Risk analysis of hull fouling on small to medium sized boats as an import vector of exotic species in the Wadden Sea

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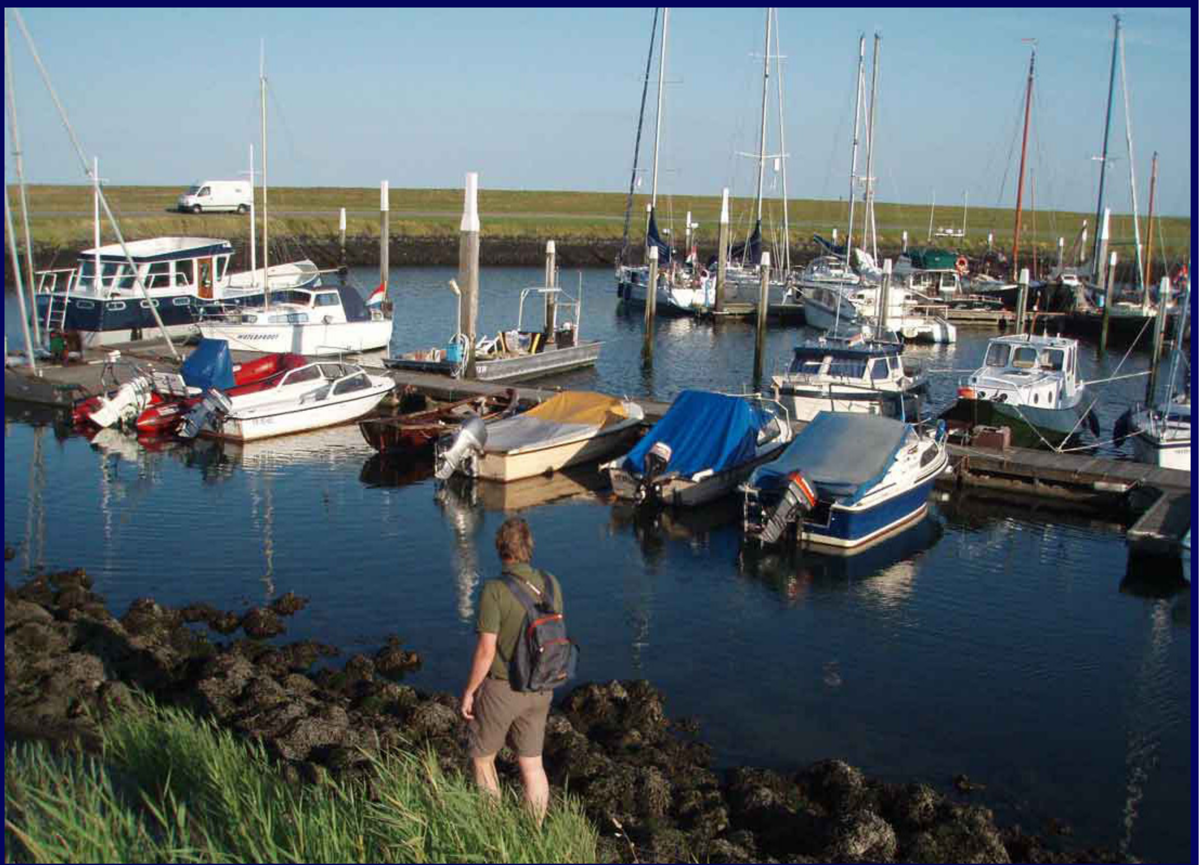

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GiMaRIS

Gittenberger Marine Research Inventory Strategy

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Pleasure craft harbour of Oudeschild, Texel, the Wadden Sea.

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Index

1. Summary

Little is known of the risks related to hull fouling on pleasure crafts in The Netherlands. Hull fouling is internationally seen as one of the main transport vectors of marine exotic species. On the basis of what is known in literature and several preliminary and unpublished studies, we here present a risk analysis of hull fouling on small to medium sized boats as import vectors of exotic species in the Wadden Sea. In the Wadden Sea by far the highest diversity of exotic species is found in pleasure craft harbours, which is much higher than on the dikes outside of the harbours, in the sand or on the mussel beds and oyster reefs. Pleasure crafts, therefore, appear to be very important if not the most import vector of exotic species in the Wadden Sea. More studies are necessary to test this hypothesis, as the available data on exotic species in these harbours is still sparse to non-existent with the exception of a species inventory in 2009.

2. Introduction

The fouling on a ship's hull, even a small film of 1 mm thick, can increase drag. This causes journeys to take longer and to cost more fuel (Minchin, 2006). For that commercial reason the hulls of most of commercial vessels are kept as clean as possible. Managers that control hull fouling do so to reduce the drag, and not to reduce the spread of exotic species (Minchin, 2006). This report focuses on hull fouling as a transport vector of exotic species (Acosta *et al.*, 2010).

Ballast water, hull fouling and aquaculture are considered to be the three main vectors of transport for exotic species in the marine environment (Dijkstra *et al.*, 2007; Gollasch, 2006; Wolff, 2005). Although the hull fouling vector is relatively unmanaged in Europe in comparison to the ballast water and aquaculture vectors, it represents a significant risk (Minchin & Gollasch, 2003). This is illustrated by the fact that non-native species were encountered in 38% of the ballast water samples, 57% of the tank sediment samples, and 96% of the hull fouling samples that were taken during a study of vessels along the coast of Germany (Gollasch, 2002). A more recent study in which an overview is given of the 96 exotic species that have established themselves in the North Sea (Gollasch *et al.*, 2009) describes that the introduction of 33, 35 and 42 of these exotic species was linked to, respectively, the vectors aquaculture, ballast water and hull fouling (Gollasch *et al.*, 2009).

Ascidian species are among the most common established exotic species (Gittenberger, 2007). Especially colonial species like *Didemnum vexillum*, which probably originating from the NW Pacific (Stefaniak *et al.*, 2009), are considered to have a large impact on the environment where they are introduced. They can overgrow large areas while smothering and killing virtually all species they come across (Gittenberger, 2007). Because colonial ascidians produce larvae with an abbreviated planktonic stage that are viable for about 12-24 hours (Daley & Scavia, 2008), the likelihood of larvae surviving in ballast water is very low (Carlton and Geller, 1993). The transport of live shellfish is also recognized as a potential vector, but as ascidians do not easily survive the surfacing and washing of the shells, which is usually done before transport, hull fouling is seen as their main transport vector (Daley & Scavia, 2008; Dijkstra *et al.*, 2007). The introduction of *D. vexillum* into New Zealand (Coutts, 2002; Coutts & Forrest, 2007), Ireland (Minchin & Sides, 2006; Minchin, 2007) and Great Britain (Griffith *et al.*, 2009; Kleeman, 2009) could be traced back to boats with hulls fouled by *D. vexillum* colonies. The species was probably also introduced into the Wadden Sea by hull fouling, as the local occurrence in the harbour of Terschelling indicates (Gittenberger *et al.*, 2010).

