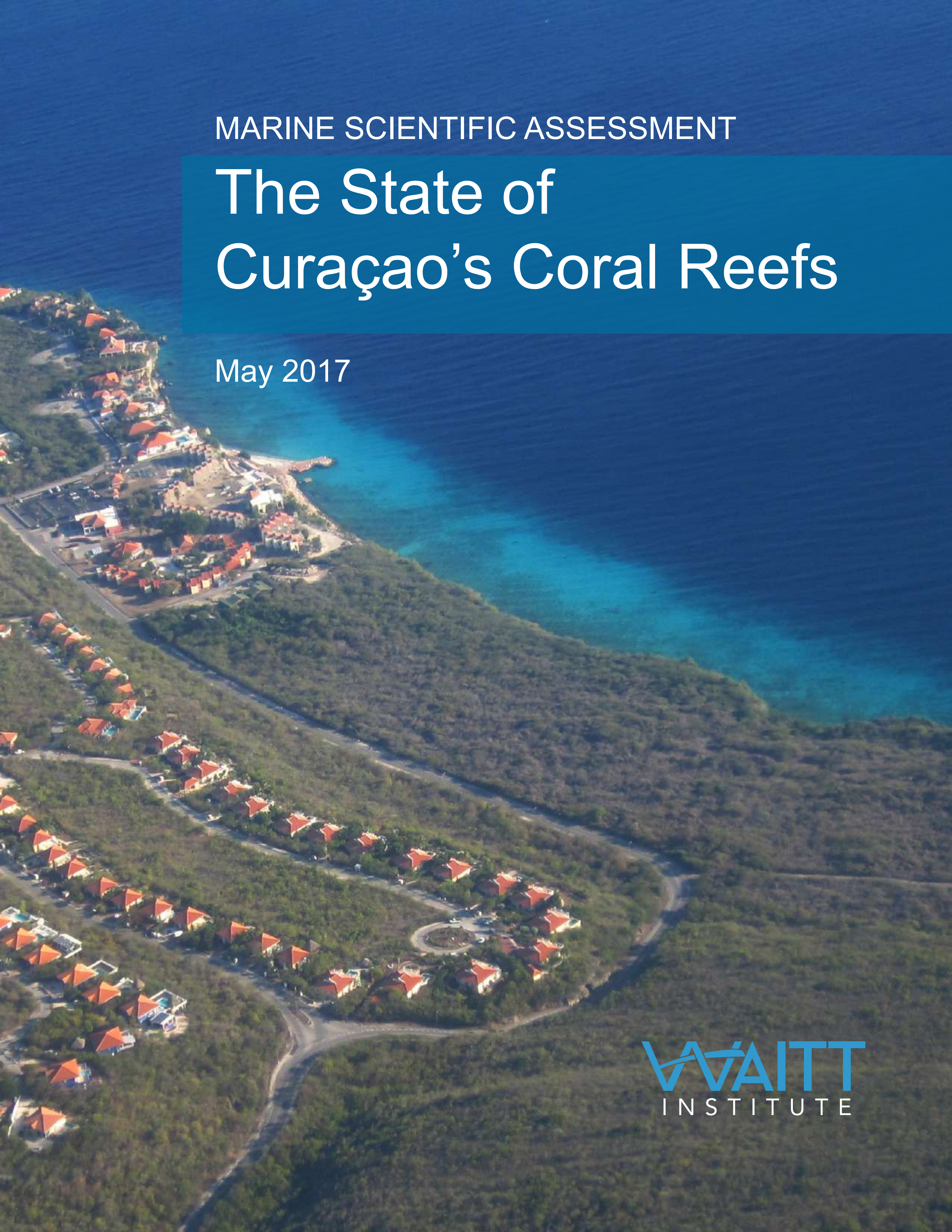
MARINE SCIENTIFIC ASSESSMENT

The State of Curaçao's Coral Reefs

May 2017



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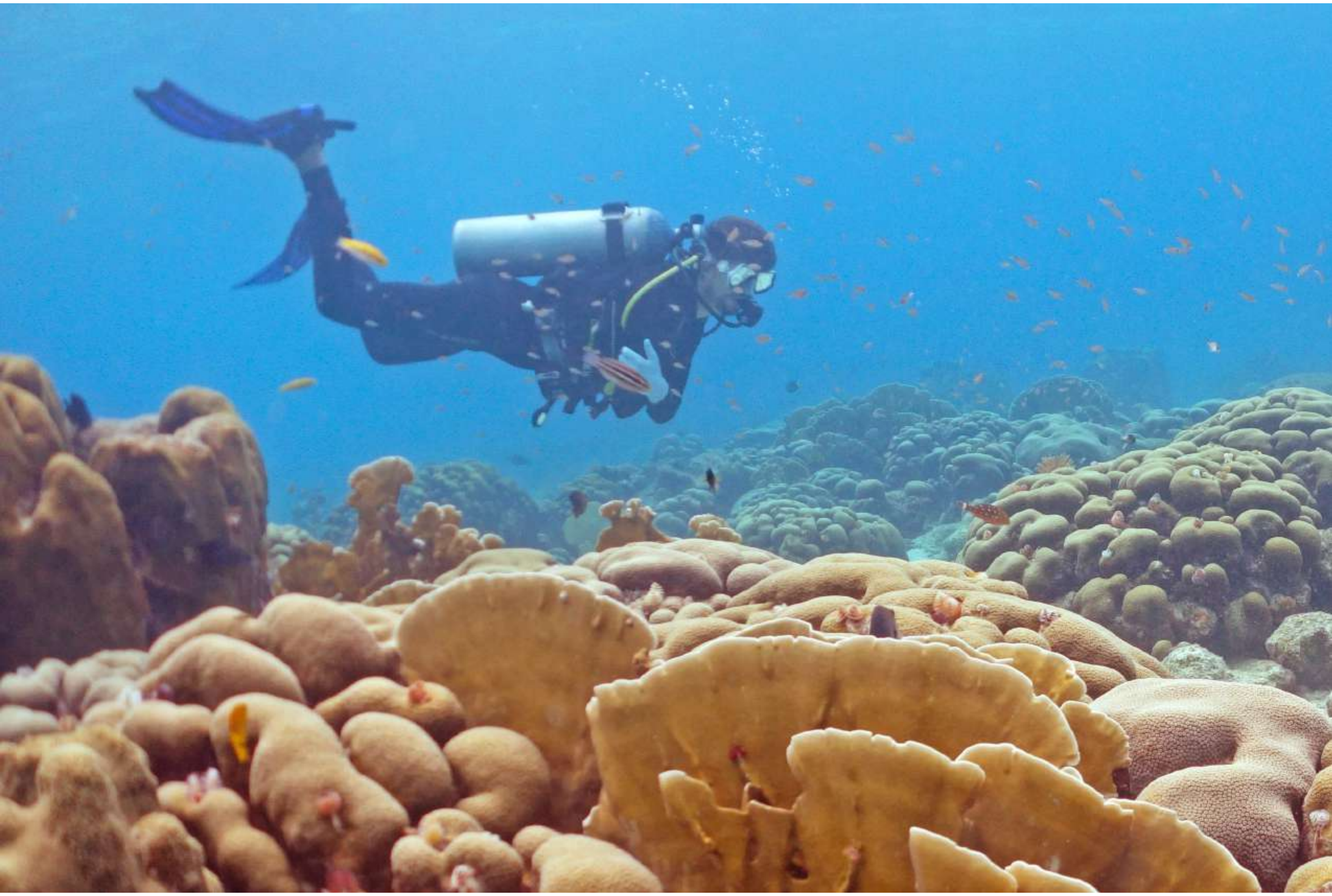

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Cover Image: Aerial view of Curaçao's nearshore environment (© Mark Vermeij, 2015). Image above: divers on a shallow fringing reef near Buoy 1, Curaçao (© Ben Mueller, 2016).

About the Waitt Institute

The Waitt Institute endeavors to ensure the economically and culturally sustainable use of ocean resources. The Waitt Institute partners with governments committed to developing and implementing comprehensive, knowledge-based, community-driven solutions for sustainable ocean management. The Waitt Institute's goal is to benefit coastal communities while restoring fish populations and habitats. The Waitt Institute's approach is to engage stakeholders, provide the tools needed to design locally appropriate policies, facilitate the policymaking process, and build capacity for effective implementation of management measures to ensure their long-term success.

About Blue Halo Curaçao

In February 2015, the Government of Curaçao and the Waitt Institute signed a Memorandum of Understanding that launched Blue Halo Curaçao, a comprehensive ocean and coastal management project. The goal of Blue Halo Curaçao is to foster the sustainable, profitable, and enjoyable use of ocean resources through the enhanced management of Curaçao's ocean and coastal waters. The Blue Halo Initiative therefore aims to empower communities to restore their oceans, and use ocean resources sustainably, profitably, and enjoyably for present and future generations. The Initiative engages stakeholders through a knowledge-based, community-driven approach. Governments, local communities, and scientists partner to develop and implement ocean policies, such as sustainable fishing practices and comprehensive marine spatial planning. The Waitt Institute provides the toolkit, and partner governments provide the political will, so people can use the ocean without using it up..

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Introduction

Coral reefs in the Caribbean are degrading rapidly with a loss of ~50% in just 4 decades. The cause of this degradation is a combination of natural and human impacts (Wilkinson 2000). If present rates of decline continue, researchers project that 60% of Caribbean coral reefs will be lost over the next 30 years. The cumulative impacts from runoff, pollution, tourism overuse, destructive fishing and climate change contribute synergistically to these region wide trends. This Assessment finds the same is true for Curacao.

The importance of coral reefs for society and the economy is enormous. As discussed in the Economic Valuation of Curaçao's Marine Resources (SFG 2016), reefs provide direct monetary value through fisheries harvest and tourism revenues. In addition, and as important, they provide indirect non-consumptive values that are less readily captured by formal markets. Such indirect values include services like protection against storm surge and flooding and providing habitat for commercial and other fish species.

Presently, a kilometer of healthy Caribbean reef is estimated to generate in excess of $1.5M annually through fisheries and tourism alone (Burke et al. 2011. The Economic Assessment valued Curaçao's coral reefs at more than $445 million per year through their support to the tourism and fishing industry alone (SFG 2016).

The purpose of this Assessment is to inform the development of a Sustainable Ocean Policy to improve the health of marine ecosystems around Curaçao so they can sustainably support coastal economies and livelihoods. To develop such policy, a marine survey was conducted in November 2015 to assess the abundance and composition of reef and fish communities and water quality at 148 sites around the island. Secondly, ocean uses (fishing and diving) were quantified at the same sites based on interviews with fishers and divers. Finally, existing information was used to evaluate changes through time in the state of Curaçao's reefs and their value to the people of Curaçao.

This Assessment complements a series of documents produced by the Waitt Institute and its partners (an analysis of Curaçao's legal system, a marine science review, and an economic valuation of the island's marine resources) that collectively can help inform the design and implementation of a Sustainable Ocean Policy.

This Assessment first summarizes the results of reef surveys around Curaçao conducted in November 2015. Based on these findings, their implications for the future of the island's marine resources is evaluated resulting in an overview of policy recommendations to ensure the sustainable use of Curaçao's marine resources. Details on the research methodology can be found in Appendix 1.

Approach

In November 2015, the Waitt Institute partnered with researchers from Carmabi (Curaçao), Scripps Institution of Oceanography (U.S.A.), Reef Support (Bonaire), the National Oceanic and Atmospheric Administration (U.S.A.), Moss Landing Marine Lab (U.S.A.), University of South Florida (U.S.A.), and San Diego State University (U.S.A.) to conduct marine surveys at 148 sites around the islands of Curaçao and Klein Curaçao. A summary of site locations and associated data can be found in Appendix 1. Sites were approximately 700 meters apart along the island's south coast and ~3

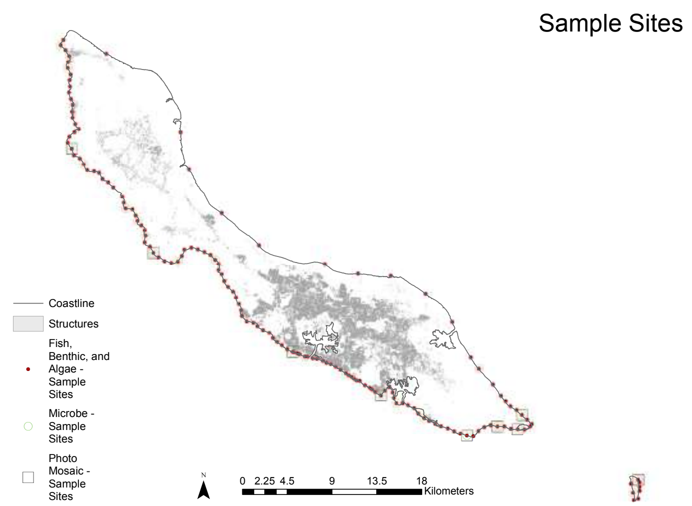


Figure 1. The location of all sample sites (red dots) for the marine surveys and water quality analyses At each site, researchers sampled five 30-meter transects at depths between 8 to 12 m following the methods preferred by the Global Coral Reef Monitoring Network (GCRMN).

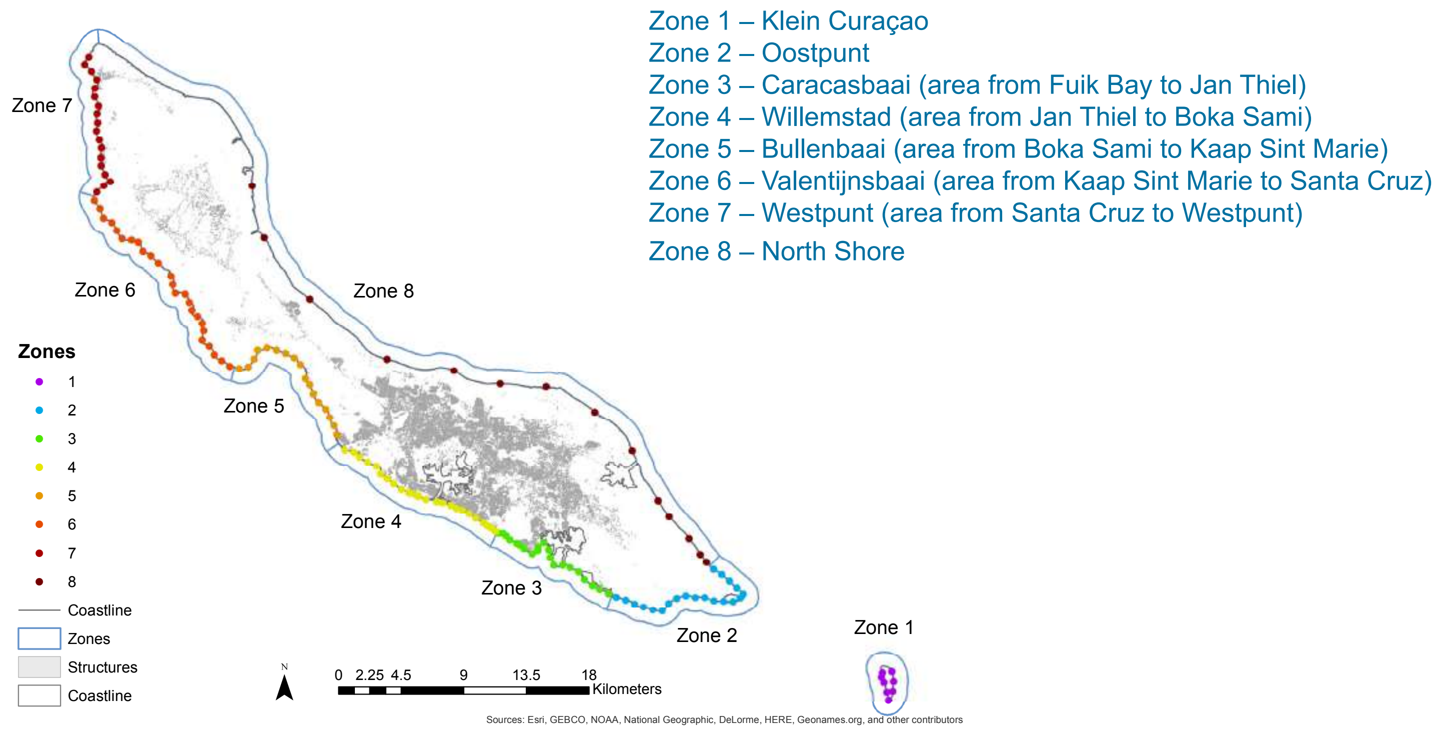


Figure 2. The eight zones of Curaçao. Each zone, in the aggregate, can be distinguished from other zones based on the combination of human impact, fish and benthic communities. Site characteristics may vary considerably within a zone, but sites in each zone are more similar to each other than other zones.

km apart along the north shore. Appendix 1 provides the protocols.

The following five indicators were used to assess the health and condition of reef communities at each site: (1) the abundance of reef building organisms and their dominant competitors to determine if reefs at a location were growing or declining, (2) the abundance of coral recruits (juvenile corals) to assess the ability of a reef to renew itself, (3) the diversity, abundance, and biomass of *all* reef associated fishes to assess the state of economically and ecologically important fish species around the island, (4) the abundance of mobile invertebrates such as lobsters and conch (not yet reported in this Assessment), and (5) water measurements to assess water quality for marine life and ocean users. Researchers conducted marine surveys at 148 nearshore sites around Curaçao (Figure 1).

Results

This section presents the results from the marine surveys (benthic cover, fish abundance and water quality), the spatial analysis of ocean usages and values (fishing and diving) as well as the degree of coastal development. While each site has its own characteristics, we found that neighboring sites were generally more similar compared to sites elsewhere on the island. To facilitate planning and decision making, we identified eight distinct Zones that exist around the island (Figure 2). The grouping analysis considered 17 indicators in total.

Sites within a zone shared ecological similarities (in terms of coral health, fish biomass, and water quality) that statistically distinguished them from reef communities in other zones (for details on methods used, see: Jain, 2009). The ecological characteristics, but also local stressors for each Zone will allow managers and decision-makers to design appropriate and tailored protection measures for specific locations around the island. The zones that were identfied are shown in Figure 2.

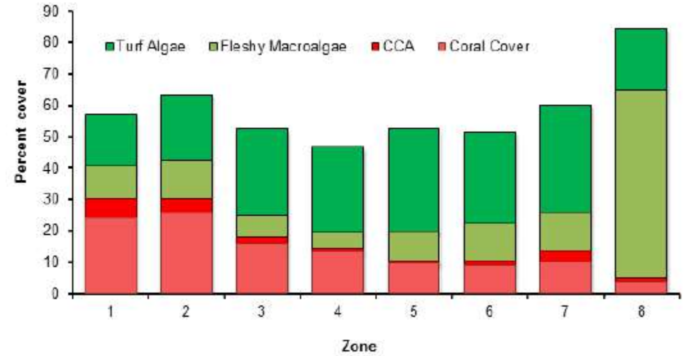


Figure 4. Average abundance (in percentage cover) of reef building organisms: corals and crustose coralline algae (CCA) and abundant algal groups (turf algae and fleshy macroalgae) that compete with reef builders for space. Other bottom cover not shown in this figure includes sponges, sand and rubble.

