Status of St. Eustatius's Reef

Five major studies of St. Eustatius' coral reefs have taken place over the past five years and have shed light on the rapid decline of the island's coral cover and the shift from coral dominated to algae-dominated benthic communities. This shift is being observed throughout the Wider Caribbean Region and is a wake-up call for all involved in the protection of coral reefs. Local threats must be minimized to enable the recovery of the island's reefs and ensure their resilience to mounting global threats such as ocean warming and severe weather events (hurricanes). The recovery of St. Eustatius' reefs is not just of great importance from an ecological standpoint but also an economic one. Approximately 10% of the island's Gross Domestic Product (GDP) is generated through coral-reef-associated tourism and fishery (Bervoets, 2010).

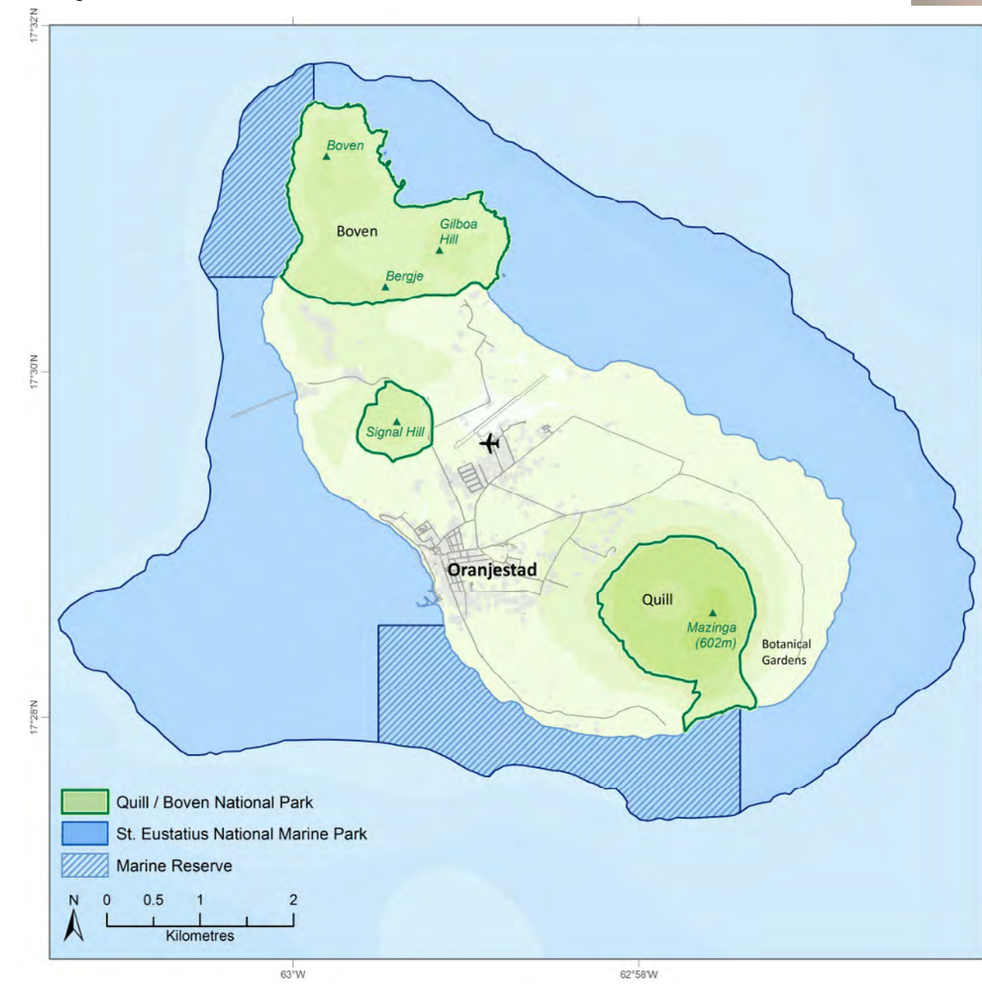
1. Geography and Reef Structure

St. Eustatius is a volcanic island located in the North Eastern Caribbean, north of the St. Kitts Bank. The island is very small, measuring 21 km2, with a maritime area of 1,591 km2 (Jackson et al., 2014). The south of the island is dominated by The Quill, a young dormant stratovolcano, while the north is dominated by the Northern Hills, which are the remains of a much older stratovolcano. In the center of the island is a central plain, the Kultuurvlakte, where the capital city of Oranjestad - and the main population center- is located. St. Eustatius is one of the least populated islands of the Dutch Caribbean, with 3,200 residents recorded in 2016 (CBS).