Pleasure craft harbours are seen as hotspots of invasive alien species when conducting exotic species inventories along the US east coast (Pederson *et al.*, 2005) and in countries like Ireland (Minchin & Sides, 2006) and The Netherlands, i.e. during an assessment of the Dutch Wadden Sea in 2009 (Gittenberger *et al.*, 2010). Regardless of this, Ashton *et al.* (2006) indicate that in the northern hemisphere no systematic surveys have been done to assess the importance of recreational boating in the distribution of marine non-natives. This is done in the southern hemisphere, for example in New Zealand and Australia where special national biofouling management guidelines have been set up (Australian Government, 2009). In July 2011 the IMO agreed on international guidelines to prevent the spread of invasive alien species by hull fouling for both commercial and non-commercial vessels as proposed by New Zealand.

In the Netherlands no specific policy or management actions yet exists focussing specifically on reducing the risk of introducing exotic species by recreational crafts. Relatively little is known about these risks and only few studies have been conducted on this topic, which is probably one of the main reasons that 11 exotic species (and one subspecies) new to the Dutch Wadden Sea, were found in a three week survey in 2009. The total number of exotic species ever recorded in the Dutch Wadden Sea was thereby raised to 64. All these species were found in pleasure craft harbours. The harbours, which were found to be hotspots of invasive species in the Dutch Wadden Sea, were never systematically searched before. As a follow up of the 2009 survey, a second survey was conducted in 2011. Again new exotic species for the Dutch Wadden Sea were discovered (unpublished data). The final results of the 2011 survey were not yet available to be included in the present report, however. Without these two exotic species surveys focusing on pleasure craft harbours, about 25% of the exotic species ever recorded in the Dutch Wadden Sea would be unknown, indicating the importance of these studies and the great lack of data that is available about pleasure crafts as transport vectors of exotic species, and pleasure craft harbours as stepping stones for the distribution of these species. A recent exotic species inventory focusing on harbours in the German Wadden Sea (Lackschewitz *et al.*, 2009) gave similar results such as records of new exotic species to the German Wadden Sea and indicated that harbours are hotspots of exotic species.

Fig. 1. Pleasure craft harbour of Oudeschild, Texel, the Wadden Sea.

In the present report we will focus on this risk of hull fouling on small to medium sized boats for the Dutch Wadden Sea, a UNESCO World Heritage Site. This concerns mainly but not exclusively recreational crafts in pleasure craft harbours (Fig. 1).

3. Methods

A literature study was carried out and the data of the Wadden Sea inventory of 2009 during which 11 new species (and 1 new subspecies) to the Wadden Sea were found (Gittenberger *et al.*, 2010) were reanalysed. These analyses were done aiming at getting a better view of the risk of hull fouling on small to medium sized vessels, to the Dutch Wadden Sea. Additionally, the present report includes some preliminary results of a study focusing on the hull fouling on pleasure crafts in the harbour of Breskens, Zeeland, and results of a study focusing on quantifying economical damage that is done by fouling species, among which exotic ones, in harbours. Finally, the results of the continuous fouling community study SETL are used, as this project focused on the assessment of the ecological water quality in Dutch sea ports for the European Water Framework Directive (Gittenberger, 2008) and the early detection of exotic species in pleasure craft harbours in general. About 200 14x14 cm PVC SETL plates that have been deployed in harbours along the coast of The Netherlands have been checked for fouling species every three months, since 2006. In the course of the project a new species to The Netherlands, i.e. the ribbon worm *Emplectonema echinoderma*, was discovered in the harbour of Den Helder (Gittenberger & Schipper, 2008), and a new exotic species to the Wadden Sea, i.e. the crustacean *Sinelobus stanfordi*, was discovered in the harbour of Harlingen (Gittenberger *et al.*, 2010). It seems likely that these species were introduced in the Wadden Sea by hull fouling (Gittenberger *et al.*, 2010; Haaren & Soors, 2009).

4. Risk assessment

4.1. Probability of introduction

Although boat owners do try to keep the hulls of their boats clean to minimize the drag caused by fouling (Minchin, 2006), macro fouling is found on a large percentage of the recreational vessels. In a study in Scotland 59% of about 500 yachts surveyed was found with macro-fouling attached to the hulls (Ashton *et al.*, 2006). This percentage varies per area, however. During a study in the harbour of Breskens in the Netherlands, only 23% of the 502 vessels showed fouling. This percentage and more specifically the diversity of fouling species may furthermore be dependent on the season. This was found in the Mediterranean, where the diversity of marco-algae in fouling assemblages was significantly different in different seasons, that is in April-May in comparison to June-October (Mineur *et al.*, 2007). The probability that exotic species are present in these hull fouling communities is high as indicated by Gollasch (2002) showing that non-native species were encountered in 96% of the fouling samples they collected from the hulls of vessels off the coast of Germany.

The export areas, the places where the recreational vessels with hull fouling come from, are mostly pleasure craft harbours. Pleasure craft harbours are generally known as hotspots of exotic taxa, as is also the case in the Wadden Sea (Gittenberger *et al.*, 2010). The number of exotic species that was found in pleasure craft harbours in the Wadden Sea was significantly higher than on the dikes outside of the harbours (Chi =6.06; $p < 0.05$) and on shellfish (Chi =5.11; $p < 0.05$), i.e. the mussel beds and oyster reefs (Fig. 2-3AB; Table 1). This is the reason why general marine exotic species inventories along the European and American Atlantic coasts focus on these harbours (Minchin, 2007; Pederson *et al.*, 2005).

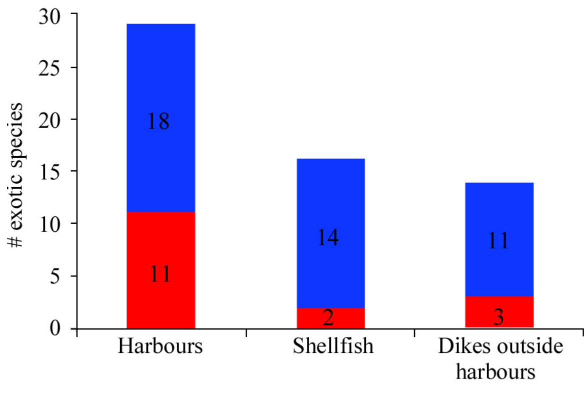

Fig. 2. The number of exotic species that was found during the Wadden Sea exotic species inventory in 2009 (Gittenberger *et al.*, 2010), in harbours, on shellfish beds and on dikes outside of harbours. Red: the number of species that was found new to the Dutch Wadden Sea.

