STATUS OF THE DUTCH CARIBBEAN REEFS

Bonaire

Curaçao

Saba

Saba Bank

St. Eustatius

St. Maarten

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STATUS OF THE DUTCH CARIBBEAN REEFS

Editor's Letter

Dutch Carribean, 2018

Following the Royal Palace Symposium in the Netherlands in December 2016, and the harsh call to action by Professor Jeremy Jackson (Scripps Institution for Oceanography) that, if drastic action is not taken to protect them, our coral reefs could disappear within the next 15 years, DCNA has spent the past year collecting and collating all the available information on the status of coral reefs in the Dutch Caribbean. This Special Edition of BioNews, containing reviews of the status of coral reefs on Bonaire, Curaçao, Saba, Saba Bank, St. Eustatius and St. Maarten, is the result of that work.

Coral reefs in the Wider Caribbean Region have suffered considerable declines in health and abundance in recent decades with serious declines in benthic coral communities and shifts from coral to macroalgae dominated reefs. Coral reefs in the Dutch Caribbean are not immune to regional trends and the effects of global climate change and are also showing signs of distress.

Bonaire and Curaçao's coral reefs have long been considered some of the healthiest and most diverse in the Caribbean. However, research spanning the past several decades reveals an alarming trend with reduction in coral cover and species composition and increases in macroalgae, turf algae and cyanobacterial mats.

Recent work providing the first evidence of coral reef resilience in the Caribbean showed that, thanks to conservation measures taken to protect Bonaire's reefs, there have been signs of recovery from the last severe bleaching event of 2010. Indications of reef resilience, such as relative abundance in juvenile reef-building coral species, have also been found on the reefs of the Saba Bank.

Overfishing of reef grazers, particularly parrotfish, has been singled out as the most damaging fisheries activity to threaten the health of reefs. While parrotfish biomass has declined around some Caribbean islands, Bonaire's ban on parrotfish catch in 2010 is proving to be a success. The average parrotfish biomass of Bonaire's leeward coast rank amongst the three highest in the Caribbean, just above Curaçao which ranks fifth, and may have helped Bonaire's reefs recover more quickly from the 2010 bleaching event.

In the Windward Islands of Saba and St. Eustatius, findings show that the reefs are also under pressures from local, regional and global stressors. First assessments of the status of St. Maarten's reef since Hurricane Irma show that the damage from the category 5+ hurricane is significant.

The devastation caused by Hurricanes Irma and Maria in September 2017 should serve as a wake up call to all of us concerned about the future of our coral reefs and a reminder about the potential for more and more severe weather events in the future. Thermal stress has also become a considerable cause for concern, with two severe bleaching events (2005 and 2010), which caused extensive coral mortality amongst Caribbean reefs and mounting concern in the scientific community about the long-term impacts of ocean acidification.

Above all, the importance of reducing local stressors in order to increase coral reef resilience cannot be underestimated. Local stressors have been identified as the most significant drivers of reef degradation throughout the Wider Caribbean, particularly overfishing, introduced species, coastal development and pollution associated with increases in tourism visitation and local populations. The resulting increases in eutrophication and sedimentation are highly detrimental to coral reef health.

The need to increase the resilience of our coral reefs has never been more pressing. Coral reefs are marine biodiversity hotspots that are not only invaluable for coastal protection but also have a high economic value through associated tourism and fisheries. Our islands are particularly dependent on the health of the coral reefs due to our economic dependence on nature-based tourism.

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Editor's Letter photo by: © Hans Leijnse

Map of the Caribbean Islands

Status of Bonaire's Reefs

References can be found in ***BioNews Issue 3***

While the coral reefs around Bonaire have suffered in recent decades from regional phenomena such as repeated bleaching events, urchin die-off, coral diseases and local impacts such as coastal development, pollution and overfishing, they are still considered some of the healthiest reefs in the Caribbean (Jackson et al., 2014). Bonaire's reefs are some of the best-studied ecosystems in the region. The different studies, such as a long-term monitoring study by Dr. Rolf Bak et al. since 1973 and an intensive study by Dr. Robert Steneck et al. since 2003, have been invaluable in providing insight into trends. They have revealed the changes that the reefs have gone through over the last 40 years with alarming trends in coral cover, species composition, macroalgae, turf algae and cyanobacterial mats. However, with effective conservation measures in place and management of the island's marine resources in the hands of dedicated professionals, and thanks to the island's location outside the hurricane belt, there appears to be hope for their survival particularly if there is a political willingness to protect them from harm. Recent work providing the first evidence of coral reef resilience[1] in the Caribbean found that Bonaire's reefs were able to recover from a disturbance such as bleaching event.

Geography and Reef Structure

Bonaire is the second-largest island in the Dutch Antilles, with a total land area of 294 km^2 (Fish et al. 2005; Van der Lely, 2013). This includes the land area of Klein Bonaire, a small, uninhabited coral limestone island located some 750 m off the central west coast of Bonaire. The Bonaire National Marine Park (BNMP) was established in 1979 and is managed by STINAPA Bonaire. The park starts at the high water mark and extends to a depth of 60 meters, covering an area of 27 km2 that includes fringing reefs, seagrass beds and mangroves.

The entire coastline is 120 km long (Jackson et al., 2014). The rough north-eastern coastline is exposed to the trade winds and made up of steep rocky cliffs and small inlets, locally known as "bokas". The sheltered western coastline is characterized by coral shingle beaches. There are numerous small pockets of sand in coves and inlets along the leeward shore and the length of the northern shore.

Bonaire's seabed environment is primarily made up of fringing coral reefs that surround the island, with some seagrass beds located in the south of the island and in inlets on the windward coast as well as small patches near Klein Bonaire. The entire reef system is protected as part of the BNMP. There are two main areas of mangrove and seagrass beds, both located on the windward shore at Lagoen and Lac Bay. Both Bonaire and Klein Bonaire are surrounded by continuous, fringing coral reefs that cover an area of some 8.7 km^2 (Debrot et al., 2017). In many places, the reef starts right at the shoreline and extends seaward into depths in excess of 70 m within 200 m of the shore. Bonaire's coral reefs harbour 57 species of hard stony and soft corals (Bak, 1977). There is some zonation within the coral community: shallow waters tend to be dominated by a mix of stony and soft corals, mid-depth reefs by *Montastrea sp*. and deeper waters by *Agaricia sp*. Maximum diversity and cover is on the upper reef slope.

Map of Bonaire
Image credit: DCNA

(1) "At its most basic level, resilience means that if coral reefs suffer damage from say a hurricane or bleaching mortality event, they will recover to their previous state " (Steneck & Wilson, 2017).

Status of Bonaire's reefs

Over the past 40 years there have been many studies of Bonaire's reefs. The first assessment of Bonaire's reefs took place in the early 1980s when van Duyl mapped Bonaire's reefs. She found that elkhorn and staghorn corals (*Acropora palmata* and *A. cervicornis*) dominated the reef landscape. This was shortly before white-band disease killed nearly 90% of elkhorn and staghorn corals and before the mass mortality of *Diadema antillarum* urchins that greatly reduced herbivory levels (Bak et al., 1984). In 1999, an Atlantic and Gulf Rapid Reef Assessment (AGRRA) determined that Bonaire's deep reefs (> 5 meter) had the second highest abundance of live coral (nearly 50%) and a relative low abundance of harmful seaweed within the Caribbean region (Kramer, 2003). Follow-up assessments by Steneck et al. since 2003 indicate that Bonaire's reefs remain amongst the best in the Caribbean.

Photo by: © Jannie Koning

Summary of major coral status surveys conducted on Bonaire's coral reefs.
(Adapted from Jackson et al. (2014))

STUDIES	TIME PERIOD	SURVEY DESCRIPTION	# SITES SURVEYED
Bak et al., 1995, 1997, 2005; Bak & Engel, 1979; de Bakker et al., 2016, 2017.	1974-ongoing	Photographs are frequently taken of permanent quadrats of $9m^2$ at Karpata and Barcadera (at depths of 10, 20, 30 and 40 m) to analyze the changes in community structures.	2
CIEE Bonaire, Peachey et al.	2007-2017	100 m x 0.4 m permanent transects that have been filmed twice per year at 12.2 m depth to analyze benthic cover.	10
CIEE Bonaire, Peachey et al., AGRRA.	2007- 2017	Reef surveys including measures on coral cover and fish counts.	>20
De Meyer, CARICOMP.	1994-1997	Reef surveys including measures on coral cover, *Diadema antillarium* and *macroalgae abundance.*	-
Grimsditch et al., 2011.	2009	Several components of the reef ecosystem were measured at varying levels of detail including coral cover, macroalgae and fishes.	21
Hawkins et al., 1997.	1991, 1994	Study including measures on coral cover.	6
Kramer, 2003; AGRRA.	1999	Reef survey including measures on coral cover, *Diadema antillarium* and fish counts.	4-6
Mücher et al., 2017.	2013, 2016	Coral reef mapping using hyperspectral imagery and detailed photographs.	18
NICO expedition organized by NIOZ and NWO-Science (PL: Visser & van Duyl)	2018	Deep reef surveys (> 30 m), mapping of cyanobacteria mats, onshore groundwaters and bathymetric maps	-
Pattengill-Semmens, 2002; Reef Check.	1993-1999, 2000-2003.	Roving Diver Technique (RDT), a visual survey method developed specifically for volunteer data collection. Divers record every observed species.	77
Relles et al., 2012, 2018.	2008-2009	Coral reef mapping using satellite remote sensing techniques and video-transects.	10
Sommer, 2011.	2008-2009	Five kilometers of photo transects to determine coral cover.	14
Steneck, 2003-2017.	2003-ongoing	Reef survey measuring coral cover and densities of macroalgae, herbivory (large parrotfish), large carnivorous fish (groupers, snappers and barracudas) and coral recruitment.	11
Sommer et al., 2011.	1982, 1988, 2008	Quantitative benthic community survey on coral and macroalgae abundance.	7
Van Duyl, 1985.	1981-1983	Classified wave energy environments and benthic habitats using aerial photography and in situ reef ground truthing surveys (0-20m depth).	Entire Leeward coast
Zanke, de Froe, Meesters (PL), 2015.	2014, 2017	Surveys (based on AGRRA and GCRMN) to assess fish and benthos communities including corals, algae, sponges down to a depth of 20 m.	115

**PL = Project Leader*

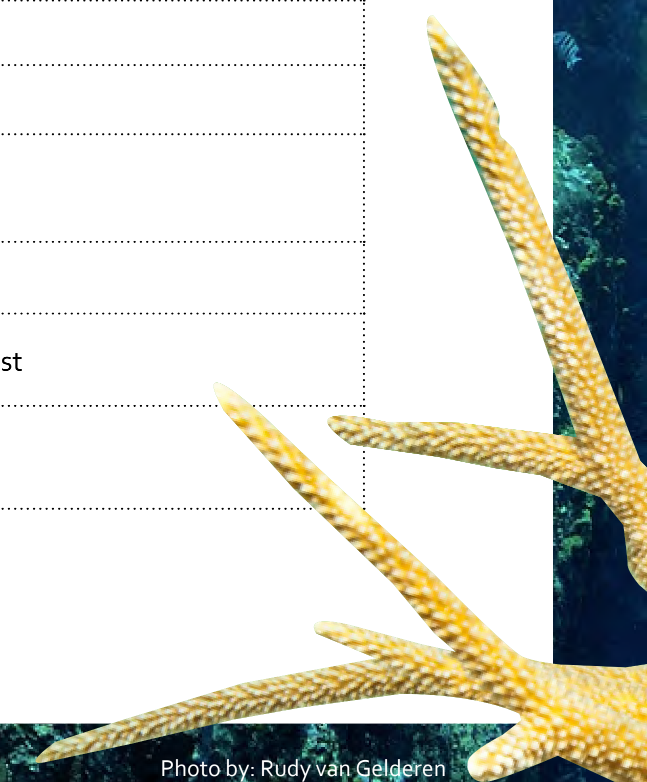


Photo by: Rudy van Gelderen

Status of Bonaire's Reefs

Two long-term studies with different approaches have recently been published on the health of Bonaire's reefs. Since 1973, Bak et al. have studied changes in the benthic community of reefs (cover of corals, algal turfs, benthic cyanobacterial mats, macroalgae, sponges and crustose coralline algae) at the Karpata and Barcadera dive sites at depths of 10, 20, 30 and 40 meters. Permanent $9m^2$ quadrants have been photographed at 3 to 6 year-intervals. This represents world-wide the longest time series from the same reef. Newer time series began in the 1990s. Steneck et al. have monitored reefs since 2003 at 11 sites around the island at a depth of 10 meters to assess changes in reef community, not just benthos composition. They are evaluating what supposedly are the keys drivers of reef health and resilience: coral cover, macroalgae, herbivory (large parrotfish), large carnivorous fish (groupers, snappers and barracudas) and coral recruitment (density of corals <40 mm diameter).

This chapter summarizes results from different studies. As different methods, time scales and sample sizes are used and different reefs are surveyed the results should be read with caution.

Benthic cover

Coral cover

Coral cover on Bonaire's reefs has historically been high, with a coral cover of nearly 50% between 1999 and 2010 (Kramer, 2003). The study by de Bakker et al. (2016) at Karpata found that the abundance of corals declined between 14 and 65% over the past 40 years (See table on page 8), with the biggest decline at a depth of 20 meters. *"The decreasing trend in coral cover occurred gradually through time in a relatively linear pattern with some exceptions"* (de Bakker, 2017). The bleaching event of 2010 caused a mortality of about 10% of corals, but the most recent study (2017) showed that after hitting a low in 2013, coral cover steadily increased and is now at post-bleaching levels with an accelerated increase to a relatively high cover of 47.3% (Figure on page 8: Steneck & Wilson, 2017). The most recent bleaching episode of 2015-2016 was found to have had little impact (Kowalski, 2017). All species, including those that were most heavily impacted by the 2010 bleaching event such as Colpophyllia colonies, were found to be recovering (Steneck & Wilson, 2017).

Two species of mountain star coral are most dominant (*Orbicella annularis, O. faveolata*), and with three other species (yellow finger coral *Madracis mirabilis*; great star coral *Montastrea cavernosa*; lettuce coral *Undaria agaricites*) comprise 75% of cover on monitored reefs (Steneck, 2017). Of these, Orbicella contribute most to the reefs' habitat architecture. Dramatic visual changes were reported when Steneck's data were compared to van Duyl's study from the early 1980's such as the large decline of Acropora assemblages that were wiped out throughout the Caribbean by the white band disease (Bowdoin & Wilson, 2005; Steneck, 2005). This has resulted in the loss of structural complexity with less shelter and resources for a wide range of organisms (Alvarez-Filip et al., 2009).

De Bakker et al. (2016) also looked at the coral species composition changes of Bonaire and Curaçao's reefs between 1973 and 2014. They found a shift both at shallow (10-20m) and upper-mesophotic reefs (30-40m) from large structural species (Orbicella spp.) to dominance of smaller opportunistic species, with a decline of cover and abundance for almost all species (de Bakker et al. 2016). This is alarming as this reduced the reef carbonate production by 67%. Another important consequence of reduced coral cover and the shift to smaller opportunistic species is the loss of reef structural complexity and its associated loss of biodiversity, coastal protection and human food security (de Bakker et al., 2016).

When looking at the spatial and temporal trends in nearshore benthic composition around the island, coral rubble areas have largely increased since the 1980's most likely due to the large decline of Acropora assemblages (Bowdoin & Wilson, 2005; Steneck, 2005; Mücher et al., 2017; Figure on page 8). The 58% increase of sandy patches around the whole island between the 1980's and 2013 indicates a significant decline in coral cover (Mücher et al., 2017).

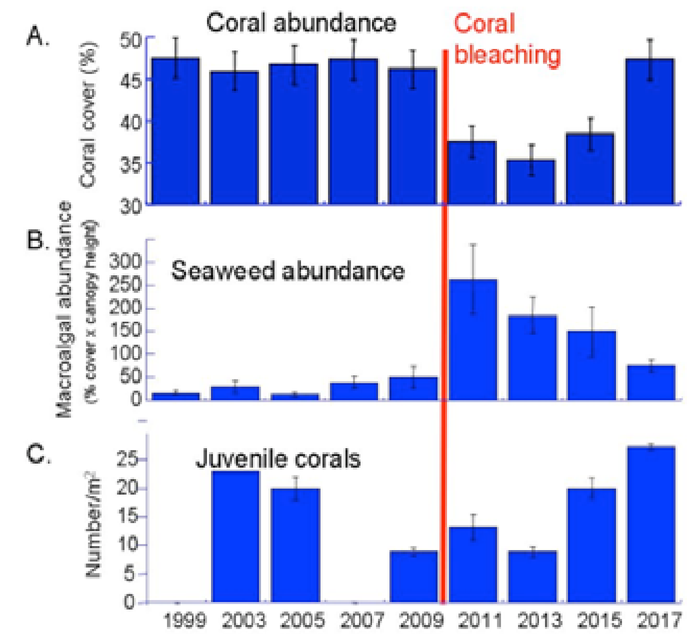
The most recent study by Steneck and Wilson (2017) showed a positive recovery of Bonaire's reefs after the bleaching event in 2010. A strong indication of the recovery and resilience of Bonaire's reefs is that the abundance of juvenile corals has greatly increased on leeward reefs since 2013 after a decline from 2003 to 2009 and a sharp decline post-bleaching (Rossin & de León, 2017). Densities in 2015 were found to be similar to densities found in 2003 and 2005 (Steneck et al., 2015). This increase in juvenile corals most likely occurred due to a decrease in macroalgae as harmful seaweed inhibits coral recruitment and *"outcompetes settling corals through shading and abrasion and subsequently reduces the available nursery habitat for juvenile corals"* (Steneck et al., 2015). The most abundant juvenile corals are lettuce coral *(Undaria agaricites)* and mustard hill coral *(Porites astreoides)* which are species with low structural complexity (Rossin & de León, 2017).

It is essential to take into account that Bonaire's coral reefs show large variations in ecological quality along the coastline (Zanke et al., 2015). This makes it is difficult to draw conclusions on the health of the entire reef based on studies from multiple depths and locations when studies have only investigated a relatively small number of preselected sites. Several sites were found to have higher than average coral cover (Forest, Klein Bonaire, and Karpata) and some sites lower than average cover (Calabas and Barcadera) (Steneck, 2017).

Photo by: Jannie Koning

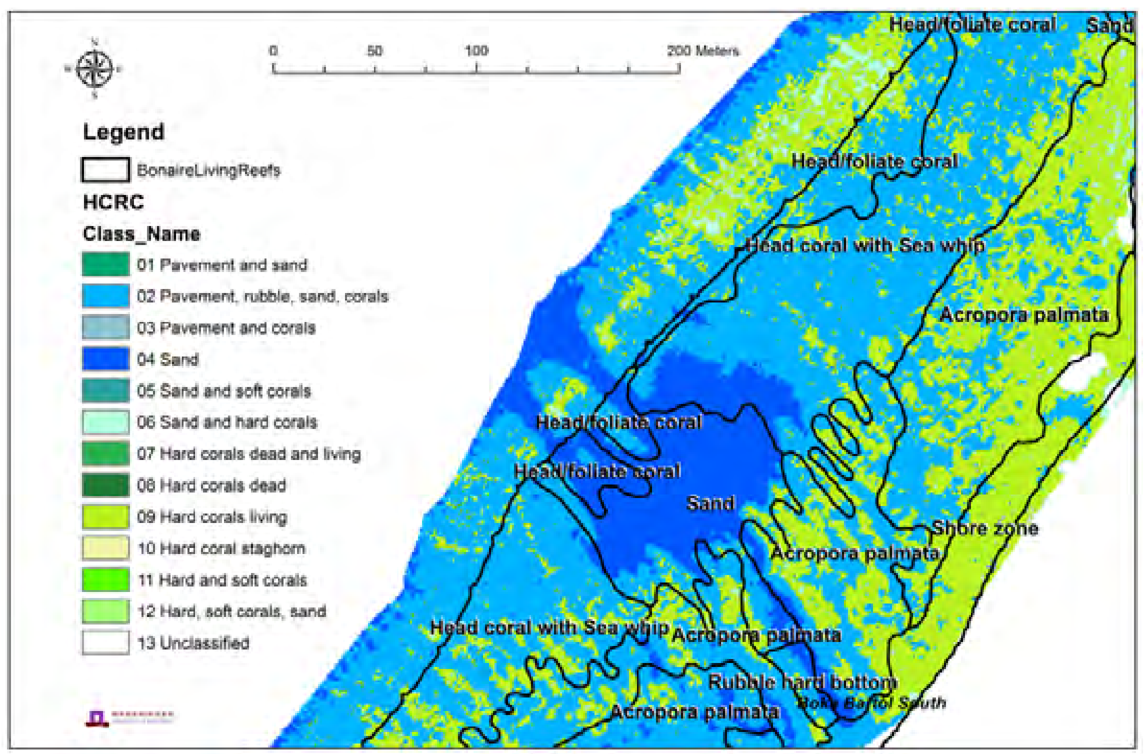
Change in coral cover of a 9 m² quadrat at a depth 10, 20, 30 and 40 meters on Bonaire.
(de Bakker et al. 2016)

Island	Reef	Depth (m)	Year span	Start coral cover (%)	End coral cover (%)	Net change (%)
Bonaire	Karpata	10	1973-2014	63	22	-41
Bonaire	Karpata	20	1973-2014	71	6	-65
Bonaire	Karpata	30	1973-2014	60	20	-40
Bonaire	Karpata	40	1973-2014	25	11	-14



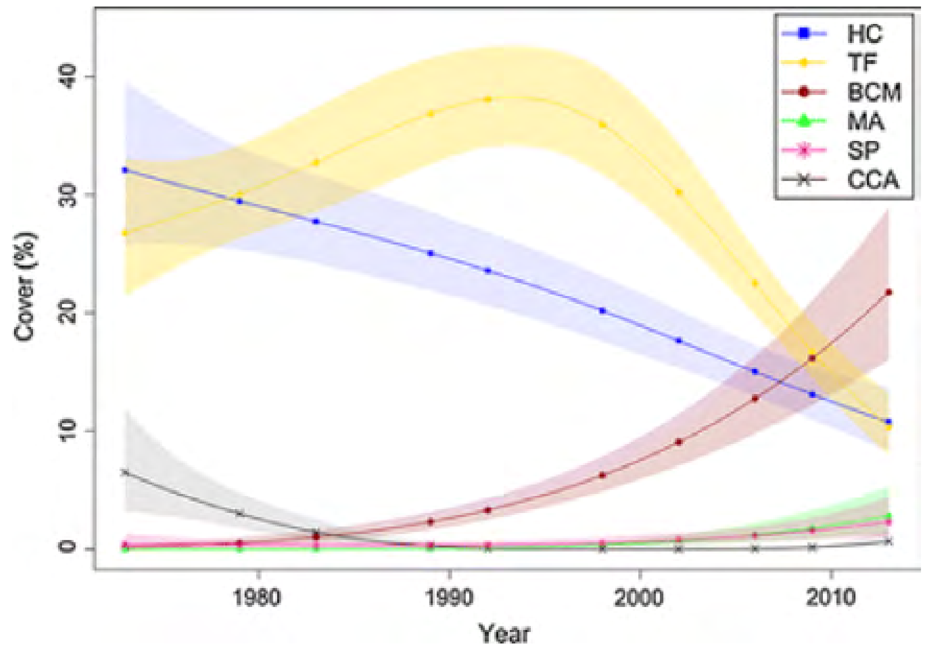
Trends in coral, seaweed, and juvenile coral densities. Recent trends since 2011 (post- 2010 bleaching) illustrate how Bonaire's coral reef ecosystem has responded since the bleaching event. For trends since 1970's we refer to de Bakker et al. (2016).
(Steneck & Wilson, manuscript in preparation)

Benthic cover compared between the 1980's and 2013. Detail of the current pixel-based hyperspectral coral reef classification, near Boca Bartol North on the Northern coast of Bonaire (hyper spectral data from 2013), overlayed with the mapping units of van Duyl's Bonaire Living Reefs map (1985).
(Mücher et al., 2017)



A former sand covered area where a storm has removed all the overlying sand showing the underlying reef bottom which consists of dead (mostly staghorn) coral colonies.
Photo by: © *Erik Meesters (WUR).*

Status of Bonaire's Reefs



Trajectories of change for six benthic groups (1973-2013): hard coral (HC, blue), algal turfs (TF, yellow), benthic cyanobacterial mats (BCM, brown), macroalgae (MA, green), sponges (SP, pink), and crustose coralline algae (CCA, black). Lines represent estimated models (with 95% confidence bands) of the change in mean percentage cover over 4 sites and depths (10, 20, 30, 40 m) at Bonaire and Curaçao.
(de Bakker et al., 2017)

Harmful seaweed and the rise of cyanobacterial mats

Many studies have shown that macroalgae and turf algae negatively impact corals by inhibiting coral recruitment and survival, slowing coral growth and making them more prone to diseases (Jackson et al., 2014). From 1973 to the early 1990s, de Bakker et al. (2017) found that calcifying organisms such as corals and crustose coralline algae were decreasing and replaced by turf algae (24.5% to 38%) and macroalgae (0% to 2%). Turf algae rapidly overgrow corals and unlike macroalgae, herbivore fish have no effect on the rate by which turf algae overgrow them (Vermeij, 2010).