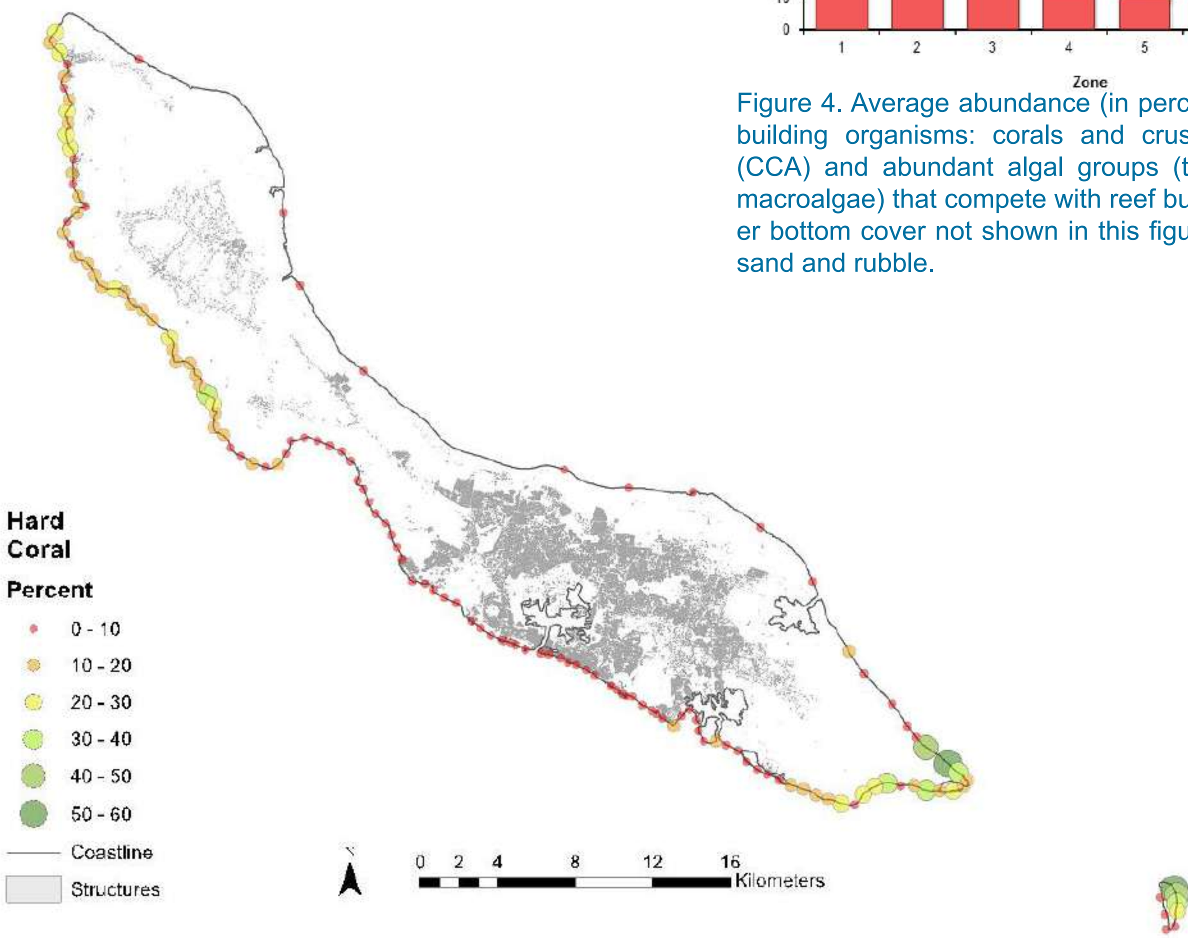


Figure 3. Average coral cover for all 148 sites.

Benthic cover

Understanding the relative cover of benthic organisms on the seabed provides insights on the quality and health of coral reefs. High abundance of calcifying (i.e., reef-building) organisms such as corals and calcifying algae (e.g., crustose coralline algae) indicate “healthy” reefs. Corals nowadays face increased competition for space from benthic algae (e.g., McCook 1999; McCook et al. 2001; Vermeij et al. 2010) and as algae increase in abundance, they actively overgrow more and more live corals or passively take over space after corals have died. High abundances of fleshy macro and turf algae therefore indicate degraded reefs.

Reefs around the island have an average coral cover of 15% or less per zone, except for Klein Curaçao (25%, Zone 1) and Oostpunt (25% Zone 2). Coral cover exceeding 40% is indicative of healthy Caribbean reefs (Gardner et al. 2003; Burke et al. 2011; Jackson et al. 2013). Individual sites with >40% coral cover are located along the east side of Klein Curaçao (Zone 1) and the east side of the Oostpunt area (Zone 2). In addition, a few sites with >40% coral cover exist near Rif Marie and Playa Kalki (Zone 6 and 7, respectively, (Figure 3).

A suite of local factors affect benthic algae abundance: (1) overfishing of herbivorous fish and (2) eutrophication (excessive nutrients in the water) resulting from the unsustainable use of coastal areas (e.g., Hughes 1994; Pandolfi et al. 2003; Vermeij et al. 2010; Mumby et al. 2014; den Haan et al. 2016). This linkage between algal growth and pollution has already been documented in Curaçao by previous researchers (Bak, 2005; Vermeij, 2012).

Favorable conditions for reef growth are located almost exclusively on the east side of Curaçao (Zones 1 and 2; Klein Curaçao and Oostpunt) where reef builders are on average over two times more abundant than elsewhere on Curaçao (Figures 3 and 4). These favorable areas also show the largest abundance of juvenile corals, a measure of a reef's ability to "renew" itself as existing corals die (Figure 5). Without healthy population of reef builders that form calcified reef structures around the island, impacts such as storms can lead to the rapid destruction of remaining coral reefs, inland bay communities and nearshore costal developments (Burke et al. 2011).

The abundance of algae on Curaçaoan reefs is high in all Zones around the island (Figure 6). The North Shore (Zone 8) of Curaçao is almost exclusively covered by *Sargassum* species, a fleshy macroalgae, growing on the seafloor in great abundance. This is a natural phenomenon due to the impact of strong wave action.

Fish abundance

Total fish biomass is highest in Zones 1–5 (Klein Curaçao to Bullenbaai), and extremely low in Banda Abao and Westpunt (Zones 6-7). Fish biomass along the North Shore (Zone 8) falls in the middle of these values (Figure 7).

While a Caribbean indicator for total fish biomass of a healthy reef does not exist, relatively healthy reefs in the Pacific with intact ecosystems show total fish biomasses between 270 - 510 g m^{-2} (Sandin et al. 2008). The highest average fish biomass on Curaçao (159 – 219 g m^{-2}, found at sites from Klein Curaçao to Boka Sami) is relatively high for Caribbean standards, but lower than values associated with proper ecosystem function. Secondly,

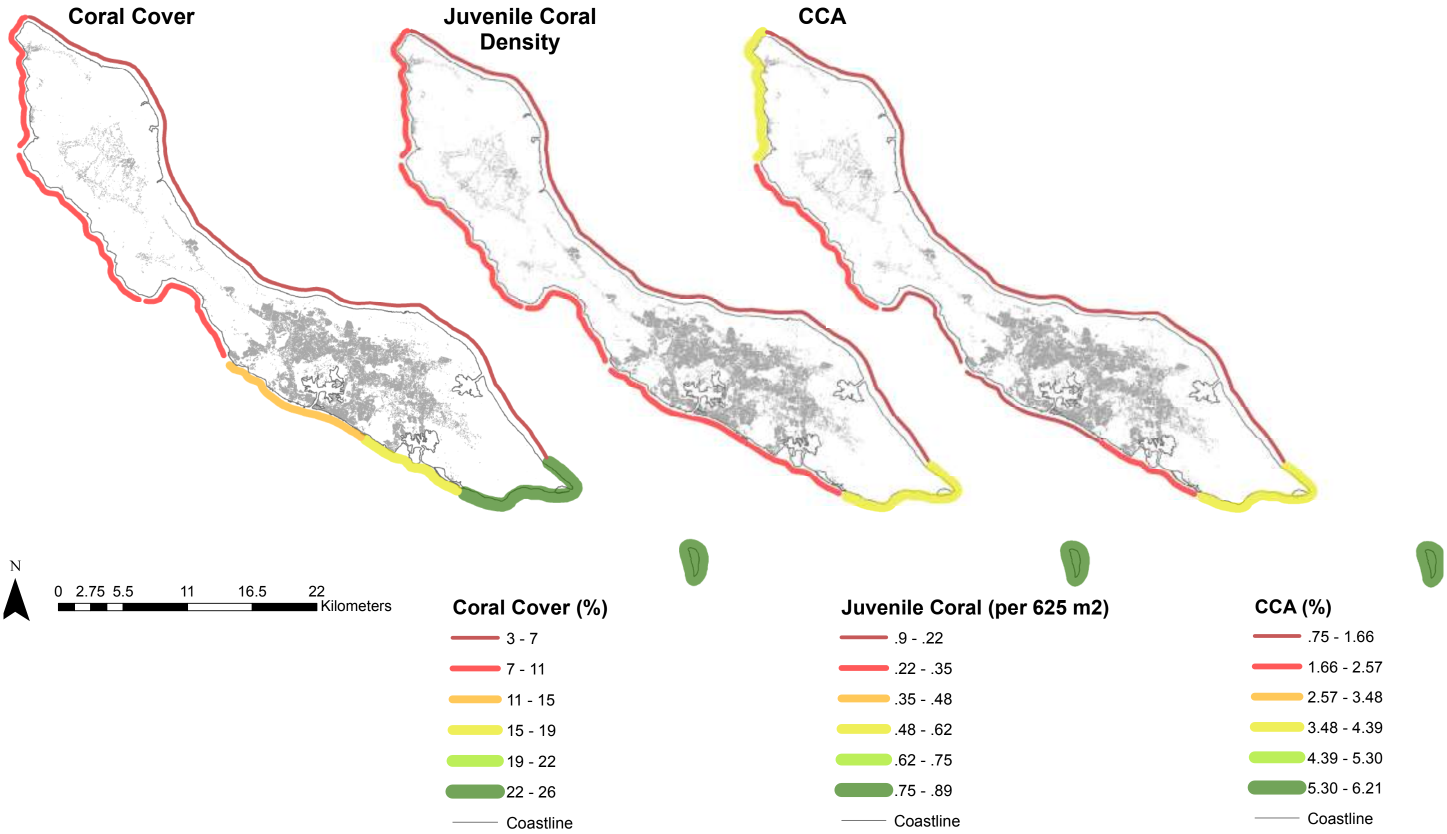


Figure 5 Spatial distribution of reef builders: coral cover (left), CCA (middle), and juvenile coral density (right).

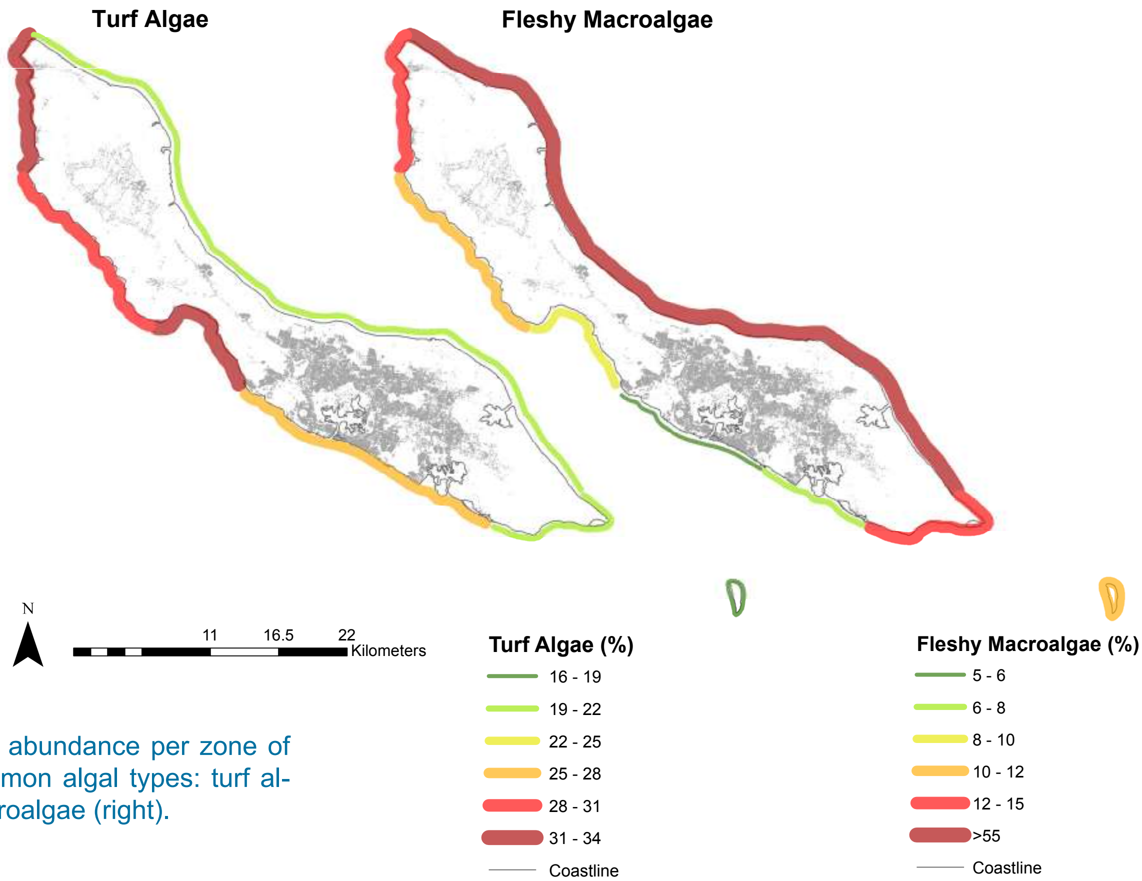
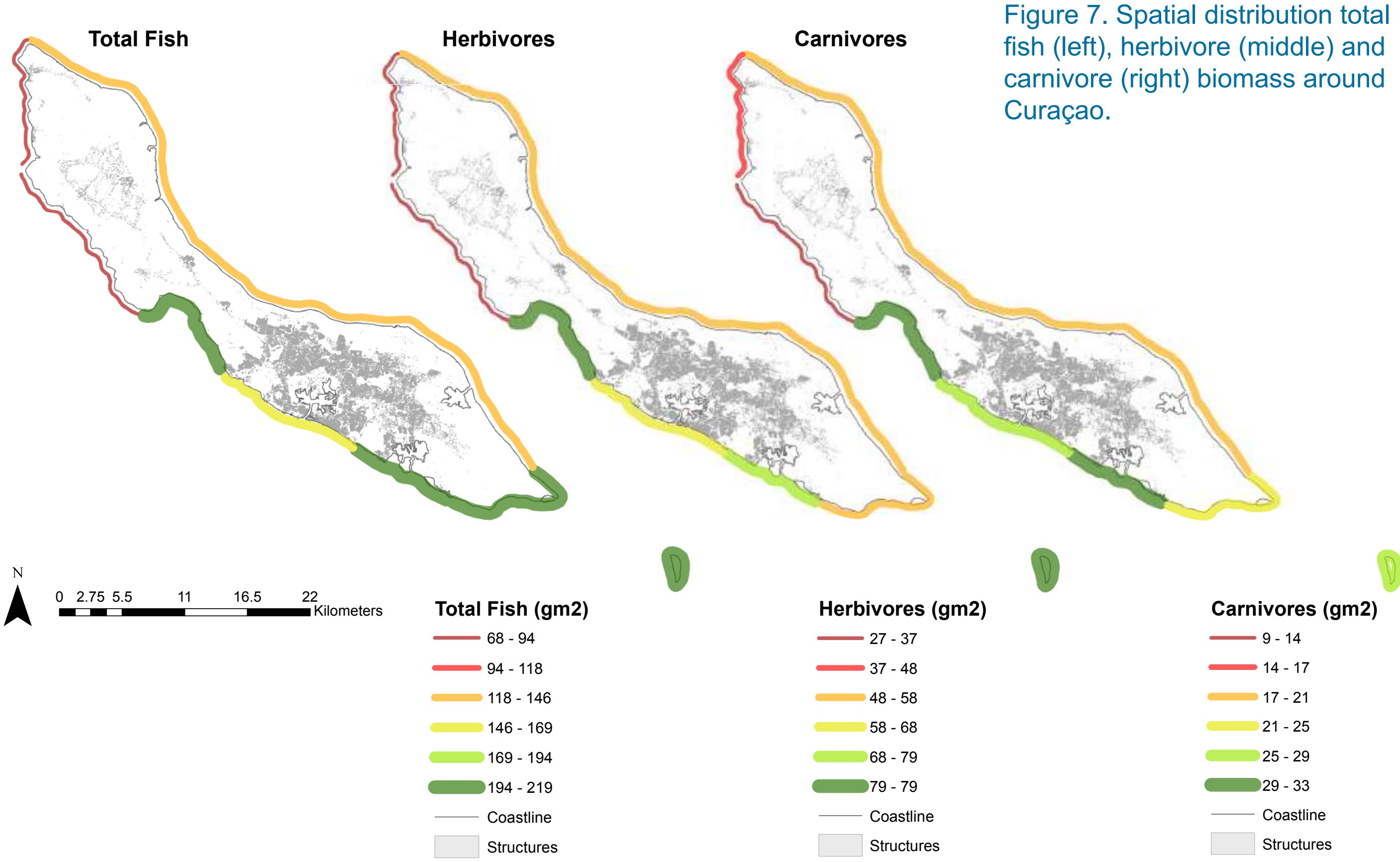


Figure 6. Average abundance per zone of the two most common algal types: turf algae (left) and macroalgae (right).

Figure 7. Spatial distribution total fish (left), herbivore (middle) and carnivore (right) biomass around Curaçao.



high biomass values on Curaçao are mainly the result of the high abundance of planktivorous fish that are relatively unimportant to reef ecosystem function or of interest to fishers.

On healthy reefs, biomass of herbivorous fish should be around 70 g m^{-2}, but preferably above 100 g m^{-2} (Edwards et al. 2014). While herbivore biomass is relatively high (58 – 89 g m^{-2}) in certain areas around Curaçao (Klein Curaçao to Willemstad and highest near Bullenbaai), herbivores in other areas on the island have decreased significantly in abundance to as low as 26 g m^{-2} in Zone 6. With this decrease in abundance comes a corresponding decrease in herbivores' ecological contributions as facilitators of coral growth.

Carnivorous fishes, such as sharks, groupers and snappers, should dominate a healthy reef fish community (Sandin et al. 2008). However, these species are found at extremely low abundances across all zones. The depletion of these species is especially worrisome as they support local fishing economies. In addition, they are important in controlling the abundance of certain fish species (e.g., damsel- and lionfish) that, when not controlled by predators, inflict significant damage to native reef communities and corals (Vermeij et al. 2015).

Water pollution

Coastal pollution (Figure 8) can arise from land-based infrastructure (coastal development), sewage and trash.The percentage of a watershed with developed infrastructure (buildings, roads, and other development) is commonly used to estimate the potential for land-based pollutants to discharge into an adjacent water body (Richmond et al. 2007). Watersheds (i.e., drainage basins) are areas of land that direct the flow of water to one point of discharge. In Curaçao, land-based pollutants can reach the sea through natural pathways, industrial pipes, sewage pipes and non-point source runoff from, e.g., boka's (bays), agriculture, cars, etc. In addition, septic systems have been shown to leach through porous limestone causing sewage water to end up in Curaçao's marine environment (van Buurt 2002).