Table 1. The exotic species that were found during the Wadden Sea species inventory in 2009 (Gittenberger et al., 2010), in harbours, on shellfish beds and on dikes outside of harbours.

		Harbours	**Shellfish**	**Dikes outside harbours**
Antithamnionella spirographidis	Algae	6.3%	4.0%	0.0%
Ceramiaceae sp.	Algae	6.3%	0.0%	0.0%
Ceramium cimbricum	Algae	12.5%	0.0%	0.0%
Codium fragile ssp. atlanticum	Algae	6.3%	0.0%	0.0%
Gracilaria vermiculophylla	Algae	18.8%	12.0%	26.3%
Polysiphonia harveyi	Algae	25.0%	8.0%	15.8%
Sargassum muticum	Algae	25.0%	8.0%	26.3%
Ulva pertusa	Algae	12.5%	4.0%	0.0%
Undaria pinnatifida	Algae	6.3%	0.0%	0.0%
Ficopomatus enigmaticus	Annelida	6.3%	0.0%	5.3%
Neodexiospira brasiliensis	Annelida	6.3%	0.0%	0.0%
Aplidium glabrum	Ascidiacea	6.3%	0.0%	0.0%
Botrylloides violaceus	Ascidiacea	37.5%	0.0%	0.0%
Didemnum vexillum	Ascidiacea	6.3%	0.0%	5.3%
Molgula socialis	Ascidiacea	68.8%	52.0%	5.3%
Styela clava	Ascidiacea	43.8%	8.0%	0.0%
Bugula stolonifera	Bryozoa	25.0%	0.0%	0.0%
Diadumene cincta	Cnidaria	12.5%	0.0%	0.0%
Balanus improvisus	Crustacea	56.3%	20.0%	26.3%
Caprella mutica	Crustacea	37.5%	4.0%	5.3%
Elminius modestus	Crustacea	81.3%	52.0%	89.5%
Eriocheir sinensis	Crustacea	18.8%	0.0%	0.0%
Hemigrapsus sanguineus	Crustacea	18.8%	16.0%	36.8%
Hemigrapsus takanoi	Crustacea	31.3%	24.0%	36.8%
Jassa marmorata	Crustacea	12.5%	4.0%	0.0%
Sinelobus stanfordi	Crustacea	6.3%	0.0%	0.0%
Mnemiopsis leidyi	Ctenophora	62.5%	8.0%	5.3%
Crassostrea gigas	Mollusca	81.3%	60.0%	78.9%
Crepidula fornicata	Mollusca	6.3%	60.0%	10.5%

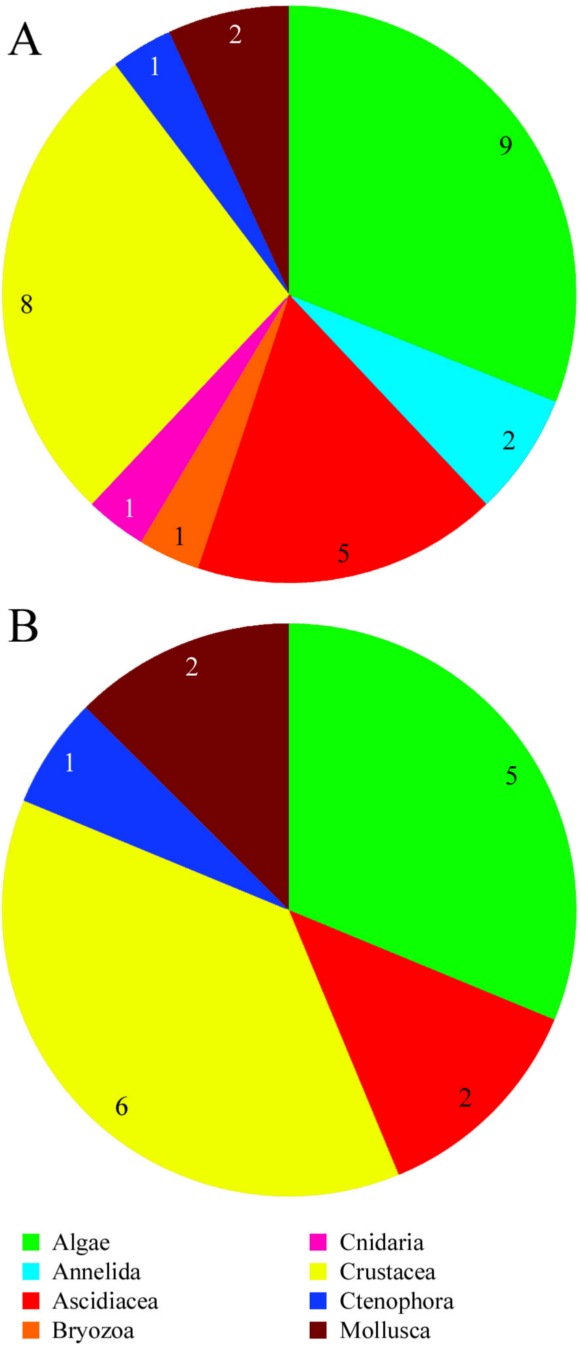

Fig. 3. The number of exotic species found in (A) pleasure craft harbours and in (B) shellfish areas during the Dutch Wadden Sea inventory in 2009 (Gittenberger *et al*., 2010) .

Table 2. The countries of the home ports of the pleasure crafts that visited the harbour of Breskens between 2002 and 2010.