Bonaire has very low levels of harmful macroalgae compared to the rest of the Caribbean (Jackson et al., 2014); in 1999, Steneck found that Bonaire's reefs had very little to no macroalgae, and levels remained low until 2010 (< 5%) (Steneck & Wilson, 2017). The 2010 bleaching event caused a steep increase in macroalgae, but levels are now low again and reefs resisted a phase shift from coral to macroalgae dominated benthic communities thanks to a relatively abundant herbivore population (Steneck et al., 2015). Macroalgae coverage declined from 15% in 2011 to 10.9% in 2015 (Steneck et al., 2015) and in 2017 monitored reefs had a macroalgal abundance of 6.02% (See top right Figure on page 8), which is close to what existed prior to the 2010 bleaching event (Steneck, 2017).

De Bakker et al. (2017) found that turf algae decreased down to 11% from 2002 to 2013. Additionally, they reported the rise of benthic cyanobacterial mats (7.1% in 2002 to 22.2% in 2013) and a small but significant increase in sponge cover (0.5 to 2.3%). Current dominance of cyanobacterial mats suggests that *"the shift from coral and crustose coralline algae towards turf and macroalgae may be a transitional phase that can further develop towards a new successional phase of benthic cyanobacterial mats and sponge dominance with a less prominent role for fleshy macroalgae"* (de Bakker et al., 2017). There is no direct link between coral cover decline and the sudden increase of other benthic competing organisms (turf algae, macroalgae, benthic cyanobacterial mats). However, these fast-growing organisms are worrisome as they have the ability to reduce the ability of corals to recover from disturbances such as storms and bleaching events (de Bakker et al., 2017).

Photo by: Rudy Van Geldere

Status of Bonaire's Reefs

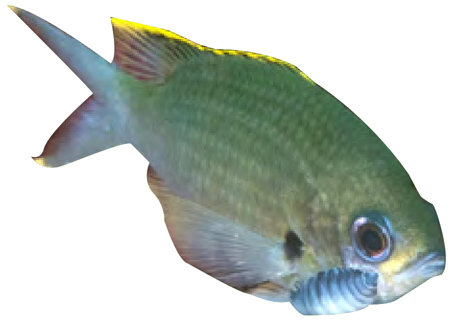
Fish

Bonaire's reefs are home to some of the most diverse fish populations in the Caribbean. A total of 362 fish species have been recorded on the island's reefs rivalling the fish diversity recorded for the entire Florida Keys (Pattengill-Semmens, 2002; Reef.org). The composition of fish assemblages on Bonaire's reefs compares well to other sites in the southern Caribbean. The five most frequent reef fish sightings are Blue Tang *(Acanthurus coeruleus)*, Bicolor Damsel *(Stegastes partitus)*, Stoplight Parrotfish *(Sparisoma viride)*, Brown Chromis *(Chromis multilineata)*, and Bluehead Wrasse *(Thalassoma bifasciatum)* (Pattengill-Semmens, 2002).

Comparing recent data to data collected in the 1950s and 60s, it is clear that large piscivores have all but disappeared from Bonaire's reefs (A. Debrot & R. Bak, personal communication, 22 august 2017). Data collected between 1994 and 2003 indicates that the number of carnivorous fish, particularly groupers and snappers which are preferentially targeted by recreational and commercial fishing, have declined significantly (Hawkins et al., 1999; Steneck and McClanahan, 2003;). Whilst data collected since 2003 shows fluctuating population numbers, there is little or no signs of recovery (Boenish & Richie, 2017).

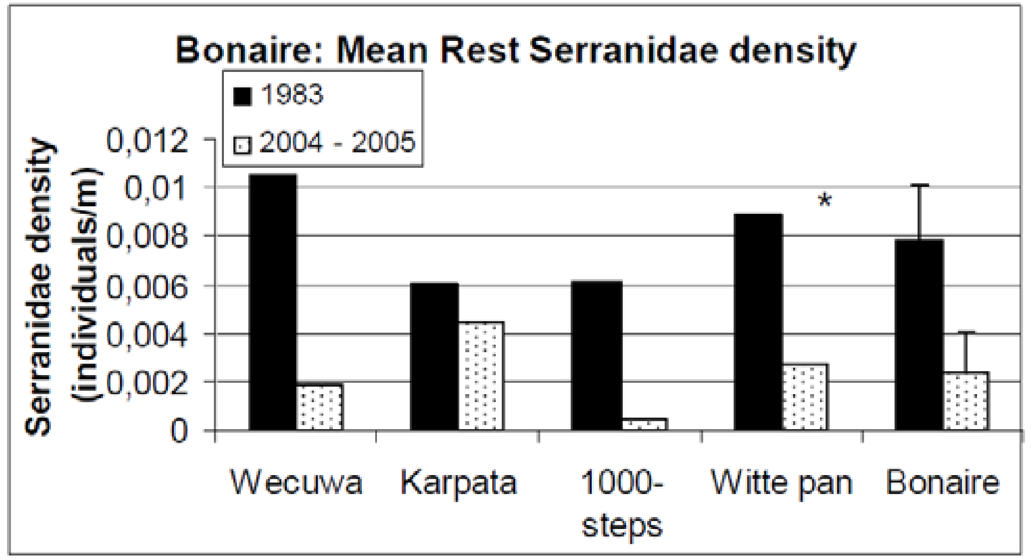
Bonaire has long taken a proactive stand towards marine conservation in general and the conservation of reef fish populations in particular with restrictions on gear and permitted fishing activities, many of which predate the establishment of the Marine Park. Spearfishing was banned in 1971 at a time when this was still a popular activity for scuba divers and annual spearfishing competitions were the norm. Since the inception of the Bonaire Marine Park, park officials have sought to restrict extractive activities and ban activities which are harmful to the marine environment.

Coral reef health requires an ecological balance of corals and algae in which herbivory is a key element that can keep the algae abundance low (Jackson et al., 2014). Of the herbivorous groups recorded on Bonaire, scarids (parrotfish) dominate both in density and biomass. Between 1987-1992 total herbivore biomass at Karpata was around 7 kg/100 m2 of which parrotfish biomass was ~5 kg/100 m2 (Rooij, Videler & Bruggeman, 1998). Parrotfish density and biomass varies among different reefs and a parrotfish biomass of around 6 kg/100m2 was calculated for 2003 based on 11 monitored reefs (Boenish and Wilson, 2017).



Photos by: Marion Haarsma

Density of groupers in 1983 and 2004-2005. The category "rest Serranidae" refers to large piscivores, excluding the common grasbys and coneys.
(Debrot & Nagelkerken, unpublished data.)



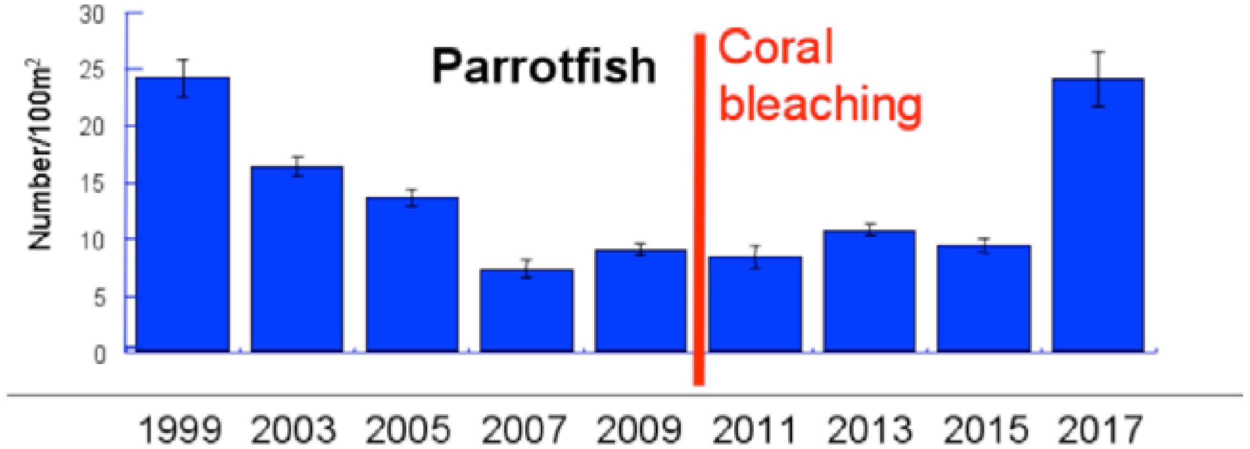
Timeline of Bonaire fishing regulations (adapted from Jackson et al. 2014)

1961	Minimum catch size for lobsters & regulation protecting sea turtles, sea turtle eggs and nesting areas
1963	Regulation of the use of dragging nets
1971	Use of spear guns banned
1975	Harvesting of corals banned
1979	Bonaire Marine Park established
2008	No fishing areas established
2010	Parrotfish catches banned; fish traps licensed for phase out; new permit system for fish nets

Bonaire's parrotfish populations are at least double those found on most other reefs in the Caribbean region (Jackson et al., 2014; Rooij, Videler & Bruggeman, 1998; Steneck and Wilson, 2017). The high numbers of parrotfish have been hailed as a significant factor in the recovery of Bonaire's reefs following the 2010 bleaching event, particularly as parrotfish enhance coral recruitment and survival through removal of macroalgal competitors (Steneck and Wilson, 2017).

From 2003 onwards parrotfish populations appear to have declined (Boenish & Wilson, 2017). This prompted the passing of enhanced legal protection, a ban on parrotfish harvest and phasing out of fish traps from 2010 onwards (Jackson et al., 2014). Data indicate that parrotfish populations stabilized between 2009 and 2015 and the most recent results show promising signs of recovery with a marked increase in herbivore density and biomass (Boenish & Wilson, 2017) Scarid biomass increased by 36% from 2015 to 2017, while density increased by 105% and approached 1999 levels suggesting that strong recruitment has occurred (Steneck and Wilson, 2017).

The current parrotfish biomass of ~3.6 kg/100 m2 indicates that compared to the historical levels there might be room for further growth (Boenish & Wilson, 2017). Historically, herbivorous fish have formed a minor part of the reef fish catch (De Graaf et al., 2016) and parrotfish were not a target species for local fishermen, but current practices are undescribed. So aside from anthropogenic impacts, this will depend on a variety of factors such as population size structure, territory structure, and food availability as *"scarids are particularly known for high levels of intra and inter-specific competition"* (Boenish & Wilson, 2017; Mumby et al., 2002).



(Steneck & Wilson, manuscript in preparation)

Status of Bonaire's Reefs

Photo by: Marion Haarsma

Local stressors

Bonaire's reefs are relatively healthy with an unusual capacity to recover from the 2010 bleaching event, however they are still threatened by a number of stressors. It is important to reduce local and regional threats to increase the resilience of the reefs to the global stressors caused by climate change such as more bleaching events (Donner et al., 2010; Steneck & Wilson, 2017).

The main users of Bonaire's reefs are fishermen and divers, which have a direct impact on the health of reef ecosystems. While fishing pressure on coral reefs has been found to be generally moderate (De Graaf et al, 2016), some differences in carnivorous fish biomass between fished and non-fished areas and the virtual absence of large-bodied groupers indicate that there is some fishing pressure (De Graaf et al, 2016; Boenish & Richie, 2017). Fishers are aware that stocks are declining and generally blame external factors such as climate change and industrial fishing offshore and support more management of fishing (Johnson & Jackson 2015).

Negative effects of diving, such as broken coral fragments, have also been documented (Lyons et al., 2015). Due to the island's reef structure, reefs are very accessible, making them more vulnerable. A study by Lyons et al. (2015) found that dive sites with heavy diving traffic had 10% less structural complexity. They also found that while sponges and gorgonians were not affected, massive stony corals (*Orbicella annularis*) were 31% less abundant at sites with heavier traffic. Divers overall consider the reefs as healthy but are aware of some decline which they primarily attribute to coastal development and overfishing (Johnson & Jackson, 2015).

Invasive grazing species such as goats significantly contribute to the island's erosion problem. These grazers consume the island's vegetation at such a fast rate that it does not have time to regenerate, leaving the ground bare and soil vulnerable to erosion (Smith et al., 2014; Roberts, 2017). Not only does the removal of soil and sediment particles reduce soil quality for native plants, but it also poses a serious threat to adjacent corals reefs. Without plants and trees to bind it, the soil it is easily blown and washed and inevitably ends up in the sea. The soil smothers corals and hinders their growth and is typically associated with coral mortality (Roberts, 2017). Several initiatives are running to reduce this threat under the natuurgelden projects that are funded by the Netherlands's Ministry of Agriculture, Nature and Food Quality (LNV).

Coastal development has increased dramatically to accommodate the large influx of visitors and residents to the island in the last years. Building near the water's edge, and even inland on a small island such as Bonaire, causes sedimentation and nutrient enrichment of the marine environment which in turn smothers and kills reef organisms. Other changes in land use, such as new car parks and beach creation, can increase the amount of pollutants entering the sea through increased run-off and sedimentation. The geology of Bonaire's leeward coast provides little space for beaches near human settlements, and artificial beaches have been created in some resorts to provide to tourists' needs. Kralendijk, located in the centre of the island, is Bonaire's main population centre and has become the focus of the islands tourism industry with the majority of hotels, dive and watersports centres and restaurants located nearby. The reefs around Klein Bonaire are some of best reefs as they have so far been spared of all the deleterious effects commonly associated with coastal development. Also, as Klein Bonaire is largely composed of carbonate rock, natural terrigenous sediment stress to the reefs is especially low (Debrot, 1997).

Pollution on Bonaire mainly comes from sewage, which makes its way onto Bonaire's coral reefs through terrestrial run-off as well as inadequate wastewater treatment and use (Goldstein, 1993). A big increase in Bonaire's inhabitants of 50% since 2001 and the growing tourist industry create more pollution. This directly affects the health of the seabed environment. The resulting raised nutrient concentrations stimulate the growth of algae, which can outcompete hard corals for settlement space (Steneck et al., 2017). De Bakker et al. (2017) suggest that the decline in water quality (Slijkerman et al., 2014), along with elevated temperatures, may have initiated the recent shift to a dominance of benthic cyanobacterial mats.

Another emerging risk for coral reefs are UV filters in sun care products like Benzophenone-3 that are introduced in our marine ecosystem directly by water users (BP-3; oxybenzone) (Slijkerman et al., 2017). Oxybenzone is a genotoxicant to corals, meaning that this synthetic organic compound can damage corals' DNA. The chemical has a toxic effect on planula (larval stage) of corals and in mature corals causes a heightened susceptibility to bleaching, interferes with growth and reproduction and causes deformities and growth anomalies (Danovaro et al., 2008; Downs et al., 2016).

Bonaire's coral reefs face a number of natural pressures including storms and coral diseases that are believed to be intensified by human activities. Hurricane Lenny (Category 3), which hit the normally sheltered southwest coast in 1999, and tropical storm Omar in 2008 caused widespread damage to the island's reefs, reducing areas of the reef slope to coral rubble. Bonaire's reefs have also suffered from a number of ongoing disease outbreaks including yellow band disease (affecting primarily the Boulder star coral Montastrea sp.) and black band disease. Besides, the island is also dealing with invasive species, notably lionfish that were first detected in 2009. A lionfish removal program was immediately started and the subsequent continuation of dive removal efforts has successfully reduced the local density of lionfish. However, this method has diving restrictions, which makes it difficult to control the lionfish population at deeper depths (De Léon et al., 2013).

Photos by: Hans Leijnse

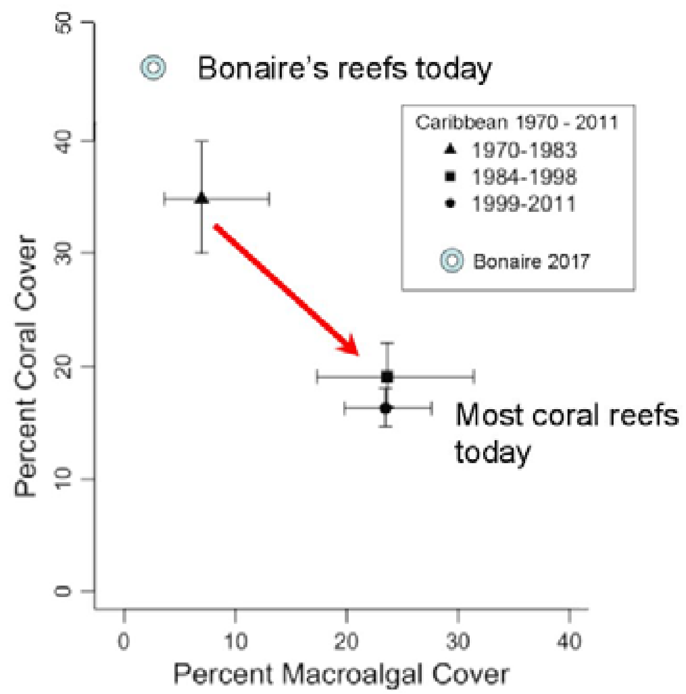
Bonaire's reefs compared to other Caribbean Reefs

While Bonaire's reefs have suffered over the last 40 years, they are considered relatively healthy when compared to the rest of the Caribbean (Jackson et al., 2014) and rate favorably on some critical indicators of reef health and functional reef communities. Bonaire has the highest net carbonate accretion of any of the Caribbean sites studied but much lower carbonate accumulation than had existed in the past when coral species such as Acropora and Orbicella were more abundant (Perry et al., 2012; de Bakker et al., 2016). All Caribbean reefs have suffered from declines in architectural complexity during the last decades (Alvarez-Filip et al., 2009), but Bonaire still has a more complex 3D structure than many other reefs within its region (Pandolfi and Jackson 2006; Green et al, 2008; Steneck and Wilson, 2017; R. Steneck personal communication, August 30th 2017).

In part due to their proactive management, Bonaire's reefs did not follow the Caribbean trend towards algal-dominated reefs (Jackson et al, 2014). Both the coral cover and parrotfish abundance of the island's leeward coast rank amongst the three highest in the Caribbean, just above Curaçao, which ranks fifth. From 2011 to 2015 average biomass of parrotfish on Bonaire's reefs was 29 g/m^2, twice the maximum reported in a large-scale study of herbivores on Caribbean reefs (Steneck et al., 2015). Also the cover of macroalgae is much lower than the Caribbean's average. In 2011, when the post-bleaching of macroalgae abundance spiked, the macroalgae index recorded on Bonaire was less than 300 whereas the Caribbean average ranged between 700 and 900 (Steneck et al., 2015).

Even though some of Bonaire's reefs are considered relatively healthy compared to other reefs in the Caribbean, they are definitely not all in a desirable state. However, with effective conservation measures in place and management of the island's marine resources in the hands of dedicated professionals, and thanks to the island's location outside the hurricane belt, there appears to be hope for their survival particularly if there is a political willingness to protect them from harm.

Photos by: Marion Haarsma



Comparison and trends in average live coral and seaweed (macroalgae) from over 35,000 studies throughout the Caribbean (Jackson et al. 2014) and Bonaire. Please note that the value for Bonaire is for the 2017 measurements of 11 monitored sites at a depth of 10 meters. It is essential to be aware that coral reefs on Bonaire show large variation in ecological quality which makes it difficult to draw conclusions on the health of the entire reef based on one study that only investigated a relatively small number of preselected sites.
(Steneck & Wilson, manuscript in preparation)

Status of Curaçao's Reefs

References can be found in ***BioNews Issue 4***

The island of Curaçao is almost entirely surrounded by narrow fringing reef that covers an estimated area of 7.85 km2 (Vermeij, 2012). These reefs, considered some of the healthiest and most diverse in the Wider Caribbean Region, have long supported the island's fishing industry and in recent decades have been the foundation for Curaçao's lucrative marine tourism industry. A number of studies have however highlighted the significant shift that the island's coral reef communities have gone through over the past four decades, with a sharp decline in both coral cover and fish biomass.

Geography and Reef Structure

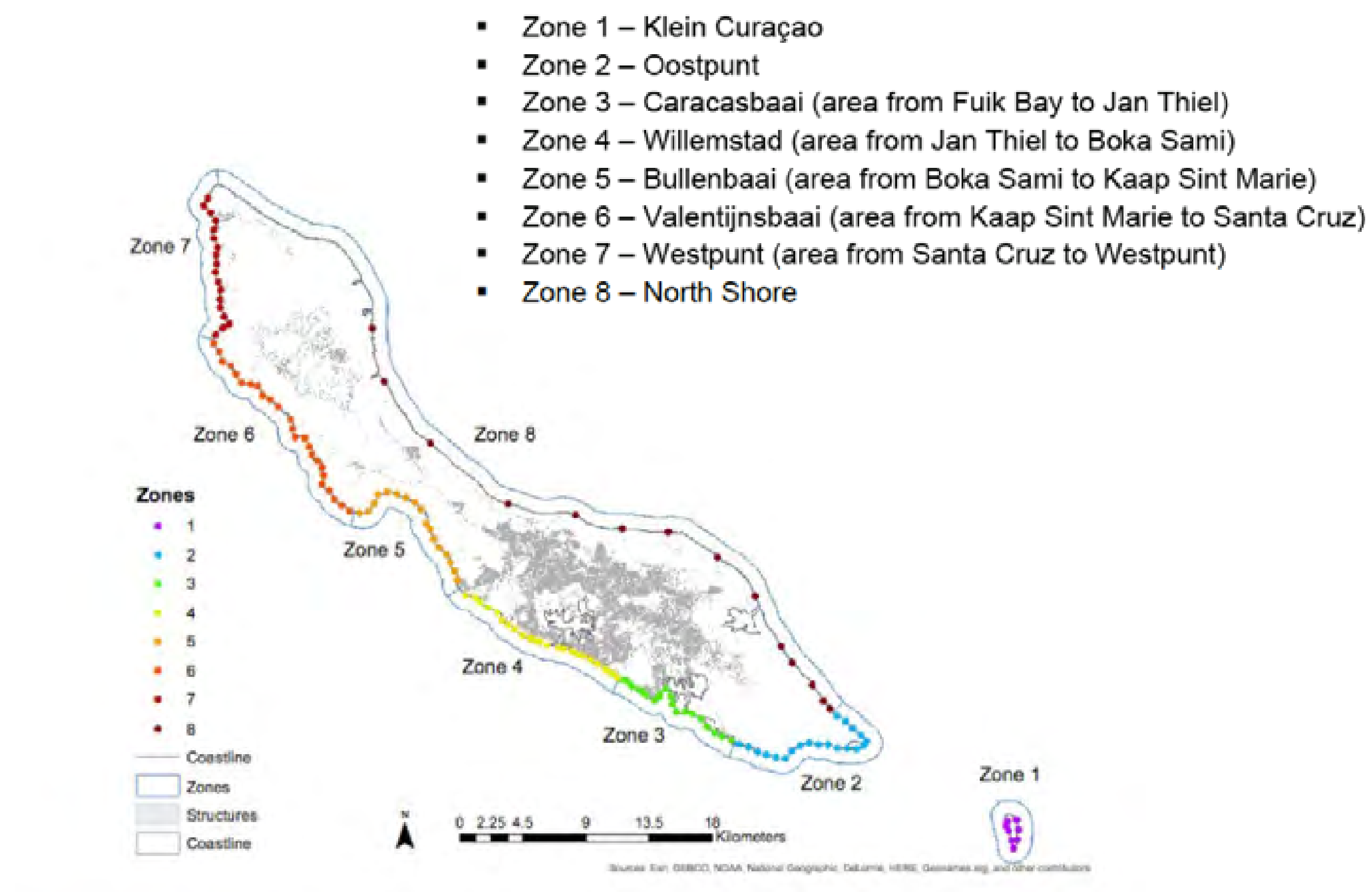
Curaçao is the largest island in the Dutch Antilles, with a total land area of 444km² and total maritime area of 4,915 km² (Van Buurt, 2009). This includes the land area of Klein Curaçao, a small, uninhabited coral limestone island located some 10 km off the southeast point of Curaçao. The island has a total coastal length of 175 km. The leeward (west) and windward (east) coasts are strikingly different. The windward coast is characterized by limestone cliff formations that are pounded by high waves rolling in from the rough open seas.The leeward coast is sheltered from the trade winds and is therefore calm with turquoise lagoons and sandy shores.

