

Photo: Christian Buschbaum. *Crepidulamylus*.

Wadden Sea Quality Status Report

Alien species

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1. Introduction

The spread of organisms is in principle a natural process, which is limited by natural geographical barriers. However, human activities have breached those barriers and have - intentionally and unintentionally - transferred species into areas beyond their natural range (Table 1). With intensified global trade, the spread of species outside their natural range was accelerated and now raises concern about biological homogenization (Capinha *et al.*, 2015), threatening of native species and ecosystems, and human health and economic issues (Nehring *et al.*, 2009). The anthropogenic introduction of alien species, in particular invasive ones, seriously violates the guiding principle of the trilateral Wadden Sea policy “to achieve, as far as possible, a natural and sustainable ecosystem in which natural processes proceed in an undisturbed way” (CWSS, 2010; see also Bouma *et al.* 2011). Most alien species became inconspicuous residents and cannot be removed without causing collateral damage to the ecosystem, and more alien species are likely to come (Seebens *et al.*, 2017).

Many alien species have reached the Wadden Sea in the last decades (e.g., see Figure 1 and [Annex](#)). This may enhance diversity in the Wadden Sea but also cause biotic homogenization among regions (Reise *et al.*, 2005; Nehring *et al.*, 2009). There is as yet no evidence that alien species have expelled native organisms from the Wadden Sea (Wolff, 2000; Buschbaum *et al.*, 2012). However, alien species have the potential to alter dominance structures, habitats, and trophic connections, like, e.g., the Pacific oyster *Magallana gigas* and the Japanese seaweed *Sargassum muticum* (Reise *et al.* 2005).

Major vectors of marine species introduction in the North Sea, respectively in the Wadden Sea, are shipping, with species travelling via ballast water and hull fouling, and species imports for aquaculture activities, with species travelling as hitchhikers (Figure 1, Nehring, 2002; Wolff & Reise, 2002; Buschbaum *et al.*, 2012; Schuchardt & Sevilgen, 2015; van der Have *et al.*, 2015). Hull fouling has been described as one of the main transport vectors (Nehring, 2002; Gittenberger *et al.*, 2017), more recent publications state ballast water to be the most important transport vector for marine alien species worldwide, followed by hull fouling (Stranga & Katsanevakis, 2021). Marine alien species reached the Wadden Sea also through secondary dispersal from sites of primary introduction (Buschbaum *et al.*, 2012).

For terrestrial and freshwater species main introduction vectors are horticulture, pet trade and transport (van der Have *et al.*, 2015). Escapes, e.g., from zoos or gardens, can lead to spread and establishment in nature (van der Have *et al.*, 2015; Zieritz *et al.*, 2017; Nehring & Skowronek, 2020; McGrannachan *et al.*, 2021). Nevertheless, it is often unknown or uncertain how an alien species has reached the Wadden Sea.

This thematic report reviews the status and trend of marine and terrestrial alien species in the Wadden Sea, assesses the effects of alien species on the Wadden Sea Plan targets and the criteria for the ‘Outstanding Universal Value’ (OUV) and gives recommendations for monitoring, research, and management.



Figure 1: Examples of alien species in the Wadden Sea (clockwise starting with top left): The Pacific amphipod *Aoroides semicurvatus* was introduced with hull fouling and/or shellfish imports (Photo: Björn Nadarzinski, Labor für Meeresbiologie, Werkstätten Materialhof), the marine yellow-green algae *Vaucheria* cf. *velutina* probably introduced by transoceanic shipping or with shellfish translocation (Photo: Karsten Reise), the Egyptian goose *Alopochen aegyptiaca* intentionally introduced by zoo and pet trade (Photo: Armin Rose), and the racoon dog *Nyctereutes procyonoides* is an escapee from fur-farms (Photo: Michael Gäbler/ [Wikimedia Commons](#)).

Aquatic	Terrestrial
ballast water (commercial shipping <i>and in larger pleasure crafts</i>)	horticulture
ships' hull fouling (commercial and recreational craft)	agriculture crops
canals	seedings
intentional and unintentional aquaculture introductions	pet trade
release from aquaria/ornamental species trade	escape from research/ botanical gardens
release of bait species	<i>Hitchhiking plants, animals and microorganisms that often spread well-hidden and therefore undetected with the listed vectors</i>
discharge of wastes following fish processing	travel and tourism
<i>trading</i> (internet and mail order)	<i>trading</i> (internet and mail order)
natural dispersal	natural dispersal

Table 1: Main possible aquatic and terrestrial vectors for global dispersal of alien species The table was taken from Schuchardt & Sevilgen (2015) who modified it after Gollasch et al. (2013) & fao.org. Additions are in italics. "Natural dispersal" as vector was added.

Definitions

The definitions are cited from the given literature.

Native species (Schuchardt & Sevilgen, 2015)

"Native species" refers to a species, subspecies or genetically distinct populations, occurring within its natural range (past and present).

Alien species^{2,3}

"Alien species" refers to a species, subspecies or lower taxon, introduced outside its natural past or present distribution; includes any part, gametes, seeds, eggs, or propagules of such species that might survive and subsequently reproduce.

Invasive alien species²

"Invasive alien species" means an alien species whose introduction and/or spread threatens biological diversity (For the purposes of the present guiding principles, the term "invasive alien species" shall be deemed the same as "alien invasive species" in decision V/8 of the Conference of the Parties to the Convention on Biological Diversity.).

Introduction²

"Introduction" refers to the movement by human agency, indirect or direct, of an alien species outside of its natural range (past or present). This movement can be either within a country or between countries or areas beyond national jurisdiction.

Intentional introduction²

"Intentional introduction" refers to the deliberate movement and/or release by humans of an alien species outside its natural range.

Unintentional introduction²

"Unintentional introduction" refers to all other introductions which are not intentional.

Problem or nuisance species

A species for which it can be assumed that based on the best available scientific evidence it will have a (significant) negative impact on the conservation goals of a Natura 2000 area.

Cryptogenic species (Tsiamis *et al.*, 2019)

"Cryptogenic species" refers to a "species with no definite evidence of their native or non-indigenous status (due to unknown origin or due to unclear mode of introduction from native range: natural spread vs human mediated)".

Questionable species (Tsiamis *et al.*, 2019)

"Questionable species" refers to a "NIS with insufficient information or new entries not verified by experts or NIS with unresolved taxonomic status.

