al.* 2007). It is also useful for analysing the effectiveness of prevention and control measures. A practical early detection strategy requires achieving balance between efficient sampling and taxonomy methods that minimize early detection costs such as time and effort with the risk associated with non-detection (Lehtiniemi *et al.* 2015). Another consideration is which habitat type, soft sediment or hard substrate, is regularly sampled, as this will lead to different rates of alien species detection.

## 1.3 MWTL and invasive alien species

The Dutch marine biodiversity is intensively monitored via different monitoring programs. The oldest of these programs is the MWTL (Monitoring Waterstaatkundige Toestand des Lands), a program that combined several older programs in 1990. The monitoring of soft-sediment macrozoobenthos in the North Sea, Wadden Sea and Delta area historically included sampling twice a year (in spring and autumn) on fixed locations in a standardized way. The older monitoring programs date from 1959 (various Delta basins) and 1970 (Western Wadden Sea). This program combines chemical, hydrographical and biological monitoring. Special emphasis is given to the monitoring of the macrozoobenthos in soft sediment communities, as this is the main food source for many protected species in the areas and indicator species of several legal frameworks (e.g. WFD, MSFD)

Currently MWTL monitoring programs are not specifically designed to detect new alien species at an early stage. The research question of this study is whether the MWTL program is suitable for early detection of alien species in the macrozoobenthos, including related epifauna, of soft sediment communities in the Dutch coastal waters and the Dutch part of the North Sea.

## 1.4 Objective of the study

The objective of this study is to investigate whether the MWTL program can be used for (early) detection of alien species in the macrozoobenthos of the soft sediment communities in Dutch coastal waters and the Dutch part of the North Sea. In this study, we evaluated locations of sampling sites, detection rate, detection lag time and detection probability. In addition, we searched for possibilities to include alien species of macroflora in the monitoring, and potential adjustments of the MWTL program to make it more suitable for early detection of alien species in the macrozoobenthos.

### 1.4.1 Research questions

1. What is the effectiveness of the MWTL-program with respect to detection rate, detection lag time and detection probability of alien species?

2. Are MWTL sampling locations, in particular fixed locations and transects, situated at strategic locations in relation to the major entry points of alien species?

3. Is it possible to include marine (benthic) macroflora in the MWTL-sampling?

4. Are there alternative sampling programs of soft sediment sediments available that are better suited for alien species detection than MWTL?

5. Which adjustments are needed to improve alien species detection by MWTL?

## 1.5 Overview

This study used data and spatial analysis of existing MWTL monitoring data, a literature review and several interviews with stakeholders to answer the above questions. The methods are described in chapter 2 and the results are presented in chapter 3. Chapter 4 involves discussion of the results and conclusions are formulated in chapter 5.

# 2 Materials and methods

## 2.1 General approach

To evaluate the effectiveness of the MWTL-program, we first carried out a literature review of alien species detection programs and methodology, followed by the creation of a list of marine alien species observed in the Netherlands.
MWTL data were subsequently used to analyse quantitative aspects of detection probability in time and space.
In a third approach, we conducted interviews with experts to provide qualitative information on sampling methods, taxonomic expert knowledge, adjustments and alternative monitoring programs.

## 2.2 Qualitative research

### 2.2.1 Literature review of marine alien species detection

Literature reviews included:

- A concise description of alternative monitoring programs;
- Importance aspects of alien species detection (i.e. selection of sampling locations, ecological parameters of interest).

### 2.2.2 List of introduced species observed in the Netherlands

Information from international and national scientific literature and data sources was used to assemble an up-to-date list of marine alien species in the Netherlands. Since most marine species are either associated with soft sediment or hard substrates, each species was categorized as a 'soft sediment' or 'hard substrate' species. This is important because the MWTL surveys are specifically designed for soft sediment benthic habitats, habitats typical for Dutch marine, estuarine and coastal habitats. When evaluating the effectiveness of the MWTL program for detection of alien species, the benthic ecological strategy (hard or soft substrates) of marine species is likely to play an essential role. A special case are naturally occurring hard substrates in soft sediments, such as mussel (*Mytilus edulis*) beds and biogenic reefs formed by Pacific oyster (*Crassostrea gigas*) or flat oyster (*Ostrea edulis*). These are relatively scarce (mussel and Pacific oyster) or very rare and local (flat oyster) and monitored in fishery policy related programs.
In addition, almost all MWTL surveys of marine soft sediment communities are conducted in estuarine or marine habitats. Only the eastern part of the Western Scheldt includes brackish habitats. Therefore, only marine species that occur at higher salinities were included in the present study, whereas typical brackish and freshwater species were omitted

The following sources that contain distribution data on alien marine species in the Netherlands were used to compose a list of marine alien marine species observed in marine ecosystems in the Netherlands:

- Non-indigenous marine and estuarine species in the Netherlands (Wolff 2005).
- Mariene uitheemse soorten in Nederland (Wijsman & de Mesel 2009, Appendix D).
- Overzicht exoten in de Eastern Scheldt, Voordelta en aangrenzende wateren (Wijsman & de Mesel 2009, Appendix E).
- Overzicht exoten in de Nederlandse Waddenzee (Wijsman & de Mesel 2009, Appendix F).
- Nonnative macrobenthos in the Wadden Sea ecosystem (Buschbaum *et al.* 2012).
- AquaNIS. Editorial Board, 2014. Information system on Aquatic Non-Indigenous and Cryptogenic Species. World Wide Web electronic publication. www.corpi.ku.lt/databases/aquanis. Version 2.36+. Accessed 2014-12-16.
- Information available via www.werkgroepexoten.nl (and references therein).
- Historische analyse exoten in de Zeeuwse delta (Wijnhoven & Hummel, 2009).
- Introduced aquatic species of the North Sea coasts and adjacent brackish waters. (Gollasch, S., Haydar, D., Minchin, D., Wolff, W.J. and K. Reise. 2009).
- Native and non-native species of hard substrata in the Dutch Wadden Sea (Gittenberger *et al.* 2009, 2012).

Correct taxonomic naming of individual species was validated by comparing the species list with common accepted names in the WoRMS (World Register of Marine Species) database. Subsequently, the taxonomic specialist Godfried van Moorsel (ecoSub) conducted a final control for errors, or missing species.

### 2.2.3 Expert interviews

Several experts with knowledge of MWTL monitoring programs, procedures and taxonomy were contacted by telephone for in-depth interviews. In-depth interviewing, also known as unstructured interviewing, is a type of interview that is typically used to elicit information in order to achieve a holistic understanding of the interviewee’s point of view or situation; it can at the same time be used to explore interesting areas for further investigation. The interview involved asking informants open-ended questions, and probing wherever necessary to obtain data deemed useful by the researcher. A checklist of topics was used. In this case, as in-depth interviewing involved qualitative data, we refer to it as qualitative interviewing.

## 2.3 Detection parameters

### 2.3.1 Data availability and data selection

The occurrences of alien species in datasets from the national MWTL survey program are evaluated in the present study. Although this survey program is still active and encompasses a long time period (starting in 1990), data that are publicly available in 2014 do not include all years.

Due to availability, only a selection of survey years and areas is analysed in the present study (Table 2.1). However, the areas included in the present study represent all major marine soft sediment ecosystems that are present in the Netherlands, from estuaries to offshore areas in the North Sea. The number of pathways is estimated for each area (Table 2.2).

*Table 2.1 Overview of MWTL datasets (four regions, areas and years) that are analysed in the present study).*

| Area | First year MWTL data | Last year MWTL data |
|---|---|---|
| *Delta* | 1990 | 2012 |
| *North Sea* | 1991 | 2008 |
| *North Sea coastal zone* | 1991 | 2008 |
| *Wadden Sea* | 1990 | 2011 |

*Table 2.2 Overview of MWTL areas that are grouped (four regions, areas and years) that are analysed in the present study.*

| Location | Start date | Area | Areas for analysis | Pathways | #Pathways |
|---|---|---|---|---|---|
| Grevelingenmeer | 19900403 | Delta | Grevelingenmeer | marine debris, aquaculture, small harbours | 3 |
| Oosterschelde | 19900312 | Delta | Oosterschelde | marine debris, aquaculture, small and large harbours | 4 |
| Westerschelde | 19900118 | Delta | Westerschelde | marine debris, small and large harbours | 3 |
| Veerse meer | 19901001 | Delta | Veerse meer | marine debris,aquaculture, small harbours | 3 |
| Breeveertien (Zuidelijke North Sea, NCP) | 19910416 | North Sea | North Sea | marine debris | 1 |
| Doggersbank (Central North Sea, NCP) | 19910425 | North Sea | North Sea | marine debris | 1 |
| Friese Front (Central North Sea, NCP) | 19910528 | North Sea | North Sea | marine debris | 1 |
| German Bight (zeegebied) | 19910423 | North Sea | North Sea | marine debris | 1 |
| North Sea (internationaal) | 19910507 | North Sea | North Sea | marine debris | 1 |
| Oestergronden (Central North Sea, NCP) | 19910424 | North Sea | North Sea | marine debris | 1 |
| Hollandse kust (Kustzone, NCP) | 19910415 | North Sea | North Sea Coastal zone | marine debris,large harbours | 2 |
| Voordelta (Kustzone, NCP) | 19910507 | North Sea | North Sea Coastal zone | marine debris, large harbours | 2 |
| Waddenkust (Kustzone, NCP) | 19910423 | North Sea | North Sea Coastal zone | marine debris, large harbours | 2 |
| Eems-Dollard | 19910320 | Wadden Sea | Eems-Dollard | marine debris, small and large harbours | 3 |
| Waddenzee oost | 19980318 | Wadden Sea | Waddenzee oost | marine debris, small harbours | 2 |
| Waddenzee west | 19900305 | Wadden Sea | Waddenzee west | marine debris, aquaculture, small and large harbours | 4 |

### 2.3.2 Detection parameters

In order to answer the specific research questions we defined detection parameters, bearing in mind an ideal monitoring program of marine alien species that includes a detection rate close to 100%, with a high detection probability of new species, a sufficient number of sampling sites located near potential introduction sites (alien hotspots), and a short time lag between introduction and detection (at most several years) (Campbell et al., 2007; Costello et al., 2007; Crooks, et al., 2005; Hoffman et al., 2011; Trebitz et al, 2009).

Three major detection parameters of the MWTL data are calculated from both qualitative and quantitative data from the literature review:

1. Detection rate, defined as '*proportion of total number of marine alien species observed in the Netherlands that is actually detected by the MWTL-program*'.
2. Time lag to detection, defined as '*time from registration of a new alien species to detection and administration within MWTL-program*'.
3. Detection probability is defined as one minus the proportion of rare species missed and depends mainly on the number of samples taken.

*Detection rate and time lag*

The first step to evaluate detection rate and time lag of alien species in the MWTL program is to assemble species lists for each the surveyed areas for the period 1991-2012 (for detailed periods see Table 2.1). Subsequently, for each species the year of first detection in MWTL surveys was determined. For alien species the first year of MWTL detection was compared with the first year of detection based on other data sources (see §2.2.2) elsewhere in the North Sea or coastal waters. Ideally, the years of first observation are similar in both MWTL and other data sources. On the other hand, a clear (positive or negative) lag or mismatch is an indication that the detection power of the MWTL survey is better or worse in comparison with other surveys.

The analysis gives insight in the rate new invasive species are detected by the MWTL program, and whether or not a time lag ('*detection delay*') is present between alien species detection based on MWTL data or other international and national data sources.

*Detection probability*

In order to investigate if detection of IAS species was related to density, a density graph was created and related to detection of species within the MWTL program. First species were ordered from most abundant to least abundant, based on their average density in the Delta area (period 1992-2010). Based on the method by Gittenberger & van Loon (2011 and 2013) a threshold value of 3% of the most abundant species was chosen to define common species (≥3% - common species). After plotting all species, the five most recently detected IAS species were plotted and labelled and related to the threshold value for common species.

The reliability of the number of observed species in MWTL surveys was evaluated by estimating the number of missed species. In general, in all biological surveys there are '*rare*' species that can easily remain undiscovered. Clearly, when entering a new area, new alien species are effectively rare at the early start of an invasion. Two methods were applied to estimate the reliability of the species estimation: (1) by fitting a lognormal distribution to the species-abundance distribution and subsequently estimating the proportion of species between zero and one, and (2) by estimating the asymptotic number of species from the species – accumulation curve.

Several models can describe the relationship between sample size and asymptotic species number and can be used to estimate the number of rare species missed in a survey of a given area (for a review and general assumptions see Gotelli & Colwell, 2009). In the present study however, the accuracy or detection probability is estimated by constructing sample-based rarefaction curves, a type of species accumulation curve. In addition, total species richness is calculated based on non-parametric Jackknife1 estimators.

For the MWTL surveys, these methods will first be applied for the year 2002, a representative year without any strong anomalies in weather or climate conditions. Secondly, these analyses are repeated for all years combined. Analyses are performed with EstimateS (version 9.0, Colwell, 2013).

## 2.4 Geographical patterns

We expect that in particular international ports (e.g. port of Rotterdam) and mussel culture plots (e.g. Eastern Scheldt) are important dispersal vectors for alien species. In harbours international ships make shore and/or change ballast water increasing the risk on dispersal of alien species, whereas mussel culture plots receive growth substrates and mussels from other areas (by either international or national transport movements). To evaluate whether or not the present distribution patterns of MTWL samples stations encompass the effect of international harbours and mussel culture plots, various spatial analysis are conducted.

*Distribution of sample stations and minimum distance analysis*
To visualize the distribution of MWTL sample stations in Dutch marine waters, a geographic map was constructed that contained all MWTL sample stations. Within this map, all international (commercial) ports and mussel culture plots are shown. Subsequently, a minimum distance analysis was conducted. Here, the distance of the nearest MWTL sample station to each harbour or mussel culture plot was calculated.

*Species dispersal maps*
For marine alien species that first settled in the Netherlands within the timeframe covered by the selected MWTL surveys (see below for data selection), dispersion maps were constructed. Dispersal maps might help to detect invasion patterns and visualize whether international ports and mussel culture plots have a strong affect in the dispersal of new alien species. Subsequently, these maps may also reveal other areas or vectors that are related to a high invasion risk.

All spatial analyses were conducted in ArcGis 10.2.

# 3 Results

## 3.1 Overview of Dutch monitoring programs and characteristics

### 3.1.1 MWTL macrozoobenthos programs

*Table 3.1 Overview of MWTL programs (macrozoobenthos). Italic rows contain historical information.*

| Program | Start | Frequency | #stations /#samples | Area and Principles |
|---|---|---|---|---|
| *MWTL North Sea* | *1991-1995* | *annual* | *25 (5 samples each)* | *Raai Noordwijk* |
| *MWTL North Sea* | *1995-2010* | *annual* | *100* | *Raai Noordwijk* |
| MWTL North Sea | 2012 | 1 per 3 years | 100 | Raai Noordwijk |
| MWTL additional | 2015 | | 67 | T0 MSFD Doggersbank, Friese Front |
| *MWTL Wadden Sea* | *1990-2011* | *twice annual* | | *Balgzand W Waddenzee* |
| *MWTL Wadden Sea* | *1998-2011* | *twice-annual* | | *Waddensea East* |
| MWTL Wadden Sea | 2011 | 1 per 3 years (twice-annual) | 14 (transects) / 235 | Balgzand en Waddenzee |
| MWTL Eems Dollard | 2011 | annual | 3 (transects) / 60 | Eems Dollard |
| MWTL Delta | 2013- | 1 per 3 years | 120/120 | Ecotype sampling:, Grevelingen,Lake Veere |
| MWTL Delta | 2013 | annual | 130 /195 | Ecotype sampling: Eastern Scheldt, Western Scheldt, |

MWTL (formerly also known as BIOMON) is commissioned by the Ministry of Infrastructure and Environment. New species are continuously detected, including climate-induced range shifters (climate shifters) and alien species. The MWTL sampling locations have a different geographical spread in different marine regions (Table 1). They are organised in several transects in the Wadden Sea (e.g. Wadden Sea west, Wadden Sea east), and North Sea and random stratified in the Delta (Grevelingen, Eastern Scheldt, Western Scheldt).

The MWTL monitoring survey of macrozoobenthos in the soft sediments of the North Sea and coastal waters has been initiated in 1991. It started with 25 stations with five box core samples taken annually. From 1995-2010 100 stations were sampled annually and since 2012 100 stations are sample once every three years. In 2015, due to a baseline study for the MSFD, 67 samples will additionally be sampled with a Triple-D (deep digging dredge).

The MWTL Wadden Sea includes three transects in the western Wadden Sea that were sampled twice-annually from 1990 onwards up to 2011. Sampling was increased to 17 transects, including the eastern Wadden Sea and the Eems-Dollard area that are sampled twice-annually. From 2011 onwards, sampling was reduced to once every three years in spring and autumn, with an exception for the “high-risk” area of Eems Dollard that is still sampled twice-annually (table 3.1).

Within the monitoring program MWTL, the benthic macrofauna of the Eastern Scheldt estuary, Lake Veere and Lake Grevelingen have been monitored since 1990, Sampling was carried out each spring and autumn until 2013. Since then, Western Scheldt and Eastern Scheldt are sampled annually in autumn, while Grevelingen and Lake Veere are sampled once every three years (table 3.1).

### 3.1.2 Other long term monitoring programs for macrozoobenthos

*Table 3.2 Overview of other long-term monitoring programs (macrozoobenthos). – missing information.*

| Program | Start | Frequency | No. stations /samples | Area and Principles |
|---|---|---|---|---|
| WOT shellfish survey | 1995 | annual | 862 | North Sea coastal zone, commercial shellfish species |
| WOT survey Wadden Sea | 1995 | annual | 1134 | Wadden Sea, littoral mussel beds |
| WOT Cockle survey | 1990 | annual | 1497 | Wadden Sea, Eastern and Western Scheldt cockles |
| SIBES | 2008 | annual | 4500 | Wadden Sea Random samples in grid, focus on relevant for feeding of birds |
| NIOZ Balgzand (littoral) | 1970 | twice-annual | 15 (750) | Wadden Sea Balgzand |
| NIOZ Balgzand (sublittoral) | 1989 | twice-annual | 3 (750) | Wadden Sea Balgzand |
| NIOZ shrimps and crabs | 1983 | - | - | Wadden Sea |
| BTS/IBTS/DFS | 1985/77/95 | annual | - | Fish stocks ICES rectangles |
| ANEMOON | 1977 | - | - | SMP: North Sea |

**WOT Shellfish Survey North Sea Coastal zone**
WOT shellfish survey is conducted since 1995 in the Dutch coastal zone.
Goal: Conducting a stock assessment of commercially relevant shellfish species, especially *Spisula* and *Ensis*. Already since the start of the survey, other (shellfish) species present in the samples are assessed as well.
Method: The samples are collected with a benthic scoop, suction dredge and Van Veen Grabber WOT data are available in the database of IMARES (Goudswaard *et al.* 2012). The program is commissioned by the Ministry of Economic affairs.

**WOT Shellfish Survey Wadden Sea**
WOT shellfish survey Wadden Sea includes several different surveys. The littoral mussel beds are monitored in spring since 1995. The annual cockle survey is conducted since 1990.

**WOT cockle survey**

WOT cockle survey is conducted in the Voordelta Wadden Sea, Eastern Scheldt and Western Scheldt since 1990.

Goal: Annual cockle stock survey.

Method: Stratified sampling with a diversity of gear (core, punch sampler, cockle scoop).

**NIOZ program Balgzand (Western Wadden Sea, tidal)**

A long-term program (started around 1970) involves twice-annual sampling (spring, autumn) of macrozoobenthos at 15 permanent sampling transects located on Balgzand, a 50 $km^2$ tidal flat area in the westernmost part of the Wadden Sea.

Goal: detect trends in population dynamics of macrozoobenthos species.

Method: Per 1-km transect (raai), 50 equally spaced samples of 0.018 $m^2$ each are taken by littoral core sampling (30 cm). Cores are sieved over a filter with a mesh size of 1mm. Abundance of macrozoobenthic species is expressed in numbers and g ash-fee dry weight per $m^2$. (Beukema & Cadeée 1997; Beukema & Dekker 2014). Until 2011, three transects were part of the MWTL Wadden Sea.

**NIOZ program Balgzand (Western Wadden Sea, subtidal)**

Due to the importance of subtidal habitats, three subtidal transects were added to the Balgzand program in 1989.

Method: Reineck Boxcorer.

**NIOZ shrimp and crab survey**

Since 1983, NIOZ has run a special sampling program for shrimp and shore crabs during the months when high numbers of just-settled bivalve post-larvae are present on the tidal flats.

Goal: Measuring bivalve predation pressure through recruitment of shrimps and crabs

Method: The program involves about twice monthly sampling from late April to at least late June at low tides at 3 intertidal stations on Balgzand.

Sampling is performed at low tide, in which period sampling with corers is relatively easy (at each station, 40 samples of 88 $cm^2$ each are taken on each sampling occasion). Abundance of epibenthic predators was expressed in g ash- free dry mass (AFDM) $m^2$, separately for shrimps and for 0- and 1-group shore crabs. For further details on the locations of stations and methods see Beukema (1991).

**SIBES Synoptic Intertidal Benthic Surveys**

In 2008, the NIOZ has started a large zoobenthic monitoring program. This program, the Synoptic Intertidal Benthic Surveys (SIBES), is the largest macrozoobenthos monitoring program in the world. It consists of 4.500 sampling points in the Dutch Wadden Sea area and covers an area of 2.483 $km^2$. The project is funded by the NAM and the ZKO and aims to fully map the spatial and temporal distribution of macrozoobenthos (Compton *et al.* 2013).

Goal: Description of the species composition of the macrozoobenthic infauna (worms, crustaceans, bivalves) as well as the particle size distribution of tidal flats. The

database is limited to macrozoobenthic species relevant as food for birds and therefore does not contain information on species groups like barnacles, hydrozoa and bryozoa.
With this information, long-term changes of the Wadden Sea macrozoobenthic fauna and the consequences for the carrying capacity shall be investigated and described. Furthermore, the introduction of alien species is being monitored.
Method: Once a year, in summer, a sediment sample is taken with a corer on a grid of 500m x 500m with 10% random locations. The whole of the sampled area is 2.483 $km^2$ large and spans 4.500 sampling locations. Information on abundance ($N/m^2$) and biomass (g $AFDW/m^2$) of the benthic infauna is collected. Polychaeta, Mollusca, crustaceans and echinoderms are being identified to genus or species level, and oligochaetes are being identified to class level. The program is commissioned by the Nederlandse Aardolie Maatschappij.