Due to the vast differences in oceanographic conditions between the island's coasts, reef structure and abundance is very different on each side. On the west coast, fringing reefs are much better developed and have a much higher coral cover, especially in shallow waters (Vermeij, 2012). The sea floor drops off steeply within about 100 m from the shore, which is known locally as the "blue edge". At a depth of 50 to 60 meters, a sandy terrace begins to slope gently until a depth of about 80 to 90m, where a second steep drop off occurs (Van Duyl, 1985; Pors & Nagelkerken, 1999). Corals on the east coast only occur past a depth of 12 meters due to much rougher conditions, such as high wave energy (Van Duyl, 1985).

"As of 2010, live coral cover on Curaçao's reefs was assessed to be 23.2%, with a coral diversity of 65 species."

As of 2010, live coral cover on Curaçao's reefs was assessed to be 23.2%, with a coral diversity of 65 species (Van Alfen & Van Vooren, 2010; Vermeij, 2012). The highest coral diversity is found on the reef slope, with a rapid decline below depths of 30-40 m (Bruckner & Bruckner, 2003). When mapping Curaçao's reefs, van Duyl (1985) found a general pattern of vertical zonation of species and therefore concluded that the island's coral species are highly affected by both depth and wave energy (Van Duyl, 1985). Shallow waters (shallower than 20 meters) are dominated by reef-building stony Montastraea spp. (Bruckner & Bruckner, 2003). Deeper waters are dominated by Agaricia spp. (Bak, Nieuwland & Meesters, 2005).

Map of Curaçao.
Image credit: DCNA



Based on the marine expedition eight zones with similar ecological conditions were identified and used for creating maps. In the Marine Scientific assessment report maps can be found with coral cover, juvenile cover density, turf- and macroalgae, fish biomass, infrastructure, sewage, trash, fishing pressure and diving pressure per zone.
Credit: WAITT Institute, Esri, GEBCO, NOAA, National Geographic, Delorme, HERE, Geonames.org, and other contributors

Status of Curaçao's Reefs

Status of Curaçao's reefs

A number of studies of Curaçao's reefs have taken place over the past four decades and have helped understand how the island's reef communities have changed over this time period (See table on page 16). In fact, along with Bonaire, Curaçao has the most comprehensive reef monitoring data set of the entire Wider Caribbean region: coral cover, composition and mortality at depths of 10, 20, 30 and 40 meters have been recorded at select sites since 1973 using fixed photo quadrants (Bak et al., 2005). Please be aware that this study only targets three sites around Curaçao and therefore we should be careful with island-wide statements.

The most recent assessment of Curaçao's reefs was carried out in 2015 by Blue Halo Curaçao (a partnership between the Waitt Institute and the Government of Curaçao in close cooperation with researchers from CARMABI and Scripps Institution of Oceanography). This Marine Scientific Assessment combined data from a marine expedition, interviews with divers and fishermen and historical sources (WAITT Institute, 2016). The expedition, which took place in November 2015, measured the abundance and composition of benthic and fish communities as well as water quality at 148 sites around the island using the Caribbean-Global Coral Reef Monitoring Network (GCRMN) baseline scientific monitoring methods. Based on this expedition Blue Halo Curaçao identified 8 zones with similar ecological conditions: Klein Curaçao (Zone 1), Oostpunt (Zone 2), Caracasbaai (Zone 3), Willemstad (Zone 4), Bullenbaai (Zone 5), Valentijnsbaai (Zone 6), Westpunt (Zone 7), North Shore (Zone 8). This chapter focuses on the results of this island-wide most recent study.

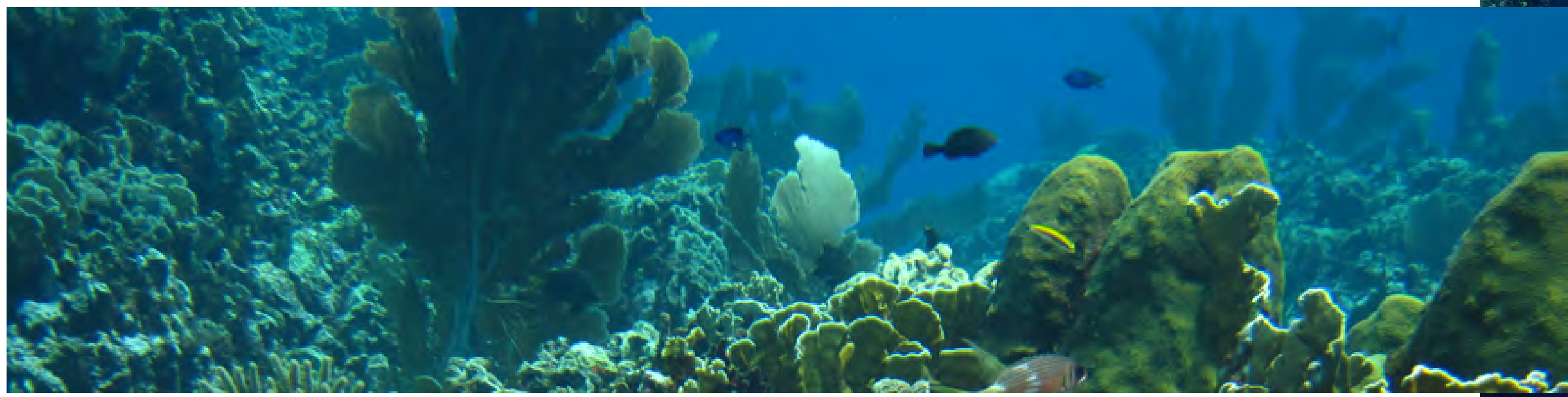


Photo by: © Mark Vermeij

Summary of major coral status surveys conducted on Curaçao's coral reefs
(Adapted from Sustainable Fisheries Group, 2015)

STUDIES	TIME PERIOD	SURVEY DESCRIPTION	# SITES SURVEYED
Bak et al., 2005; Bak, Nieuwland, 1995; de Bakker et al., 2016,2017.	1973-ongoing	Photographs are frequently taken of permanent quadrats of $9m^2$ at 10, 20, 30 and 40 m depths at the Leeward side of the island (Carmabi Buoy One (sites I and II) and Carmabi Buoy Two (site III)) to analyze the changes in community structures. In addition to these three sites, another site that is located at the far south-eastern side of Curaçao, was included with a quadrat positioned at 10 m (since 1983) and 20 m (since 1992) depth.	4
Bruckner and Bruckner, 2003.	1997, 1998 and 2000	Belt transect surveys to determine coral abundance, diversity and health.	9
Nagelkerken & Nagelkerken, 2004.	1969-2000	Sampling quadrats to determine the change in occurrence, cover, and sociability of coral species of shallow (1–3 m depth) coral reefs along the entire southwest coast of Curaçao.	16
Nagelkerken et al., 2005.	1973-2003	Transect surveys to quantify benthic cover.	9
NICO expedition organized by NIOZ and NWO-Science (PL: Visser & van Duyl)	2018	Deep reef surveys (> 30 m), mapping of cyanobacteria mats, onshore groundwaters and bathymetric maps	-
Reefcare Coral Monitoring.	1997-ongoing	Transect surveys were used to classify benthic cover and data on coral cover, state of health, amount and algae cover and type. Four sites surveyed at a depth of 7 and 14 m every 3 months.	Currently: 6
Sandin et al., 2008.	2008	Data collection on coral reef fish and benthic community structure.	5
Van Duyl, 1985.	1981-1983	Classified wave energy environments and benthic habitats using aerial photography and in situ reef ground truthing surveys (0-20m depth).	Entire leeward coast
WAITT Institute, 2016.	2016	A large marine scientific assessment combined data from a marine expedition (GCRMN method), interviews with divers and fishermen and historical sources.	148

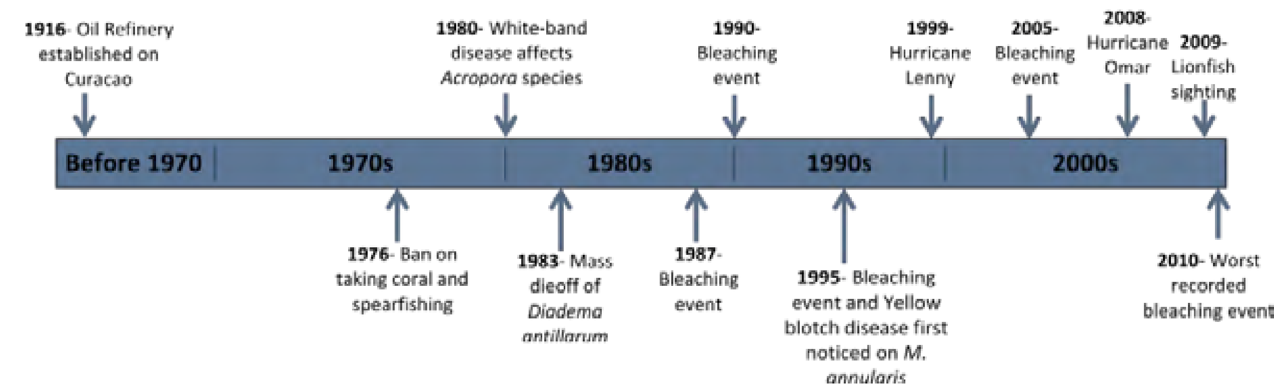
**PL = Project Leader*

Photo by: © Mark Vermeij

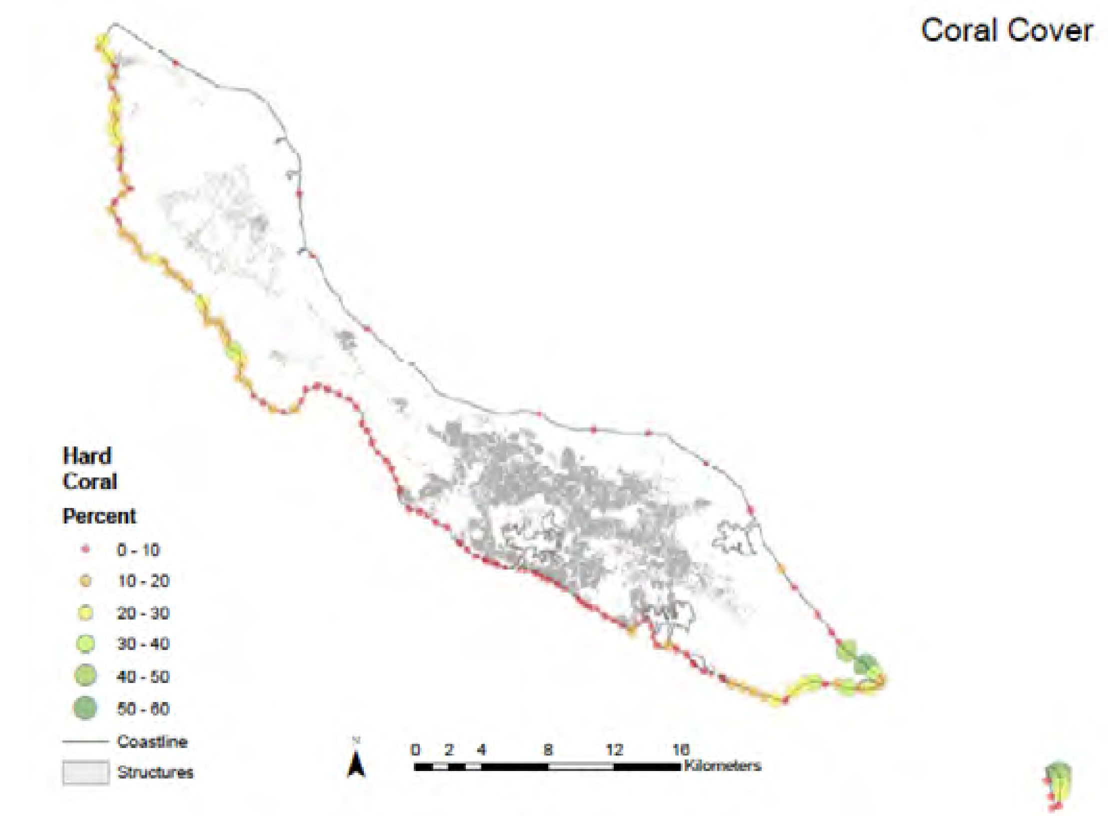
Benthic cover
Coral cover

Like many reefs in the Caribbean, Curaçao's reefs suffered over the past decades from anthropogenic and natural stressors such pollution, coastal development, overexploitation, bleaching events, tropical storms, the mass mortality of *Diadema antillarum* urchins in 1983 that greatly reduced herbivory levels on competitive algae (Bak et al., 1984) and the white-band disease that killed nearly 90% of elkhorn and staghorn from the late seventies to the mid-eighties (Bries et al., 2002; Mumby et al., 2014).

The overall decline in coral cover for the island's reefs ranges from 42% [1980-2012] (Sustainable Fisheries Group, 2015) to over 50% [1982-2015] (WAITT Institute, 2016). Blue Halo Curaçao found that, with the exception of Klein Curaçao and Oostpunt, the average coral cover for the island in 2015 was 15%. The north shore has the lowest coral cover (3-7%) due to the oceanographic conditions that inhibit coral reef growth. The area from Boka Sami to the North Shore (Zones 5 to 7) also has a low coral cover (7-11%).



Timeline of major natural and anthropogenic events that have impacted coral reef habitats in Curaçao. (Sustainable Fisheries Group UC Santa Barbara, 2015)



Coral cover by site level average.
Credit: WAITT Institute, Esri, GEBCO, NOAA, National Geographic, Delorme, HERE, Geonames.org, and other contributors.

Status of Curaçao's Reefs

Photo by: © Rudy van Gelderen

The use of photo quadrants has also revealed an important loss in coral cover loss over the past 40+ years (de Bakker et al., 2016, 2017). Indeed, from 1973 to 2014 de Bakker et al. (2016) found that coral cover decreased between 5.5% to 47.4% at 10, 20, 30 and 40 m depths. While overall cover and abundance declined for almost all species (de Bakker et al. 2016), reef-building species such as Orbicella spp. have suffered the biggest loss. There has been an overall shift towards small colonies with reefs now dominated by smaller, opportunistic species (e.g. *Madracis mirabilis, Porites astreoides, Diploria strigosa*, and *Agaricia lamarcki*), although even these species have suffered an overall loss in cover (de Bakker et al., 2016). Important consequences of reduced coral cover and the shift to smaller opportunistic species is reduced carbonate production, loss of reef structural complexity and its' associated loss of biodiversity, coastal protection and human food security (de Bakker et al., 2016).

Curaçao's healthiest reefs are located on the island's east side. Klein Curaçao (Zone 1) and Oostpunt (Zone 2) were found to have an average coral cover of 25%, with a number of individual sites on the eastern side of these zones averaging >40% cover (See figure on page 17) (WAITT Institute, 2016). A few sites near Rif Marie (Zone 6) and Playa Kalki (Zone 7) were also found to have a coral cover >40%. Current estimates suggest that healthy Caribbean reefs have a coral cover of over 40% (WAITT Institute, 2016). Both the Klein Curaçao and Oostpunt zones also have the most favorable conditions for reef growth, as juvenile corals of reef-building species are about twice as abundant in these zones than in other parts of the island.

Vermeij et al. (2014) found that the abundance of juvenile corals may be another good measure of reef health alongside coral cover as such an abundance "*reflects the relative success or failure of reef functional processes (recruitment, growth and survival) on a timescale meaningful to both ecology and conservation*" (Vermeij, 2014). The relative abundance in juvenile reef-building coral species helps to predict how well a reef area will renew itself once existing corals die, with reef-building species most important in building calcified reef structures that protect shore communities from extreme weather events such as tropical storms (WAITT Institute, 2016). Juvenile corals (<4cm) on Curaçao's reefs decreased on average by 55% from 1975 to 2005 (Vermeij, 2011).

Curaçao is located on the southern edge of the hurricane belt, and on average one tropical storm passes within 200km (100mi) of the island every 4 years (Sustainable Fisheries Group, 2015). These create high seas and intense wave action that causes localised damage to the reefs and the coastal zone. Curaçao sustains considerable damage from hurricanes approximately once every 100 years. There have been no hurricanes in the past 20 years (Jackson et al., 2014).

Place	Reef	Depth (m)	Year span	Start coral cover (%)	End coral cover (%)	Net change (%)
Curaçao	CARMABI Buoy 1 (1)	10	1973-2014	48.5	1.1	-47,4
		20	1973-2014	34.6	8.7	-25,9
		30	1973-2014	22,4	4,4	-18
		40	1973-2014	12,9	1,4	11,5
	CARMABI Buoy 1 (2)	10	1973-2014	22.7	5.9	-16,8
		20	1973-2014	32,9	5,6	-27,3
		30	1973-2014	19,7	14,2	-5,5
		40	1973-2014	17,6	6,9	-10,7
	CARMABI Buoy 2 (3)	10	1973-2014	37	24	-13
		20	1973-2014	34.9	16.6	-18.3
		30	1973-2014	31	9.6	-21.4
		40	1973-2014	36.1	18.4	-17.7

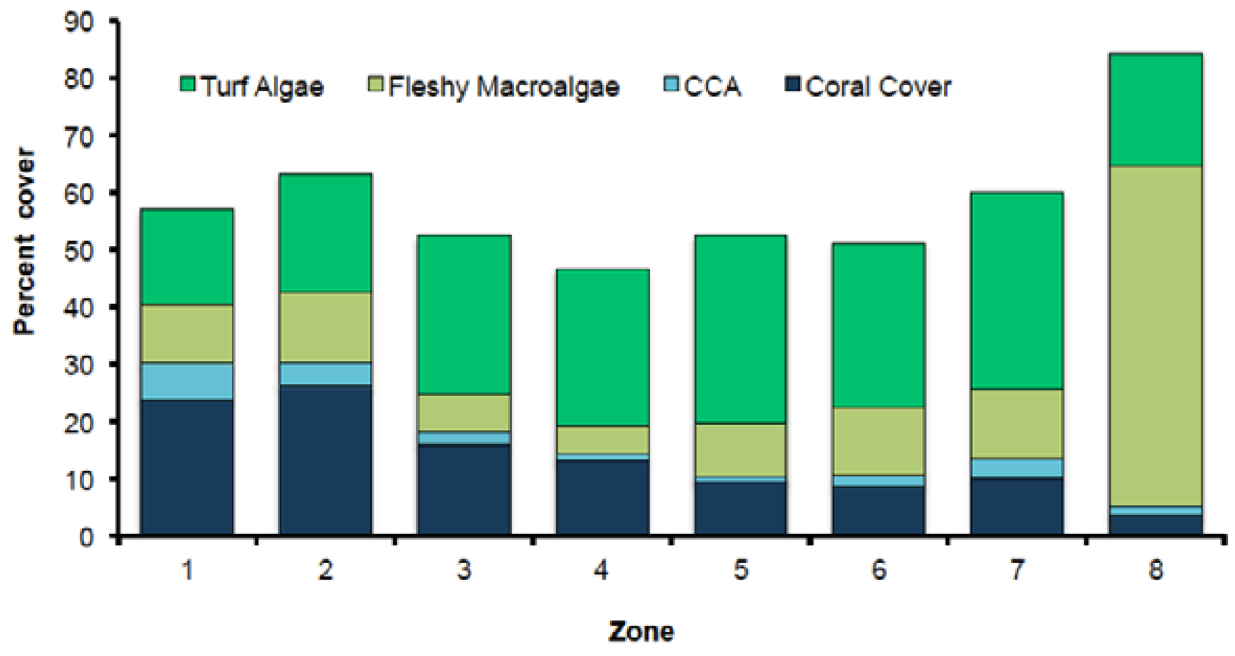
Change in coral cover of a 9 m² quadrat at a depth of 10, 20, 30 and 40 meters at three different sites on Curaçao.
(de Bakker et al., 2016)

Algae and cyanobaterial mats

Macroalgae are a natural part of a reef community but many reefs in the Wider Caribbean Region have seen a shift from coral to algae dominated benthic communities. Studies have shown how damaging macroalgae can be to coral health, inhibiting coral settlement and recruitment, slowing coral growth and making them more prone to disease (Jackson et al., 2014). A study on Curaçao has revealed how macroalgae can negatively impact coral larval recruitment (Vermeij, 2006). Larval settlement was found to be good on the experimental panels that were totally covered in crustose coralline algae between 1979 and 1981. However, by the early 2000s the upper surfaces of these panels were totally covered in macroalgae and larval settlement declined five-fold.

Macroalgae cover on Curaçao remains low compared to the rest of the Caribbean, largely due to the relatively high biomass of parrotfish that keep macroalgae in check. However, one worrying trend is the increase in turf algae, most likely due to an increase in nutrients in the water. Turf algae rapidly overgrows coral and unlike macroalgae, herbivore fish have no effect on the rate by which turf algae overgrow corals (at a rate of 0.34 mm/3 wk) (WAITT Institute, 2016; Vermeij, 2010). Except for the east coast of the island, all zones have a much higher percentage cover of turf algae than macroalgae, with turf algae covering 40.3% of the reef bottom on Curaçao's southern shore .
The windward coast (Zone 8) has an unusually high cover of macroalgae; it is almost completely covered by Sargassum species due to the area's strong wave action and resulting low coral cover (WAITT Institute, 2016).