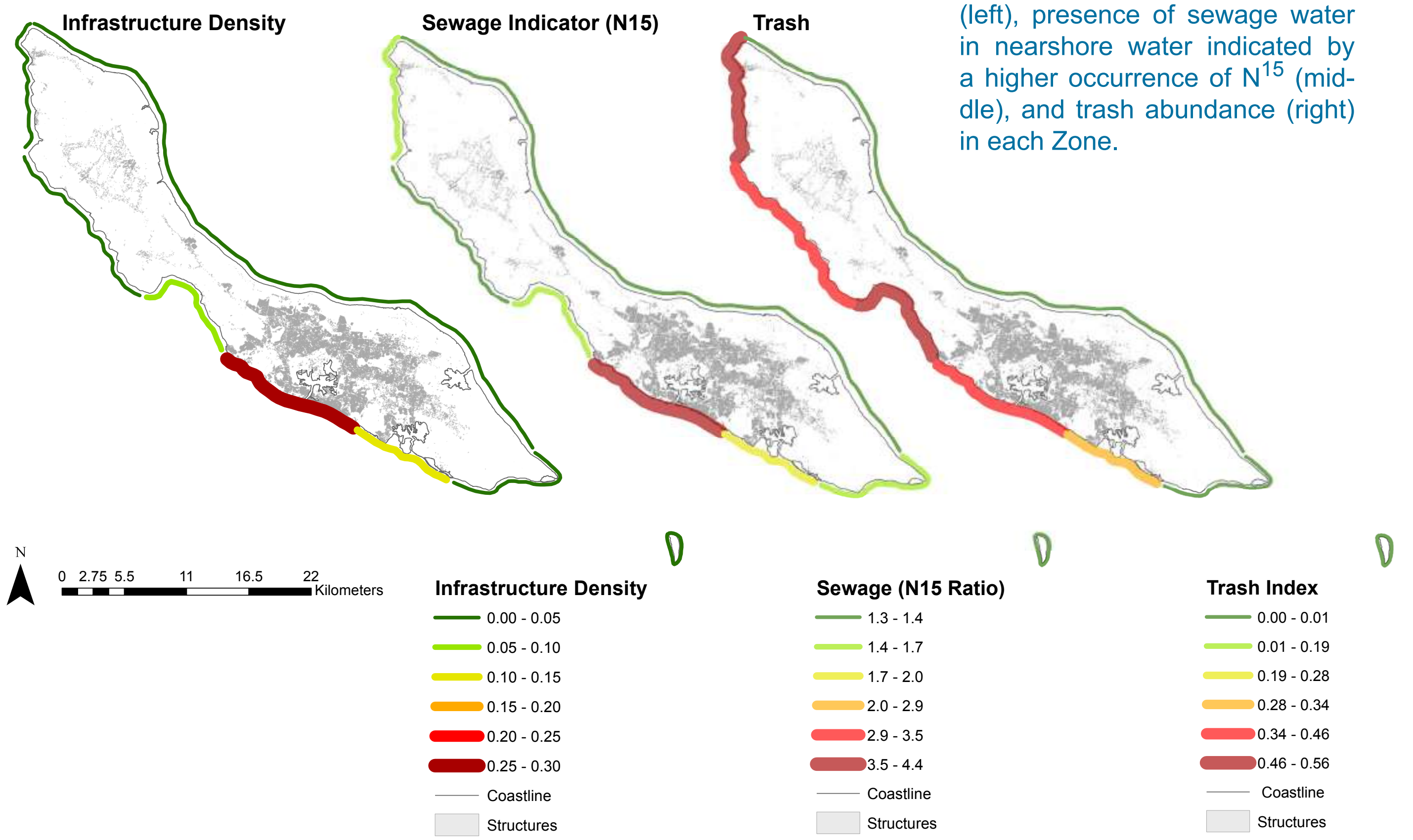


Figure 8. Coastal development (left), presence of sewage water in nearshore water indicated by a higher occurrence of N^{15} (middle), and trash abundance (right) in each Zone.

The presence of sewage can be measured by quantifying the amount of stable isotopes (N^{15}) in organisms that utilize nitrogen in the water column such as algae. Trash on the reef can be a product of at-sea pollution from fishing and other vessels in Curaçao's waters, land-based sources, and from sources outside of Curaçao's waters. Examples of trash include abandoned or lost fishing nets or lines that can damage marine life and can include plastics that can cause illness and mortality if ingested by fish, sea turtles, and marine birds (Eriksen et al. 2014).

Sewage pollution of nearshore waters is highest in Zone 4 (Willemstad), which is the most developed region of Curaçao (Figure 8). One site near the megapier having an N^{15} ratio that is an order of magnitude higher than the other zones as isotopes are measured on a logarithmic scale.

Trash is common on reefs in Zones 5 (Bullenbaai) and 7 (Westpunt). Extensive dumping has occurred historically on the north shore in Zone 8 and piles of car tires were observed at depths between 25 and 40 meters over an area that is multiple kilometers in length.

How are coastal waters used?

Reef fisheries have long sustained coastal communities by providing sources of both food and livelihoods. When well managed, such fisheries can be a sustainable resource, but growing human populations, more efficient fishing methods, and increasing demands from tourism and international markets have significantly impacted fish stocks. Removing just one group of fish from the reef food web can have cascading effects across the ecosystem. While large predatory fishes such as grouper and snappers are often preferred target species, fishers move to smaller, often herbivorous reef fish as the numbers of larger fish decline rapidly (in a process known as "fishing down the food chain") (Sandin et. al, 2010). Heavily fished reefs are thus left with low numbers of mostly small fish and, without herbivores, become prone to algal overgrowth. Such overfished reefs may be less resilient to (global) stressors, more vulnerable to disease, and slower to recover from other natural and human impacts (Hughes et. al, 2007).

Fishing pressure is highest in Zone 7 (Westpunt) and Zone 1 (Klein Curaçao) based on survey response from 62 fishers (Figure 9). Most fishing takes place offshore targeting deep-water or pelagic fish species (WI Listening Tour, 2016, Dilrosun, 2003) so the effect of this fishing effort on reef-associated fish communities is likely smaller than expected from Figure 9.

Fish stocks near Oostpunt (Zone 2), coastal waters off Willemstad (Zone 4) and along the north shore (Zone 8) experience the lowest fishing pressure on the island resulting relatively healthy fish stocks in this zone. Lack of fishing in Zone 4 (Willemstad) likely reflects the conflict between shipping traffic and small fishing vessels (e.g., wake waves from larger vessels may impact smaller fishing vessels). Rough ocean conditions and the long distance that vessels must travel from fishing ports to the North Shore likely prevents intensive fishing in this area.

Divers mostly visit Zone 3 (Caracasbaai) and Zone 7 (Westpunt) the most based on survey responses from 68 divers (Figure 10). Zones 3 and 7 also are areas experiencing high fishing pressure and value. Accessibility to divers and utility to dive operators are likely major factors in determining the value of a dive site. The potential for conflict from high overlap of use and value is thus greatest in these areas.

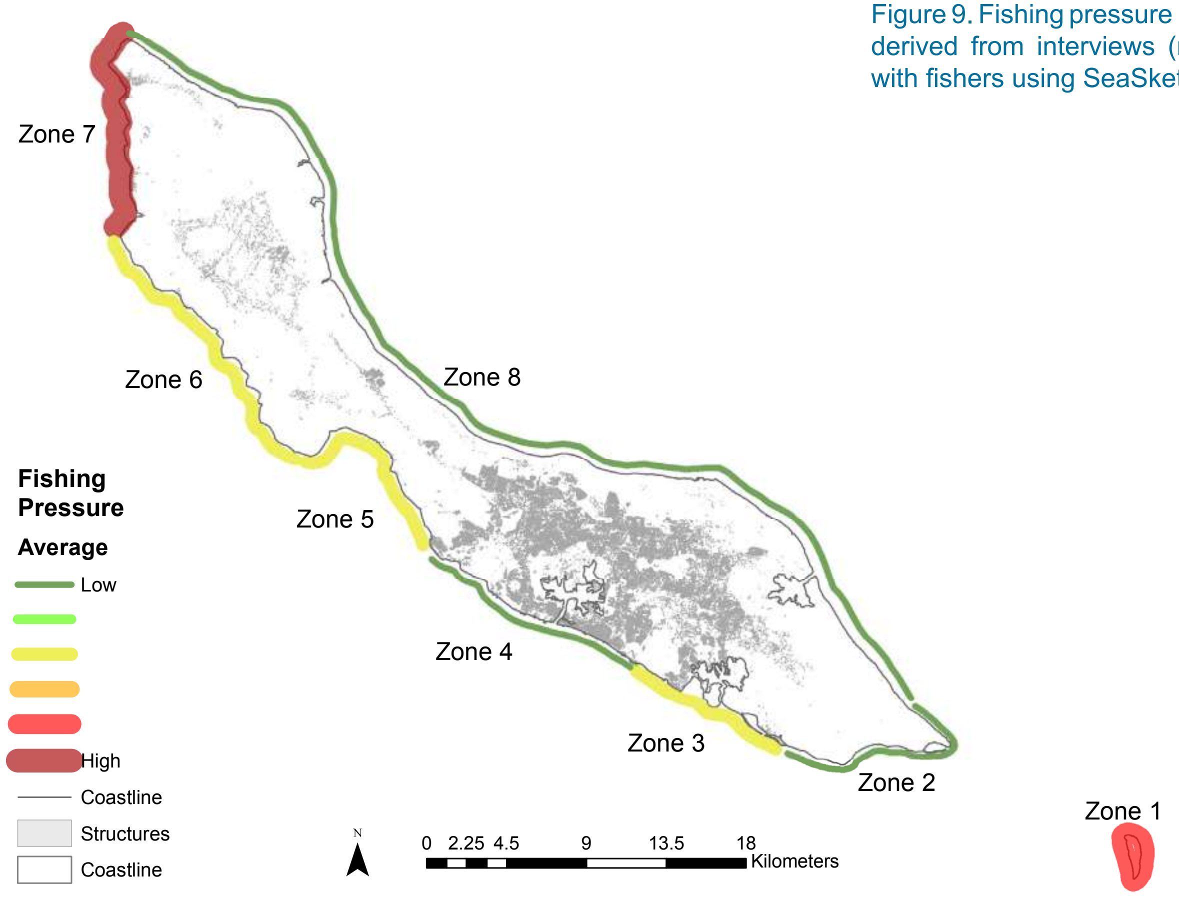


Figure 9. Fishing pressure by Zone derived from interviews (n= 119) with fishers using SeaSketch).

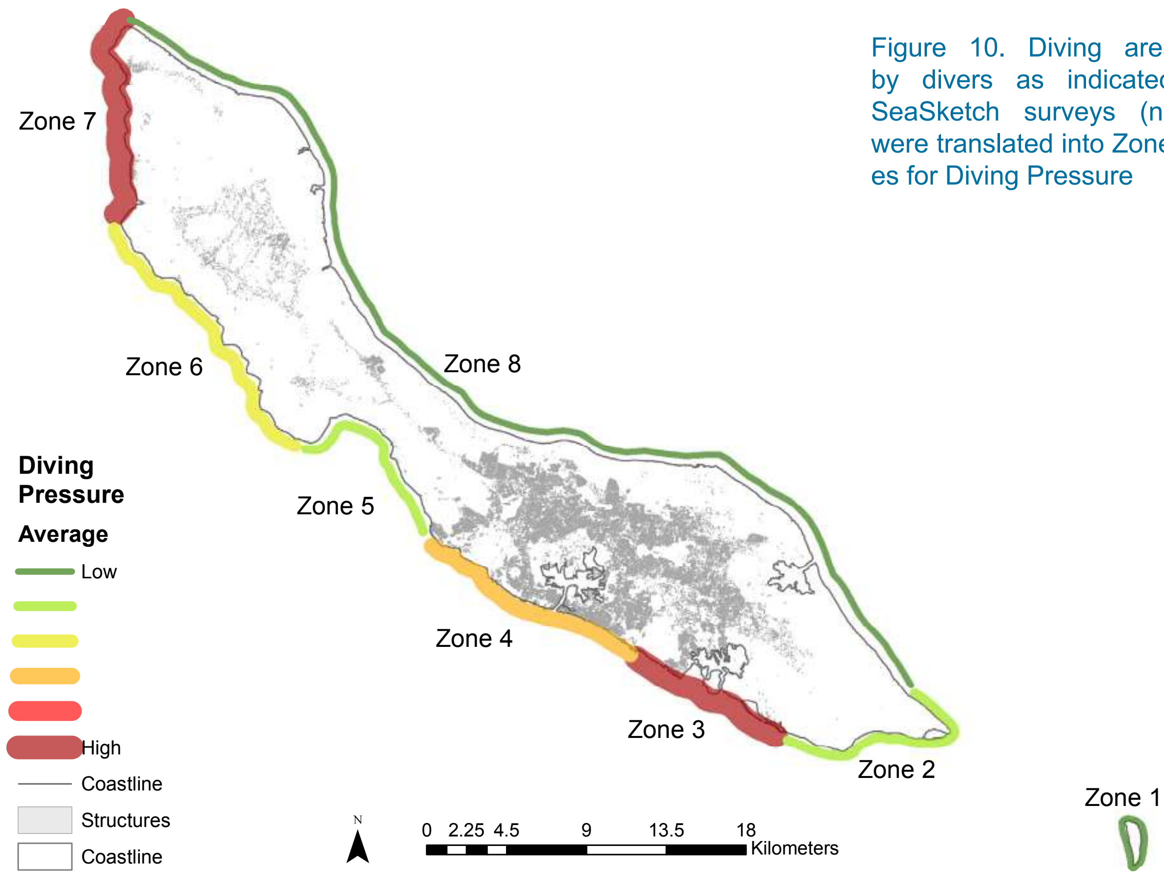


Figure 10. Diving areas used by divers as indicated during SeaSketch surveys (n= 1652) were translated into Zone averages for Diving Pressure

Table 1. Ecosystem Indicator Data by Zone.

Zone	Coral cover	Crustose coralline algae (CCA)	Juvenile coral abundance	Turf	Fleshy macroalgae
	Percentage cover	Percentage cover	(n per 0.06m2)	Percentage cover	Percentage cover
1	23.85	6.21	0.88	16.51	10.44
2	25.97	4.25	0.52	20.85	12.23
3	15.90	2.04	0.27	27.55	6.86
4	13.19	0.95	0.29	27.33	5.11
5	9.52	0.75	0.26	32.84	9.29
6	8.76	1.75	0.30	28.91	11.77
7	10.02	3.48	0.27	34.32	12.21
8	3.59	1.48	0.09	19.66	59.57

Zone	Total fish abundance	Herbivorous fish abundance	Carnivorous fish abundance	Fishing pressure	Diving pressure
	Biomass (gm^2)	Biomass (gm^2)	Biomass (gm^2)	Index	Index
1	219.38	83.18	28.69	6.19	0.88
2	194.68	57.90	24.46	3.98	1.86
3	218.91	74.34	32.54	4.86	6.70
4	156.34	68.31	27.92	3.71	4.14
5	206.82	89.36	32.39	5.24	1.86
6	68.34	26.68	9.77	5.26	2.68
7	88.05	33.06	15.62	7.54	5.65
8	144.27	56.23	18.71	3.43	0.10

Zone	Coastal development	Pollution by sewage	Marine trash	Coral cover (2015)	Coral cover (1982)
	Percentage of coastal zone with structures	(N15:N14 Ratio)	Index	Percentage cover (estimate)	Percentage cover (estimate)
1	0.00	1.26	0.00	27.94	n/a
2	0.00	1.47	0.08	34.85	48.50
3	0.14	1.83	0.30	16.12	24.05
4	0.30	4.39	0.35	12.22	22.00
5	0.05	1.52	0.53	10.12	31.76
6	0.02	1.32	0.36	14.82	35.60
7	0.03	1.55	0.56	12.53	41.22
8	0.02	1.35	0.00	2.68	37.14

Discussion

The following discussion provides a synthesis and evaluation of the Assessment's results. Current challenges to overcome include habitat loss, low juvenile coral density, depleted fish stocks, degraded water quality, and the cumulative impacts of human use including coastal zone development, fishing, and diving. First, the discussion examines the status of Curaçao's reef communities compared to other Caribbean islands. Second, it provides an overview of major and minor challenges that should be addressed to improve the condition of Curaçao's marine resources and ensure their sustainable use. The third section of this chapter provides a discussion on designing effective marine protected areas. It cites examples within the Caribbean and around the world to illustrate how these successes and lessons learned can be applied in Curaçao. Fourth, one-page summaries are provided, highlighting the status of reef communities and specific issues related to conservation and marine spatial planning in each zone.

Curaçao compared to other Caribbean Islands

From a Caribbean-wide perspective, Curaçao still harbors some of the best reefs in the region. They provide the island an opportunity to leverage the economic benefits of coral reefs and protect an important ecosystem that is becoming increasingly rare elsewhere in the Caribbean (Figure 11).

Curaçao's reefs are among the healthiest in the region, especially the reefs of Eastern Curaçao (Zones 1 and 2 in particular) (Figure 11). The absence of substantial hills and year-round rainfall likely contributes to the healthy reefs observed on islands in the Southern Caribbean. Hills and rain increase terrestrial run-off, which in turn carries nutrients and other pollutants to the sea. However, considering that average coral cover was close to 50 - 60% (Gardner et al. 2003; Jackson et al. 2013) in the Caribbean when researchers conducted robust surveys in the late 1970's, one quickly realizes that reefs on Curaçao have degraded over time,but to a lesser extent than most other islands in the Caribbean.

Curaçao therefore still has a unique asset compared to other islands in the Caribbean, but Curaçao's reefs are certainly in decline. With this decline comes the loss of ecosystem services including fishing and tourism as well as protection against storm surge and e.g., bioprospecting.

Issues to be addressed to prevent further decline of Curaçao's coral and fish communities

The following section discusses Curaçao's most significant challenges that must be overcome to restore the health and status of the nation's marine resources. These include the reversal of coral decline, overfishing, and degraded water quality, as these three factors—coral cover, fish and water quality—are essential to ensure proper system functioning in the long term (Kaufman et. al, 2011).

Issue: decreasing abundance of reef building corals

In the early 1980's reef building corals made up ~34% of Curaçao's reefs (Van Duyl 1985). In 2010, that number had already dropped to 23.2% (Vermeij 2012), indicating that coral cover had decreased by 42% in only three decades. This worrisome trend is confirmed by the findings of this 2015 Assessment, that now estimates 16% coral cover along Curaçao's southern coast. The 1982 surveys by Van Duyl focused exclusively on the south side of the island, but comparing this data

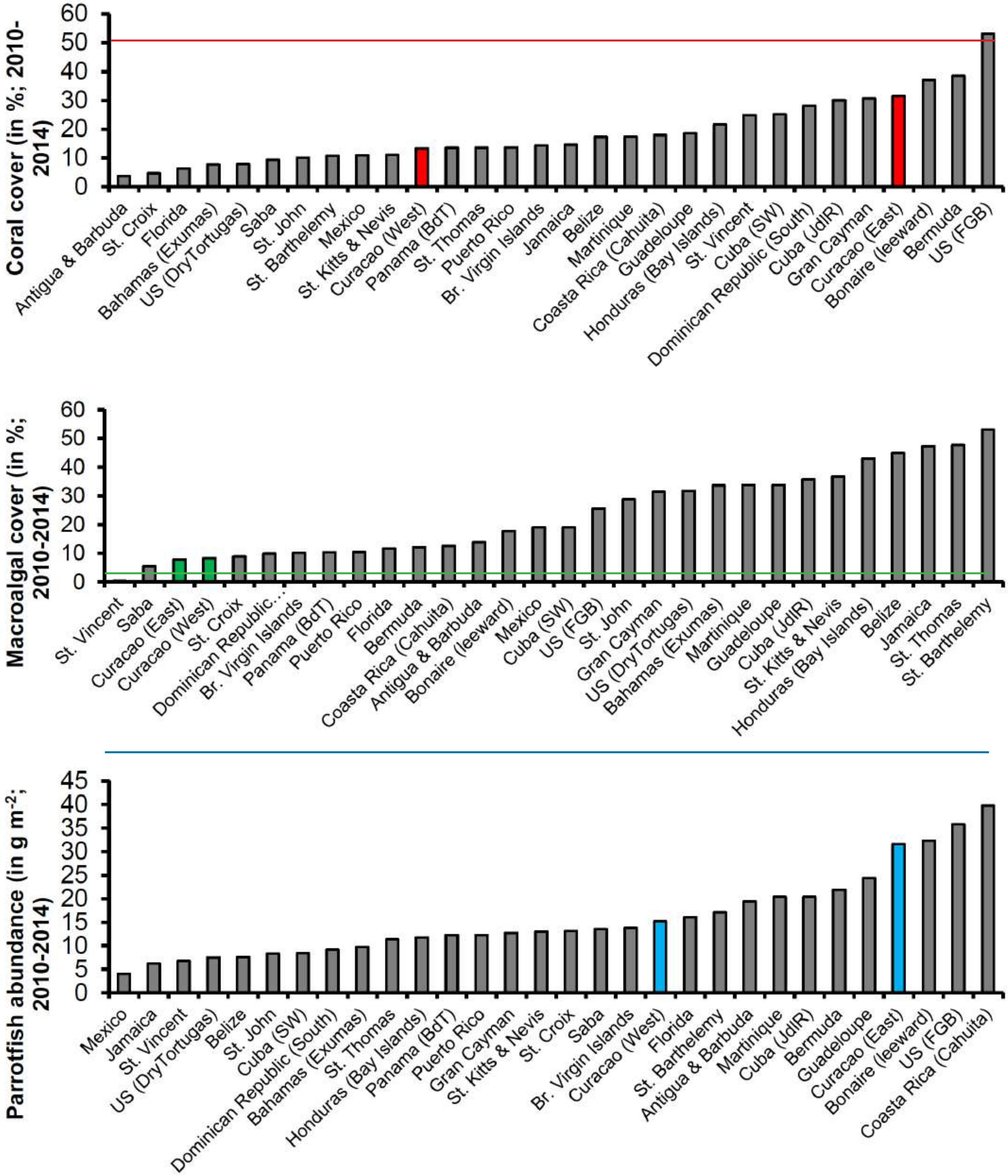


Figure 11. Overview of commonly used metrics for coral ecosystem health of Curaçao's coral reefs in comparison to other Caribbean islands and nations. Horizontal lines indicate accepted values for healthy reefs. Note that in the middle panel algal abundance should be under the horizontal line for a reef to be considered healthy. 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 are not included in this comparison).