**ICES BTS IBTS and Demersal Fish surveys (DFS)**
BTS include fish stock assessments. Macrobenthos is administrated as well (including macro- and megabenthos) (Boois & Bol 2012).
Method: Sediment trawl, mesh size 40 mm. Applied in ICES rectangles. The program is commissioned by the Ministry of Economic affairs.

**ANEMOON monitoring programs for volunteers**
ANEMOON foundation runs several long-term programs using volunteers. The SMP (Beach Monitoring Project) runs from 1977 and includes beach finds (www.anamoon.org).

Apart from macrozoobenthos of soft sediments several other long term programs of marine species exist including mobile fauna epifauna (eg. BTS, DFS), epifauna of naturally occurring hard substrates in soft sediments (eg. WOT shellfish survey oyster and mussel beds), and species of hard-substrates (SETL-project, Gittenberger & van Stelt 2011; LIMP and MOO program, www.anamoon.org). The listed programs in this paragraph are however restricted to macrozoobenthos of soft sediments.

### 3.1.3 Project monitoring for macrozoobenthos

*Table 3.3 Overview of project monitoring of soft-sediment macrozoobenthos.*

| Project | Area |
|---|---|
| Baseline non-native species Wadden sea | Wadden sea |
| PRODUS | Wadden Sea (subtidal) |
| Waddensleutels | Wadden Sea (tidal) |
| Sandmotor | North Sea |
| Tweede Maasvlakte | North Sea |
| Offshore windparks | North Sea |
| Triple D (deep digging dredge) | North Sea |
| Mussel stocks PO Mossel | Wadden Sea |
| Zandhonger/Galgeplaat Suppletion | Delta (Eastern Scheldt) |

**Baseline study of non-native macroflora and -fauna of soft sediments and hard substrates in the Wadden Sea, including mussel culture plots (2014 and 2009, 2011)**
In 2014, a system-wide survey of non-native macroflora and -fauna in soft sediments and on hard substrates in de Wadden Sea was carried out by NIOZ/GiMaRIS. This baseline study was additional to earlier in 2009 and 2011 (Gittenberger *et al.* 2009 and 2012) was repeated.

Method: The inventory focused on hard-substrate locations with a high probability of finding alien species. Each sampling location was examined till it was expected that a duplicate search time yielded less than one new species. The soft sediment sampling by NIOZ included 100 of the random sampling locations of the SIBES project and samples on strategic locations (marinas, mussel and oyster beds). Additional to the SIBES data, all macroflora and -fauna were included and not limited to certain species (groups) (Sander Smolders pers. comm; Gittenberger et al, in prep).

**PRODUS Subtidal macrozoobenthos Western Wadden Sea (2008)**
For a good description of natural values of habitat 1110_A, sandbanks benthic invertebrate fauna was sampled in the western Dutch Wadden Sea on a system wide scale. The PRODUS 2008 survey (Dekker & Drent 2013) was primarily meant as a resampling of the points of the 1981 - 1982 survey (Dekker 1989).
Method: The area investigated comprises the subtidal part of the western Dutch Wadden Sea, westwards of the tidal watershed of the island of Terschelling. The 2008 survey included resampling of 397 box core stations (0.06 $m^2$- 15 cm). For the comparison between both surveys these sessile hard - substrate species were excluded, as well as were the mysid shrimps.

**NIOZ Triple-D dredge (various years, 1997, 2006 t/m 2008, 2001)**
Different cruises performed bij NIOZ in various projects have resulted in sampling of 421 locations of the Dutch Continental shelf with a Triple-D (deep digging dredge, Witbaard et al 2013). The NIOZ Triple D (deep digging dredge) is a sampling gear for large and sparse occurring infauna from sea floor soft sediments deployed from the NIOZ vessel RV Pelagia. The Triple D catch gives an integrated estimated of infaunal species.

**Waddensleutels food web monitoring (2013)**
The effect of the intertidal mussel beds on fauna density, biodiversity and food web complexity in the Dutch Wadden Sea was studied by sampling al benthic flora and fauna, fish and birds in 2013.
Method: Sampling of macrozoobenthos was carried out on 6 locations covering 4 tidal basins. On each location 10 benthos cores (area 0.0173m$^2$, 25cm deep) were collected over a 1 mm sieve.

Other project monitoring includes Sandmotor, Tweede Maasvlakte, several off shore wind farms, (North Sea area) Sand Suppletion Galgeplaat (Delta area), mussel stocks and Pacific oyster stock. These projects include effects of specific measures and are often part of/ included in Environmental Impact Assessments (EIAs).

Data of project monitoring are typically not open-access, since they are either used for scientific publications (PRODUS, Waddensleutels) or commissioned by market parties (Tweede Maasvlakte, off shore wind farms, mussel stocks). However, some digital reports on project data are available online.

A vast amount of other studies are specifically aiming at hard substrate species. Examples include Den Helder military harbour study (Gimaris 2014), North Sea wrecks biodiversity study (Bureau Waardenburg 2013), steel slag research in the Eastern Scheldt (Stichting Zeeschelp various years), Off shore platform monitoring (IMARES various years).

## 3.2 Basic aspects of marine alien monitoring

Some basic aspects that need to be incorporated in a monitoring program for marine alien species (Campbell et al., 2007; Collin *et al*. 2013; Costello et al., 2007; Hoffman et al., 2011; Trebitz et al., 2009)

1. A clear definition of alien species
2. Baseline studies
3. Optimisation of effort and design
4. Knowledge on natural dispersal patterns (including currents)
5. Optimisation of sampling methods

Several of these aspects are highlighted in peer-reviewed scientific literature and discussed in the following paragraphs.

### 3.2.1 Effort and design

There are two basic aspects to any monitoring effort related to the detection of (alien) species: 1) the overall effort (e.g. number of samples) and 2) the design of the sampling effort (i.e. the spatial and temporal distribution of effort) (Collin et al 2013). With regard to the first aspect, more effort creates a greater probability of detection, but with obvious associated costs. The latter is less obvious and requires knowledge of both the likely time and location of introductions. However, it is unlikely that the initial colonists will arrive in numbers sufficiently high to be detected, and thus most monitoring efforts functionally focus on detecting the subsequent first generations (e.g. Kraft and Johnson, 2000; Hayesetal, 2005)(cited from Collin *et al.* 2013).

### 3.2.2 Incorporating knowledge on patterns of natural dispersion of marine species

Natural dispersal of alien species is often considered as an unmanageable vector (Kanary *et al.* 2011). If the dispersal potential is known, sampling stations can then be positioned at appropriate distances away from suspected points of introduction. However, patterns of dispersal are, in reality, very poorly known. It is not clear how applicable large-scale land-based dispersal models are when working in the marine environment or at the finer spatial scales over which the dispersal of some newly introduced AIS typically occurs. Moreover, the extent to which water motion (e.g. tides, currents) influences the distribution of propagules is unknown. For effective monitoring, it is thus essential to know the scales of effective dispersal (i.e. the range of dispersal) as well as the degree and predictability of any heterogeneity within that range in order to appropriately assign sampling effort. Otherwise, sampling will be haphazardly assigned or take place at too large a scale (i.e. outside the dispersal range) (cited from Collin *et al.* 2013).

From a theoretical standpoint, natural dispersal should assume a kernel function (e.g. integro-difference models, Kot *et al.* 1996) that describes patterns of recruitment in relation to the location of the adult population. This approach has been successfully used in landscape ecology to model dispersal in plants and insects.

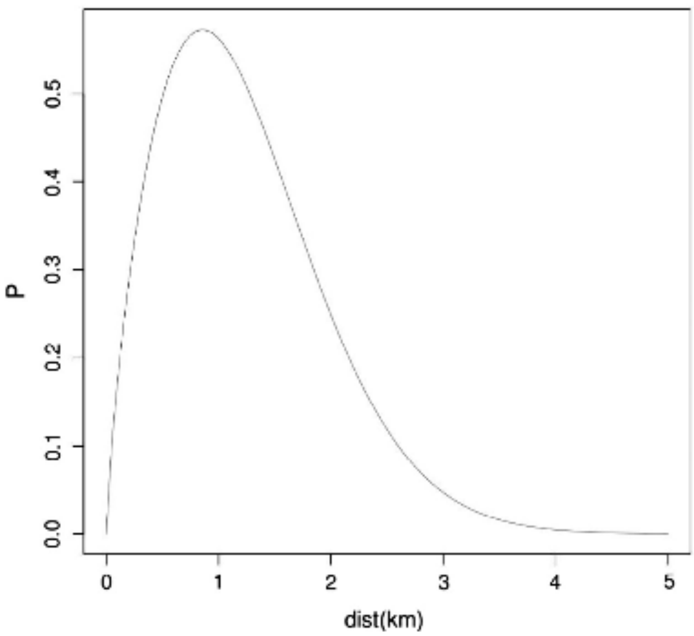



*Figure 3 Weibull function dispersal kernel fit to Ciona intestinalis larval recruitement (Source: Collin et al. 2013)*

The pattern of recruitment of the sea squirt *Ciona* in Canada fitted a Weibull function (Fig 3) better than a negative exponential decay curve. In this case the lack of recruitment in or close to the source populations consisting of adult individuals. From a management perspective, sampling at mid-range distances (1 km), rather than close to the source population, would thus be more effective for detecting invasions of alien species for this species.

## 3.3 List of marine alien species

Based on the sources listed in §2.2 a list of 200 species was created. In order to select marine and estuarine species that are expected within MWTL soft-sediment benthos sampling species were selected based on taxonomy and ecological features
Of this list 66 species of algae, kelp, fungids and fish species were omitted. Another eight species were omitted based on false taxonomy or ambiguity of information on native origin. Species that are characteristic for hard substrates, brackish ecosystems or freshwater were omitted as well.

Not omitted were 17 soft sediment species and therefore expected to occur within MWTL macrozoobenthos sampling (Table 3.4).

*Table 3.4 Overview of marine and estuarine soft sediment alien species.*

| Species | Date NL | Source | Species | Date NL | Source |
|---|---|---|---|---|---|
| *Alitta virens* | 1903 | Wolff 2005 | *Petricolaria pholadiformis* | 1905 | AQUANIS |
| *Aphelochaeta marioni* | 1940 | AQUANIS | *Goneplax rhomboides* | 2008 | AQUANIS |
| *Crassostrea gigas* | 1928 | AQUANIS | *Marphysa sanguinea* | 2008 | AQUANIS |
| *Crepidula fornicata* | 1929 | AQUANIS | *Mercenaria mercenaria* | 1933 | AQUANIS |
| *Ensis directus* | 1981 | AQUANIS | *Rapana venosa* | 2005 | AQUANIS |
| *Hemigrapsus takanoi* | 2000 | AQUANIS | *Ruditapes philippinarum* | 2010 | AQUANIS |
| *Marenzelleria viridis* | 1983 | AQUANIS | *Syllis gracilis* | | Wolff 2005 |
| *Microphthalmus similis* | 1962 | AQUANIS | *Neomysis americana* | 2010 | Wittmann et al 2012 |
| *Mya arenaria* | 1250 | AQUANIS | | | |

## 3.4 Detection parameters

### 3.4.1 Observed marine alien species

A total of 24 marine alien species were detected in the marine, estuarine and coastal MWTL soft sediment surveys and included eleven species of the phylum Polychaeta (worms), six species of the phylum Mollusca (shellfish), five of the sub phylum Crustacea (crustaceans) and two of the sub phylum Tunicata (sea squirts) (Table 3.5). A substantial proportion of these species are salt tolerant (estuarine of marine habitats) and occur in soft sediments (§3.3).

MWTL data enabled detection of 12% of the total aliens species list. The majority of hard substrate species, algae, fish, pelagic species and brackish species were not detected.

Of species listed in Table 3.4 four species have not yet been detected by MWTL, these are *Goneplax rhomboides, Rapana venosa*, *Mercenaria mercenaria* and *Neomysis americana*. Of these species *Goneplax rhomboides* is a climate shifting species (Neuman et al. 2010; 2013) *Neomysis americana* only has arrived recently, in 2010 and is a pelagic species. Since North Sea data are included from 1990-2008 the arrival can only be detected outside the current dataset. On the Dutch Continental shelf a single live specimen of *Rapana venosa* has only be detected in 2005 (Kerkhoff et al. 2006), whereas further records include empty shells that were collected during beach monitoring (Goud 2013). Finally *Mercenaria mercenaria* is established only locally at the Slikken van Vianen in the Eastern Scheldt (www.anemoon.org).

As discussed in this section, a majority of established marine alien species, which typically or mainly occur in soft sediments have been detected by the MWTL surveys, suggesting that the detection rate of the MWTL surveys is specifically, and solely high for estuarine and marine soft sediment species. These species generally do not occur on hard substrates and are not detected in hard substrate surveys. However, this subset includes only a small portion of the total list of marine alien species.

*Table 3.5 Overview of observed marine alien species within MWTL data. Pathway analysis is given of marine alien species in the delta according to Wijnhoven & Hummel (2009), with year of first record in Netherlands, year of first record in delta, area of entry, year of first record in MWTL and presumed vector.*

| **Species** | **First year NL** | **First in delta** | **Point of entry** | **First year MWTL** | **Vectors cf. Wijnhoven & Hummel** |
|---|---|---|---|---|---|
| *Mya arenaria* | 1250 | 1765 | OS | 1990 | shipping |
| *Molgula manhattensis* | 1762 | ? | ? | 1990 | hull fouling |
| *Rhithropanopeus harrisii* | 1874 | 1977 | VM | 1990 | unknown |
| *Petricola pholadiformis* | 1906 | ? | ? | 1990 | possibly oyster culture |
| *Alitta virens* | 1915 | 1950-1960 | ? | 1990 | unknown |
| *Boccardiella ligerica* | 1919 | 1960-1970 | Haringvliet | 1991 | unknown |
| *Crepidula fornicata* | 1929 | 1929 | OS | 1990 | oyster transport |
| *Corophium sextonae* | 1930 | ? | ? | 1990 | shipping |
| *Eriocheir sinensis* | 1930 | ? | ? | 1990 | ballast water |
| *Syllis gracilis* | 1940 | 1990 | GR/OS | 1990 | oyster transport |
| *Proceraea cornuta* | 1941 | 1941 | OS/WS | 1991 | oyster transport |
| *Syllidia armata* | 1943 | 1985-1990 | OS | 1990 | oyster transport |
| *Elminius modestus* | 1946 | ? | HvH | 1995 | shipping |
| *Aphelochaeta marioni* | 1951 | ? | ? | 1990 | unknown |
| *Microphthalmus similis* | 1962 | 1988 | WS | 1990 | possibly shipping |
| *Crassostrea gigas* | 1964 | 1964 | OS | 1990 | oyster transport |
| *Ficopomatus enigmaticus* | 1968 | 1968 | VM | 1990 | shipping |
| *Tharyx killariensis* | 1970 | - | - | 1998 | unknown |
| *Styela clava* | 1974 | 1974 | OS | 1990 | shipping or oyster transport |
| *Ensis directus* | 1981 | 1988 | OS/WS | 1990 | ballast water |
| *Marenzelleria viridis* | 1983 | 1995 | VD | 1990 | ballast water |
| *Hemigrapsus takanoi* | 1999 | 2000 | OS | 2007 | oyster transport |
| *Marphysa sanguinea* | 2008 | 2008 | OS | 2008 | shellfish transport |
| *Ruditapes philippinarum* | 2008 | 2008 | OS | 2009 | shellfish transport |

The number of detected marine alien species differs between areas and varied from one to five in the North Sea and North Sea coastal zone (including Hollandse kust, Voordelta and Waddenkust), four to twelve in the Wadden Sea (Eems-Dollard and Waddenzee west, respectively) and ten to 16 in the delta (Western Scheldt and Eastern Scheldt, respectively). This is generally related to the number of pathways, which varies from one in North Sea to two in North Sea coastal zone, two to four in the Wadden Sea and three to four in the delta.

The relationship between presumed pathways and distribution and spread of marine alien species in the MWTL survey is analysed in detail in Wijnhoven & Hummel (2009). This is summarized in Table 3.5. The analysis included also older monitoring programs of the NIOO-CEME in the period 1960 – 1989. The vectors discussed were hull fouling of small and large boats which frequent small (recreational) and large (commercial) harbour, ballast water of large ships in large harbours, shellfish transports (oysters and mussels) and secondary dispersal. Shipping was indicated for nine introductions, shellfish transports of mainly oysters were indicated for nine introductions and the vector was unknown for five species (Table 3.5). All shellfish introductions occurred almost exclusively in the Eastern Scheldt, while the area of entry of species presumably transported by ships were generally unclear. The first of occurrence of the sea squirt *Styela clava* in the Eastern Scheldt seems therefore also more likely to be linked with oyster transports.

### 3.4.2 Detection time lag

Another positive quality of an adequate alien species detection system would be a short time lag between introduction and detection. Unfortunately, most marine alien species detected in the MWTL surveys were introduced and became established before the start of the surveys in 1990 (between 1250 and 1983, Table 3.4, 3.5, 3.6). Only three species became established after 1990 (Table 3.6): the Asian shore crab *Hemigrapsus takanoi* (1999, Faasse *et al.* 2002, van den Brink *et al.* 2012), the polychaete worm *Marphysa sanguinea* (2008, Wijnhoven & Dekker, 2010) and the Manila clam *Ruditapes philippinarum* (2009, de Bruyn *et al.* 2013). It is assumed that the Asian shore crab, the Manila clam and *M. sanguinea* were introduced first in the Eastern Scheldt (de Bruyn *et al.* 2013, Wijnhoven & Dekker, 2010). The time lag between the first observation and MWTL detection is five years for the Asian shore crab and one year for the Manila clam. *Marphysa sanguinea* was detected for the first time in the Netherlands by the MWTL survey in the Eastern Scheldt (Wijnhoven & Dekker, 2010). Several other alien species related to hard substrates have been detected in the Eastern Scheldt after 1990, including *Hemigrapsus sanguineus* (1999, intertidal under rocks), *Molgula complanata* (2004, subtidal hard substrate), *Tubulanus superbus* (2007, under rocks at 24 m depth), *Didemnum vexillum* (1999, hard substrate).

*Table 3.6* *Overview of marine alien species that were detected in the MWTL surveys. Only Hemigrapsus takanoi, Ruditapes philipinarum and Marphysa sanguinea became established in the Netherlands within the time frame of the MWTL survey. Species are ordered according to year of first record in the Netherlands.*

| | First year NL | first year MWTL | Western Scheldt | Lake Veere | Eastern Scheldt | Grevelingenmeer | Voordelta | Hollandse Kust | Waddenkust | Noordzee | Waddenzee west | Waddenzee oost | Eems-Dollard |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| First year MWTL survey | | | 1990 | 1990 | 1990 | 1990 | 1991 | 1990 | 1991 | 1990 | 1990 | 1998 | 1990 |
| Last year MWTL survey | | | 2011 | 2011 | 2011 | 2011 | 2008 | 2008 | 2008 | 2008 | 2011 | 2011 | 2011 |
| **species** | | | | | | | | | | | | | |
| *Mya arenaria* | 1250 | 1990 | 1990 | 1990 | 1990 | 1990 | 1992 | - | - | - | 1990 | 1998 | 1991 |
| *Molgula manhattensis* | 1762 | 1990 | - | 1990 | - | 1990 | - | - | - | - | - | - | - |
| *Rhithropanopeus harrisii* | 1874 | 1990 | - | 1990 | - | - | - | - | - | - | - | - | - |
| *Petricola pholadiformis* | 1906 | 1990 | 1990 | 1991 | 1990 | 1990 | 2005 | - | 1992 | - | 1991 | - | - |
| *Alitta virens* | 1915 | 1990 | 1992 | 1991 | 1990 | 1990 | - | - | 1992 | - | 1990 | 2009 | 2006 |
| *Boccardiella ligerica* | 1919 | 1991 | - | 1993 | 1991 | 1993 | - | - | - | - | | - | - |
| *Crepidula fornicata* | 1929 | 1990 | 1990 | 1991 | 1990 | 1990 | - | - | - | - | 2001 | - | - |
| *Corophium sextonae* | 1930 | 1990 | - | - | 1990 | - | - | - | - | - | - | - | - |
| *Eriocheir sinensis* | 1930 | 1990 | 1990 | - | - | - | - | - | - | - | - | - | - |
| *Syllis gracilis* | 1940 | 1990 | - | - | - | 1990 | - | - | - | 2002 | - | - | - |
| *Proceraea cornuta* | 1941 | 1991 | 1995 | - | 1991 | 1993 | - | - | - | - | - | - | - |
| *Syllidia armata* | 1943 | 1990 | - | 1990 | 1992 | 1992 | - | - | - | - | - | - | - |
| *Elminius modestus* | 1946 | 1995 | - | - | - | - | - | - | - | - | 1995 | - | - |
| *Aphelochaeta marioni* | 1951 | 1990 | 1990 | 1990 | 1990 | 1990 | 1993 | - | 1999 | 1998 | 1990 | 1998 | 1991 |
| *Microphthalmus similis* | 1962 | 1990 | 1990 | - | 1991 | 1991 | - | - | - | 1995 | 1990 | - | - |
| *Crassostrea gigas* | 1964 | 1990 | 1990 | 1996 | 1991 | 1990 | - | - | - | - | 2003 | - | - |
| *Ficopomatus enigmaticus* | 1968 | 1990 | - | 1990 | - | - | - | - | - | - | | - | - |
| *Tharyx killariensis* | 1970 | 1998 | - | - | - | - | - | - | - | 2000 | 1998 | - | - |
| *Styela clava* | 1974 | 1990 | - | - | 1991 | 1990 | - | - | - | - | | - | - |
| *Ensis directus* | 1981 | 1990 | - | 1991 | 1992 | 1994 | 1991 | 1992 | 1992 | 1992 | 1990 | 1998 | |
| *Marenzelleria viridis* | 1983 | 1990 | - | - | - | - | - | - | - | - | 1990 | 1998 | 1994 |
| *Hemigrapsus takanoi* | 1999 | 2007 | 2007 | 2005 | 2004 | - | - | - | - | - | 2007 | - | - |
| *Marphysa sanguinea* | 2008 | 2008 | - | - | 2008 | - | - | - | - | - | - | - | - |
| *Ruditapes philippinarum* | 2008 | 2009 | - | 2010 | 2009 | - | - | - | - | - | - | - | - |
| *Goneplax rhomboids* | 2008 | - | - | - | - | - | - | - | - | - | - | - | - |
| *Neomysis americana* | 2010 | - | - | - | - | - | - | - | - | - | - | - | - |
| # alien species | 24 | 24 | 10 | 14 | 16 | 14 | 4 | 1 | 4 | 5 | 12 | 5 | 4 |

### 3.4.3 Detection probability: species accumulation curves and species richness

Average densities of IAS species detected by MWTL vary widely. Five species that were most recently detected by MWTL (Table 3.5) are detected at both high and low densities. By selecting a threshold value of 3% of the most abundant species (see method in Gittenberger & van Loon 2011; 2013) *Hemigrapsus takanoi* (high: 390 speciemens/m$^2$), *Marenzelleria viridis* and *Ensis directus* are included as "common species" whereas for *Ruditapes philippinarum* and *Marphysa sanguinea* (low: 50 specimens/ m$^2$) densities are below this threshold. This indicates that the MWTL program detects IAS species with both high densities and low densities.