Country	**Continent**	**Visits**
Netherlands	Europe	9950
Belgium	Europe	2719
United Kingdom	Europe	1807
Germany	Europe	474
France	Europe	472
Sweden	Europe	45
Norway	Europe	27
Denmark	Europe	28
Finland	Europe	19
Guernsey	Europe	13
Luxembourg	Europe	9
Jersey	Europe	8
Poland	Europe	6
Czech Republic	Europe	4
Italy	Europe	4
Russia	Europe	4
Spain	Europe	4
Austria	Europe	3
Estonia	Europe	2
Greece	Europe	1
Iceland	Europe	1
Lithuania	Europe	1
Malta	Europe	1
Slovenia	Europe	1
Switzerland	Europe	1
United States of America	North America	12
Canada	North America	2
British Virgin Islands	North America	2
Martinique	North America	1
Mexico	North America	1
Japan	Asia	1
Australia	Australia	2
New Zealand	Australia	1
Nigeria	Africa	2
South Africa	Africa	2
Sierra Leone	Africa	1
	Total	15,631

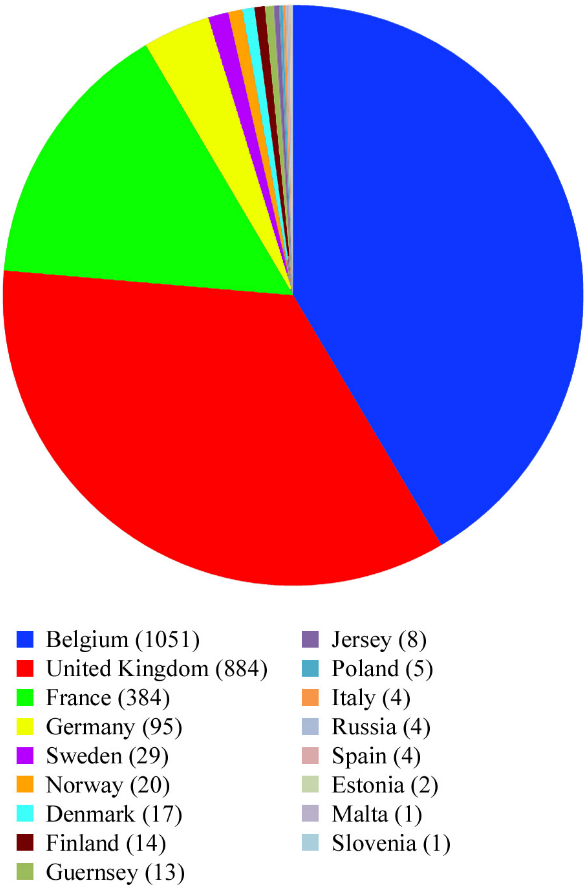

Fig. 4. Pleasure crafts with marine home ports in Europe that visited the harbour of Breskens between 2002 and 2010.

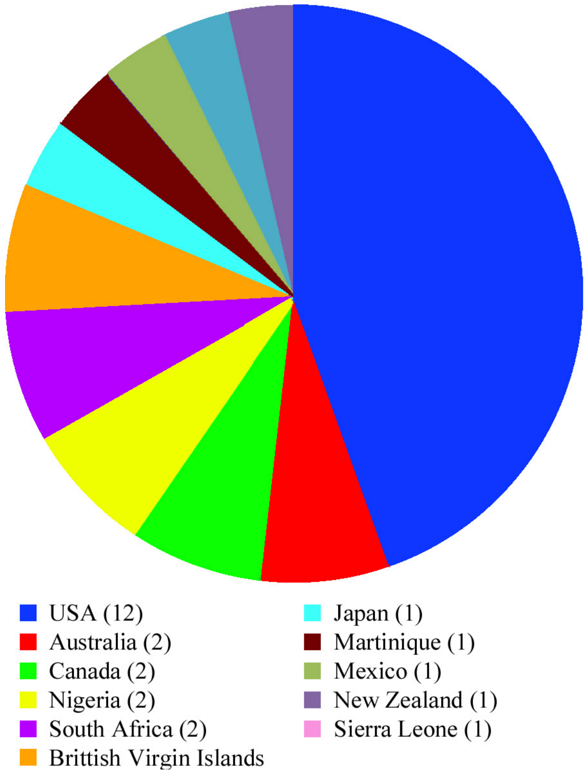

Fig. 5. Pleasure crafts from other continents than Europe that visited the harbour of Breskens between 2002 and 2010.

Next to the high diversity of exotic species present, the harbours also form a relatively high risk because of the recreational vessels that arrive there without having to be checked for fouling. We here present the results of a study on the origin of 15631 boats that arrived in the Dutch harbour of Breskens in the province of Zeeland between 2002 and 2010 (Table 2). Although Breskens is not located in the Wadden Sea, it can be assumed that recreational vessels with similar origin arrive there. About 36% of the 15631 recreational boats that visited the harbour of Breskens had a homeport outside of The Netherlands. About half of those vessels came from France and the United Kingdom (Fig. 4), which are known as countries from where many exotic species have been introduced into The Netherlands (Wolff, 2005). A relatively small number of boats that may pose a relatively high risk of introducing exotic species arrives in Breskens from the continents America, Africa, Asia, Australia and New Zealand (Fig. 5).

Although exact percentages and numbers cannot be given because hull fouling in the Wadden Sea has not been studied in the past, one can conclude that it is very likely that exotic species are introduced by this vector.

4.2. Probability of settlement

Boats arriving in the harbour of Breskens from outside of the Netherlands, virtually all come from marine homeports, but of the boats coming from within the Netherlands 74% comes from a freshwater harbour. The fouling species that

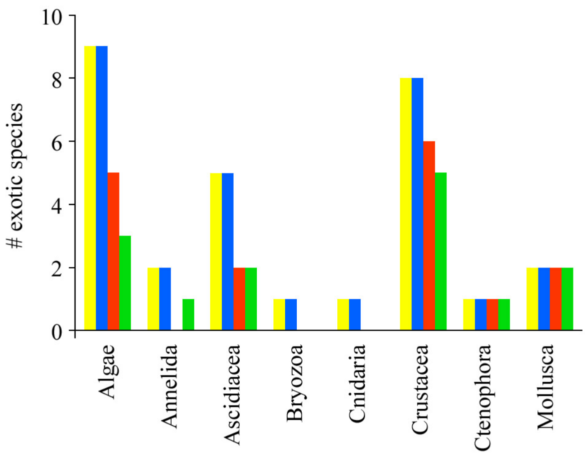

Fig. 6. The number of exotic species found per taxon during the Wadden Sea exotic species inventory in 2009 (Gittenberger et al., 2010). Yellow: All exotic species found; Blue: Exotic species in pleasure craft harbours; Red: Exotic species in shellfish areas; Green: Exotic species on dikes outside of harbours.

have grown on these boats probably do not survive in marine harbours and will therefore not settle. Marine fouling species evidentially have a much higher chance of settling in a marine harbour. Especially when boat owners encounter fouling and clean their boat in the water of the harbour where they have arrived, the chance of the species settling there is high. This is probably one of the main reasons why pleasure craft harbours are hotspots of exotic species, next to the fact that these harbours are ideal refugia, i.e. with relatively clear, calm and nutrient rich water (Gittenberger, 2010). All exotic species that were found during the Wadden Sea inventory in 2009, were found in pleasure craft harbours, while much less exotic species were found on other hard substrata that were assessed during that inventory, i.e. the dikes outside of harbours and shellfish areas (Fig. 6).