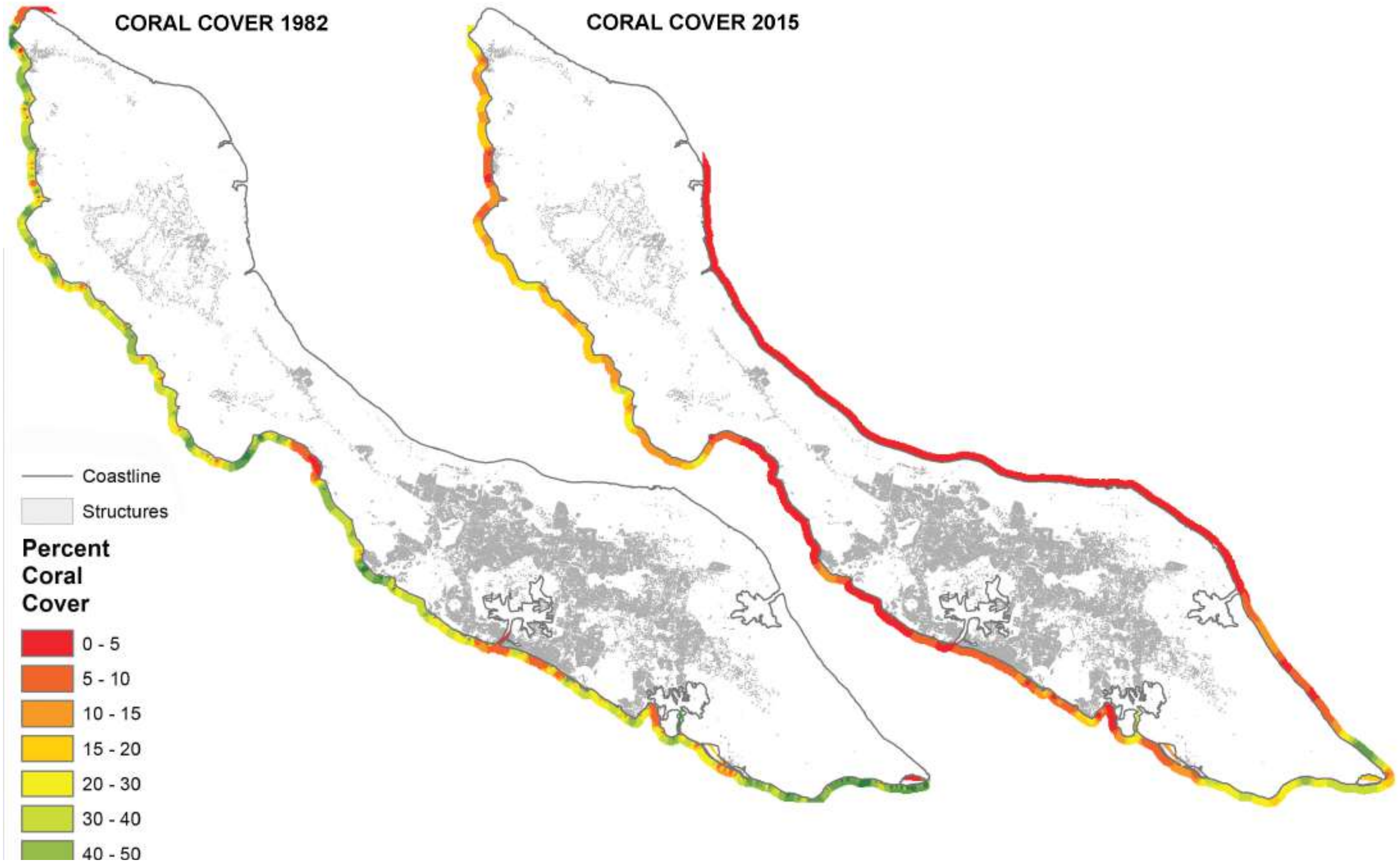


Figure 12. Massive, island wide declines in coral cover over the past 30 years. Note that information from the North shore is unavailable for 1982.

set to the one presented here shows that Curaçao has experienced a drastic decline in coral cover (Figure 12). In 1982, coral cover was 34% on average and exceeding 75% in many areas along the south coast, but is now below 20% and in many locations below 10%. These findings indicate that between 1982 and 2015, Curaçao has lost over 50% of its living coral. Given that tourism makes up 18% of Curaçao's economic sector (SFG, 2016) and much of the ocean-based tourism is dependent on the health and beauty of Curaçao's marine resources, this figure highlights the critical need for a strong management system to ensure coral reef ecosystem health and recovery into the future.

Reef conditions are highly variable in the waters surrounding Curaçao. Large sections along the middle and western side of the island have coral abundances slightly below the regional average (Figure 11, top). However, the island also has a significant amount of reefs with coral abundances that approach the regional maximum. For example, almost one-third (29%) of all surveyed sites have a coral cover above the Caribbean regional average (16.8%). The relatively high abundance of areas with high coral cover and arguably functional reef communities makes Curaçao's reefs different from the reefs of many other Caribbean countries. Curaçao stands together with Bonaire and has been identified as one of the few places in the Caribbean where healthy reefs can still be found (Jackson et. al 2014).

Curaçao has a low abundance of macroalgae compared to other locations in the region (Figure 11, middle). This is likely contributable to the high biomass of herbivores (Figure 11, bottom) that keep macroalgal abundance low through grazing. Figure 13 shows the changes in turf algae, macroalgae and coral cover through time based on 12 sites around Curaçao. It shows that coral cover has declined precipitously. While the low abundance of macroalgae is a hopeful signal, the rise

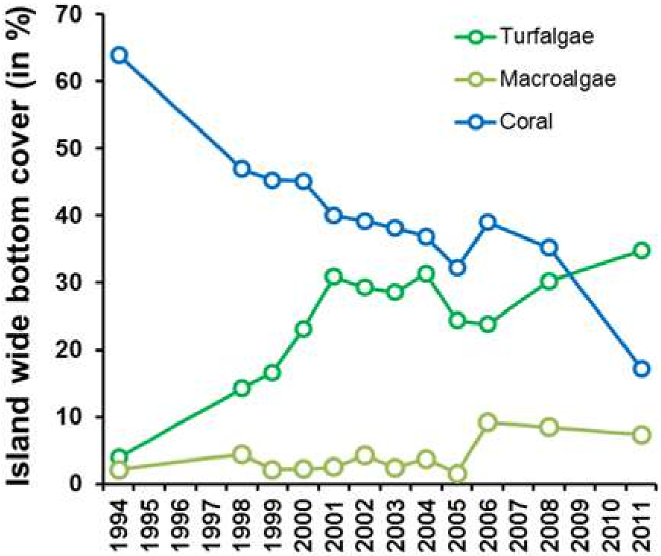


Figure 13. Example of the shift in Caribbean reef community structure from coral dominance to turf algae. While the abundance of macroalgae has increased, the increase in turf algae is much larger and both algal groups are indicative of reef decline. Shown are the averages of 12 sites around the island of Curaçao (Carmabi, unpubl. data).

of turf algae is worrisome. Turf algae are multi-species communities of small marine algae that are becoming a dominant component of coral reef communities around the world. A study found that turf algae cover 40.3% of the reef bottom on Curaçao's south shore (i.e., all bottom not covered by sand), and cause both visible (overgrowth) and invisible negative effects (reduced fitness) on neighboring corals (Vermeij et al. 2010).

When increased nutrients are present in the water, turf algae rapidly overgrow corals (at a rate of 0.34 mm 3 wk^{-1}). In contrast to macroalgae, herbivores have no effect on the rate by which turf algae overgrow corals (Vermeij et al. 2010). The combined effect of nutrient loading and herbivore ineffectiveness gives turf algae a competitive advantage over corals, raising serious concerns regarding the future health of Curaçao's coral reef systems.

Traditional conservation measures to reverse coral-to-algae phase shifts focus on reducing algal abundance, i.e., increasing herbivore populations by establishing marine protected areas or strengthening fishing regulations. Such an approach may not reduce the negative impact of turf algae on local coral communities. Because turf algae have become the most abundant benthic group on Curaçao (and likely elsewhere in the Caribbean), new conservation strategies are needed to mitigate their negative impact on coral communities. Such approaches should focus on improving coastal water quality, especially as it relates to nutrient inputs from sources including sewage and septic systems.

The ability for Curaçao's reefs to regrow through the establishment of new corals appears compromised. A comparison of the community structure of juvenile corals between 1975 and 2005 already showed a decline of 54.7% in juvenile coral abundance (Vermeij et al. 2011), and this Assessment confirmed these results. In 2005, the island wide average density of juvenile corals was still approximately 10 individuals m^{-2}, but decreased to 5.4 individuals m^{-2} in 2015. Only Klein Curaçao and Oostpunt reefs (Zones 1 and 2) still harbor juvenile coral communities indicative of healthy reefs, and make up approximately half all recruits found during this Assessment.

Because the maintenance and recovery of coral communities depends (amongst other things) on the successful establishment, early survival, and subsequent growth of coral larvae, these observations are worrisome and once again illustrate the magnitude of the changes that have occurred in only three decades in Curaçao reef communities. Although the 54.7% decline in juvenile abundance between 1975 and 2005 can be both a cause and consequence of the decline in adult coral cover on these reefs, these findings indicate that fundamental processes required for population main-

tenance and recovery are operating at rates well below their historic baselines.

Issue: overfishing

In comparison to other locations in the Caribbean, the reefs of Curaçao have fair, but not high, fish abundances. Reef fish abundance also varies greatly among sites along the island's southwest coast.

As discussed previously, herbivorous fishes play an important role in keeping reefs free of excess algal growth. Less algae means more space for coral growth. Therefore maintaining and enhancing Curaçao's herbivorous fish populations is an important element in maintaining and enhancing Curaçao's coral reefs as a whole.

Reef fish species of commercial interest (e.g., large snappers, groupers, barracuda's) are relatively rare (<5 grams per square meter) at the sites examined and only represent 4% of the total fish biomass on Curaçao's reefs.

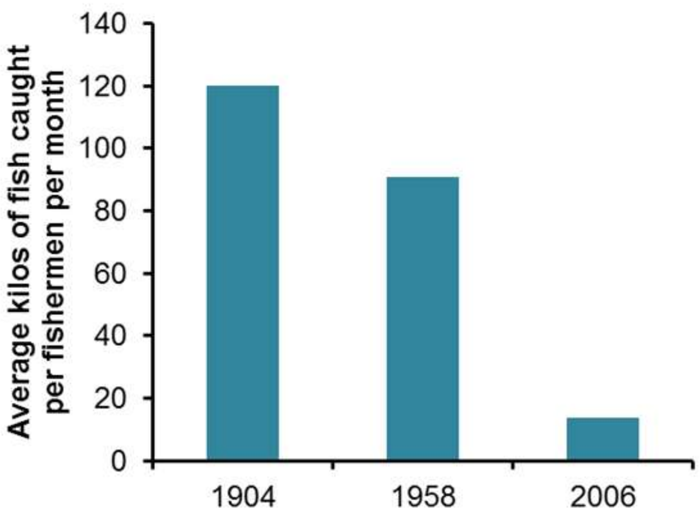


Figure 14. Catch per unit effort (CPUE) of hand-line fishing on Curaçao over three time points across a hundred year time scale. Data: Carmabi unpubl. report.

The 90% decline in catches between 1904 and 2006 (Figure 14, Carmabi, unpubl. data) can be attributed to severe overexploitation of the waters surrounding Curaçao during the last century. Because the introduction of nylon fishing lines in 1934 and the use of larger and faster fishing vessels allowed fishers to catch more and larger fishes (Boeke 1907; Zanenveld 1961), one would expect the catch in 1958 to be higher than in 1904. Nevertheless and despite the increased fishing efficiency, the catch has decreased by 25% over this 50 year period, suggesting that the first effects of overfishing were already evident in the mid twentieth century.

Catch per unit effort has decreased substantially between 1904 and 2006 due to a drastic decline in demersal and pelagic fish abundance. This has led to a shift from demersal towards pelagic species and forced fishers to target low market value species. The largest decrease in abundance was found for large predators who are virtually absent from the reefs at present. Moreover, the severe decline in coral cover over the last decades caused by pollution, eutrophication, physical destruction of habitats, outbreaks of disease, invasions of introduced species, and human induced climate change also contributed to the decline of reef fish abundance, warning against simplistic views whereby fishers alone are held responsible for the current depauperate status of commercial reef fish communities.

The story of lowering fish catches in Curaçao is a common one throughout the world's oceans. In many locations, artisanal fisheries have depleted coastal and pelagic waters by overharvesting populations of large predatory fish species, resulting in a present day fish community that differs markedly in composition and abundance to communities observed decades or centuries ago (Jackson et al. 2001). In many cases, these predatory fishes have become so rare that they no longer interact with other community members in the ecosystem and phenomenon referred to as "ecological extinction" (Stallings 2008). The removal of predators also reduces their role in controlling community members. This loss has ecological consequences (e.g. the outbreaks of diseases, the proliferation of invasive species, changes in herbivory) further down the trophic chain, a phenomenon known as "trophic downgrading" (Sandin et al. 2010).

Once again, these effects demonstrate the interconnected nature of the coral reef ecosystems, which means that achieving a sustainable ocean policy in Curaçao may require a diversity of approaches to tackle the most pressing challenges.

Issue: degraded water quality

Human activities far inland can impact coastal waters and coral reefs. At the coast, sediments, nutrients, and pollutants disperse into adjacent waters. Such impacts can be reduced where mangrove forests or sea grass beds serve as a buffer and filter between land and the reefs. In high quantities, sediments can smother, weaken, and kill corals and other benthic organisms. The discharge of excessive nutrients like nitrogen and phosphorus in shallow coastal waters (i.e., eutrophication) can encourage an explosion of phytoplankton in the water column, known as an algal bloom.

Such blooms reduce light levels reaching the corals and can cause vigorous growth of algae and seaweeds on the seabed that out-compete or overgrow corals. In severe cases (which have

occurred on Curaçao in 2009 and 2011 (Vermeij, 2012)), eutrophication can lead to hypoxia (i.e. depletion of oxygen). As algal blooms run their course and decompose, the microbes that enable such decomposition consume the oxygen in the water column. This loss of oxygen can become so low that animals cannot survive. Known as "dead zones," fish that cannot escape them die and eventually nearshore ecosystems can collapse.

In addition to nutrients, coral reefs change when carbon-based compounds enter the system. Such compounds come from sewage and other land-based sources such as sediment runoff. Carbon-based compounds provide food to microbes. As a result microbes increase in abundance and become increasingly more pathogenic (Rosenberg et. al, 2007, Havell et. al, 2007). Therefore, as for nutrients, unnatural carbon sources (e.g., sewage, terrestrial run off) should be minimized in order to prevent the rise of pathogens (i.e., "microbialization") on Curaçao's coral reefs.

Excessive levels of nutrients like nitrogen and phosphorus in shallow coastal waters (i.e., eutrophication) can encourage blooms of phytoplankton in the water, which block light from reaching the corals and seagrasses, or they can cause vigorous growth of algae and seaweeds on the seabed that out-compete or overgrow corals. In severe cases (which have occurred on Curaçao in 2009 and 2011), eutrophication can lead to hypoxia (oxygen deficiency), where decomposition of algae and other organisms consumes all of the oxygen in the water, leading to "dead zones." With dead zones comes fish kills and eventually complete nearshore ecosystem collapse.

Similar to nutrients, coral reefs change when carbon-based compounds ("sugars') enter the water. Addition of carbon compounds fuels local microbial communities that feed on these compounds. As a result microbes increase in abundance and become increasingly more pathogenic for marine life and people using these waters. Therefore, in addition to nutrients, unnatural carbon sources (e.g., sewage, terrestrial run off) should be minimized in order to prevent the rise of pathogens (i.e., "microbialization") of Curaçao's coral reefs.

Sedimentation is another challenge that often occurs in the process of coastal development in the absence of proper safeguards. In high quantities, sediments can smother, weaken, and kill corals and other benthic organisms.

Mangroves and sea grass beds reduce sediment and other pollution impacts by serving as filters to land-based pollution and sediment traps, but these resources are also threatened by pollution. Curaçao has a small amount of seagrass habitat (~10 hectares) that serves as a nursery ground for fish. Like corals, seagrasses require sunlight to survive and their growth can be inhibited by algal blooms that come with nutrient pollution. Eutrophication of coastal waters is currently the largest threat to Curaçao's seagrass habitat (Govers et al. 2014; Green and Short 2003).

Minor challenges related to ocean usages

In addition to coral reef decline, overfishing, and degraded water quality, both diving and boating can have negative impacts on the health of Curaçao's marine ecosystem (Saphier et. al, 2005). While impacts from diving and boating are significant, they are minor in comparison to the primary factors driving the decline of Curaçao's marine resources. Addressing these challenges will provide benefits and reduce cumulative impacts, but will not provide the magnitude of relief that repairing water treatment facilities and designating no take zone's will provide.

Undertaking efforts to mitigate these challenges should not impede or replace action needed to address the major challenges described in the previous section.

Curaçao is a popular dive destination that attracts approximately 58,000 divers each year who conduct an average of 4 dives per visit (SFG, 2015) (Croes et. al, 2015). The diving industry is an important economic sector in Curaçao estimated at $32.8M (SFG Economic Valuation, 2015). However, diving can cause structural damage to corals and impact coral health, reducing ecosystem services provided by coral reefs in the long term (Barker et. al, 2004).

Diving impacts can be minimized, however. Researchers have demonstrated that effective management practices and diver training through predive can significantly reduce the impacts of diving activities on coral reefs (Medio et. al 1997). In addition, briefings are rendered more effective when dive instructors engage in intervention after a diver makes contact with a reef (Barker and Roberts, 2004).

Over 3,000 boats are registered on the island of Curaçao, and conversations with the port authority indicate that there are estimated to be an additional 1,200 unregistered boats. Curaçao's shelf is narrow, and there are limited areas for safe anchorage. Further, most boats are restricted to the south shore due to rough conditions on the north shore. Many deploy anchors on the reef and can become stuck, thereby damaging it. Though not quantified, during the course of the marine surveys, divers saw many anchors lodged into the reef (typically home made). Similar to diving, the effects of anchoring causes immediate and acute physical damage to the reef, and can accumulate causing significant long-term impacts (Forrester et. al, 2015). Providing clearly marked anchorage areas and public moorings can yield a predictable outcome by eliminating anchoring on coral reefs.