The total coastline of the island measures 23 km long (Jackson et al., 2014). The coastline consists primarily of rocky cliffs or slopes, with a rapid expansion of seagrass beds consisting mostly of the invasive seagrass species *Halophila stipulacea*, which is found all around the island (E. Houtepen, personal communication, 8th of August 2017). There are two large beaches on the west coast (Gallows Bay) and the east coast (Zeelandia). St. Eustatius is mostly surrounded by fringing corals reefs, for a total reef area of 12 km2 (Jackson et al., 2014). The structure of the coral reefs results from the island's volcanic origins, with most reef communities occurring on large volcanic rocks and boulders that were blown out from The Quill centuries ago (Research group at Scripps Institution of Oceanography UC San Diego, personal communication, June 15, 2017). The spur and groove system's coral fingers in the south of the island are made from hardened ancient lava that flowed from The Quill volcano. Volcanic activity in the north, south and west of the island has also produced patch reefs, and in the northern and southern ends of the island corals have settled on large, shallow ridges and ledges formed by basaltic rocks (Westermann and Kiel, 1961; Roobol and Smith, 2004).

St. Eustatius's reef system is dominated by algae, rubble and low relief gorgonian habitats (Debrot et al., 2014). The dominant hard coral species on shallow reefs include *Porites astreoides, Diploria sp., Montastraea sp.* and *Dendrogyra cylindrus.* Soft corals are most common at depths in excess of 20m, particularly at the drop off. In deeper areas, the coral communities are dominated by *Agaricia* species. The island's reefs are protected by the St. Eustatius National Marine Park (SNMP), which was established in 1996 and is managed by STENAPA.

Map of St. Eustatius.
Image credit: DCNA



2. Status of the reefs of St. Eustatius

In the past five years five major studies have looked at the health of St. Eustatius' coral reefs (Table 1). Between October 2012 and August 2013, Debrot et al. (2014) did a quantitative assessment of habitat diversity and biodiversity of the benthic seascape. Based on 869 video assessments they mapped St. Eustatius' nearshore shelf at depths of 5-30 meters including sea grass beds, coral reefs and algal fields. In June 2015, Naturalis Biodiversity Center in collaboration with 'ANEMOON Foundation' organized a marine biodiversity expedition to St. Eustatius to create a species list against which future studies on the island's marine fauna and flora can be compared (Hoeksema, 2016). The expedition's multi-disciplinary team assessed species composition and richness of various groups of organisms including corals, seaweeds, sponges, mollusks, tunicates and fishes (Hoeksema and Schrieken, 2016). Baseline data was collected from 40 dive stations and 20 shore-side locations down to a depth of 30 m. Biological samples and photographs were taken at each station to document the present state of St. Eustatius's marine biodiversity (Hoeksema, 2016).

In 2015, Piontek and de Graaf surveyed 20 sites within the St. Eustatius National Marine Park at depths between 8 and 18 m to set up a baseline of St. Eustatius's reef health (de Graaf et al., 2015; Piontek, 2016). The Caribbean-Global Coral Reef Monitoring Network (GCRMN) protocol was used to assess the health of St. Eustatius's coral reef ecosystems (Table 2) and the island's fish population was additionally evaluated through the CARIPES survey (EU BEST project) [1]. GCRMN surveys have been repeated every year since 2015 to follow changes and trends. In addition, 104 stereo Baited Remote Underwater Videos (sBRUV) were deployed in 2015 to assess the relative finfish community composition, density and distribution in the shallow coastal waters of the St. Eustatius Marine Park (Van Kuijk et al., 2015).

