Preliminary overview of exotic and invasive marine species in the Dutch Caribbean

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Summary

The marine exotic species of the Dutch Caribbean are less well-known than its terrestrial exotics. So far, only 27 known or suspected marine exotic species, some of which are also invasive are documented for one or more islands of the Dutch Caribbean. Four of these were documented only once or were only present for a certain period of time and are no longer present. Six of the species are marine epidemic diseases. As very little is known about these diseases, they might actually be native, but based on the literature and their ecological signature we regard them as special cases of invasive species.

In addition to these documented species, 76 other exotic species that have already been observed elsewhere in the Caribbean may already be present or can be expected to arrive in the Dutch Caribbean in the near future. The marine communities of the Dutch Caribbean have suffered major changes based on a handful of marine exotic and/or invasive species, particularly in the special case of (opportunistic) pathogens. In certain cases experience shows that after decades, the affected systems/species may show slow signs of recovery from initial impacts (e.g. the green turtle fibropapillomas), while in other cases the impact may be long-lasting and recovery doubtful (e.g. sea fan mortality).

Compared to terrestrial exotic species, eradication and control have been proven difficult or impossible for marine exotics. Therefore, management practices aimed at controlling unwanted species introductions should focus on preventing the arrival of such species by ships-- that transport exotics in their ballast water or as fouling communities on their hulls-- and (accidental) introductions from aquaculture or the aquarium trade. Busy harbors can be expected to be the areas where most marine exotics likely establish first.

Because of dispersal of marine exotics is facilitated by ocean currents, local approaches to prevent their arrival or reduce their numbers will be less effective compared to similar efforts for terrestrial species. In the case of marine exotics and invasives, it is paramount that prevention, control and management efforts should be regionally integrated. We conclude this report by listing a number recommendations on how to develop effective management approaches with which to address the impacts and risks associated with marine exotic species.

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1 Introduction

The arrival of exotic species to native communities is a large and increasingly more frequently occurring problem world-wide, including the Caribbean (Williams and Sinderman 1992; Williams *et al.* 2001; Kairo et al. 2003; Lopez and Krauss 2006). While many are unsuccessful, some new arrivals become extremely abundant and widespread which can negatively impact native flora and fauna. Such introduced species are often referred to as "invasive alien species" (IAS). IAS presently cause major economic losses worldwide (Pimentel *et al.* 2005) and rank amongst the most important drivers of local and global reductions in biodiversity (World Conservation Monitoring Centre 1992; Vitousek *et al.* 1997; Mooney and Hobbs 2000). While IAS often cause economic losses, there are also examples of species that may benefit fisheries or even provide the basis for new fisheries.

This topic has been identified as a critically important issue for nature conservation in the Dutch Caribbean since the drafting of the first nature policy plan 2001-2005, and remains so today (Debrot *et al.* 2011). Particularly little is has been documented on the extent to which exotic species have invaded marine communities around the islands in the Dutch Caribbean (Aruba, Bonaire, Curaçao, St. Eustatius, St. Maarten, Saba), the consequences to marine biodiversity in general, and whether possibilities exist to limit their effect in the future.

In light of the fact that IAS remain an urgent concern, the Dutch Ministry of Economic Affairs, Agriculture and Innovation commissioned IMARES to provide an update and overview of exotic and invasive species for the Caribbean Netherlands. In this report we briefly review the marine exotics presently recorded for the Dutch Caribbean, identify which species can be expected to be documented (or arrive newly) in the near future and discuss which if any measures could be undertaken to prevent the introduction and establishment of new exotics, or to minimize the impacts of those that have established themselves.

While the focus of this report is the Caribbean Netherlands (Bonaire, Saba, St. Eustatius), the need to include the other three island territories of the Dutch Caribbean (Aruba, Curaçao and St. Maarten) in our review was dictated by:

- General interconnectedness of the Dutch Caribbean islands in terms of short geographical distances for motile marine species
- A centuries-long common history of exposure to exotic species and actual introductions
- The intensive and enduring economic ties and material and human traffic between the islands
- The fact that the IAS problem is truly a shared problem, with a high degree of overlap in species and issues.
- The fact that IAS are often costly to combat, optimally calling for a joint and coordinated approach based on a shared awareness.

2 Objectives

We here conduct a literature with as its main objectives to: (1) review known marine exotic and invasive species from the six islands of the Dutch Caribbean; (2) review exotic marine species that are expected to be documented or arrive newly in the Dutch Caribbean in the near future and (3) provide key recommendations to design management approaches to deal with the impacts and risks associated with marine exotic species.

We further include in our discussion a small number of marine species introduced for aquaculture purposes, but do exclude aquarium species brought in for aquarium purposes but which have not been found in the wild. Whereas household aquaria in the Dutch Antilles are almost all closed systems located far from sea, aquaculture systems have up to now not been closed systems. Therefore, even though important precautions have, and continue to be taken to limit risks of releasing cultured animals and/or pathogens into the wild these species are still included in assessment.

Several new pathogens and epidemic diseases are also included. Several of these appear to be introduced not from afar but from nearby (terrestrial) habitats via man-mediated contamination and erosion. However, once in the marine environment these organisms then appear to spread on their own. While these species generally carry the "ecological signature" of invasive species (e.g. spreading characteristics and association with disturbance), whether or not to include them as invasive species is debatable and depends on definitions. However, we do include them here.

3 Results

The findings are presented in the form of two tables in the appendices. Appendix A provides an overview of the marine exotic species presently documented for one or more areas of the Dutch Caribbean. This overview includes cryptogenic species that are neither demonstrably native nor introduced (Carlton 1996). Due to the absence of detailed species inventories in the past, the recent increase in the abundance of formerly unnoticed species could be explained by either a recent introduction (i.e., historic invasions including natural expansions and human introductions) or an unnatural population increase of native species, i.e., indigenous or endemic taxa, which include prehistoric expansions. The presence of cryptogenic species about which little is known, hampers accurate quantification of the number of invasive species. High abundance of a cryptogenic species may negatively impacts native flora and fauna, and will often concern an invasive species. Because many cryptogenic species are likely also true invasives, this warrants the inclusion of both groups in the overview of known and expected invasive and exotic species currently present in the Dutch Caribbean.

