Short review on zooplankton in the Dutch Wadden Sea

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Considerations for zooplankton monitoring

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Wageningen Marine Research

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Contents

Summary

The KB 36 project on Zooplankton in the Wadden Sea aims to elaborate and set up an operational monitoring of zooplankton in the Wadden Sea. This report provides background information on the ecology of zooplankton in general and knowledge on zooplankton in the Wadden Sea, to identify issues to take into account when setting up monitoring of zooplankton. Although the zooplankton includes many sizes of organisms, the focus is on mesozooplankton (0.2-20 mm). It consists mainly of the abundant copepod crustaceans and larvae of zoobenthic species, and forms a link between the primary production (phytoplankton) and predators such as fish.

Some challenges in designing a monitoring programme in the Wadden Sea are related to its high turbidity, shallowness and spatial variability. High turbidity may hamper the application of in situ optical and acoustic methods to detect zooplankton, whereas the shallowness complicate the use of traditional horizontal or oblique net hauls, which are common practise in the open sea. Since the spatial variability in the Wadden Sea is high, with channels connected to the North Sea and shallow tidal flats, the horizonal variation in the composition of zooplankton communities is also likely to be high. Observations should be therefore be made at appropriate temporal, horizontal and vertical resolution to resolve multiscale natural variability. Also the frequency of sampling should be high enough to take account of the (seasonal) life-cycles of zooplankton species, including the larval stage of benthos, especially during the summer half-year.

1 Introduction

1.1 Background and motivation

Ecosystems by nature are complex systems, with many relations among the species they contain. Understanding the presence of species, the interactions among them, and how and why they change, is key to the overall protection, as well the sustainable exploitation of marine resources.

In the Dutch Wadden Sea, the attention for underwater biodiversity has broadened and intensified in the past decades. For example, in May 2018 an illustration of the underwater world in the Wadden Sea was produced in collaboration with WUR on behalf of the "Programma naar een Rijke Waddenzee (PRW) (*Figure 1*). It visualizes several species and habitats, including blow-ups for phyto- and zooplankton (top right), with the explanation: "Animal plankton is a community of thousands of (mostly) microscopic animals. They are an important link in the food web. Some fish depend on it as a main source of food, such as sprat and herring. However, zooplankton research in the Wadden Sea Sea has received limited attention during the past decades in comparison to most other research domains and species (Jak et al., 1999).

The 2019-2022 Program Plan of the Program for a Rich Wadden Sea (PRW) pays particular attention to underwater nature. One of the objectives is "to promote cooperation with other research institutions that have relevant underwater nature knowledge. This concerns, among other things, Wageningen Marine Research (WMR), which carries out the monitoring of the effects of various (shellfish) fishing covenants and for the Wadden Sea's Legal Research Task (WOT). "Another objective of this program is" boosting a major transition to a Wadden knowledge infrastructure that helps for policy and management and exploits the international top position Wadden knowledge, also for the Northern economy. "

This KB36 project on zooplankton aims to strengthen PRW's program activities around underwater nature, while also paying attention to the translation of the results into policy, development and management, also internationally, such as the Swimway program[1] on habitat use, reproduction and migration behaviour and of fish in the Wadden Sea.

Figure 1 *Illustration of the Wadden Sea underwater world*[2]

[1] https://swimway.nl/

[2] https://rijkewaddenzee.nl/wp-content/uploads/2018/05/KustZeeGids_2018_Waddenzee_Onderwaternatuur_Versie-2.pdf

So far, no structural monitoring has been performed during the last decades on zooplankton in the Dutch Wadden Sea. It is thus unknown what the current biodiversity of zooplankton species is and what seasonal effects in density and composition are. It is therefore also unknown what the grazing pressure is from zooplankton to phytoplankton, and therefore what the carrying capacity is or could be for fisheries (pelagic fish, shrimps). In turn, the carrying capacity of all other trophic levels, including top end natural predators is also unknown, such as fish-eating birds and seals for which conservation targets have been set.
In other words, knowledge is missing about an essential link in the food web of the ecosystem, knowledge that is important for both nature conservation, fisheries and aquaculture in the Wadden Sea area.

1.2 Objective of the report

The primary objective of this KB 36 project on Zooplankton in the Wadden Sea is to elaborate and set up an operational monitoring of zooplankton in the Wadden Sea. The method(s) must be cost-effective and suitable for implementation by vessels of the Dutch government shipping company of Rijkswaterstaat (Rijksrederij). Part of the study is to explore whether innovative detection methods based on DNA metabarcoding, automatic species recognition using Image Analysis and self-learning programs (Artificial Intelligence) and hydro-acoustics (high-frequency echo sounders and sonar techniques) can be used for this. Another aim is to specify the needs for monitoring information for the management of the Wadden Sea.

This report aims to provide a concise introduction to zooplankton in general and on zooplankton monitoring in the Wadden Sea.

Additional reports will review information of available monitoring techniques, with respect to research questions to be answered. The applicability of the various techniques in the shallow turbid ecosystem of the Wadden Sea will be discussed, with a focus on imaging and acoustic techniques.

2 Zooplankton: a general introduction

2.1 Definition of zooplankton

The term 'plankton' was coined by the German founder of quantitative plankton and fisheries research Victor Hensen (1887). It is derived from the Greek word 'πλανάω' (planao) meaning to wander and it has the same etymological root as 'planet'. Plankton encompasses all organisms drifting in the water whose abilities of locomotion are insufficient to withstand currents, as opposed to nekton, the community of actively swimming organisms such as large crustaceans, cephalopods, fishes, aquatic birds and mammals.

Zoo- in the word zooplankton- , is derived from the Greek word "Zoon", meaning "animal", and thus comprises all animals like plankton. Whereas most zooplankton species are permanently free-floating in the water column, others can only be present for shorter periods of their lifecycle, such as larva of larger crustaceans like crabs, or bivalve-larva for example. Hence, the zooplankton community has therefore a strong interaction with both the pelagic and the benthic ecosystem.

2.2 Classifications of zooplankton

Various groups of plankton and zooplankton can be distinguished, each with their own ecological niche and importance. Zooplankton is a biodiverse group that cover many phyla and taxa, starting at unicellular amoeba and other protozoa till larger animals such as shrimps and krill being much larger reaching up to several mm and cm up to giant jellyfish of 2 m diameter (Carlotti et al., 2000). The size of zooplankton is important in monitoring since equipment for sampling and detection should be suitable for the target (size) group of study.

In addition to the phylogenetic taxonomic classification, other systems are used to classify zooplankton, reflecting the high diversity between and within zooplankton communities. Classifications are based on differences in size, function (food), life-cycle and habitat.

Given the range in ecological niches in sizes, covering multiple magnitudes, the method to sample zooplankton should be adopted accordingly to the main focus groups of study.

Zooplankton can also be classified into meroplankton and holoplankton. Meroplankton are larvae that eventually change into non-planktonic life forms such as worms, molluscs, crustaceans, coral, echinoderms, fishes, or insects (*Figure 2*). Holoplankton are species that remain planktonic for their entire life cycle and include e.g. free-swimming pelagic sea snails and sea slugs (pteropods), arrow worms (chaetognaths),or copepods. Depending the life stage (meroplankton) a species will alter its position in the water column. E.g. after a larvae is transformed into its adult life form, it can be settled on or into the sediment (worms) or be free swimming (fish).