Curaçao's industrial shipping industry also possesses numerous challenges to ocean users and local ecosystems. Large vessel traffic can cause impacts to local users including large wakes that preclude use of small boats in Zone 4 and 5 (Willemstad and Bullenbaai). More significantly, accidents involving large vessels have the potential to cause drastic and irreversible damage to coral reef and mangrove ecosystems. In 2012, a large oil spill occurred near the Bullenbaai facility. The spill impacted Jan Kok, a RAMSAR site, fouling it with crude oil that covered mangroves, birds, and other fauna in oil and causing mass mortality. Scientists have recently confirmed dramatic long-term effects of the oil spill on coral communities. Such research indicates that crude oil exposure on reefs significantly reduces the ability of coral larvae to settle on a reef (Hartmann et. al, 2015). This impact to larvae has concerning implications for the new generations of corals that are necessary to maintain healthy reefs.

Information not included in this report

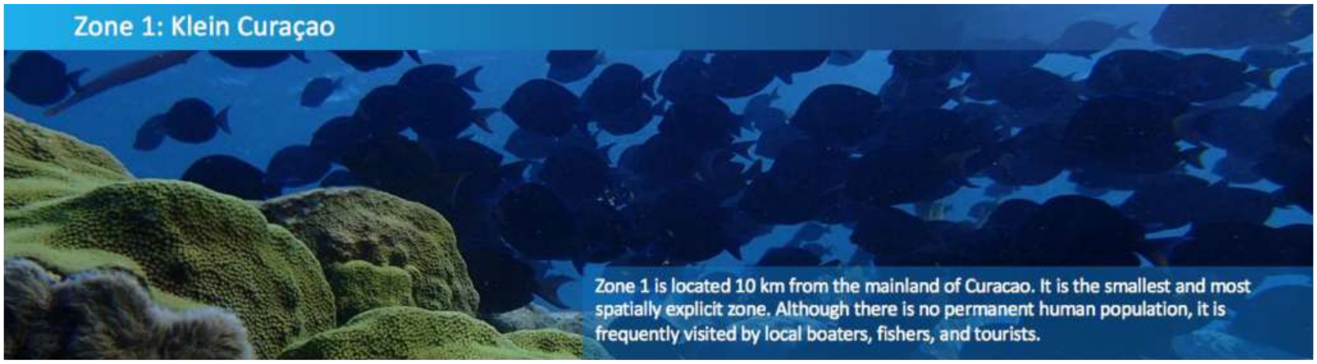
This Scientific Assessment largely focuses on the coral reefs of Curaçao. It was beyond the scope of this assessment to evaluate the crucial resources of inland bays, including seagrass beds and mangroves, as well as mesotrophic reefs, deep sea systems and offshore habitats. Such habitats provide important services in their own right. They also support healthy coral reef ecosystems. Some of these ecosystems are already targeted for protection, including nine sites proposed as RAMSAR wetlands of international significance. Furthermore, this Assessment did not evaluate threatened and endangered species or other depleted species in detail, including sea turtles, cetaceans and sharks. These species are the focus of existing protection efforts as well.

In addition, it was beyond the scope of this assessment to evaluate all of the threats to Curaçao's marine ecosystems. These include assessing and evaluating impacts from oil and other toxic compounds, climate change impacts including warming, acidification and sea level rise, and unsustainable coastal development practices.

An overview of existing knowledge on these topics is included in the Appendices at the end of this document.

Zone summaries

We identified eight distinct zones of Curaçao's nearshore environment. Ecosystem characteristics and human influence varied significantly between zones reflecting the distribution and intensity of cumulative impacts, or lack thereof. With that, each zone presents specific opportunities and challenges for management to protect and/or restore the assets of each zone. This section provides a summary of each zone that highlights key characteristics of the marine environment, identifies the status of ecosystem indicators in comparison to other zones and the greater Caribbean, and discusses conservation opportunities that provide the largest impact. Note that each summary is based on a zone average, and does not reflect within zone variability.



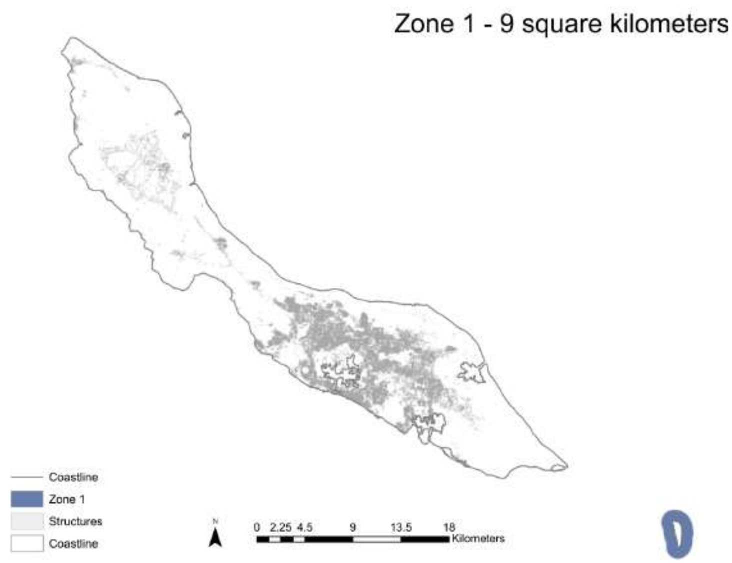
KEY FINDINGS

- Zone 1 has the highest density of juvenile corals and the second highest live coral cover. Recruitment of corals is over three times higher than any other zone on the island except Zone 2 (Oostpunt).
- Zone 1 has the highest average fish biomass on Curaçao, although fishing pressure is relatively high in this general area. Herbivore biomass (parrotfish and surgeonfish) is also among the highest of all zones, comparable only to Zone 5 (Bullenbaai).

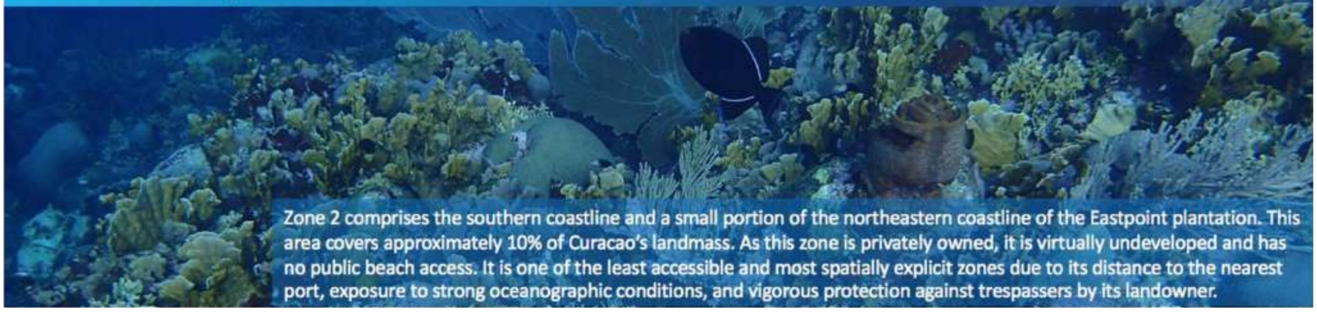
CONSERVATION OPPORTUNITIES

- The high fish biomass and coral cover coupled with its remoteness make Klein Curaçao an excellent candidate for protection (e.g., as a RAMSAR area); however enforcement may be provide challenges.

CORAL	COVER	Very High
	JUVENILE CORALS	Highest
	CORAL HEALTH	60%
	DECLINE	NA
BIOMASS	TOTAL FISH	Highest
	HERBIVORES	Very High
	CARNIVORES	High
POLLUTION	INFRASTRUCTURE	Very Low
	SEWAGE	Lowest
	TRASH	Lowest
USE	FISHING	Very High
	DIVING	Very Low



Zone 2: Oostpunt



Zone 2 comprises the southern coastline and a small portion of the northeastern coastline of the Eastpoint plantation. This area covers approximately 10% of Curacao's landmass. As this zone is privately owned, it is virtually undeveloped and has no public beach access. It is one of the least accessible and most spatially explicit zones due to its distance to the nearest port, exposure to strong oceanographic conditions, and vigorous protection against trespassers by its landowner.

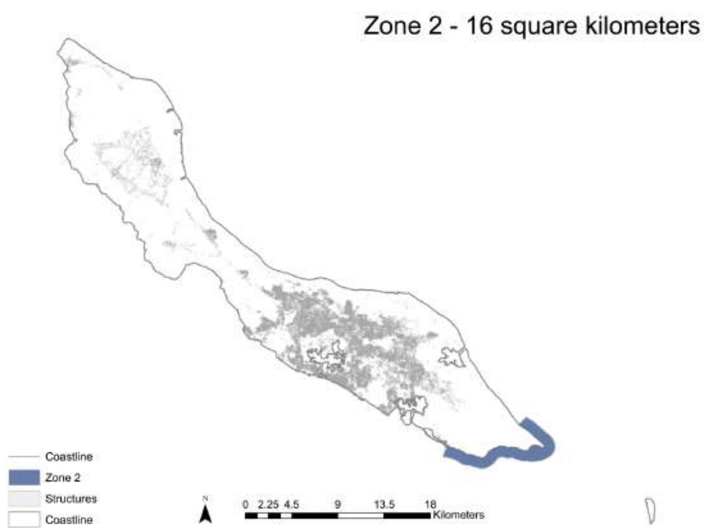
KEY FINDINGS

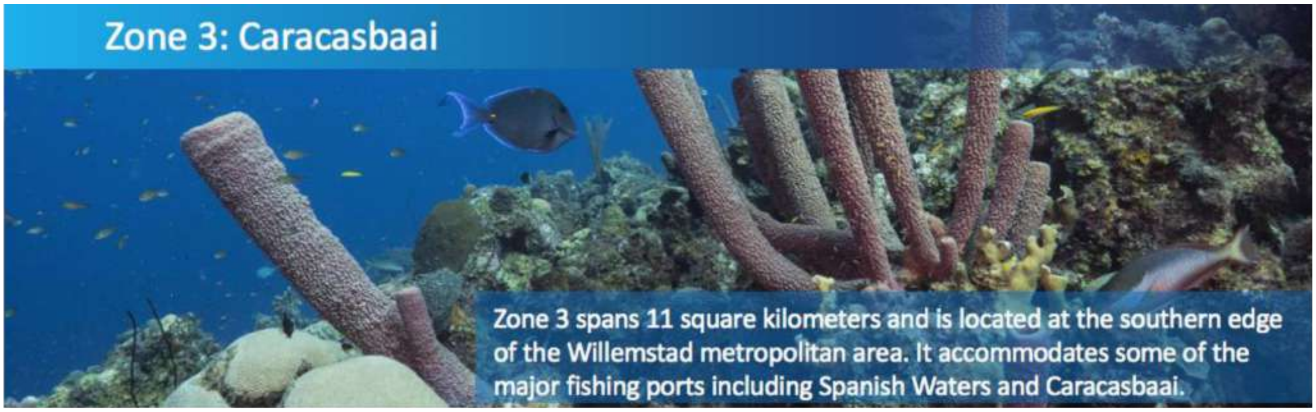
- Zone 2 has a high percentage of live corals. It also has the second highest density of juvenile corals, being two times higher than other zones.
- This zone has above average fish biomass.
- Use from fishers and divers is low, as is water pollution from trash and sewage

CONSERVATION OPPORTUNITIES

- Zone 2 is another excellent candidate for protection to preserve this area of high coral recruitment that is important to the long-term survival of coral reefs in Curaçao. Other biological and physical characteristics that support the creation of a protected area in Zone 2 include high fish biomass, already low use from fishers or divers, and the lack of development as well as its up-current location from significant infrastructure.

CORAL	COVER	Highest
	JUVENILE CORALS	Very High
	CORAL HEALTH	65%
	DECLINE	14%
BIOMASS	TOTAL FISH	High
	HERBIVORES	Average
	CARNIVORES	Average
POLLUTION	INFRASTRUCTURE	Lowest
	SEWAGE	Very Low
	TRASH	Very Low
USE	FISHING	Low
	DIVING	Low





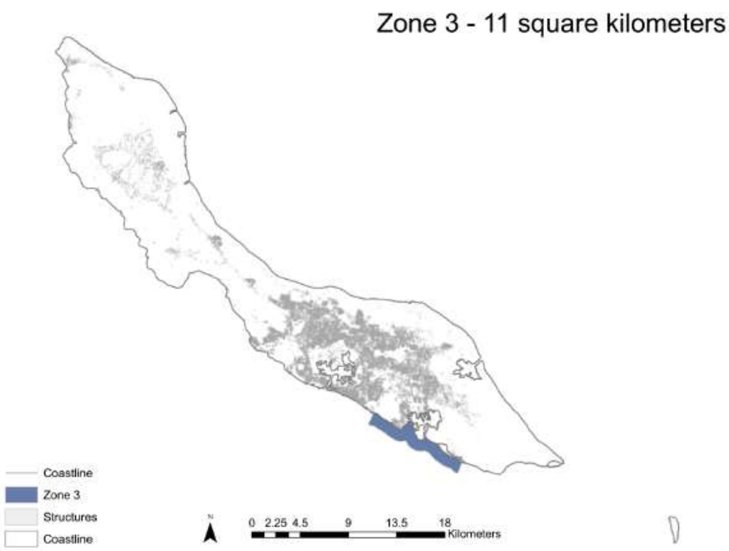
KEY FINDINGS

- This area has the most divers in all of Curaçao.
- Zone 3 has the second highest fish biomass in Curaçao although major ports are located in this area.
- Zone 3 marks the shift into low coral recruitment across the remaining south shore. This is of particular concern as juvenile corals represent the future of Curaçao's reefs and should be one of the highest priorities for conservation.
- Although infrastructure density is the second highest in the country, water pollution from sewage and trash is average.

CONSERVATION OPPORTUNITIES

- Zone 3 should remain a multi-use zone due to its high and diverse level of use. However, small but highly enforced measures could allow coral cover to increase which may subsequently improve fish stocks. For instance, implementing an anchoring ban and requiring dive briefings can greatly reduce the amount of physical destruction inherent to boating and diving which cause significant long-term damage (Saphier et. al, 2005).

CORAL	COVER	Above Average
	JUVENILE CORALS	Below Average
	CORAL HEALTH	40%
	DECLINE	8%
BIOMASS	TOTAL FISH	Very High
	HERBIVORES	High
	CARNIVORES	Highest
POLLUTION	INFRASTRUCTURE	High
	SEWAGE	Average
	TRASH	Above Average
USE	FISHING	Average
	DIVING	Highest



Zone 4: Willemstad

KEY FINDINGS

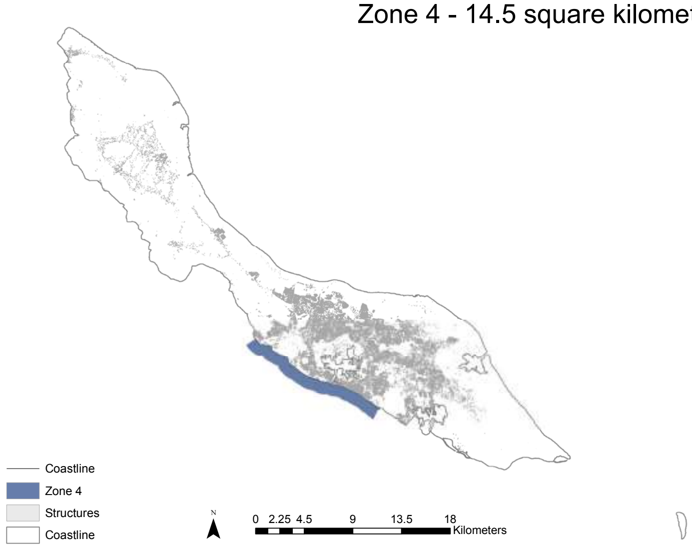
- This is the most polluted zone across Curaçao with high N^{14}/N^{15} ratios. The zone average is 4.4 but goes up 12.0 near the cruise terminal where two sewage outflow pipes are located (in contrast the unpopulated Oostpunt average is 1.47). These pollution levels indicate that wastewater is not being properly managed.
- Despite water pollution, Zone 4 receives an above average amount of diving.
- Coral cover is slightly below the Caribbean average of 16%, and fish biomass is average.

CONSERVATION OPPORTUNITIES

- Zone 4 should remain a multiple use zone. However, Curaçao should prioritize strict enforcement of pollution requirements and expand management of land-based and at-sea pollutants to restore coastal water quality to safe levels.

CORAL	COVER	Average
	JUVENILE CORALS	Below Average
	CORAL HEALTH	33%
	DECLINE	10%
BIOMASS	TOTAL FISH	High
	HERBIVORES	Above Average
	CARNIVORES	Above Average
POLLUTION	INFRASTRUCTURE	Highest
	SEWAGE	Highest
	TRASH	Above Average
USE	FISHING	Low
	DIVING	High

Zone 4 - 14.5 square kilometers



KEY FINDINGS

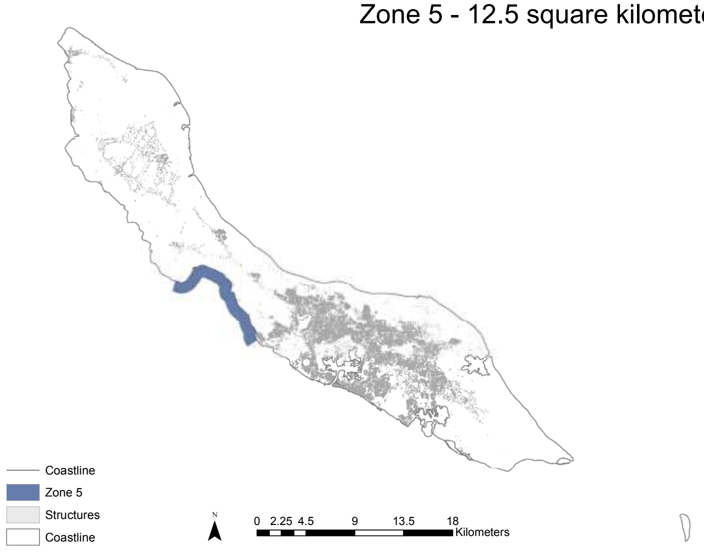
- Zone 5 has high fish biomass and contains the highest herbivore biomass across the island. It is likely that fishers utilizing this zone do not target herbivores or are not able to fish them due to shipping traffic.
- Average coral cover is low within the eastern half of the bay, but is significantly higher in robust reefs near the western point of the bay.

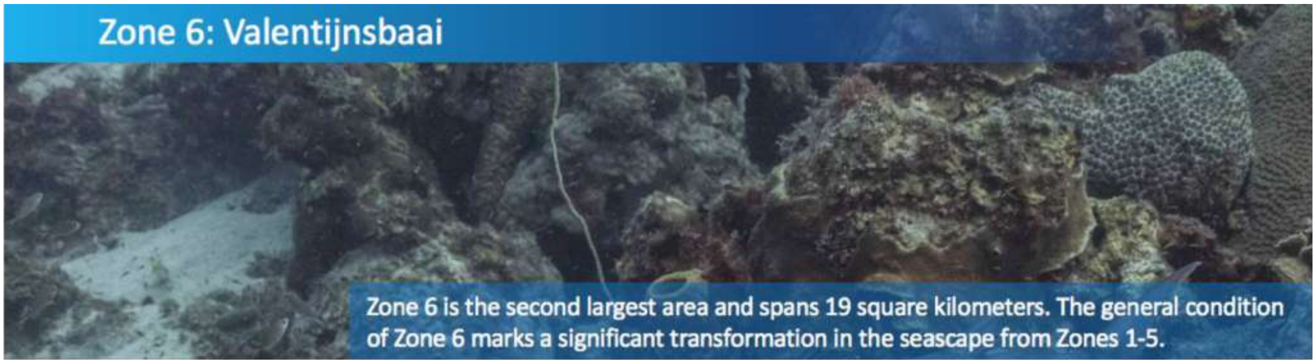
CONSERVATION OPPORTUNITIES

- Robust fish population, above average coral reefs on the western side of the bay, and potential protection of fish provided by industrial shipping traffic indicate that additional protection in Zone 5 may yield significant benefits from spillover for adjacent zones.
- Formally designated industrial shipping lanes to exclude recreational and fishing vessels should also be considered to avoid conflict with other vessels.

