Status of Curaçao's Reefs

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.

1. 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, 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

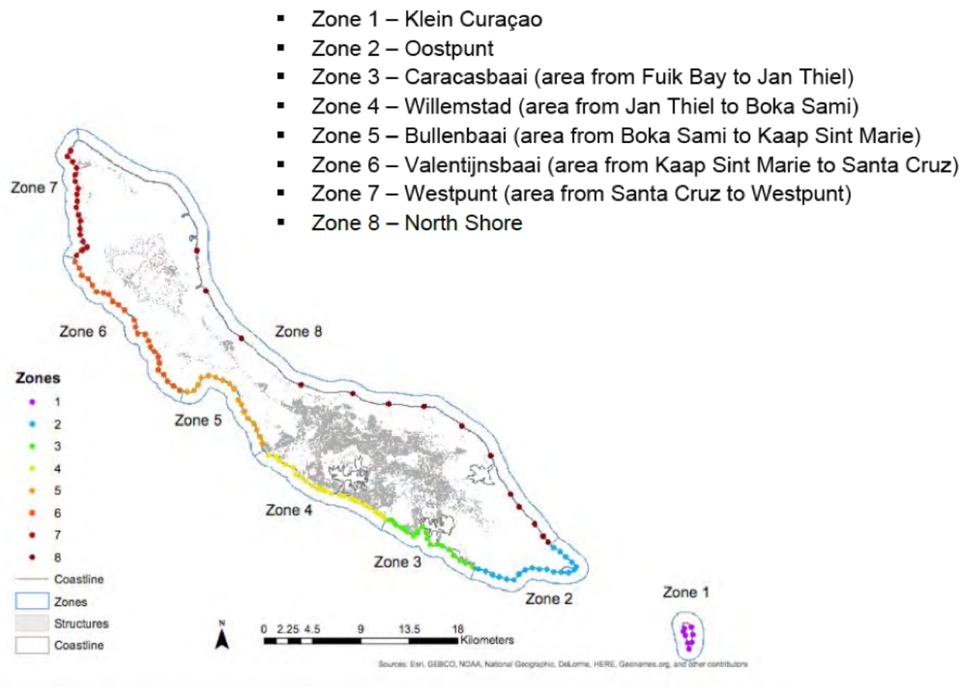

Figure 1. *Based on the marine expedition eight zones with similar ecological conditions were identified and used for creating maps. In the Marine Scientific assessment report maps can be found with coral cover, juvenile cover density, turf- and macroalgae, fish biomass, infrastructure, sewage, trash, fishing pressure and diving pressure per zone.*
Credit: WAITT Institute, Esri, GEBCO, NOAA, National Geographic, Delorme, HERE, Geonames.org, and other contributors

2. 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 (Table 1). 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 Curacao 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) (Figure 1). This article focuses on the results of this island-wide most recent study.

Photo by: © Mark Vermeij

Table 1: *Summary of major coral status surveys conducted on Curacao's coral reefs*
(Source: 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 9m2 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
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

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2.1 Benthic cover
Loss in coral cover

Like many reefs in the Caribbean, Curacao'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; Figure 2) 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 Curacao 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%) (Figure 3).

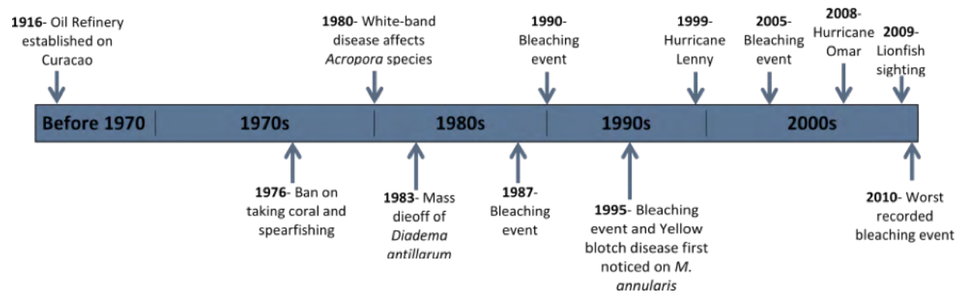

Figure 2: *Timeline of major natural and anthropogenic events that have impacted coral reef habitats in Curaçao. Source: Sustainable Fisheries Group UC Santa Barbara, 2015.*