Holoplanktonic Taxa	Meroplanktonic Taxa
Cnidaria Class: Scyphozoa, Hydrozoa	**Cnidaria** Class: Anthozoa, Hydrozoa
Ctenophora	**Bryozoa**
Annelida	**Annelida** Class: Polychaeta, Echiura, Hirudinea
Mollusca Class: Gastropoda, Cephalopoda	**Mollusca** Class: Gastropoda, Cephalopoda, Bivalvia, Polyplacophora
Arthropoda Class: Maxillopoda Malacostraca, Ostracoda, Branchiopoda	**Arthropoda** Class: Maxillopoda, Malacostraca, Chelicerata
Echinodermata Class: Crinoidea	**Echinodermata** Class: Crinoidea, Echinoidea, Asteroidea, Ophiuroidea, Holothuroidea
Chordata: Class: Thaliacea, Appendicularia, Osteichthyes	**Chordata:** Class: Osteichthyes

Figure 2 *Example of taxonomic groups with taxa of holoplanktonic and/or meroplanktonic organisms (from Zuercher and Galloway, 2019).*

Zooplankton also carry out a so called diel vertical migration. This migration can have diurnal patterns, steered by e.g. temperature, light, food availability and predator presence (1996). However, in the shallow Wadden Sea, mixing of the water column is rather intense and vertical migration is unlikely to be relevant.

Besides the vertical position that can change during the life stages, the transformation within a life cycle also shows large differences in appearance of one species. To determine zooplankton within ecosystem, it is also necessary to understand their life history and identify all developmental stages. Each life stage of zooplankton species has a different morphological form. However, species descriptions of copepods are mostly based on the characteristics of the adult male and female and descriptions of diagnostic characters for the other five copepodite and six naupliar stages of copepod species are uncommon which hamper taxonomic identification of the species. In fact, larval and juvenile stages of holoplankton and meroplankton are generally challenging or impossible to identify to species level.

> The sampling strategy for zooplankton should consider the diversity in life stages that may be present.

Table 1 *Overview of plankton types and their sizes, including examples of organisms. (Karlson & Lopes, 2009, based on Sieburth et al., 1978; other sources see also text)*

Criteria	**Category**	**Attributes**
Taxonomy	Viroplankton	Viruses
	Bacterioplankton	Bacteria
	Protoplankton	Protozoan
	Phytoplankton	Algae
	Zooplankton	Animals (Metazoa)
	Seston	All living and dead floating particles
Life cycle	Holoplankton	Entire life cycle planktonic
	Meroplankton	Part of life cycle planktonic
	Tychoplankton	Fish larvae
Size	Femtoplankton	< 0.2 µm
	Pico- (ultra)plankton	0.2-2 µm
	Nanoplankton	2-20 µm
	Microzooplankton	20-200 µm
(Net plankton:)	Mesozooplankton	0.2-2 mm
	Macrozooplankton	2-20 cm
	Megaloplankton	> 20cm
Distribution	Estuarine plankton	Estuaries with range in salinities
	Coastal plankton	Shallow coastal zone
	Neritic plankton	Continental shelf (<200 m depth)
	Oceanic plankton	Oceans (> 200 m depth)
Habitat	Epiplankton	Living in upper 180 m (100 fathom) of the water column
	Pleuston	Living at the sea/air interface
	Neuston	Living floating on/in the surface film
	Bathyplankton	Living in the bathyal zone (200-2000 m depth)
	Hypoplankton	Living at greatest depths (> 2000 m)
Food	Herbivoric	Feeding on algae
	Mixotrophic	Able to live both autotrophic (as a plant) and heterotrophic (as an animal)
	Carnivorous	Feeding on other animals
	Detrivorous	Feeding on dead material

2.3 Role in the ecosystem

Zooplankton occupies a key position in the marine pelagic food web (Carlotti et al., 2000). Zooplankton transfers organic energy produced by unicellular algae through photosynthesis, to higher trophic levels such as pelagic fish. As such zooplankton has an important provisioning role in the ecosystem (*Figure 3*).

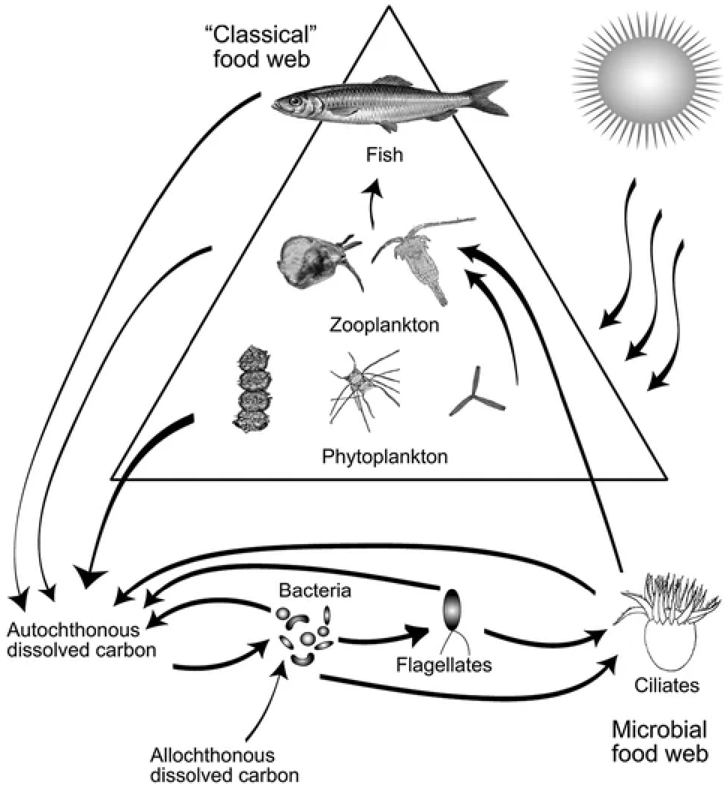

Figure 3 *"A simplified model of the pelagic food web, showing groups of organisms and the transfer of organic material in the food web. In the "classical pelagic food web ", energy is channelled from the phytoplankton (mainly diatoms and dinoflagellates) to mesozooplankton (mainly copepods and cladocerans) and from there to fish. In the microbial food web , energy is channelled from heterotrophic bacteria to heterotrophic flagellates and further to ciliates, then to mesozooplankton and finally to fish. In reality, the pelagic food web is much more complicated, e.g. by mixotrophy . Figure: © Kristina Viklund", taken from from Andersson et al., 2017*

Zooplankton are heterotrophic and feed on various food types. While many are herbivores feeding on phytoplankton, others are carnivores, detritivores, or omnivores. Zooplankton utilize different strategies to obtain food. Suspension feeders draw in food particles from the surrounding water via a filtering or trapping mechanism, while raptorial feeders actively hunt their prey (Kiørboe, 2011). In turn, the size and the feeding strategy of their predators (fish, whales) steer the top down control of zooplankton.

Typically, zooplankton biomass and species diversity decreases with depth in the ocean, which is related to food availability decreasing with depth. Seasonal patterns of zooplankton abundance are similarly related to patterns of food abundance, usually algal blooms, light conditions and or temperature as a starting point. Usually increased zooplankton abundance follows spring phytoplankton bloom, as well as the smaller fall plankton blooms (Fransz & Arkel, 1983). Seasonal cycles of phytoplankton are thus important in steering zooplankton dynamics.

The presence of zooplankton of a certain size and at a certain place and time during feeding period of fish larvae has a crucial role not only for fish stocks and fisheries, but also for various ecological processes.

Zooplankton forms an integral aspect at the base of the marine food web, making them important indicators for ecosystem state. Changes in zooplankton communities can affect all higher food web levels, since these organisms are supported either directly or indirectly by zooplankton.

3 Wadden Sea zooplankton

3.1 Wadden Sea zooplankton

The Wadden Sea is a shallow sea enclosed by a row of islands belonging to the Netherlands, Germany and Denmark, with a surface area of approximately 6000 km2. Between the barrier islands, water exchange with the North Sea takes place by tidal currents. The Wadden Sea is thereby subdivided in a series of tidal basins, filled and emptied by tidal channels. In the western part of the Dutch Wadden sea, the residence time of the water is about 10 days, whereas in the Ems-Dollard it takes on average about a month before it reaches the North Sea (Eertman & Smaal 1995).