In conclusion, it seems that hull fouling species have a good chance of settling in the Wadden Sea harbours where they arrive as long as the salinity is not too high or too low for the species
12

4.3. Probability of spread

Although exotic fouling species introduced through hull fouling into the Wadden Sea may well be able to settle in the harbours, many will probably not spread throughout the Wadden Sea after settlement because the environment is unsuitable for them. Most hull fouling species are hard substratum related while most of the Wadden Sea has a sandy bottom. In addition, the hard substrata that are present outside of the harbours, i.e. the dikes, mussel beds and oyster reefs, also appear to be unsuitable environments for most of the exotic fouling species in the Wadden Sea (Fig. 2, 6). This appears to be the case for the invasive sea-squirt *Didemnum vexillum* that was found to be introduced in the pleasure craft harbour of Terschelling (Gittenberger *et al.*, 2010). The harbours are much more vulnerable to this species than the open water in the Wadden Sea according to Gittenberger (2010) when the exotic species vulnerability assessment methodology of Leewis & Gittenberger (2011) was followed. Although many of exotic fouling species will therefore not pose a risk to the Wadden Sea, they probably can use the harbours as ideal stepping stones, which will help them spread to uninfested areas along the German and Danish Wadden Sea and further north along the European coast, where hard substrata and seemingly more suitable rocky habitats are common (Gittenberger, 2010).

4.4. High risk areas

Not every harbour is equally vulnerable to exotic species introduced by the hull fouling of small to medium sized boats. Only a harbour with a habitat that forms a suitable environment for the fouling species concerned, is at risk. As is clearly illustrated in the figures 7-8 the amount of native and non-native species found in the various harbours in the Wadden Sea varies greatly. The diversity of both native and non-native species in the island harbours is significantly higher than

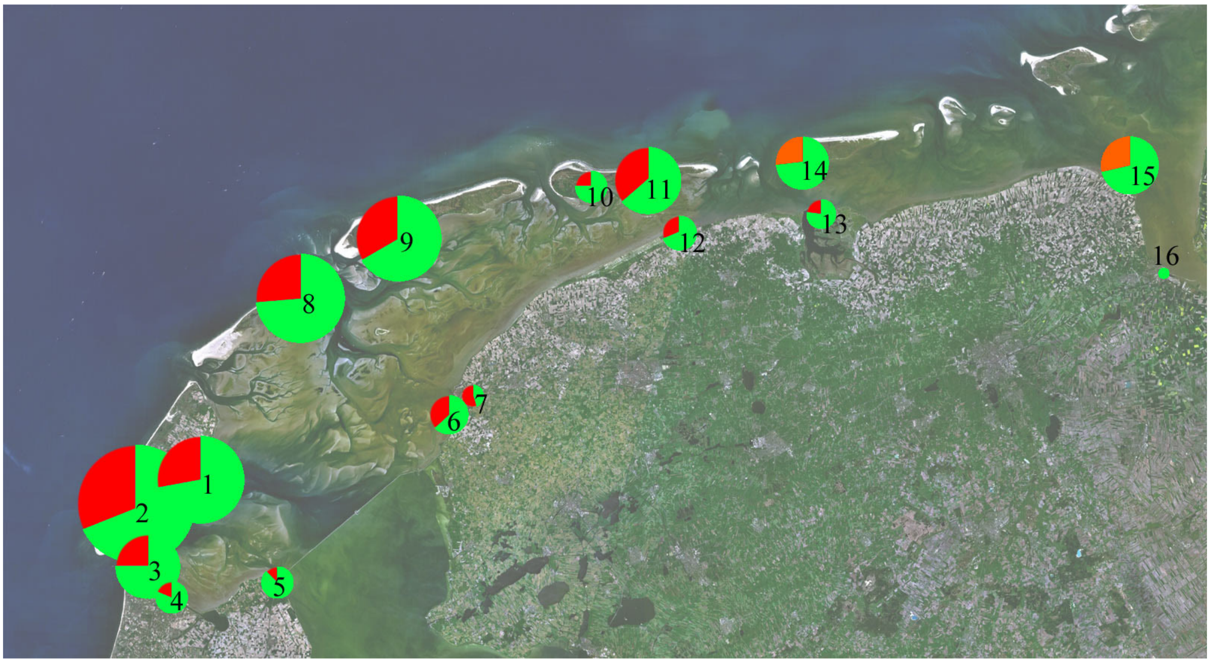

Fig. 7. The harbours in the Dutch Wadden Sea. The pie diagram at each harbour indicates the ratio between native species (green) and exotic species (red). The size of each pie diagram indicates the relative number of species recorded. 1: Oudeschild; 2: ‘t Horntje; 3; Den Helder A, the pleasure craft harbour of Den Helder; 4: Den Helder B, the military harbour; 5: Den Oever; 6: Harlingen A, Willemshaven; 7: Harlingen B; the pleasure craft harbour; 8: Vlieland; 9: Terschelling; 10: Ameland A, the floating dock of the KRM, the Royal Rescue Society; 11: Ameland B, the pleasure craft harbour; 12: Holwerd; 13: Lauwersoog; 14: Schiermonnikoog; 15: Eemshaven; 16: Delfzijl.

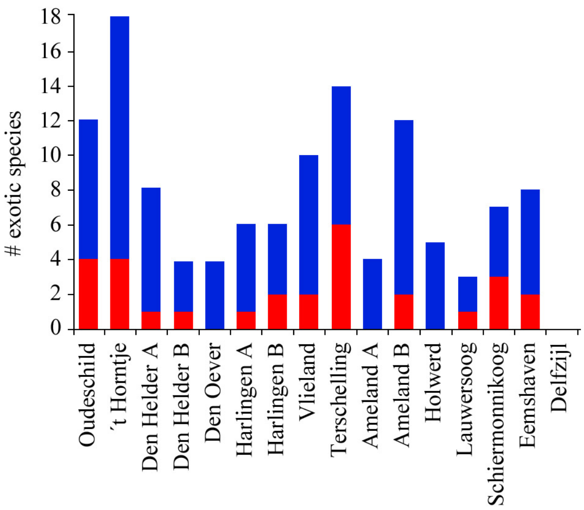

Fig. 8. Number of exotic species found in the harbours in the Dutch Wadden Sea (fig. 7). Red: the number of exotic species that was found new to the Dutch Wadden Sea.

in the harbours along the mainland, which may be linked to the fact that the salinity in the mainland harbours is relatively low (Gittenberger *et al.*, 2010). This inhibits the settlement of many marine fouling species. Of the number of exotic species that was recorded as new to the Wadden Sea by Gittenberger *et al.* (2010), most were found in the harbours of Texel and Terschelling in the western Wadden Sea (Fig. 8). On the basis of this data one can conclude that those harbours are most at risk and may act as stepping stones for exotic fouling species to other harbours and areas in the Wadden Sea.