Table 1: *Summary of major coral reef status surveys conducted on St. Eustatius' coral reefs.*

Data Contributors	Time period	Survey Description	# Sites Surveyed
AGRRA (Klomp & Kooistra, 2003)	1999	Post hurricane (Lenny) rapid assessment of reefs including measures on coral cover and bleaching.	10
Debrot et al., 2014	2012-2013	Video assessments for the benthic map and seascape assessment.	869
White et al., 2006	2004	Fisheries baseline assessment of St. Eustatius's Marine Park.	16
Reef Check	2005, 2007, 2008, 2009, 2010	Monitoring corals, *Diadema antillarum* and macroalgae.	2
McClellan, 2009	2008	Reef fish surveys and measures on substrate composition and habitat complexity.	17
Data monitoring officer	2013-2014	Fish surveys.	15
GCRMN (2015: CARIPES) (De Graaf et al., 2015; Piontek, 2015, 2016)	2015-ongoing	Status and trends of key reef indicators; coral cover, macroalgae cover, coral recruitment, coral disease, biomass herbivore and commercial fish, macroinvertebrates and water quality.	20
Naturalis Biodiversity Center	2015	Marine expedition including assessments on the variation in marine species composition and species richness, the marine benthic diversity (i.e. algae, corals, mollusks, tunicates and fishes) and interspecific associations (host species and parasites, commensals, other symbionts).	40
Scripps Institute of Oceanography and the WAITT Foundation	2016	Coral reef assessments following the GCRMN protocol and a selection of 11 coral reef environments was mapped using 3D imagery.	20
Van Kuijk et al., 2015	2015	The relative finfish community composition, density and distribution in the shallow coastal waters of the St. Eustatius Marine Park based on baited video stations.	104
STENAPA	2017	Post hurricane (Irma & Maria) damage assessment of among others coral reefs.	So far: 7

[1] http://ec.europa.eu/environment/nature/biodiversity/best/pdf/fs_caripes.final.pdf

In November 2016, conservation organizations from Saba, St. Eustatius and St. Maarten joined a research expedition organized by the Scripps Institute of Oceanography and the WAITT Foundation to conduct a rapid scientific assessment of the coral reefs around the windward Caribbean islands (Sandin et al., 2016). The GCRMN protocol was used to establish a regional scale perspective of reef health, with surveys taking place in the fore-reef habitat at depths between 7 and 15 m (Sandin et al., 2016). In St. Eustatius, eleven coral reef environments were mapped with 3D imagery to gather data on benthic and reef fish communities, including their structure and composition (Sandin et al., 2016). The results of these surveys have not yet been released but footage can be seen here: *https://drive.google.com/drive/folders/0By3cTucxJ9GFd3VtUUVueHhpbEU (100IslandChallenge.org,* Scripps Institution of Oceanography at UC San Diego, in partnership with the Waitt Institute). The goal is to repeat the assessment in two years so that changes in reef health can be gauged. At the moment STENAPA is doing a nature damage assessment to determine the damage caused by hurricanes Irma and Maria.

2.1 Benthic cover

Coral cover

De Graaf et al. (2015) used the Reef Health Index (RHI) to describe the island's reef status based on recent survey results. Using the most conservative results, the overall RHI scored St. Eustatius's reefs as "poor" in 2015 (Figure 1) (de Graaf, 2015). The coral cover of St. Eustatius' reefs has declined significantly over the past 15 years. In 2003, the cover of reef-building corals was assessed at 22% (Klomp and Kooistra, 2003) but hit a historic low in 2015/2016 with 5% in 2015 and 5.2% in 2016 (de Graaf, 2015; Piontek, 2016). This seems to be the result of coastal development, coral bleaching events and possible water quality issues (erosion) (MacRae and Esteban, 2007; de Graaf et al., 2015).

Fifty-two species of stony corals (Scleractinia, Milleporidae, Stylasteridae) were observed during the Naturalis Biodiversity Expedition, 50 of which could be identified with certainty (Hoeksema and van Moorsel, 2016). This is higher than previous coral species counts for the island, due in part to the fact that small azooxanthellate species were included (Hoeksema and van Moorsel, 2016). The island's octocoral population was found to be similar to Curaçao with poor species diversity. A total of 35 species of octocoral were identified, with the most common species belonging to the Plexauridae and Gorgoniidae families (Lau, 2016). Gorgonian seafans, such as *Gorgonia mariae*, have decreased in abundance in Curaçao but are still common on St. Eustatius (Lau, 2016). Shallow-water *Acropora palmata* forests used to be found at many places along the shores of St. Eustatius but in the 1980's were almost all killed over the span of a few years by white-band disease, which happened throughout the entire Caribbean region. (Debrot et al., 2014).