It is a dynamic system with high rates sediment transport, and a range of human activities that shape and affect the system, including dredging, bottom fisheries, and the culturing and extraction of shellfish. Although nutrient inputs are decreasing during the last decades (van Beusekom et al., 2019), the system can still be considered as eutrophic, resulting in a high production of the biological system. This is amongst others reflected by high winter nitrogen/phosphorous ratio, elevated chlorophyll concentrations as compared to background levels, and the occurrence of macroalgal blooms in parts of the Wadden Sea (Van Beusekom et al., 2019). The high production of phytoplankton and microphytobenthos feeds consumers such as filter-feeders in the sediment, mainly bivalves, and in the water column by zooplankton.

The number of trophic levels is relatively limited, but biodiversity and the food web is relatively complex despite of the strongly fluctuating levels in salinity, temperature and other parameters. Nevertheless, the nature values of the Wadden Sea are considered high and the Wadden Sea has been listed as UNESCO World Heritage site for its outstanding value on geological and ecological processes and high biodiversity (Reise et al., 2010 in Baptist et al., 2019). The Wadden Sea has also status as Natura 2000 area, and several habitat types, and populations of species are being protected and measures are taken to recover or maintain their quality and size (Ministerie van Infrastructuur en Milieu, 2016).

Zooplankton is not directly part of any of the conservation objectives considered by Natura 2000. However, several issues from the management plan (I&M, 2016) for the Wadden Sea are relevant:

- The total biomass of fish stocks has decreased and also the function as nursery area for fish has decreased. This may be a result of reduced zooplankton stocks;
- More gradual transitions between fresh and marine waters are planned to remove barriers for migratory fish species (sea lamprey, river lamprey, twait shad (i.e. Zeeprik, Rivierprik, Fint)). The habitats for these fish species need to be suitable for reproduction, where juvenile fish is likely to feed on zooplankton;
- Several species of terns (little tern, common tern, arctic tern, sandwich tern (i.e. dwergstern, visdief, noordse stern, grote stern) have breeding colonies in the Wadden Sea, and in addition to suitable breeding sites, there needs to be sufficient supply of food, which consists of small zooplanktivorous fish.

In spite of its position as nature conservation area, several types of human use are allowed, part of them regulated by permits under the Nature conservation Act (Wet Natuurbescherming). Various activities in the management plan are exempted from licensing, but specific conditions apply (IenM, 2016):

"In the Wadden Sea it concerns the following regular activities: use of mussel culturing plots, passive fishing gears, seal sighting tours, demonstration fishing, organized regular fishing events, kite surfing, maintenance dredging works including the distribution of dredging spoil, sand replenishment in the context of coastline nourishment, maintenance of structures (including cables and pipes), gas extraction Groningenveld, existing industrial discharges, regular monitoring activities, regular emergency response exercises, low flying (limited target group), some activities of the Ministry of Defense (search for ammunition residues, ammunition tests Breezanddijk) and damage control."

In addition, there are various activities that require a permit such as: many forms of professional fishing (mussel seed, shrimp, cockles, smelt, oysters), mechanical extraction of lug-worms, large-scale events, shell extraction, project-oriented research and military flight activities. When the permits for these activities expire, a new license or license renewal must be requested from the authorised supervision. In this management plan, assessment frameworks are included for many, but not all activities, which require a permit, that the competent authority uses in the assessing a new permit application.

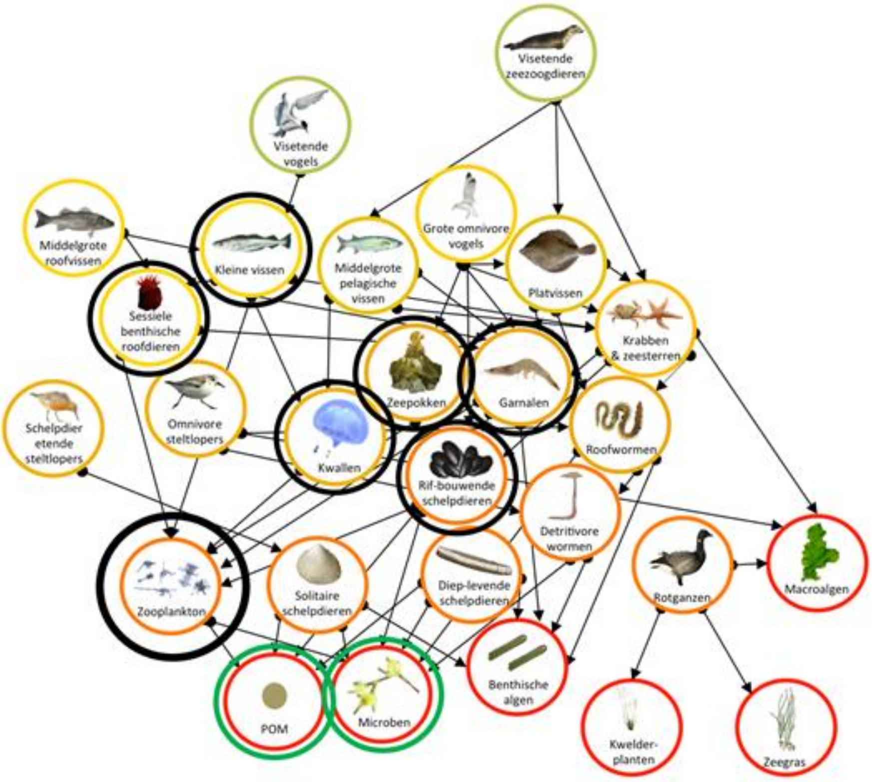

Figure 4 *Links in the food web of the Wadden Sea, with zooplankton and its direct higher trophic interactions encircled in black bold lines, and green for lower trophic levels*[3]

The Wadden Sea ecosystem is subject to several environmental stressors (QSR, 2017), including:

- Climate warming
- (Reduced) eutrophication
- Fisheries
- Infrastructural changes
- Invasive species
- Pollution

Factors driving zooplankton production and community composition may especially be related to (changes in) temperature and eutrophication. In addition, invasive species could be of importance in case these are predators of zooplankton, like the ctenophore *Mnemiopsis leidyi*.

[3] http://penyu.nl/research/

3.2 Zooplankton in the Wadden Sea

3.2.1 Spatial and temporal trends

Most of the knowledge on zooplankton distribution in the (Dutch) Wadden Sea stems from research in the late 70s and start of the 80s of the last century (Fransz, 1983). Fransz showed that the zooplankton in the western Wadden Sea was dominated by calanoid copepods and polychaete larvae. Some other studies focused on smaller parts of the Wadden Sea, such as those by George (1996) in the German part, who pointed to the importance of meroplankton, i.e. the larvae of benthic species occurring in the Wadden Sea, whereas copepods dominated the waters that entered from the North Sea. There is only one time-series available for the (German) Wadden Sea. Martens and van Beusekom (2008) reported time-series (1984-2005) in the Northern Wadden Sea (List Tidal Basin), showing high interannual variability in monthly mean biomass levels. In spite of this, trends were observed related to the increase in sea surface temperature. In the first place, copepod development started earlier in the season, and biomass was still elevated during late summer (September) as compared to earlier years.

The spatial and temporal distribution and dynamics are steered by:

- Seasonal dynamics, and fluctuations therein
- Long-term trends, impacted by temperature rise
- Local conditions as related to gradients in salinity, affected by water inflow from the North sea and freshwater inputs from estuaries
- Presence of benthic infauna (larvae) and epibenthic species
- Other factors including food availability, suspended particulate matter concentrations, and oxygen saturation.