4.5. High risk vessels

As becomes clear from the hull-fouling study in the harbour of Breskens, not all vessels pose a similar risk. The chance that fouling species, living on vessels that come from fresh water har-

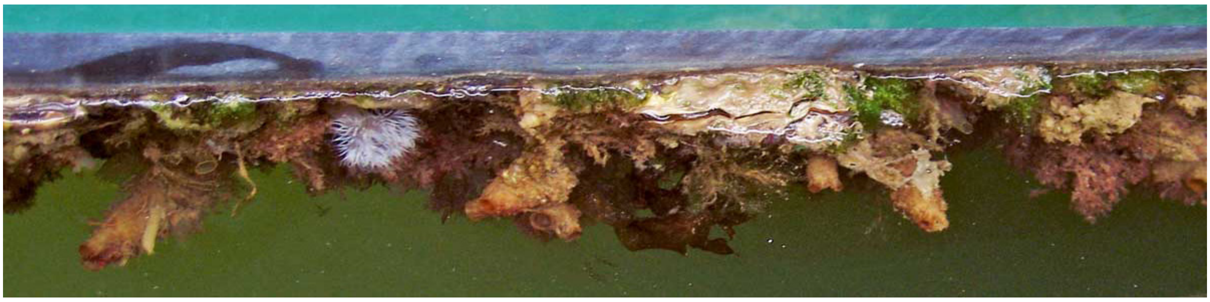

Fig. 9. Hull fouling. Most of the fouling on the hull of this sailing boat concerns invasive species. Clearly visible are the glass tunicate *Ciona intestinalis*, the Japanese club tunicate *Styela clava*, the Japanese oyster *Crassostrea gigas*, the sea-anemone *Metridium senile*, a green algal species *Entromorpha* sp. and a red algal species.

bours to marine harbours will survive, is small. These vessels (74% of the Dutch boats visiting the harbour of Breskens) therefore form no risk.

A significant difference was found between motorboats and sailing boats in Breskens as one third of all motorboats was fouled (51 out of 156) compared to about one sixth of all sailing boats (60 out of 338). This could not be explained by the material of the hulls, as virtually all the boats were made of polyester.

About one third of the recreational vessels that arrive Breskens comes from outside of the Netherlands. Such vessels of course form a higher risk than the Dutch ones. The ones that come from within Europe (Table 1; Fig. 4) may aid the secondary spread of exotic species introduced to Europe. The ones that come from different continents may even introduce new exotic species to Europe if fouling is not managed. Although such boats are relatively rare, boats of all continents have arrived in the harbour of Breskens over the last 8 years (Table 1; Fig. 5). Assuming that Breskens is not an exceptional marine pleasure craft harbour, the number of recreational vessels that has come from other continents to western Europe over the years must have been considerable.

A category of vessels that may pose the highest risk, are the neglected yachts and boats that have not been cleaned for long periods of time (Mineur *et al.*, 2008). Such boats are often for sale as the owner does not have the time or money to use them. When these boats are sold, new owners do not always clean them in the harbour where they purchase them. They may clean them in their own home harbour, introducing a wide range of fouling species. The fouling on such boats can be extreme, including a large diversity of fully grown animals and macro algae as is shown in figures 9-10.

Fig. 10. The hull of a boat with a specimen of Wakame (Undaria pinnatifida), an invasive macro-algae species that can become up to 2 meter in size and was introduced in the Wadden Sea where it was only found in the pleasure craft harbour of Terschelling during the Wadden Sea inventory of exotic species in 2009 (Gittenberger et al., 2010).

A final category of vessels that may be of importance to the Wadden Sea, are the military vessels arriving in the military harbour of Den Helder. If the article on March 18th 2011 in the newspaper the Telegraaf is authentic (we were unable to check), the hull fouling on these vessels can form an extremely high risk. The article describes a submarine returning from a mission in Somalia, which arrived in the harbour of Den Helder with great delay because its hull had massively become fouled by "snails, shells and macro algae" (Klopper, 2011). Regardless of the seemingly high risk factor, the article did not mention the potential import of invasive species by the hull fouling on this submarine. It only described that the fouling caused the submarine to slow down and was therefore considered a nuisance.

4.6. Micro habitats on vessels

Within the Wadden Sea, pleasure craft harbours form hotspots of native and non-native fouling species (Fig. 2).

Within pleasure craft harbours, excluding the hull-fouling on vessels, floating docks are the hotspots of native and non-native fouling species (Fig. 11). Especially in high saline marinas they are usually heavily fouled (Fig. 12) and probably the primary source of fouling organisms on the hulls of vessels. Vice versa the hulls are probably the primary source of fouling organisms on the docks.

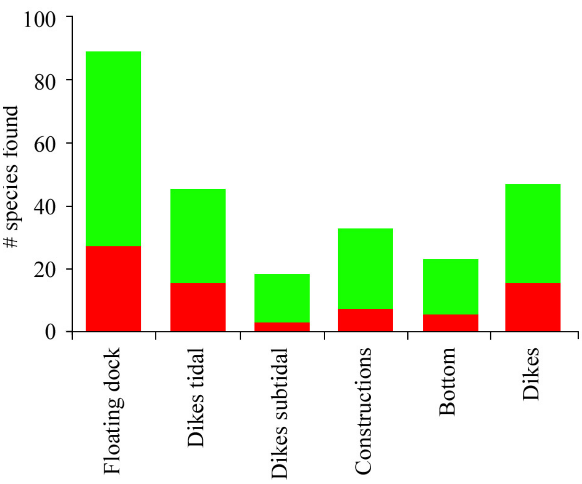

Fig. 11. The total number of species found in the different habitats in the harbours of the Dutch Wadden Sea during the exotic species assessment 2009 (Gittenberger *et al.*, 2010). Green: native species; Red: exotic species.