Presently, 27 exotic and cryptogenic marine species have been recorded for one or more islands of the Dutch Caribbean (Appendix A). Two of these may regard uncertain identification while two others regard aquaculture species that were never documented in the wild. None of these four species are still present in the Dutch Caribbean, either in the wild or in captivity.

Appendix B lists exotic and cryptogenic species that occur close to (i.e. <300km or at an up-current location from) (an island of) the Dutch Caribbean and can be expected to arrive at one of the islands in the near future ("watchlist"). Most of these species are listed by Perez *et al.* (2007) who reviewed the exotic, invasive and cryptogenic marine species occurring along the Venezuelan coast. Because the close proximity (< 70 km) of Venezuela to especially the Leeward Island of the Dutch Caribbean (i.e., Aruba, Bonaire and Curaçao) these species are assumed to have a high potential to ultimately also arrive on these island with the prevailing currents. Estuarine species and rare species listed by Perez *et al.* (2007) are not included. Species which are limited to estuarine habitats constitute a relatively low risk for natural dispersal to the Dutch Caribbean where suitable estuarine habitat is very limited. While species that are presently rare in the region may develop into problems in the future, for the purpose of this report are considered low risk because of their low reproductive potential. Therefore, they were not included in our watchlist.

4 Documented Species

4.1 Fishes

Tilapia, *Oreochromis mossambica* (invasive)
Introduced Mozambique tilapia (*Oreochromis mossambica*) are found in salt, fresh and brackish waters on Aruba, Curaçao and Bonaire (Debrot 2003). They can also be found in the permanent waters of the tertiary finishing ponds of the Bubali wastewater plant in Aruba and at the wastewater treatment facility at Klein Hofje in Curaçao. Tilapias were brought to the islands for aquaculture in the 1950s (Curacao) (Zaneveld 1959) and 1980s (Bonaire) (Debrot 2003, Hensen and Grashof 1994), and subsequently used to help control the populations of algae in ponds. On Curaçao, tilapia are now present in natural water reservoirs and streams and apparently reduced the abundance of native crustacean and fresh and brackish water fish species (Debrot 2003). Similar negative impacts have been observed in nearby Venezuela by Perez *et al.* (2003). During annually reoccurring periods with no rainfall, tilapia largely disappear, but reappear during the wet season, most likely due to reinfection from estuarine marine areas. While the species prefers freshwater, it is able to live for long periods in saltwater, and therefore is included here. The species is also common in estuarine waters of St. Maarten (R. Hensen, pers. comm.).

Machuri, *Poecilia vandepolli* (invasive)
This species is endemic to the Leeward Dutch Caribbean but has been introduced to St. Maarten and has become naturalized in the fresh and brackish water habitat there (Poeser 1992). Ecological consequences for the native estuarine communities remain unknown.

Lionfish, *Pterois volitans* / miles (invasive)
The lionfish, a native marine species from the Indo-Pacific region, has spread throughout the Caribbean, starting in Florida, since 1992 (Morris *et al.* 2008) and is capable of rapid population growth after establishment. In October 2009 they were first detected on Aruba, Curaçao and Bonaire. In 2010 they were first observed on Saba and Saba Bank. There are two closely related species *Pterois volitans* and *Pterois miles* that are difficult to distinguish in the field so they are generally referred to as *Pterois volitans*/miles. The lionfish eats large numbers of juvenile native fishes and crustaceans (Albins and Hixon 2008) and is expected to have serious detrimental effects on native coral fish populations. Albins and Hixon (2008) showed that lionfish are capable of locally reducing effective recruitment by native reef fishes by up to 80%. Interesting would be to see how this compares to the effect of native predators. The species may be spreading so rapidly partly because it is able to occupy the empty niche that was formerly filled by native piscivores (e.g. groupers) that have been fished out by man. Lionfish are very suitable for human consumption once the venomous spines are removed. In areas where ciguatera occurs (e.g., the Saba Bank, St. Eustatius), lionfish can be ciguatoxic due to the accumulation ciguatoxins , a phenomenon common to other predators of reef fish (e.g., barracuda, groupers, jacks). It is suggested that in time native predators will develop resistance to the lionfish venom which will eventually result in higher predation rates on this species (Maljković and van Leeuwen 2008). Indeed, usually invasive species will "settle in" after the initial expansion phase.

Bonaire and Curaçao are one of the few islands that currently run large volunteer based removal programs using divers equipped with modified spear guns along the islands' leeward coasts. The total area effectively harvested, assuming an average width of 200 m per dive site amounts to approximately 20% of the total coastline and preliminary data (De Leon and Vermeij; unpubl. data) shows a 3-8 fold reduction in lionfish biomass depending on habitat type. The species ranges to depths of 300 m (Vermeij pers. obs.), but harvest takes generally place shallower than 30 m due to limitations of compressed-air diving. While removal efforts seem effective on Bonaire and Curaçao, Barbour *et al.* (2011) predicted that an annual exploitation rate between 35 and 65% is required to reduce recruitment in lionfish populations. Lionfish also quickly recover from high removal rates, likely as a result of secondary invasion from upstream locations where active eradication efforts are absent. A lasting and long-term reduction of adult lionfish abundance thus requires a long-term and regional commitment (Barbour *et al.* 2011). Effective eradication may be feasible only in small, localized areas where annual exploitation can be intense over many years. At the very least, the current lionfish removal programs on Curaçao and Bonaire not only help buy time to delay local adverse ecological impacts of this fish but also provide a good opportunity for new insights into the effects and effectiveness of removal. Therefore, these volunteer programs should continue and be improved as new techniques for lionfish control are tried and developed.

Barbour *et al.* (2010) found that the lionfish also invades mangrove areas. This means that the fish nursery habitats on the islands such as Lac (Bonaire) and Spanish Waters (Curaçao) might be especially vulnerable to this species. Lesser and Slattery (2011) document major shifts from coral to (less desirable) algal domination on Bahamian deep reefs as lionfish reduced the abundance of herbivores through predation.