3.2.2 Seasonal dynamics

A general seasonal succession can be described for the Wadden Sea, which may vary geographically, and may show year-to-year variation (sources, see text below):

Season	Density	Type of zooplankton
Winter	Low	Holoplankton (winter stock and from the North Sea)
Spring	Increase	Meroplankton (polychaetes, cirripeds)
Summer	Peak	Holoplankton (copepods; Acartia spp.)
Autumn	Decrease	Meroplankton (mollusc larvae)

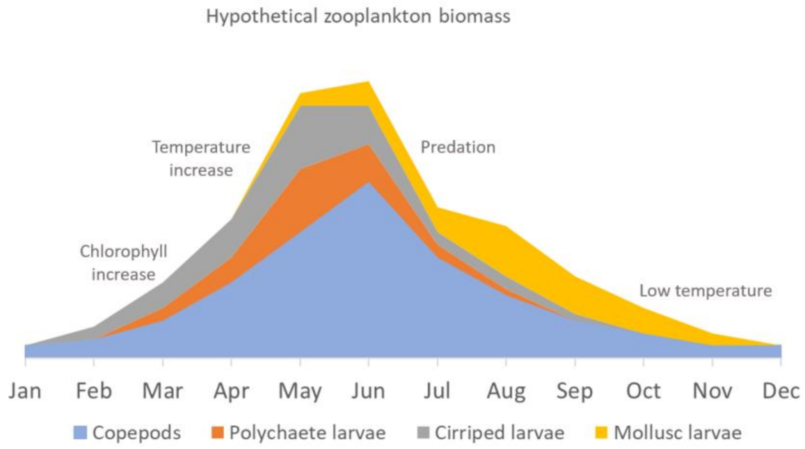

Figure 5 *Schematic seasonal development of major zooplankton groups in the Wadden Sea and the main driving factors.*

Winter
During winter zooplankton is dominated by holoplankton, mainly copepods (George, 1996). Densities are low and the overwintering stock is considered important for the forthcoming season (George, 1996). It seems that copepods reproduce even during winter, since George (1996) observed their nauplii larvae during winter.

Spring
In early spring, increases of meroplankton larvae (mainly spionid polychaete larvae and cirripeds (barnacle larvae) were observed by Martens (1995) and George (1996) in the German Wadden Sea. This coincided with a rise in chlorophyll-a values. The increase in predators including *Pleurobrachia pileus* and hydromedusa seem to be associated with meroplankton density (Fransz & Arkel, 1983). Also copepods start to increase in early, especially *Pseudocalanus* sp. and *Temora longicornis* that are adapted to relatively low temperatures (Fransz & Arkel, 1983). In late spring (May-June) copepods decline, which is being attributed to predation by invertebrates (hydromedusa, comb jellies) (Fransz & Arkel, 1983).

Summer
In summer the copepods *Acartia* spp. and *Centropagus hamatus* dominate the zooplankton (Fransz & Arkel, 1983), although numbers are low due to predation. These species prefer higher temperatures and larger phytoplankton particles.

Autumn
Numbers, and biomass, of all zooplankton decreases except for larvae of molluscs (Georg, 1996).

Variability
Year-to-year variations may occur as a result of severe winters that may cause declines in zooplankton predators (Fransz & Arkel, 1983). High phytoplankton production in spring (light, temperature) stimulates zooplankton production (Niesel & Günther, 1999).

3.2.3 Long term trends

Long term trends in mesozooplankton communities are only available for one location in the northern Wadden Sea (since 1984) near the island of Sylt (Martens & van Beusekom, 2008). These long term trends show that compared to 1984, in recent years the following is observed:
- a longer copepod season;
- an increase in abundance of *Acartia* sp. in April-May;
- increase in abundance of the carnivorous cyclopoid copepod *Oithona similis*;
- no clear overall trend in copepod abundance.

This is expected to be a result of temperature increase.

In addition, at Texel shellfish larvae (Phillipart et al., 2014) and jellyfish (van Walraven et al, 2015) are being monitored by the NIOZ.

Van Beusekom et al (2019) discuss that the decreasing trend in phytoplankton, observed since the late 1980s, is not a result of an increased top-down control by either zooplankton or macrozoobenthic biomass, even though there appears to be a close relation between phytoplankton growth rates and microzooplankton grazing during summer (Loebl & van Beusekom, 2008). In the Dutch part of the Wadden Sea, chlorophyll levels of phytoplankton appear to be closely related to riverine nutrient inputs (van Beusekom et al., 2019), suggesting that phytoplankton growth is limited by phosphorous and nitrogen. In the southern Wadden Sea (Netherlands), higher eutrophication levels are observed as compared to the northern part. Van Beusekom et al. (2019) suggest that this is due to the more intense coastal accumulation of organic matter produced in the North Sea.

Many invasive benthic species colonize the Wadden Sea (Bütger et al., 2017, QSR 2017). Overall, 81 species have been classified as being alien species, i.e. all life stages of a species, subspecies or genetically distinct populations, introduced outside its natural past or present distribution. Most of the alien species in the Wadden Sea are hard substrate-related species that live on floating docks in marinas (Gittenberger et al., 2010). Also dominant soft-sediment species including the pacific oyster *Magallana gigas*, the American razor clam *Ensis directus* and the spionid worm *Marenzelleria viridis* have been invasive during the last decades. Most of these macrofaunal species have planktonic larvae that occur in the water column for some period of time and thus form part of the plankton. Changes in the macrozoobenthos communities, such as the increase of Shore crabs (*Carcinus maenas*) after 2000, may result in changes in the density and timing of larvae in the water column.

Although little is known on the zooplankton in the Wadden Sea, it may be expected that zooplankton forms an important food source for many higher trophic levels, including:

- shrimps (e.g. the brown shrimp *Crangon crangon*);
- (small) fish, including herring, sprat and sand eel;
- filter-feeding benthos (mussels and other bivalves, barnacles, sea-anemones);
- gelatinous plankton (jellyfish and ctenophores).

Changes in the abundances of these zooplankton predators, induced by e.g. fisheries and climate change, will also have an impact on the composition, biomass and production of zooplankton. Vice versa, changes in zooplankton by bottom-up regulation (i.e. mainly via phytoplankton) will affect the zooplankton predators. So far, zooplankton research has made no link with predation by fish, only to larger zooplankton (hydromedusa, comb jellies) (van Walraven et al., 2017) or invertebrate predation (Daan, 1989).
The invasive ctenophore species *Mnemiopsis leidyi* is responsible for most of the predation pressure of gelatinous plankton on the mesozooplankton in the Wadden Sea (van Walraven et al., 2017). Grazing pressure on zooplankton is especially high during August-October when bivalve larvae of *Magallana gigas* and *Ensis directus* are abundant. In some occasions, high densities of *M. leyidyi* may be able to control zooplankton stocks (copepods) as well.
The scarce data suggest that between the 1980s and 2012 the abundance of native gelatinous zooplankon (jellyfish) species either showed no clear trend or had decreased. Also grazing rates on zooplankton are found to be low (Van Walraven et al., 2017).

Main conclusions on predation of gelatinous species on mesozooplankton are (van Walraven, 2017):

- jellyfish (scyphomedusa, hydromedusa) densities have somewhat decreased were never an important predator of mesozooplankton in the western Wadden Sea;
- the ctenophore Pleurobrachia pileus, present in spring, has decreased in abundance but was an important predator of mesozooplankton in the 1980s and 1990s;
- the invasive ctenophore Mnemiopsis leidyi (known from the Wadden Sea since 2006) reaches very high densities during autumn and may be able to control mesozooplankton.

In addition to gelatinous species, also pelagic fish is likely to be an important predator of mesozooplankton in the Wadden Sea. A study by Couperus et al. (2016) suggest that the biomass of pelagic fish in summer is an order of magnitude higher in the Western Wadden Sea than the biomass of demersal (flat)fish. Main species observed were sprat (*Sprattus sprattus*), young herring (*Clupea harengus*), anchovy (*Engraulis encrasicolus*) and pilchard (*Sardinus pilchardus*). In spring also sandeel (*Ammodytes* spp.) contributed substantially to the biomass. All these fish species are known to feed mainly on mesozooplankton. Due to their small size, these small pelagic fish form an important food source for predatory fish, sea birds and also sea mammals. In this way, they form a link between the zooplankton and the higher trophic levels.