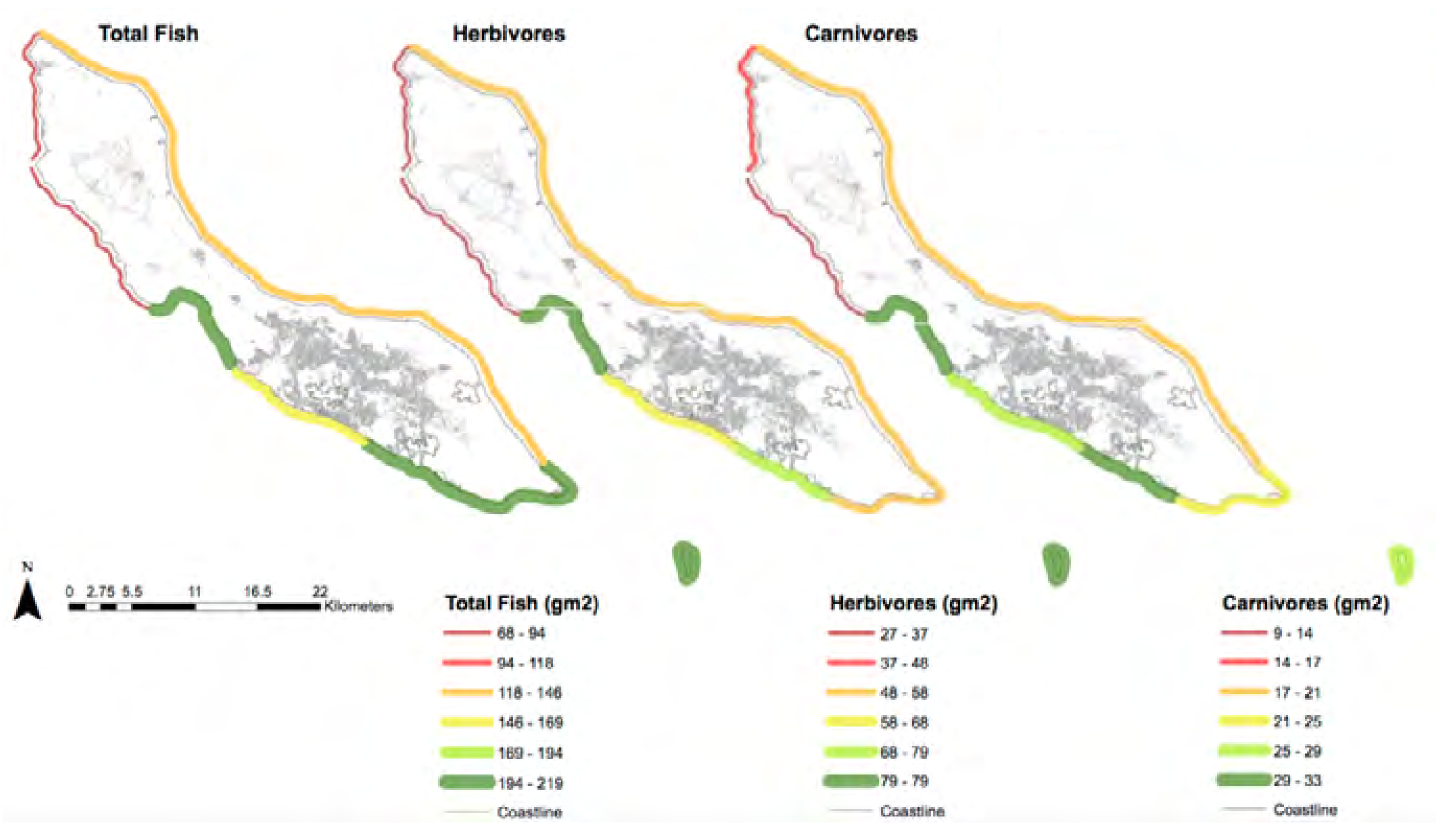
Another worrying trend is the rise of benthic cyanobacterial mats (Mumby et al., 2014) that can also negatively impact reef communities by *"inhibiting recruitment (Kuffner et al., 2006), act as pathogens (Carlton and Richardson 1995), overgrow and smother reef benthos (Ritson-Williams et al., 2005; de Bakker et al., 2016b), create an anoxic environment (Brocke et al., 2015b) and produce chemicals that cause coral and fish mortality (Nagle and Paul 1998)"* (de Bakker et al., 2017). This trend is further described in in chapter 1, on page 9.



Average abundance (in percentage cover) of reef building organisms: corals and crustose coralline algae (CCA) and abundant algal groups (turf algae and fleshy macroalgae) that compete with reef builders for space. Other bottom cover not shown in this figure includes sponges, sand and rubble.
(WAITT Institute, 2016)

Status of Curaçao's Reefs

Photo by: © Hans Leijnse



Spatial distribution of fish around Curaçao.
(WAITT Institute, 2016)

Fish biomass

There is currently no indicator within the Caribbean of what total fish biomass indicates a "healthy" reef, although healthy reefs in the Pacific have been found to show total fish biomasses between 270 – 510 g/m2 (WAITT Institute, 2016; Sandin et al., 2008). While the three areas in Curaçao that have the highest fish biomass (>200 g/m2) do not fall within this "healthy" range, their value is still high compared to other parts of the Caribbean. Klein Curaçao (Zone 1) has the highest total fish biomass of the island (219 g/m2), closely followed by Caracasbaai (Zone 3). Fish biomass is higher east of Kaap Sint Marie (Zones 1 to 5) with a range of 159 – 219 g/m2 and lower in the north-east of the island (Valentijnsbaai and Westpunt, Zones 6 and 7) .

The abundance of carnivorous and herbivorous fish are important indicators of functional reef communities. High densities of predatory fish such as groupers dominate healthy reef fish communities. If their abundance diminishes, the trophic structure of the reef fish assemblage is affected, which in turn affects reef health – for example, fewer predatory fish may lead to an increase in damselfish, which are known to hurt the reef when their population becomes too high (Vermeij, 2015). Herbivorous fish species, notably parrotfish, have a crucial ecosystem role within reefs as they keep algae from overgrowing coral (Jackson et al., 2014).

Currently, the biomass of carnivorous fish is low across all zones, with the lowest abundance found from Kaap Sint Marie to Westpunt and all down the east coast (Zones 6 to 8) (WAITT Institute, 2016). The biomass of herbivorous fish is still quite high (58 – 89 g/m2) in certain areas (Klein Curaçao to Willemstad) when compared to other parts of the Caribbean. The highest biomass is found near Bullenbaai and falls within the range at which herbivorous fish are able to keep algae from overgrowing coral (>70 g/m2). However, certain areas have shown a significant decrease in herbivorous fish populations, with the lowest biomass (26 g/m2) found from Kaap Sint Marie to Santa Cruz (Zone 6).

Photo by: © Mark Vermeij

Photo by: © Marion Haarsma

Local stressors

As is the case for most reefs around the world, Curaçao's coral reefs have suffered from a sharp increase in local stressors over the past few decades. These stressors, such as pollution and coastal development, have had a drastic impact on reef health and led to an decline in coral cover and fish biomass. It is important to reduce local threats to increase the resilience of the reefs to the global stressors caused by climate change such as coral bleaching events.

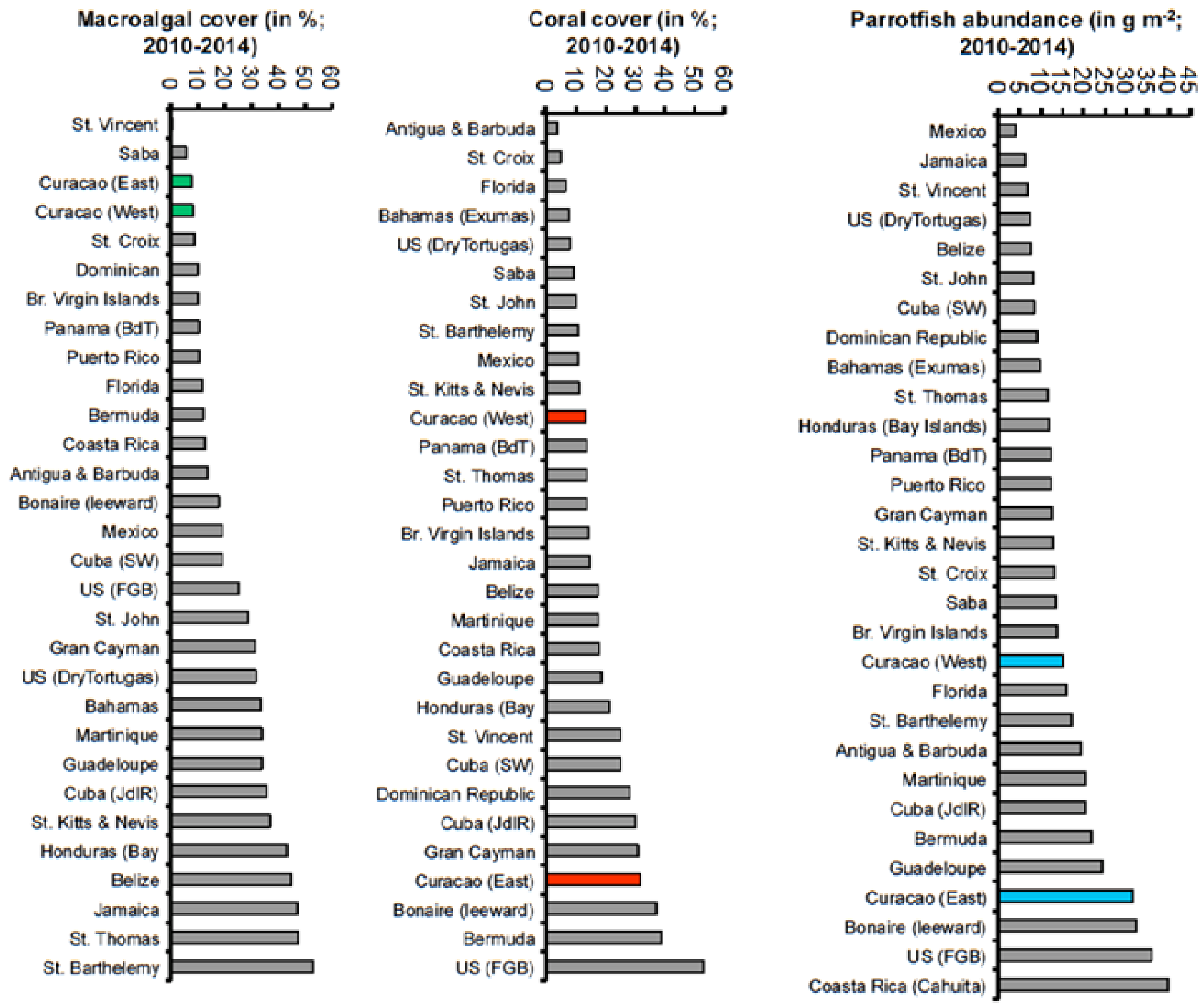
Coral cover loss has been the highest around the island's densely populated areas, especially around the capital city of Willemstad. Curaçao has a population of 160,337 inhabitants and is the second most densely populated island of the leeward islands with just over 354 inhabitants per km^2 (CBS, 2017). The Blue Halo Curaçao study assessed the island's coastal pollution from both sea and land sources. Land-based pollutants were found to contaminate ocean waters through run-off, sewage, industrial pipes and trash. As expected, sewage pollution was found to be the highest around Willemstad, the island's biggest agglomerate of urban area (Zone 4). Lots of trash was found in Bullenbaai (Zone 5) and Westpunt (Zone 7).

While fishing pressure is limited on the island's reefs due to the fact that most fishing now takes place offshore and in deep waters, there are still certain reef areas around the island that have historically been overfished or are being overfished (Vermeij, 2012; Kraan, 2017). The two areas with the highest fishing pressure are Westpunt (Zone 7) and Klein Curaçao (Zone 1) (WAITT Institute, 2016). The total fish biomass at Klein Curaçao remains high (likely because most fishermen target pelagics rather than reef fish), but the low fish biomass at Westpunt indicates that the area is severely overfished. Westpunt is also one of the most visited dive areas and greatly valued by both fishermen and divers, meaning that there is great potential for conflict between these two user groups (WAITT Institute, 2016). The windward side of the island has a low fishing pressure due to rougher waters that deter most fishermen. Fishing is also limited around Willemstad (Zone 4), most likely due to the presence of large ships, and near Oostpunt (Zone 2), which has limited shore access for fishermen.

Curaçao's reefs compared to other Caribbean Reefs

Curaçao's reefs are considered relatively healthy compared to the rest of the Caribbean (WAITT Institute, 2016) and rate favorably on some critical indicators of reef health and functional reef communities (See page 22). The coral cover of the island's leeward coast (31%) is amongst the five highest of the Caribbean, just below Bonaire's leeward coast (35%). Coral cover of the east coast is much lower (12%) due to the oceanographic conditions of that coast, but still higher than Saba (9%). Parrotfish abundance of Curaçao's leeward coast is also amongst the five highest in the Caribbean, just below Bonaire's leeward coast (31 g/m^2). The north shore has a much lower parrotfish abundance (15 g/m^2), around the same range as Saba (13 g/m^2). The macroalgal cover for both the east and west coast rate low (both 8%), while Saba rates even lower (5%).

While the health of Curaçao's reefs has significantly worsened over the past decades, they are still healthy enough to provide the island with important economic gains. In 2016, Curaçao's reefs were valued at more than USD 442 million per year (Sustainable Fisheries Group, 2016). These economic benefits will however disappear if Curaçao's reefs become too damaged, alongside invaluable functions such as storm protection and carbonate production. So far, the loss in Curaçao's coral cover has led to a 67% reduction in reef carbonate production (de Bakker et al., 2016). Drastic actions to ensure the proper management and conservation of the island's reefs, such as the designation of no take zones and the repair of its water treatment facility, is therefore urgently needed and must become an absolute priority for the island.



Overview of commonly used metrics for coral ecosystem health of Curaçao's coral reefs in comparison to other Caribbean islands and nations. High coral cover and high abundance of parrotfish are considered signs of functional reef communities, whereas high macroalgal abundance is indicative of degraded reefs. (Note: the more common turf algae and cyanobacteria are not included in this comparison).
(WAITT Institute, 2016)

Photo by: © Marion Haarsma

Status of Curaçao's Reefs

Status of Saba's Reefs

References can be found on ***DCNA's website***

Saba is nicknamed the "Unspoiled Queen" due to its pristine nature and high level of terrestrial and marine biological diversity. Each year, approximately 22,500 visitors come to enjoy the island's natural treasures, with the majority of these visitors taking part in diving and hiking activities. The most recent research on the health of Saba's reefs however revealed a decline of the island's coral reef health most likely mainly due to regional and global stressors such as the mass mortality of *Diadema antillarum* urchins, bleaching events and hurricane impacts.

Geography and Reef Structure

Saba is located in the North Eastern Caribbean within the Lesser Antilles island group. The island was formed about 500,000 years ago as the result of volcanic activity and is the youngest of the three Windward Islands (Westermann and Kiel, 1961). It is the peak of a single dormant volcano, Mount Scenery, which rises 877 meters above sea level and is the highest point of the Kingdom of the Netherlands (Westermann and Kiel, 1961).

Saba is the smallest island of the Dutch Caribbean, with a land area of 13km² and a maritime area of 10,367 km² (Jackson et al., 2014). The island has two small rocky islets, Green Island and Diamond Rock, which are home to breeding seabird colonies. Saba's coast, which measures 16 km, is dominated by steep and rocky cliffs (Jackson et al., 2014). Consequently, there are no mangrove stands or extensive *Thalassia* seagrass beds, although there are small patches of *Syringodium* on the leeward western coast and east of Fort Bay (Buchan, 1998).

The island is very mountainous with numerous hills surrounding the main peak of Mount Scenery, including Booby Hill, Bunker Hill and Great Hill. Much of the island is covered by relatively dense vegetation; the upper slopes of Mount Scenery are covered in cloud forest with an exceptional canopy height of up to 15m (Stoffers, 1960). The slopes of Mount Scenery have many V- and U-shaped valleys, locally known as guts, which carry water and sediments directly to the ocean during heavy rains. The island's population, which reached 1,947 in 2016, is mostly concentrated around the capital, The Bottom, in the south-east (CBS, 2016).

Saba has a few reefs and a large number of sand habitats. The most common coral species in Saba's reefs are *Orbicella faveolata, Siderastrea siderea* and *Porites astreoides* (Hildebrand, 2017). The island's bathymetry is characterized by nearshore drop-offs at Flat Point, Spring Bay, and Corner Point (Deslarzes, 1994). The shelf surrounding Saba is typically 300-500 m wide within a 60m depth limit, but measures around 1,000m at its widest point in the north of the island (Deslarzes, 1994).

Map of Saba.
Image credit: DCNA

Photo by: © Hans Leijnse

Most of Saba's reefs reflect the island's volcanic origins, with corals growing on volcanic structures such as lava formations, boulders and pinnacles (Klomp & Koostra, 2003; van 't Hof, et al., 1991; Polunin & Roberts, 1993). The island's reefs are also home to a number of deep underwater seamounts, known as pinnacles, with the majority located 1.8 km off Saba's western coast. These pinnacles are nourished by deep ocean currents and therefore covered in rich marine life. Saba does have true reefs - that is reefs with a carbonate framework - in the south-western part of the island at the Giles Quarter reef complex (Polunin & Roberts, 1993).

The Saba National Marine Park (SNMP) was established in 1987 and includes all the waters around the island from the high-water mark to a depth of 60m, including the seabed and overlying waters. It includes a total area of 1300 ha. The park has one no-take zone, which covers 33% of the park's area, in which fishing and anchoring or mooring by larger recreational vessels are prohibited but diving is permitted (Menger, 2017). The Yarari Marine Mammal and Shark Sanctuary, which comprises all the waters around Bonaire, Saba and St. Eustatius, was established in 2015.

Status of Saba's Reefs

Summary of major coral status surveys conducted on Saba's coral reefs

Studies	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.	-
Esteban & Kooistra, 2005.	2005	Report on observations of coral bleaching (ReefCheck protocol).	4
GCRMN, (Project lead: WUR, van der Vlugt, 2016; Menger, I., 2017; Hildebrand, 2017)	Annual since 2015	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
NICO expedition organized by NIOZ and NWO-Science (van Duyl & Meesters, 2018)	2018	Mapping the windward side of Saba with video transects and the multibeam echo sounder.	-
Polunin & Roberts, 1993; Roberts, 1995; Roberts & Hawkins, 1995; Noble et al, 2013.	1991-2008	Underwater visual censuses (UVCs) of fish abundance and habitat variables were conducted within the Saba Marine Park	15
Scripps Institute of Oceanography and the WAITT Foundation	2016	Coral reef assessments following the GCRMN protocol and selection of 8 coral reef environments was mapped using 3D imagery.	14
SCF with staff of local dive schools Saba Divers, Sea Saba and Explorer ventures	2017-2018	Post hurricanes (Irma and Maria) damage assessment of coral reefs using GCRMN method.	Planned: 50 in SNMP and 25 on the Saba Bank
Van Beek, 2013; Kuramae & van Rouendal, 2013	1992, 2013	Benthic habitat mapping.	276

Status of Saba's reefs

Only a few studies have assessed the health of Saba's reefs since the early 1990s. Before this time, Saba's reefs have suffered like all reefs in the Caribbean from the mass mortality of *Diadema antillarum* urchins in 1983 that greatly reduced herbivory levels on competitive algae and the white-band disease that killed nearly 90% of elkhorn (*Acropora palmata*) and staghorn corals (*Acropora cervicornis*) from the late seventies to the mid-eighties (van de Vlugt, 2016). In 1992 a baseline study was carried out to identify the benthic habitats in the coastal waters of Saba (Van Beek, 2013). In 2013, benthic habit mapping was done again with video-drops at 276 locations (Kuramae & van Rouendal, 2013). In 1999, the reefs of the windward Netherlands Antilles were assessed using the Atlantic and Gulf Rapid Reef Assessment (AGRRA) protocol to assess the damage caused by Hurricane Lenny (Klomp & Kooistra, 2003). A reef check was also done to assess the damage during the 2005 severe bleaching event (Esteban & Kooistra, 2005). In 1991, 1993, 1994, 1995 and 2008, one long-term study looked at fish communities in the Saba Marine Park by carrying out Underwater Visual Censuses (UVCs) of fish abundance and habitat variables at 15 different sites within the park (Noble et al., 2013). However, to better understand the current status of Saba's reefs and to enable comparison of data from year to year, a yearly ongoing monitoring survey began in 2015. Twenty sites around the island have been surveyed according to the protocols of the Global Coral Reef Monitoring Network (GCRMN). On each site the following coral reef indicators were measured by students of WUR: fish biomass and density, coral and macroalgae cover, coral health, density of coral recruits, density of sea urchins and cucumbers, and water quality (van der Vlugt, 2016; Menger, I., 2017; Hildebrand, 2017).

Conservation organizations from Saba, St. Eustatius and St. Maarten joined a research expedition organized by the Scripps Institute of Oceanography and the WAITT Foundation in November 2016 to conduct a rapid scientific assessment of the coral reefs around the windward Caribbean islands (Sandin et al., 2016). The GCRMN protocol for the Caribbean was used to establish a regional scale perspective of coral reef health across the islands, with surveys taking place in the forereef habitat at depths between 7 and 15 meters. In addition to coral reef assessments following the GCRMN protocol, a selection of coral reef environments on Saba were mapped using 3D imagery. Photography and advanced image post-processing are used to create photomosaic images of large reef areas up to 100 square meters. These images provide a snapshot view of large-area coral reef communities and their compositions, enabling data collection of benthic communities. Not all results of these surveys have been released yet. The first preliminary results on juvenile corals and turf algae are included in this chapter and footage can be seen here: https://drive.google.com/drive/folders/0By3cTucxJ9GFVmZKcVZxSjQxcG8?usp=sharing.

In March 2018 researchers aboard the Pelagia research vessel collected invaluable data on the Windward islands during the "Netherlands Initiative Changing Oceans (NICO)" marine expedition organized by the Royal Netherlands Institute for Sea Research (NIOZ) and NWO-Science. The research team mapped for the first time the largely unknown benthic communities and bathymetry on the windward side of Saba with video transects and the multibeam echo sounder (van Duyl & Meesters, 2018).

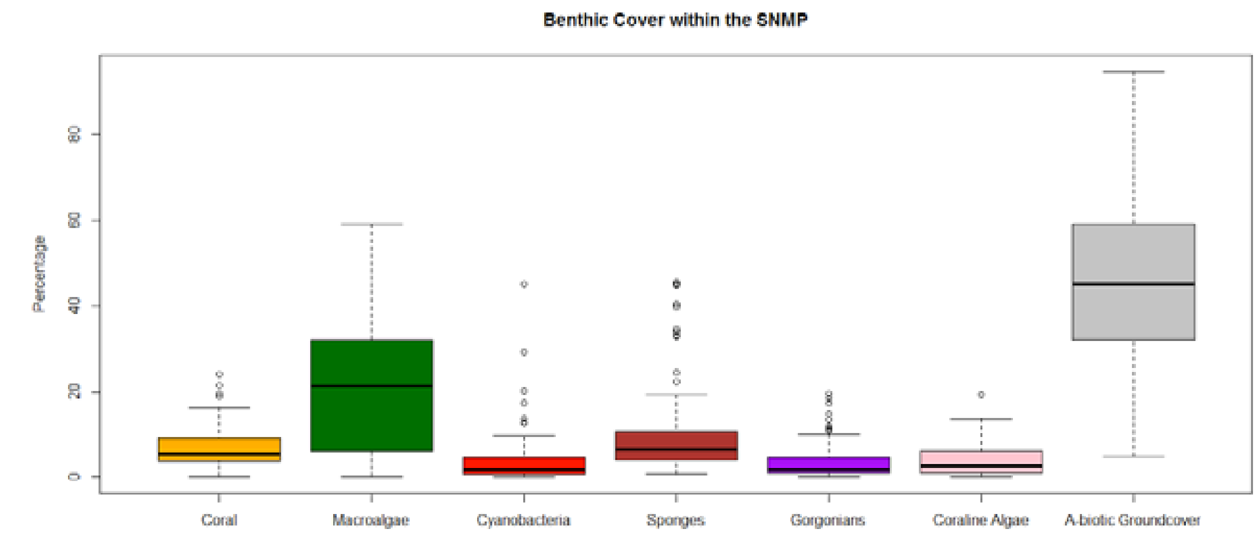
Benthic cover

Seven habitats occur in Saba's Marine Park: bare sand, bare rock, diffuse patch reef, dense patch reef, coral reef, sea grass beds and algae fields (Kuramae & Rouendal, 2013).