Table 2: *Elements of the coral reef ecosystem that the GCRMN method uses to assess its health*

	Elements of the coral reef ecosystem
1	Abundance and biomass of key reef fish taxa (i.e. parrotfish, surgeon fish, groupers, snappers)
2	Relative cover of reef-building organisms (corals, coralline algae) and their dominant competitors (macroalgae)
3	Assessment of health of reef-building corals
4	Recruitment of reef-building corals
5	Abundance of key macro-invertebrate species (i.e. *Diadema antillarum*)
6	Water quality (i.e. water transparency (Secchi-disk)

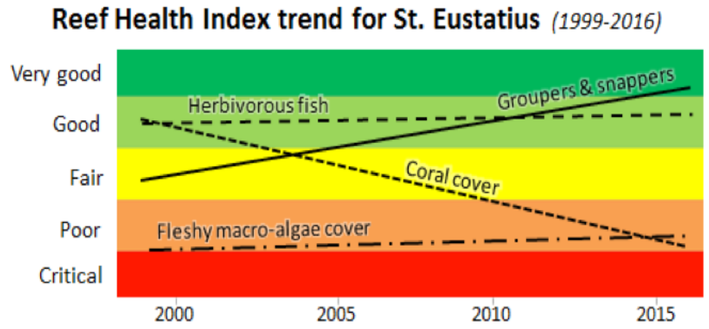


Figure 1: *Reef Health Index trend for St. Eustatius (1999-2016). Source: www.dcbd.nl.*

There are indications that under low stress conditions coral cover will increase in the future as coral recruitment has been assessed as "good". The density of coral recruits was nearly 12 coral recruits per m2 in 2015 and 10 recruits/m2 in 2016 (Piontek, 2016). This is much higher than the average reported for the Wider Caribbean (~4 coral recruits per m2 between 1997 and 2004) (Kramer, 2003). Forty percent of observed recruits belonged to one species, *Siderastrea sidereal* (Piontek, 2016).

Despite the large impacts of Hurricane Irma from last September on land, the short-term impact on St. Eustatius's reefs seems to be relatively small. First observations show that *"in the National Marine Park seven of the most important dive sites have weathered the storm relatively well. There is minor damage to the reef. The hard and soft corals such as sea fans retained their cover. Except for damage to mostly medium-size Giant Barrel Sponges the sites have retained their cover"* (BES reporter, 2017). However, the impact on land where hundreds of trees on the island were uprooted and damaged may lead to erosion and resulting sediment-runoff onto the island's reefs.

"A week later after Hurricane Maria a middle-sized staghorn field located in the southwest of the island (not a dive site) was devastated. Only small fragments remain of what was once a reasonable sized field with healthy bushes of staghorn. This field was on a depth of around 10 to 15m, shallower than the seven dive sites mentioned above. A larger staghorn field to the south of the island in the White Wall was similarly affected by both hurricanes, resulting in large scale damage to all inspected corals. These colonies have been fully destroyed and often no living tissue was found on coral locations and therefore the recovery will take many years. Elkhorn corals have been impacted less by both hurricanes, it appears that the stronger attachment to the seafloor makes these corals stronger and more sturdy" (STENAPA, 2017).

Macroalgae & sponges

Many studies have shown how damaging macroalgae (seaweed) can be to reef health, inhibiting coral settlement and recruitment, slowing coral growth and making them more prone to disease (Jackson et al., 2014). The shift from coral to macroalgae dominance seen in many parts of the Caribbean has also taken place on St. Eustatius's reefs. The cover of macroalgae is very high, averaging 28% in 2015 and 27% in 2016 (Piontek, 2010). Of great concern is also the high cyanobacteria cover, which averaged 15% in 2015 and 16.5% in 2016, as it indicates an increase in local threats, notably eutrophication, and is linked to coral diseases (Piontek, 2016). Cyanobacteria grow over macroalgae so the biomass of this harmful seaweed is likely higher than what was recorded (Piontek, 2016). Factors such as coastal development, coral bleaching events, possible water quality issues (erosion) and the reduction of algae grazing herbivores probably played a role for this shift to algal dominance (de Graaf et al., 2015).