As a result of climate change, the spring blooms of phytoplankton in the Wadden Sea occur ever later in the Wadden Sea but earlier in the North Sea. The Quality Status Report (QSR, 2009) reports: "As a result, fish larvae and young shrimp occur earlier in the Wadden Sea. Such shifts in seasonal dynamics lead to a mismatch between phytoplankton and zooplankton peaks, between shrimp and shellfish larvae, between zooplankton and fish, and between fish and sea birds (Beaugrand et al., 2003; Edwards and Richardson, 2004). These observations indicate that shifts in population sizes of many species may be expected, which may lead to mis-matches with lower and higher trophic levels (Ferreira et al., 2023).

4 Zooplankton species

4.1 Sources for Wadden Sea zooplankton biodiversity

In order to study the biodiversity of zooplankton in the Dutch Wadden Sea, an overview is needed of the species that may inhabit the Wadden Sea and other Dutch coastal and transitional waters.

A number of data sets have been taken into consideration to compile a list of species:

- Fransz, 1983;
- Van Ginderdeuren et al., 2012;
- Greve et al., 2004.

4.1.1 Species in the Wadden Sea

The paper by Fransz (1983) covers all zooplankton species that occur in the Dutch, German or Danish Wadden Sea. This concerns "real" zooplankton species (holoplankton) and larvae of benthic animals (meroplankton). The list does not contain vertebrates (fish). For each species, it is indicated in which countries it was found. For some species it is also indicated whether it is a common species, whether it is a North Sea species or whether it is a brackish water species.

In order to prepare a gross list, it was decided to select all species, regardless of the country of occurrence and generality. In addition to the species name, one or two higher taxonomic classifications have been given for the species. Example: *Harmothoe imbricata* belongs to the Errantia, which in turn forms part of the Polychaeta. Because the list is already old, species names may have changed.

The list contains the true Wadden Sea species, i.e. brackish water species and coastal zone species. The naming can be outdated.

4.1.2 Species from the Belgian part of the North Sea

Van Ginderdeuren et al. (2012) drew up a list of marine species that were found in the Belgian part of the North Sea in 2009-2010. This concerns 137 taxa, a number of which were not previously known for this part of the North Sea. A distinction has been made between holoplankton, meroplankton and tychoplankton (fish larvae). In addition to invertebrates, fish are included as meroplankton.

For each species it is indicated what the average and maximum density was, in which season the species was found and whether the species was found along the coast, offshore and / or in between.

The list is an up-to-date list of the most common species in the shallow coastal zone. These species could also be present in the Wadden Sea in particular.

4.1.3 Species around Helgoland

Greve et al (2004) distinguished 76 mesozooplankton taxa and 367 macrozooplankton taxa from around the isle of Helgoland in the German Bight of the North Sea. The list also contains length classes or larval stages for some species. These have been removed for the purpose of including a species only once in the list. In addition, a number of taxa were identified not by the species level but only to the genus level. These "species" were placed in the list, but only if no other species of the same genus were listed. In a number of cases, higher taxa (families, orders, group name) are also in the list. These have all been removed from the selection. In the end, 142 species and 41 genera remained.

The list contains species that mainly occur somewhat further offshore. Many taxa are not identified by type but by genus or higher level.

4.2 Species list

The data sets above have been combined to arrive at a single list of species appointed to a higher level taxon. Duplications have been removed from the list and genus names have been deleted if there are also species of the same genus in the list. Subspecies have been reduced to species name and deleted when duplicated. For the finally selected taxa, it is indicated from which dataset(s) the species originates. The combined list contained 414 species (or genera/taxa) and is presented in Annex 1. *Table **2*** shows the distribution of these taxa over the higher taxonomic groups. The zooplankton is dominated by crustacean species.

Table 2 Distribution of numbers of species (n) over different taxonomic groups, based on compiled data from several sources (see text)

Group	Number
Chromista	29
Ctenophora	5
Cnidaria	59
Bryozoa	4
Phoronida	1
Platyhelminthes	3
Nemertea	1
Rotifera	8
Chaetognatha	4
Annelida	53
Mollusca	31
Arachnida	1
Crustacea	170
Echinodermata	10
Chordata	35
Total	414

5 Monitoring zooplankton

Several factors should be taken into account when designing a monitoring programme for zooplankton in the Wadden Sea, including the parameters of interest, the diversity and life cycles of zooplankton and characteristics of the Wadden Sea.

Recently, an inventory was made of the policy aims for zooplankton in the Wadden Sea (Jak & van Walraven, 2022) (and also North Sea (Jak et al., 2022)). It was concluded that the zooplankton is an important part of the underwater nature of the Wadden Sea and contributes to the achievement of targets for higher trophic levels (fish and fish-eating birds) and the quality of habitat types (due to the planktonic larvae of benthos species and the significance for the nursery/ growing up function). In addition, the zooplankton as a grazer of phytoplankton also influences the assessment of the eutrophication of the Wadden Sea.

Parameters of interest identified by Jak & van Walraven (2022) were timeseries that provide insight into the trends in:

- biodiversity, including invasive species
- the role in the food web as a contribution to higher trophic levels (fish and fish-eating birds)
- the seasonal development in biomass and species composition, for holoplankton and meroplankton (larvae of benthic animals).

Since the composition of zooplankton communities is very diverse with regard to taxonomy, size and role in the foodweb, it should be specified what the focus is of the monitoring. Most of the interest is in the mesozooplankton size-fraction, consisting of species retained by a 200 µm net, and passing a 2 cm net. This size fraction mainly includes copepod species that are part of the holoplankton (species that stay in the water column during their complete life-cycle) and meroplankton (benthic species of which the larvae grow up in the water column).

Challenges for zooplankton monitoring in the Wadden Sea relate to its high turbidity, shallowness and spatial variability. High turbidity may hamper the application of in situ optical and acoustic methods to detect zooplankton, whereas the shallowness complicate the use of traditional horizontal or oblique net hauls, which are common practise in the open sea. Surveys could take this into account by sampling shallower locations during high tide and/or by using fixed nets that make use of the water current to let water with plankton pass the net. Since the spatial variability in the Wadden Sea is high, with channels connected to the North Sea and shallow tidal flats, the horizonal variation in the composition of zooplankton communities is also likely to be high.

Observations should be therefore be made at appropriate temporal, horizontal and vertical resolution to resolve multiscale natural variability (Karlson & Lopes, 2009). It is essential to make observations at frequencies high enough to resolve natural variability, but also not high enough to make unneeded costs. Point measurements at a low temporal frequency (e.g. monthly) does not provide information with adequate detail on the variability of phyto- and zooplankton biomass, biodiversity, primary production, secondary production and other important parameters and may produce artefacts (aliasing) which disguise the actual signal. Systematic long term sampling and measurements are likely to be the only way to assess deviations from natural variation, such as the effects of fisheries, conservation management and/or climate change.

6 Quality Assurance

Wageningen Marine Research utilises an ISO 9001:2015 certified quality management system. The organisation has been certified since 27 February 2001. The certification was issued by DNV.