Establishment

"Establishment" refers to the process of an alien species in a new habitat successfully producing viable offspring with the likelihood of continued survival.

Risk analysis²

"Risk analysis" refers to: (1) the assessment of the consequences of the introduction and of the likelihood of establishment of an alien species using science-based information (i.e., risk

assessment), and (2) to the identification of measures that can be implemented to reduce or manage these risks (i.e., risk management), taking into account socio-economic and cultural considerations.

¹ <https://www.cbd.int/decision/cop/?id=7197>

² Species occurring naturally in neighboring countries of the Wadden Sea and entering independently due to e.g. climate change, do not fall under this definition (Schuchardt & Sevilgen, 2015).

³ NIS = Non-Indigenous Species. The report uses the term “alien species”, the term NIS is cited when used in literature sources. Both terms are considered synonymous in this report.

2. Status and trends

2.1 Status and trends of marine alien species introduction in the Wadden Sea

Within the Wadden Sea Area (see WG-AS & GITTENBERGER 2019), alien species are subject to national monitoring programs. A proposal for a comprehensive trilateral monitoring was developed (Van der Have & Lensink, 2017). Previous records originate from scientific research while since 2009 various national assessments have been carried out (Gittenberger *et al.*, 2009, 2019; Bouma *et al.*, 2011; Schuchardt & Sevilgen, 2015; van der Have *et al.*, 2015; Gittenberger, 2016; see also [Annex](#)) so that the knowledge on alien species in the Wadden Sea countries is continuously developing. Beyond surveys focusing on alien species detecting, several trilateral and national monitoring programs and actions, e.g. blue mussel monitoring or benthos monitoring, deliver valuable additional information about alien occurrences.

The baseline for a further trend evaluation was accomplished (Buschbaum *et al.*, 2012; Gittenberger *et al.*, 2015; Lackschewitz *et al.*, 2015; Rohde *et al.*, 2015) and these activities are relatively new as compared to all other monitoring efforts in the Wadden Sea. So far, efforts to detect alien species in the three countries mainly focused on macrofauna and -flora/macroorganisms, on (semi-)terrestrial and freshwater plants. Other groups are mostly detected by chance in the German and Danish parts of the Wadden Sea. In the Dutch part of the Wadden Sea seaweed species and gelatinous zooplankton are also specifically targeted in surveys on alien species (Gittenberger *et al.*, 2019). Microorganisms are usually not monitored, but specific investigations provide records, such as sanitary programs on bivalve shellfish, proofed the Pacific oyster virus (*Ostreid herpesvirus-1* μ var) to be present in the Wadden Sea.

The trilateral list of Wadden Sea alien species (see [Annex](#)) displays the latest status of 113 alien species recorded in the Wadden Sea Area. The list includes only marine species but ignores terrestrial and freshwater taxa occurring on the Wadden Sea islands.

The alien species inventory list of the [Wadden Sea Quality Status Report 2017](#) included 90 species of which the ascidian *Botryllus schlosseri* was removed after revision because it was later considered to be native. The brackish water bivalve *Rangia cuneata* and the hydrozoan *Garveia franciscana* were only found inside a lock, but not in the Wadden Sea Area, so that the 2017 list must be reduced to 87 species in total, respectively the numbers for each country (compare Figure 2). Accordingly, 26 new marine alien species were detected until 2020 in the Wadden Sea Area.

Five species were detected in the margins (e.g., Kiel canal) of the Wadden Sea Area ([Annex](#)). Some of these

alien species were included in the Trilateral alien species list of the [QSR 2017](#). They are not included in the Trilateral alien species list of 2021 however, as it was trilaterally decided in 2019 to focus alien species management on the Wadden Sea Area, and these species were recorded outside of this area. The borders of this area are illustrated in the Trilateral Wadden Sea Management and Action Plan for Alien Species (WG-AS & Gittenberger, 2019).

In the [Annex](#), two species, which have recently been found, are described in more detail by way of example.

2.1.1 The Netherlands

In the Netherlands, four surveys were done in 2009, 2011, 2014 and 2019, which specifically focused on the detection of alien species in the Dutch Wadden Sea (Gittenberger *et al.*, 2009, 2010, 2012, 2015, 2019). These surveys provided almost 35 new alien species for the Dutch Wadden Sea, raising the number of registered aliens in the Dutch Wadden Sea to 90 (Gittenberger *et al.*, 2015; Gittenberger, 2016). Many of these alien species were probably already present in the area far before the first survey in 2009. They might have been missed because the other monitoring programs focussed primarily on soft substrates and natural environments while most of the alien species in the Wadden Sea are associated with hard substrates, such as floating docks in marinas (Gittenberger *et al.*, 2010, 2019).

2.1.2 Germany

In the German Wadden Sea, 52 alien species were registered until 2010 (Buschbaum *et al.*, 2012). Between 2009 and 2015, 9 additional species were recorded for the first time by a rapid assessment survey (RAS) for the German Wadden Sea. Detailed information on most of the species is summarized in Lackschewitz *et al.* (2015). Between 2017 and 2020, another 9 species were detected, not including pelagic microbiota. Since 2009, on average about two alien species are discovered annually in the German Wadden Sea. Until 2016, 69 alien species were detected for the German Wadden Sea (Figure 2), considering also other survey data beyond the RAS (Gittenberger *et al.*, 2013). Today, 92 alien species of the macrobiota are known for the German Wadden Sea, 103 species when the microbiota is included.

2.1.3 Denmark

For all Danish Waters (including North Sea and Skagerrak, Kattegat, Limfjorden, Belt Sea, western Baltic), 2 new species were identified per decade from 1900 to 1980, while between 1980 and 2014, 16 new species were identified per decade (Stæhr *et al.* 2016). The report does not provide separate data for the Danish Wadden Sea Area. Until 2016, 27 alien species were detected for the Danish Wadden Sea (Figure 2). In 2017, two new annelid species, *Eteone heteropoda* and *Streblospio benedicti*, were found at Esbjerg, raising the number of alien species to 29.