Cobia, *Rachycentron canadum* (exotic)
At present, the only exotic species present in the Dutch Caribbean for aquaculture purposes is the cobia *Rachycentron canadum.* It is kept at a facility far from open seawater on Bonaire. However, the species has been known to carry exotic parasites that have been introduced to marine communities elsewhere in the Caribbean (Williams and Bunkely-Williams 2006). Risks can be minimized when appropriate measures are taken to prevent the escape or accidental transfer of live non-native pathogens from such facilities.

4.2 Molluscs

Sea hares, *Aplysia* spp. (cryptogenic)
The presence of three cosmopolitan or possibly exotic species of the sea-slug genus *Aplysia* ("sea hares") has been documented for Curaçao (De Jongh and Coomans 1988). It is highly likely that they occur on the other islands too, as larvae of *Aplysia* species can remain plantonic for >100 days and thus easily be carried by currents from one island to another (Kempf 1981). These animals graze on algae in the shallow sub tidal zone. Very little is known about the potential effects of these animals on native marine communities.

Exotic triton seashells, (exotic)
Two exotic mollusc species collected in Curacao have been reported elsewhere as *Galagno succineta* and *Oenebra muricoides* (Lopez and Krauss 2006, van Buurt 1999). These were reportedly found in 1997 and 1998 in Curaçao. It is not certain which species were actually concerned, and no similar finds have been reported since. These records may have been erroneous.

Giant clam, *Tridacna derasa* (exotic)
This species was introduced to Bonaire in 1988 for aquaculture purposes (Hensen and Grashof 1994a, 1994b). The species was never kept in open-systems and has not been observed on reef communities on Bonaire. When the mariculture facilities shut down, the remaining specimens were exported from Bonaire (R. Hensen, pers. comm.). Williams and Sinderman (1992) and Williams and Bunkley-Williams (1999) point out risks for introduction of exotic diseases or new strains of already present diseases associated with introductions of aquaculture species. Particularly notorious with the giant clam are mortalities

associated with *Perkinsus* outbreaks. These cause mass mortalities in molluscs and are not species-specific, which makes thorough screening even more important (Williams and Bunkley-Williams 1990).

4.3 Crustaceans

Ecuador White shrimp *Peneaus vannamei* (exotic)

Ecuador White shrimp (*Penaeus vannamei*) were also cultured at the aquaculture facilities near Sorobon on Bonaire (Hensen and Grashof 1994a, 1994b). After the original owner left, the facilities were rented out to a commercial aquaculture company (" Sea Hatch"), which used the facilities for many years. This company also had similar aquaculture facilities at Savaneta, Aruba. A breeding stock of Ecuador white shrimp was kept at these facilties and post-larvae were exported to various neighbouring countries, mostly Venezuela and Surinam, and occasionally to Panama and Honduras. The company was eventually forced to close down both facilities, due to the introduction of Tauro shrimp virus in Venezuela, which led to an import prohibition for post-larvae in Venezuela, thus depriving them of their main market. Occasionally other species of shrimp such as *Penaeus stylirostris*, were also cultured on special request. When commercial production of post-larvae stopped, the Sorobon facility was rented by a company named Dragon Feeds, which operated on a smaller scale. The facilities were used to test the effectiveness of various artificial foods for shrimp larvae, post-larvae and adult shrimp. The facilities at Sorobon were producing shrimp post-larvae till the 2008 financial crisis, which finally forced their shutdown. The brood stock of shrimp was maintained till 2009, but unfortunately could not be sold as such and was finally sold for consumption. The outflow of water from the facilities goes into the Salt ponds of the Bonaire Salt works and is thus effectively sterilized. The chance that a seabird caught specimens in the aquaculture ponds and accidentally dropped them in Lac is small since none of the shrimp species grown at the facility were ever found in the surrounding waters either in Bonaire or on Aruba.

Even though *P. vannamei* has never been reported from the surrounding waters, or from the wild elsewhere on Bonaire or Aruba, the species is listed here as it was kept in large numbers in an open system close to the sea. Perez *et al.* (2007) do not list the species as cryptogenic for Venezuela despite the fact that it is widely cultured there. This may suggest that it may not be able to easily establish itself in the wild in the Caribbean.

4.4 Bryozoa

Brown bryozoan, *Bugula neritina* (cryptogenic)

Bugula neritina, an invasive widespread bryozoan has been observed on Curaçao by Mackie *et al.* (2005). The species forms flexible bushy, branching colonies to about 10cm high and is purplish-brown in color. The species appears to be capable of tolerating high levels of pollution. It is commonly transported attached to ship hulls. Its short larval duration causes this species to settle rapidly once introduced and as such it is commonly found in harbors.

4.5 Algae

Brown alga, *Dictyota hamifera* (cryptogenic)

Littler *et al.* (2010) list two cryptogenic algal species for the Saba Bank. One of these is the brown alga, *Dictyota hamifera,* a species originally described for the Central Pacific. The species is widely spread throughout the Caribbean but nothing is known about its potential effects on native marine communities, though the species is also observed in Venezuela (Perez *et al.* 2007) indicating that this species is probably already widespread in the Southern Caribbean. The Saba Bank has been intensively used as anchorage for large tankers and in recent years has seen reductions in coral cover and an increased occurrence of algal blooms (H. Meesters pers. comm.). While the potential involvement of *D. hamifera* in either dynamic is presently not confirmed, the possibility remains that this species could be at least partially responsible for the observed changes in benthic community composition on the Saba Bank.

Green alga, *Caulerpa serrulata* (cryptogenic)

The other cryptogenic species described by Littler *et al.* (2010) for the Saba Bank is the green alga *Caulerpa serrulata*. The species has been widely documented in the Caribbean region, and is also found on Bonaire (Littler and Littler 2006). It is a potential invasive species. As with most marine invasives that have been poorly documented, nothing is further known about the potential effects of this species.