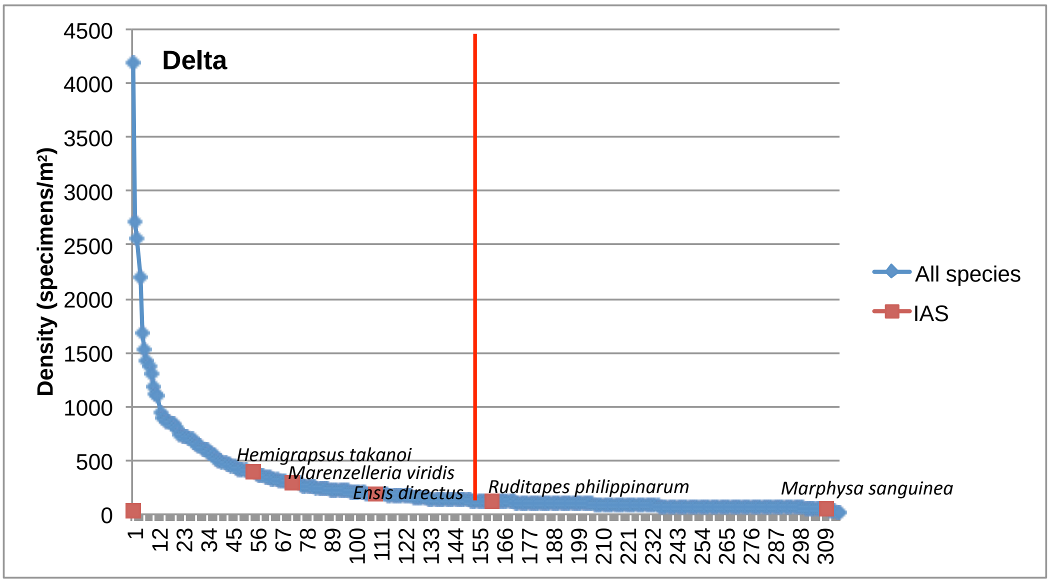



*Figure 3.1 The average densities (specimens/m$^2$, period 1992-2010) of species in the Delta area in the MTWL data set. The species are ordered from most abundant tot least abundant. Alle species left of the red line (≥ 3% of most abundant species) are classified as common.*

Species richness is estimated for six different areas: North Sea (including North Sea coastal zone areas Voordelta, Hollandse kust, Waddenkust), Wadden Sea (including WS west, WS east and Eems–Dollard) and Delta (Grevelingen, Eastern Scheldt, Western Scheldt and Lake Veere separately, Table 3.7). First a large number of survey years was combined. The total number of species found varied from 115 (Lake Veere) to 352 (North Sea including NS coastal zone). The Jack1 estimates for (asymptotic) species richness varied from 134 (Wadden Sea) to 404 (North Sea). These estimates suggest that overall a proportion of rare species is missed giving detection probabilities around 0,9 for most areas, except Western Scheldt and Lake Veere (near 0,8). Because species richness and sampling intensity varies between areas this implies that in absolute numbers a substantial number of rare species is missed in the North Sea (high diversity, number of samples relatively low). The number of species missed in the Wadden Sea is relatively small due to the much higher number of samples and lower species richness (Table 3.7, Fig 3.2).

The number of samples taken in a given year is much lower, which can lead to a lower number of species and lower detection probability (Table 3.7). This is in particular the case for the North Sea, but not for the Wadden Sea. Furthermore, a single year, like 2002, accounts for only 20% (Western Scheldt) to 50 % (Eastern Scheldt) of the total estimated species.

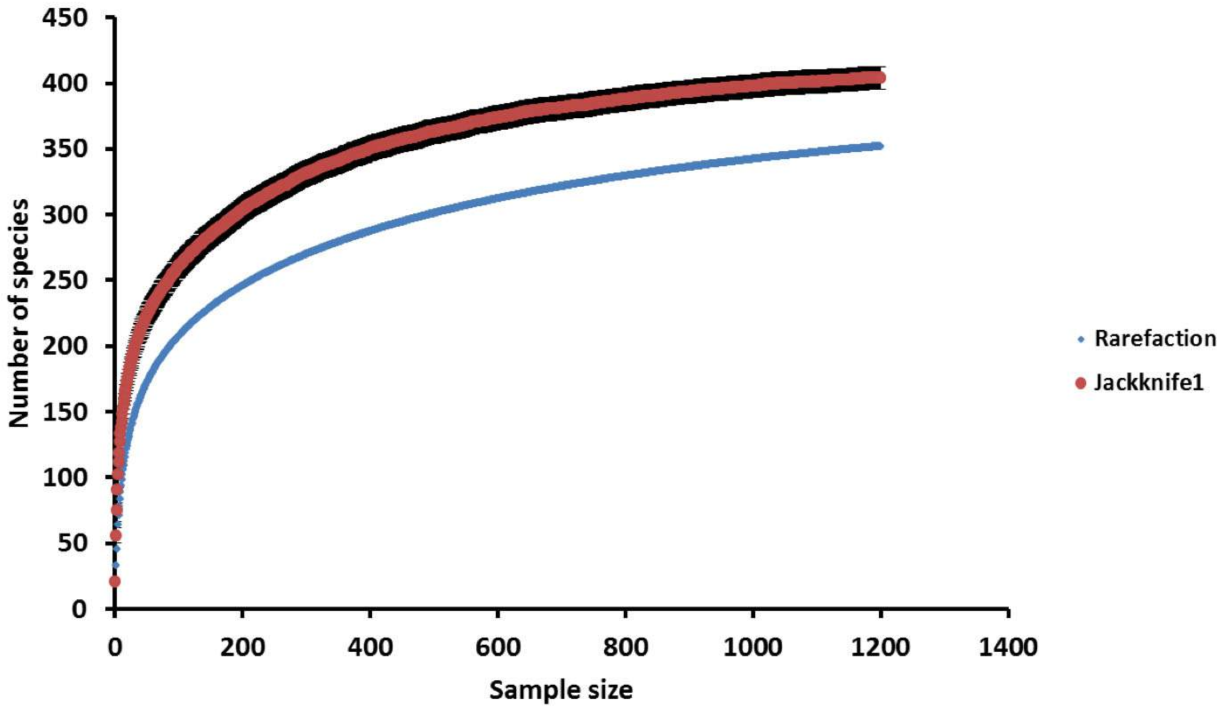
*Table 3.7 Species richness statistics for six different areas of the MWTL-survey, with monitoring period, total number of species observed, Jack1 estimates (± s.e.), sample size, number of missing species, number of unique species (observed in only one sample), number of duplicates (observed in only two samples) and detection probability (1-proportion of missed species).*

| | **Monitoring period** | **# Species all years)** | **Estimates (Jack1)** | **Sample size** | **# Missing species** | **# Unique species** | **# Duplicate species** | **Detection probability** |
|---|---|---|---|---|---|---|---|---|
| North Sea | 1991-2005 | 352 | 404.0±8.6 | 1 200 | 52 | 52 | 38 | 0.87 |
| Wadden Sea | 1990-2011 | 124 | 134.0±3.2 | 7 850 | 10 | 10 | 10 | 0.93 |
| Grevelingenmeer | 1990-2010 | 145 | 163.0±4.2 | 2682 | 18 | 18 | 6 | 0.89 |
| Eastern Scheldt | 1990-2011 | 219 | 243.0±4.9 | 4089 | 24 | 24 | 12 | 0.90 |
| Western Scheldt | 1990-2011 | 241 | 295.0±9.1 | 4641 | 54 | 55 | 23 | 0.82 |
| Lake Veere | 1990-2010 | 115 | 135.0±4.7 | 2074 | 20 | 20 | 7 | 0.85 |

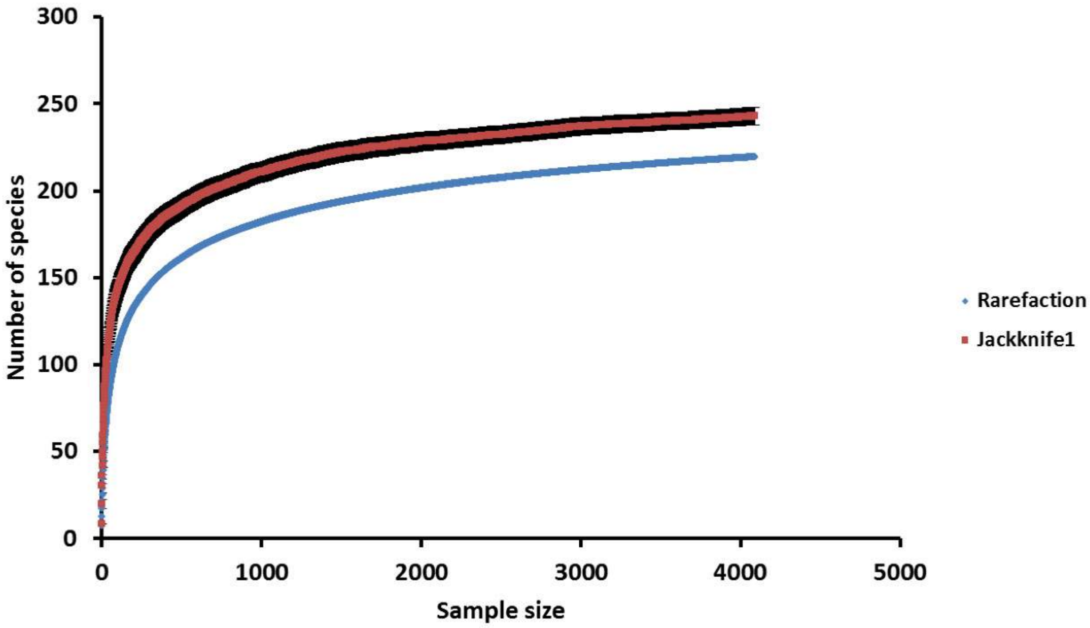
*Table 3.8 Species richness statistics for six different areas of the MWTL-survey in 2002, (with monitoring period), total number of species observed, Jack1 estimates (± s.e.), sample size, number of missing species, number of unique species (observed in only one sample), number of duplicates (observed in only two samples) and detection probability (1-proportion of missed species).*

| | **Monitoring period** | **# species (2002)** | **Estimate s (Jack1)** | **Sample size** | **# Missing species** | **# Unique species** | **# Duplicate species** | **Detection probability** | **% Total estimated species** |
|---|---|---|---|---|---|---|---|---|---|
| North sea | 1991-2005 | 191 | 230±7.03 | 100 | 39 | 40 | 18 | 0.83 | 47 |
| Wadden sea | 1990-2011 | 61 | 63±1.41 | 429 | 2 | 2 | 8 | 0.97 | 46 |
| Grevelingenmeer | 1990-2010 | 65 | 81.83±4.24 | 104 | 17 | 17 | 3 | 0.79 | 40 |
| Eastern Scheldt | 1990-2011 | 118 | 143.86±5 | 237 | 26 | 26 | 15 | 0.82 | 49 |
| Western Scheldt | 1990-2011 | 58 | 70.93±3.75 | 207 | 13 | 13 | 12 | 0.82 | 20 |
| Lake Veere | 1990-2010 | 33 | 40.91±3.03 | 96 | 8 | 8 | 2 | 0.81 | 24 |

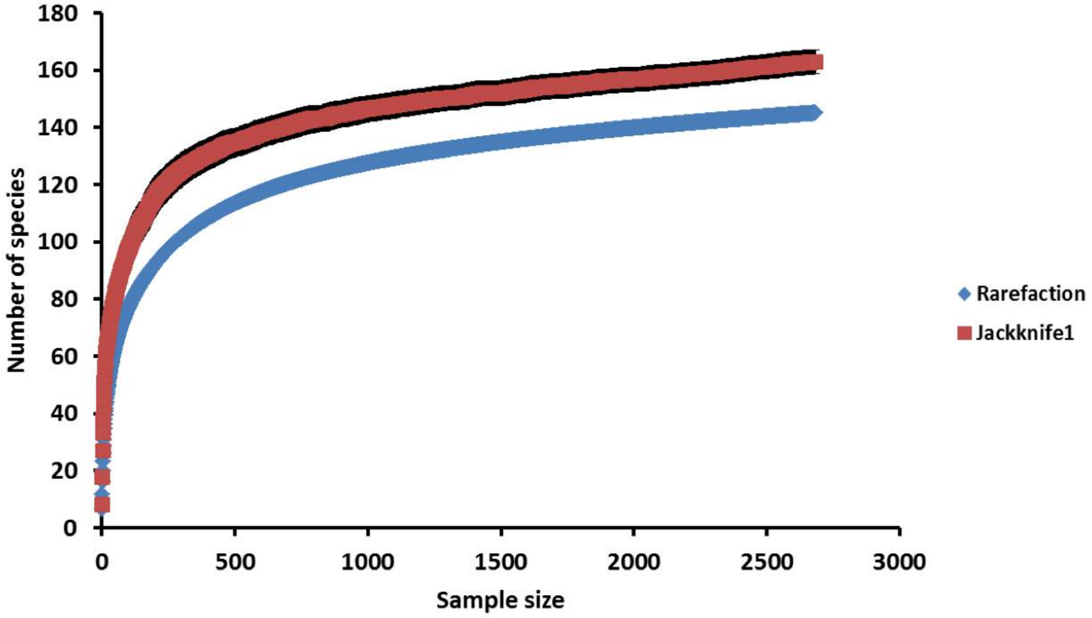
**a. North Sea**



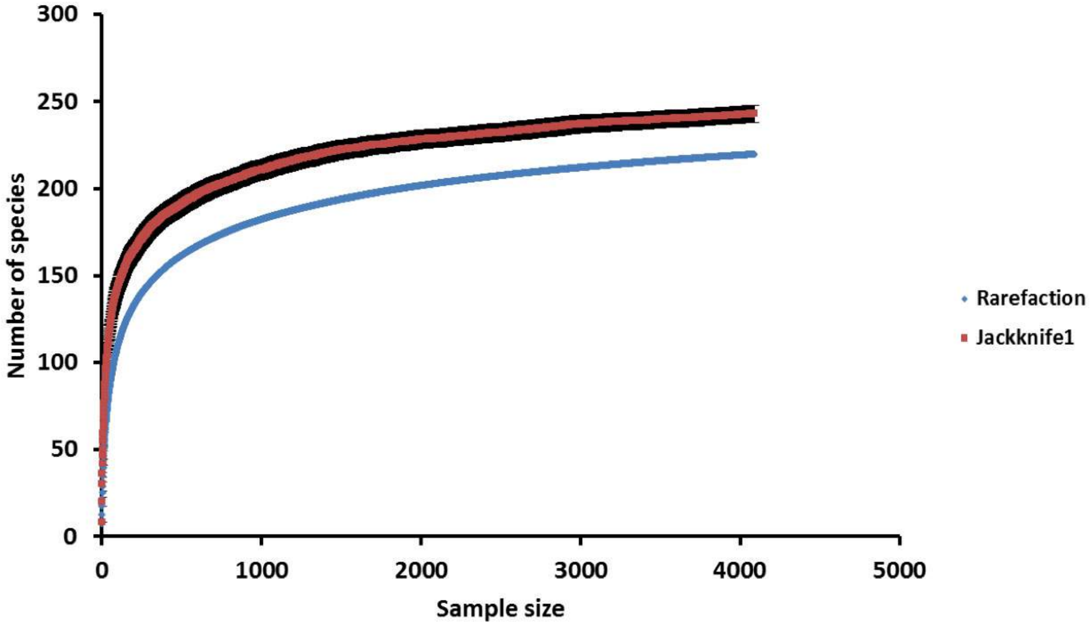

**b. Wadden Sea**



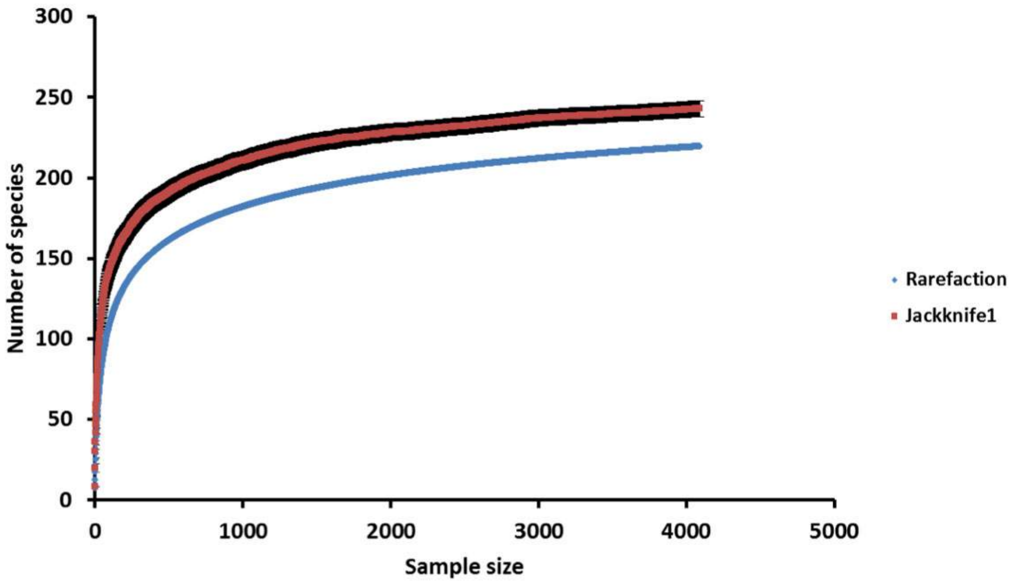
**c. Grevelingenmeer**




**d. Eastern Scheldt**



**e. Western Scheldt**




**f. Lake Veere**

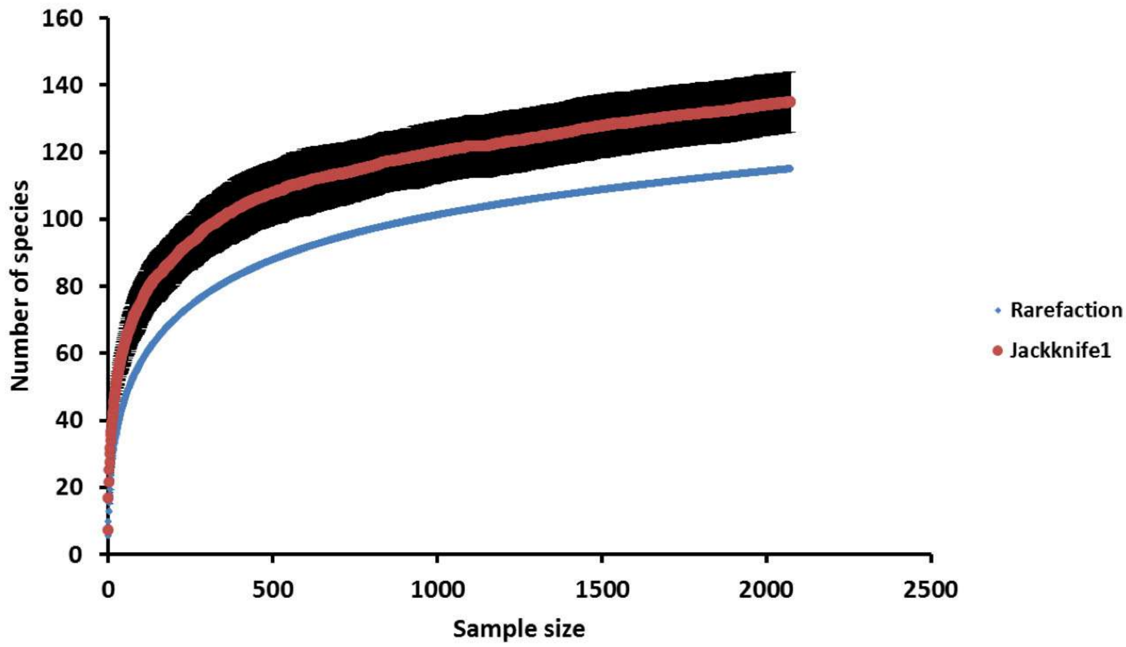



*Figure 3.2* *Sample-based rarefaction curves (blue lines) and Jack1 estimators (first-order Jackknife species richness, red lines with black standard error bars) for six areas surveyed by the MWTL-program for the whole monitoring period a. North Sea, b. Wadden Sea, c. Grevelingenmeer, d. Eastern Scheldt, e. Western Scheldt, f. Lake Veere.*

## 3.5 Geographical patterns

### 3.5.1 Sample station distribution and minimum distance

*Sample station distribution*

In total, the selected MWTL data set contained 4608 unique sample stations. In Figure 3.3 (and Appendix 1) the distribution of the sample stations in Dutch marine waters is shown. The density of sample stations in the Western Scheldt, Eastern Scheldt and Grevelingen is relatively high. In de Wadden Sea, the number of sample stations is still high but sample stations are clustered close together in permanent transects and not evenly distributed over the entire Wadden Sea. In contrast, samples stations on the North Sea are evenly distributed over a large area that consequently resulted in a relatively large inter sample distance.

### 3.5.2 Minimum distance analysis

The minimum distance between harbours and the first MWTL sample stations varies between 315 and 23433 m, whereas the average distance was 8433 m ± 6952 SD (Table 3.9). For mussel culture plots, minimum distance ranged between 0 and 15737 m, whereas the average distance was 4638 m ± 4737 SD (Appendix 3). Although minimum distance varies, most harbours lay within 10 km distance to the nearest MWTL sample station. The minimum distance of sample stations to mussel culture plots is considerably smaller, most plots lay within a 5 km distance range to a MWTL sample station.