Coral Cover

Coral cover on Saba, that is the amount of reef surface covered by live stony corals, has declined over the past three decades. In the early 1990s, mean hard coral cover ranged from 7.8% to 21.9% and reached 29% in certain reef areas (Deslarzes, 1994). According to other estimates, it reached up to 38% in 1994 (Noble et al., 2013). *Orbicella annularis* was most dominant overall, followed by *Agaricia* spp., *Millepora* spp. and *Diploria strigosa*. In 1999, the AGRRA assessment found that the island's average coral cover was still high but had decreased to 18% with the assemblage of ≥ 10 cm stony corals primarily composed of small-sized colonies, one third of which belonged to the *Orbicella annularis* complex (Klomp & Koostra, 2003). By 2008, coral cover was said to be less than 10% (Noble et al., 2013; Hildebrand, 2017). While the different assessments of coral cover over the years used different methodologies and are therefore difficult to compare, there is an overall visible downward trend in live hard coral cover.

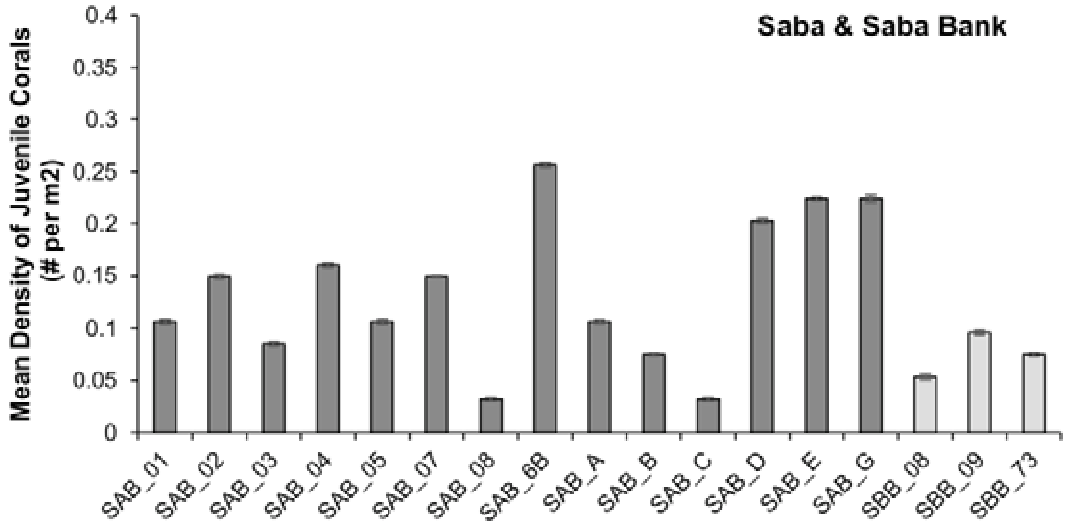
Coral recruitment of Saba's reefs seems to be low, which hinders the replenishment of the island's coral populations. While the 1999 AGRRA assessment found an average of 3.8 recruits per m2, in 2016 this number had dropped to 1.5 recruits per m2 (Klomp & Kooistra, 2003; Hildebrand, 2017). Tent Reef had the most recruits, while Greer Gut had none (Hildebrand, 2017). The expedition by the Scripps Institute of Oceanography and the WAITT Foundation in November 2016 found lower juvenile densities with a mean density of +/- 0.14 recruits per m2 (See figures on next page, Sandin et al., 2016).



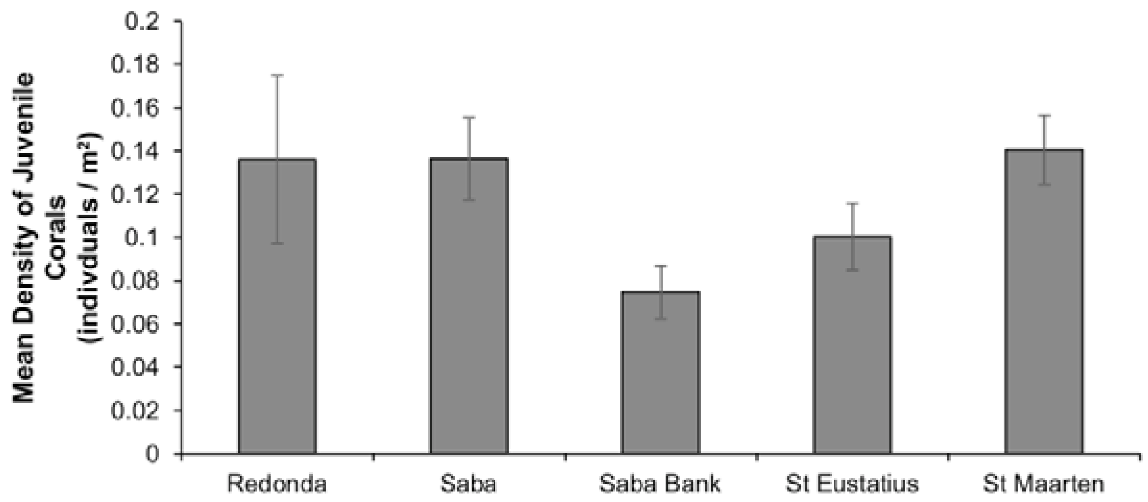
Benthic cover within the SNMP in 2016.
(Hildebrand, 2017)

Photo by: © Mark Vermeij

Status of Saba's Reefs



Mean density of juvenile corals
(Sandin et al., 2016)



Mean density and standard error of density of juvenile stony corals per island (number of individuals per m2)
(Sandin et al., 2016)

Reef complexity, which is vital to reef health as it provides a variety of habitats for invertebrates and reef fish species to hide in, is often used to assess the condition of a reef as it typically indicates whether or not coral cover is adequate (Noble et al., 2013). This is however not the case on Saba as most of the reef structure is made from volcanic rock formations rather than the more typical coral limestone skeleton deposit (Polunin, Roberts, 1993). No significant link was therefore found between habitat complexity and other health indicator variables (e.g. coral cover, macroalgae cover, coral recruits) (Hildebrand, 2017). The total Polunin score for reef complexity of the SNMP was 2.7% in 2015 and 2.6% in 2016, which is between the categories “low but wide-spread relief” and “moderate complexity with numerous caves and overhangs”, meaning that the reefs offer a good environment for reef life (Hildebrand, 2017).

Coral disease on Saba’s reefs seems low, with 2.5% of corals affected in 2015 and 2.4% in 2016 (Hildebrand, 2017). The most common coral disease in 2016 was red band disease, which is caused by cynobacteria, while in 2015 it was black band disease. The species most affected are *Orbicella faveolata* followed by *Siderastrea sidereal* (Hildebrand, 2017).

As seen throughout the Caribbean, bleaching events have impacted Saba’s reefs. In 2005, Esteban et al. (2005) reported intensive bleach-ing of the island’s corals down to a depth of 25 meters and estimated that 80% of all colonies of *Montastraea cavernosa* and brain corals were > 90% bleached. Coral bleaching was low in 2016, with 2% of corals totally bleached (Hildebrand, 2017).

Macroalgae

Macroalgae have been found to inhibit coral settlement and recruitment and slow coral growth (Jackson et al., 2014). Due to the volcanic nature of the island macroalgae grows well here (Hildebrand, 2017). In 2013, the island's sand habitats were mapped and sand habitats covered with algal and/or cyanobacteria mats were found around the entire island further ashore, of which the majority were at a depth of 30-50 meters (Kuramae & van Rouendal., 2013). In 2016, the median macroalgae cover of the SNMP's reefs was measured at 21%, which is comparatively low to the 30% Caribbean average (Hildebrand, 2017). On the other hand, a relatively higher turfalgae height was found on Saba than on the Saba Bank, St. Eustatius and St. Maarten (Sandin et al., 2016).

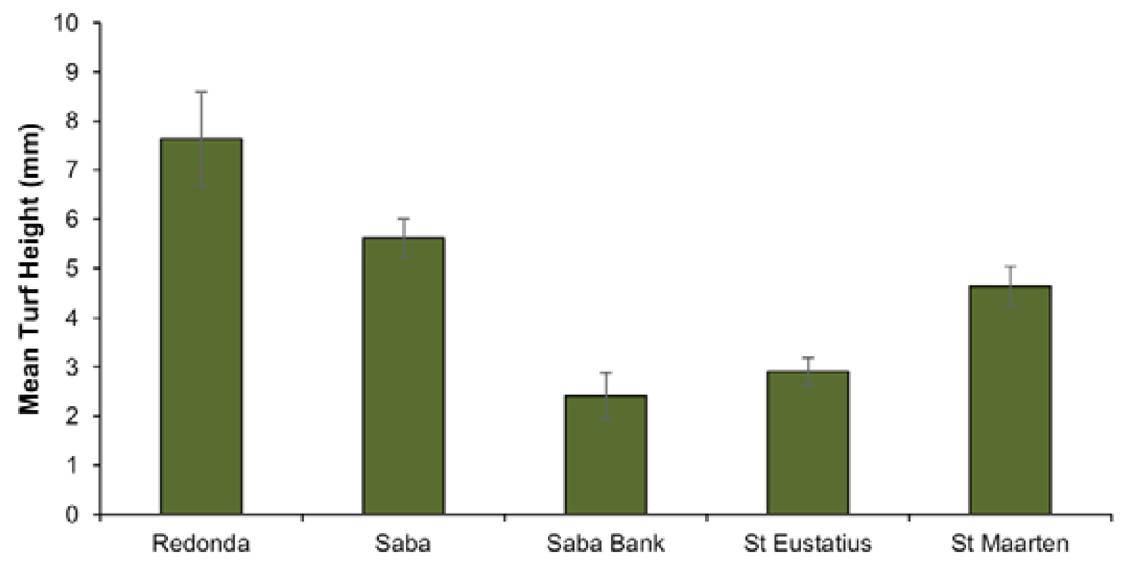


Photo by: © STINAPA Bonaire

Mean height and standard error (mm) of turf by island.
(Sandin et al., 2016)

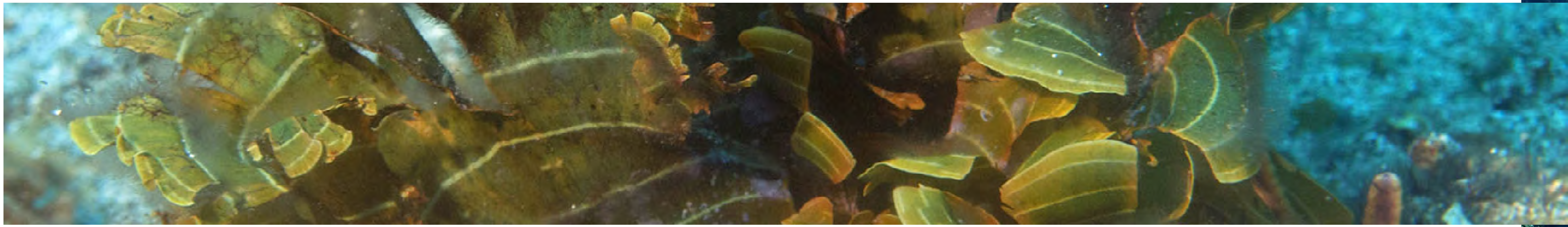


Photo by: © Marion Haarsma

Status of Saba's Reefs

Fish

Saba's fish biomass was measured as part of the 1999 AGRRA assessment and the study found that the island had a fish biomass of 11 kg/100 m2, with a herbivorous fish biomass of 5.8 kg/100 m2 and a density of 4.5 individuals/100 m2 for commercially significant species (Klomp & Kooistra, 2003). Fish species richness was found to be much lower in 2008 than throughout the 1990s with a drop of > 50% (Noble et al., 2013).

Herbivorous Fish

Herbivores are an important part of coral reef ecosystems as they help to maintain an ecological balance between corals and algae. Herbivores can control seaweed from overgrowing coral and keep substrate free from algae so that coral recruits can settle (Jackson et al., 2014; Mumby & Steneck, 2008). Noble et al. (2013) found an increase in density between 1995 and 2008 of 49%.

Commercial Fish

Noble et al. (2013) reported a 68% loss of carnivorous reef fishes across all zones of the SMNP from the 1990s to 2008, with historically low carnivorous fish density across all zones in 2008. Despite effective spatial protection of the Saba Marine Park (SMP) by local managers, Noble et al. (2013) concluded that the differences in fish biomass, density and species richness within the SNMP seems to be most likely explained by differences in the depth of reefs and associated live coral cover than the park's zoning plan. Noble et al. (2013) documented the effects of a marine protected area zoning on fish density, biomass and species richness over 21 years (1991, 1993, 1994, 1995, 2008) through the use of Underwater visual censuses (UVCs) of fish abundance and habitat variables. They found that while all fish species had a significantly greater biomass in unfished sites, this was only the case in shallow zones (5 m depth) and not in deeper habitats (15 meters). Density showed little or no mean difference across zones but herbivorous fish density did increase 49% in shallow habitats. Shallow habitats in the unfished sites also had higher species richness. Deeper habitats in unfished sites were found to have overall lower coral cover, which may explain differences in biomass and density between different depth zones. Many reef fish prefer to settle into live hard coral habitats, which is why "substantial coral loss can substantially alter fish *community structure and species richness on coral reefs, with numerous studies documenting significant declines in the abundance of adult reef fishes who depend on live coral for food and/or habitat when reefs incur major losses of live coral cover"* (Noble et al., 2013). The historically low density of carnivorous fish across all zones of the SNMP noted by Noble et al. (2013) in 2008 may also be a delayed response to the loss of preferred coral reef habitat in the park.

Photo by: © Hans Leijnse

Local stressors

Saba is, like most Caribbean islands, economically dependent on tourism. The island receives 22,500 visitors on an annual basis. The total expenditure of tourists is USD 31.7 million per year, of which around USD 6 million is directly attributable to nature (Cado et al., 2014). Most tourists come to the island to dive and hike, making the island's reef a valuable resource. This resource is however under threat as recent studies have revealed a decrease in coral cover. It is most likely that regional and global stressors are responsible for this degradation as local stressors are believed to be minimal (Wulf, K. personal comment 2018).

The two main uses of Saba's reefs are diving and fishing, and both uses seem to have limited impacts on the health of the reefs. One long-term study of diving activities within the SNMP found that these led to no significant damage of the park's coral reefs (Hawkins et al., 2005). A few recreational fishers use line fish from the shore or line-based trolling around the island (Toller et al., 2010). Since 2016 traps have been prohibited in the SNMP.

Overgrazing of the island's vegetation and the resulting sedimentation is an issue on the island (Hildebrand, 2017). Saba's goat population has increased over the past decades, and their veracious appetite has led to much vegetation loss, causing sediment to wash up into the ocean during heavy rains (Burke et al., 2011; Hildebrand, 2017). Sediment run-off can directly smother coral reefs or decrease light availability to reefs, limiting their growth and making them more susceptible to disease. An initiative is running to reduce the number of free-roaming goats under the *natuurgelden* projects that are funded by the Ministry of Agriculture, Nature and Food Quality (LNV).

Saba's population is small compared to some other islands in the Caribbean, with fewer coastal developments and overall less pressure on the island's marine resources. There is nevertheless some concern over the island's sewage system and its potential impact on the reefs (Hildebrand, 2017). Sewage is captured under each house and filtered through the island's volcanic stone, and eventually ends up in the ocean. No study has been carried out to assess how many nutrients end up in the water as a result of this process.

Besides, Saba 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). SCF has a lionfish removal program and a project started in 2017 in close collaboration with commercial fishermen to try to actively remove lionfish with specific traps on the Saba Bank, especially from deeper reefs inaccessible to divers (Kuramae, 2018).

Saba's reefs also face natural pressures including storms and bleaching events, which are likely intensified by global warming (Bender et al., 2010). Hurricanes can have a significant impact on Saba's reefs, both in terms of limiting reef development and causing damage to existing living hard corals. In September 2017, Irma, a Category 5 hurricane, one of the strongest Atlantic hurricanes ever observed, passed Saba that was shortly followed by another Category 5 hurricane named Maria. Saba's reefs appear to have incurred limited damage by Hurricanes Irma and Maria with the exception of sponges which shown some damage. There were massive, unusual northern swells in March 2018, which did much damage to the shallow reefs on Saba's west coast. For the first time in recent memory, waves were observed breaking on the Saba Bank.

Status of Saba Bank's Reefs

*References can be found in **BioNews Issue 8***

The Saba Bank remained an unexplored and mysterious offshore submerged carbonate platform until very recently. Research on the Saba Bank was first initiated under the Central Government of the Netherlands Antilles due to fishing pressure on the Bank and after fishery legislation was first enacted. After the constitutional change in 2010 when the Saba Bank became the direct responsibility of the Netherlands, there was more attention for the Saba Bank and there have been several research expeditions to assess the state of the fisheries, coral reef health and shark population (Bos et al., 2016). A known biodiversity hotspot, the Saba Bank is of special interest to scientists because it has remained relatively pristine thanks to its remote location (DCNA, 2016; Bos et al., 2016). But the Saba Bank is by no means immune to global and regional impacts including the effects of climate change.

It is essential that action is taken to increase the resilience of the Saba Bank as much as possible in order to buffer the effects of climate change including the very real possibility of more, and more intense bleaching events and hurricanes as well as the insidious impact of ocean acidification.

Geography and Reef Structure

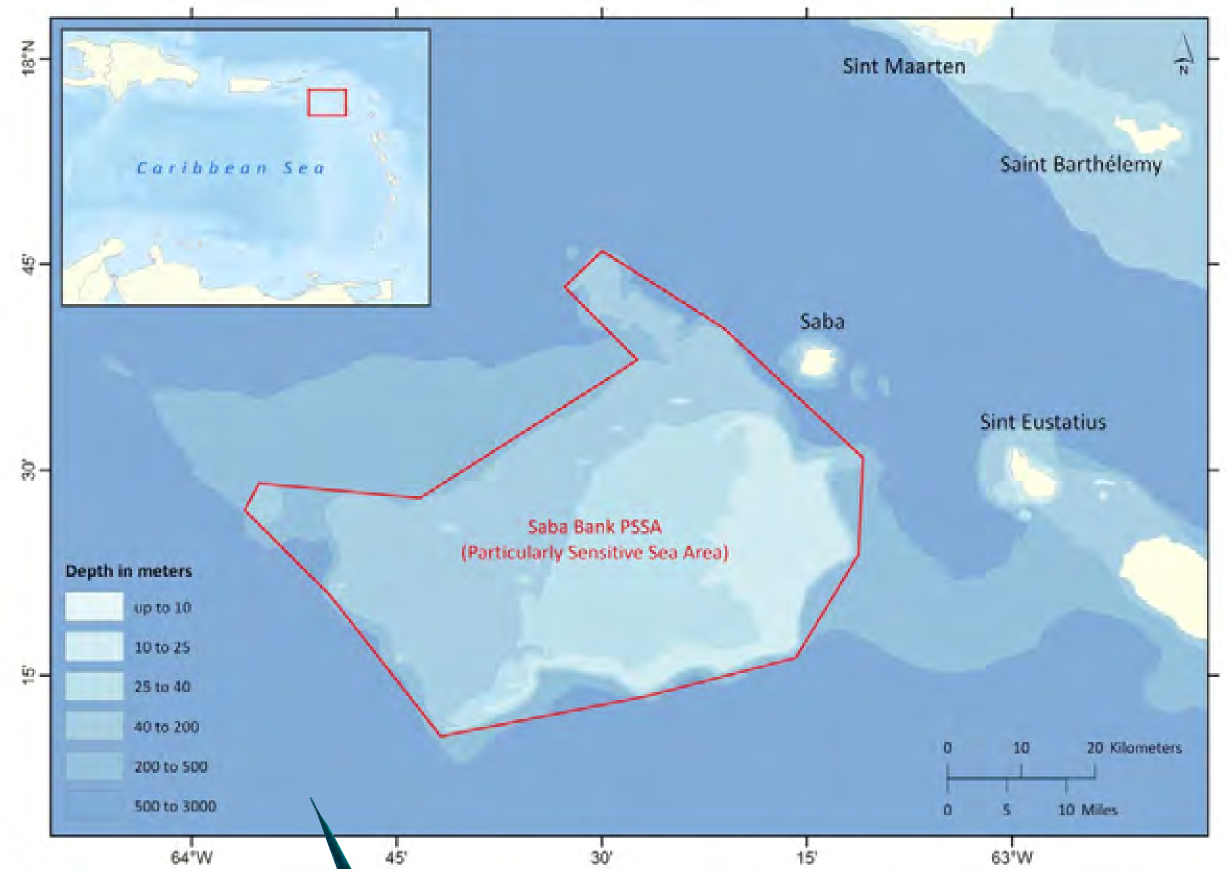
The Saba Bank lies just 5 kilometers southwest of the island of Saba but extends almost 70km from the Saba coastline. It covers 268.000 hectares, an area roughly the size of the Dutch part of the Wadden Sea or, more evocatively, about the same size as Luxembourg. About one quarter of the Bank lies within Saban territorial waters (DCNA, 2017).

The Saba Bank is the second largest submerged carbonate platform of its kind and the largest in the Atlantic Ocean basin (Meesters et al., 2009). It was an island during the last glacial period until about 5,000 years ago (Van der Land 1977). There are reef crests, lagoon and beach formations, which probably formed during this and previous glaciations when the Bank was above sea level (DCNA, 2017).

This submerged carbonate platform rises from the sea floor and is crowned at the summit by a 150 km² expanse of growing coral reef (Meesters et al., 1996; DCNA, 2016). Most of the Bank lies at depths of 20 to 50 meters, but a considerable area to the east lies between 10 and 20 meters and has extensive reef development (Meesters et al., 1996). It reaches a plateau at a depth of about 15 m (Klomp and Kooistra, 2003). The western edge is deeper (50 m) and believed to be dominated by sand (Klomp and Kooistra, 2003).

Considered to be one of the world's marine biodiversity hotspots (Church and Allison, 2004), the Saba Bank is recognized under the Convention of Biological Diversity (CBD) as an Ecologically and Biologically Significant Area (EBSA). It forms a regionally unique and relatively pristine ecosystem characterized by high biological diversity and productivity (Meesters, 2013). The Bank is home to some of the richest diversity of marine life of the Dutch Caribbean (Bos et al., 2016) including sea turtles, migratory humpback whales (*Megaptera novaeangliae)* and more than 200 species of fish. It contains many different habitat types including coral reefs (patch reefs and spur and groove reefs with sandy channels), fields of calcareous algae, algal fields, sand plains, as well as limestone pavements overgrown with unique and diverse plant assemblages (Lundvall, 2008; Meesters, 2016; DCNA, 2017).