CORAL	COVER	Below Average
	JUVENILE CORALS	Below Average
	CORAL HEALTH	24%
	DECLINE	22%
BIOMASS	TOTAL FISH	High
	HERBIVORES	Highest
	CARNIVORES	Very High
POLLUTION	INFRASTRUCTURE	Below Average
	SEWAGE	Below Average
	TRASH	Very High
USE	FISHING	Above Average
	DIVING	Low

Zone 5 - 12.5 square kilometers





KEY FINDINGS

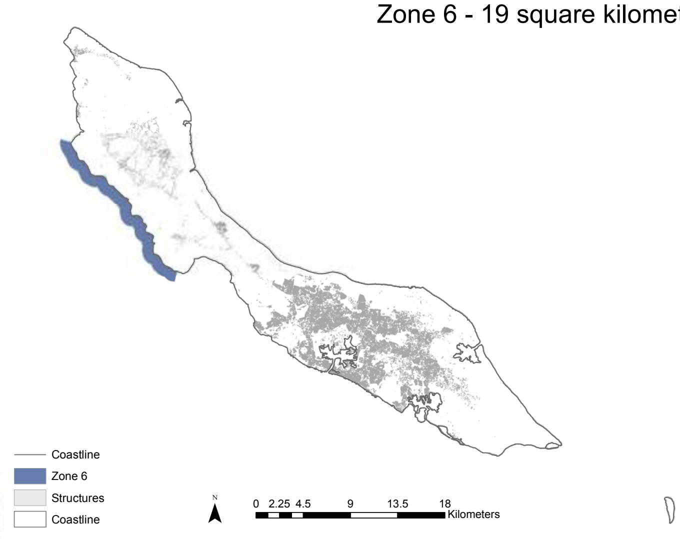
- Zone 6 has the lowest fish biomass in Curaçao even though fishing pressure is average.
- Coral cover and recruitment are also low: coral cover declined from 35% in 1982 to 9% in 2015. This decline is likely related to a combination of hurricane damage, coral bleaching and chronic stress from fishing and diving.
- In-zone variability is lower in Zone 6 than in Zones 1-5.

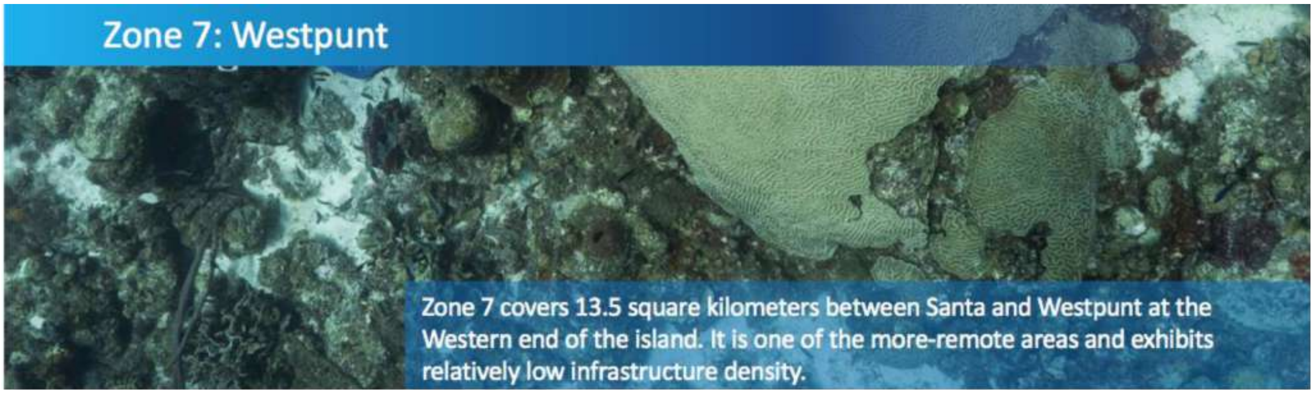
CONSERVATION OPPORTUNITIES

- Zone 6 presents an excellent opportunity to implement restoration and protection actions. Given the poor existing conditions, these measures may yield in significant improvements to fish biomass and coral health over time.

CORAL	COVER	Below Average
	JUVENILE CORALS	Below Average
	CORAL HEALTH	22%
	DECLINE	21%
BIOMASS	TOTAL FISH	Lowest
	HERBIVORES	Lowest
	CARNIVORES	Lowest
POLLUTION	INFRASTRUCTURE	Low
	SEWAGE	Very Low
	TRASH	Above Average
USE	FISHING	Above Average
	DIVING	Average

Zone 6 - 19 square kilometers





KEY FINDINGS

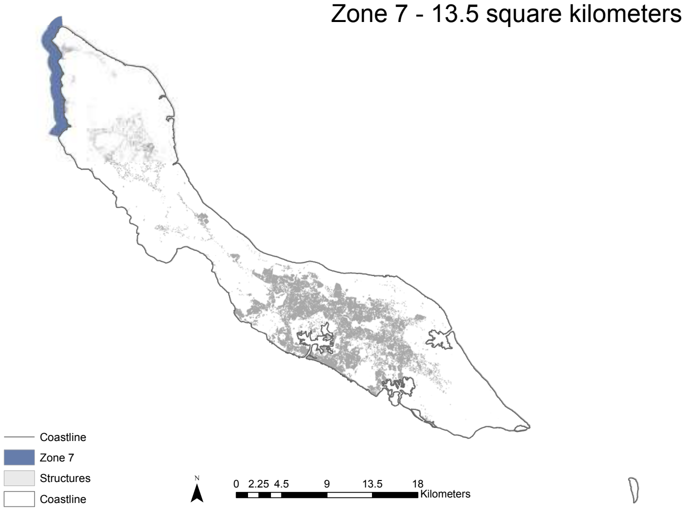
- Zone 7 has the highest fishing pressure and the lowest fish biomass in Curaçao.
- Similar to Zone 6, coral cover has been impacted significantly by hurricanes, coral bleaching and coral diseases.
- Trash on the seafloor is highest in Zone 7 when compared to other zones.
- Ocean use by divers is high despite its remote location.

CONSERVATION OPPORTUNITIES

- Zone 7 would benefit from management actions to reduce fishing pressure, including through enforcement of existing regulations, limited access permitting, or gear-based restrictions.
- Installation of moorings could help reduce anchor damage to reefs.
- In addition to specific fisheries management tools, modest protection could reduce physical destruction in some areas of Zone 7 and provide areas for fish stocks to increase.

CORAL	**COVER**	Below Average
	JUVENILE CORALS	Below Average
	CORAL HEALTH	25%
	DECLINE	29%
BIOMASS	**TOTAL FISH**	Very Low
	HERBIVORES	Very Low
	CARNIVORES	Low
POLLUTION	**INFRASTRUCTURE**	Low
	SEWAGE	Below Average
	TRASH	Highest
USE	**FISHING**	Highest
	DIVING	Very High

Zone 7 - 13.5 square kilometers



KEY FINDINGS

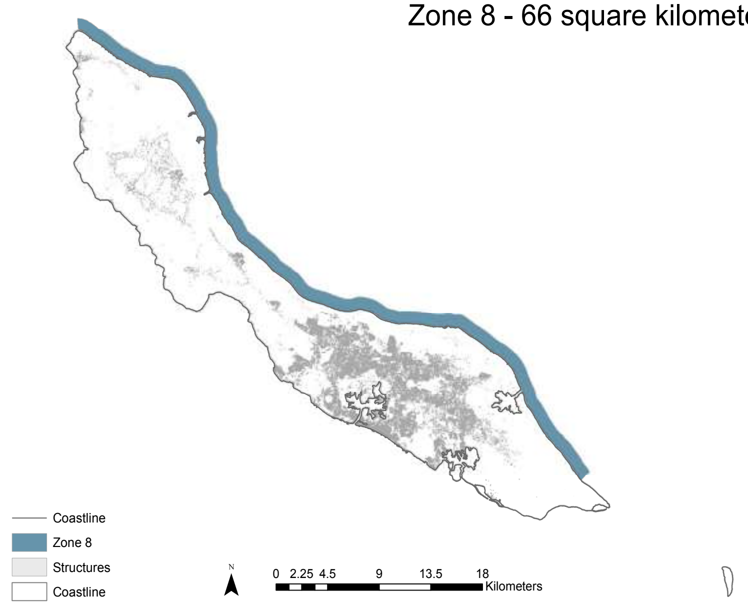
- Zone 8's has the most consistent and continuous shallow habitat, which is almost entirely comprised of dense sargassum covering the seafloor.
- Coral cover and recruitment are lowest in all of Curaçao in Zone 8, which is likely due to rough oceanic conditions that inhibit coral reef growth. That said, there are patches of extremely high coral cover (up to 100%) in >20m.
- Although there is little trash in Zone 8, there are dense quantities of automobile tires extending for more than 12 kilometers along the coast. The authors do not know the source of the tires or when they were deposited.
- Reports indicate ongoing illegally discharge untreated sewage in Zone 8.

CONSERVATION OPPORTUNITIES

- Zone 8 is a good candidate for protection due to its unique habitats and limited human activity from diving or fishing. It should also be a target for enforcement of sewage dumping restrictions.
- This Zone also presents an excellent opportunity for continued research to better understand if these habitats play a critical role in conserving the coral and fish communities of Curaçao due to their inaccessibility from human impact.

CORAL	COVER	Lowest
	JUVENILE CORALS	Lowest
	CORAL HEALTH	NA
	DECLINE	37%
BIOMASS	TOTAL FISH	Average
	HERBIVORES	Average
	CARNIVORES	Low
POLLUTION	INFRASTRUCTURE	Low
	SEWAGE	Very Low
	TRASH	Lowest
USE	FISHING	Below Average
	DIVING	Lowest

Zone 8 - 66 square kilometers



A path forward

The purpose of this Marine Scientific Assessment is to inform the development of a sustainable ocean policy that will improve the health of Curaçao's marine ecosystems, support coastal economies and support livelihoods. Building on this report and other assessments, the Waitt Institute developed a suite of recommendations for a Curaçao Sustainable Ocean Policy, which were submitted to the Government of Curaçao and the Curaçao Parliament in July 2016.

In designing a Sustainable Ocean Policy, Curaçao should build on the knowledge gained through this research, past scientific endeavors, and the other assessments that support Blue Halo Curaçao. When considering actions, five key approaches stand out: (1) protect and restore existing coral reef ecosystems; (2) maintain and improve Curaçao's marine-based economy, including fishing, diving and tourism; (3) minimize water pollution to support ecosystem and human health; (4) achieve coordinated and efficient governance; and (5) ensure a system of sustainable finance.

Protecting and Restoring Marine Ecosystems

Curaçao is one of the few remaining islands in the Caribbean that maintains healthy coral reef and fish populations. These include Zone 1 (Klein Curaçao) and Zone 2 (Oostpunt). Curaçao can depend on these zones as nursery areas that support reef and fish communities elsewhere on the island. These areas not only provide valuable ecosystem services to Curaçao, but are also important draws for tourism and will provide continued revenue into the future with effective management.

One key way to protect and enhance these areas and other potential sites is to establish marine protected areas (MPAs) that are "no-take marine reserves"—i.e. areas that prohibit the harvest of any species. A primary function of MPAs is to decrease the harvest of fish. Less fish harvest leads to increased abundance and size of fish. Larger fish have been proven to have exponentially more reproductive potential, meaning that with larger fish come more fish larvae.

MPAs have been implemented around the world since the designation of the first MPA in 1935 (Gubbay, 1995). Studies of MPAs over time have revealed key factors that determine the success or failure of protected areas at achieving conservation goals. These include: (1) ensuring maintenance of ecosystems; (2) ensuring ecological connectivity between sites; (3) conserving multiple sites to ensure resilience; (4) ensuring adequate size and location to ensure viable management and enforcement; (5) protecting representative sites to support all ecosystems; and (6) maintain support for sustainable use of the marine ecosystem (GRID-Arendal 2014). Special focus in Curaçao should be given to preserving 1) nursery functions 2) existing healthy fish stocks, and 3) designating areas for recovery.

The best sites to consider for establishing no-take reserves and other types of MPAs to maintain or enhance coral reef ecosystem health are Zones 1, 2 and 3 (Klein Curaçao, Oostpunt and Caracasbaai) (Figure 15). Among these, Zone 2 (Oostpunt) is the best candidate for protection in whole or in part, because it has the highest coral cover and high coral recruitment along with low fisher and diver use. In order to maintain connectivity, specific areas in Zones 4-8 should be partially protected with a focus on those areas that maximize ecosystem health and minimize displacement of fishers and divers. Such protected areas enable connectivity and spill-over effects into nearby fishing areas. Particular areas to consider include the above average coral reefs on the western side of Bullenbaai in Zone 5 and the deeper coral areas (>20 meters depth) with extremely high coral cover (nearly 100%) along the North Shore (Zone 8), as well as other deeper coral environments in other zones. Not only will no-take zones promote the recovery of ecologically and economically important fish species, corals are also 6 times more likely to regrow after a disturbance when protected by a no-take reserve (Mumby et al. 2014). Additional sites to consider for protection are the sites home to critically endangered coral species (e.g., *Acropora* and *Montastraea* spp.) and mangrove and seagrass habitats that are important nursery habitats for a large number of reef fish on Curaçao

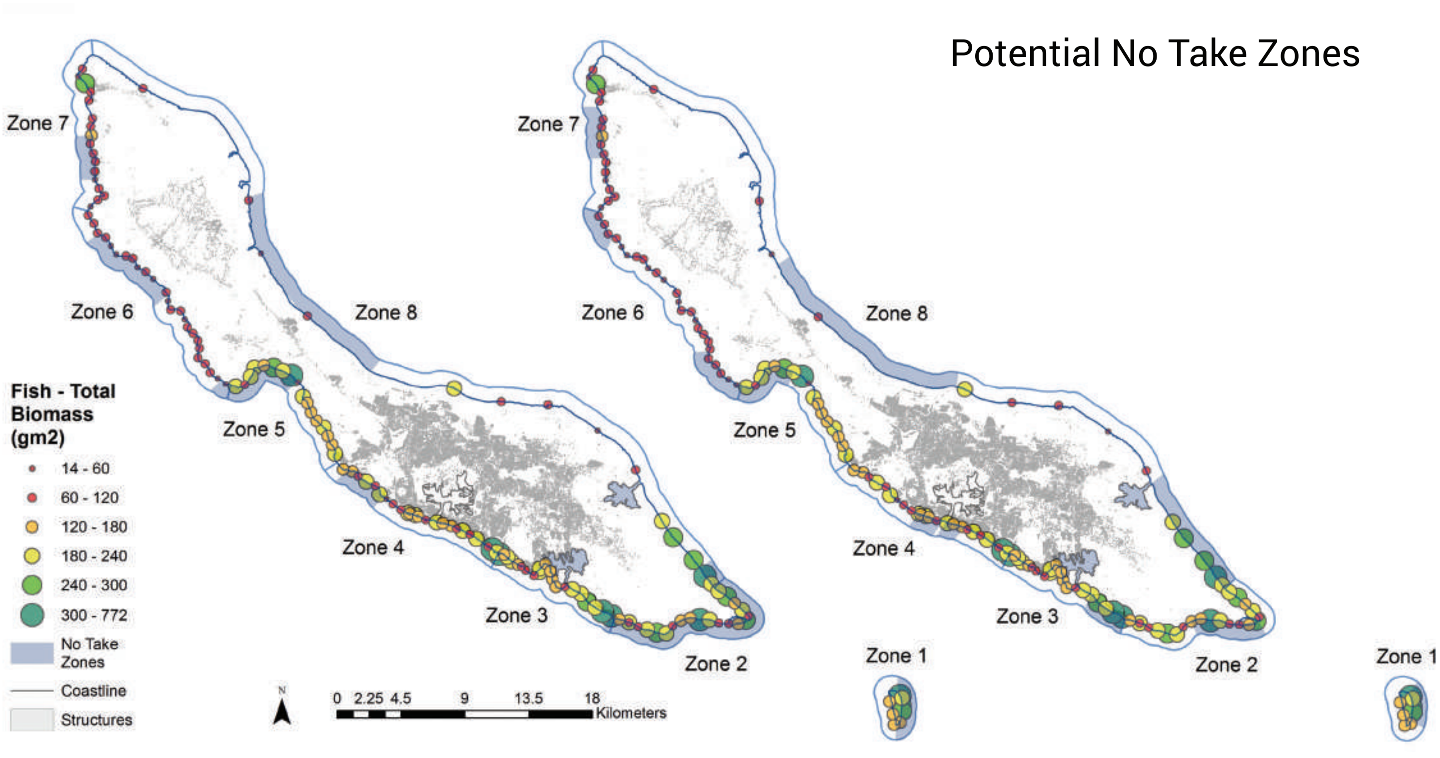


Figure 15. Potential no take zone networks around Curaçao. These plans are designed to protect nursery areas (inland bays), existing robust fish stocks, and to support impact areas as they recover. The plan on the left is optimized for protection and restoration of fish biomass and the plan on the right is optimized for the protection and restoration of fish biomass and the preservation of high value fishing and diving areas.

(Nagelkerken et al. 2000; Verweij et al. 2008).

Protecting reefs and fisheries serve as natural mechanisms to restore habitats. In addition to protection, active mitigation and restoration actions can prevent harm and help restore Curaçao's damaged habitats. Given that Zone 3 has the most diving among the eight zones, Curaçao should consider strategies to mitigate diving impact along with protection of this zone through diver education and establishment and maintenance of mooring buoys. Other types of restoration and mitigation strategies include active restoration by planting mangroves, seagrasses and corals; and removal of trash in the water and on beaches.

Improving Domestic Fisheries

Several approaches to support improvement of domestic fisheries include: protecting key stocks while ensuring ongoing access to marine resources; improving fisheries management measures related to gear usage, permitting, and other common tools; improving ecosystem, fisheries, and socioeconomic monitoring to inform adaptive decision-making; and ensuring compliance through collaboration, education and enforcement. Of particular concern for fisheries management is Zone 7, which is a high use and high value fishing zone. This zone ranks among the second lowest for fish biomass of all the zones on the island indicating severe overfishing.

Domestic fisheries in Curaçao are small in scale and fishers generally fish in specific locations. This means that while fishing is distributed across the island, place-based decisions will affect different fishers in different ways. For instance, because Zone 1 is a highly valued and utilized fishing area for some fishers and is an important site for protection, Curaçao should consider balancing fishing and protection with the use of territorial use rights for fisheries (TURFs) or other area-based licensing or fishing rights. While existing domestic fisheries permits are area-based in nature, most fishers are not required to have a permit. A more robust TURF system could help both small and larger scale domestic fishers ensure access to resources and achieve sustainable fisheries.

Curaçao has a rich history in marine research focused on the marine ecology of Curaçao's coral reef environments. Less studied are the deep sea and pelagic habitats, as well as mesophotic reefs that exist between depths of 30 to 100 meters. In addition, fisheries data are lacking and difficult to collect with small vessels using a large number of ports over a large geographic area (Dilrosun 2002). This lack of data makes it difficult to formally evaluate fishing practices. In addition, and like most places worldwide, socioeconomic research regarding ocean use and users is lacking. To overcome these challenges, a more robust system of research and monitoring is needed to support science-based management decisions.

Unlike many small island nations, Curaçao has a substantial at-sea presence and the capacity to take strong enforcement actions. Discussed in the Legal Framework Report (ELI 2016), Curaçao could improve its ability to enforce its fisheries laws by updating certain legal provisions to enable easier enforcement. However, achieving compliance is not just about enforcement. Crucial to it is creating a legitimate system of management, educating the fishing community, and engaging fishers in management and decision-making.