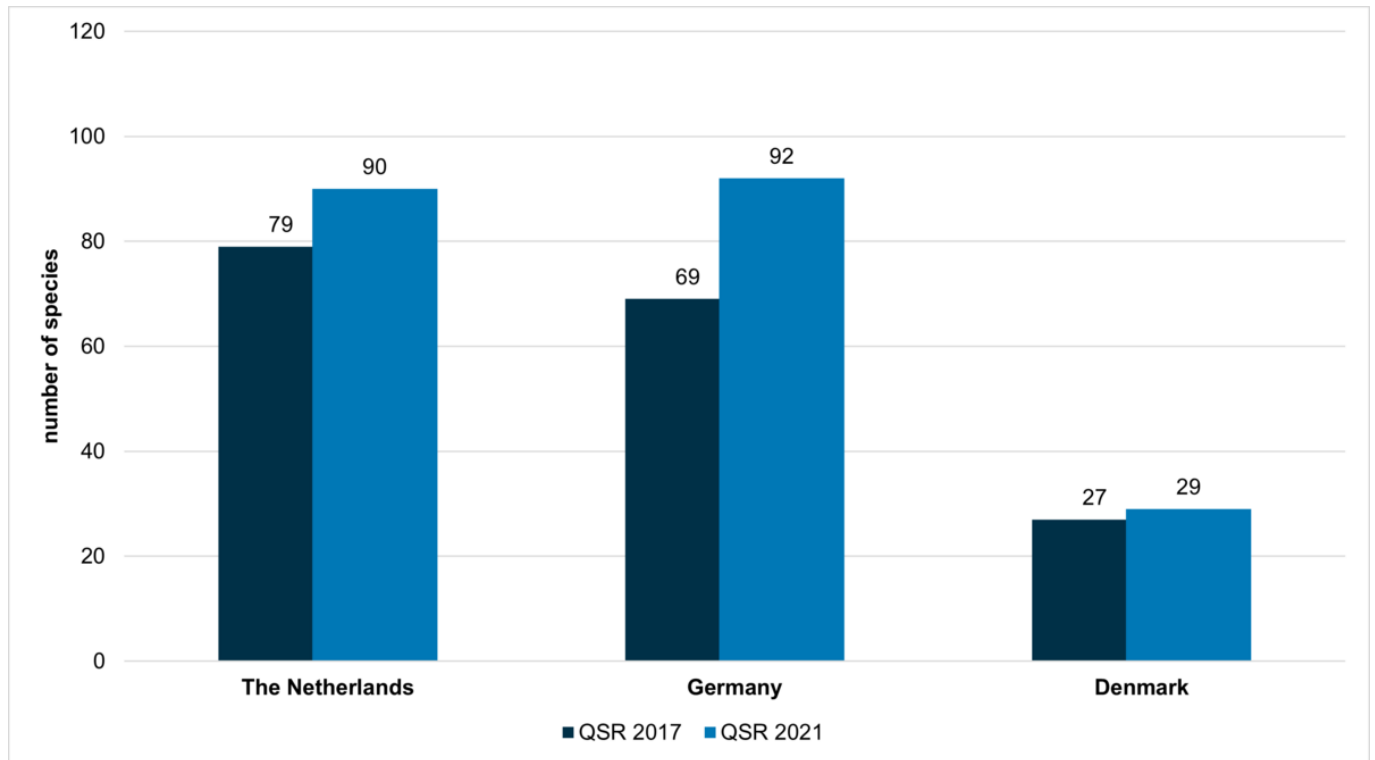


Figure 2: Number of alien benthic species ,including algae, invertebrates and one vascular plant, in the Netherlands, Germany and Denmark according to the trilateral alien species list. The figure comparatively displays the corrected data (see text) from the [QSR 2017](#) (grey bars – Gittenberger 2016) and the updated records up to 2020 (coloured bars – Gittenberger 2021, see [Annex](#)).

2.1.4 Possible vectors and species origin

Possible vectors for the introduction of marine alien species into the Wadden Sea Area (given in Figure 3) can only be identified with uncertainty because species may have been introduced by more than a single vector to various parts of the Wadden Sea. Moreover, the vectors (not including "natural distribution") responsible for the introduction into the Wadden Sea and for the initial introduction to Europe might not be identical. There are numerous examples of species that have initially been introduced to Europe by an anthropogenic vector, such as oyster imports or shipping, but subsequently spread throughout Europe by natural range expansion.

Almost half of the marine alien species originate from the Pacific, whereas almost one third of the species come from the Atlantic and few species from the Mediterranean, Ponto-Caspian or the Southern Hemisphere (Figure 4). For about 20 % of the species the origin is unknown.