Introduced macro algae are widely abundant throughout the oceans and introductions increase exponentially in time (Lyons and Scheibling 2009). Spreading in individual species can occur at the rate of 10s to 100s of kilometres per year (Lyons and Scheibling 2009). Anthropogenic vectors appear to play the key role in dispersing algae beyond their natural dispersive range(Lyons and Scheibling 2009), and increased land-based sources of nutrient pollution further support the establishment and spread of invasive algal species (Lapointe *et al.* 2005).

4.6 Crustose corallines

Calcareous alga, *Ramicrusta* sp. (cryptogenic)

The Eckrich *et al.* (2010) have recently described an unknown, possibly undescribed crustose calcareous alga, *Ramicrusta sp.*, smothering benthic communities near Lac Bay, Bonaire. Slijkerman *et al.* (2011), suggest that the bloom of this aggressive species may be facilitated by eutrophication documented in the same bay.

4.7 Seagrasses

Halophila seagrass, *Halophila stipulacea* (invasive)

The exotic seagrass *Halophila stipulacea* is aggressively invading shallow water communities throughout the Caribbean (Willette and Ambrose 2009, Ruiz and Ballantine 2004). The ecological consequences of this invasion are unknown. In Bonaire the species has invaded the central portion of Lac bay where it is already ubiquitous and creates thick beds completely covering the bottom and excluding all other species (Debrot, pers. obs.). It has also been observed on St. Maarten (Vermeij, pers. obs.). Because the sea grass beds of Lac had never been described quantitatively before, the impact of this aggressive sea grass species is not known. It is clear that *H. stipulacea* is effectively monopolizing space and thereby limiting natural communities of seagrasses and algae. Currently, a seagrass baseline community description is underway for Lac, which can serve as a baseline for future reference.

Polychaet worms, *Fycopomatus miamensis*, Tube worm, *Hydroides elegans* and Limy tubeworm, *H. dianthus(exotic)*

Practically nothing is known about the occurrence and distribution of native and exotic polychaets in the waters of the Dutch Caribbean. The only study that mentions the presence of exotic species is a thesis by Djohani and Klok (1988) whose results were never published. All three species concerned are known biofoulers and typically transported from port to port via ship hulls. The species were all observed in the busy harbors of Curacao.

4.8 Didemnids (colonial ascidians)

Overgrowing mat tunicate, *Trididemnum solidum* (cryptogenic)
Didemnids are well known for their invasive capabilities. The genus *Trididemnum* has 53 species. *Trididemnum solidum* is an aggressive competitor for space on the reef and several studies have been conducted on its ecology in the Dutch Caribbean (Bak *et al.* 1981, 1996, Duyl *et al.* 1981; Sommer *et al.* 2010). Once non-native ascidians become established, they produce large amounts of larvae that will occupy space in adjacent marine communities (Lambert 2002). *Trididemnum solidum* has locally aggressively invaded coral reef communities in the Dutch Caribbean, especially on Bonaire's deep reefs (Sommer *et al.* 2010).

4.9 Corals

Orange tube coral, *Tubastrea coccinea* (exotic)
Tubastrea coccinea is native to the Indo-Pacific oceans. This coral is thought to have arrived with ballast water. In the Caribbean, the species was first noted in Puerto Rico and Curaçao in 1943. On Curacao the species became fully established in the early 1950's. The damage this species might have caused took place a long time ago. Because of the lack of early baseline studies, its effects, if any, are hard to reconstruct. It is also possible (but unlikely) that it occupied an ecological niche which was previously unoccupied by native coral species (i.e., cryptic or extremely shallow habitats). The use removal and transplantation experiments is one way to gain insight into the potential effects of this species.

4.10 Marine diseases and epidemics

Black band coral disease (invasive)
Frias-Lopez *et al.* (2002) studied black band disease in corals of Curaçao and concluded that these were being caused by sewage associated enteric bacteria, i.e., foreign agents introduced into the marine environment where they do not occur naturally.

Long-spined Sea urchin disease agent (presumably invasive)
In 1983, a unknown disease killed almost all Long-Spined Sea urchins (*Diadema antillarum*) in the Caribbean, including the islands of the Dutch Caribbean. The disease spread very rapidly and within 2 weeks or less >95% of the sea urchins had died. Other species of sea urchin were not affected. It is commonly believed that this disease was introduced from the Pacific Ocean in ballast water of a ship. The disease was first observed in San Blas (Panama) in January 1983 and then spread to Curaçao, against the prevailing currents but along the major shipping routes. Its pattern of spreading and association with major shipping routes has suggested to some that this is an exotic species introduced into the Caribbean. From Curaçao, it rapidly spread throughout the Caribbean between 1983 and 1984 in a clockwise direction with the prevailing currents (Lessios *et al.* 1984). By February 1984 *Diadema* had been eliminated from most of its native range (Knowlton 2001). The causative agent has never been identified. Starting in the late 1950's regulations were introduced to clean up ballast water which, till then, was an important source of oil pollution. At the time it was not realized that cleaner ballast water caused many organisms to survive transportation from one ocean to another. Newer IMO (International Maritime Organization) regulations and guidelines (use of chlorine and UV light to kill propagules) partially address this problem. However, these practices are only being phased in now and are not required of old vessels.

The *Diadema* die-off had very serious consequences for Caribbean reef ecosystems since *D. antillarum* kept the reef free of algae. Before the die-off the density of *Diadema* on the shallow reef in Curaçao ranged from 3 to 20 per square meter and dropped to 0.01 per square meter after the die-off (Bak *et al*. 1984). Their grazing allowed corals to remain free of algal overgrowth and created surfaces where coral larvae could settle. *Diadema antillarum* was also an important source of food for fish such as triggerfish and Spanish hogfish. Throughout the Caribbean, many coral reefs severely degraded in response to the *D. antillarum* die-off and while many other factors likely contributed, the demise of the *Diadema* is generally considered one of the dominant causes (Edmunds and Carpenter 2001). The pathogen responsible for the *Diadema* die-off could arguably be regarded as the invasive species that caused most damage to Caribbean marine communities. Presently, more than 25 years later, *Diadema* seems to be making a slow come-back. In Curaçao their numbers have been slowly increasing in recent years and larval supply is similar to that before the die-off (Vermeij *et al*. 2010). In Barbados (Hunte & Younglao 1988) and Jamaica (Cho and Woodley 2000) a similar recovery has been observed.