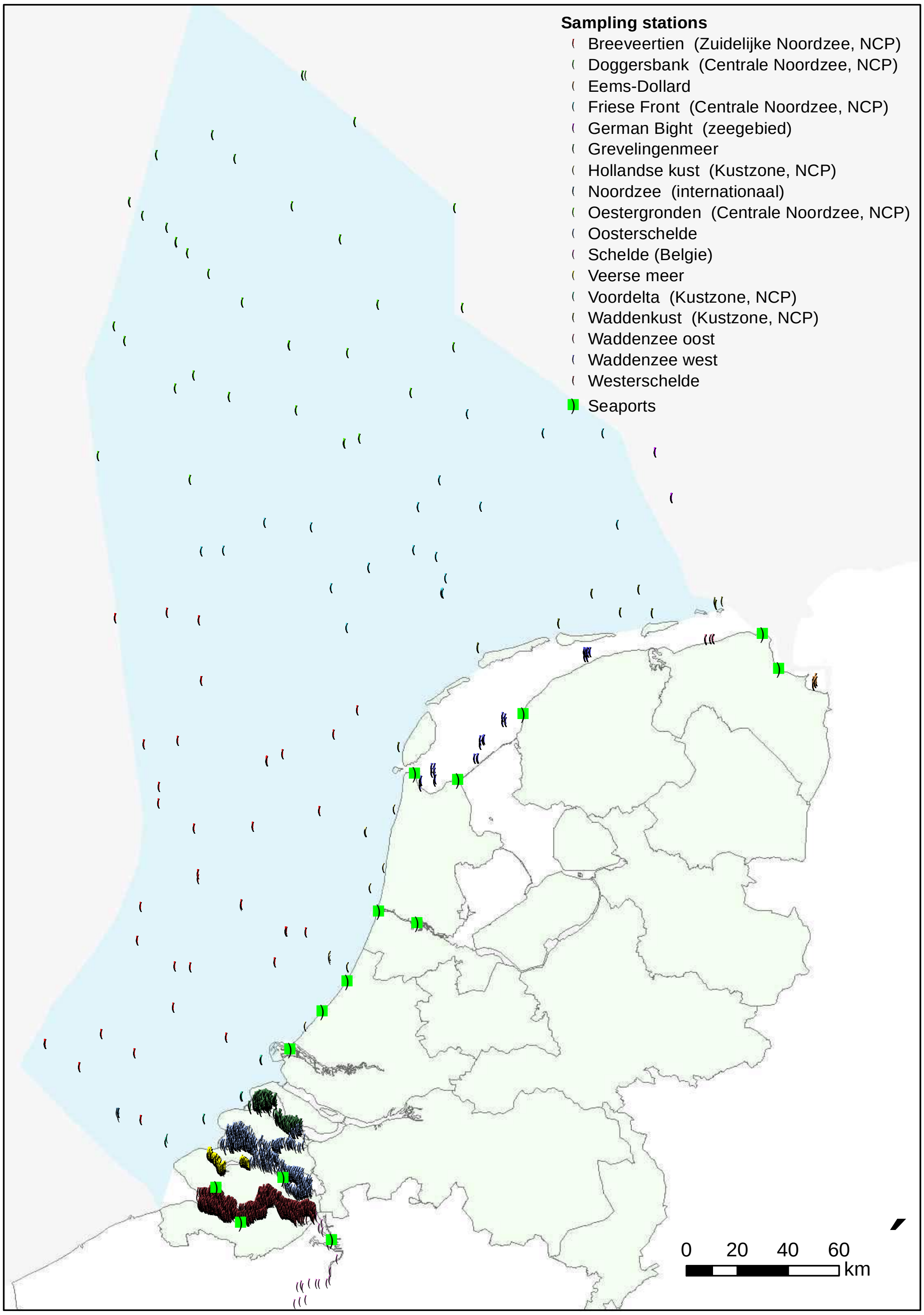



*Figure 3.3 Distribution of selected MWTL sample stations (n=4608).*

*Table 3.9 Shortest distance between international and national commercial Dutch ports and the first MWTL sample station.*

| Port | Nearest sampling station | Distance (m) |
|---|---|---|
| Rotterdam | TERHDE1_20050411_71406-451521 | 11193 |
| Scheveningen | TERHDE1_20050411_71406-451521 | 8842 |
| Terneuzen | 14260_WesterscheldeC_20090903_45757_374491 | 1972 |
| Amsterdam | HOLLSKT03_19950523_96893-506965 | 23433 |
| Delfzijl | HERPT1110_19910320_271454-589948 | 14456 |
| Ijmuiden | HOLLSKT03_19950523_96893-506965 | 10079 |
| Den Helder | BALGZDB_19940308_117034-550105 | 3689 |
| Eemshaven | GRONGWD04_19980326_232082-606841 | 19362 |
| Harlingen | MOLRKS3_19900305_150133-575121 | 7119 |
| Den Oever | BALGZDC_19940309_122584-550683 | 8949 |
| Vlissingen-Oost | 14635_WesterscheldeW_20091019_36222_385763 | 838 |
| Katwijk | NOORDWK2_19920331_87980-475024 | 5687 |
| Antwerpen | PLAATKKLSMRE_19900901_80525-363767 | 2130 |
| Yerseke | 15016_OosterscheldeO_20100908_62804_390877 | 315 |

### 3.5.3 Port of Rotterdam

Since the port of Rotterdam is the largest port of the Netherlands and has the most international ship movements, the port is considered as a major point of entry for alien species. Therefore, the frequency of sample stations with respect to distance to the port is analysed in more detail (Table3.11, Figure 3.4). At close distance from the harbour, the coverage by existing MWTL sampling points is only low. The two closest sample stations are located at 10-15 km distance of the port. The next two sample stations are located at 25-30 km distance of the port. From 35-40 km distance, there is a steady coverage by MWTL sample stations.

*Table 3.11 Frequency of occurrence of MWTL sample stations (in 5 km zones) in a distance gradient to the port of Rotterdam.*

| Distance to Port of Rotterdam | Number of stations |
|---|---|
| 0-5 km | 0 |
| 5-10 km | 0 |
| 10-15 km | 2 |
| 15-20 km | 0 |
| 20-25 km | 0 |
| 25-30 km | 2 |
| 30-35 km | 0 |
| 35-40 km | 1 |
| 40-45 km | 3 |
| 45-50 km | 3 |
| 50-55 km | 1 |
| 55-60 km | 1 |
| 60-65 km | 3 |
| 65-70 km | 1 |
| 70-75 km | 4 |
| 75-80 km | 1 |
| 80-85 km | 3 |
| 85-90 km | 0 |
| 90-95 km | 2 |
| 95-100 km | 3 |
| >100 km | 70 |

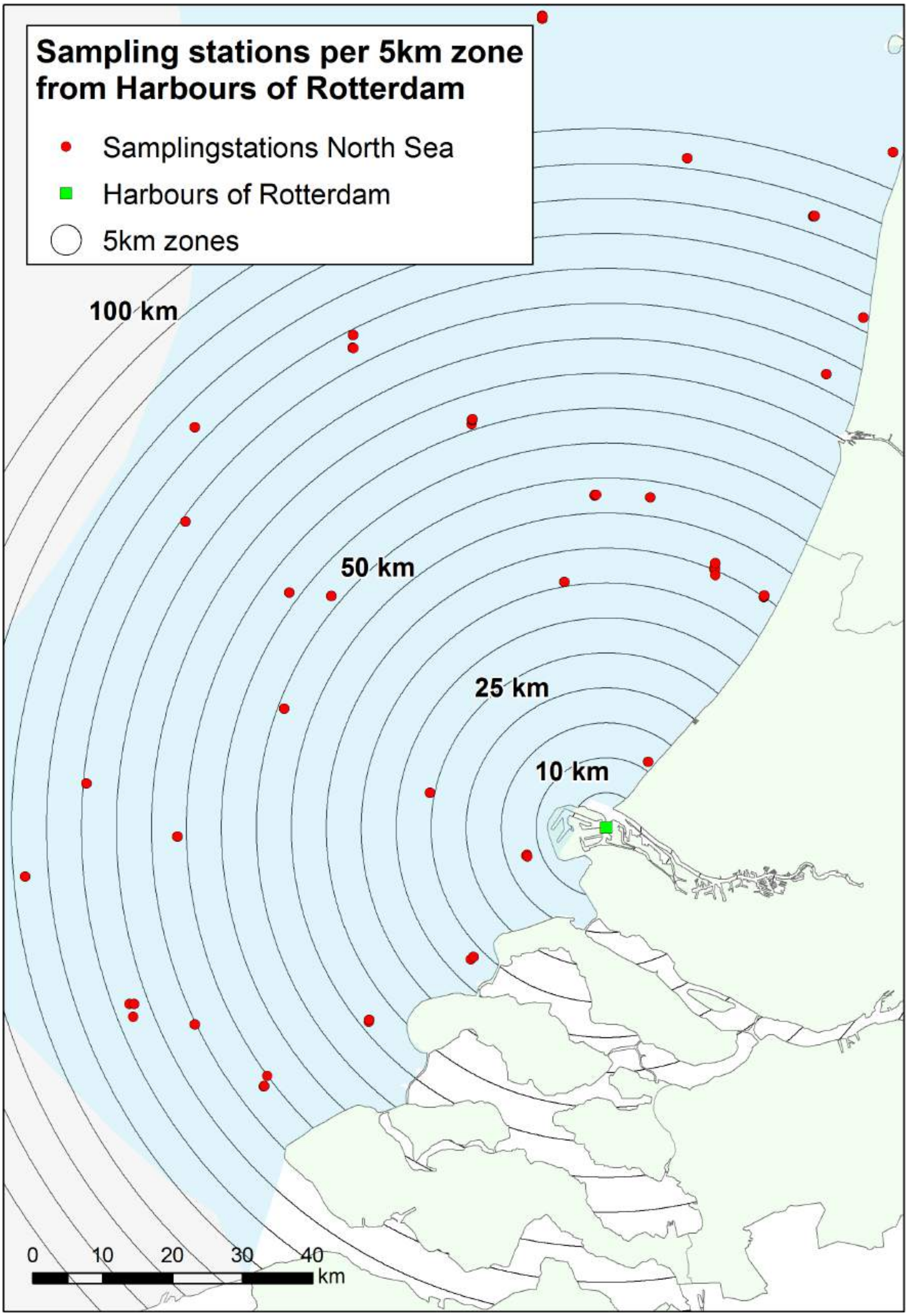



*Figure 3.4 Frequency distribution map of the occurrence of MWTL sample stations (in 5 km zones) in a distance gradient to the port of Rotterdam.*

### 3.5.4 Dispersal maps

Three species that settled within the selected MWTL surveys were suited to produce dispersal maps. The species *Hemigrapsus takanoi* settled both in the Delta area and in the Wadden Sea (Figure 3.5 and 3.6), whereas *Ruditapes philippinarum* (Figure 3.7), and *Marphysa sanguinea* (figure 3.8) settled in the Delta area.

***Hemigrapsus takanoi***

The Asian shore crab predominantly inhabits intertidal areas of mudflats, estuaries and lagoons with sufficient shelter opportunities, typically among rocks and boulders, but can also be found in soft sediment and occasionally in subtidal regions (Asakura & Watanabe, 2005, van den Brink *et al.* 2012). Hence the species is not a true soft sediment species but a mobile species than *can* be detected when sampling soft sediments.

Based on MWTL data, *Hemigrapsus takanoi* settled for the first time in the Wadden Sea in 2007 close to Den Helder and distribution remained constant in 2008 (Figure 3.6). In 2009 the species was also observed in a sample station farther away from Den Helder, but dispersal did not continue to other locations in the Wadden Sea. Up to 2011, the species remained distributed to sample stations close to Den Helder. Since its first record in the Eastern Scheldt in 1999 (Wijnhoven & Hummel; Nijland & Beekman 2000), the species was detected for the first time by MWTL Delta in 2004. A wide spread occurrence in Lake Veere, Grevelingen and Eastern Scheldt was detected in 2010 (Figure 3.5). In 2011, sampling was restricted to the Eastern Scheldt. In 2012, the species was not picked up by the MWTL monitoring program.

***Ruditapes philippinarum***

For *Ruditapes philippinarum*, first observed in 2009 in the Delta, there is no clear dispersal pattern visible (Figure 3.7). The species occurs at various sample stations, including the Lake Veere and Eastern Scheldt but is not continuously expanding through the Delta.

***Marphysa sanguinea***

During the annual autumn monitoring of the macrozoobenthic communities of the Dutch Delta specimens of *Marphysa sanguinea* were encountered in 2008 and 2009, 2010 and 2011 (Figure 3.8). All observations were from the same region within the Eastern Scheldt: in the eastern part in the vicinity of Yerseke, centre of aquaculture in this area.

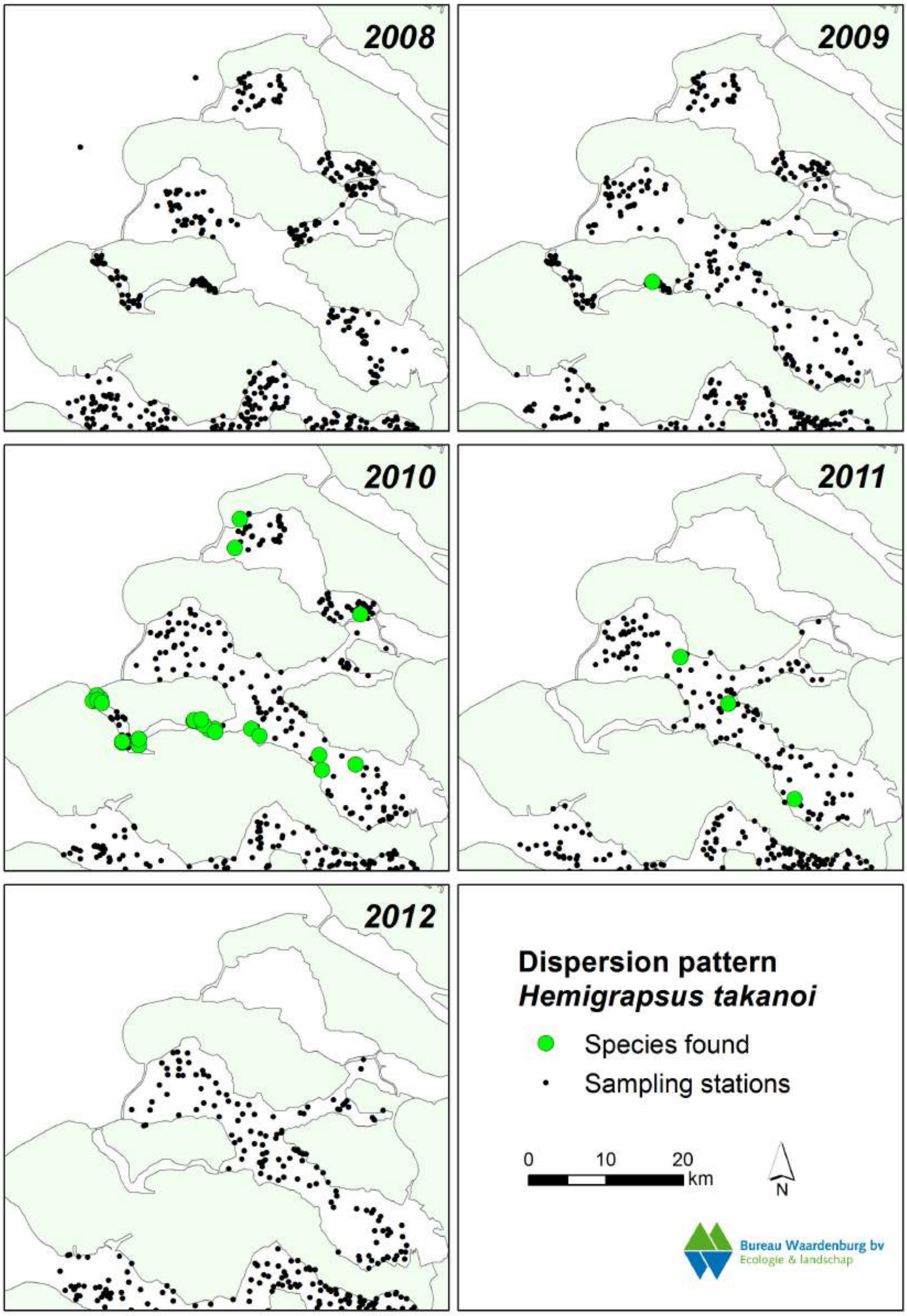



*Figure 3.5 Dispersal map of Hemigrapsus takanoi in the Delta area Sea based on the coverage by MWTL sample stations.*

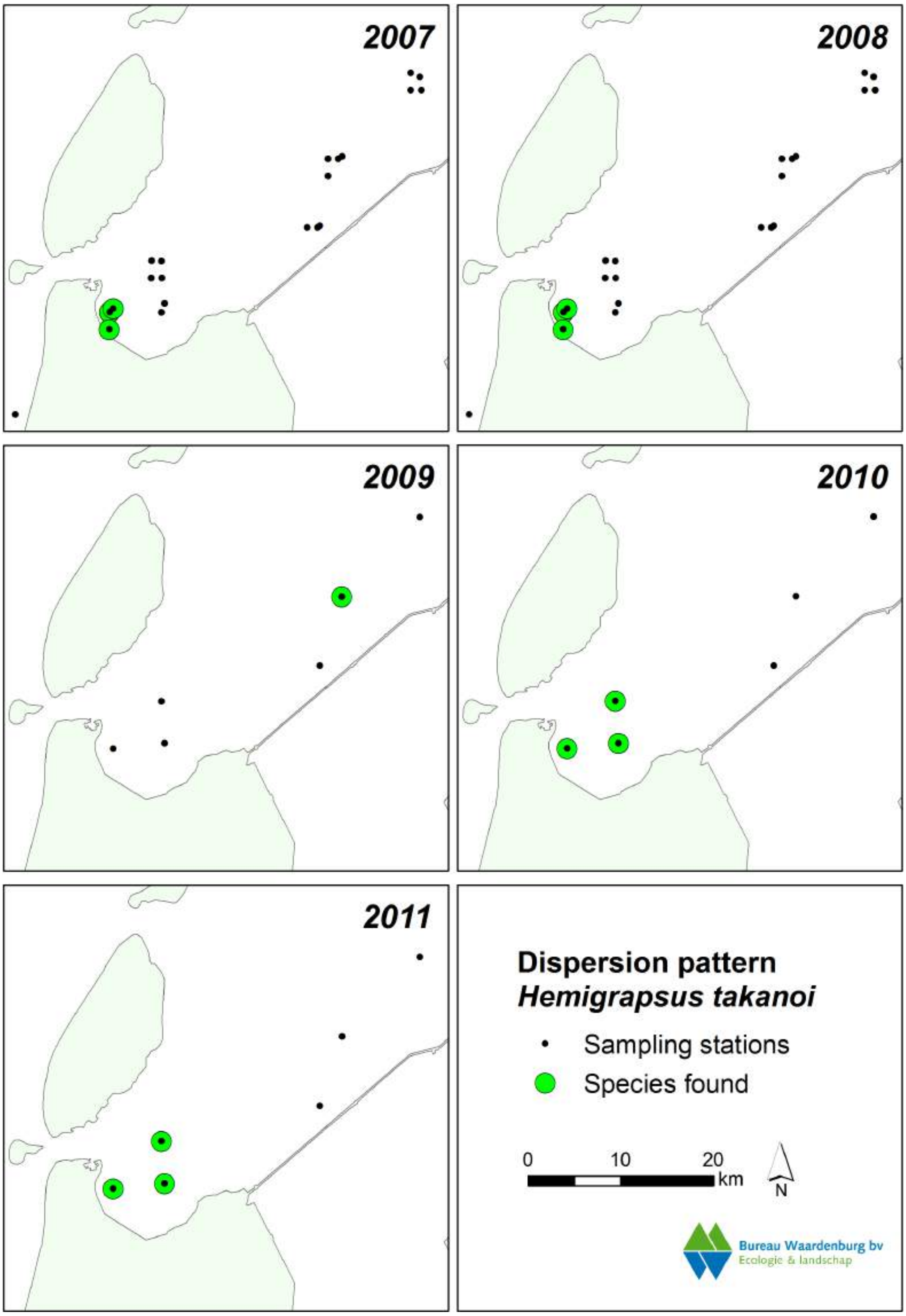



*Figure 3.6 Dispersal map of Hemigrapsus takanoi in the Wadden Sea based on the coverage by MWTL sample stations.*

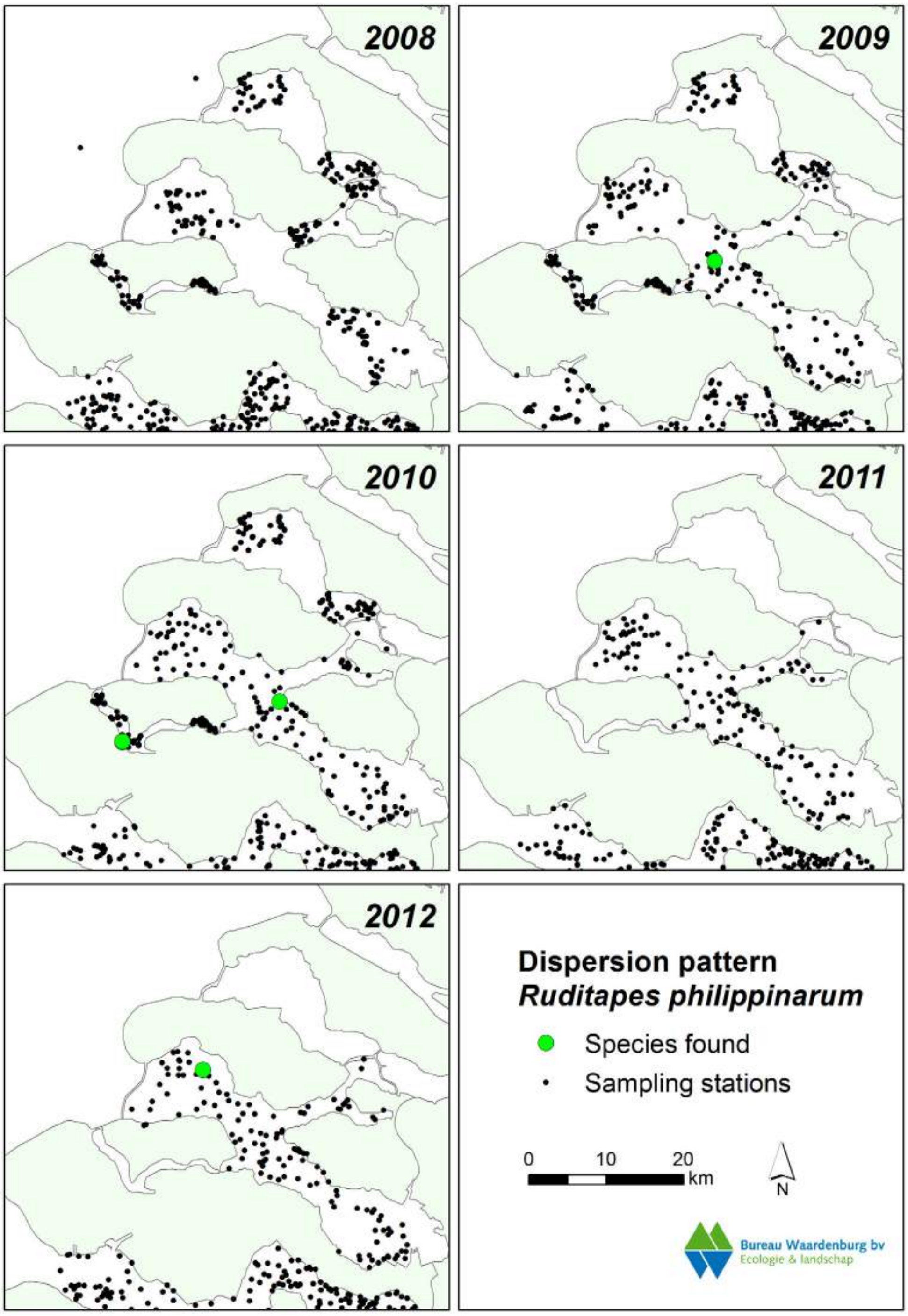



*Figure 3.7 Dispersal map of Ruditapes philippinarum in the Delta area based on the coverage by MWTL sample stations.*