Minimizing Water Pollution

Protection of Curaçao's marine environment requires maintaining existing good water quality and improving areas of poor water quality. While Curaçao should address water quality island-wide, the water quality of Zone 4 is particularly problematic as it has the highest levels of sewage among all zones. Additional data from Carmabi also indicate that other forms of waterborne pollutants are common in this area, such as fecal bacteria, antibiotic-resistant bacteria and toxic algae that can cause fish kills. Curaçao should ensure the safe disposal of human waste to reduce coastal sewage pollution, which can damage reefs and cause human disease to people swimming, diving or otherwise spend time in the ocean. Sewage should be treated instead of dumped in the ocean through one of approximately 60 dump locations between the Seaquarium and Piscadera. Klein Hofje, the largest sewage treatment plant on the island, is currently not operational and re-opening this facility deserves the highest priority.

Like fisheries research and monitoring, water quality research and monitoring is lacking. Of utmost importance is to monitor coastal water quality for human pathogens that could cause illness to beachgoers, swimmers, divers and others in contact with the coastal environment. Such regular monitoring can help inform government where to target limited resources and inform ocean users as to where and when polluted waters should be avoided.

Improving Ocean Governance

Many nations face the challenge of having disparate government bodies managing ocean resources. Without coordination or a cohesive management system, cumulative impacts from multiple human uses and conflict among ocean users can prevent sustainable management. Two approaches can help overcome this challenge: (1) marine spatial planning; and (2) coordinated ocean governance.

Marine spatial planning is the ocean equivalent of land-use planning—using best available science and public participation, this planning approach understands existing use and the ecosystem, and develops a spatial plan to ensure long-term sustainable use into the future. This zone-based Scientific Assessment provides Curaçao with a strong starting point for the development of a marine spatial plan. It provides a baseline of the existing status of marine resources and the use of the coastal ecosystem for fishing and diving. To start, Curaçao should revisit the data, including the zone summaries, and further evaluate the site-based characteristics to determine the best path forward. This marine spatial plan should be forward-looking to minimize conflict among diving, fishing conservation, and other ocean and coastal uses; maximize ecosystem services and economic well-being of ocean users; minimize cumulative impacts to the ecosystem, including impacts from land-based sources; and ensure community well-being.

In addition to a marine spatial plan, Curaçao would benefit from coordinated inter-ministerial collaboration. Already it has formed the Blue Ribbon Committee to support Blue Halo Curaçao, which includes civil servant representatives from most of Curaçao's ministries. Formalization of this Committee to guide Blue Halo Curaçao would be a strong step in the direction of enabling more informed and efficient decision-making.

Financing a Sustainable Ocean Policy

In conclusion, these approaches mean little without the necessary funding to implement them. Long-term financing of sustainable ocean management requires a multi-prong approach including two major elements: (1) the use of taxes, fees, and fines to support ocean management; and (2) the creation of a dedicated fund to ensure that those taxes, fees and fines support ecosystem management and are not diverted for other government purposes.

Given that tourism is a crucial part of Curaçao's economy and relies heavily on the health and aesthetics of Curaçao's ocean ecosystems, Curaçao should identify opportunities to impose reasonable taxes and fees on island visitors. Such taxes and fees should target cruise-ship passengers, divers, snorkelers, and non-resident recreational sport-fishers, as well as fees accompanying hotel stays.

Other fees should come from those adversely impacting marine resources as part of a mitigation framework. For instance, developers who injure coral reefs, mangroves or seagrass beds should pay the cost to restore those injuries to the condition that would have existed had the resource not been injured. Such an approach will help prevent further loss of valuable resources and put the cost in the hands of those who gain from the impact.

Finally, fines from illegal activities should also support management and enforcement. Fines relate to (1) illegal activities such as illegal dumping or illegal fishing and (2) accidents such as accidental oil spills or other harmful discharges into the marine environment.

Closing Note

Curaçao is at an exciting and important milestone as it embarks on a path to improve the well-being of its human and marine communities through improved ocean governance. The purpose of this assessment is to inform the development of a Sustainable Ocean Policy and is part of a larger body of research including community consultations, an analysis of Curaçao's legal framework, and an economic valuation of Curaçao's marine resources. As such, this Report and the Waitt Institute's recommendations for a Sustainable Ocean Policy mark an important milestone for the Blue Halo Curaçao partnership.

The opportunity presents itself to preserve existing functional marine ecosystems and to improve damaged resources to maximize the benefits that Curaçaoan's derive from their ocean now and in the future. In doing so, Curaçao has the opportunity to become a leader in ocean conservation by protecting and improving some of the best remaining coral reef communities left in the Caribbean for the benefit of its people of and the greater Caribbean community. Sustainable resource management will require tradeoffs that balance short-term and long-term gains that benefit not only the ecosystems, but also the local communities and economies. Cooperative and efficient compromises between ocean stakeholders and the government will be necessary from both sides and will lead to greater efficiencies in recovery.

Significant challenges exist and must be overcome to reverse the damages that have been done to coral and fish communities. Fortunately, Curaçao is actively taking the steps to cultivate a culture that safeguards its ocean resources for the benefit its people now and into the future. It is a testament to the priorities of Curaçaons that they actively seek to know and protect their ocean to preserve their way of life. The Waitt Institute looks forward to continuing to support the Blue Halo Curaçao partnership as it works towards the development and implementation of a sustainable ocean policy.

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Appendix I: Methodology

Researchers collected data by scuba diving at each survey site. For each site, researchers conducted five transects (Figure A, right panel) that were 30 meters (30 m) in length. For each transect, researchers quantified the number, size and identity of all fish as well as coral abundance (Figure A, left panel). At ten meter intervals along each of the five transects (Figure 2, red squares), researchers measured the abundance of juvenile corals ("recruits") and the height of turf algae (measure for herbivory) three times. After researchers finished counting fish while traveling in one direction along the transect line, they reversed course and counted the number of mobile invertebrates (e.g., sea cucumbers, conch, lobsters) on the way back to the starting point (Figure A, black line). Along the same transect line, researchers assessed benthic cover (Figure A, blue squares). All transect lines followed a constant water depth of 8 to 12 m.

Methods: Reef building organisms and their dominant competitors

Percent cover is the percent of the seafloor that is covered by a given species or group of organisms. Researchers evaluated percent cover of reef building organisms and dominant competitors (algae) along the transect lines described previously. At each site, researchers took 75 photographs of the reef bottom (15 per transect) (blue squares in Figure 2) to measure the seafloor ("benthos") coverage from reef

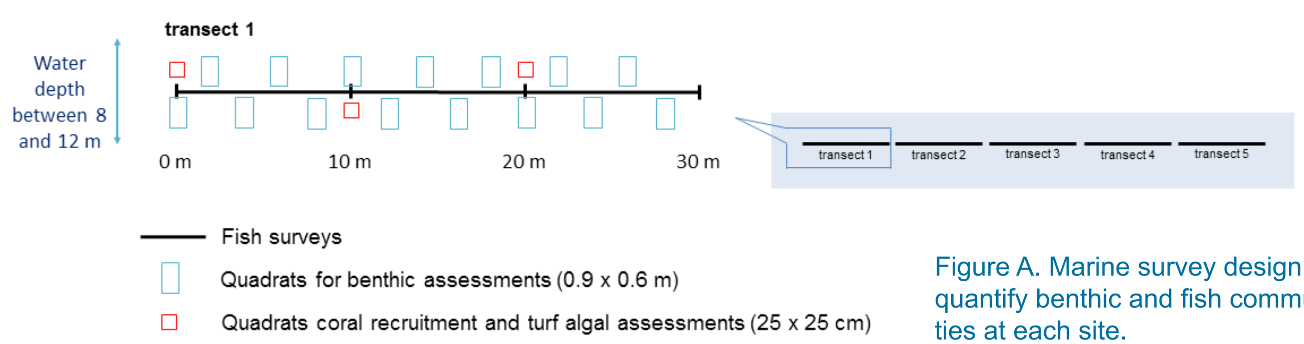


Figure A. Marine survey design to quantify benthic and fish communities at each site.

building species (corals and crustose coralline algae) and their dominant competitors (fleshy macroalgae and turf algae). For each photo, researchers later measured percent cover of all organisms under 25 randomly placed points using specialized software (Coral Point Count, Kohler and Gill, 2007). This approach follows the benthic classifications of the GCRMN (available from: http://www.car-spaw-rac.org/?The-GCRMN-Caribbean-guidelines,639) . Researchers then averaged values to produce site-wide estimates of species' abundance and cover.

Methods: Juvenile Corals and herbivory

The goal of data collection for coral recruitment is to estimate the density of young ("juvenile") corals that are likely to contribute to the next generation of adult corals. For each transect, researchers counted and identified all juvenile coral colonies between 0.5 – 4 cm in diameter in three 25 x 25 cm (625 m^2) areas ("quadrats") at 10 m intervals along the transects used for benthic surveys. Because the survival of juvenile corals depends on herbivores (animals that eat plants) removing turf algae that compete with corals for space, researchers also measured the height of turf algae at five random points in the quadrats and averaged these results. "Shorter" turf algae are indicative of higher herbivory at a location and so provide a measure of herbivory.

Methods: Fish Biodiversity, Abundance, and Biomass

To measure fish biomass, researchers counted and sized all fish in 5 cm bins (0-5 cm, 6-10 cm, etc.) along each transect line (utilizing a belt transect approach of 30 m length x 2 m width). Survey times per transect were limited to approximately 6 minutes per transect. This time limit is used to prevent a longer search that leads to inflated fish biomass and diversity estimates.. At each site, researchers surveyed five transects and pooled the data to provide an average estimate of the density and size structure of all fish species at each site.

Methods: Mobile Invertebrate Abundance

Common mobile invertebrates on Caribbean coral reefs include sea urchin species, sea cucumbers, conch, lobster and other invertebrates found moving over reefs. Many species of sea urchin, especially the historically common long-spined sea urchin (*Diadema antillarum*), are important herbivores on Caribbean reefs with a capacity to control the overabundance of macroalgae (large fleshy algae that compete with coral for seafloor space). As such, sea urchins can play an important role comparable to that of seaweed-consuming herbivorous fishes. Research to evaluate the abundance mobile invertebrates following GCRMN's preferred methodology is ongoing and not reported in the Assessment. Prior research and our preliminary review of assessment data both indicate that their abundance is extremely low. The Waitt Institute and collaborators will provide data and analysis on mobile invertebrates to the Government of Curaçao by the summer of 2017.

Methods: Water quality

To measure water quality, researchers collected five samples of the fleshy algae Dictyota along each transect. Using stable isotope analysis (Risk et al., 2009) the ratio of nitrogen 15 (N^{15}) to nitrogen 14 (N^{14}) can be determined. N^{15} increases in relative abundance in higher trophic level organisms (i.e. organisms that consume things are the top of the food chain). The waste from such organisms provides a distinct signal over lower trophic level waste and is therefore indicative of organic waste products, including sewage water (Kendell et al. 2007). Algae absorb both forms of nitrogen based on the availability of N^{14} and N^{15} in water column. Water polluted with sewage will have more N^{15} than waters without sewage, and therefore the ratio of N^{15} to N^{14} will be higher in the algae that live in waters polluted with sewage. Such N^{15} ratios can consequently be used to generate a time-integrated measure of water quality.

Additionally, researchers counted and identified all pieces of trash at each site. Researchers categorized trash as follows: (1) trash smaller than 1 m in length (e.g., bottles, cups etc.), (2) trash larger than 1 m (e.g., construction materials etc.) and (3) fishing gear (lines and gill nets). The researchers used these observations to create an index to reflect the amount and variety of trash present at each site, whereby 0.33 points were assigned to a site for each type of trash encountered. For instance, a site with a bottle and a length of fishing line would receive an index score of 0.66.

Methods: Mapping Ocean Use: who does what, where?

In addition to the marine surveys, researchers interviewed fishers and divers to gain a better understanding of ocean use patterns, and how these ocean users value Curaçao's marine ecosystems. These surveys helped establish an inventory of areas that were most used and most valued by fishers and divers. To conduct the surveys, the Waitt Institute partnered with SeaSketch and local college students. Between January and May 2016, the team completed 130 surveys with 62 fishers and 68 divers. These surveys were independent from the Ocean Stakeholder Survey and the Fisher Survey that supported the community consultation report.

Each survey instrument asked fishers to draw their fishing grounds on a map using an interactive mapping tool, SeaSketch (McClintock, 2013). In addition, researchers asked fishers to identify how much they value each area they fish or dive. Researchers compiled all responses to generate island-wide maps indicating which areas were fished and valued the most. This resulted in two types of maps: (1) a fishing pressure map indicating use; and (2) a fishing value map indicating the importance of various sites to fishers and divers respectively. Because not all of Curaçao's fishers participated in this survey, these data show relative patterns (i.e., "more" vs. "less" fished areas), but do not reflect total fishing activity or intensity. Researchers repeated the same process for divers producing the same types of maps as those described above for fishing.

Methods: Secondary Data Sources

In addition to primary data collection efforts described above, this Assessment incorporates existing spatial data sources such to provide information on coastal development, population density and historical coral cover. The Department of Spatial Planning provided spatial data delineating all structures and roads on the island of Curaçao. The Dutch Caribbean Nature Alliance (DCNA) provided information on the island's watersheds. By combining these data, researchers evaluated human development in each watershed. Such data serve as a proxy for land-based sources of human impact in the coastal waters adjacent to each watershed. Researchers digitized and geo-referenced the Atlas of the Living Reefs of Curaçao and Bonaire (Netherlands Antilles (Van Duyl, 1985) and used these data to understand historical abundance of reef-building corals along Curaçao's leeward ("South Shore"). Comparing the 1982 and 2015 data sets, researchers evaluated differences in coral cover South Shore based on methods described by Childs (2004).

Appendix II: Local concerns related to coral reef conservation and responses

Climate change

The work of the Intergovernmental Panel on Climate Change (IPCC)—a panel of more than 2,000 scientists whose consensus findings are approved by all participating governments, including the United States—makes it ever clearer that "warming of the climate system is unequivocal...", that most of the observed increase...is very likely due to the observed increase in anthropogenic greenhouse gas concentrations," and that the growing accumulation of greenhouse gases in the atmosphere resulting from human activities is exceeding the historical levels that keep the Earth habitable. The world's climate is indeed changing: higher average temperatures (both air and ocean) are being experienced, as well as, rising sea levels and an increase in the intensity and frequency of storms and tropical cyclones (Pachauri and Reisinger 2007). Climate change will affect Curacao not only through changes in temperature and precipitation but also through extreme events (frequency and intensity), sea level rise, the destruction of ecosystems (particularly coral reefs) due to ocean acidification and an increase in diseases and invasive species (UN 2011). For the Caribbean region in general, the major effects of climate change will lie in the warming and acidifying of the oceans causing coral bleaching and loss of coastal ecosystems.

The rise in average temperatures on Curacao is already notable and large, i.e., 1.0 ^{o}C over the last 50 years, while there is no indication that precipitation patterns have changed during that same period (Willmott et al. 2001). Warming oceans have depleted zooplankton and have resulted in considerable coral bleaching in some SIDS regions. Coral bleaching has the capacity to eliminate more than 90% of the corals on a reef, destroying the ecosystem, leaving islands exposed to ocean waves and storms. In 2005, high ocean temperatures in the tropical Atlantic and Caribbean resulted in the most severe bleaching and another severe bleaching event occurred in 2010, directly "hitting the southern Caribbean (including Curaçao) where little bleaching has been seen in the past. Thermal stress during the 2010 event exceeded any observed from the Caribbean in the prior 20 years of satellite records and 150 years of reanalyzed temperatures, including the record-setting 2005 bleaching event. The return of severe thermal stress just 5 years after the 2005 bleaching event suggests that we may now be moving into conditions predicted by climate models where severe bleaching in the Caribbean becomes a regular event. This does not bode well for tropical marine ecosystems. On Curaçao 12% of the bottom covered by reef building coral "bleached" (although in certain areas this value exceeded 30%) and of all affected corals 10% subsequently died. This means that in the course of only a few months, Curaçao lost approx. 1% of its living corals. Corals near Westpunt were most heavily impacted (10-70%), and survival of affected colonies was highest near Oostpunt (96-100%).

Temperature is also considered to be the most important climate variable in the analysis of nations' tourism demand because beyond a certain range it affects comfort. There have been few studies on the impact of climate change on tourism demand in the Caribbean. Of note is the study by Uyarra (2005) examining the significance of environmental characteristics in influencing the choice of tourists visiting Bonaire and Barbados. The study found that warm temperatures, clear waters and low health risks were the main environmental attributes that were important to tourists visiting the islands, in addition to marine wildlife attributes (Bonaire) and beaches (Barbados). The majority of visitors (80%) mentioned that they would not return to the islands when the effects of climate change (e.g., coral bleaching, disappearing beaches, more diseases, sea-level rise) would become visible, a finding confirmed by various other studies (Mather et al. 2005) resulting in millions lost in tourism revenue (Moore 2010).

Hurricanes in the Caribbean are expected to increase by 27% on an annual basis. Haites (2002) used the example of 1995 hurricanes (Luis and Marilyn) to determine the cost in terms of income loss from the tourism sector and found that tourism expenditures decreased by about 17%. Therefore, with a 27% increase in hurricanes due to climate change and an estimated 17% decrease in tourist expenditures when a hurricane strikes, it is estimated that tourist expenditures are expected to decrease by 21.6% due to increases in extreme events.

Sea levels will rise because increases in global temperatures bring about thermal expansion of water, melts glaciers, polar ice caps and polar ice sheets (Pachauri and Reisinger 2007; Solomon et al. 2007). For Small Island Developing States (SIDS), sea level rise (especially in combination with an increasing number of storm events) is arguably the most certain and potentially devastating climate change impact (Kelman and West 2009) resulting in land loss, loss of hotel infrastructure and loss of coastal marine ecosystems. For Curacao, experts estimate that erosion due to climate changes will result in a land loss valued at $300M to $600M (depending on whether IPCC's A2 or B2 climate scenario is used) by 2050 (UN 2011). The United Nations Environment Programme

Table A: Possible example of adaptation measures and barriers to their implementation (taken from: UN 2011)

Adaptation measures	Barriers to implementation	Measures to remove barriers
Mainstreaming adaptation in planning	Lack of information on which to base policy initiatives	Improve targeted collection of relevant data
Include climate risk in tourism regulations and codes	Lack of information on which to base policy initiatives	Improve targeted collection of relevant data
Reduces pressures on coral reefs	Reducing pressures without degrading experiences	Improve wastewater management practices
Reduce pressures on other marine resources	Unsustainable harvesting and lack of regulation/ enforcement	Strengthen community based management of marine resources
'Soft' Coastal Protection	Lack of credible options that have been demonstrated and accepted	Demonstration of protection for assets and communities
Improved Insurance Cover	Lack of access to affordable insurance	Ensure insurance sector is aware of actual risk levels and adjust premiums
Desalination, rainwater catchments and storage	Lack of information on future security of freshwater supplies	Provide and ensure utilization of targeted information, based on climate risk profile.
Drainage and pumping systems	Wasteful practices; Lack of information to design adequate systems	Provide and ensure utilization of targeted information, based on climate risk profile.
Enhanced design and siting standards	Lack of information needed to strengthen design and siting standards	Provide and ensure utilization of targeted information.
Tourism activity/product diversification	Lack of credible alternatives that have been demonstrated and accepted	Identify and evaluate alternative activities and demonstrate their feasibility.

(UNEP) (2008) has pointed out that there have already been many instances of coral bleaching in the Caribbean region and that as much as 80% of living coral reefs in the Caribbean have already been lost (Jackson et al. 2013). There is no doubt that coral reefs are a key resource for Caribbean nations. They provide protection along the coastline for many Caribbean countries and they represent a significant source of biodiversity for the region. They are also a very important tourism resource in the region.