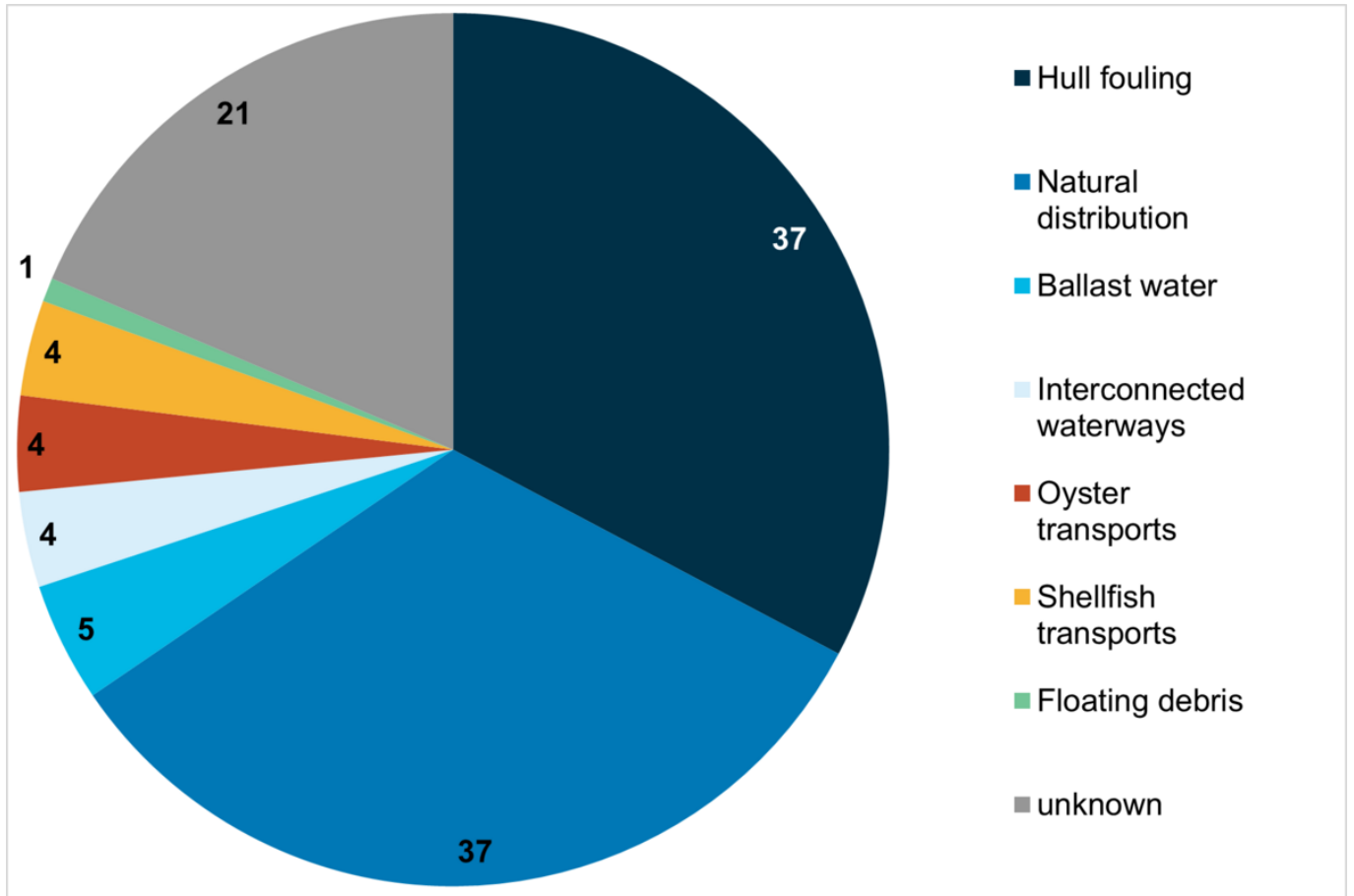


Figure 3: Possible introduction vectors of marine alien species in the Wadden Sea Area including records up to 2020 (Gittenberger 2021, see [Annex](#)). Numbers indicate the total count of taxa for each vector.

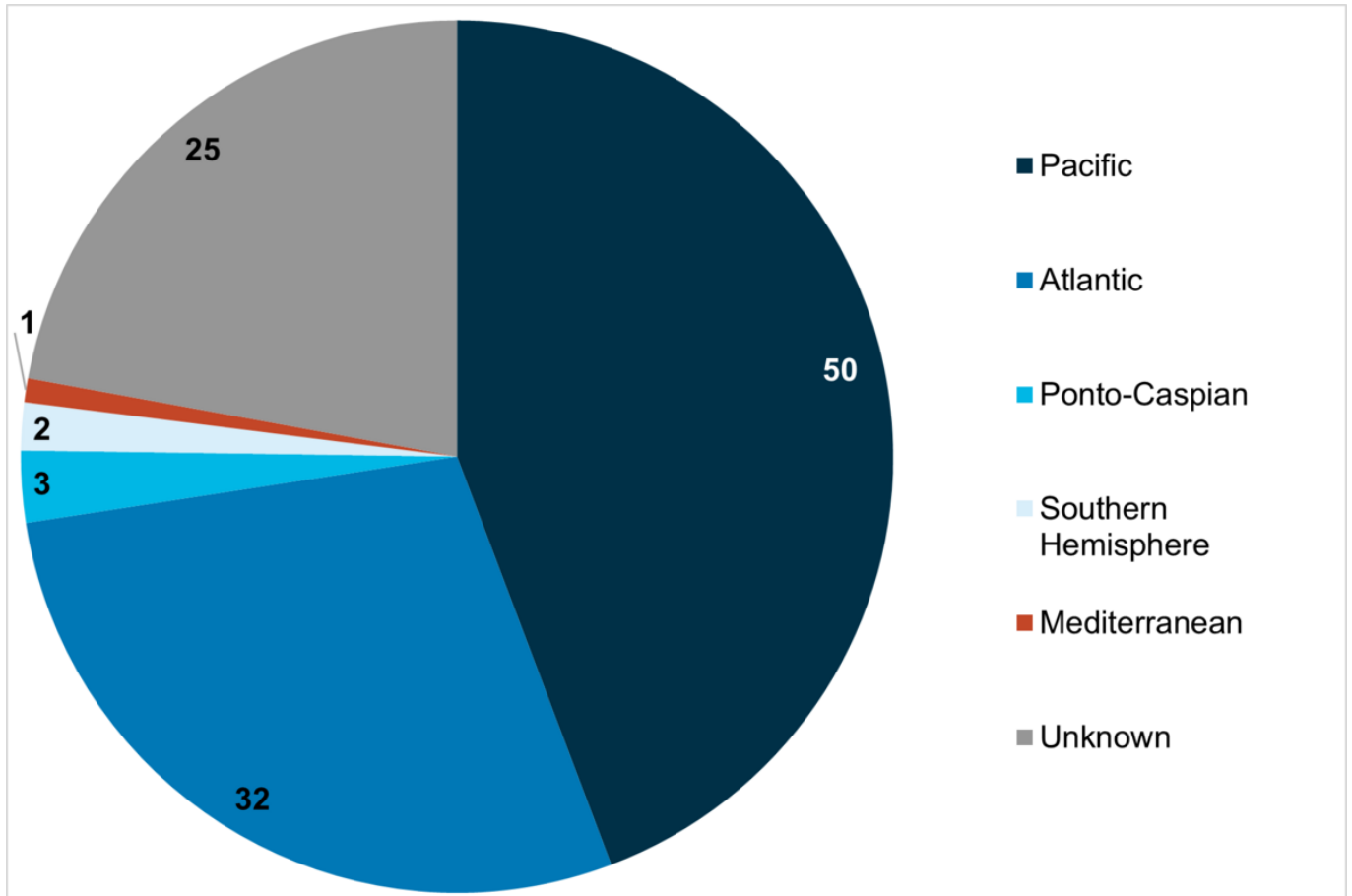


Figure 4: Origin of alien taxa in the Wadden Sea according to the trilateral alien species list (Gittenberger, 2021, see [Annex](#)). Numbers indicate the total count of taxa for each region of origin.