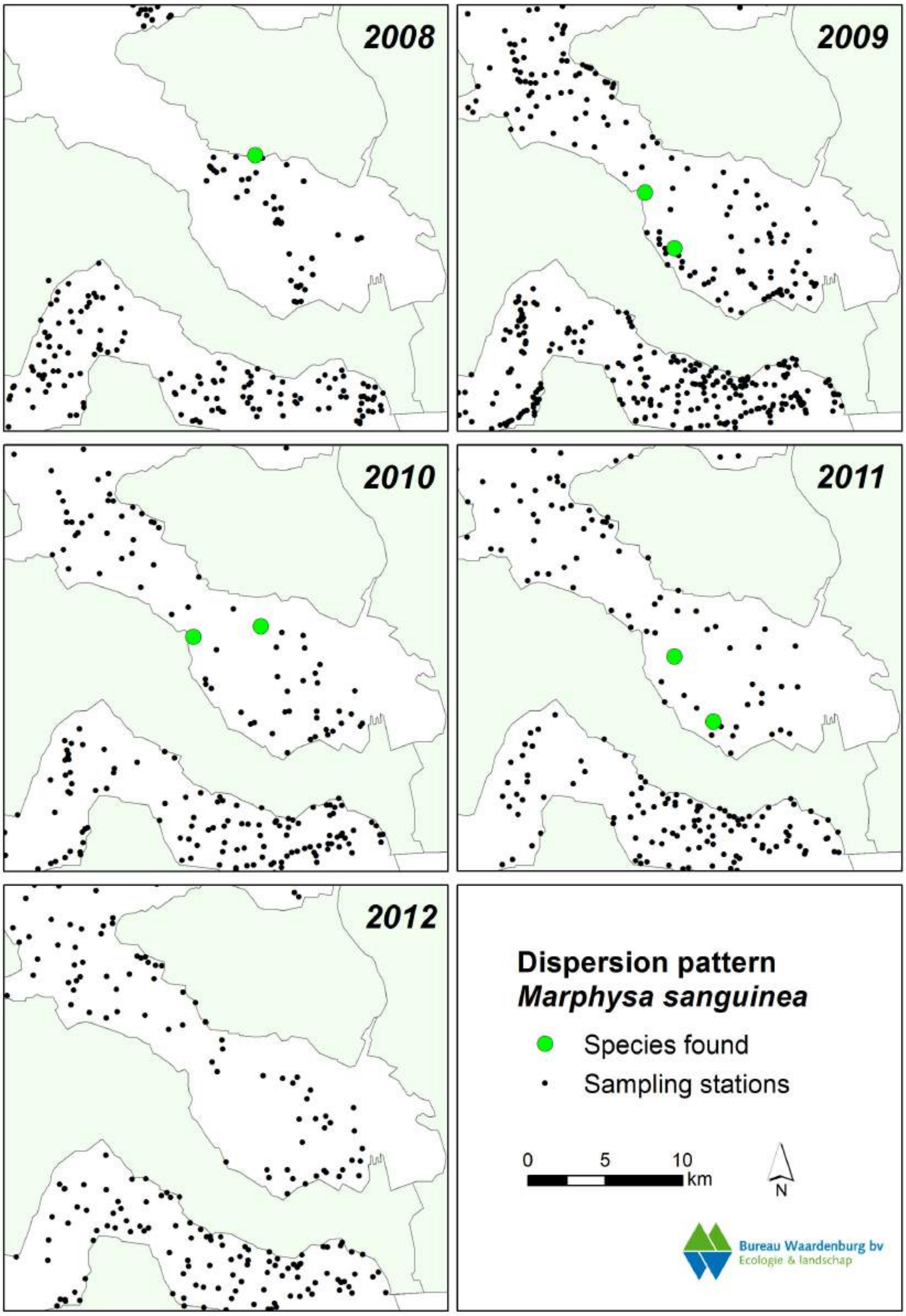



*Figure 3.8 Dispersal map of Marphysa sanguinea in the Delta area based on the coverage by MWTL sample stations.*

## 3.6 Expert analysis

### 3.6.1 General remarks

There are different aspects that are mentioned more then one time by experts (Appendix 4):

**Method**

- Since soft-sediment sampling includes small surface areas, the total area sampled is very small compared to the total area of the soft-sediment.
- Due to the small surface area and characteristics of soft-sediment benthos species MWTL can mainly detect species that are abundant and wide spread.
- For rare species, increasing the number of samples will not easily increase detectability.
- MWTL data and reports are public and accessible via Servicedesk Water. However, whilst separate data files and reports for each year can be accessed there is no central database. The initiative “Informatiehuis Marien” (www.informatiehuismarien.nl), an information-sharing platform, will possibly provide central access to marine MWTL data in the future.

**MWTL data and alien species**

- New species are mentioned in a separate section of the MWTL report. New species include a combination of northerly, southerly, cryptic and marine alien species, with no emphasis on the latter, nor an official status of the latter.
- There is currently no specific label for alien species.
- A large percentage of marine alien species are hard-substrate species that are not sampled by soft-sediment sampling.
- Open parts of the North Sea (excluding the coastal zone) have few marine alien species.
- MWTL is useful for detecting a specific set of alien species: soft sediment species that are abundant and widespread. MWTL sampling will eventually lead to the detection of these species and enable the construction of dispersal patterns.
- The MWTL sampling, or soft-sediment sampling in general, cannot easily be used for early warning or signalling since densities are (too) low and surface area sampled small.

**Sampling frequency**

- Historically MWTL included annual sampling. Since the sampling frequency is now reduced to once every three years for most areas (North Sea, Wadden Sea excluding Eems-Dollard, Grevelingen, Lake Veere) it may take up to four years for a wide spread marine alien to be detected (sampling frequency plus one year for identification and report).

- Decreasing the frequency will reduce the detection probability of marine alien species and time lag from invasion to detection shows a possible threefold increase.

**Locations**
- MWTL North Sea includes 100 fixed, historically selected, locations. In 2015 67 additional samples will be collected in protected areas.
- MWTL Wadden Sea includes fixed, historically selected locations, but was expanded to fixed locations in the Wadden Sea East and Eems Dollard.
- MWTL Delta includes random samples that cover all habitats (ecotype sampling).
- Except for Eems Dollard, none of the sample stations are selected based on the distance to a specific harbour.
- MWTL locations can be and were adjusted through time based on the information needs.

**Taxonomic expertise**
- Although expert knowledge is restricted to a few experts in the Netherlands, all experts reviewed the quality standard of identifying macrozoobenthos as high.
- Initiatives to standardise information of species (Nederlands Soortenregister, Taxoncode Waterbeheer Nederland TWN, Werkgroep Exoten), including marine alien species/ marine species lists are fragmented and there is not a single source that is complete and accurate.
- Lists that include all species (including terrestrial species) often lack sufficient knowledge on marine species, thereby generating incomplete lists that are not used by experts.
- Status of new species is not always clear and highly dependent on the definition of alien species (*e.g*. climate-induced range shifters like southerly species or marine alien species can be mixed depending on definition).
- There is as yet no national authority (official person or body) responsible for granting alien species status or the status “invasive alien” explicitly to species in MWTL or TWN monitoring programs and related databases and this status is therefore not added to the species lists.

**Incorporation of macro-algae**
- Sampling macroalgae involves different techniques and expertise then currently used in MWTL macrozoobenthos.
- Taxonomic expertise of algae is rare in the Netherlands.
- A visual census with collection of some material would be useful. It seems possible to incorporate the sampling within the MWTL sampling design with little extra effort and associated costs.

**Other monitoring of macrozoobenthos**
- Other monitoring programs mentioned include: NIOZ Balgzand monitoring, NIOZ SIBES monitoring, WOT shellfish survey and beach monitoring by volunteers (Stichting Anemoon).

- Other project-based monitoring includes Zandmotor, Maasvlakte, Zandhonger, Offshore wind, PRODUS, Waddensleutels, NIOZ Triple D dredge.
- Since the frequency of MWTL is reduced to every three years an information gap might occur. This gap may need to be bridged, leading to an increase in project monitoring.
- It is desirable that project-monitoring data are made available as open access data, adding to the information of MWTL, that has now been reduced.

### 3.6.2 Adjustments

**Standardised marine species list**
To encourage up to date information on species found in the Dutch part of the North Sea it would be useful to link to WoRMS (World Register of Marine Species). The taxonomical content is globally controlled by the international taxonomic experts of the (WoRMS) and not by database managers with no background in taxonomy. As of yet WoRMS contains no records of species with a distribution “Dutch Coast”, “Dutch Part of the North Sea”, “Dutch Exclusive Economic Zone (EEZ)”, even though it is possible to label species with this status. If this distribution would be included it would be possible to create a list including the most recent taxonomic information added by experts. The Belgian Part of the North Sea is already included (see BERMS).

**Standardised marine alien species list**
Detection of alien species for policy and management would be facilitated if a standardised list of marine alien species would be available. Different labels could be added to e.g. the TWN list or to a “standard marine species list” as is just mentioned above. It is important to explicitly state the definition of “alien species” and “invasive alien species” that are used. The list should be dynamically adjusted and providing open access with possible moderations will increase the quality. Linking to WoRMS will help to overcome taxonomic errors. List that are created for a single purpose, at one point in time or all species (including terrestrial) are not regarded as suitable for this purpose.

**Increasing sample stations or frequency**
Increasing the number of samples will not easily improve the detection probability of rare species. Adding stations near the port of Rotterdam could lead to earlier detection, but most marine alien species originating from the port are hard-substrate species that are therefore not detected in MWTL sampling.
Increasing the frequency will improve the detection probability of marine alien species and lag time from invasion to detection will show a possible threefold decrease.

**Incorporating macroalgae**
Since sampling methods and taxonomic expertise are different from the current MWTL program it is suggested to start of with a feasibility study. An additional person could be added to the MWTL teams in order to perform a specific algae survey. In this way logistics needed for arriving at the numerous sampling stations are easily combined and additional costs will be lower then with a separate program. The limited of

taxonomic knowledge on algae in the Netherlands is a point of concern and it is advised by experts to improve this.

# 4 Discussion

In general the following characteristics of MWTL are highlighted in this study:

**Advantages of MWTL**

- Data are continuously collected (long-term monitoring program)
- Data and annual reports are accessible via Servicedesk Water (open access).
- Method includes large and small specimen (>1mm)
- Quality of taxonomic expertise of macrozoobenthos of soft sediments is sufficient to detect alien species and all organisms with sufficient material are identified to species level.

**Disadvantages of MWTL**

- MWTL program samples only macrozoobenthos of soft sediments, thereby excluding the majority of alien species (e.g. plankton, epifauna and hard substrate species).
- MWTL program and database do not have specific labels for alien species.
- Of areas that are sampled every 3 years annual lists of new species cannot be established and time lag from establishment to detection by MWTL can be up to 4 year at minimum.
- Open access data are generally 2-6 years behind (for different areas years to 2008, 2011 and 2012 were obtained in 2014).
- Design and locations do not include minimum distances to important first entry points of aliens.

**Added value of a species list**

Marine alien species are detected in the Netherlands by professionals in various monitoring programs and rapid assessments aimed at alien species and by dedicated amateurs, including divers. The monitoring intensity aimed at alien species varies but is generally increasing due to a higher awareness of alien species and actual and planned legislation. However a centralisation of these efforts, including access to a "marine alien species list" or "marine species list" will help detecting *new* alien species (*e.g.* on an annual basis) and facilitate the rapid inclusion of new finds in that list. The need for such a list is mentioned several times by experts and is considered of great value especially if this list would be dynamical, updated reguraly and connected to the taxonomic expertise available via the World Register of Marine Species (WoRMS).

**Alternative monitoring programs**

In general, most soft sediment monitoring programs include a relatively small number of samples compared to the total species richness. Even when a large number of samples is taken, some species, including alien species, will be missed.

Due to logistics and elaborated taxonomic knowledge applied, sampling and identification of macrozoobenthic species in soft sediments is expensive. Therefore using all available existing monitoring data is a good way to collect information on marine alien species of soft-sediment communities. For a good comparison of alternative monitoring programs with the MWTL program it is necessary to first define and evaluate the detection parameters of alien species of these programs. Some programs contain more locations thereby covering large areas in higher densities and closer to main entry points, but the sample protocol leads to exclusion of smaller species or certain taxonomic groups (e.g. SIBES in the Wadden Sea, WOT shellfish survey in the coastal zone). Without adjustments of these monitoring programs (i.e. including all taxonomic groups), these programs are not clearly better equipped than the MWTL program.

Since monitoring programs are designed for a specific policy and management goal, and none of the available soft-sediment programs has “detecting alien species” as a specific goal, there is not a single program that is clearly most suitable for this purpose. In addition, alternative monitoring programs need to be complementary with respect to focal habitats. Soft sediments, which are very common in and typical for the marine, estuarine and coastal regions in the Netherlands, contain relatively few alien species. Most alien species, however, depend on hard substrates, during transport and establishment in harbours and in or near aquaculture areas.

**Effectiveness**

A total of 24 species of marine alien species were detected in the soft sediments surveyed by the MWTL program in the period 1990 - 2011.

17 species were already established for several decades before the start of the program. Three soft sediment species were introduced in the Netherlands during the MWTL program (Asian shore crab *Hemigrapsus takanoi*, the polychaete worm *Marphysa sanguinea* and the Manila clam *Ruditapes philippinarum*). Four species were introduced in the delta in the ten years just before the start of the MWTL program (the polychaetes *Syllis gracilis*, *Marenzelleria viridis* and *Micropthalmus similis*, and the American razor clam *Ensis directus*). Other monitoring activities (often including dedicated amateurs) found several other marine alien species related to hard substrate in particular in the delta.

**Vectors and major entry points**

Marine alien species were introduced in the Netherlands by various vectors related to shipping (hull fouling and ballast water) and aquaculture (oyster and mussel transports). Overall more alien species were found in areas with more vectors present (Eastern Scheldt and western Wadden Sea, section 3.3).

The distance from harbours and mussel culture plots to the nearest MWTL station varies strongly. In the Delta area the distance is generally small, due to a high density of sample stations. However North Sea and Wadden Sea ports are often located further away from the nearest sampling station (>10 km). Incorporating a few extra sampling locations near major entry points could help to overcome these large distances.

**Detection parameters**

An adequate and efficient monitoring program of alien species will detect all potential species (high detection rate), rapidly (within one or two years time lag) and with high probability (with a cost-efficient number of samples). Detection of newly introduced alien species in a monitoring program is determined by many factors. The probability that a new alien species is detected after its introduction depends first of all on its size and the number of propagules (reproductive units) and their survival. If the alien species survives, reproduces and becomes established, then the probability will increase depending on the numbers present and subsequent dispersal and establishment away from the introduction site. Alien species, which have been recently introduced and that do not survive or spread are not likely to be picked up by monitoring surveys, but still might indicate that prevention is not effective. Alien species surveys are therefore generally biased towards invasive alien species.

Other important factors are habitat and location of the samples. The number of alien species potentially detected is limited to the species that regularly occur in this habitat. In the case of the MWTL survey this refers to estuarine and marine soft sediments. In addition, introduction sites are not randomly distributed but concentrated in so-called hotspots, where more than one vector is regularly present, for example harbours with small recreational vessels and larger commercial ships close to aquaculture facilities.

**Detection rate**

The MWTL surveys detected only 24 marine alien species out of a total of 545 species recorded in the entire MWTL dataset used. However, the MWTL surveys are limited to soft sediments and mainly in estuarine and marine habitats and therefore more likely to detect mainly species occurring in estuarine and marine soft sediment communities. Comparison of the list of relevant marine alien species (Table 3.4, n=17) with the 24 species detected in the MWTL program shows that virtually all relevant soft sediment alien species (n=13) were detected in the MWTL surveys. Species not detected include two recent introductions that fall outside the dataset, one locally established species (*Mercenaria mercenaria*) and one rare species (*Rapana venosa*). In addition, ten alien species, which regularly occur in other marine or brackish habitats (hard substrate, pelagic, to list some of them), were also detected in the soft sediment surveys. The overall detection rate of relevant marine alien species of soft sediments of the MWTL program is, therefore, close to 100 %.

**Detection time lag**

The exact moment of introduction is usually not well known. By the time a species is detected by any planned or unplanned sampling it is usually established and had already spread to other sites. We have compared the year of first detection in the MWTL program with the year of first detection in planned or unplanned sampling. A short time interval between these observations suggests that the MWTL does not perform much worse than other sampling efforts, but also does not give any information about the real time period between first introduction and detection. Although the number of species involved (3) is very small, the time lag varied between zero and five years and was on average two years. This implies that increasing the time interval of the monitoring to three years will increase the time lag to at least three years and probably more if the detection probability is low due to a smaller number of samples.

Two recently arrived species have not yet been detected: *Goneplax rhomboids* (arriving in 2008) and *Neomysis americana* (arriving in 2010). Since North Sea data from 1990 to 2008 were incorporated, their arrival is most likely detected outside the current dataset.

**Detection probability**

Marine aliens with high (e.g. *Ensis directus*) and low (e.g. *Marphysa sanguinea*) densities are detected by the MWTL program. Although the chance of detection of an alien species depends highly on intrinsic characteristics such as size, reproduction characters, habitat and ecology, the relative detection probability in a monitoring program depends mainly on the number of samples, their location relative to introduction sites and the number of species present in the community. If fewer samples are taken a smaller number of species will be detected, in particular if many species are rare. The number of samples relative to the number species present will give information about the power of the sampling or its detection probability. In this study we define detection probability as 1 minus the proportion of missed species estimated from a species accumulation curve. The estimated detection probabilities were good in North Sea, Lake Veere and Western Scheldt varying between 0,81 and 0,87 and were relatively high in Grevelingen, Eastern Scheldt and Wadden Sea varying between 0,87 and 0,97. This implies that in particular in the North Sea with several hundreds of species present and a relatively small numbers of samples many rare species, including newly introduced alien species, will remain undetected.

# 5 Conclusions

## 5.1 Detection efficiency of MWTL

*What is the effectiveness of the MWTL-program with respect to detection rate, detection lag time and detection probability of alien species?*

- A total of 24 marine alien species were detected in the MWTL program, of which 14 are characteristic for, or occur typically in, estuarine and marine soft sediments.
- 21 species were already established for several years of even several decades before the start of the program. Only three soft sediment species were introduced in the Netherlands during the MWTL program (Asian shore crab *Hemigrapsus takanoi*, the polychaete worm *Marphysa sanguinea* and the Manila clam *Ruditapes philippinarum*).
- The detection rate of the MWTL program is only high for species typical for estuarine and marine soft sediments.
- The MWTL program doe not detect 88% of the total number of marine alien species, including plankton, epifauna and species typical for hard substrates.
- The MWTL program detects marine alian species with both high densities and low densities.
- More alien species were detected in areas with more vectors present (Eastern Scheldt and western Wadden Sea).
- The detection time lag is two years on average but this will increase threefold with the switch from annual to once every three years.
- The detection probability is high Grevelingen, Eastern Scheldt and Wadden Sea and somewhat lower in North Sea, Lake Veere and Western Scheldt.
- The MWTL program is only adequate for monitoring alien species limited to estuarine and marine soft sediment species. This is only a small part of the total number of marine alien species actually or potentially present in Dutch coast and marine ecosystems.

## 5.2 Locations

*Are MWTL sampling locations, in particular fixed locations and transects, situated at strategic locations in relation to the major entry points of alien species?*

- The design of MWTL is not related to the distance to major entry points of alien species (harbours, aquaculture plots) but based on historically selected fixed sampling points (Wadden Sea, North Sea) or random sampling of all ecotypes (Delta). However through time locations have been dynamically added and changed based on the information needs behind the MWTL program as defined by RWS WVL.

- The minimum distance between harbours and MWTL sample stations varies between 315 m (Yerseke) and 23433 m (Amsterdam) and for mussel culture plots between 0 (Neeltje Jans) and 15737 m.
- Although minimum distance varies, most harbours are situated within 10 km distance to the nearest MWTL sample station and most plots are situated within a 5 km distance range to a MWTL sample station.
- The MWTL stations nearest to the Port of Rotterdam are at 10-15 km distance, whilst the majority of sample stations is located at > 40 km distance.
- Dispersal maps of alien species can be created based on MWTL data and relations with obvious vectors or entry points might be detected (i.e. *Marphysa sanguinea* in the vicinity of Yerseke, an important centre for aquaculture).
- However dispersal maps are mostly useful for species that are abundant and wide spread and occur in water systems that are sampled annually.

## 5.3 Including macroalgae

*Is it possible to include marine (benthic) macroflora in the MWTL-sampling?*

- Since method and taxonomic expertise are different in the current MWTL program for macrozoobenthos macroalgae are not included at this point.
- An additional person could be added to the MWTL teams in order to perform a specific algae survey. In this way logistics needed for arriving at the numerous sampling stations are easily combined and additional costs will be lower than with a separate program.
- The limited taxonomic knowledge on algae in the Netherlands is a point of concern and open for improvement.
- A feasibility study that specifically aims at incorporating a specific macroalgae sampling protocol in the existing MWTL procedures, thereby including an estimate of additional costs could be useful.

## 5.4 Other monitoring programs

*Are there alternative sampling programs of soft sediment sediments available that are better suited for alien species detection than MWTL?*

- Several long-term monitoring programs include macrozoobenthos sampling.
- However the sampling method, effort and design are always shaped to a specific goal of the program and there is not a single program yet specifically aimed at detecting alien species or species near major entry points and therefore “better suited”.
- Data that not identified to species level or sampling that only includes larger fractions, commercial species or species important for birds are not readily usable for detecting alien species.