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Justification

Report C003/23
Project Number: 4318300116

The scientific quality of this report has been peer reviewed by a colleague scientist and a member of the Management Team of Wageningen Marine Research

Approved: Lodewijk van Walraven
Researcher

Signature: 

Date: 30 January 2023

Approved: Tammo Bult
Director

Signature: 

Date: 30 January 2023

Annex 1 Species list

List of species that may be present in the Dutch Wadden Sea, based on the following sources:

1. Fransz, H. G. (1983). Zooplankton species of the Wadden Sea. In W. J. Wolff (ed.). Marine Zoology, Ecology of the Wadden Sea. 4. Invertebrata. Balkema, Rotterdam: 12–23.
2. Van Ginderdeuren K., Fiers F., De Backer A., Vincx M., Hostens K. (2012). Updating the zooplankton species list for the Belgian part of the North Sea. Belg. J. Zool., 142 (1) : 3-22
3. Greve W., Reiners F., Nast J., Hoffman S. (2004). Helgoland roads meso- and macrozooplankton time-series 1974 to 2004: lessons from 30 years of single spot, high frequency sampling at the only off-shore island of the North Sea. Helgoland Marine Research 58: 274–288.

Numbers in the table refer to the source the species (or taxon) is mentioned, numbers between brackets indicate that only the genus (and not the species) was reported.

Group	**Species / taxa**	**Source 1**	**Source 2**	**Source 3**
Ciliata	*Lohmaniella spiralis*	1		
Ciliata	*Mesodinium rubrum*	1		
Ciliata	*Strombidium conicum*	1		
Ciliata	*Strombidium strobilus*	1		
Ciliata	*Strombidium styliferum*	1		
Ciliata	*Strombilidium acuminatum*	1		
Ciliata	*Strombilidium caudatum*	1		
Ciliata	*Strombilidium marinum*	1		
Ciliata	*Strombilidium pelagicum*	1		
Ciliata	*Vorticella marina*	1		
Ciliata	*Vorticella microstoma*	1		
Ciliata	*Zoothamnion abusculum*	1		
Dinoflagellata	*Noctiluca milliaris*	1		
Dinoflagellata	*Noctiluca scintillans*		2	3
Foraminifera	*Pulvinulina spp.*	1		
Radiozoa	*Plagiacantha arachnoides*	1		
Tintinnina	*Amphorella subulata*	1		
Tintinnina	*Dadayella jorgenseni*	1		
Tintinnina	*Favella ehrenbergii*	1		
Tintinnina	*Favella serrata*	1		
Tintinnina	*Tintinnidium incertum*	1		
Tintinnina	*Tintinnopsis beroida*	1		
Tintinnina	*Tintinnopsis campanula*	1		
Tintinnina	*Tintinnopsis fimbriata*	1		
Tintinnina	*Tintinnopsis lobiancoi*	1		
Tintinnina	*Tintinnopsis parvula*	1		
Tintinnina	*Tintinnopsis tubulosa*	1		
Tintinnina	*Tintinnopsis turbo*	1		
Tintinnina	*Tintinnopsis ventricosa*	1		
Ctenophora	*Beroe cucumis*	1		3
Ctenophora	*Beroe gracilis*	1	2	3
Ctenophora	*Bolinopsis infundibulum*	1		3

Ctenophora	*Mnemiopsis leidyi*		2	
Ctenophora	*Pleurobrachia pileus*	1	2	3
Anthozoa	*Alcyonium digitatum*	1		
Anthozoa	*Arachnactis bournei*	1		(3)
Anthozoa	*Peachia spp.*			3
Anthozoa	*Sagitaria*	1		
Hydrozoa	*Agastra mira*			3
Hydrozoa	*Aglantha digitale*	1		3
Hydrozoa	*Amphinema dinema*		2	3
Hydrozoa	*Amphinema rugosum*			3
Hydrozoa	*Aurelia aurita*	1	2	3
Hydrozoa	*Bougainvillia britannica*			3
Hydrozoa	*Bougainvillia macloviana*			3
Hydrozoa	*Bougainvillia principis*			3
Hydrozoa	*Bougainvillia ramosa*	1		3
Hydrozoa	*Chrysaora hysoscella*	1	2	3
Hydrozoa	*Cladonema radiatum*			3
Hydrozoa	*Clytia hemisphaerica*		2	
Hydrozoa	*Cosmetira pilosella*			3
Hydrozoa	*Cyanea capillata*	1		3
Hydrozoa	*Cyanea lamarckii*	1	2	3
Hydrozoa	*Ectopleura dumortieri*	1		3
Hydrozoa	*Eirene viridula*			3
Hydrozoa	*Eucheilota maculata*	1	2	3
Hydrozoa	*Euphysa aurata*			3
Hydrozoa	*Eutima gegenbauri*	1		3
Hydrozoa	*Eutima gracilis*		2	3
Hydrozoa	*Eutima insignis*			3
Hydrozoa	*Eutonina indicans*		2	3
Hydrozoa	*Helgicirrha cari*			3
Hydrozoa	*Helgicirrha schulzei*			3
Hydrozoa	*Hybocodon prolifer*	1		3
Hydrozoa	*Laodicea undulata*			3
Hydrozoa	*Leuckartiara octona*			3
Hydrozoa	*Lizzia blondina*	1		3
Hydrozoa	*Lovenella clausa*		(2)	3
Hydrozoa	*Margelopsis haeckeli*	1	2	3
Hydrozoa	*Melicertum octocostatum*			3
Hydrozoa	*Mitrocomella brownei*			3
Hydrozoa	*Mitrocomella polydiademata*			3
Hydrozoa	*Muggiaea atlantica*			3
Hydrozoa	*Nanomia cara*			3
Hydrozoa	*Nemopsis bachei*	1	2	3
Hydrozoa	*Obelia*	1	(2)	(3)
Hydrozoa	*Phialella quadrata*			3
Hydrozoa	*Phialidium haemisphaericum*	1		3
Hydrozoa	*Podocoryne borealis*			3
Hydrozoa	*Podocoryne carnea*			3
Hydrozoa	*Rathkea octopunctata*	1	2	3

Hydrozoa	*Rhizostoma octopus*	1		3
Hydrozoa	*Rhizostoma pulmo*		2	
Hydrozoa	*Sarsia eximia*			3
Hydrozoa	*Sarsia gemmifera*	1		3
Hydrozoa	*Sarsia prolifera*			3
Hydrozoa	*Sarsia tubulosa*	1	2	3
Hydrozoa	*Steenstrupia nutans*	1		3
Hydrozoa	*Tiaropsis multicirrata*			3
Hydrozoa	*Tima bairdi*			3
Hydrozoa	*Tubularia larynx*	1		
Hydrozoa	*Turritopsis matriculata*	1		
Hydrozoa	*Zanclea costata*			3
Bryozoa	*Bryozoa sp.*		2	
Bryozoa	*Electra crustulenta*	1		
Bryozoa	*Electra pilosa*	1		
Bryozoa	*Membranipora membranacea*	1		
Phoronida	*Phoronis muelleri*	1	(2)	
Platyhelminthes	*Platyhelminthes sp.*		2	
Turbellaria	*Alaurina composita*	1		3
Turbellaria	*Plagiostomum vittatum*	1		
Nemertea	*Nemertea sp.*		2	
Rotifera	*Brachionus mülleri*	1		
Rotifera	*Keratella cruciformis*	1		
Rotifera	*Notholca acuminata*	1		
Rotifera	*Synchaeta littoralis*	1		
Rotifera	*Synchaeta triophtalma*	1		
Rotifera	*Synchaeta vorax*	1		
Rotifera	*Testudinella clypeata*	1		
Rotifera	*Trichocerca marina*	1		
Chaetognatha	*Parasagitta elegans*		2	
Chaetognatha	*Parasagitta setosa*		2	
Chaetognatha	*Sagitta elegans*	1		3
Chaetognatha	*Sagitta setosa*	1		3
Annelida	*Anaitides maculata*	1		
Annelida	*Arenicola marina*	1		
Annelida	*Autolytus branchycephalus*	1		(3)
Annelida	*Autolytus edwardsi*	1		(3)
Annelida	*Autolytus prolifer*	1		(3)
Annelida	*Capitella capitata*	1		
Annelida	*Chaetopterus variopedatus*	1		
Annelida	*Eteone longa*	1		
Annelida	*Eulalia viridus*	1		
Annelida	*Harmothoe imbricata*	1		
Annelida	*Harmothoe impar*	1		
Annelida	*Heteromastus filiformis*	1		
Annelida	*Lanice conchilega*	1		(3)
Annelida	*Laonice cirrata*	1		
Annelida	*Lepidonotus squamatus*	1		
Annelida	*Magelona papillicornis*	1		(3)