2.1.5 Introduction rate

Between 1900 and 1989, 2-4 species were introduced per decade into the Wadden Sea Area. Since 1990 the rate increased to 10-15 species per decade (VAN DER HAVE & LENSINK 2017, Figure 5). For the period 2011-2020, the rate almost doubled, with more than 20 species added during that decade. One reason for the high number of alien species recorded since ~2009 is the increased monitoring effort and awareness of alien species. Before that time, no targeted surveys throughout the Wadden Sea have been conducted with a specific focus on the detection of alien species.

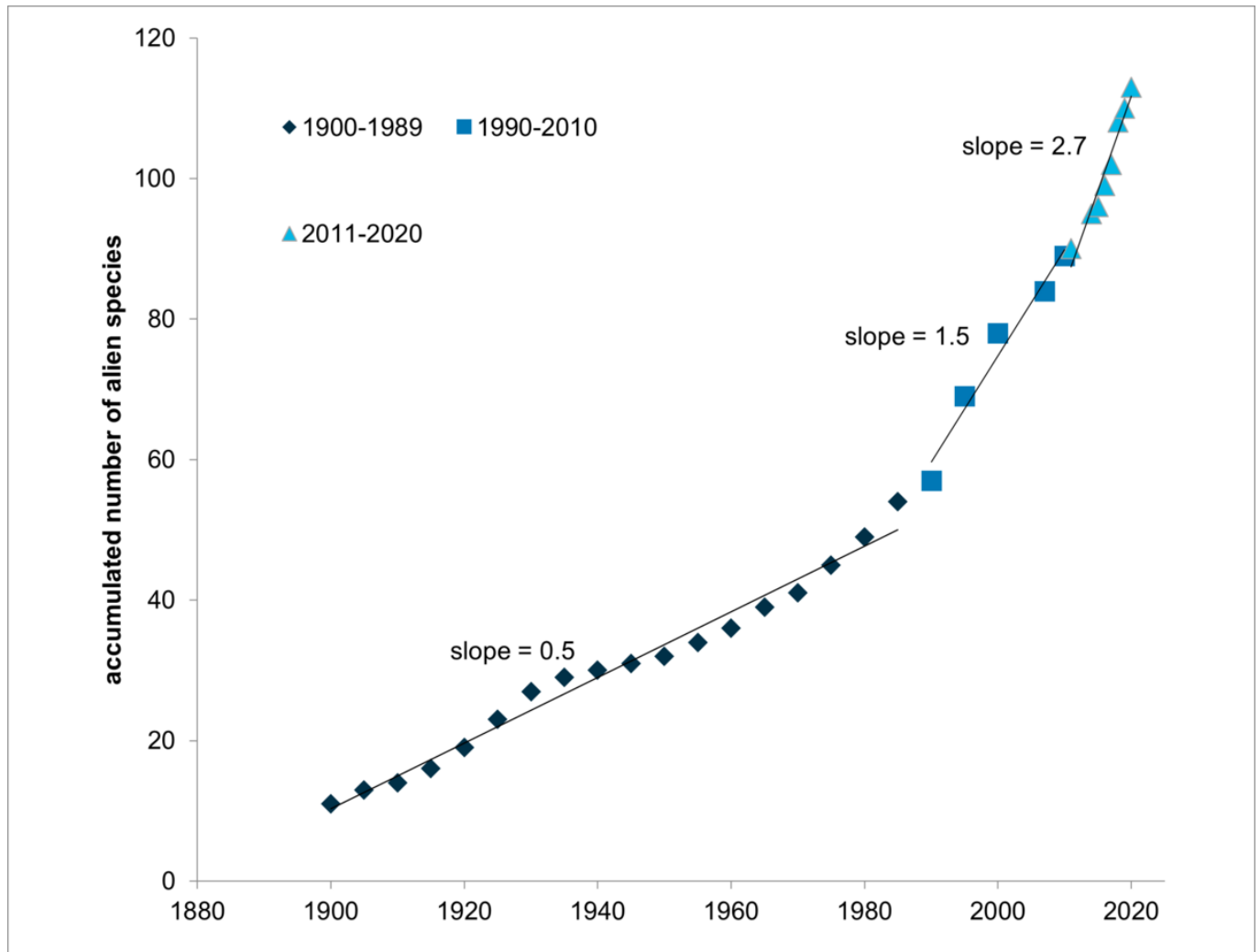


Figure 5: The accumulated number of alien species in the trilateral Wadden Sea Area is presented for the periods 1900-1989, 1990-2010 and 2011-2020. For each species, the year of the first proof of introduction was used (Gittenberger, 2021). The time periods are chosen for comparison with the cumulative number of alien species in Danish marine surveys (Stæhr *et al.*, 2016). Figure taken from Van der Have & Lensink (2017) and updated.

2.2 Status and trends of terrestrial and freshwater alien species introduction in the Wadden Sea Area

Alien species occur in all terrestrial habitats in the Wadden Sea region, from intertidal salt marshes via dunes and dune slacks to forests, and in freshwater habitats like ponds and streams. There is no trilaterally harmonized monitoring or management program on alien species in the terrestrial realm of the Wadden Sea Cooperation Area. Moreover, reliable data for assessing the overall changes in the number and abundance of alien species or their effects on biodiversity and functioning of ecosystems are lacking.

Lensink *et al.* (2015) provided a list of (potentially) threatening alien species on the Dutch Wadden Sea islands and a chapter on terrestrial alien species in the German Wadden Sea is included in Schuchardt & Sevilgen (2015). A first overview of alien species on the German and Danish islands was prepared (Büttger *et al.*, 2017), but a common list for the entire Wadden Sea region is still missing.

2.2.1 Freshwater and terrestrial vascular plants

In 2016, the European Union published a first list of Invasive Alien Species of Union concern, which was updated in 2017 and 2019 (https://ec.europa.eu/environment/nature/invasivealien/list/index_en.htm). Currently, this list contains 62 freshwater and terrestrial vascular plants, of which 20 occur in at least one of the countries of the Trilateral Wadden Sea cooperation. *Baccharis halimifolia* (Eastern baccharis) is the only plant of these 20 species, which is directly associated with characteristic Wadden Sea habitats (dunes and salt marshes). In addition, 13 of the 20 plants of 'Union concern' occurring in Denmark, Germany and/or the Netherlands occur in freshwater ecosystems like wetlands, ponds, lakes or streams, and could thus potentially occur also in the Wadden Sea region.