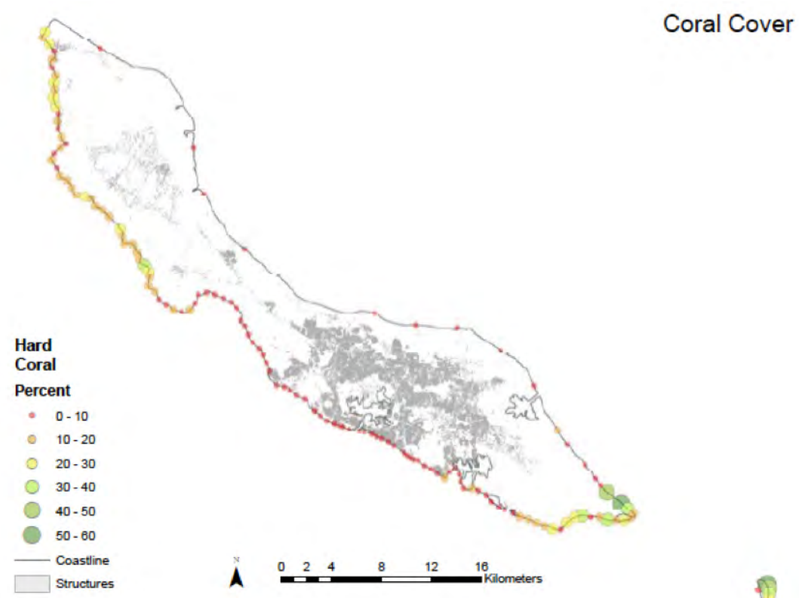

Figure 3: *Coral cover by site level average. Credit: WAITT Institute, Esri, GEBCO, NOAA, National Geographic, Delorme, HERE, Geonames.org, and other contributors.*

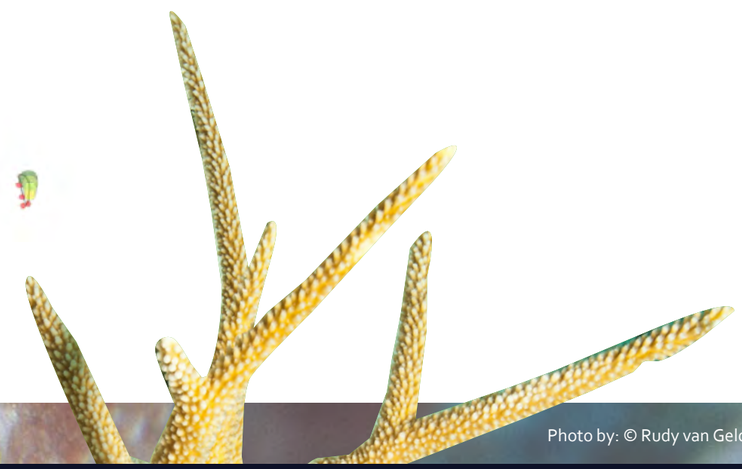

Photo by: © Rudy van Gelderen

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 (Table 2). 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 (Figure 3) (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 (Figure 3). Juvenile corals (<4cm) on Curaçao's reefs decreased on average by 55% from 1975 to 2005 (these small corals could however be as old as 13 years) (Vermeij, 2011).

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

Table 2: *Change in coral cover of a 9 m2 quadrat at a depth 10, 20, 30 and 40 meters at three different sites on Curacao.*
(Source: De Bakker et al., 2016)

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). 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).