Annelida	*Nephtys caeca*	1		
Annelida	*Nephtys ciliata*	1		
Annelida	*Nephtys hombergii*	1		
Annelida	*Nereis diversicolor*	1		
Annelida	*Nereis succinea*	1		
Annelida	*Nereis virens*	1		
Annelida	*Nereis zonata*	1		
Annelida	*Nicolea zostericola*	1		
Annelida	*Oligochaeta sp.*		2	
Annelida	*Owenia fusiformis*	1		
Annelida	*Pectinaria auricoma*	1		(3)
Annelida	*Pectinaria belgica*	1		(3)
Annelida	*Pectinaria koreni*	1		(3)
Annelida	*Pholoe minuta*	1		
Annelida	*Polydora caeca*	1		
Annelida	*Polydora ciliata*	1		
Annelida	*Polydora hermaphroditica*	1		
Annelida	*Polydora ligni*	1		
Annelida	*Polydora pulchra*	1		
Annelida	*Polydora quadrilobata*	1		
Annelida	*Polydora redekei*	1		
Annelida	*Prionospio cirrifera*	1		
Annelida	*Prionospio malmgreni*	1		
Annelida	*Prionospio steenstrupi*	1		
Annelida	*Proceraea cornuta*	1		
Annelida	*Proceraea prismatica*	1		
Annelida	*Pygospio elegans*	1		
Annelida	*Sabellaria spinulosa*	1		
Annelida	*Scolelepis foliosa*	1		
Annelida	*Scolelepis squamata*	1		
Annelida	*Scoloplos armiger*	1		
Annelida	*Spio filicornis*	1		
Annelida	*Spiophanes bombyx*	1		
Annelida	*Spiophanes kröyeri*	1		
Annelida	*Streblospio shrubsoli*	1		
Annelida	*Tomopteris helgolandica*	1	2	3
Annelida	*Tomopteris septendrionalis*			3
Mollusca	*Angulus tenuis*	1		
Mollusca	*Bivalvia sp.*		2	
Mollusca	*Cerastoderma edule*	1		
Mollusca	*Coecum glabrum*	1		
Mollusca	*Crepidula fornicata*	1		
Mollusca	*Ensis sp.*		2	
Mollusca	*Gastropoda sp.*		2	
Mollusca	*Hydrobia ulvae*	1		
Mollusca	*Hydrobia ventrosa*	1		
Mollusca	*Limapontia capitata*	1		
Mollusca	*Littorina littorea*	1		
Mollusca	*Loligo sp.*		2	

Mollusca	*Lora turricola*	1		
Mollusca	*Macoma baltica*	1		
Mollusca	*Mya arenaria*	1		
Mollusca	*Mya truncata*	1		
Mollusca	*Mysella bidentata*	1		
Mollusca	*Mytilus edulis*	1		
Mollusca	*Nassarius reticulatus*	1		
Mollusca	*Natica catena*	1		
Mollusca	*Natica poliana*	1		
Mollusca	*Onoba vitrea*	1		
Mollusca	*Pectinidae sp.*		2	
Mollusca	*Philine quadripartita*	1		
Mollusca	*Piliscus sp.*			3
Mollusca	*Retusa retusa*	1		
Mollusca	*Scrobicularia plana*	1		
Mollusca	*Spisula subtruncata*	1		
Mollusca	*Teredo navalis*	1		
Mollusca	*Venus striatula*	1		
Mollusca	*Zirfaea crispata*	1		
Arachnida	*Acari sp.*		2	
Amphipoda	*Amphilochus neapolitanus*		2	
Amphipoda	*Apherusa bispinosa*		2	
Amphipoda	*Apherusa clevei*	1		
Amphipoda	*Apherusa ovalipes*		2	
Amphipoda	*Atylus falcatus*		2	
Amphipoda	*Atylus swammerdami*		2	
Amphipoda	*Bathyporea pelagica*	1	(2)	
Amphipoda	*Bathyporea pilosa*	1	(2)	
Amphipoda	*Bathyporea sarsi*	1	(2)	
Amphipoda	*Calliopius rathkei*	1		
Amphipoda	*Caprella linearis*	1	2	(3)
Amphipoda	*Corophium arenarium*	1		
Amphipoda	*Corophium insidiosum*	1		
Amphipoda	*Corophium lacustre*	1		
Amphipoda	*Corophium sextoni*	1		
Amphipoda	*Corophium volutator*	1	(2)	
Amphipoda	*Gamarellus angulosus*	1		
Amphipoda	*Gammarus crinicornis*		2	
Amphipoda	*Gammarus locusta*	1		
Amphipoda	*Gammarus oceanicus*	1		
Amphipoda	*Gammarus salinus*	1	2	
Amphipoda	*Gammarus zaddachi*	1		
Amphipoda	*Hippomedon denticulatus*	1		
Amphipoda	*Hyperia galba*	1	2	
Amphipoda	*Hyperia galba*		2	
Amphipoda	*Hyperoche medusarum*			
Amphipoda	*Jassa falcata*	1		3
Amphipoda	*Jassa herdmani*		2	
Amphipoda	*Leucothoe incisa*		2	

Amphipoda	*Marinogammarus marinus*	1		
Amphipoda	*Megaluropus agilis*		2	
Amphipoda	*Melita palmata*	1		
Amphipoda	*Microprotopus maculatus*	1	2	
Amphipoda	*Monoculodes carinatus*	1		
Amphipoda	*Nototropis falcatus*	1		
Amphipoda	*Nototropis swammerdami*	1		
Amphipoda	*Nototropis vedlomensis*	1		
Amphipoda	*Orchomenella nana*		2	
Amphipoda	*Parathemisto oblivia*	1		
Amphipoda	*Pariambus typicus*		2	
Amphipoda	*Phthisica marina*	1		
Amphipoda	*Pontocrates altamarinus*	1	2	
Amphipoda	*Pontocrates arenarius*		2	
Amphipoda	*Rivulogammarus duebeni*	1		
Cirripedia	*Balanus balanoides*	1		(2)
Cirripedia	*Balanus crenatus*	1		(2)
Cirripedia	*Balanus improvisus*	1		(2)
Cirripedia	*Elminius modestus*	1		
Cladocera	*Evadne nordmanni*	1	2	
Cladocera	*Evadne spinifera*	1		(3)
Cladocera	*Penilia avirostris*		2	3
Cladocera	*Pleopsis polyphemoides*	1		
Cladocera	*Podon intermedius*	1		
Cladocera	*Podon leuckarti*	1	2	(3)
Copepoda	*Acartia bifilosa*	1		
Copepoda	*Acartia clausi*	1	2	
Copepoda	*Acartia discaudata*	1		
Copepoda	*Acartia longiremis*	1		(3)
Copepoda	*Acartia tonsa*	1		(3)
Copepoda	*Anomalocera patersoni*	1		3
Copepoda	*Calanus finmarchicus*	1		(3)
Copepoda	*Calanus helgolandicus*	1	2	(3)
Copepoda	*Caligus rapax*	1		(3)
Copepoda	*Candacia armata*		2	3
Copepoda	*Centropages hamatus*	1	2	3
Copepoda	*Centropages typicus*	1	2	3
Copepoda	*Corycaeus anglicus*	1	2	(3)
Copepoda	*Cyclopinoides littoralis*	1	2	(3)
Copepoda	*Cymbasoma germanicum*		2	
Copepoda	*Eurytemora affinis*	1		
Copepoda	*Euterpina acutifrons*	1	2	3
Copepoda	*Giardella callianassae*		2	
Copepoda	*Isias clavipes*	1	2	
Copepoda	*Labidocera wollastoni*	1	2	3
Copepoda	*Metridia lucens*		2	
Copepoda	*Microsetella norvegica*	1		(3)
Copepoda	*Monstrilla spp.*			3
Copepoda	*Oithona nana*	1	2	