Heart urchin, *Meoma ventricosa*, disease agent (presumably invasive)
Nagelkerken *et al.* (1999) described a localized, short-lived die-off of heart urchins in Curaçao, caused by a pathogenic bacterium and originating from the harbor of Willemstad. The fact that the disease originated from a busy harbor makes it possible or even likely that the agent was introduced via a ship's ballast water.

Seafan aspergillosis, *Aspergillus syndowii* (presumably invasive)
In 1995 the seafans of the Caribbean suffered extensive and wide-spread mortalities caused by an infection with the fungal species *Aspergillus syndowii* (Nagelkerken *et al.* 1977a, 1997b). This species is historically a terrestrial fungus which was probably introduced to the marine environment with terrestrial run-off, while others relate it to Sahara-dust blown into the Caribbean as associated with deforestation (Shinn *et al.* 2000). Ten years after its introduction and outbreak, sea fans populations remain seriously affected by this disease (Nugues and Nagelkerken 2006). Toledo-Hernández *et al.* (2008) found no host resistance development in sea fan populations to this disease, which means that they remain as vulnerable as ever.

Sea turtle fibropapilloma (presumed invasive)
Williams *et al.* (1994) described a Caribbean-wide infestation of Caribbean green sea turtles with fibropappilloma tumors. The original outbreak was suggested to be associated with a wide geographic spreading (i.e. invasive behaviour) of the disease. After the major outbreak, this disease continues to be recorded albeit at reduced levels.

White pox disease in Acroporid corals (invasive)
White pox disease affecting coral colonies of the genus *Acropora* has been widely observed throughout the Dutch Caribbean and is presumably caused by a faecal enteric bacterium possibly of human origin (Patterson *et al.* 2002). These bacteria are not native to the marine environment.

5 Watchlist Species

Annex B lists 77 species that can be expected to arrive or already be present in the waters of the Dutch Caribbean. Some of these are known invasive species, others possibly poorly-known cosmopolitan species. Only further research can evaluate whether or not most of these species are to be considered exotic and what if any ecological or economic effect they may have. The list includes such taxa ranging from fish and crustaceans all the way to algae and sea grasses. Most prominent are algae (23 spp.), molluscs (23 spp.) and crustaceans (13 spp.). These three groups account for 76% of the watchlist species. For most species very little is known about their origin, current region-wide distribution and possible effects. Only a few noteworthy cases are highlighted here.

A particularly worrisome species is the invasive Indo Pacific green mussel, *Perna viridis*. From its initial introduction in Venezuela for aquaculture purposes, it has since spread around the Wider Caribbean, including Trinidad (1990), Jamaica (1998) and Florida (1999) (Buddo *et al.* 2003). The species particularly invades mangrove systems.

In Venezuela the introduced red algae *Kappaphycus alvarezii*, causes large-scale bleaching of coral reefs (Barrios *et al.* 2007), and is also a species of particular concern. In addition to the invasive seagrass *Halophila stipulacea* which has been found to be aggressively occupying space in the seagrass communities of Bonaire and St. Maarten, Short *et al.* (2010) have recently also documented another invasive seagrass species (*H. ovalis*) for the Caribbean. If *H. ovalis* behaves anything like *H. stipulacea*, this could spell very bad news for seagrass beds of the Dutch Caribbean, particularly if these two related species complement each other in their competitive ability.

Finally, a recent introduction into the Gulf of Mexico is the black sun coral (*Tubastrea micrantha*). The species is similar to *T. coccinea* which has spread widely throughout the Caribbean. After being introduced from the Indo-Pacific. *Tubastrea micracantha* was recently found growing on an oil platform in the Gulf of Mexico in August 2010. It seems likely that it will eventually spread throughout the Caribbean. It remains to be seen whether the presence of this coral will become a problem or whether its presence will be rather benign, whether it will compete with *T. coccinea* or complement it in monopolizing substrate niches on the reef.

6 Discussion

This is the first overview of marine exotic, and potential exotic species for the Dutch Caribbean. The two other main reference studies are that by Lopez and Krauss (2006) for the Wider Caribbean Region (including Florida, Bermuda, the Bahamas and the Gulf of Mexico) and that by Perez *et al.* (2007) for nearby Venezuelan waters. Lopez and Krauss (2006) report a total of 118 marine invasive species, of which only 31 for the Caribbean Sea proper. In our review we found 27 species that are exotic, invasive or cryptogenic to at least parts of the Dutch Caribbean, most of which were not included in the list by Lopez and Krauss (2006). This indicates that directed attention has (and should) rapidly lead to the documentation of large numbers of additional exotic, invasive and or cryptogenic species. The later and more detailed and thorough work by Perez *et al.* (2007) for Venezuelan waters likewise shows that the initial assessment by Lopez only shows the tip of the proverbial ice berg. As pointed out by Campbell *et al.* (2007), to be able to address the increasingly urgent marine invasives issue, nations need to know what species are present in their waters. Our preliminary work here therefore only emphasises the urgent need for a thorough assessment for the Dutch Caribbean.

The species we compiled for the Dutch Caribbean cover a wide range of taxa, ranging from fishes to microbes. For most species their effects and potential impacts on ecology and economy remain unknown. The marine resources of the Dutch Caribbean have suffered severely from only a handful of marine invasives, particularly from the special case of pathogens causing diseases to corals and key-stone species such as *Diadema antillarum*, arguably the most important herbivore on Caribbean reef systems. Experience (for instance in the case of *Diadema*) shows that after decades, the affected systems/species appear to show slow signs of recovery from initial impacts (Vermeij *et al.* 2010).

Based on the fact that most invasive species are small during at least part of their life cycle, invasion through ballast water (ships) is likely foremost acting as a vector for such invasions. A particularly disturbing development is the growing number of pathogens into the marine environment from contaminated freshwater and terrestrial runoff. Examples include white pox disease, black band disease and sea fan aspergillosis, which all were introduced to the marine environment relatively recently and have since caused extensive mortalities in various benthic reef taxa. So we are seeing that diseases which under normal circumstances might only have limited and localized effects, recently have been behaving more like invasive and epidemic species affecting large areas. This may largely be ascribed directly to actions by man that a) favour the introduction of such agents, b) favour their establishment and c) reduce the natural resilience of systems and species (to resist such infestations).