Macroalgae, turf 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 (Figure 6). 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 (Figure 4). 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 BioNews 3-2017 ("Status of Bonaire's reefs" ("Harmful seaweed and the rise of cyanobacterial mats" on page 7: *http://www.dcnanature.org/wp-content/uploads/2017/09/1.-Bionews-Issue-3-online.pdf)).*

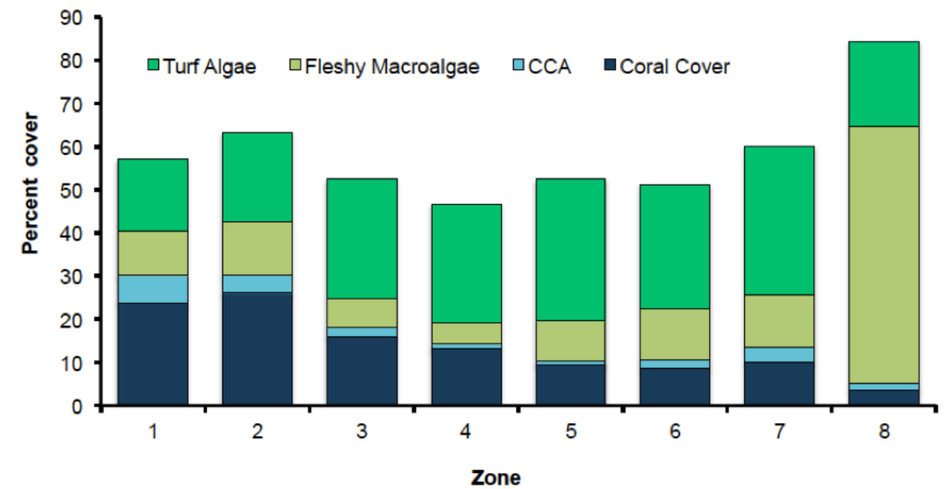

Figure 4: *Average abundance (in percentage cover) of reef building organisms: corals and crustose coralline algae (CCA) and abundant algal groups (turf algae and fleshy macroalgae) that compete with reef builders for space. Other bottom cover not shown in this figure includes sponges, sand and rubble.*
Source: WAITT Institute, 2016.