Map of the Saba Bank
Image by: © DCNA



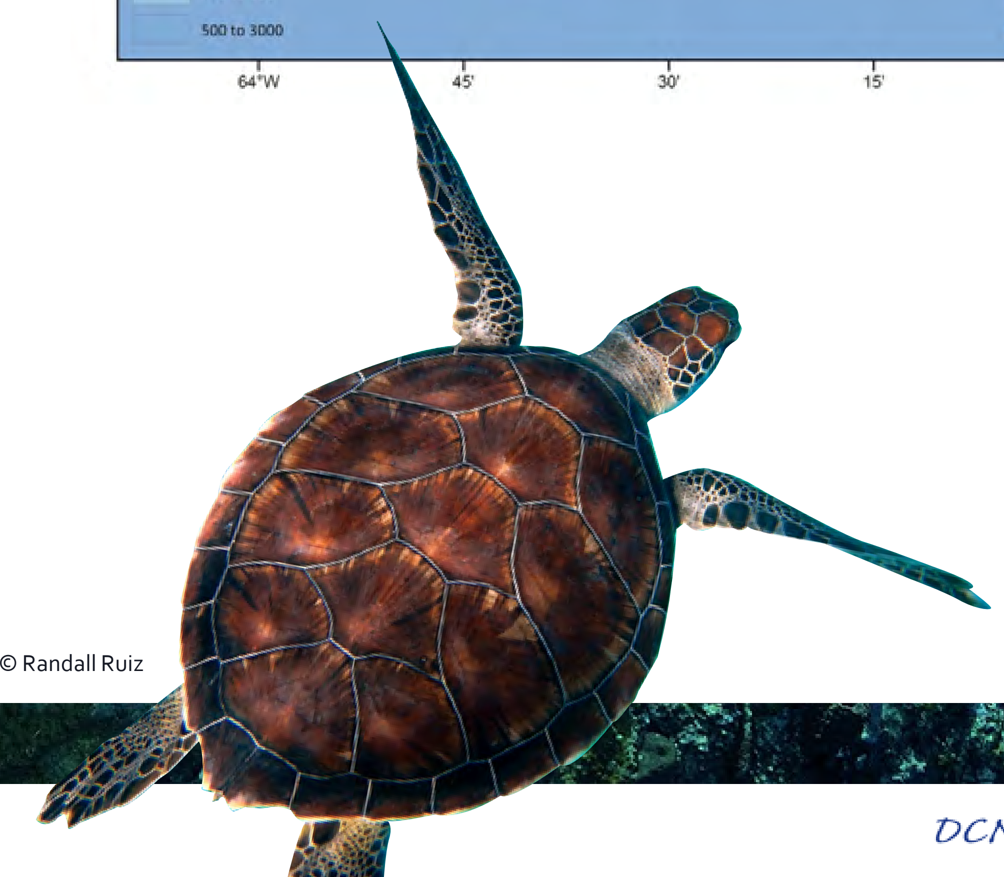


Photo by: © Randall Ruiz

Photo by: © Hans Leijnse

A Symposium dedicated to the Saba Bank was organized by the University of Wageningen in Den Helder in December 2016. The Symposium brought together researchers and conservationists from throughout the Kingdom to share their knowledge and to provide an overview of the current state of scientific knowledge about the Saba Bank. A special BioNews edition *http://www.dcnanature.org/wp-content/uploads/2018/08/BioNews-Saba-Bank.pdf* was created to capture the wealth of information presented at the Symposium. Additionally a book was produced by Wageningen University, which can be downloaded here: *http://edepot.wur.nl/400225* (Bos et al., 2016).

Status of Saba Bank's Reefs

Status of the reefs of the Saba Bank

The first scientific expeditions to the Saba Bank took place in the 1970s with mixed results: one study concluded that the Saba Bank had minimal reef development but abundant crustose coralline algae and sponges (MacIntyre et al., 1975), while a study published soon after found that the Bank's two large windward reefs had abundant coral growth (Zonneveld, 1977). During an expedition with research vessel H.M.S. Luymes of the Royal Netherlands Navy in 1972, natural history specimens were collected that could serve as baseline material for future biodiversity studies (Van der Land, 1977; Hofker, 1980; Logan, 1990; Thacker et al., 2010; Hoeksema et al., 2011).

In the 1980s the reefs on the Saba Bank have experienced Caribbean-wide disease induced mass mortalities such as the die-off of the main urchin species in the Caribbean *(Diadema antillarum)* in 1983 (Aronson & Precht, 2001). In 2006, Scientists from Conservation International (CI), the Netherlands Antilles government and Smithsonian Institution's Museum of Natural History carried out a two-week expedition to the Saba Bank. They uncovered a rich and healthy coral fauna, confirming Zonneveld's prior findings (1977). The Bank was recognized as a regionally unique area with relatively pristine ecosystems characterized by high biological diversity and productivity, as well as being a possible source of fish and coral larvae to downstream areas.

Research on the Saba Bank gained momentum when the Bank became the responsibility of the Netherlands in October 2010, and since then several research expeditions have taken place to assess the Bank's fish communities, coral reef health and shark population (Bos et al., 2016). As a known biodiversity hotspot, the Saba Bank is of special interest to scientists because it has remained relatively pristine thanks to its remote location, offering researchers the opportunity to study the effects of global change and reef resilience compared to other reefs in the region (Meesters et al., 2016; Bos et al., 2016).

Three research expeditions conducted by Wageningen Marine Research (formerly IMARES) took place between 2011 and 2015 to gather data on the Bank's biodiversity, ecological functioning and ecosystem changes triggered by mounting environmental pressures. The 2015 expedition was a joint expedition with the Royal Netherlands Institute for Sea Research (NIOZ Sea Research) (van Duyl, 2016). The data collected during these surveys will be invaluable to ensure the sustainable management of the Bank.

In November 2016 conservation management 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 in the windward Caribbean islands (Sandin et al., 2016). The Global Coral Reef Monitoring Network protocol for the Caribbean (GCRMN-Caribbean) was used to establish a regional perspective of coral reef health, surveying the fore-reef habitat at depths between 7 and 15 meters. In addition to GCRMN coral reef assessments, a selection of coral reef environments on the Saba Bank were mapped using 3D imagery. The footage can be found at: *https://drive.google.com/drive/folders/0By3cTucxJ9GFcEYyUi16OG4ycok?usp=sharing* (Scripps Institution of Oceanography).

In March 2018 researchers aboard the Pelagia research vessel collected invaluable data on the Saba Bank during the "Netherlands Initiative Changing Oceans (NICO)" marine expedition organized by NIOZ Sea Research and NWO-Science (ENW). The first project focused on the deep-sea habitats (100m and beyond) and their main goal was to determine the biodiversity of the deep slopes and describe how environmental conditions such as turbulence, currents, mixing and food-supply influence live in the deep-sea. During the second project the researchers mapped the benthic habitats (from 10 until 100m depth) and investigated benthic-pelagic coupling of different benthic habitats with focus on net calcification, organic matter (bio)deposition/ mineralization and oxygen dynamics in the benthic boundary layer (van Duyl & Meesters,2018).

Summary of major coral status surveys conducted on Saba Bank's coral reefs.
(DCNA, 2017)

Studies	Time period	Survey Description	# Sites Surveyed
CICAR Expedition (Van der Land, 1977)	1972	The first recorded expedition to the Saba Bank. Collections of the benthos were made by hand by Dutch Naval divers.	25 by Scuba diving
Corwith Cramer Cruise C-103 (Joyce, 1989)	1989	During this expedition a depth Recorder profile and sediment sample transect lines were completed.	112
Netherlands Antilles Department of Environment (MINA) survey (Meesters, 1996)	1996	The expedition focused on the central and eastern part of the Saba Bank and surveyed approximately 1.8% of the total area.	-
AGRRA (Klomp & Kooistra, 2003)	1999	Post-hurricane (Lenny) rapid assessment of reefs including measures on coral cover and bleaching.	3
Conservation International expedition	2006	Rapid Assessment of the Saba Bank	17
Royal Dutch Navy, MINA, Harte Research Institute, Conservation International (CI), and SCF	2007	This survey focused on octocorals as well as surveys of fish and conch. For the first time monitoring included surveys for crustaceans as well as some ROV deep water exploration. Using multibeam sonar data from the Dutch Navy a high resolution (2 m) bathymetric GIS map was prepared	40 (5 zones)
CARIBSAT expedition, M.V. Caribbean Explorer	2010	A ground truthing expedition to the Saba Bank to find ways to use satellite images to map the benthic communities. Data were collected using video camera drops and underwater video transects at 7 places.	200
IMARES and NIOZ	2011, 2013, 2015	Three expeditions aimed to collect data on benthic and reef fish communities; connectivity; sponges and nutritional sources of the sponge community; seabirds and marine mammals; net coral reef calcification, water quality, water velocity and other physical parameters.	11
NIOZ and IMARES (NWO funded project entitled "Caribbean Coral Reef Ecosystems - interactions of anthropogenic ocean acidification and eutrophication with bio-erosion by coral excavating sponges")	2016	Researchers wanted to gain a better understanding of the hydrography of the Saba Bank and to determine if net ecosystem calcification is occurring. This expedition integrates ecological mapping (Spatial coverage of corals and other calcifying organisms), (carbonate) chemistry, net calcification, and physical oceanography.	61
Scripps Institute of Oceanography and the WAITT Foundation	2016	Coral reef assessments following the GCRMN protocol and a selection of 2 coral reef environments were mapped using 3D imagery.	3
NICO expedition organized by NIOZ and NWO-Science (PL: van Duyl & Meesters, 2018; Duineveld & Mienis)	2018	Biodiversity of deep-sea habitats (>100m), mapping of benthic habitats (10 - 100m), benthic-pelagic coupling of different benthic habitats with focus on net calcification, organic matter (bio)deposition/ mineralization and oxygen dynamics in the benthic boundary layer.	-
GCRMN by SCF	Planned	Coral reef assessments following the GCRMN protocol after hurricanes Irma and Maria	Planned: 25

**PL = Project Leader*

Status of Saba Bank's Reefs

Benthic cover

Coral

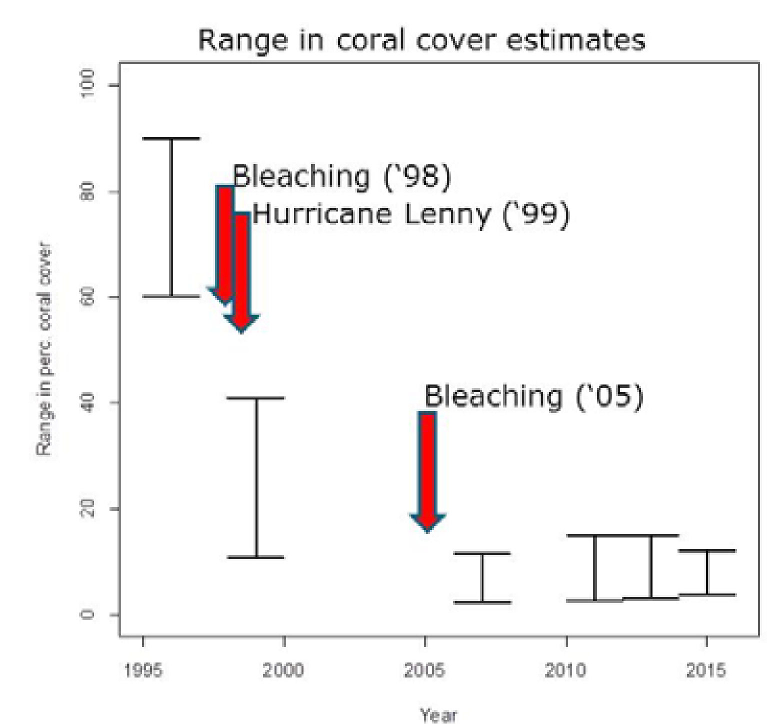
Coral cover is the amount of bottom surface covered by live stony corals, contributing to the three-dimensional framework of the coral reef. The Saba Bank had a rich coral fauna and high coral cover in the 1990s and 2000s according to a number of studies. During a 1996 expedition on the Saba Bank, 28 hard coral species and 14 soft coral species were recorded and hard coral cover was estimated at 60 to 90% (Meesters et al., 1996). A decade later, scientists from Conservation International (CI), the Netherlands Antilles government and Smithsonian Institution's Museum of Natural History carried out a survey of the Bank and found the hard and soft coral fauna of the Bank to be very rich, abundant, diverse and representative of the Caribbean (Lundvall, 2008). Researchers counted 40 hard coral species and found a rich and abundant gorgonian fauna with 20 different species of soft coral documented. In 2015, a biodiversity assessment of the Bank recorded nearly 50 species of reef-building corals (Hoeksema et al., 2017).

However, there has been a significant decrease in coral cover in the last 15 to 20 years. Quantitative surveys carried out at 10 different locations as part of the 2011, 2013 and 2015 IMARES research expeditions revealed an important decline (Becking & Meesters, 2017), although coral cover remained stable between 2011 and 2015 (Becking & Meesters, 2017). In 2011, living hard coral cover was only 8%, which is much lower than the coverages of 40-60% reported in 1996 (Bos et al., 2016). Some variety was found between sites, with the lowest coral cover found at "Tertre de Fleur" (2.6%) and the highest recorded on the southern edge of the Bank at "Gorgonian Delight" (15.5%) (Meesters, 2016). It is hard to pinpoint what caused this drastic decline, but a mix of events including climate change related impacts such as several bleaching events (1998 and 2005) are likely to blame (Meesters 2016; Becking & Meesters, 2017).

Beyond the stabilization of coral cover between 2011 and 2015, there are some encouraging signs regarding the Saba Bank's reef health. During NIOZ's 2016 research expedition, many new coral areas were discovered, as well as other habitats (Becking & Meesters, 2017). The 2011-2015 expeditions also found numerous small young coral colonies and little evidence of disease, which are good indicators for reef resilience (Becking & Meesters, 2017). Meesters et al. (1996) also described the virtual absence of diseases back in the 1990s (Meesters et al., 1996). Furthermore, it was discovered that the species-poor locality "Tertre de Fleur" harbours a unique assemblage of free-living corals, so-called coralliths, which is probably related to the special oceanographic conditions offered by the Saba Bank (Hoeksema et al., 2017).

Whilst just 9% of the Saba Bank's coral reefs were bleached in 1999 (Klomp & Kooistra, 2003), the 2005 Caribbean-wide bleaching event had devastating consequences for the Bank's reefs. It is estimated that over 50% of coral cover in the Caribbean was lost (Eakin et al., 2005), and while no accurate data for the Saba Bank is available, similar loss of coral cover was recorded on neighboring islands of Saba and St. Eustatius and many other islands in the northeastern Caribbean (Esteban & Kooistra, 2005). Anecdotal data such as comparison of before and after photographs of an identical spot on the Bank from 2003 and 2007 show an almost complete loss of coral cover (Lundvall, 2008; DCNA, 2017). A rapid assessment of stony corals in January 2006 found evidence of bleaching at 82% of the sites assessed with 43 colonies bleached (McKenna, 2010).

De Bakker et al. (2016) assessed the role of the Saba Bank as a potential reservoir of diversity for the surrounding reefs by examining the population genetic structure, abundance and health status of two prominent benthic species, the coral *Montastraea cavernosa* and the sponge *Xestospongia muta*. Data indicates that there is genetic connectivity between populations on the Saba Bank and nearby Saba as well as multiple locations in the wider Caribbean, ranging in distance from 100s–1000s km (de Bakker et al., 2016). The combined results of apparent gene flow among populations on the Bank and surrounding reefs, the high abundance and unique genetic diversity and the upstream position with respect to the wider Caribbean indicate that the Saba Bank could function as an important buffer for the region. Either as a natural source of larvae to replenish genetic diversity or as a storehouse of diversity that can be utilized if needed for restoration practices (de Bakker et al., 2016; Becking & Meesters, 2017).



Coral cover estimates for the Saba Bank from 1995 to 2015
(Meesters, 2016)

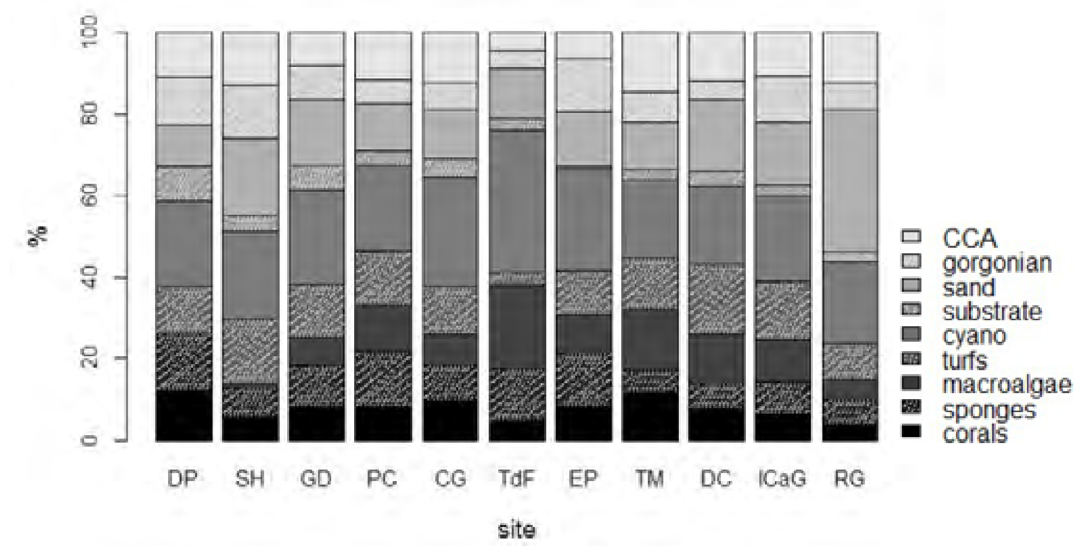
Status of Saba Bank's Reefs

Sponges, algae and cyanobacteria

Corals, sponges, macrolagae, turf algae and cyanobacteria are all naturally occurring components of the benthos which compete with each other for space. Macroalgae, turf algae and cyanobacteria appear to benefit from eutrophication (de Bakker et al., 2017). From 2012 to 2015 a shift was seen on the Saba Bank from turf algae to a cyanobacteria dominated systems, possibly linked to increasing water temperatures and/or low grazing pressure on cyanobacteria (Wiltink, 2016). It is hypothesized that increased macroalgae, turf algae and cyanobacteria densities might be beneficial to sponges as they feed on the dissolved organic carbon they release (Wiltink, 2016; de Bakker et al., 2017). This, in combination with a reduction of spongivores due to overfishing, decreasing pH and climate changed induced increasing seawater temperatures, may give sponges a competitive advantage over reef building corals in the future (Wiltink, 2016; de Bakker et al., 2017). More disturbed eutrophic coral reefs in the Caribbean have changed into sponge-dominated reefs where corals abundance largely declined (Becking & Meesters, 2017). This is currently not the case on the Saba Bank where sponge cover is not considered to be high and does not appear to be increasing (Wiltink, 2016; Becking & Meesters, 2017).

Sponges are essential components of reef ecosystems (de Goeij et al., 2013). They filter small particulate material including pathogens from the water, provide habitat for many species and convert dissolved organic matter into food particles for other species (de Goeij et al., 2013; Bos et al., 2016). At least 131 species occur on the Saba Bank (Witlink et al., 2017) and at present, *"the cover and diversity of sponges indicates a resilient community"* (de Bos et al., 2016). Sponge cover is generally slightly higher on the Bank than coral cover (Wiltink, 2016). One of the species that contributes most to total sponge cover is the Giant Barrel sponge (*Xestospongia muta*) and there seems connectivity between populations on the Saba Bank and Belize and the Bahamas (Wiltink, 2016; de Bakker et al., 2016). There is some concern about the health Gian Barrel sponges on the Saba Bank. A study by de Bakker et al. (2016) found the vast majority of the Giant barrel sponge (> 80%) showed signs of presumed bleaching in 2013 (although the densities and genetic diversity of X. muta on Saba Bank indicate a healthy population) (de Bakker et al, 2016). This is of concern as *"a reduction in X. muta populations would likely cause a significant change in ecosystem functioning"* (de Bakker et al, 2016).

During the 2006 Conservation International expedition, the Saba Bank was discovered to have an exceptionally high diversity of macroalgae (Conservation International, 2006). Littler et al. (2010), who carried out a marine macroalgal diversity assessment of the Bank during the expedition, not only found a high cover of algae (mainly *Dictyota* spp. and *Lobophora* spp.) on the reefs but also observed few filamentous and thin sheet forms indicative of stressed or physically disturbed environments (Littler et al., 2010). Acknowledged algae experts M. and D. Littler stated that the Saba Bank is without doubt the richest area in the Caribbean for macroalgae (Littler et al., 2010). The following year, macroalgae were found to be the most conspicuous component of the Bank's benthic communities, most likely due to environmental conditions which favor the growth of many different types of macroalgae (Lundvall, 2008). In 2015 mean macroalgae cover was 9% which was lower than the dominant cyanobacteria cover of 23% (Wiltink, 2016). Macroalgae are a natural part of a reef community, but many studies have shown how harmful they can be to corals, inhibiting coral settlement and recruitment, slowing coral growth and making them more prone to disease (Jackson et al., 2014).



Benthic cover on the Saba Bank in 2015.
Mean cover values include: corals 7.82% +/- 1.26; sponges 9.62% +/- 1.48; macroalgae 9.01% +/- 2.64; turf algae 12.02% +/- 1.78; cyanobacteria 23.02% +/- 2.22
(Wiltink, 2016).

Photo by: © Hans Leijnse

Status of Saba Bank's Reefs

Fish

The Saba Bank has a very diverse and rich fish fauna. A biodiversity-assessment survey carried out on the Saba Bank between 2006 and 2007 recorded a total of 270 fish species, raising expectations that the final count may exceed 400 species (Williams et al. 2010).

Fish density, however, has remained low over time. In 1996, researchers observed low fish densities on the Bank (Meesters et al., 1996). During the 2011 IMARES expedition, the visual surveys (UVC) demonstrated that fish abundance was quite low, varying between 23 and 100 fish per 100m2 (van Beek & Meesters, 2014). The 2013 expedition did record a considerably higher fish abundance, varying between 51 and 175 fish per 100m2 (van Beek & Meesters, 2014). However, the visual surveys in 2011, 2013 and 2015 indicate that the biomass of key herbivorous and commercial fish (snappers, groupers and grunts) families is low, *"indicating possibly a poor status of these fish families"* (van Beek & Meesters, 2013; Becking & Meesters, 2017).

The low density of commercial fish could have a serious economic impact for Saba as the Bank is a vital fisheries resource for the island, bringing the island an estimate annual revenue of US$ 1.38 million (Lely, 2014). Fishing efforts focus mainly on a trap fishery, targeting lobster (*Panulirus argus*) and deep-water snappers (redfish) (Dilrosun 2000, Toller 2008, van Gerwen 2013, Boonstra 2014; de Graaf et al., 2017). The mixed reef fish landings are significantly lower than mixed reef fish harvest in the region (de Graaf et al., 2017).

The Saba Bank has revealed itself as an important spawning ground for fish species, making the Bank an important natural resource for the surrounding region. *"The Saba Bank is a unique area, invaluable for neighboring Saba, but also for the region as a whole as a source of coral, fish, lobster, and queen conch larvae" explains Paul Hoetjes (RCN). "I'd say it is the richest biodiversity area of the entire Kingdom"* (DCNA, 2017). Spawning aggregations of red hind, queen triggerfish - locally called moonfish - and squirrelfish have been confirmed (Lundvall, 2008). Since December 2013, the spawning aggregation site on the Moon Fish Bank (northeastern corner of the Saba Bank) is closed to fisheries for three months each year to protect the populations of red hind (*Epinephelus guttatus)* and queen triggerfish *(Balistes vetula)* (Lundvall, 2008).

Recent work on the Bank has revealed that the Saba Bank has a healthy population of sharks. Since 2012, researchers from Wageningen Marine Research (IMARES), in partnership with local partners, have used simple, non-invasive stereo Baited Remote Underwater Videos (sBRUV) to gather baseline information on the size, diversity, species composition and abundance of shark populations across different management zones in the Dutch Caribbean. To this date, 165 BRUVs have been deployed and initial results point to the Bank having a higher abundance of sharks compared to similar BRUV surveys in the wider Caribbean region (Stoffers, 2014; Becking & Meesters, 2017). The two most common species on the Bank are the nurse shark *(Ginglymostoma cirratum)* and the Caribbean reef shark *(Carcharhinus perezi)*. In 2013, BRUV deployments recorded an average of 0.23 reef shark sightings per hour - including a 3-meter long hammerhead -which is higher than sightings at study sites on Belize and the Bahamas (Brooks et al., 2011, Bond et al., 2012; Stoffers, 2014; Winter, 2016). For nurse sharks and Caribbean reef sharks also behavioural studies are carried out using acoustic telemetry (Winter et al., 2015). The 8 receivers that were placed on the Saba Bank are part of a larger network that covers the reefs of Saba, St. Eustatius and St. Maarten. With this study individual movements and scale of home ranges can be assessed.