According to lists on alien species of the Wadden Sea in The Netherlands and Germany provided by Lensink *et al.* (2015) and Schuchardt & Sevilgen (2015), a large share belongs to vascular plants (e.g. *Spartina anglica*; *Rosa rugosa*, Figure 6, Figure 7), but also mosses (*Campylopus introflexus*) and animals of various taxonomic groups (*Branta canadensis*, *Dreissenia polymorpha*, *Cyprinus carpio*, *Felis catus*) are considered invasive aliens.

Many plant species, nowadays considered as invasive aliens in the Wadden Sea region, were intentionally introduced by humans because of their 'beneficial' effects: *Spartina anglica* on tidal flats for coastal erosion control, *Rosa rugosa* to decrease sand drift in dunes and as a beautiful ornamental plant, *Prunus serotina* for improving the nutrient availability in nutrient poor coastal forests. Furthermore, aliens threatening the species-rich vegetation of dune slacks like *Crassula helmsii* are widely reared in aquaria or garden ponds and have escaped or been released from these anthropogenic habitats. Overall, there is a clear positive relation between the number of human inhabitants per island and the occurrence of aliens on Dutch Wadden Sea islands (Lensink *et al.*, 2015). The distance to roads or houses is a major predictor for the occurrence of *Rosa rugosa* in dunes in Denmark (Kollmann *et al.*, 2009).



Figure 6: Common Cordgrass (*Spartina anglica*) in the Wadden Sea. Detailed picture (right) and overview of a local *Spartina*-population (left) (Photos: Kai Jensen).



Figure 7: *Rugosa rose (Rosa rugosa)* (Photo: Martin Stock).

2.2.2 Vertebrates

Several alien vertebrate species occur in the Wadden Sea region. Of these, some are listed on the Union list (see also 2.2.1. and Table 2). Various species, e.g. racoon dog, live on the mainland coast but have a relevant impact as predator on ground-breeding birds (Schwemmer *et al.*, 2021).

Table 2: Examples of wild living alien vertebrates of the Union list in the Wadden Sea region and their possible impacts (Lensink et al. 2015; The Danish Environmental Protection Agency 2017; Nehring & Skowronek 2020).

Scientific name	Name in English, Dutch, German, Danish	Possible impacts (Nehring & Skowronek 2020)
<i>Alopochen aegyptiaca</i>	Egyptian goose Nijlgans Nilgans Egyptisk gås	Competes with other bird species for nesting sites and territories
<i>Nyctereutes procyonoides</i>	Raccoon dog Wasbeerhond Marderhund Mårhund	Predation on eggs and young birds, reptiles, and amphibians. Mainland coast, relevant as predator on ground-breeding birds (Schwemmer <i>et al.</i> , 2021)
<i>Ondatra zibethicus</i>	Muskrat Muskusrat Bisam Bisamrotte	Heavy predation on aquatic and riparian plants and occasionally on animals (e.g., mussels, crayfish, amphibians)
<i>Oxyura jamaicensis</i>	Ruddy Duck Roeiendeend met zwarte kop Schwarzkopf-Ruderente Sortædeåre	Removed in Schleswig-Holstein, hybridises with the European White-headed Duck (<i>Oxyura leucocephala</i>), resource competition with other water birds
<i>Procyon lotor</i>	Racoon Wasbeer Waschbär Vaskebjørn	Heavy predation on eggs and young birds, bats, fish, reptiles, and amphibians; mainland coast, but probably relevant as predator on ground-breeding birds

2.2.3 Alien to the area or not?

It is often challenging to determine whether a species is to be considered native or alien. While foxes are native to the Wadden Sea region, they have not been established naturally on the Wadden Sea islands and thus they could be considered alien species there. Another example is the recent invasion of dunes in Denmark by the grass *Deschampsia flexuosa*, which is native and wide-spread in inland ecosystems but has been absent from coastal dunes half a century ago (Nielsen *et al.*, 2011). Finally, it may be questioned whether the grass *Spartina anglica* is an alien in the Wadden Sea region at all. The species was considered the ‘most important invasive plant in the Wadden Sea’ by Nehring *et al.*, (2009), and it is listed by the World Conservation Union to be among the 100 ‘World’s Worst’ invaders (Lowe *et al.*, 2000). *Spartina anglica* ‘naturally evolved’ by spontaneous hybridization between a native European and an introduced American *Spartina* species and subsequent ‘natural polyploidization’ in southern England by the end of the 19th century. Later, the species was deliberately introduced and planted in the Wadden Sea region but would probably also have expanded naturally from Southern England to the Wadden Sea ([Annex](#) and [Thematic Report on Salt Marshes](#)).

Although *S. anglica* was extensively used as the example of a species with great negative impact on native biodiversity and ecosystem functioning, it is not listed as ‘invasive alien species of union concern’ (EU 2016, 2017, 2019). Recently, Granse *et al.* (2021) indeed documented positive effects of the invasion of *Spartina anglica* on both native plant species richness and on accretion rates in Wadden Sea salt marshes. In addition, LANGE *et al.* (2019) showed in a mesocosm experiment, that marine consumer species differ in the use of *Spartina anglica* as food source. The native surface deposit feeding snail *Peringia ulvae* was able to increase its biomass using *S. anglica* as food source.

3. Assessment

In accordance with the UNESCO World Heritage Committee request of 2009, §26 of the Sylt declaration (2010) and §33 of the Tønder Declaration (2014), the Wadden Sea Board initiated the development of a common strategy for dealing with alien species in the Wadden Sea (see [Annex](#)) and the TWSC's ad hoc Expert Group Alien Species (EG-AS) developed the trilateral alien species management and action plan (MAPAS) (WG-AS & Gittenberger, 2019, see also [Annex](#)), in order "to prevent threats from alien species to marine and terrestrial ecosystems in the Wadden Sea Area and to sustain the Outstanding Universal Value (OUV) and integrity of the Wadden Sea World Heritage property by preventing, managing or controlling alien species through a coordinated effort, in line with international conventions and treaties, the EU directive on invasive alien species (EU-IAS), the Marine Strategy Framework Directive (MSFD) and other relevant policies".

The following assessment of this thematic report focuses on the effects of alien species on the Wadden Sea Plan targets (chapter 3.1) and the criteria for the 'Outstanding Universal Value' (OUV; chapter 3.2).