- The large number of samples collected in some programs will lead to a better coverage of water systems than MWTL (e.g. SIBES in the Wadden Sea of WOT shellfish in the coastal zone). However, sampling protocols should be adjusted for detection of alien species at the species level, which can lead to additional costs.
- Apart from long-term programs, project monitoring is abundant and could be used for alien species detection.
- Providing open access data is an important aspect that will enable the use of alternative monitoring programs and project monitoring for alien species detection.

## 5.5 Optional adjustments

*Which adjustments are needed to improve alien species detection by MWTL?*

- A standard list of marine alien species is currently not available. In order to label species as “alien” or “invasive alien” such a list, including the status invasive, should be created and made publicly available.
- It is recommended that this list is dynamic, regularly updated, linked to WoRMS (World Register of Marine Species) and to a “standard list of marine species” that is also not available (and could be incorporated in WoRMS as well).
- Due to the small sampling surface for each sample, increasing the number of samples will not easily improve the probability of detection of rare species (including alien species at early stages of invasion).
- Adding stations near major points of entry (e.g. the port of Rotterdam) could lead to earlier detection, however most alien species originating from the port are hard-substrate species, that are therefore not detected in MWTL sampling.
- Increasing the frequency from once every three years to annually will improve the detection probability of rare species, including marine alien species and time lag from invasion to detection will show a possible threefold decrease.

## 5.6 Recommendations

Only 7% of marine alien species are typical for marine and estuarine soft sediments. In spite of the effectiveness of MWTL in detecting the majority of soft-sediment species, the monitoring program does only include a minority of the total list of marine alien species.
In order to detect a more complete set of marine aliens other habitats should be included within the monitoring as well. Both hard-substrate monitoring, mobile species monitoring and pelagic monitoring will add to a more complete set of habitats targeting hard-substrate species, algae, plankton and fish. Existing monitoring programs and projects, outside MWTL, might be available that can be used. Aggregating existing monitoring programs for this purpose aids cost minimization.

# 6 Literature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# Appendix 1 Sampling stations of MWTL

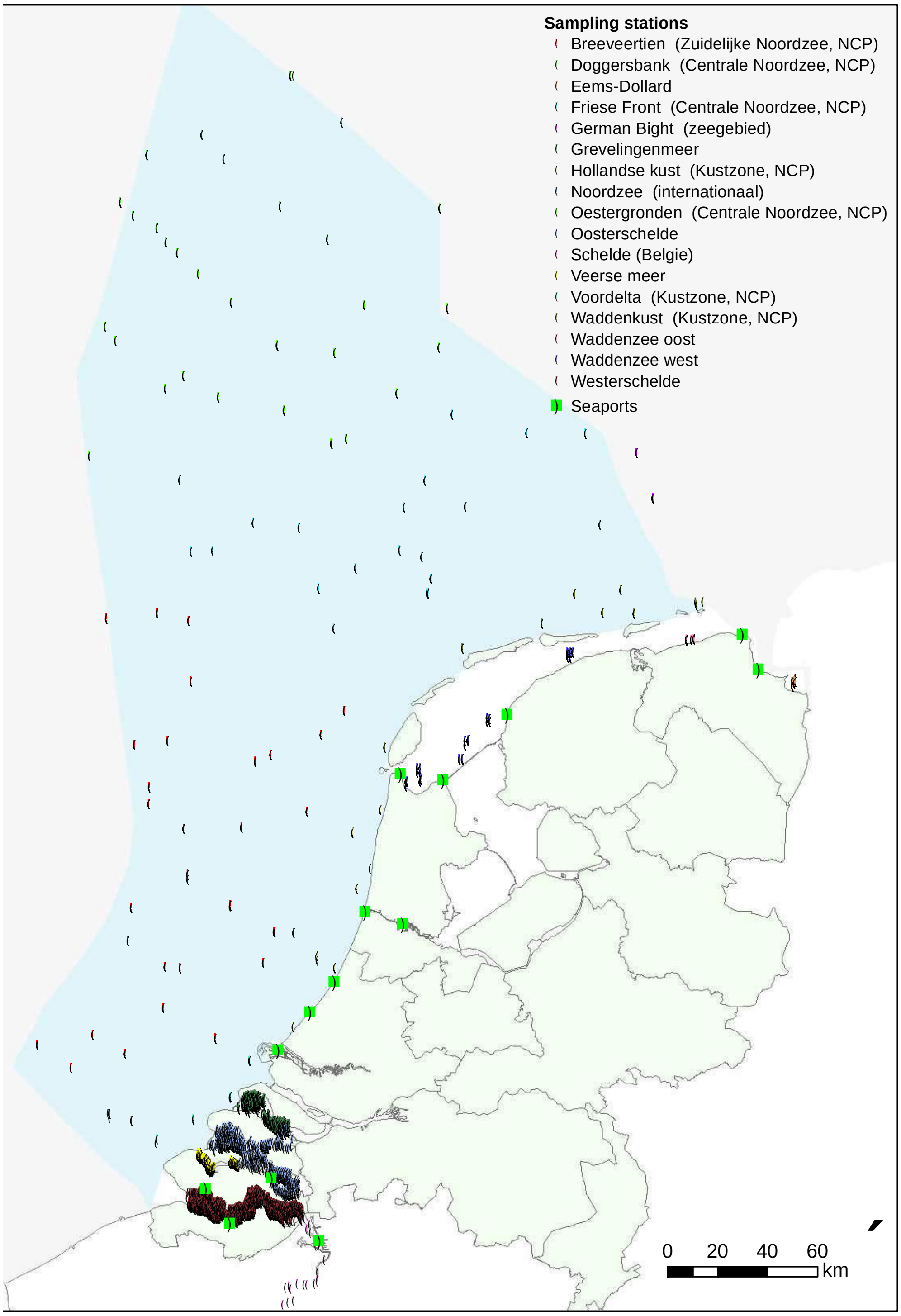



*Figure I.1. Overview of MWTL stations for soft sediment macrozoobenthos (1990-2012).*


*Figure I.2. Detail of MWTL stations for soft sediment macrozoobenthos Wadden Sea (1991-2011).*

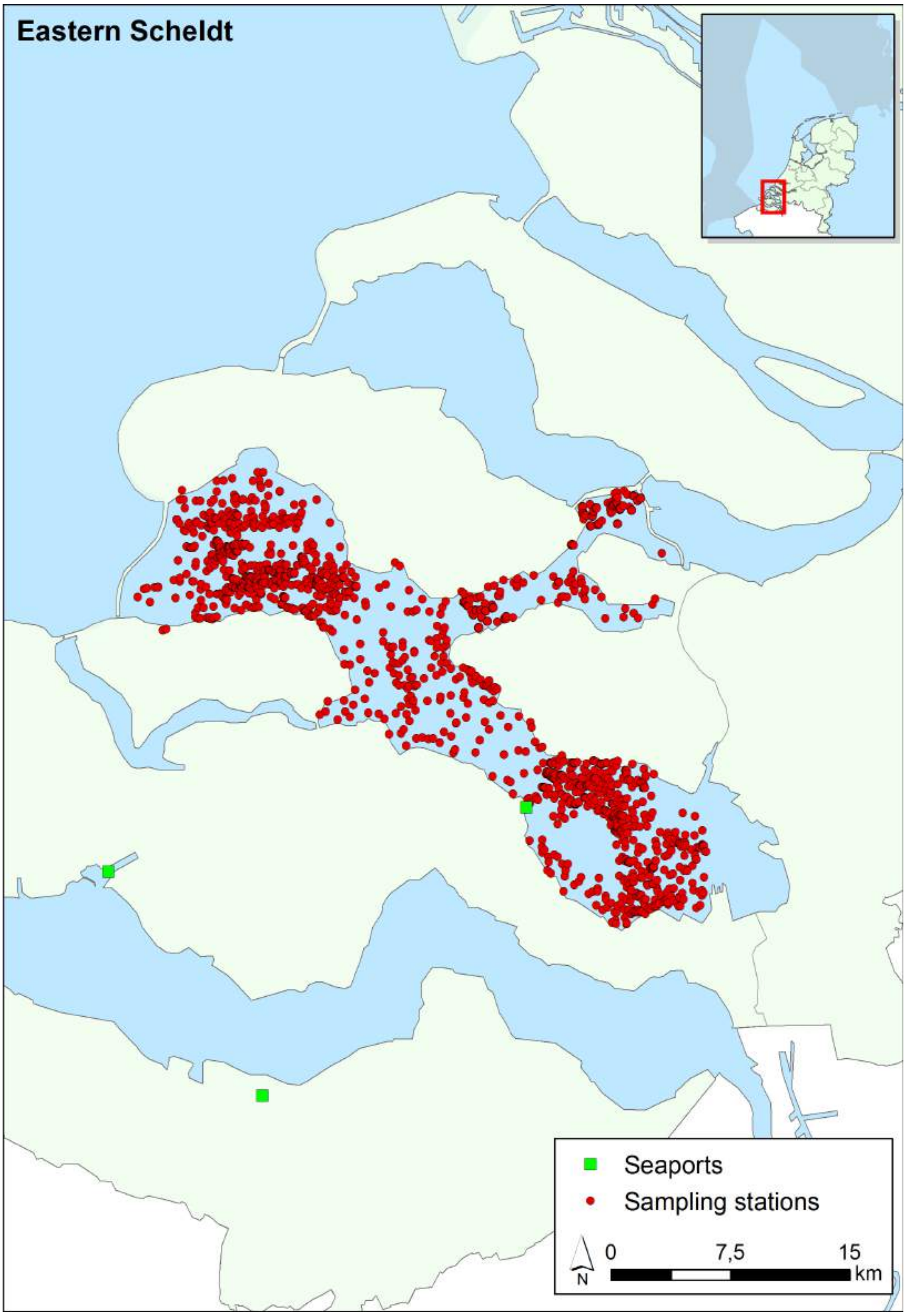


*Figure I.3. Detail of MWTL stations for soft sediment macrozoobenthos Eastern Scheldt (1990-2012).*

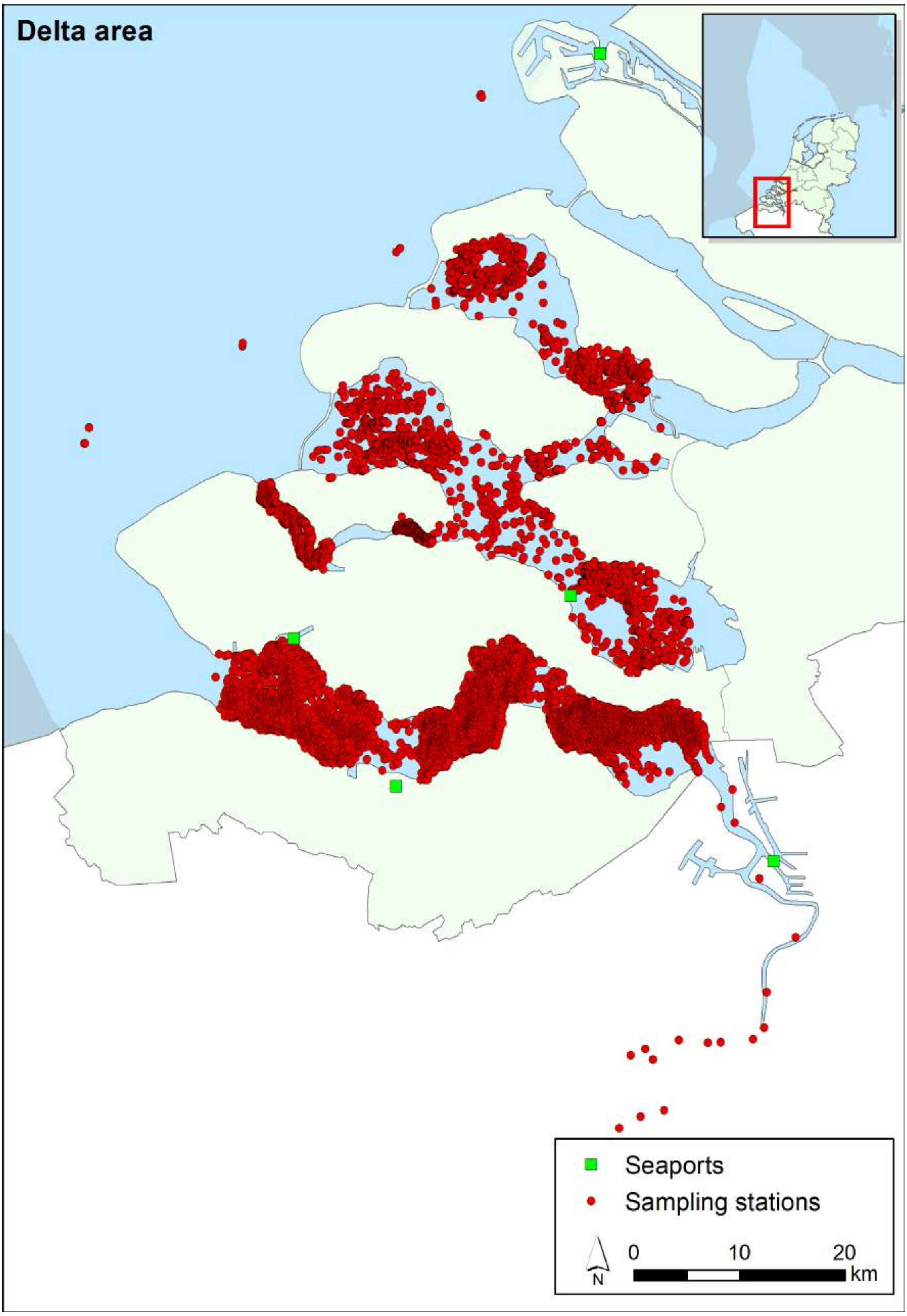



*Figure I.4. Detail of MWTL stations for soft sediment macrozoobenthos Delta area (1990-2012).*

# Appendix 2 Other programs and projects

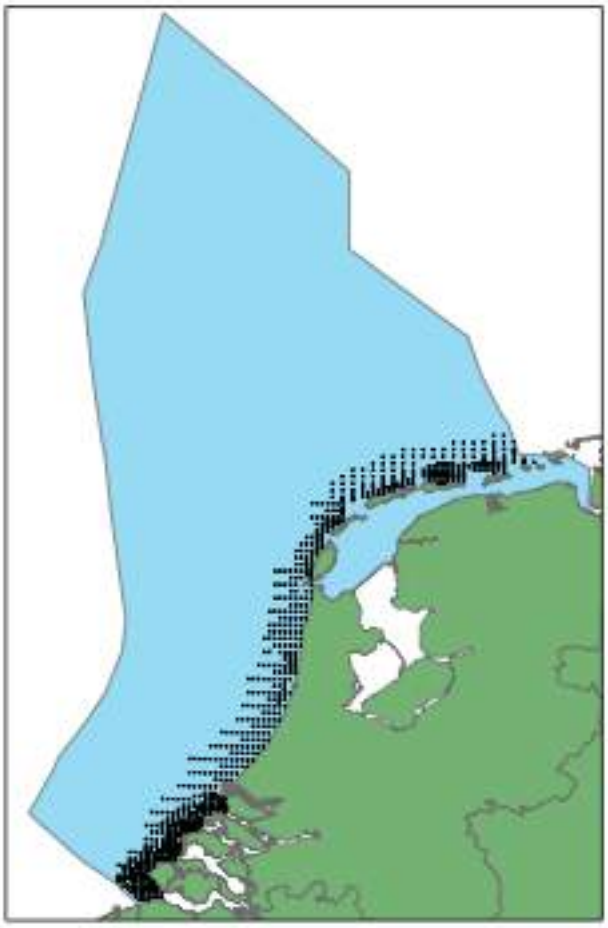


*Figure II.1. WOT Shellfish survey (Source: DeMesel et al. 2012).*

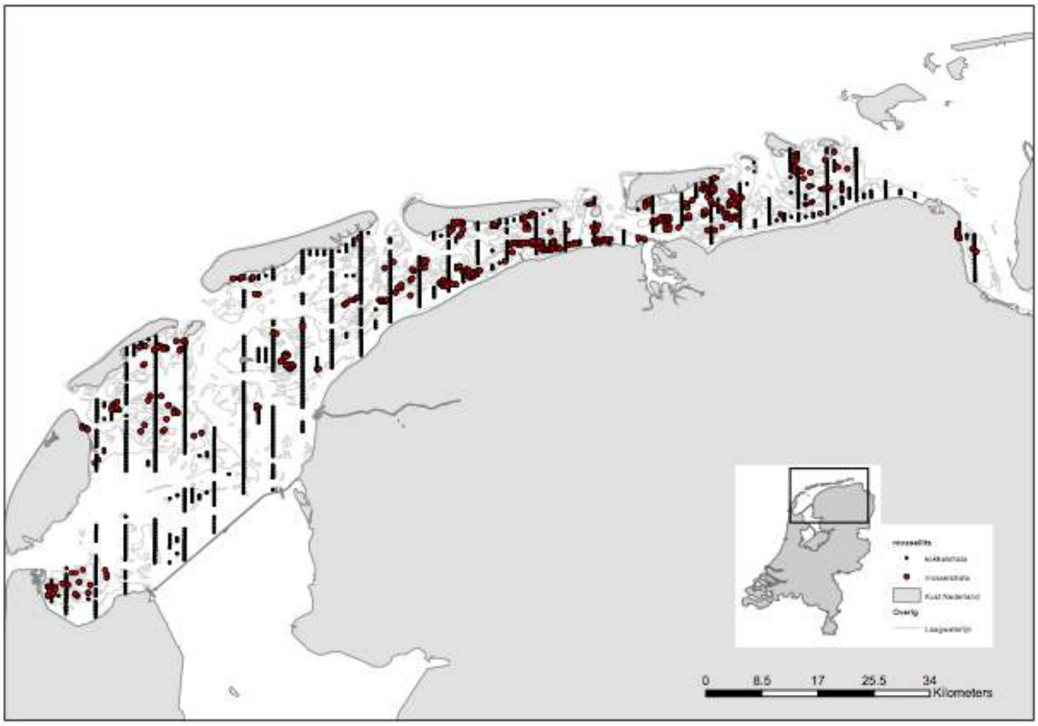



*Figure II.2 WOT Sampling locations used for the estimation of the mussel biomass in the Wadden Sea. Pink dots represent locations within mussel or oyster beds, black dots are locations sampled during the cockle survey (Source: Van den Ende et al. 2014).*