Establishment of marine invasive species is further often aided by disturbance and pollution (Piola and Johnston 2008). Busy harbors are therefore likely areas where most exotics and invasives establish their first footholds. Because of marine connectivity, localized approaches are less effective than with terrestrial species. Therefore, solutions need to be sought in regional approaches and programs to limit and reduce risks. Because of their aqueous medium, as a rule, marine exotics are also much more difficult to manage than terrestrial exotics. Once invasive species establish themselves in the marine environment, eradication and even control are difficult or impossible. Therefore prevention is the key. Ballast water is recognized as a key vector for marine invasives. In 2004 the IMO ballast water convention was adopted to help set BW management standards worldwide (Lopez and Krauss 2006). Active participation and local implementation prior to the convention coming into force is highly recommended. Some have raised the question whether the prevalence of coral diseases in the Caribbean could have been due to new strains of pathogens, coming in from the Indo-Pacific to which Caribbean corals would have had less resistance. Such diseases could have come in with cleaner ballast-water after regulations to reduce oil in ballast-water started to become effective in the 1970's. The long-spined sea urchin disease causative agent would be an example of such a pathogen coming in from the Indo-Pacific. Unfortunately very little is known about this subject.

Aside from ballast water, aquaculture is an important mechanism for introduction of invasive species. In their review of aquaculture exotic introductions in the Caribbean, Williams and Bunkley-Williams (1999), indicate showed that 44 of the 83 species that were at the time introduced into the Caribbean for aquaculture purposes had established themselves in the wild. The authors further commented that local regulations are generally totally inadequate and rely largely on the "enlightened self-interest of the culturalists". In the Dutch Caribbean, aquaculture related introductions include the Nile tilapia, *Oreochromis mossambica*, the shrimp *Peneaus vannamei*, the giant clam, *Tridacna derasa*, and the cobia, *Rachycentron canadum*. Of these only *Oreochromis mossambica* has established itself principally in some fresh and brackish waters in Curaçao and Aruba. Overall it can be said that aquaculture initiatives and associated introductions have been few and that due to preventive action they appear to have had little lasting effects in the Dutch Caribbean. This is in contrast to introductions for instance in Venezuela (Perez *et al.* 2007).

A worrisome trend comprises the rise of exotic and opportunistic pathogens and disease agents, including those of terrestrial/freshwater origin that are entering the marine environment through man-mediated pollution and changes in near-shore land use. These taxa are extremely hard to quantify through standard visual surveys of marine communities because of their microscopic size. Because native microbial communities remain often undescribed, it is also extremely difficult to assess whether such pathogens are true exotics or comprise microbes that have simply increased in abundance due to changing environmental conditions.

One (local) practice which may contribute to the establishment of marine exotics and should be prohibited is the scraping of ships hulls by divers while anchored near shore. This can directly transfer viable, reproducing individuals of exotic species to the seafloor where they can establish themselves long after the ship on which they came has left. However, this type of ship maintenance work does not appear to take place often any more.

Our review most importantly shows that introduction and detection of marine exotics in the Caribbean have grown rapidly in recent years and will continue to grow. New exotics or problems with invasives can be expected in the near future (Table 2). To be able to address the increasingly urgent marine invasives issue, surveys are need to know what species are currently present. In this, a pragmatic approach is urgently needed and can be fruitful. For instance, Campbell *et al.* (2007) describe rapid survey methods used to assess the marine invasive problem. Ashton *et al.* (2006) demonstrate the usefulness of a rapid assessment approach focusing on a limited number of species and the most important sites. This allows some quantitative assessment and possible grip on the situation. We recommend that a baseline field assessment is urgently needed. At a later stage, tailor-made monitoring programs for these species would be needed as most often invasive species are not adequately pick up in biodiversity monitoring. Finally, Hayes and Silwa (2003) further describe a method to develop a "next pest" list. For that they suggest the following criteria: (a) species has been reported in a shipping vector or has a ship-mediated invasion history; (b) the vector still exists; (c) the species is responsible for economic or environmental harm; and, (d) it is exotic to (a region) or present in (a region) but subject to official control. By accurately predicting the "next pest" it may be possible to anticipate its arrival and take preventive measures. However, for most species, too little is known about their ecology to know what measures might actually be effective.

7 Recommendations

1. Waste water treatment to limit chronic input of sewage-borne pathogens into the near shore environment should be further implemented. The operation of existing plants (of Curaçao and Aruba also) should be improved and special attention should be given to new projects and building activities in porous calcareous areas, which should have their own wastewater treatment systems in areas where they cannot be connected to the main facilities.
2. Develop legislation regulating the importation of and trafficking with aquaculture and aquarium species.
3. Prohibit the practice of cleaning ships hulls from bio-fouling while anchored in Dutch Caribbean coastal waters.
4. Review current ballast water practices inside the Dutch Caribbean and implement the recommended IMO guidelines in advance of the Ballast Water Convention
5. Conduct a baseline field assessment of marine invasive species focusing on a limited number of species and the most important sites.