So far, alien species have not caused the extinction of native species in the Wadden Sea and most alien species become inconspicuous residents. However, some alien species have the potential to alter dominance structures, habitats, and trophic regimes, which are fundamental for the ecosystem and to the guiding principle of the trilateral Wadden Sea policy, the Wadden Sea Plan targets as well as for 'Outstanding Universal Value' (OUV). It clarifies the need to implement the MAPAS.

3.1 Wadden Sea Plan Targets

In the Wadden Sea Plan 2010 (CWSS, 2010b) several habitat targets were defined, which might be affected by alien species, but no specific targets for alien species were formulated. Table 3 summarizes those targets and lists examples of the effects of aliens and measures taken.

3.2 Outstanding Universal Value (OUV)

The Wadden Sea was inscribed on the World Heritage List under the natural criteria (viii), (ix) and (x) for the 'Outstanding Universal Value' (OUV). Table 4 gives an overview of these criteria and their key values and how they might be affected by alien species. With the inscription of the Wadden Sea on the World Heritage List, the World Heritage Committee recommended to "implement a monitoring programme on invasive species associated with ballast water and aquaculture".

Table 3: Targets of the Wadden Sea Plan 2010 (CWSS, 2010b), which might be affected by alien species. Examples of alien species impacts are given.

Categories	Targets	Alien species impact – examples
Landscape and Culture	Identity - to preserve, restore and develop the elements that contribute to the character, or identity, of the landscape, which forms the basis for life of the people living in the region.	So far no effects known.
	Variety - to maintain the full variety of cultural landscapes, typical for the Wadden Sea landscape.	
Water and Sediment	Improvement of habitat quality for conservation of species.	So far no effects known.
Salt Marshes	To maintain the full range of variety of salt marshes typical for the Wadden Sea landscape.	Spread of the alien species <i>Spartina anglica</i> , locally dominant (see also sub-section 8.4).
	A salt marsh vegetation diversity reflecting the geomorphological conditions of the habitat with variation in vegetation structure. Favourable conditions for all typical species.	
Tidal Area	A natural dynamic situation in the tidal area.	Blue mussel beds are overgrown by Pacific oysters (<i>Magallana gigas</i>) and several other alien species settle on mussel beds. Dominance structure of the associated species community changed (Büttger <i>et al.</i> , 2008; Markert <i>et al.</i> , 2010).
	A natural size, distribution and development of natural mussel beds, <i>Sabellaria</i> reefs and <i>Zostera</i> fields.	
Beaches and dunes	An increased presence of a complete natural vegetation succession.	Invasion of non-native species such as <i>Rosa rugosa</i> threatens native species
Estuaries	Maintaining and where possible restoring natural habitats and tidal dynamics typical of estuaries.	E.g., the Chinese mitten crab (<i>Reicher sinensis</i>) occurs in the tidal part of the rivers Elbe and Weser. Damages fishery equipment and embankments, preys on fish, leads to competition for space and food with native fish and invertebrates and at the same time they are food for native fish species (see Lackschewitz <i>et al.</i> 2015).
Offshore Area	The targets for birds, marine mammals and fish are relevant for the offshore area.	Atlantic jack knife clam (<i>Ensis directus</i>) increase abundance in the subtidal, increasing role as food for, e.g., Eider ducks (<i>Somateria mollissima</i>) (Cadée, 2006; Tulp <i>et al.</i> , 2010; Schwemmer <i>et al.</i> , 2017)
	Targets on water quality see chapter "Water and Sediment".	
Rural Area	Favourable conditions for flora and fauna, especially migrating and breeding birds.	So far no effects known.
Birds	Stable or increasing numbers and distribution taking into account that abundance of species is in line with prevailing physiographic, geographic and climatic conditions.	Changes in food availability, e.g., for Eider ducks due to dominance of Pacific oysters or Atlantic jack knife clam (Cadée, 2006; Tulp <i>et al.</i> , 2010; Schwemmer <i>et al.</i> , 2017)
	Fluctuations in food stocks determined by natural processes.	
	Habitat, food stocks and connectivity between habitats supporting a favourable conservation status.	
Marine Mammals	Viable stocks and a natural reproduction capacity of the harbour seal, including juvenile survival.	So far no effects known.
	Viable stocks and a natural reproduction capacity of the grey seal, including juvenile survival.	
	Viable stocks and a natural reproduction capacity of the harbour porpoise	

Table 4: Key values of the OUV, which might be affected by alien species.

Criterion	Key value	Alien species impact – examples
Criterion (viii): Outstanding geological processes	Unbroken tidal flat and barrier system	So far no effects known.
	Typical geomorphological diversity	So far no effects known.
	Ongoing natural geomorphological processes	So far no effects known.
Criterion (ix): Ongoing ecological and biological processes	Intact natural intertidal ecosystems	Blue mussel beds are overgrown by Pacific oysters (<i>Magallana gigas</i>) and several other alien species settle on mussel beds. Dominance structure of the associated species community changed.
	Linked geomorphological, biophysical and biological processes	So far no effects known.
	High biomass production typical for the Wadden Sea	Alien species might alter the dominance structure within the biomass.
	Key site for sustaining abundant wildlife beyond its borders	Pacific oysters (<i>Magallana gigas</i>), dominating former blue mussel beds, affect food availability for mussel eating birds (Scheiffarth <i>et al.</i> , 2007; Markert <i>et al.</i> , 2013; Waser <i>et al.</i> , 2016).
Criterion (x): Vital habitats for in-situ biodiversity conservation	High typical biodiversity	Invasive species like <i>Spartina anglica</i> and <i>Rosa rugosa</i> can be dominant and decrease biodiversity (Isermann, 2008; Nehring & Hesse, 2008) The invasive seaweed <i>Sargassum muticum</i> is a habitat forming species, which can increase epibiont biodiversity and promote rare native snake pipefish in the Wadden Sea (Buschbaum <i>et al.</i> , 2006; Polte & Buschbaum, 2008).
	Staging, moulting and wintering area for migratory birds	Changes in food availability e.g. for Eider ducks due to dominance of Pacific oysters or Atlantic jack knife clam (Cadée, 2006; Tulp <i>et al.</i> , 2010; Schwemmer <i>et al.</i> , 2017)
	Essential stopover for the East Atlantic Flyway	Pacific oysters (<i>Magallana gigas</i>), dominating former blue mussel beds, affect food availability for mussel eating birds (Scheiffarth <i>et al.</i> , 2007; Markert <i>et al.</i> , 2013; Waser <i>et al.</i> , 2016).