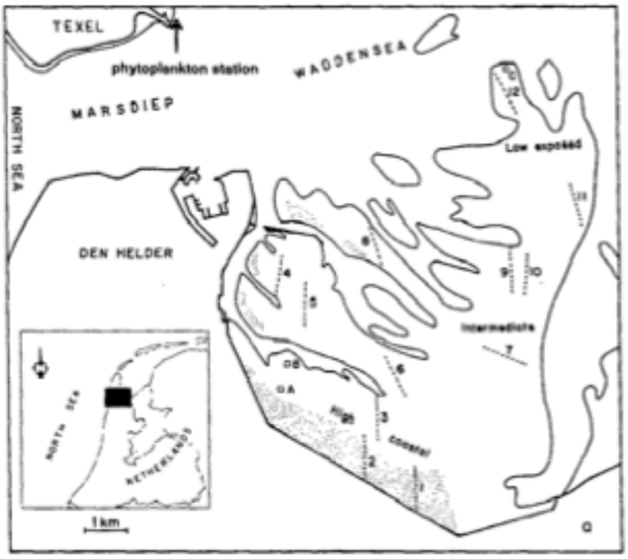



*Figure II.3 NIOZ Balgzand transects (Source: Beukema& Cadée 1997).*

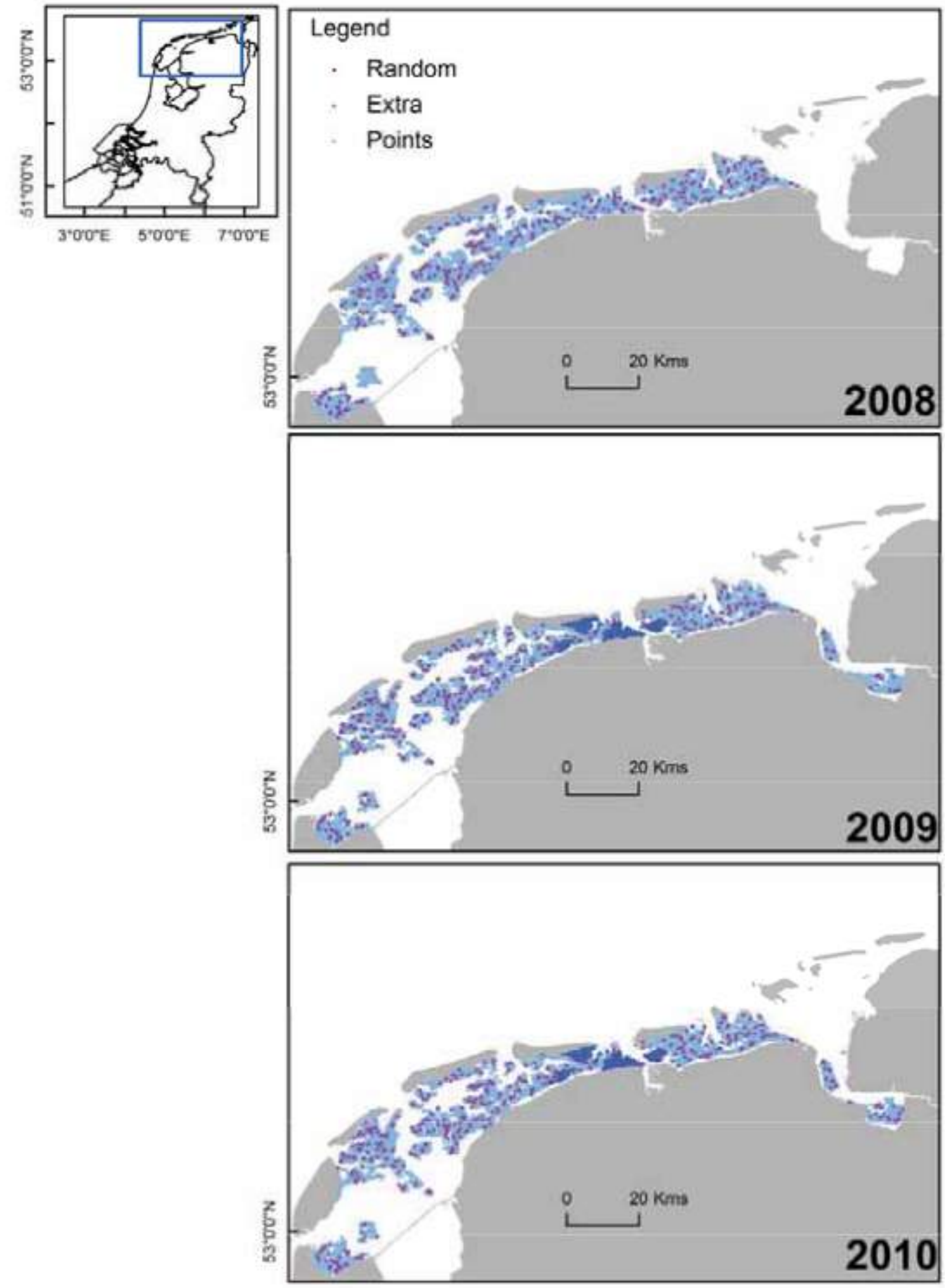



*Figure II.4 SIBES points (Source: Compton et al. 2012).*

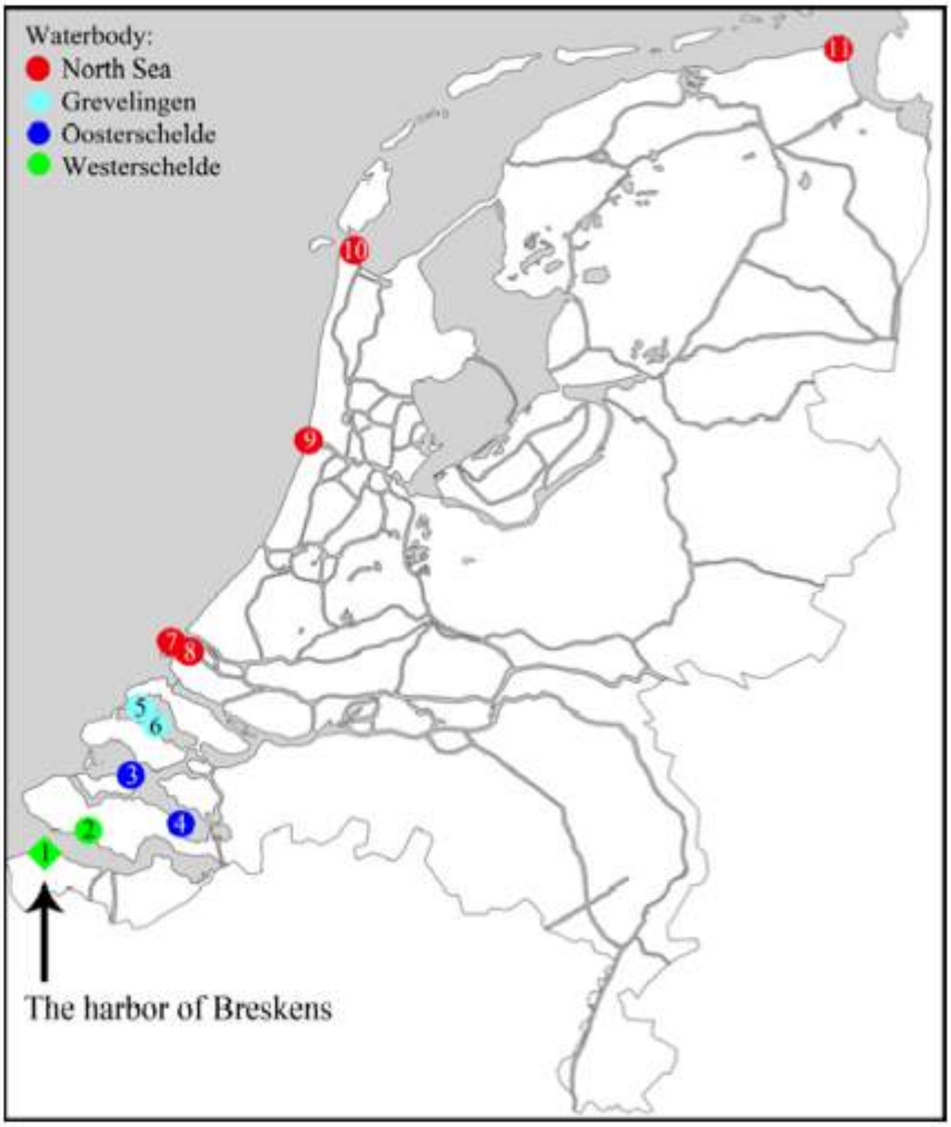



*Figure II.5 SETL locations (Source: Gittenberger & van Stelt 2011).*

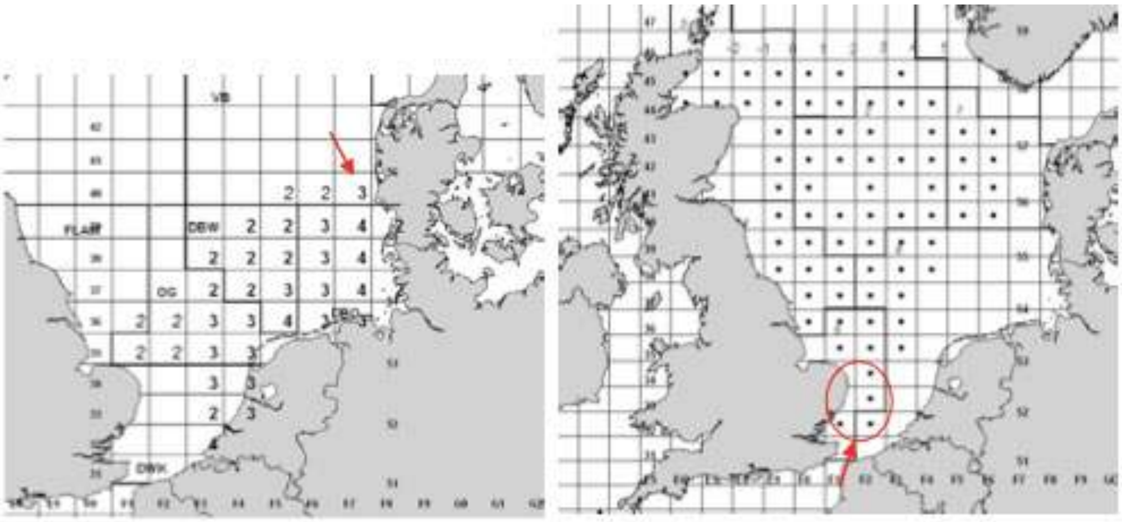


*Figure II.5. BTS sampling (year 2011). Left: Number indicate number of trawl transects.*

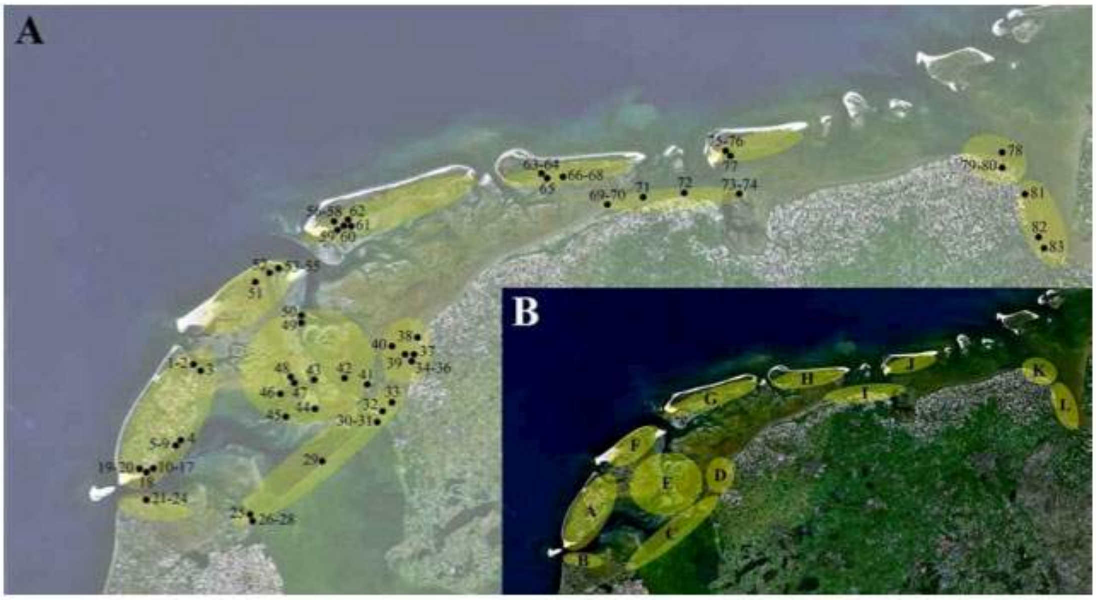



*Figure II.6. Baseline Wadden Sea (year 2009; Source Gittenberger et al. 2009).*

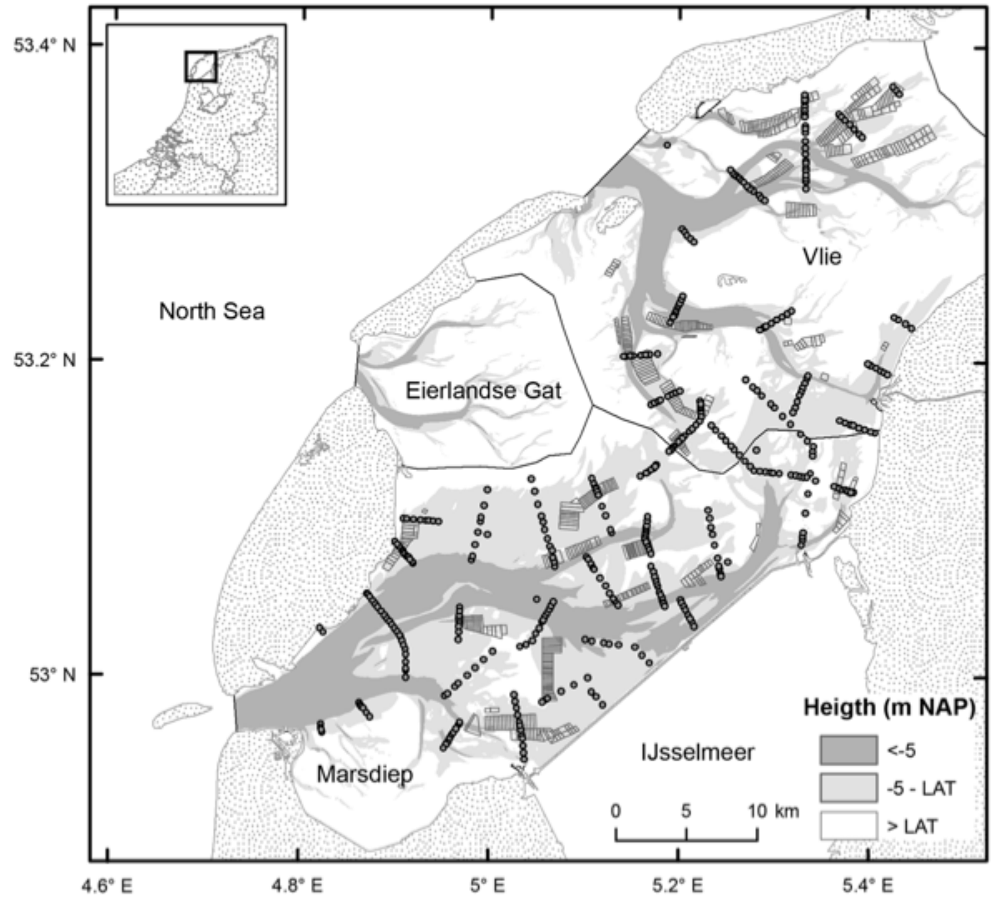



*Figure II.7. PRODUS sampling (year 2008 (Source: Dekker & Drent 2013).*

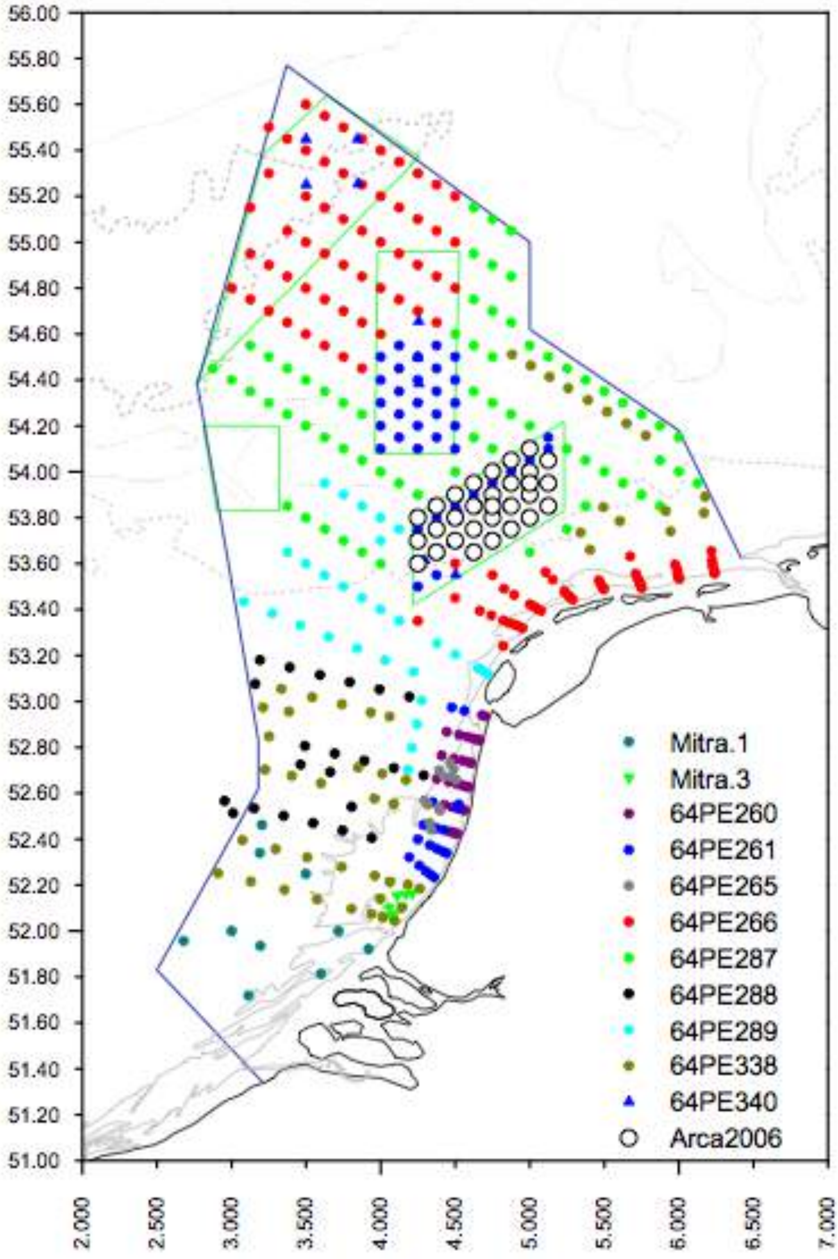



*Figure II.8. Triple-D dredge sampling (Source: Witbaard et al. 2013).*

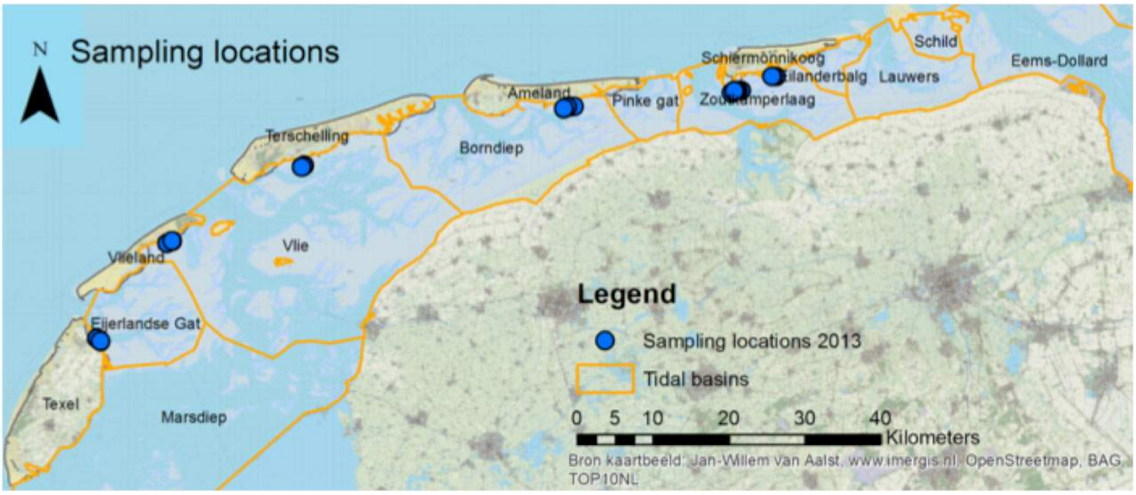



*Figure II.9. Waddensleutels sampling (year 2013)(Source: Marjolijn Christianen).*

# Appendix 3 Distance to mussel culture plots

*Table III.1 Shortest distance between mussel culture plots and the first MWTL sample station.*

| Mussel culture name: | Object | Mussel cuture plot | Nearest sampling station | Distance (m) |
|---|---|---|---|---|
| Malzwin | 106 | MZI percelen van experimenteerders | BALGZDJ_19940301_121160-555268 | 2537 |
| Malzwin | 107 | MZI percelen van experimenteerders | BALGZDJ_19940301_121160-555268 | 2353 |
| Neeltje Jans West | 108 | MZI percelen van experimenteerders | 15483_OosterscheldeW_20110915_41815_405808 | 0 |
| Scheurrak 64 | 109 | MZI percelen van experimenteerders | SCHEURRKS2_19900305_140222-566300 | 6323 |
| Malzwin | 110 | MZI percelen van experimenteerders | BALGZDJ_19940301_121160-555268 | 2895 |
| Zuidwal | 111 | MZI percelen van experimenteerders | BALGZDJ_19940301_121160-555268 | 1770 |
| Vuilbaard Noord | 112 | MZI percelen van experimenteerders | OOSTSDWT_19920910_49719-405330 | 48 |
| Malzwin | 113 | MZI percelen van experimenteerders | BALGZDJ_19940301_121160-555268 | 2792 |
| Schaar van Renesse Kavel 1 | 114 | MZI percelen van experimenteerders | VOORDTA4_19940525_46048-423245 | 4093 |
| Malzwin | 115 | MZI percelen van experimenteerders | BALGZDJ_19940301_121160-555268 | 2578 |
| Scheer 13 | 116 | MZI percelen van experimenteerders | BALGZDJ_19940301_122223-555229 | 8197 |
| Vuilbaard Noord | 117 | MZI percelen van experimenteerders | OOSTSDWT_19901019_50102-405230 | 31 |
| Schaar van Renesse Kavel 3 | 118 | MZI percelen van experimenteerders | KABBLBHVN_19900403_49356-419777 | 3552 |
| Zuidwal | 119 | MZI percelen van experimenteerders | BALGZDJ_19990317_121147-553413 | 2833 |
| Schaar van Renesse Kavel 3 | 120 | MZI percelen van experimenteerders | KABBLBHVN_19900403_49356-419777 | 3545 |
| Schaar van Renesse kavel 1 | 121 | MZI percelen van experimenteerders | VOORDTA4_19940525_46048-423245 | 4093 |
| Zuidwal | 122 | MZI percelen van experimenteerders | BALGZDJ_19940301_121160-555268 | 996 |
| Zuidwal | 123 | MZI percelen van experimenteerders | BALGZDJ_19940301_121160-555268 | 2696 |
| AD1 | 124 | MZI percelen uitgegeven door Productschap mosselen | SCHEURRKS2_19900305_140217-564446 | 5323 |
| AD2 | 125 | MZI percelen uitgegeven door Productschap mosselen | SCHEURRKS2_19900305_140217-564446 | 5418 |
| AD3 | 126 | MZI percelen uitgegeven door Productschap mosselen | SCHEURRKS2_19900305_140217-564446 | 5554 |
| AD4 | 127 | MZI percelen uitgegeven door Productschap mosselen | SCHEURRKS2_19900305_140217-564446 | 5671 |
| VZ1 | 128 | MZI percelen uitgegeven door Productschap mosselen | BALGZDJ_19940301_122223-555229 | 8714 |
| VZ2 | 129 | MZI percelen uitgegeven door Productschap mosselen | BALGZDJ_19940301_122223-555229 | 8531 |
| VZ3 | 130 | MZI percelen uitgegeven door Productschap mosselen | BALGZDJ_19940301_122223-555229 | 8227 |
| VZ4 | 131 | MZI percelen uitgegeven door Productschap mosselen | BALGZDJ_19940301_122223-555229 | 8800 |
| VZ5 | 132 | MZI percelen uitgegeven door Productschap mosselen | BALGZDJ_19940301_122223-555229 | 8651 |
| VZ6 | 133 | MZI percelen uitgegeven door Productschap mosselen | BALGZDJ_19940301_122223-555229 | 9600 |
| VZ7 | 134 | MZI percelen uitgegeven door Productschap mosselen | BALGZDJ_19940301_122223-555229 | 9759 |
| VZ8 | 135 | MZI percelen uitgegeven door Productschap mosselen | BALGZDJ_19940301_122223-555229 | 9539 |
| VZ9 | 136 | MZI percelen uitgegeven door Productschap mosselen | BALGZDJ_19940301_122223-555229 | 9890 |
| VZ10 | 137 | MZI percelen uitgegeven door Productschap mosselen | BALGZDJ_19940301_122223-555229 | 9185 |
| GS1 | 138 | MZI percelen uitgegeven door Productschap mosselen | JAVRGNS1_19900306_137963-558889 | 5997 |
| GS2 | 139 | MZI percelen uitgegeven door Productschap mosselen | JAVRGNS1_19900306_137963-558889 | 5615 |
| GS1 | 140 | MZI percelen uitgegeven door Productschap mosselen | JAVRGNS1_19900306_137963-558889 | 5489 |
| GS2 | 141 | MZI percelen uitgegeven door Productschap mosselen | JAVRGNS1_19900306_137963-558889 | 5412 |
| GS5 | 142 | MZI percelen uitgegeven door Productschap mosselen | JAVRGNS1_19900306_137963-558889 | 5288 |
| GS6 | 143 | MZI percelen uitgegeven door Productschap mosselen | JAVRGNS1_19900306_137963-558889 | 5219 |
| GS7 | 144 | MZI percelen uitgegeven door Productschap mosselen | JAVRGNS1_19900306_137963-558889 | 5121 |
| ZM1 | 145 | MZI percelen uitgegeven door Productschap mosselen | TERSLG4_19940601_139320-603215 | 15083 |
| ZM2 | 146 | MZI percelen uitgegeven door Productschap mosselen | TERSLG4_19940601_139320-603215 | 15254 |
| ZM3 | 147 | MZI percelen uitgegeven door Productschap mosselen | TERSLG4_19940601_139320-603215 | 15147 |
| ZM4 | 148 | MZI percelen uitgegeven door Productschap mosselen | TERSLG4_19940601_139320-603215 | 15309 |
| ZM5 | 149 | MZI percelen uitgegeven door Productschap mosselen | TERSLG4_19940601_139320-603215 | 15245 |
| ZM6 | 150 | MZI percelen uitgegeven door Productschap mosselen | TERSLG4_19940601_139320-603215 | 15345 |
| ZM7 | 151 | MZI percelen uitgegeven door Productschap mosselen | TERSLG4_19940601_139320-603215 | 15593 |
| ZM8 | 152 | MZI percelen uitgegeven door Productschap mosselen | TERSLG4_19940601_139320-603215 | 15737 |
| BH1 | 153 | MZI percelen uitgegeven door Productschap mosselen | VOORDTA4_19940525_46048-423245 | 3983 |
| BH2-e | 154 | MZI percelen uitgegeven door Productschap mosselen | VOORDTA4_19940525_46048-423245 | 4092 |
| BH3 | 155 | MZI percelen uitgegeven door Productschap mosselen | VOORDTA4_19940525_46048-423245 | 4166 |
| BH4 | 156 | MZI percelen uitgegeven door Productschap mosselen | KABBLBHVN_19900403_49356-419777 | 3513 |
| BH5-e | 157 | MZI percelen uitgegeven door Productschap mosselen | KABBLBHVN_19900403_49356-419777 | 3545 |