On the recreational boats the hotspots of native and non-native fouling species are niche areas like grids, openings in the hull, anchors, anchor wells, cooling pipes, sewage and bilge tanks, the keel, the propeller, its shaft and the rudder (Australian Governement, 2009; Geens, 2008). Within these hotspots, the surroundings and ridges of the rudder and the propeller (Fig. 13) are fouled most often (Mineur *et al.*, 2007). The highest diversity of fouling species is also found in this area, as was concluded from the hull fouling study in the harbour of Breskens in which hulls were divided in 10 areas (Fig. 14). In the area next to the rudder, i.e. F, most species were identified , i.e. 17. The lowest numbers of species, i.e. about 3, were found in the areas C and H. In the other areas, on average about 10 species, were distinguished.

Fig. 12. A heavily fouled floating dock lifted from the water for maintenance. A, Overview; B, Close-up photograph of the fouling. The blue grid lines (used for estimating the fouling cover) form 14x14 cm squares.

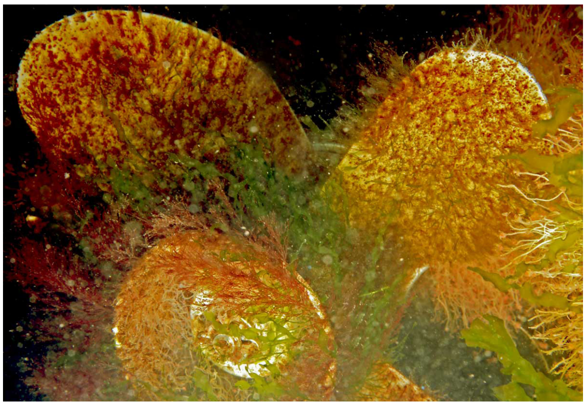

Fig. 13. The propellor of a recreational vessel fouled by various algae and hydroid species.

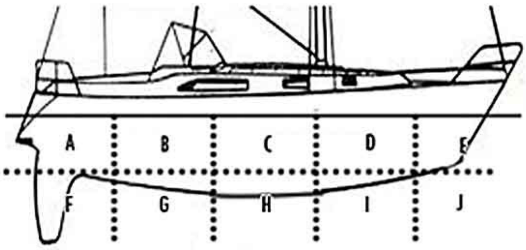

Fig. 14. During the hull fouling study in 2010 in the pleasure craft harbour of Breskens, fouling species were scored on vessels in the illustated areas A-J.

4.7. Impact

The ecological, economical and social impact of exotic hull fouling species in the Wadden Sea, can best be described on a species level as was for example done for the colonial sea-squirt *Didemnum vexillum* that was found in the Wadden Sea in 2009 (Gittenberger *et al.*, 2010). *D. vexillum* is known for its high reproduction rate, its population growth rate, its ability to overgrow benthic organisms, its rapid dispersal by fragmentation and its toleration to a wide range of environmental conditions (Daley & Scavia, 2008). Regardless of this all, the potential impact of the species *D. vexillum* may be limited to only a relatively small part of the Dutch Wadden Sea, because it prefers salinities between 26-30 ppt and salinities below 26 ppt are found (at least temporarily) in most parts of the Wadden Sea (Gittenberger *et al.*, 2010). Furthermore, as many hull fouling species like *D. vexillum* are hard substratum related, the impact of these species on the Wadden Sea may be negligible because most of the bottom is soft substratum. In addition most of the hard substrata environments in the Wadden Sea outside of the harbours, e.g. the mussel beds, oyster reefs and dikes, also appear to be unsuitable for many of the exotic fouling species that have settled in the harbours (Fig. 2). Some hull fouling species can have a large impact on the Wadden Sea however. Exotic fouling species like the Japanese oyster Crassostrea gigas have proven to be extremely harmful. In the areas where it is introduced this oyster induces changes in plankton composition, habitat heterogeneity and biodiversity, carrying capacity, food webs and parasite life cycles (Troost, 2010). A general economical impact of exotic fouling species in the Wadden Sea, is the intensified need for maintenance of the docks in the harbours. The Japanese oysters are much harder to remove than the native fouling species among which mussels. As a test, the time was compared that it takes to clean area fouled by mussels to an area fouled by Japanese oysters. On both two floating docks in the harbour of Breskens and on 40 m2 of dike in the Oosterschelde estuary, it took about five times longer to get rid of oysters than of mussels, scraping with an iron shovel (unpublished data). To assess the extra maintenance cost linked to exotic fouling species along our coast, we interviewed 56 stakeholders of (mainly pleasure craft) harbours along the Dutch coast (Fig. 15). The minimal annual costs directly related to fouling species in these harbours is € 945,000 of which ~ 22 % (€ 207,000) concerns extra costs related to exotic fouling species. Most of these costs concerned boat, scraping & spraying, and scuba-diving costs (Fig. 16). Structures that were most costly to keep clean were the oil screens in Rotterdam harbour (screens that can be used to minimize the spread of oil in case of an oil spill), and more in general along the coast the floating docks and the dikes (Fig. 17).

Fig. 15. Harbours along the Dutch coast of which the stakeholders, e.g. harbour masters and owners, were interviewed about the economical costs of marine fouling organisms in harbours.

5. Risk Management

5.1. Prevention

The best way to prevent exotic hull fouling species to be introduced to the Wadden Sea is by encouraging harbour masters and boat owners to prevent fouling on hulls and by taking action against neglected, usually heavily fouled boats before they can act as vectors (Mineur *et al.*, 2008). Regular inspections of the hull and an early removal of arising biofouling are considered effective ways to minimize the risk of the spread of exotic species (Geens, 2008). Hull fouling usually starts with a biofilm of mainly bacteria that thickens and then enables the growth of macro fouling organisms. A relatively easy method of at least reducing the amount of fouling in-water is by "so now and then" switching between close by fresh and marine water harbours. Especially in their young stages, many

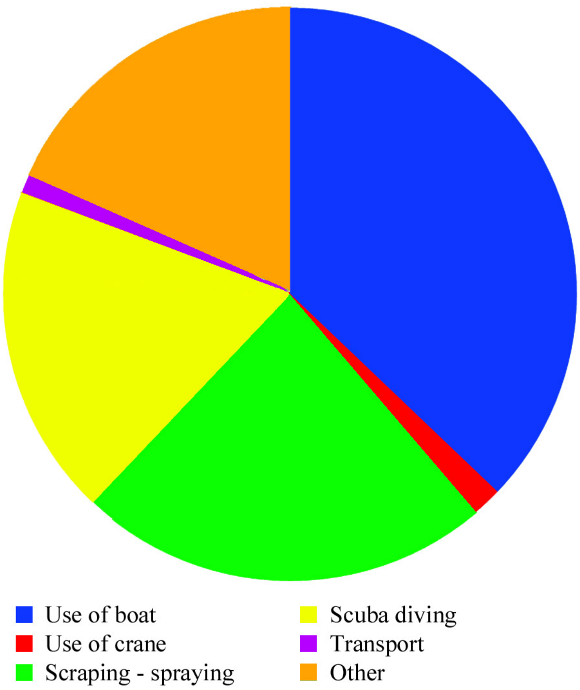

Fig. 16. Relative annual cleaning costs of fouling organisms along the Dutch coast: cleaning methods.