The Saba Bank compared to other reefs within the Caribbean Region

The Saba Bank is home to some of the richest diversity of marine life of the Dutch Caribbean (Bos et al., 2016). Not only are there stoney coral reefs, but the Bank is particularly rich in gorgonians, benthic cyanobacteria and macroalgae, including algal assemblages never described before (Littler et al., 2010; Wiltink, 2016). The high species abundance on the Saba Bank prompted Conservation International to designate it an important "biodiversity hotspot" within the Caribbean (Hoetjes, 2010). The abundance of shallow water gorgonians is 10-30% higher than at other sites in the Caribbean, with 43 recorded species and the discovery of a new species of *Pterogorgia* (Etnoyer et al., 2010). More gorgonian species remain to be discovered on the Bank, though richness is already higher than other study sites in the West Atlantic (Etnoyer et al., 2008). Sponge diversity on the other hand seems lower than in other Caribbean locations even though these studies are difficult to compare as they were done in different habitats (Thacker et al., 2010; Wiltink, 2016).

Photo by: © Marion Haarsma

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"Nurse sharks are caught in about 60% of trips using lobster traps."

Local stressors

Unregulated fishing was a serious concern for the Saba Bank in the 1980s and 1990s, but since the mid-1990s fishing activities have become much more regulated. Management of the Saba Bank dates back to 1994 with the declaration of the Exclusive Fishery Zone in the Dutch Caribbean and the passing of a national fishery ordinance which made it illegal for foreign vessels to fish on the Bank without a license. This effectively ended most illegal, unreported and unregulated (IUU) fishing on the Saba Bank, with lobster and fin fisheries practiced only by local, licensed fishermen (DCNA, 2017). Since 2002, researchers from the Wageningen Marine Research institute have been involved with fishermen and SBMU staff in the structural monitoring of fishing activities (de Graaf et al., 2017) and there have been regular coast guard patrols (by plane) above the Saba Bank.

Saban fishermen have been actively involved in the regulation of fisheries on the Bank (Becking & Meesters, 2017). Recent concerns over the status of redfish populations led Saban fishermen to broker an agreement in 2016 that introduces a number of self-imposed restrictions aimed at protecting redfish populations from over-exploitation, such as a 6-month closure for redfish beginning in April 2017 (de Graaf et al., 2017). Once the closure ends, licensed fishermen will only deploy 25 traps per fisherman and use large mesh sizes. Another decision that was made with the support of local fishermen is the seasonal closure of the Moonfish Bank Spawning Aggregation Area. Since December 2013, fishing for red hind, whether by traps or lines, is now prohibited on the Moonfish Bank from December to February (DCNA, 2017). This will help protect their spawning aggregation from being fished out.

Whilst fishermen do not actively target reef fish, some are caught as by-catch in lobster traps. Between 2012 and 2015 the landings of mixed reef fish caught in lobster traps increased from 6.6t to 13.6t, which appears low in comparison to other areas in the Caribbean (de Graaf et al., 2017). However, no conclusions can be made about differences in fishing pressure compared to other areas in the region. Therefore, besides landings, differences in observed fish biomass need to be taken into account. This has not yet been evaluated.

By-catch is a potentially important issue for the lobster fishery with nurse sharks being caught in about 60% of the trips using lobster traps (de Graaf et al., 2017). Under the redfish agreement above, signed in 2016, Saban fishermen have also pledged to release trap caught sharks to the reef alive (DCNA, 2017).

On average 0.6 traps are lost per fishing trip. This amounts to between 400-600 lobster traps lost annually, which can trap sea life as 'ghost traps'. Work is underway to refine the trap design to make them more sustainable. Current recommendations include increasing the mesh size to over 38mm and making sure traps are made with biodegradable material and include a biodegradable panel to prevent ghost fishing (De Graaf et al., 2017).

The rules and regulations of both the lobster and deep-water snapper trap fisheries will need to be updated in the near-future to provide the responsible management authorities with the appropriate tools to ensure their sustainability (Becking & Meesters, 2017). At this time it is unclear how the Bank's reef communities will fare and what impact fishing activity is having on the reefs.

Prior to the designation of the Saba Bank as the world's 13th Particularly Sensitive Sea Area (PSSA) by the International Maritime Organisation in 2012, ships and tankers were a significant threat to the Bank's reefs. Many freighters, tankers and cruise ships passed over the Bank, with reports of oil spills and the emptying of sewage tanks. Tankers frequently anchored on the shallow Saba Bank while waiting to unload at the St. Eustatius Oil Terminal to avoid anchoring fees in the territorial waters of nearby St. Eustatius, causing significant damage to the Bank's reefs as well as other benthic communities (Meesters et al., 1996). Before anchoring was prohibited in 2010, it was estimated that in 2009 a minimum of 24 vessels anchored on the Saba Bank for a total of 187 days (Resolution MEPC 226(64), 2012). This was an underestimation as the surveys only covered 40-60% of the Bank.

In 2008, Lundvall listed the four main threats to the Saba Bank as followed: overexploitation of fishery resources, impacts from tanker anchorage on benthic communities, impacts of tanker traffic on fishermen and traps and global climate change (Lundvall, 2008). The first three of these threats have been either removed or decreased as a result of active management. It is important to keep monitoring those threats and enforcement of regulations should be further improved. Even though the Saba Bank is not influenced by coastal processes because of its distance from land—its remoteness means that it has been spared many of the insidious anthropogenic effects such as eutrophication and increased sedimentation—global threats such as climate change appear to be on the increase. Extreme weather events in the Caribbean Region have become much more common and intense bleaching events have already taken their toll on the Bank's coral reef communities (Meesters et al., 2016). It is vital that future management plans for the protection of the Bank's reefs anticipate the potential negative impact of these threats as well as their ever-evolving nature and take the appropriate actions to increase the resilience of the Bank's reefs (Meesters et al. 2016).

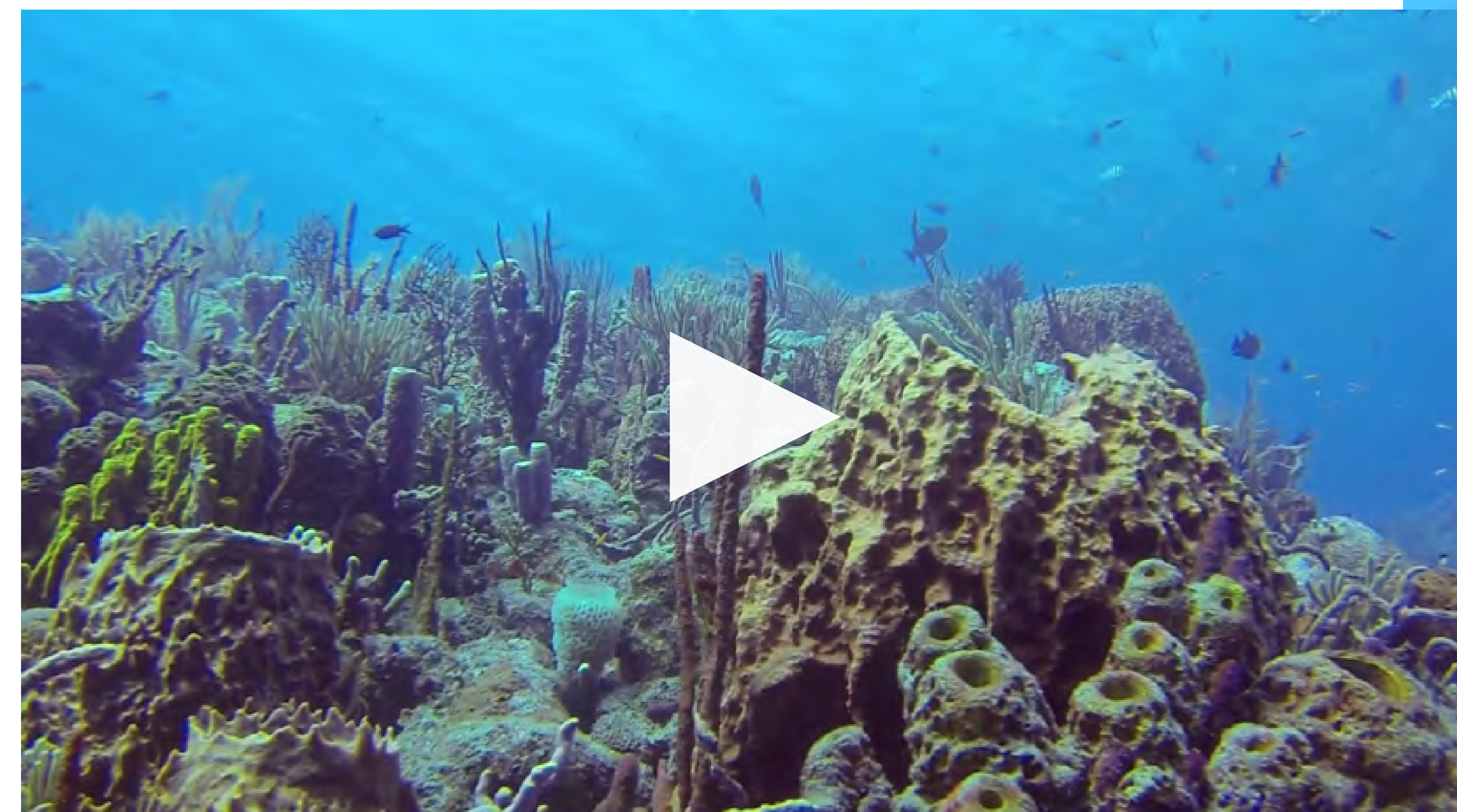
Conservation activities

A PSSA is an *"area that needs special protection through action by IMO because of its significance for recognized ecological or socio-economic or scientific reasons and which may be vulnerable to damage by international maritime activities"* (IMO, 2017). The Saba Bank was designated as a PSSA in 2012, and with the designation came the establishment of a new mandatory 'no anchoring' area for all ships and a new 'area to be avoided' (for ships of 300 gross tonnage or over). The Bank was declared a Nature Park in 2010 and came under the management of the Saba Conservation Foundation (SCF) in 2012. That same year (2012) the Saba Bank was also recognized as an area of regional importance by the Specially Protected Areas and Wildlife (SPAW) Protocol and in 2013 it was recognized as an Ecologically/Biologically Significant Marine Area (EBSA) by the Convention on Biological Diversity (CBD). The "Save our Sharks" DCNA awareness project is being implemented from 2015-2017 (grant from National Postcode Lottery). In September 2015, thanks in major part to the efforts of Saba's Commissioner Chris Johnson, facilitated by a regional meeting promoting shark protection organized by the PEW Trust, the Saba Bank became part of the Yarari Marine Mammal and Shark Sanctuary covering all waters of Saba and Bonaire. As part of a multi-year program funded by the Ministry of Economic Affairs (MinEZ) (now the Ministry of Agriculture, Nature and Food Quality (LNV)) , the collaborating parties are working out the steps needed towards implementing marine mammal management and policy measures for the Yarari Sanctuary (Becking and Meesters, 2017).

The Saba Bank Management Unit (SBMU) was established by the MinEZ in 2012, in close co-operation with SCF and the Saba Island Government. The SBMU is responsible for day-to-day management of the Saba Bank. It is staffed by two fulltime staff and its tasks consist of surveillance and reporting of shipping or fishing violations, facilitating and conducting scientific research on the Bank, monitoring of fish landings and liaising with local resource users (DCNA, 2017).

Photo by: © Hans Leijnse

Recently the management of the Saba Bank National Park by SCF (SBMU) during the period 2012-2017 was evaluated. Thanks to the support of the MinEZ, SCF and the Island Government of Saba "*and to the work of the various agencies and resource users involved, the Saba Bank is to a large extent an effectively managed protected area, in a region where many marine protected areas are legally established but do not benefit from active management in the field. When measured against the goals and objectives of the Saba Bank Special Marine Area Management Plan, the impacts and outcomes of the management effort have been significant. However, at current level, the financial, human and technical resources available to the SBMU through the SCF are insufficient to allow it to perform all its tasks and functions effectively, and are not commensurate with the size, the ecological and economic value of the Saba Bank nor with the conservation and resource management mandates arising from the status of the area as a Nature Park, PSSA, EBSA and critical component of the Yarari Sanctuary. So far, the achievements of the SBMU were only possible thanks to the collaboration with the SCF, to the support provided by the SCF beyond the terms of the Agreement between the MinEZ and SCF, and to the SCF's and the SBMU's ability to work under challenging conditions. The two main planning instruments that have guided management, namely the Saba Bank Management Plan and the terms of reference for the management of the Saba Bank, have proven adequate, but now need updating.* (Renard & Hoogerduijn, 2017)"



Video Saba Bank: https://vimeo.com/195774102

Status of St. Eustatius's Reefs

References can be found in ***BioNews Issue 5***

Five major studies of St. Eustatius' coral reefs have taken place over the past five years and have shed light on the 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).

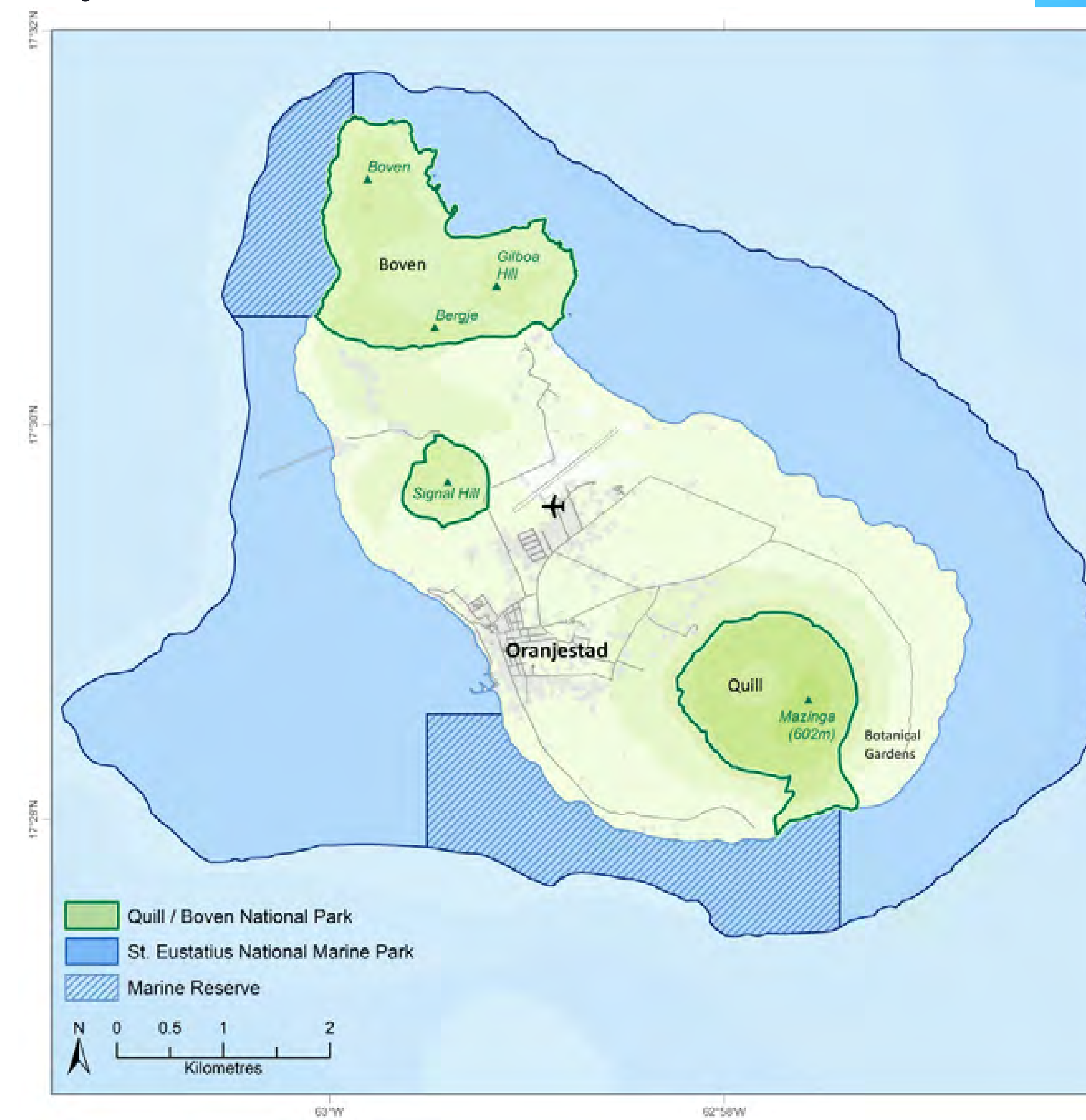
Geography and Reef Structure

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 km^2, with a maritime area of 1,591 km^2 (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



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. 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 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).

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
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
Debrot et al., 2014	2012-2013	Video assessments for the benthic map and seascape assessment.	869
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
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
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
STENAPA	2017	Post hurricane (Irma & Maria) damage assessment of among others coral reefs.	So far: 7
NICO expedition organized by NIOZ and NWO-Science van Duyl & Meesters, 2018)	2018	Mapping the windward side of St. Eustatius with video transects and the multibeam echo sounder.	-

[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 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). Recently, researchers mapped the windward side of St. Eustatius during the "Netherlands Initiative Changing Oceans (NICO)" marine expedition organized by the Royal Netherlands Institute for Sea Research (NIOZ Sea Research) and NWO-Science (van Duyl & Meesters,(2018).

Benthic cover

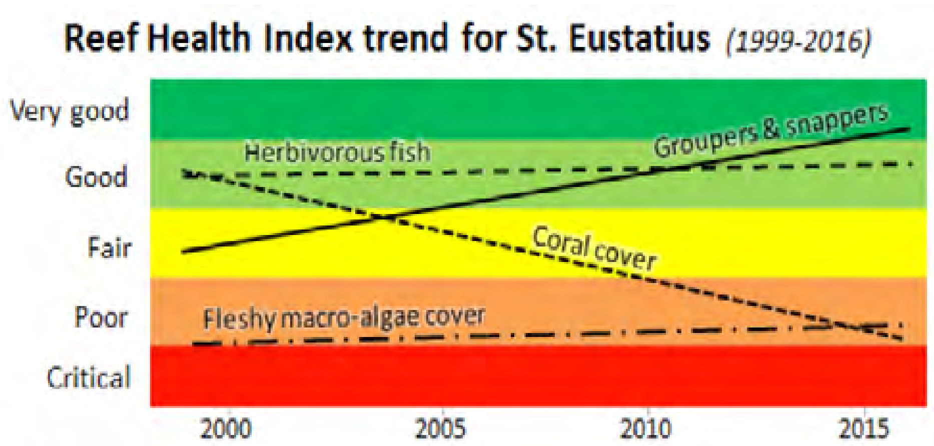
Coral cover

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 (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).

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)



Reef Health Index trend for St. Eustatius (1999-2016).
(www.dcbd.nl)

Status of St. Eustatius's Reefs

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 m^2 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 m^2 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).

Photo by: © Hans Leijnse

Status of St. Eustatius’s Reefs

Fish

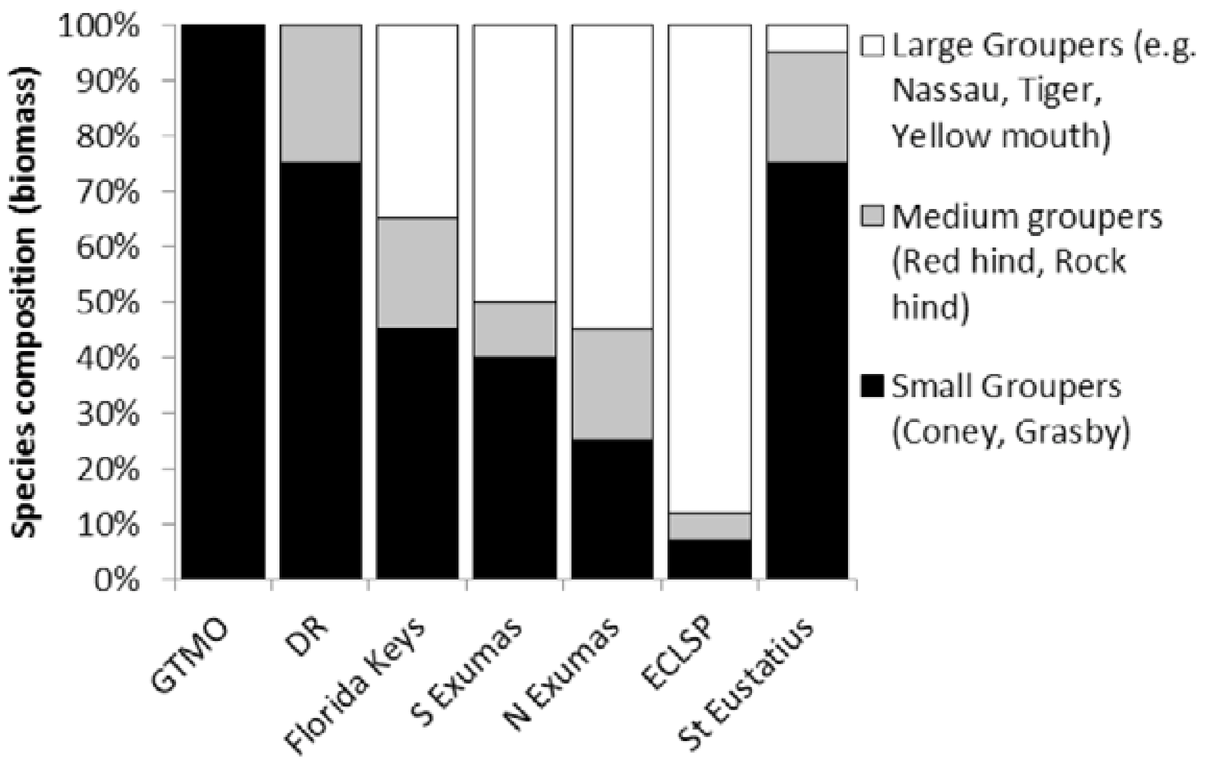
Herbivores have a crucial role within reefs as they can control seaweed from overgrowing coral (Jackson et al., 2014). The density of the herbivorous long-spined sea urchin *Diadema antillarum* is very low (<1 urchin/m2) following its Caribbean-wide mass mortality in 1983/1984 (de Graaf et al., 2015). 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. 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).

Condition of St. Eustatius's reefs compared to other Caribbean reefs

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.