Macroalgae were sampled at 40 different locations during the 2015 Naturalis Biodiversity Expedition (Hoeksema, 2016). Specimens and samples are now being analyzed in the herbarium collection of the Naturalis Biodiversity Center, and more than 175 species are expected to be documented. A new record has also been made for the Atlantic*: Parvocaulis exiguus* (Van der Loos and Prud'homme van Reine, 2016).

Sponges are also an important competitive benthic group (Loh et al., 2015). The coral reef habitats of St. Eustatius appeared to be dominated by macroalgal coverage, next were sponges and finally corals (Debrot et al., 2014). In 2015 sponges were sampled at 36 sites, and 1,457 sponges were recorded, 90% of which belonged to the Demospongiae class. Barrel sponges and several other sponge species were affected by an unknown type of illness/bleaching (García-Hernández et al., 2016).

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2.2 Fish

Herbivores have a crucial role within reefs as they can control seaweed from overgrowing coral (Jackson et al., 2014). The density of the herbivorous long-spined sea urchin *Diadema antillarum* is very low (<1 urchin/m2) following its Caribbean-wide mass mortality in 1983/1984 (de Graaf et al., 2015). Statia's population of herbivore fish, parrotfish and surgeonfish was "reasonable at best" in 2015 as is the case for many parts of the Wider Caribbean Region (de Graaf et al., 2015). The species composition around St. Eustatius largely or even fully lacks certain fish species such as the parrotfish species *S. coeruleus* and *S. guacamaia* due to the natural absence of mangroves (Van Kuijk et al., 2015). While the population of parrotfish is higher than the Caribbean average, with a "fair" biomass, the high contribution of surgeonfish to the catch of the trap fishery is reason for concern (de Graaf et al., 2015). The biomass of key herbivorous fish was "very good" in 1999 but only scored "fair" in 2008 and 2014. According to the GCRMN surveys the populations improved as in 2015 and 2016 herbivorous fish scored "very good" again (Piontek, 2016).

The biomass of predatory fish (groupers and snappers) - which are targeted by commercial fisheries - is "reasonable" compared to the Wider Caribbean average (de Graaf et al., 2015). One worrying trend is the near absence of large groupers and snappers (de Graaf et al., 2015; Piontek et al, 2016; Figure 2). Of all the groupers spotted during the extensive fish survey of St. Eustatius's reefs with the use of sBRUV, only about 2% belonged to the large grouper species (Van Kuijk et al, 2015). The lack of slow-growing large apex predators can be a sign of overfishing and is undesirable for population recovery (de Graaf et al., 2015).

St. Eustatius has a relatively healthy population of reef sharks, most likely due to the fact that they are not targeted by coastal fisheries (de Graaf et al., 2015). During the 2015 fish survey, 42 sharks were sighted during 104 sBRUV deployments (de Graaf et al., 2015). Caribbean reef sharks and nurse sharks were most often spotted. *"As top predators, these sharks play an important ecological role in healthy reefs and their higher abundance around St Eustatius compared to most other areas of the Caribbean may contribute to and be a useful indicator of overall coastal ecosystem health"* (de Graaf et al., 2015).

3. Condition of St. Eustatius's reefs compared to other reefs within the Caribbean Region

The average Caribbean-wide coral cover declined sharply between 1970-1983 and 1984-1999 but has remained stable since 1999 (Jackson et al. 2014). *"On St Eustatius, however, the trend in coral cover continued to decline since 1999 reaching a historic low level in 2015. Like in the rest of the Wider Caribbean Region, the macroalgal cover has been high since 2007 and the reef community is at present dominated by macroalgae"* (de Graaf et al., 2015). The +/- 25% macroalgae cover is similar the the average reported for the whole Caribbean.