Copepoda	*Oithona similis*	1	2	(3)
Copepoda	*Oncea venusta*	1	(2)	
Copepoda	*Paracalanus parvus*	1	2	3
Copepoda	*Parapontella brevicornis*	1		
Copepoda	*Pseudocalanus elongatus*	1	2	3
Copepoda	*Temora longicornis*	1	2	3
Copepoda	*Tisbe furcata*	1		(3)
Cumacea	*Bodotria arenosa*		2	
Cumacea	*Bodotria pulchella*	1		
Cumacea	*Bodotria scorpioides*	1	2	
Cumacea	*Cumopsis goodsirii*	1		
Cumacea	*Diastylis rathkei*	1	2	3
Cumacea	*Iphinoe trispinosa*			3
Cumacea	*Lamprops fasciata*	1		
Cumacea	*Monopseudocuma gilsoni*		2	
Cumacea	*Pseudocuma longicorne*	1	2	
Cumacea	*Pseudocuma simile*		2	
Cumacea	*Pseudocuma sp.*		2	3
Decapoda	*Anomura megalopa*		(2)	3
Decapoda	*Athanas nitescens*			3
Decapoda	*Brachyura sp.*		2	
Decapoda	*Callianassa subterranea*		(2)	3
Decapoda	*Cancer pagurus*	1		3
Decapoda	*Carcinus maenas*	1		3
Decapoda	*Caridea sp.*		2	
Decapoda	*Caridion steveni*			3
Decapoda	*Corystes cassivelaunus*			3
Decapoda	*Crangon allmanni*			3
Decapoda	*Crangon crangon*	1	2	3
Decapoda	*Decapoda sp.*		2	
Decapoda	*Ebalia spp.*			3
Decapoda	*Eualus occultus*			3
Decapoda	*Eualus pusiolus*			3
Decapoda	*Eupagurus bernhardus*	1		
Decapoda	*Galathea spp.*			3
Decapoda	*Hippolyte varians*			3
Decapoda	*Homarus gammarus*			3
Decapoda	*Hyas araneus*	1		(3)
Decapoda	*Liocarcinus sp.*			3
Decapoda	*Macropipus holsatus*	1		
Decapoda	*Macropodia rostrata*			3
Decapoda	*Pagurus bernhardus*			3
Decapoda	*Palaemon adspersus*	1		(3)
Decapoda	*Palaemon elegans*	1		(3)
Decapoda	*Palaemon longirostris*	1		(3)
Decapoda	*Pandalina brevirostris*			3
Decapoda	*Pandalus montagui*	1		3
Decapoda	*Philocheras bispinosus*			3
Decapoda	*Philocheras trispinosus*			3

Decapoda	*Pilumnus hirtellus*			3
Decapoda	*Pinnotheres pisum*			3
Decapoda	*Pisidia longicornis*		2	
Decapoda	*Processa modica*		2	3
Decapoda	*Thia scutellata*			3
Decapoda	*Upogebia spp.*			3
Euphausiacea	*Nyctiphanes couchii*		2	3
Euphausiacea	*Thysanoessa inermis*			3
Euphausiacea	*Thysanoessa longicaudata*			3
Euphausiacea	*Thysanoessa raschii*			3
Isopoda	*Eurydice pulchra*	1		3
Isopoda	*Eurydice spinigera*		2	
Isopoda	*Idotea baltica*			3
Isopoda	*Idotea linearis*	1		3
Isopoda	*Idothea balthica*	1		
Isopoda	*Idothea chelipes*	1		
Isopoda	*Idothea granulosa*	1		
Isopoda	*Idothea pelagica*	1		
Isopoda	*Isopoda sp.*		2	
Mysida	*Acanthomysis longicornis*		2	
Mysida	*Anchialina agilis*		2	3
Mysida	*Erythrops spp.*			3
Mysida	*Gastrosaccus sanctus*		2	3
Mysida	*Gastrosaccus spinifer*	1	2	3
Mysida	*Leptomysis mediterranea*	1		3
Mysida	*Mesopodopsis slabberi*	1	2	3
Mysida	*Mysis mixta*	1		
Mysida	*Neomysis integer*	1		3
Mysida	*Neomysis longicornis*			3
Mysida	*Paramysis arenosa*			3
Mysida	*Paramysis helleri*			3
Mysida	*Paramysis kervillei*	1		3
Mysida	*Paramysis ornata*	1		3
Mysida	*Paramysis spiritus*	1		3
Mysida	*Praunus flexuosus*	1		3
Mysida	*Praunus inermis*	1		3
Mysida	*Schistomysis kervillei*		2	
Mysida	*Schistomysis ornata*		2	
Mysida	*Schistomysis spiritus*		2	
Mysida	*Siriella armata*	1	2	3
Mysida	*Siriella clausi*			3
Mysida	*Siriella norvegica*	1		
Tanaidacea	*Tanais dulongii*		2	
Echinodermata	*Amphiura filiformis*			3
Echinodermata	*Asterias rubens*	1	2	3
Echinodermata	*Echinocardium cordatum*	1	(2)	
Echinodermata	*Echinocyamus pusillus*	1		
Echinodermata	*Echinus esculentis*	1		
Echinodermata	*Ophiothrix fragilis*	1	2	

Echinodermata	*Ophiura albida*	1	(2)	(3)
Echinodermata	*Ophiura texturata*	1		
Echinodermata	*Psammechinus miliaris*	1	2	3
Echinodermata	*Solaster papposus*	1		
Appendicularia	*Appendicularia*			3
Appendicularia	*Fritillaria borealis*	1		3
Cephalochordata	*Branchiostoma lanceolatum*		2	(3)
Pisces	*Agonus cataphractus*			3
Pisces	*Ammodytes marinus*		2	
Pisces	*Ammodytes tobianus*		2	
Pisces	*Ammodytidae sp.*		2	
Pisces	*Anguilla anguilla*			3
Pisces	*Arnoglossus laterna*		2	
Pisces	*Buglossidium luteum*		2	
Pisces	*Callionymus sp.*		2	
Pisces	*Clupea harengus*		2	
Pisces	*Crystallogobius sp.*			
Pisces	*Cyclopterus lumpus*			3
Pisces	*Echiichthys vipera*		2	
Pisces	*Engraulis encrasicolus*		2	
Pisces	*Gobiidae sp.*		2	
Pisces	*Hyperoplus lanceolatus*		2	
Pisces	*Limanda limanda*		2	
Pisces	*Merlangius merlangus*		2	
Pisces	*Osmerus eperlanus*		2	
Pisces	*Pisces sp.*		2	
Pisces	*Pleuronectes platessa*		2	
Pisces	*Pleuronectiformes sp.*		2	
Pisces	*Pomatoschistus sp.*		2	
Pisces	*Sardina pilchardus*		2	
Pisces	*Solea solea*		2	
Pisces	*Sprattus sprattus*		2	
Pisces	*Syngnathus rostellatus*		2	
Pisces	*Trachinus draco*		2	
Pisces	*Trachurus trachurus*		2	
Pisces	*Triglidae sp.*		2	
Tunicata	*Doliolum nationalis*			3
Tunicata	*Oikopleura dioica*	1	2	3
Tunicata	*Oikopleura labradorensis*	1		

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With knowledge, independent scientific research and advice, **Wageningen Marine Research** substantially contributes to more sustainable and more careful management, use and protection of natural riches in marine, coastal and freshwater areas.

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