| | | | | |
|---|---|---|---|---|
| NJ1-e | 158 | MZI percelen uitgegeven door Productschap mosselen | 10737_OosterscheldeW_20061002_40445_404936 | 428 |
| NJ2 | 159 | MZI percelen uitgegeven door Productschap mosselen | 15611_OosterscheldeC_20121017_40818_404846 | 282 |
| NJ3 | 160 | MZI percelen uitgegeven door Productschap mosselen | 15611_OosterscheldeC_20121017_40818_404846 | 268 |
| NJ4 | 161 | MZI percelen uitgegeven door Productschap mosselen | OOSTSDWT_19910422_41628-404857 | 180 |
| NJ5 | 162 | MZI percelen uitgegeven door Productschap mosselen | OOSTSDWT_19910422_41666-404856 | 139 |
| VB1 | 163 | MZI percelen uitgegeven door Productschap mosselen | OOSTSDWT_19930927_50285-404762 | 0 |
| VB2 | 164 | MZI percelen uitgegeven door Productschap mosselen | OOSTSDWT_19930927_50551-404633 | 32 |
| VB3 | 165 | MZI percelen uitgegeven door Productschap mosselen | OOSTSDWT_19930927_50449-404326 | 30 |
| VB4 | 166 | MZI percelen uitgegeven door Productschap mosselen | OOSTSDWT_19930927_50449-404326 | 25 |
| VON-w 1 | 167 | MZI percelen uitgegeven door Productschap mosselen | 14957_OosterscheldeC_20100906_53613_401643 | 516 |
| VON-w 2 | 168 | MZI percelen uitgegeven door Productschap mosselen | 15679_OosterscheldeC_20120827_53619_401071 | 397 |
| VON-n 1 | 169 | MZI percelen uitgegeven door Productschap mosselen | 15651_OosterscheldeC_20120829_54086_403267 | 504 |
| VON-n 2 | 170 | MZI percelen uitgegeven door Productschap mosselen | 15651_OosterscheldeC_20120829_54086_403267 | 406 |
| Afsluitdijk | 171 | MZI gebieden volgens Uitvoering Visserij Regeling | JAVRGNS1_19900306_139324-559070 | 4227 |
| Texel Oudeschild | 172 | MZI gebieden volgens Uitvoering Visserij Regeling | BALGZDJ_19940301_121160-555268 | 5598 |
| Vogelzand | 173 | MZI gebieden volgens Uitvoering Visserij Regeling | BALGZDJ_19940301_122223-555229 | 8177 |
| Scheurrak Omdraai | 174 | MZI gebieden volgens Uitvoering Visserij Regeling | SCHEURRKS2_19900305_140217-564446 | 7954 |
| Gat van Stompe | 175 | MZI gebieden volgens Uitvoering Visserij Regeling | JAVRGNS1_19900306_137963-558889 | 5121 |
| Zuidmeep | 176 | MZI gebieden volgens Uitvoering Visserij Regeling | TERSLG4_19940601_139320-603215 | 15062 |
| Zoutkamperlaag | 177 | MZI gebieden volgens Uitvoering Visserij Regeling | WADDKT06_19950613_207969-617211 | 13062 |
| Scheer 16 | 178 | MZI gebieden volgens Uitvoering Visserij Regeling | BALGZDJ_19940301_122223-555229 | 8379 |
| Scheurrak 27 | 179 | MZI gebieden volgens Uitvoering Visserij Regeling | SCHEURRKS2_19900305_140222-566300 | 5075 |
| Scheurrak 34a | 180 | MZI gebieden volgens Uitvoering Visserij Regeling | SCHEURRKS2_19900305_140222-566300 | 3359 |
| Neeltje Jans æoostÆ | 181 | MZI gebieden volgens Uitvoering Visserij Regeling | OOSTSDWT_19920401_42144-404691 | 60 |
| Neeltje Jans ætransitie 2013Æ | 182 | MZI gebieden volgens Uitvoering Visserij Regeling | 15617_OosterscheldeC_20120828_40543_403793 | 17 |
| Roggenplaat | 183 | MZI gebieden volgens Uitvoering Visserij Regeling | OOSTSDWT_19930407_44423-407701 | 0 |
| Vuilbaard æzuidÆ | 184 | MZI gebieden volgens Uitvoering Visserij Regeling | OOSTSDWT_19930927_50685-404569 | 0 |
| Vondelingsplaat æwestÆ | 185 | MZI gebieden volgens Uitvoering Visserij Regeling | 15679_OosterscheldeC_20120827_53619_401071 | 265 |
| Vondelingsplaat ænoordÆ | 186 | MZI gebieden volgens Uitvoering Visserij Regeling | 15651_OosterscheldeC_20120829_54086_403267 | 123 |
| Hammen 40 | 187 | MZI gebieden volgens Uitvoering Visserij Regeling | 14986_OosterscheldeW_20100907_49426_409984 | 410 |
| Hammen 41 | 188 | MZI gebieden volgens Uitvoering Visserij Regeling | 14986_OosterscheldeW_20100907_49426_409984 | 254 |
| Hammen 42 | 189 | MZI gebieden volgens Uitvoering Visserij Regeling | 14986_OosterscheldeW_20100907_49426_409984 | 184 |
| Hammen 43 | 190 | MZI gebieden volgens Uitvoering Visserij Regeling | 14986_OosterscheldeW_20100907_49426_409984 | 115 |
| Hammen 44 | 191 | MZI gebieden volgens Uitvoering Visserij Regeling | 14986_OosterscheldeW_20100907_49426_409984 | 36 |
| Hammen 49 | 192 | MZI gebieden volgens Uitvoering Visserij Regeling | 14986_OosterscheldeW_20100907_49426_409984 | 403 |
| OSWD 188 | 193 | MZI gebieden volgens Uitvoering Visserij Regeling | 14668_OosterscheldeC_20091027_55652_396730 | 345 |
| OSWD 189 | 194 | MZI gebieden volgens Uitvoering Visserij Regeling | 14668_OosterscheldeC_20091027_55652_396730 | 475 |
| Slaak 3 | 195 | MZI gebieden volgens Uitvoering Visserij Regeling | 7374_OosterscheldeN_20020419_68334_408458 | 212 |
| Slaak 7 | 196 | MZI gebieden volgens Uitvoering Visserij Regeling | 15025_OosterscheldeN_20100910_71135_406609 | 543 |
| Slaak 8 | 197 | MZI gebieden volgens Uitvoering Visserij Regeling | 15025_OosterscheldeN_20100910_71135_406609 | 279 |
| Schaar van Renesse æKavel 2Æ | 198 | MZI gebieden volgens Uitvoering Visserij Regeling | VOORDTA4_19940525_46048-423245 | 4010 |

# Appendix 4 Interviews

**Rob Dekker, Royal NIOZ**
Function: scientist
Related topic: **MWTL Wadden Sea 1989 t/m 2011**
**NIOZ program Balgzand (1969 – recent)**

**History of Balgzand-MWTL monitoring**

- MWTL macrozoobenthos Wadden Sea was started by the ministry of Transport and Public Works around 1989. From 1994 onwards 3 of the total of 15 transects at Balgzand sampled by NIOZ were incorporated in this MWTL-program and financed by the ministry.
- The Balgzand program runs as a long-term program on estuarine invertebrate population dynamics from 1969 and involves twice-annual sampling (late winter, late summer) of macrozoobenthos at 15 permanent sampling transects and permanent quadrats located on Balgzand, a tidal flat area in the westernmost part of the Wadden Sea.
- By MWTL 3 out of 15 transects (raaien) sampled by NIOZ were financed by the ministry of Infrastructure and Environment (I&M) (then Transport and Water Management) from 1994 to 2011. Since 2012 the entire Balgzand program continues in the same annual frequency with 100% NIOZ financing.
- The aim of the Balgzand program is to detect trends in population dynamics of macrozoobenthos species. The purpose is merely scientific and leads to publications in peer-reviewed journals. Output includes a database and papers, but no annual (internal) reports.
- The method includes sorting live specimens. Lag time from sampling to data availability is always a few months.

**Taxonomic remarks**

- Taxonomic knowledge is available at NIOZ has increased over the years and is dependent on the natural interest of the person that is responsible. Taxonomic knowledge is sought externally if needed.
- DNA barcoding is sometimes used for specific genera (i.e. *Arenicola, Scoloplos*). However these techniques cannot replace taxonomic identification in the near future.
- New species are sent to experts and published in journals if relevant. The program included no records of new species so far for the Netherlands, but few new species for the Wadden Sea.
- Historically there was no specific interest in new species or marine alien species.

**MWTL Wadden Sea**

- From 2012 onwards the frequency of MWTL has been reduced to once every 3 years (exception Eems-Dollard) with a different method (i.e. sampling, report) and is now run as a separate program from the long-term NIOZ program and executed by third parties (companies).

- Decreasing the frequency will reduce the detection probability of marine alien species and lag time from invasion to detection shows a possible threefold increase.
- Due to the small surface area and hidden characteristics of soft-sediment benthos species MWTL can only detect species that are abundant and wide spread.
- Under water visual census, used for hard substrate species, will not detect new alien species in soft-sediments. Increasing the number of samples will not easily help.

**Monitoring programs other then MWTL**

- Other projects and programs for macrozoobenthos monitoring include SIBES (program) and PRODUS 2008 monitoring (project). Furthermore IMARES runs annual shellfish surveys in the coastal area.

**Including macroalgae**

- Sampling macroalgae involves different techniques and expertise then currently used in MWTL.
- A visual census with collection of some material would be useful. An additional person could be added to the MWTL teams in order to perform a specific algae survey.
- Taxonomic expertise of algae is rare in the Netherlands.

**Remarks and points of concern:**

- Of great important in this context is the exact definition of alien species. There is currently no standard list. As an example *Mya arenaria* often listed is a species is known to occur in the Netherlands for 800 years.
- Another question is at which stadium of an invasion signalling is desirable. Invasive, widespread, alien species are eventually detected but when density is low, detection probability is low.
- Substantial knowledge at ministries on history and background of macrozoobenthos ecology and scientific methods has been lost over the years due to re-organisations.
- Currently the loss of information due to discontinuation of long-term programs seems to be valued less then gains of financial cuts/ reduced monitoring effort.
- Early detection of soft-sediment molluscs could additionally be achieved by coastal/ beach monitoring (e.g. separate program by volunteers).

**Godfried van Moorsel, Ecosub**
Function: Marine ecologist, taxonomic expert
Area of expertise: **MWTL North Sea**, sampling, identification of species, reporting

**MWTL North Sea**

- Sampled area is small compared to the total area of the Dutch part of the North Sea.
- Method (Reineck Boxcore) only includes soft sediment species. A large percentage of marine alien species are hard-substrate species that are not sampled by this method.
- Until 2012, new species were mentioned in a separate section of the MWTL report. (In the year report 2012 elaboration on new species was no longer executed and was not required by the client). New species include a combination of northerly, southerly, cryptic and marine alien species, with no emphasis on the latter, nor an official status of the latter.
- Since the sampling frequency is now down to once every 3 years (historically it included annual sampling) it may take up to 4 years for a marine alien to be detected (sampling frequency plus one year for identification and report).
- Open parts of the North Sea (excluding the coastal zone) have few marine alien species. Increasing sampling effort (i.e. number of samples) in this part of the North Sea will therefore not lead to numerous new marine alien species.

**Taxonomic remarks**

- Without the right taxonomic knowledge, marine alien species may be missed or lumped with native species.
- Initiatives to standardise information of species (Nederlands Soortenregister, TWN, Werkgroep Exoten), including marine alien species/ marine species lists are fragmented and there is not a single source that is complete and accurate. This is due to reduced knowledge on marine species at the level of data managers who often focus on terrestrial or freshwater organisms, or due to the fact that no funds are made available to enter data on marine organisms.
- Status of new species is not always clear: *e.g.* southerly species or marine alien species can be mixed depending on definition. There is as yet no official person or body involved in granting this status explicitly to species in MWTL.
- Taxonomic expertise is guaranteed through *e.g.* self-learning, ISO 17025 (Wadden Sea/DELTA) and courses in the UK. International experts are consulted if needed.
- There are few Dutch taxonomic experts of North Sea species. This has not changed since it has always been a small working field.
- Due to the free market system, including completion, contact among taxonomic experts of different institutes / companies is limited.
- It is advisable to publish in the scientific literature on alien species or taxonomic problems, but funds to do so are usually lacking in projects.

- Taxonomic errors can re-occur for decades due to using old literature. Nowadays WORMS (World Register of Marine Species) is a good and constantly improving source for accepted nomenclature.
- DNA or eDNA is hardly used and not yet replacing species identification.
- There is no standard marine species list available for the Dutch part of the North Sea, nor of marine alien species. I include information on www.werkgroepexoten.nl, however this list is filled with fragmented information and includes all alien groups, not only marine species

**Monitoring programs and projects other then MWTL**

Soft sediment samples are part of:

- WOT (Triple D-dredge): This includes a large number of samples, but only the large fraction. So far the small fraction was not collected.
- Monitoring of the Sand Engine
- Monitoring of offshore windparks

Project monitoring is often annual but local. Background developments in windparks are hardly available on a North Sea scale because they are only sampled once every 3 years. It would be advisable to allocate some project-monitoring effort to other, parts of the North Sea in order to gain more knowledge on background development. This also allows, marine alien species to be sampled in a higher frequency compared to the current MWTLeffort.

**Including Macroalgae**

There is currently only 1 taxonomic expert on macro-algae in the Netherlands. Furthermore, the most recent standard work for species in the Netherlands dates back to 1983 (Herrenga & Mol 1983).

If algae would have to be included both the sampling technique should be adjusted and the taxonomic expertise should be expanded.

**Possible improvements**

- Decreasing time lag. Turnaround time for large species or species that are obviously different could be decreased by identification on board or during handling of the samples. However, for small species (i.e. amphipods) this is not an option. Increasing the sampling frequency to every year will improve results.
- Standardisation of taxonomic information: There is a need to centralise information on (introduced) marine benthos species, for example to create species lists. To encourage up to date information on species found in the Dutch part of the North Sea it would be useful to link to WoRMS (World Register of Marine Species). The taxonomical content is controlled by internationally respected taxonomic experts of the WoRMS and not by database managers without a full background in taxonomy. Dutch specialists should feed to WoRMS on presence of species and alien species in the Netherlands, but taxonomy stays up to date. A Belgian example of such an exercise already exists (BERMS).

**Arie Naber**

Function: Technical advisor RWS CIV

Related topic: MWTL North Sea, MWTL Wadden Sea, MWTL Delta (all 2007 – recent)

**MWTL programs**

- MWTL programs are issued by RWS WVL (Water Transport and Environment, contact person Gerrit Vossebelt/ Jaap Graafland). The actual status of information needs is incorporated in the lay out of the program by the CIV. Conventions and legal frameworks (national and international) are leading in shaping the information needs. Legal frameworks include the Water Framework Directive, Marine Strategy Framework Directive and the different River Commissions.
- The role of CIV is to translate the information needs into a monitor program and to decide whether the work is carried out by RWS itself or by market participation. If the market is involved the role of the CIV is to ensure that the work is carried out in time, reports delivered and to check de quality of the data delivered. The latter in close cooperation with the RWS laboratory. Recommendations that are part of the digital reports will be presented as feedback to WVL
- There is no emphasis on publishing information of alien species. However a part of the standard MWTL report mentions "new species" (a combination of rare, cryptic and alien species).
- The programs are often adjusted to changing information needs and budgets.
- The monitoring of macrozoobenthos in the Wadden Sea started in 1990 as a partial financing of three transects of a NIOZ program in the Western Wadden Sea, but has expanded to Eems-Dollard and Eastern Wadden Sea and is now a separate program. Hence overlap could take places in some years at Balgzand when RWS and NIOZ are sampling at the same time in the same transects. The frequency for most areas is now once every three years (instead of annual).
- The MWTL Delta program is adjusted to information needs of the MONEOS program (Western Scheldt). Optimisation research in 2007/2008 has led to a change from fixed transects to "ecotype sampling" (random sampling of all habitats). The frequency of Grevelingen meer and Lake Veere is down to once every three years. Based on ANT status of Eastern Scheldt (Autonomous Negative Trends) and channel widening in the Western Scheldt they are characterised by annual sampling.
- The results of the different programs are both data files and annual digital reports.
- Data files and reports are not directly available online but can be requested via Helpdesk Water.
- Historical and recent data of MWTL are stored at several different locations at CIV and are accessed through contact persons (e.g. Arie Naber). At the moment there is no single database that can be accessed at once.

**Taxonomic remarks**

- There is no specific label for alien species.

- All species are entered following TWN (Taxoncode Waterbeheer Nederland) nomenclature. The data files are stored containing the TWN name of a specific year and are not updated to newer taxonomy.
- The laboratory of CIV checks the species lists and new species have to be added to the TWN system.
- The TWN species list contains both historical and accepted names and is maintained by the CIV Laboratory.

**Including macroalgae**

- Sampling macroalgae involves different techniques and expertise then currently used in MWTL.
- A review on how this monitoring could be incorporated within MWTL would be useful, since MWTL monitoring includes a lot of sample stations that are visited that might easily be sampled for algae as well (f time at low tide permits).

**Possible improvements**

- If there is a need of a labelling alien species, this can be requested and formulated as an “information need”. It is possible to add this label to the database of MWTL and species list of TWN. However an important first question is what is the definition of “alien species”? and Does a standard list of marine alien species exist?

- Increasing the frequency for detecting alien species species is a matter of redefining the information need (responsibility by WVL). In freshwater MWTL program an additional sampling is added that is specifically focussed on alien species in large rivers.

**Suzanne Stuijfzand**
Function: policy advisor RWS WVL
Area of expertise: **MWTL North Sea**, use of MWTL for descriptor 2 in MSFD

**Marine alien species within the Dutch Marine Strategy**

- The Dutch MSFD (Marine Strategy Framework Directive) has led to the Dutch Marine Strategy part 2: MSFD Monitoring program. NIS species/ marine alien species are described in §9.2.7 of this report.
- The Dutch Marine Strategy (part 2) explicitly states "existing monitoring programs are preferably used as a source of information."
- Once established in the marine environment, invasive species are generally not removable, hence the policy aims at preventing new introductions.
- Early warning is therefore not included in the policy/ Dutch Marine Strategy. The monitoring programs are designed to evaluate the state of the benthic habitats, but not suitable for early detection/ early warning/ signalling.
- For macrozoobenthos within descriptor 2, several surveys are used (monitoring frequency every 3 years, except for WOT, which is performed yearly):
    - MWTL North Sea boxcorers: a small area is sampled, but the whole community is analysed, making it suitable for evaluating diversity, etc.
    - MWTL North Sea dredge: new survey off shore, larger sampling surface, but excluding the very small benthos species (mesh)
    - WOT shellfish survey (Min EZ), dredge, larger sampling surface, but excluding the very small benthos species (mesh).
    - Hard sediment (CloverBank): MWTL: new survey using video and Hamon grab

Monitoring data are used to give a status report on marine alien species once every 6 year (MSFD obligation).

- The Dutch Marine Strategy (part 2) states that "Determining the invasiveness of alien species is not an explicit goal of the monitoring, but if an alien species is increasing strongly in the sampled areas, this will be apparent in the data. The additional research effort which may be needed, for example for a risk assessment by the NVWA, falls outside the regular monitoring program".

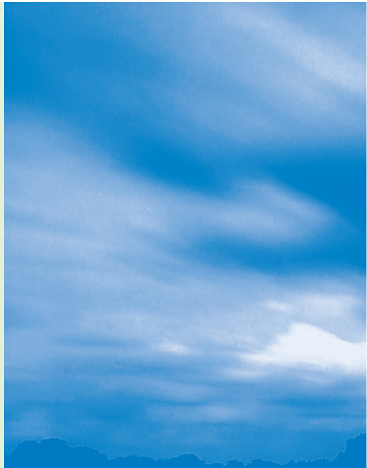
**MWTL North Sea**

- Information from MWTL sampling, including marine alien species are issued through the Informatiehuis Marien (IHM), who has a coordinating role in information management.
- There is no emphasis on publishing information of new species: the sole purpose is the MSFD obligation once every six years (so alien species will be part of this report).
- One adjustment that will be made to the monitoring program is adding the status "marine alien: YES/NO" specifically to species lists. However there is currently no "standard list" available. Apart from a marine alien list, it should be listed which alien species are considered invasive.

- Another adjustment is that in 2015 67 samples will be added to the MWTL program (Natura 2000 area), leading to a total of 167 samples.

**Possible improvements**

There is a need of a standard list of marine alien species including its status (Invasive YES/NO). We are in the process of requesting such a list to the Ministry of Economic Affairs.



**Bureau Waardenburg bv**
Research and consult for ecology and landscape
P.O.Box 365, 4100 AJ Culemborg
Tel: +31 345-512 710, Fax: +31 345-519 849
E-mail info@buwa.nl, www.buwa.nl