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. (de Graaf et al., 2015)

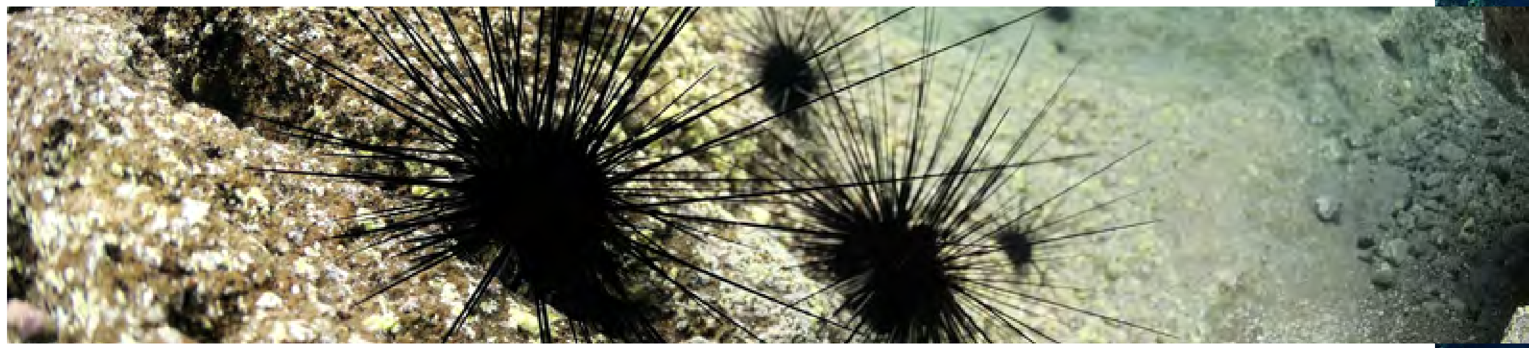


Photo by: © Hans Leijnse

Local stressors

The 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 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). An initiative is running to reduce the erosion problem under the natuurgelden projects that are funded by the Ministry of Agriculture, Nature and Food Quality (LNV).

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.

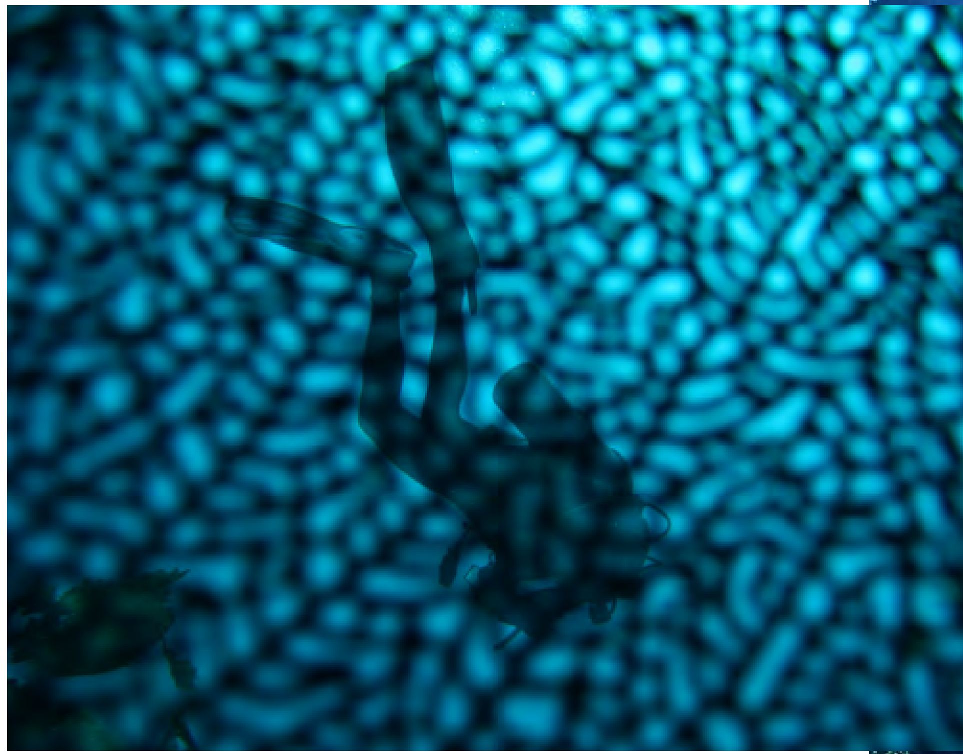


Photo by: © Mark Vermeij

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. In September 2017 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).

Status of St. Maarten's Reefs

References can be found in ***BioNews Issue 7***

In September 2017, major category 5+ Hurricane Irma caused widespread damage to St. Maarten. This was a strong reminder of the urgency to preserve the natural buffers that protect our islands from storm damage, such as coral reefs and mangroves, and increase their resilience. Coral reefs are marine biodiversity hotspots that are not only invaluable for coastal protection but also have a high economic value through associated tourism and fishery.

There is limited information on the status of St. Maarten's reefs over the past three decades as only a few studies have taken place. Therefore the St. Maarten Nature Foundation (NFSXM) started in 2016 monitoring the reefs with the GCRMN baseline scientific method to follow the trends. Coral reef assessments since Hurricane Irma showed that the damage is extensive and significant; coral cover has reduced by 40% but the Man of War Shoal Marine Protected Area showed greater resilience than reefs outside of the protected area.

Geography and Reef Structure

St. Maarten is an island made of magma and limestone rocks located in the North Eastern Caribbean, on the Anguilla Bank. It is part of the outer arc of the Lesser Antilles, which consists of the islands Sombrero up to and including Marie Galante. The oldest rock strata date from +/- nearly 50 million years ago and the island is older than Saba and St. Eustatius (Rojer, 1997)..

St. Maarten is the largest of the Dutch Caribbean's Windward Islands, with a land area of 37 km^2 and a maritime area of 434 km^2. St. Maarten is actually part of a larger landmass (96 km^2) that is divided between two sovereign governments - the Dutch and the French. St. Maarten makes up the smaller, southern side and is an autonomous country within the Kingdom of the Netherlands. Saint-Martin makes up the larger (59 km2), northern side and is a French Overseas Territory (MacRae, 2007).

Except for the lowlands in the west, St. Maarten is hilly. The east end has a range of conical hills: Cole Bay Hill (215m), Sentry Hill (344m), Saint Peter's Hill (317m) and Flagstaff (386m) (Rojer, 1997). Before hurricane Irma, the island was covered with evergreen forests, deciduous and mixed evergreen thorn woodlands, and succulent evergreen shrubland (NFSXM, 2017a).

The numerous bays and lagoons along St. Maarten's coast give the island its irregular shape (Rojer, 1997). The west end is dominated by Simpson Bay Lagoon, one of the largest lagoons in the Lesser Antilles. The lagoon, as well as RAMSAR site Mullet Pond, are home to the island's largest mangrove forests (NFSXM, 2017a). Seagrasses are found mainly along the southern and south-western shores, from Great Bay to Cupecoy Beach. The rest of the coastline, which measures in total 27 km2, is made up of steep rocky cliffs and white sandy beaches. The island is surrounded by a number of small uninhabited islands such as Pelican Rock and Molly B'day. These offshore islands are important nesting sites for migratory and resident seabirds and have been listed by Birdlife International as Important Bird Areas (DCNA, 2017).

St. Maarten's reefs are primarily fringing reefs (Jackson et al., 2014). Patch reefs are found in shallow waters close to shore along the eastern, western and southern coasts. Many upper reef slopes on the eastern part of the island have spur and groove formations (NFSXM, 2017b). The Dutch Caribbean's youngest protected area, the Man of War Shoal Marine Park, was established in 2010. The Marine Park is located off the southern shore of the island and covers an area of 31 km^2. St. Maarten was also declared a shark sanctuary in 2011.

Map of St. Maarten.
Image by: © DCNA

Status of the reefs of St. Maarten

There has only been a limited number of studies over the past twenty years that have investigated the health of St. Maarten's reefs. In the late 1999, the reefs of the windward Netherlands Antilles were assessed at 24 sites to assess the damage caused by hurricane Lenny (Klomp & Kooistra, 2003). The Atlantic and Gulf Rapid Reef Assessment (AGRRA) protocol was used with modifications to detect the hurricane impact. In 1999 and 2001, a joint project between Nature Foundation S.t Maarten (NFSXM) and ReefKeeper International surveyed coral species at 3 of the island's main dive sites (Hen & Chicken, Molly Béday and Mike's Maze) (St. Maarten ReefMonitor Update, 1999; 2001). In 2013 two dive sites in the Man of War Shoal Marine Park were filmed as part of the Catlin Seaview Survey to assess the state of coral reefs over larger scales and in more precise *(www.globalreefrecord.org)*.

The conservation organizations from Saba, St. Eustatius and St. Maarten joined a research expedition organized by the Scripps Institute of Oceanography and the WAITT Foundation in November 2016 to conduct a rapid scientific assessment of the coral reefs around the windward Caribbean islands (Sandin et al., 2016). The Global Coral Reef Monitoring Network protocol for the Caribbean (GCRMN Caribbean) was used to establish a regional scale perspective of coral reef health across the islands, with surveys taking place in the forereef habitat at depths between 7 and 15 meters (Sandin et al., 2016). In addition to coral reef assessments following the GCRMN protocol, eleven coral reef environments on St. Maarten were mapped using 3D imagery (Sandin et al., 2016). Photography and advanced image post-processing are used to create photomosaic images of large reef areas up to 100 square meters. These images provide a snapshot view of large-area coral reef communities and their compositions, enabling data collection of benthic communities. The results of these surveys have not yet been released but footage can be seen here: *https://drive.google.com/drive/folders/0By3cTucxJ9GFbmdGd1lFZ3du alk* [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. Most recently, NFSXM researched the impacts of the 2017 hurricane season using the GCRMN guidelines.

Summary of major coral status surveys conducted on St. Maarten's coral reefs

Studies	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.	-
NFSXM and ReefKeeper International	1999 and 2001	Survey of coral species.	3
Esteban, Kooistra (2005)	2005	Report on observations of coral bleaching in St Maarten's Marine Park.	-
Catlin Seaview Survey	2013	Underwater scooter-assisted SV II survey camera system to conduct reef surveys.	2
GCRMN	Since 2016	Abundance and biomass of key reef fish taxa, relative cover of reef-building organisms (corals, coralline algae) and their dominant competitors (macroalgae), assessment of health of reef-building corals, recruitment of reef-building corals, abundance of key macro-invertebrate species (i.e. *Diadema antillarum*), and water quality (i.e. water transparency (Secchi-disk).	7 (mainly within the Man of War Shoal Marine Protected Area)
Scripps Institute of Oceanography and the WAITT Foundation	2016	Coral reef assessments following the GCRMN protocol and selection of 11 coral reef environments were mapped using 3D imagery.	18

Photo by: © Marion Haarsma

Status of St. Maarten's Reefs

Benthic cover

Coral cover

In 1999, live coral cover of the reefs of the Dutch Caribbean's Windward islands was assessed at 18%, with most hard corals made up of small-sized colonies (Klomp & Kooistra, 2003). However, the joint study between NFSXM and ReefKeeper International in 1999 found St. Maarten's reefs to be in good health with an overall hard coral bottom cover of 34% and a moderate species diversity of 13 hard coral species (St. Maarten ReefMonitor update, 1999). When the study was repeated in 2001, hard coral cover had dropped to 30% (St Maarten ReefMonitor update, 2001).

In the early 2000s, St. Maarten's reefs showed signs of disturbance, notably sedimentation and bleaching - bleaching was noted in 44% of colonies (Klomp & Kooistra, 2003). The island's reefs have suffered from a number of severe bleaching events over the years, notably in 1998 and 2005. Following the severe bleaching event of 2005, many coral colonies were found to be affected (Esteban & Kooistra, 2005). At Mike's Maze dive site, 70% of all fire coral were bleached. At Proselyte Reef, 60% of all hard corals were affected at a depth of 14 meters. At Fort Amsterdam, at least 75% of corals were severely affected at a depth of 6.5 meters, including branching, mound and brain corals, as well as various soft corals (Esteban & Kooistra, 2005). In 2006, a fairly high level of residual coral bleaching was observed, notably in *Montastrea cavernosa* and *Agaricia agaricites colonies* (Goreau, 2006).

In September 2017, major category five storm Irma caused widespread damage to the island, a strong reminder of the urgency to preserve our natural buffers that protect our islands from storm damage, such as coral reefs, and increasing their resilience. The first survey results showed large coral and sponge die-off, especially at the shallow reefs and direct damage to branching corals such as Elkhorn corals. (NFSXM, 2017c). Recently the analyzed GCRMN data revealed that hard coral cover reduced from 6.1% to 3.7% since 2017's hurricane season. Scientific research found that coral cover mostly declines the year after large hurricanes and therefore there are concerns to observe a larger reduction during the 2018 surveys later this year. The observed decrease in coral bleaching could be favorable for the health of the corals and is likely caused by the lower sea-water temperatures and decreased visibility after the storms. The reefs in the Man of War Shoal Marine Park showed a higher resilience than reefs outside of the protected area with higher densities of coral recruits (Mitchell, A. 2018).

Macroalgae

Macrolagae negatively impact corals by inhibiting coral recruitment and survival, slowing coral growth and making them more prone to diseases (Jackson et al., 2014). Macroalgal cover was found to be low for the reefs of the Windward islands in 1999 (Klomp & Kooistra, 2003). This was partly attributed to the high biomass of grazing herbivorous fishes in the region (Klomp & Kooistra, 2003). However, the joint study between NFSXM and ReefKeeper International in 1999 found a much higher algal cover of 25% (St. Maarten ReefMonitor Update, 1999). In 2001, all the reefs surveyed had nearly the same percentage of algae cover (27%) (St. Maarten ReefMonitor Update, 2001). The high algae cover by Dictyota was also reported by Goreau (2006): *"there are moderately high nutrient levels even in areas that are not exposed to land based sources of nutrients. This suggests that there are high natural inputs from deep cold waters, probably caused by the shallow thermocline and the activity of breaking internal waves in Atlantic waters to the east of Sint Maarten. High natural nutrient backgrounds offshore indicate that even stricter control of land-based sources of nutrient pollution is needed to prevent explosive weedy algae overgrowth, or eutrophication, of coastal waters."* (Goreau, 2006).). After the 2017's hurricane season the macroalgae has further increased to > 50% at all sites, being highest outside the Marine Park (Mitchell, A. 2018).

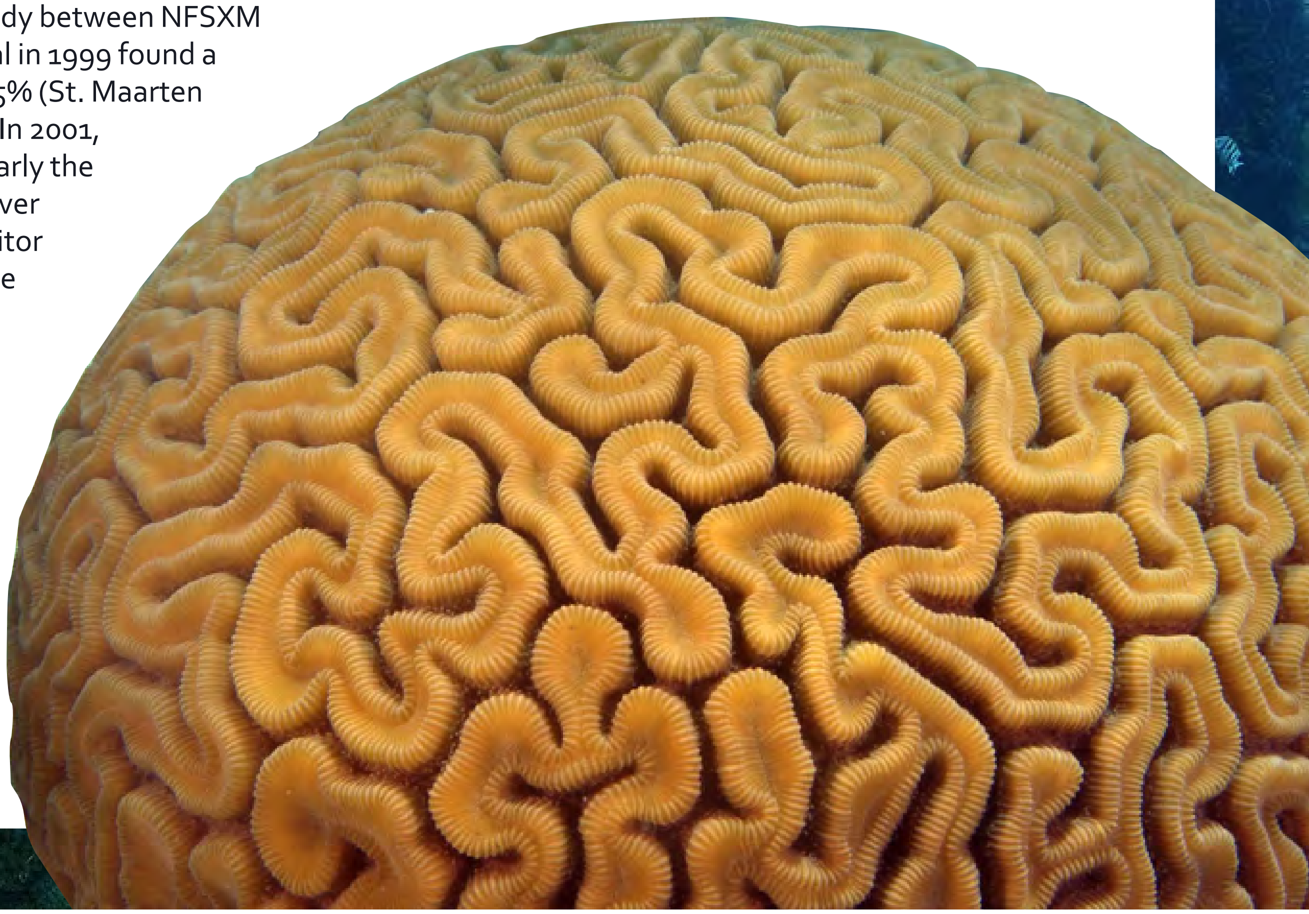


Photo by: © Marion Haarsma

Fish

St. Maarten's reefs are home to 153 species of reef fish. The most common reef fish species are blue tang *(Acanthurus coeruleus)*, bluehead *(Thalassoma bifasciatum)*, sergeant major (*Abudefduf saxatilis*), spotted goatfish (*Pseudupeneus maculatus*) and ocean surgeonfish (*Acanthurus bahianus*) (NFSXM, 2017a). The fish communities of the island's offshore and protected areas have recently been described as "noticeably robust and intact" with relatively common sightings of bigger fish, which highlights the success of fish management initiatives on St. Maarten (Research group at Scripps Institution of Oceanography UC San Diego, personal communication, June 15, 2017).

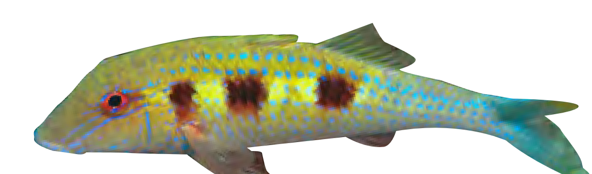
The island has a healthy shark population. Since 2015, Baited Remote Underwater stereo Video (stereo-BRUV) has been used to gather data on St. Maarten's shark population. Caribbean reef sharks (*Carcharhinus perezii*) and nurse sharks (*Ginglymostoma cirratum*) are the most abundant shark species. Between February and August 2016, 477 Caribbean reef sharks were sighted, along with 70 nurse sharks (*Ginglymostoma cirratum*) and one hammerhead shark (*Sphyrnidae sp.*) (DCBD, 2017). The abundance of these species is higher in the marine park, and is markedly more abundant within the park's Conservation Zone (Kramer & Odinga, 2015). This may be the result of their preference for reef habitats. Their distribution could also be affected by the shark-feeding excursions that used to be organized for tourists (Kramer & Odinga, 2015).

Caribbean Reef Sharks , Photo by: © Jim Abernethy

Local stressors

While there is limited information regarding the current status of St. Maarten's reefs, there are clear indications that these reefs are under a number of man-made and natural pressures. In 2003, signs of disturbance such as sedimentation and increased bleaching were already noticeable compared to the other Windward Islands (Klomp & Kooistra, 2003). It is important to reduce local threats to increase the resilience of the reefs to the global stressors caused by climate change such as intensified bleaching and storm events (Bender et al., 2010; Walther et al., 2002). In light of the considerable worth of the island's reefs, adequate management measures must be put in place to protect this invaluable resource.

Ocean Surgeonfish , Photo by: © Hans Leijnse



Spotted Goatfish , Photo by: © Marion Haarsma

Status of St. Maarten's Reefs

The economy of St. Maarten is extremely dependent on marine-based activities, with the reefs generating approximately USD $58 million through coral reef associated tourism and fishery (Bervoets, 2010). Tourism has increased greatly over recent decades, and continues to do so. From 2011 up to the end of 2015, the island has seen the number of stay-over tourists grow from 424,340 to 505,374 (Heyliger, 2017). Most visitors make use of the marine environment, from lounging on a beach to enjoying a fishing or boating excursion and taking part in watersports activities such as snorkelling and SCUBA diving. St. Maarten is also a major port of call for Caribbean cruise ships (Klomp & Kooistra, 2003), and in 2015 Port St. Maarten catered to over 1.9 million cruise passengers (Port St. Maarten, 2016). These passengers also partake in the island's many water-based activities.

The rapid and continuous growth in tourist numbers as well as residents (from 5,000 in 1960 to 41,338 in 2017) has led to thoughtless landscaping and building near the waters' edge to accommodate them. Unsustainable development is one of the most serious threats to St. Maarten's reefs. It causes sedimentation and nutrient enrichment of the marine environment which in turn smothers and kills reef organisms (MacRae, 20007; NFSXM, 2017b). Development for tourism has resulted in further habitat destruction and degradation of habitats such as the lagoon and the numerous salt ponds on the island (Yokoyama, 2010).

The increase in the permanent and temporary population of St. Maarten has also led to an increase in pollution. Pollution on St. Maarten mainly comes from sewage, fuel and litter. These directly affect the health of the seabed environment. The resulting raised nutrient concentrations stimulate the growth of algae, which can out compete hard corals for settlement space. The seagrasses in Simpson Bay Lagoon and in Oyster Pond have all but disappeared as a result of pollution, anchoring and eutrophication caused by excessive nutrients entering coastal waters (MacRae, 2003). However, the little available evidence indicates that water quality is generally good within St. Maarten's open water environments (MacRae, 2003).

Small-scale commercial and artisanal fishing takes place on the island's reefs. There are seven active fishing vessels with an estimated 490 kg total catch per week (Lindop et al., 2015). Commercial fishing targets snappers *(Ocyurus chrysurus* and *Lutjanus campechanus*), pelagic species (*Acanthocybium solandri, Coryphaena hippurus, Thunnus sp. and Selar crumenophthalmus*), and lobster (*Panulirus argus*) (Dilrosun, 2004). The island's fishing grounds have been described as poor with few large specimens of carnivorous fish such as groupers and snappers, most likely the result of overfishing throughout the 1970s and 1980s (MacRae, 2007; Dilrosun, 2004). Illegal spearfishing takes place to some extent, and conch are taken unsustainably (MacRae, 2007). The creation of the Man of War Shoal Marine Park in 2010 has had a positive impact on commercial species. In 2013, grouper and snapper populations increased by 10-15% within the Marine Park, with fishers reporting an increase in catch (Bervoets, 2014).

Besides, St. Maarten 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). In its efforts to manage and control the infestation NFSXM has been catching these fish and distributed lionfish collection materials to the various dive centers and fishermen. Twice a year the Nature Foundation also holds a lionfish derby.

St. Maarten is located in the Atlantic hurricane zone, and on average is hit by a hurricane every 4 to 5 years. These hurricanes not only limit reef development but also cause great damage to island's seabed (Klomp & Kooistra, 2003). In the late 1990s, six hurricanes hit St. Maarten 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). For example, the heavy seas generated by Hurricane Luis shifted sand which smothered coral colonies, and shallow strands of Acropora palmata suffered breakage (Smith et al., 1997). In September 2017, St. Maarten was hit by the strongest hurricanes in history in the Atlantic 'Irma' and caused severe major damage to the environment and infrastructure. In addition to storm damage, St. Maarten's reefs have also suffered from other natural impacts. An outbreak of white band disease between 1980 and 1982 killed 90% of the Caribbean's populations of Acropora cervicornis and Acropora palmata. This was followed by a mass mortality of Diadema antillarum, one of the most important grazers on Caribbean reefs (MacRae, 2007).

Blackfin Snapper, Photo by: © Hans Leijnse

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