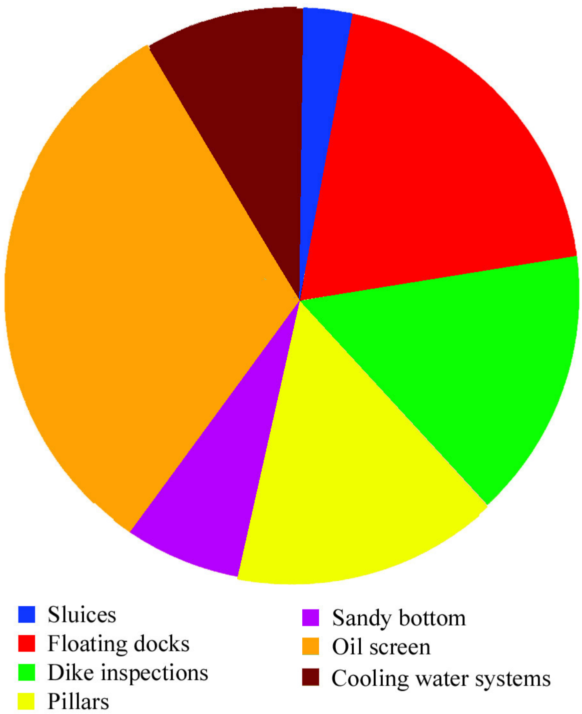

Fig. 17. Relative annual cleaning costs of fouling organisms along the Dutch coast: structures cleaned.

marine fouling species do not easily survive in fresh to slightly brackish water, and fresh water species do not easily survive in a marine environment. Additionally the cleaning of floating docks should be promoted as these may be a significant source of species that foul hulls.

Once fouling assemblages have developed on hulls, they can be removed via a combination of manual scraping or scrubbing with wire brushes, and using high-pressure water jets (Minchin *et al.*, 2006). This should be done well and repeated on a regular basis or else the risk of hull fouling may even increase instead of decrease (Minchin *et al.*, 2006). Commonly, traces of barnacle and oyster cement, byssal threads and soft tissues of sponges, hydroids or ascidians are left behind after insufficiently cleaning a hull, after which these left overs may act as positive settlement cues and non-toxic platforms for a range of larvae (Burke 1986; Pawlik 1992), which may result in more fouling than before the hull was cleaned.

Geens (2008) promotes in water cleaning because cleaning in a dry dock may be hampered by economical constraints like the loss of time for a ship, and the absence of infrastructure, i.e. sufficient capacity in the dry docks. In many pleasure craft harbours this is impossible however. For example in water cleaning in Australia is not allowed without special permissions (Australian Government, 2009) and in the Netherlands scuba-diving or snorkelling is usually banned in pleasure craft harbours because of safety regulations.

The most commonly used method to prevent hull fouling, is the application of antifouling. To date, the majority of the ships worldwide is provided with a layer of paint that has antifouling characteristics by the release of a chemical that prevents biofouling (Geens, 2008). TBT is one of the most commonly used chemicals. Studies have shown that TBT not only prevents hulls from becoming fouled, but also induces imposex in gastropod species that live close by (Bryan *et al.*, 1987). This caused the local extinction of native gastropod species like the dog-whelk Nucella lapillus in many places. In a reaction to these scientific results countries like the Netherlands, France, Britain, Sweden, USA and Canada prohibited the use of TBT-containing paint. This prohibition first targeted the smaller boats since they tended to be present in near-shore waters, which are important reproduction areas for a large number of organisms. Later on the IMO made a resolution to improve water quality by banning the application of organotins to all hulls from January 2003 (Minchin, 2006). Since 2008 no vessels are expected to have such paints on their hulls. How long it will take until the TBT releases in port waters stop, is questionable however as Eklund *et al.* (2008) proof that TBT is still being released from pleasure craft boats even though it has been banned on such boats for 19 years. They conclude that the source of the TBT that they measured beneath these boats, is most likely the older paint that has been covered with newer coats.

A negative consequence of the banning of TBT is that exotic gastropod species that are sensitive to TBT may now have a higher chance of settling in areas where they could not settle in the past. Faasse & Ligthart (2007) hypothesize that the American oyster drill *Urosalpinx cinerea* could settle in The Netherlands because of the ban on TBT.

As an alternative to the anti fouling paints with biocides, several non toxic paints and coatings like Intersleek and Ecospeed have been introduced to inhibit hull fouling. Although these more nature friendly alternatives do reduce the amount of fouling, it remains important to inspect and clean the hulls on a regular basis as fouling will form when the boats lie at rest for too long (Geens, 2008; Mineur *et al.*, 2007). During a macro-algae hull fouling study in the Mediterranean the type of antifouling was found to be the most important influence on the fouling assemblages (Mineur *et al.*, 2007). The one ship that carried an unusually high number of species (18), was the only one with a non-toxic coating, i.e. Intersleek (Mineur *et al.*, 2007).

5.2. Eradication

Eradication of marine exotic species after they have settled is found to be very difficult. In the Wadden Sea and especially in the pleasure craft harbours it is an option however. Many exotic species that have probably been introduced by hull fouling in the Wadden Sea may only occur in the pleasure craft harbours where they have been introduced, at least at first (Figs. 2, 6; Gittenberger, 2010). Furthermore, within these pleasure craft harbours, they may only occur on the floating docks (Fig. 11). If that is the case, one can take these floating docks out of the water and clean them to eradicate the species. This eradication method is described in more detail in Gittenberger (2010).

5.3. Control

To reduce the chance that hull fouling exotic species, which are constantly introduced to the Wadden Sea, do not use the pleasure craft harbours as stepping stones in their spread along the European coast, one should clean the floating docks on a regular basis.

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