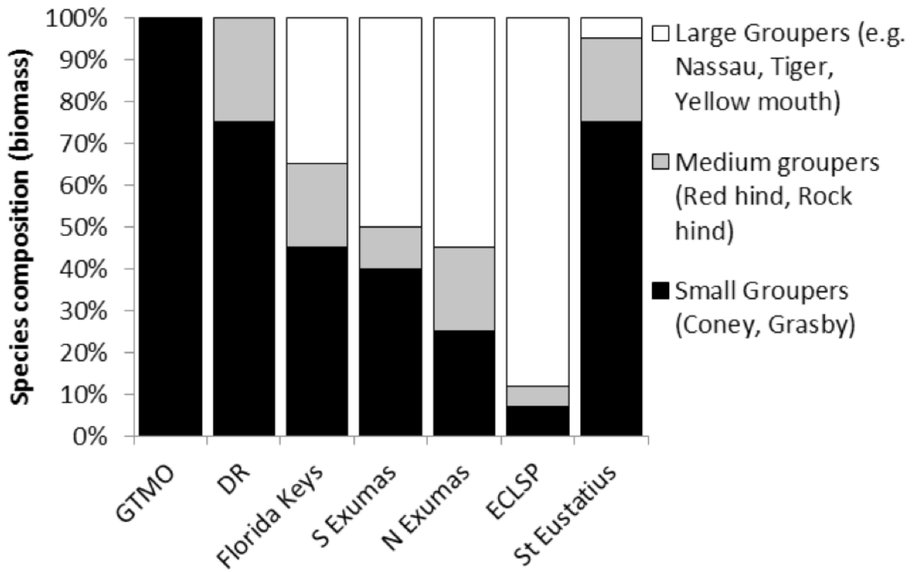

Figure 2: *Composition of grouper assemblages in Guantanamo Bay Naval Base, southeastern Cuba (GTMO), southeastern Dominican Republic (DR), Florida Keys, Southern and Northern Exumas, and the Exuma Cays Land and Sea Park (ECLSP) (redrawn from Chiappone et al., 2000) compared with St Eustatius. From GTMO to ECLSP fishing pressure decreased and management and protection increased. Source: de Graaf et al., 2015.*

Photo by: © Hans Leijnse

4. Local stressors on the reef of St. Eustatius

The dramatic decline in the health of St. Eustatius's reefs and the shift from coral to algal dominance is a clear indication that they are under mounting pressure from local, regional and global stressors. Local threats must be minimized to enable the recovery of the island's reefs and ensure their resilience to mounting global threats such as ocean warming. Bleaching events, for example, have been observed in the Windward Islands since 2005 and have caused significant damage to coral reefs around St. Eustatius. The severe bleaching event of 2005 led to a great loss in coral cover in some of the island's shallower reefs. Coral cover loss of 78.6% was recorded in one dive site (Mushroom Gardens) located in the SNMP's Southern Marine Reserve (MacRae and Esteban, 2007).

Fishermen are the primary users of St. Eustatius' reefs. The island's fisheries are small-scale, with 5 active fishermen and 15 to 20 small boats (> 10m) (de Graaf et al., 2015). The annual catch is 18 tons per km2/y. The island's most important fishery is the Caribbean spiny lobster (*Panulirus argus*) with an annual catch of 11 tons per km2/y, which is the highest recorded through its range (de Graaf et al., 2015). One of the main concerns with this fishery is that 41 % of the landed lobsters - which are caught with lobster traps - are under the minimum legal size (de Graaf et al., 2015).

The status of St. Eustatius's mixed reef fish fishery, with annual catches of 4 tons per km2/y, has been found to be "at most reasonable" but in slightly better shape than the Caribbean average (de Graaf et al., 2015). While the density of reef fish remains reasonable, there is concern about the high contribution of herbivores to the catch of the trap fishery (de Graaf et al., 2015). Currently, approximately 50 % of the annual mixed reef fish catch is made up of small groupers and key herbivore surgeonfish (de Graaf et al., 2015). There is also a near absence of large groupers, which is a potential sign of overfishing (Van Kuijk et al., 2015). To reduce the bycatch of narrow-bodied surgeonfish, escape slots could potentially be introduced. Furthermore, the pelagic fishery is underdeveloped and managers could potentially divert fishing activity from the reef to the pelagic environment.