8 Internet Resources

A short-list of important web sites and key sources regarding prevention and management of marine invasive species is as follows:

CBD. 2005. Towards the development of a joint work plan for the management of marineinvasive alien species. UNEP/CBD/SBSTTA/11/INF/10. http://www.biodiv.org/doc/meetings/sbstta/sbstta-11/information/sbstta-11-inf-10-en.doc

Global Invasive Species Programme (GISP) 2005. South America Invaded. 80 pp. http://www.gisp.org/publications/invaded/gispSAmerica.pdf

International Council for the Exploration of the Sea (ICES). 2005. ICES Code of Practice on the Introductions and Transfers of Marine Organisms 2005. ICES, Copenhagen, Denmark. COPYRIGHT: ICES 42

International Maritime Organization (IMO). 1997. Guidelines For The Control And Management Of Ships' Ballast Water To Minimize The Transfer Of Harmful Aquatic Organisms And Pathogens. 17 pp. http://globallast.imo.org/868%20english.pdf

International Maritime Organization (IMO). 2004. International Convention for the Control and Management of Ships Ballast Water and Sediments. 38 pp. http://www.bsh.de/de/Meeresdaten/Umweltschutz/Ballastwasser/Konvention_en.pdf

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Quality assurance

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

Justification

Report C188/11
Project Number: 4308202004

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

Approved: Dr. M. de Graaf

Signature:

Date: 23 December 2011

Approved: F.C. Groenendijk, MSc.
Head of Department

Signature:

Date: 23 December 2011

Appendix A: List of known and suspected marine exotic species present or formerly present in the wild or in culture in Dutch Caribbean islands

Red shading = species present, Blue shading = No longer present

Species	**Common name**	**Status: exotic / cryptogenic / introduced**	**Area of origin**	**Mode of introduction**	**Aruba**	**Bonaire**	**Curacao**	**Saba Bank**	**Saba**	**St Eustatius**	**St Maarten**	**Key reference**	**Known impact**
Fish													
Oreochromis mossambica	Red tilapia	**I**	Africa	aquaculture	red	red	red				red	Debrot 2003	?
Poecilia reticulata	Guppy	**I**	S. America	aquarium pet							red	Poeser 1992	?
Pterois miles, P. volitans	Lionfish	E	Pacific	aquarium trade	red	red	red	red	red	red	red		catastrophic
Rachycentron canadum	Cobia	I	Americas	aquaculture		red							?
Molluscs													
Aplysia cervina		C	Cosmopolitan	long larval stage?			red					de Jongh and Coomans 1988	?
Aplysia dactylomela		C	Cosmopolitan	long larval stage?			red					de Jongh and Coomans 1988	?
Aplysia parvula		C	Cosmopolitan	long larval stage?			red					de Jongh and Coomans 1988	?
Galagno succineta???	Lesser grilled triton	I (misidentified?)	Pacific	Ballast water?			blue					Buurt 1999, Lopez and Krauss 2007	?

Oenebra muricoides???	Adam's dwarfed triton	I (misidentified?)	Pacific	Ballast water?								Buurt 1999, Lopez and Krauss 2007	?
Tridacna derasa	Giant clam	I	Pacific	Aquaculture								Hensen and Grashof 1994	?
Crustaceans													
Litopenaeus vannami	Whiteleg shrimp	I	Eastern Pacific	Aquaculture								Hensen and Grashof 1994	?
Bryozoa													
Bugula neritina	Brown bryozoan	E		Fouling								Mackie et al 2005	
Brown algae													
Dictyota hamifera			Central Pacific	Ballast water?								Littler et al. 2010	?
Green Algae													
Caulerpa serrulata		C	Indian ocean	Ballast water?								Littler et al. 2010	?
Crustose coralline													
Ramicrusta sp.		C										Eckrich et al 2010	large, local
Sea grasses													
Halophila stipulacea	Halophila seagrass	E	Red Sea	Ballast water?								Willette and Ambrose 2009	large, local
Hydroids/Polycheats													
Fycopomatus miamensis		C	Amphi-American	ship hulls								Djohani and Klok 1988	?
Hydroides elegans		E	Indian Ocean	Fouling								Djohani and Klok 1988	large

Hydroides dianthus	Slimy tubeworm	C	Northeast Atlantic	Fouling								Djohani and Klok 1988	?
Didemnid colonial ascidians													
Trididemnum solidum		?	?	?								Bak et al. 1981, 1996, Sommer et al. 2010	smothers reefs
Corals													
Tubastrea coccinea	Orange tube coral	E		Fouling								Boschma 1953, Roos 1971, McKenna and Etnoyer 2010	competes for space
Pathogens													
Black band disease		E	terrestrial	sewage runoff								Frias-Lopes et al. 2002	extensicve longterm
Diadema disease		E	Pacific Ocean?	Panama canal?								Bak et al. 1984	catastrophic longterm
Meoma disease		??	??	Assoc. with harbour and disturbance								Nagelkerken et al. 1999	locally acute
Aspergillus syndowii	Seafan disease	E	terrestrial	terrestrial runoff								Nagelkerken et al. 1997a,b	regionwide mortalities
Sea turtle fibropapilloma		C										Williams et al 1994	mortalities C. mydas
White pox Acropora disease		E	terrestrial	sewage runoff								Patterson et al 2002	extensive, longterm mortalities

Appendix B. Marine exotic and cryptogenic species recorded from nearby waters: a marine watchlist for the Dutch Caribbean.

Species	area of origin	mode of introduction	Neares location	Reference	Known Impact
Fish					
Omobranchus punctatus	Indo Pacific	Ballast water?, Panama Canal	Ven.	Perez et al. 2007	?
Sparisoma frondosum	S. W. Atlantic	Natural range expansion?	Ven.	Perez et al. 2007	?
Malacostraca					
Charibdis helleri	Indo Pacific	Ballast water?	Ven.	Perez et al. 2007	?
Rhithropanopeus harrisii	Northeast Atlantic	Ballast water?	Ven.	Perez et al. 2007	?
Callinectus arcuatus	Pacific		Ven.	Perez et al. 2007	?
Cycloxanthops sexdecimdentatus	N.E. Pacific		Ven.	Perez et al. 2007	?
Leptoduis tridentatus	E. Pacific		Ven.	Perez et al. 2007	?
Daira amiricana	E. Pacific		Ven.	Perez et al. 2007	?
Microphrys platysoma	E. Pacific		Ven.	Perez et al. 2007	?
Pyromaia tuberculata	N.E. Pacific		Ven.	Perez et al. 2007	?
Grapsus grapsus	N.E. Pacific		Ven.	Perez et al. 2007	?
Geograpsus lividus	E. Pacific		Ven.	Perez et al. 2007	strong invader
Pilumnus spinohirsutus	E. Pacific		Ven.	Perez et al. 2007	extremely invasive
Pilumnus stimpsoni	N. E. Pacific		Ven.	Perez et al. 2007	?
Maxillopoda					
Porcellidium sp.	Indo Pacific		Ven.	Perez et al. 2007	?
Barnacles					
Balanus amphitrite	Indian/Pacific oceans	Fouling/ 1950s	Ven.	Perez et al. 2007	highly invasive
Balanus trigonus	Indian/Pacific oceans	Fouling/ 1950s	Ven.	Perez et al. 2007	?
Ascidacea					
Styela clava	Central pacific	Fouling/Ballast water?	Ven.	Perez et al. 2007	?
Clavelina oblonga	W. Atlantic		Ven.	Perez et al. 2007	?
Distaplia bermudensis	W. Atlantic		Ven.	Perez et al. 2007	?
Diplosoma listeriarum	W. Atlantic		Ven.	Perez et al. 2007	?
Botrylloides nigrum	W. Atlantic		Ven.	Perez et al. 2007	?
Miscrocosmus exasperatus	W. Atlantic		Ven.	Perez et al. 2007	?
Red algae					
Kappaphycus alvarezii	Eastern Pacific	Aquaculture	Ven.	Barrios et al. 2007	large
Pterocladia media	North Pacific		Ven.	Perez et al. 2007	?
Titanoderma corallinae	E. Atlantic		Ven.	Perez et al. 2007	?
Predaea pusilla	Mediterranean		Ven.	Perez et al. 2007	?