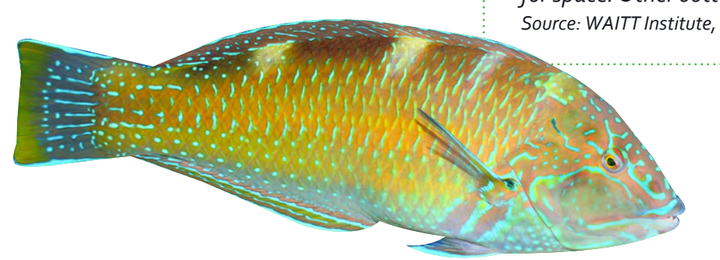

Photo by: © Hans Leijnse

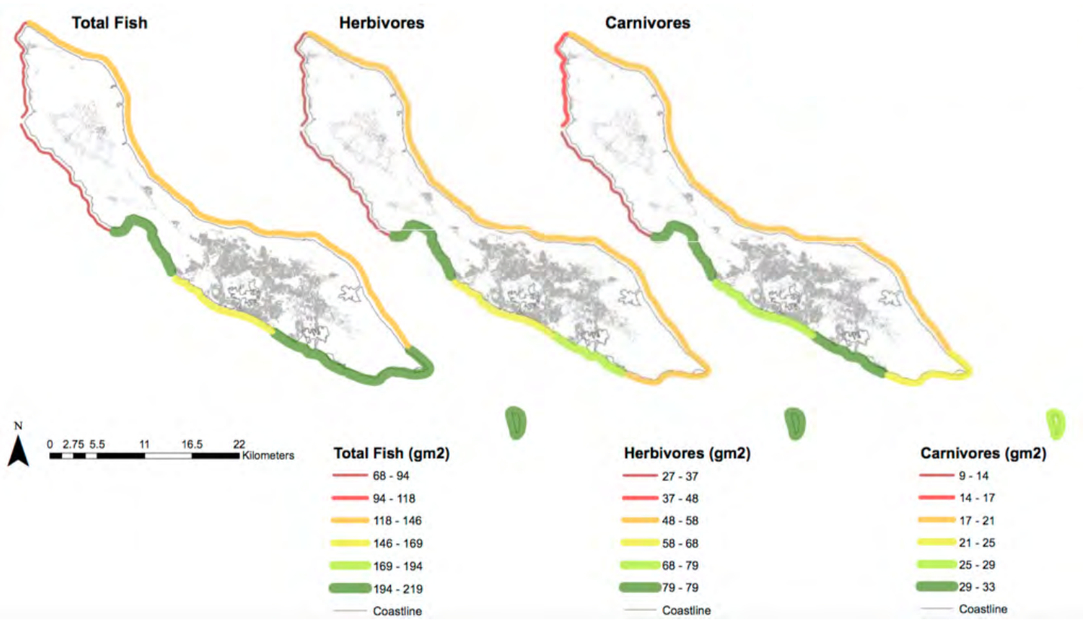

Figure 5: *Spatial distribution of fish around Curaçao.*
Source: WAITT Institute, 2016

2.2 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) (Figure 5).

The abundance of carnivorous and of herbivorous fish are important indicators of functional reef communities. High densities of predatory fish such are 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) (Figure 5) (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) (Figure 5). 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).

3. Local stressors on Curaçao's reefs

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 important 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 km2 (CBS, 2017). The Blue Halo Curaçao study assessed the island's coastal pollution from both at 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 over-fished (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 (Figure 5). 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.

4. Condition of Curaçao's reefs compared to other reefs within the Caribbean Region

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 (Figure 6). 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/m2). The north shore has a much lower parrotfish abundance (15 g/m2), around the same range as Saba (13 g/m2). 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.