Divers also make great use of St. Eustatius's coral reefs. Snorkelers and divers from all around the world come to enjoy the island's unique reef formations. The effect of divers on coral reefs is not clear although there are documented negative effects such as broken coral fragments (Lyons et al, 2015).

There are mounting concerns over St. Eustatius's water quality and the resulting impact on the island's coral reef communities. In the early 2000s, erosion and resulting sedimentation was believed to most likely be *"the key and possibly only major factor impacting water quality on St. Eustatius"* (Debrot and Sybesma, 2000). While erosion does occur naturally, overgrazing by free-roaming feral cattle, goats and donkeys has made the problem much worse. Eutrophication is now also a growing issue. The island has no wastewater treatment plant and therefore untreated water from septic tanks and private cesspits is reaching coastal waters and the fringing reefs (de Graaf et al., 2015). Excess nutrients *"may stimulate macroalgal growth resulting in overgrown, abraded and even poisoned stony coral colonies, reduced coral recruitment and/or increased coral disease* (de Graaf et al., 2015). Long term monitoring data to assess trends in sedimentation and nutrient levels are missing. In June 2016 CNSI started taken monthly measurements of nutrients (ammonium, phosphate and nitrate) in the coastal waters around St. Eustatius. Their preliminary results show that nitrate concentrations are particularly high, especially in well water and cistern water (CNSI newsletter, 2016).

Another threat to the island's water quality is the oil terminal NuStar. Oil spills, such as the October 2012 spill, result in the exposure of corals to oil, which interrupts coral larvae settlement (Hartmann et al, 2015). Chemicals and toxins may also leak into the surrounding water of the terminal (de Graaf et al., 2015). The anti-fouling agent Tributyltin (TBT) used on large vessels may cause Imposex, a disorder in marine snails where female marine snails develop male reproductive organs (de Graaf et al., 2015). This disorder has been observed in *Lobatus gigas* on St. Eustatius (de Graaf et al., 2014). Oil tankers can also cause direct damage to reefs. Since the early 1980s, tankers have anchored in the waters of Oranje Bay whilst waiting to bunker at St. Eustatius Terminals. STENAPA has been drawing attention to this problem and sending damage reports to the police, harbor master and the Public Entity.

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St. Eustatius's reefs also face natural pressures including storms, which are likely intensified by global warming (Bender et al., 2010). St. Eustatius is located in the Atlantic hurricane zone, and the island's seabed has suffered great damage from hurricanes over the past decades. In the late 1990s, six hurricanes hit St. Eustatius and had profound impacts on the island's reefs (hurricanes Luis and Marilyn in 1995, hurricane Bertha in 1996, hurricane Georges in 1998 and hurricanes Jose and Lenny in 1999) (Jackson et al., 2014). Shallow coral reefs were the most impacted by the series of hurricanes, with many broken colonies of branching *Acropora palmata*. From 2004 to 2014, the island was hit by seven hurricanes. Last September St. Eustatius was hit by category five storm Irma and Maria, one of the strongest Atlantic hurricanes ever observed. It is important to reduce local threats to increase the resilience of the reefs to the global stressors caused by climate change.

Besides, St. Eustatius's is also dealing with invasive species, notably lionfish that were first sighted in 2010 and are reported to negatively impact native coral fish populations (Albins and Hixon, 2008). Sanguinet (2015) reports that the culling program on St. Eustatius has been fairly efficient

Photo by: © Marion Haarsma, taken in St. Eustatius

in minimizing the well-established lionfish population, with marine park staff killing more than 50% of lionfish observed annually since 2012 in the Southern Marine Reserve. However, this method has diving restrictions, which makes it difficult to control lionfish at deeper depths (De Léon et al., 2013).

An adaptive management plan with "*clearly defined quantifiable objectives, targets and reference points of coral reef health indicators"* needs to be put in place, with all stakeholders involved in the decision-making process (de Graaf et al., 2015). The annual monitoring of the island's reefs must also carry on to keep track of changes in reef health and assess the efficiency of management actions (Piontek, 2016). The annual monitoring of 20 sites within the SNMP "*provides a 50% chance of documenting a change of 5% in coral cover as a general guideline"* (Piontek, 2016).

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