4. Recommendations

Following the status and increasing trend of alien species introduction and the trilateral progress in alien species assessment in the Wadden Sea Area, recommendations for monitoring, management and research are given.

4.1 Science

- Effects of alien species on food webs and communities need higher attention in research.
- Knowledge about the effects of non-native parasites and their interactions with native species is still scarce and should be given more attention.
- The potential benefits (early detection, easy and efficient) and disadvantages of the eDNA and other DNA-based methodologies to detect alien species should be further investigated. This study can be based on several recent (pilot) studies done in the Danish, German and Dutch parts of the Wadden Sea (Markert *et al.*, 2014; Gittenberger *et al.*, 2019; Andersen *et al.*, in prep., Project "Genetic tools for Ecosystem health Assessment in the North Sea region" (GEANS)).

4.2 Monitoring

- Fully operationalize the proposed harmonized monitoring program in the MAPAS (Management and action plan for Alien Species) for alien species in the Wadden Sea. The monitoring proposal is mostly in line with the requirements of OSPAR and MSFD (WG-AS & Gittenberger, 2019).
- So far, detection of alien species in the Wadden Sea is focussing on macrobenthic species in harbours, marinas and at shellfish farming sites as well as on terrestrial and freshwater species. Future monitoring should also consider phytoplankton, zooplankton, fish, and birds. The observation of viruses and other microorganisms should not be disregarded completely, although knowledge about these taxonomic groups is still very limited and should be considered for future research, to create a baseline.
- Different substrates for settling/ habitats need to be monitored (tidal flats and subtidal soft bottom well as artificial hard substrates). The monitoring of alien species in salt marshes and dunes could be easily incorporated in the existing monitoring procedures. The monitoring program needs a solid financial fundament and has to be in line with the requirements of the MSFD for Descriptor 2 and Regulation 1143/2014 on invasive alien species.
- The trilateral alien species list should cover zooplankton, phytoplankton, fish, birds and terrestrial taxa as well.
- A common trilateral portal should be established to support networking and to exchange knowledge about the Wadden Sea alien species list as well as species alerts.

4.3 Management

- A common and continuously updated trilateral list of aquatic and terrestrial alien species based on national and trilateral monitoring programs is needed.
- MAPAS and the Sylt Declaration refer to the Wadden Sea Area for alien species: e.g., marine aliens species found inside locks would not belong to the species list although they might reach the Wadden Sea Area easily. These should be included in the list, marked accordingly,
- A trilateral Wadden Sea early warning and reporting system is needed. Supporting elements for such a system could include a network platform, which will be a microsite attached to the website of the CWSS or a harmonised guideline for risk assessment, which will be integrated into the website of the CWSS. This platform could also provide a harmonised guideline for the risk assessment of newly established non-native species
- Already established populations of alien species cannot be removed. All measures for managing such alien species should be based on a critical evaluation of collateral damages.
- Eradication has the risk of unforeseeable collateral damages. Therefore, introduction of alien species should be prevented by limiting the chances of introduction through the vectors.
- The operationalization of the Wadden Sea Area communication and education plan for alien species needs to be developed and supported.
- Next to ballast water transport, ship biofouling is the most important vector for the introduction of alien species into the Wadden Sea and adjacent areas. Therefore, a harmonized approach to define options for the implementation of the IMO's Guidance (recreational boats) and Guidelines for the Control and Management of Ships' Biofouling is needed.
- Aquaculture related import and transport activities may support the spread of alien species if left unmanaged. A trilateral common policy on potential shipping and shellfish transportation related transport vectors and pathways of alien species into and within the Wadden Sea, may be developed using the Trilateral Wadden Sea Management and Action Plan for Alien Species (WG-AS & Gittenberger, 2019) as a baseline. In addition to human mediated spread and establishment of NIS, natural dispersal capacities and habitat preferences should be considered.

5. Summary

So far, there is no evidence that alien species have caused the extinction of native species in the Wadden Sea, and most alien species become inconspicuous residents. However, some alien species have the potential to

alter dominance structures, habitats, and trophic regimes.

In accordance with the UNESCO World Heritage Committee request of 2009, the Sylt declaration (2010) and the Tønder Declaration (2014), the Wadden Sea Board initiated the development of a common strategy for dealing with alien species in the Wadden Sea and the TWSC's ad hoc Expert Group Alien Species (EG-AS) developed the trilateral alien species management and action plan (MAPAS) (WG-AS & Gittenberger, 2019).

Currently, the trilateral alien species list of the Wadden Sea Area focusses on marine species and comprises 113 species, not including birds, invertebrates and other terrestrial species. Between 1900 and 1989, 2-4 species were introduced per decade into the Wadden Sea Area. Since 1990 the rate increased to 10-15 species per decade (Van der Have & Lensink, 2017). For the period 2011-2020, the rate almost doubled, with more than 20 species added during that decade. Most of these marine alien taxa originate from the Pacific or from the Atlantic. Major vectors are transoceanic shipping and aquaculture; intentional or unintentional introduction (horticulture, pet trade and transport) is the most important pathway for terrestrial plants. A common trilateral alien species list for terrestrial taxa of the Wadden Sea Area is still missing.

The following assessment of this thematic report focuses on the effects of alien species on the Wadden Sea Plan targets (chapter 3.1) and the criteria for the 'Outstanding Universal Value' (OUV; chapter 3.2).

In summary, there is no evidence that alien species endanger the Wadden Sea Plan targets and the natural criteria (viii), (ix) and (x) for the 'Outstanding Universal Value' (OUV) fundamentally. They have not caused the extinction of native species in the Wadden Sea so far, and most alien species become inconspicuous residents. However, some alien species have the potential to alter dominance structures, habitats, and trophic regimes, which are fundamental for the ecosystem and the Wadden Sea Plan targets as well as for 'Outstanding Universal Value' (OUV). It clarifies the need to implement the MAPAS.

The given recommendations focus on the implementation of a harmonized alien species monitoring program and a continuously updated trilateral list including macrobenthos, algae, phytoplankton, zooplankton, fish, birds and terrestrial species (e.g., plants, mammals).

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