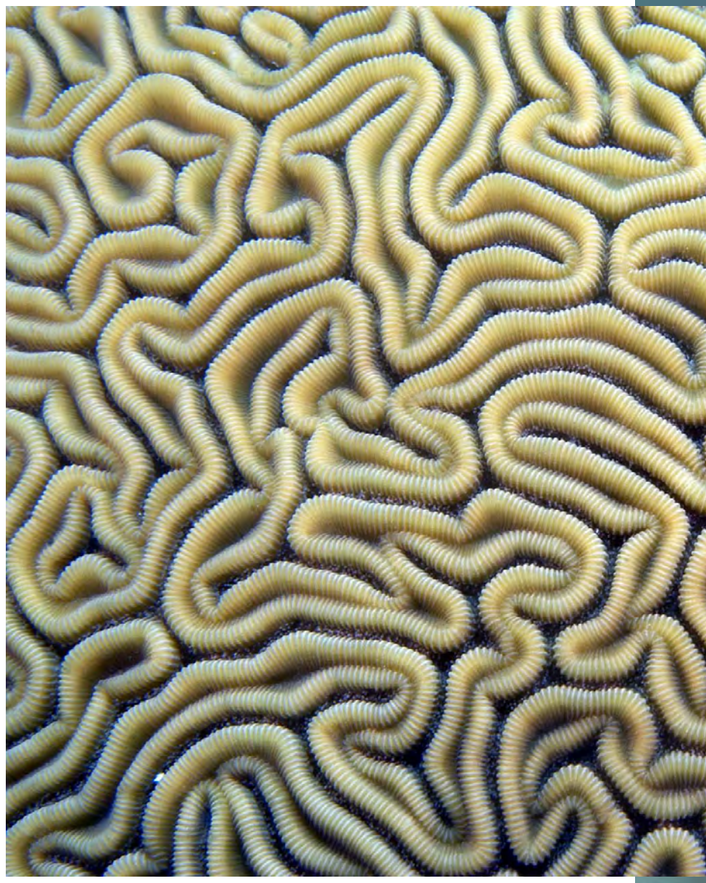

Photo by: © Marion Haarsma

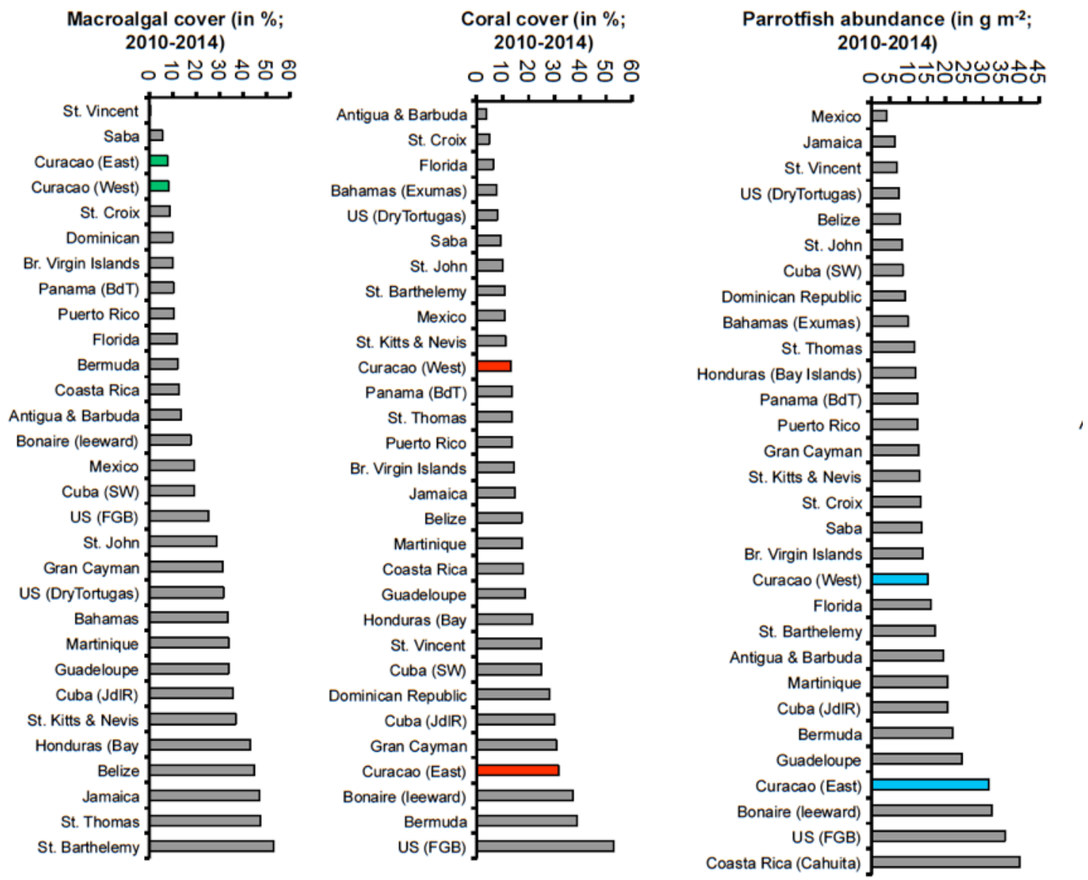

Figure 6: *Overview of commonly used metrics for coral ecosystem health of Curaçao's coral reefs in comparison to other Caribbean islands and nations. High coral cover and high abundance of parrotfish are considered signs of functional reef communities, whereas high macroalgal abundance is indicative of degraded reefs. (Note: the more common turf algae and cyanobacteria are not included in this comparison).*
Source: WAITT Institute, 2016.

Photo by: © Marion Haarsma

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