Gracilaria textorii	W. Pacific		Ven.	Perez et al. 2007	?
Gymnogongrus crenulatus	E. Atlantic		Ven.	Perez et al. 2007	?
Rhodymenia pacifica	N. E. Pacific		Ven.	Perez et al. 2007	?
Chondrophycus intermedius	W. Pacific		Ven.	Perez et al. 2007	?
Chondrophycus perforatus	W. Pacific		Ven.	Perez et al. 2007	?
Osmundea pinnatifida	E. Atlantic		Ven.	Perez et al. 2007	?
Laurencia decumbens	W. Pacific		Ven.	Perez et al. 2007	?
Neosiphonia tongatensis	W. Pacific		Ven.	Perez et al. 2007	?
Brown Algae					
Hincksia sandriana	N.E. Atlantic		Ven.	Perez et al. 2007	?
Stilophora tenella	N.E. Atlantic		Ven.	Perez et al. 2007	?
Sphacelaria fusca	N.E. Atlantic		Ven.	Perez et al. 2007	?
Sphacelaria novaehollandiae	Pacific		Ven.	Perez et al. 2007	?
Dictyota canaliculata	C. Pacific		Ven.	Perez et al. 2007	?
Sargassum desfontainesii	N.E. Atlantic		Ven.	Perez et al. 2007	?

Species	area of origin	mode of introduction	Neares location	Reference	Known Impact
Green Algae					
Ulva reticulata	Indian Ocean	Accidental introduction	Ven.	Perez et al. 2007	large
Cladophora ordinata	Indian Ocean		Ven.	Perez et al. 2007	?
Cladophora ruchingeri	N.E Atlantic		Ven.	Perez et al. 2007	?
Caulerpa scalpelliformis	Pacific		Ven.	Perez et al. 2007	?
Codium spongiosum	C. Pacific		Ven.	Perez et al. 2007	?
Sea grass					
Halophila ovalis	Indo Pacific		Antigua	Short et al. 2010	probably large
Bivalves					
Perna viridis	Indo Pacific	Aquaculture	Ven.	Buddo et al. 2003	large
Perna perna		Range expansion?	Ven.	Perez et al. 2007	?
Musculista senhousia		Ballast water?	Ven.	Perez et al. 2007	on mangrove roots
Rangia mendica	Pacific	Ballast water?	Ven.	Perez et al. 2007	?
Lyrodes pedicellatus	Indo Pacific		Ven.	Perez et al. 2007	?
Bankia carinata	E. Pacific		Ven.	Perez et al. 2007	?
Bankia martinense	E. Pacific		Ven.	Perez et al. 2007	?
Gregariella corallophaga	E. Atlantic		Ven.	Perez et al. 2007	?
Pteria hirundo	E. Atlantic		Ven.	Perez et al. 2007	?
Clausinella gayi	S.W. Atlantic		Ven.	Perez et al. 2007	?
Clasinella fasciata	S.W. Atlantic		Ven.	Perez et al. 2007	?
Circomphallus strigillinus	Pacific		Ven.	Perez et al. 2007	?
Arca pacifica	W. Pacific		Ven.	Perez et al. 2007	?
Mactronella exoleta	E. Pacific		Ven.	Perez et al. 2007	?
Thracia distorta	E. Atlantic		Ven.	Perez et al. 2007	?
Polycheata					
Salmacina incrustans	Atlantic/mediterr.	epibiont	Ven.	Perez et al. 2007	?
Tharyx annulosus	Atlantic		Ven.	Perez et al. 2007	?
Polydora websteri	Pacific/W. Atlantic	epibiont	Ven.	Perez et al. 2007	?
Exogone dispar	Cosmopolitan		Ven.	Perez et al. 2007	?
Branchiosyllis exilis	Circum tropical/temperate		Ven.	Perez et al. 2007	?
Terebella petrocheata	Cosmopolitan	epibiont	Ven.	Perez et al. 2007	?
Gastropods					
Aplysia brasiliana	Cosmopolitan	long larval stage?	Ven.	Perez et al. 2007	?
Aplysia juliana	Cosmopolitan	long larval stage?	Ven.	Perez et al. 2007	?
Babylonia areolata	Indo-Pacific		Ven.	Perez et al. 2007	?
Fusinus barbarensis	Pacific		Ven.	Perez et al. 2007	?
Fusinus marmoratus	Mediterranean		Ven.	Perez et al. 2007	?
Vasum ceramicum	Indian Ocean		Ven.	Perez et al. 2007	?
Umbraculum plicatulus	Mediterranean		Ven.	Perez et al. 2007	?
Modulus cerotes	Eastern pacific		Ven.	Perez et al. 2007	?
Corals					
Tubastrea micracantha	Pacific	Fouling	Gulf Mexico	xxxxx	probably large