Boka Sami during storm Matthew October 4th 2016 Foto: Tico Christiaan

According to the IPCC (Solomon et al. 2007), sea levels will rise at least 0.18 m during the 21^{st} century and perhaps as much as 0.59 m. IPCC though, explicitly does not provide an upper bound to the maximum possible sea level rise, stating that the final maximum rise by 2100 might exceed these projections, partly because of inputs from ice sheet break up in Greenland and Antarctica. In the small likelihood that the West Antarctic Ice Sheet collapses raising global mean sea level by approximately five meters (Vaughan and Spouge 2002), the coastal zones of all SIDS would be entirely flooded, covering many entire SIDS and a significant proportion of most SIDS' capital cities and ports. Care must be taken before assuming island destruction due to sea-level rise, because the expected physical changes to low-lying islands under sea-level rise scenarios have not been well-studied. Significant geomorphological changes are likely, but complete inundation and loss of all land is not inevitable (e.g., Kench and Cowell 2002).

For just these three categories—increased hurricane damages, loss of tourism revenue, and infrastructure damages—the Caribbean's annual cost of inaction is projected to total $22 billion annually by 2050 and $46 billion by 2100. These costs represent 10 percent and 22 percent, respectively, of the current Caribbean economy (Bueno et al. 2008). The Economic Commission for Latin America and the Caribbean of the United Nations (UN 2011) estimated that the islands of the former Netherlands Antilles (i.e., thus not specific calculations to Curacao) would also lose billions due to the effects of climate change in the 21st century. At present, Curacao will lose a substantial part of its GDP due to effects of climate change when it decides to work under a "business as usual" scenario: 7.7% in 2025 rising to 36.0% in 2100 (Bueno et al. 2008).

Possible example of adaptation measures and barriers to their implementation are shown in Table A (taken from: UN 2011).

Marine invasive species

The marine exotic species of the Dutch Caribbean are less well-known than its terrestrial exotics. So far, only 27 known or suspected marine exotic species, some of which are also invasive are documented for one or more islands of the Dutch Caribbean (Debrot et al. 2011b). Four of these were documented only once or were only present for a certain period of time and are no longer present. Six of the species are marine epidemic diseases. In addition to these documented species, 76 other exotic species that have already been observed elsewhere in the Caribbean may already be present or can be expected to arrive in the Dutch Caribbean in the near future. The marine communities of the Dutch Caribbean have suffered major changes based on a handful of marine exotic and/or invasive species, particularly in the special case of opportunistic) pathogens. In certain cases experience shows that after decades, the affected systems/species may show slow signs of recovery from initial impacts (e.g. the green turtle fibropapillomas), while in other cases the impact may be long-lasting and recovery doubtful (e.g. sea fan mortality).

Compared to terrestrial exotic species, eradication and control have been proven difficult or impossible for marine exotics. Therefore, management practices aimed at controlling unwanted species introductions should focus on preventing the arrival of such species by ships-- that transport exotics in their ballast water or as fouling communities on their hulls-- and (accidental) introductions from aquaculture or the aquarium trade. Busy harbors can be expected to be the areas where most marine exotics likely establish first. Because of dispersal of marine exotics is facilitated by ocean currents, local approaches to prevent their arrival or reduce their numbers will be less effective compared to similar efforts for terrestrial species. In the case of marine exotics and invasives, it is paramount that prevention, control and management efforts should be regionally integrated.

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

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

The long-spined sea urchin disease causative agent would be an example of such a pathogen coming in from the Indo-Pacific. Unfortunately very little is known about this subject. Aside from ballast water, aquaculture is an important mechanism for introduction of invasive species. A review of aquaculture exotic introductions in the Caribbean, (Williams and Williams 1999) showed that 44 of the 83 species that were at the time introduced into the Caribbean for aquaculture purposes had established themselves in the wild. The authors further commented that local regulations are generally totally inadequate and rely largely on the "enlightened self-interest of the culturalists". In the Dutch Caribbean, aquaculture related introductions include the Nile tilapia,*Oreochromis mossambica*, the shrimp *Peneaus vannamei*, the giant clam, *Tridacna derasa*, and the cobia, *Rachycentron canadum*.

A worrisome trend comprises the rise of exotic and opportunistic pathogens and disease agents, including those of terrestrial/freshwater origin that are entering the marine environment through man mediated pollution and changes in near-shore land use. These taxa are extremely hard to quantify through standard visual surveys of marine communities because of their microscopic size. Because native microbial communities remain often undescribed, it is also extremely difficult to assess whether such pathogens are true exotics or comprise microbes that have simply increased in abundance due to changing environmental conditions. A recent review on marine exotics on Curaçao (Debrot et al. 2011b) shows that the introduction and detection of marine exotics in the Caribbean have grown rapidly in recent years and will continue to grow. New exotics or problems with invasives (i.e., those present in Venezuela but not yet on Curaçao) can be expected in the near future (see: Debrot et al. 2011b for an overview). To be able to address the increasingly urgent marine invasives issue, surveys are need to know what species are currently present.

Lionfish

The increase in lionfish on Curaçaoan reefs continues since the species arrived on the island in October 2009. In the Bahamas, researchers observed that the lionfish reduce the number of small reef fishes (including the young of species that later grow to larger size and species that are important to the health of a reef as an adult such as parrotfish) by an estimated 80%. On one occasion, a lionfish was observed consuming 20 small wrasses during a 30 minute period. It was not unusual to observe lionfish consuming prey up to 2/3 of its own length. The huge reduction in recruitment of juvenile fishes associated with predation by lionfish may eventually result in substantial, negative ecosystem-wide consequences. It is also important to note that lionfish have the potential to act synergistically with other existing stressors, such as climate change, overfishing, and pollution, making this invasion of particular concern for the future of Caribbean coral reefs. While complete eradication does not seem realistic, Curaçao now has a lionfish elimination program. A recent study by the Bonaire Marine Park in collaboration with Carmabi has shown that one year of active eradication efforts decreased lionfish abundance 2 to 8 times depending on habitat type and depth (De León et al. 2013). These results indicate that eradication efforts in which divers use modified spears to kill lionfish are successful and lessen this species' ecological impacts. Recovering and maintaining healthy populations of potential native predators of lionfish, such as large grouper and sharks, may also help reduce the deleterious effects of these voracious invasive predators.

For lionfish, a removal rate between 35 and 65% of the adult biomass per year (Barbour et al. 2011) or a monthly 27% reduction in adult lionfish density are required to significantly reduce population renewal (Morris et al. 2011). The >2-fold reduction in lionfish density and biomass in fished locations suggests that present removal efforts exceed aforementioned removal rates estimated to achieve negative population growth on a local level. Removal efforts involving hundreds of volunteer divers thus generate removal rates high enough to reduce the local population of lionfish, confirming similar observations elsewhere in the Caribbean (Frazer et al. 2012). Larger lionfish generally occurred at greater depths (> 35m). Size differences of lionfish across depth have been associated with ontogenic shifts from shallow to deeper reefs as individual fish mature. Such behavior likely reduces the effectiveness of local removal efforts as large, and therefore more fecund, lionfish occur at depths largely inaccessible for divers. Complete removal will thus be impossible as lionfish populations on the windward sides of both islands and those below traditional diving limits (i.e. ~40 m) remain largely unfished. In addition to the influx of larvae from other Caribbean locations (Ahrenholz and Morris 2010), larvae produced by these locally unfished populations will likely permanently offset the effect of removals on the leeward side assuming that local retention of larvae occurs to some degree. Lionfish control efforts can therefore never cease as local populations are likely replenished by recruitment from external sources and native predators feeding on or learning to feed on lionfish are presently rare throughout the Caribbean (Mumby et al. 2011). Although the study strongly suggests that removal efforts are effective in reducing the number and size of invasive lionfish, it remains unknown if the reduction in lionfish results in any ecological benefit. Nevertheless, our data show that local removal efforts using volunteers represent a cost-effective, rapid-response option that is successful at significantly reducing the density and biomass of invasive lionfish on Curacao.

Invasive seagrass

The exotic seagrass Halophila stipulacea is aggressively invading shallow water communities throughout the Caribbean (Willette and Ambrose 2009). This invasive alien species originates from the Red Sea and Persian Gulf, and was first discovered in the Caribbean region in 2003 near Grenada. From that moment it has rapidly expanded its distribution and is now found throughout the entire Caribbean region. The ecological consequences of this invasion are increasingly becoming evident. In Bonaire the species has invaded the central portion of Lac bay where it is already ubiquitous and creates thick beds completely covering the bottom and excluding all other species (Debrot, pers. obs.). It has also been observed on St. Maarten and in St. Joris and Fuik Bay on Curaçao (Vermeij, pers. obs.). It is clear that H. stipulacea is effectively monopolizing space and thereby limiting natural communities of seagrasses and algae.

Threatened & endangered species

There are many marine threatened and endangered species on Curaçao (see Table B), but information on their abundance, critical habitats and population trends is scarce or absent for most species.

Threatened & endangered species: corals

Most information is available for critically endangered coral species (*Acropora* spp. and *Montastraea* (*Orbicella*) spp. Acropora species were dominant constituents of the shallow (<10m) reef fauna and were found along Curacao's entire coast. In the early '80's *Acropora cervicornis* and A. palmata covered 5% and 7% of the shallow reef terrace respectively (Duyl 1985) before they experienced a massive Caribbean-wide decline in 1981 caused by white-band disease (Bak and Criens

Table B Overview of endangered and protected species on Curaçao (continued on next page).

Critically endangered IUCN Red List Species		
Fish	*Epinephelus itajara*	Goliath grouper
Fish	*Hyporthodus nigritus*	Warsaw Grouper, Black Grouper
Sharks and rays	*Pristis pectinata*	Smalltooth, Wide Sawfish
Sharks and rays	*Pristis perotteti*	Largetooth Sawfish
Reptiles - turtles	*Eretmochelys imbricata*	Hawksbill Turtle
Reptiles - turtles	*Dermochelys coriacea*	Leatherback, Leathery Turtle
Corals-stony	*Acropora cervicornis*	Staghorn coral
Corals-stony	*Acropora palmata*	Elkhorn coral
Endangered IUCN Red List Species		
Corals-stony	*Millepora striata Bladed*	Box Fire Coral
Corals-stony	*Montastraea annularis*	Mountainous Star Coral
Corals-stony	*Montastraea faveolata*	Mountainous Star Coral
Fish	*Epinephelus striatus*	Nassau grouper
Fish	*Pagrus pagrus*	Red Porgy
Sharks and rays	*Dipturus laevis*	Barndoor Skate
Sharks and rays	*Leucoraja ocellata*	Winter Skate
Sharks and rays	*Sphyrna mokarran*	Great Hammerhead Shark
Sharks and rays	*Sphyrna lewini*	Scalloped hammerhead
Mammals - cetacean	*Balaenoptera borealis*	Coalfish Whale
Mammals - cetacean	*Balaenoptera musculus*	Blue Whale
Mammals - cetacean	*Balaenoptera physalis*	Fin Whale
Mammals - cetacean	*Eubalaena glacialis*	North Atlantic Right Whale
Reptiles - turtles	*Caretta caretta*	Loggerhead Turtle
Reptiles - turtles	*Chelonia mydas*	Green Turtle
Vulnerable IUCN Red List Species		
Corals-stony	*Agaricia lamarcki*	Leaf Coral
Corals-stony	*Dendrogyra cylindrus*	Pillar Coral
Corals-stony	*Dichocoenia stokesii*	Elliptical Star Coral
Corals-stony	*Montastrea franksi*	Bumpy Star Coral
Corals-stony	*Mycetophyllia ferox*	Rough cactus coral
Corals-stony	*Oculina varicosa*	Large Ivory Coral
Fish	*Balistes vetula*	Queen Triggerfish
Fish	*Batrachoides manglae*	Cotuero Toadfish
Fish	*Dermatolepis inermis*	Marble Grouper
Fish	*Epinephelus flavolimbatus*	Yellowfinned Grouper
Fish	*Hippocampus erectus*	Lined Seahorse
Fish	*Hypoplectrus providencianus*	Masked Hamlet
Fish	*Hyporthodus flavolimbatus*	Yellowfinned Grouper
Fish	*Hyporthodus niveatus*	Snowy Grouper
Fish	*Lachnolaimus maximus*	Hogfish
Fish	*Lujanus cyanopterus*	Cubera snapper
Fish	*Lutjanus analis*	Mutton snapper
Fish	*Mycteroperca interstitialis*	Yellowmouth grouper
Fish	*Thunnus obesus*	Bigeye tuna
Sharks and rays	*Alopias superciliosu*	Bigeye Thresher Shark
Sharks and rays	*Alopias vulpinus*	Thresher Shark
Sharks and rays	*Carcharhinus longimanus*	Oceanic whitetip shark
Sharks and rays	*Carcharhinus obscurus*	Dusky shark
Sharks and rays	*Carcharhinus plumbeus*	Sandbar shark
Sharks and rays	*Carcharhinus signatus*	Night shark
Sharks and rays	*Carcharias taurus*	Greay nurse shark
Sharks and rays	*Carcharodon carcharias*	Great white shark
Sharks and rays	*Centrophorus granulosus*	Gulper shark

Species protected under the SPAW protocol

Class	Order	Family	Genus	Species	Common name	# Species on Curacao
Hydrozoa	Milleporina	Milleporidae		All spp.	Fire corals	4
	Stylasterina	Stylasteridae		All spp.	Lace corals	1
Anthozoa	Anthipatharia			All spp.	Black corals	10
	Scleractinia			All spp.	Stony corals	69
Mollusca	Mesogastropoda	Strombidae	*Strombus*	*gigas*	Queen conch	1
Crustacea	Decapoda	Panuliridae	*Panulirus*	*argus*	Spiny lobster	1

1981). The decline in *Acropora* over the last four decades is estimated at 98% (Vermeij et al. 2003) and continues to decline (Bright et al. 2013). The decline of both *Acropora* species has also resulted in a decline of *Acropora*- associated fish and coral species (Nagelkerken and Nagelkerken 2004). Locally healthy patches and well developed *Acropora* communities exist (Figure B), especially of *A. palmata*, usually at exposed sites (i.e. the southeast facing shorelines near Oostpunt, Klein Curacao and Rif Marie) along the island's protected Southeastern shore.

Effective recruitment of both species currently approaches zero (Vermeij et al. 2011) leaving asexual propagation as the main mechanism by which both species could increase in abundance in the near future. Recovering populations of *A. palmata* and *A. cervivornis* occur locally but are frequently impacted by storms, territorial damselfish and coastal development slowing the recovery of both species (Vermeij et al. 2003; Bries et al. 2004; Nagelkerken and Nagelkerken 2004; Vermeij et al. 2015). When both species are present the hybrid *A. prolifera* is frequently observed. Genetic variability in

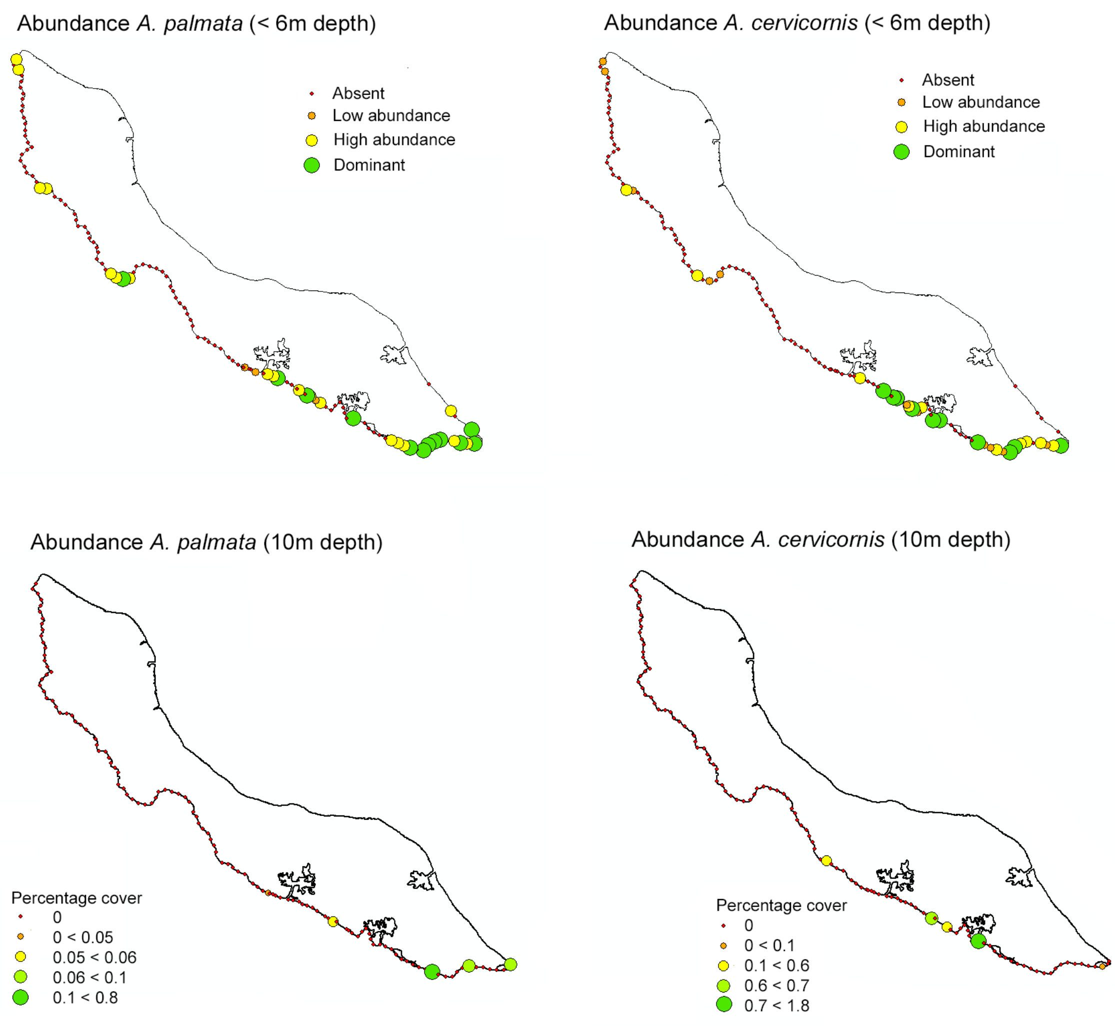


Figure B Distribution and abundance of *A. palmata* an *A. cervicornis* along Curacao's leeward coast in 2015

A. palmata populations on Curacao are among the highest in the Caribbean and could act as a reservoir for future adaptation (Baums et al. 2006).

Leeward reefs of Curaçao were dominated by extensive communities of members of the *M. annularis* complex between depth of 3 to 30m (Bruckner and Bruckner 2006). In 1998, colonies of the *M. annularis* complex accounted for more than 45% of all species >10 cm decreasing to 38% of all colonies in 2005, most likely due to several coral disease outbreaks (Bruckner and Bruckner 2006). Remaining communities were especially hit by Yellow band disease (YBD) emerged shortly after the 1995 bleaching event and several storms (Bries et al. 2004) causing high rates of mortality. Recruits of *Montastraea* spp. are virtually absent on Curaçao's reefs today (Vermeij et al. 2011). *Montastraea* spp. are currently abundant along the islands eastern Leeward shore and at certain locations along the island's western shore (Figure C). Large populations of extremely large (i.e., > 5 m diameter) *M. faveolata* colonies occur locally along the island's windward shore between depths of 20 and 40m. In 2015, *M. annularis* and M. faveolata each covered on average 1.6 % (n= 147 sites) of the reef bottom respectively. In contrast to *Acropora*, *Montastraea* populations on Curacao appear dominated by a few genets dominated and should be considered genetically depauperate relative to other locations in the Caribbean (Foster et al. 2013).

The distribution and abundance of all protected coral species (Table A) at 10m depth is shown in Figure D. While the abundance of these corals can be high at individual sites, larger sections of reef where endangered/ protected corals can be found occur near Watamula, Rif Marie, the east side of Klein Curaçao, but especially near Oostpunt.

Threatened & endangered species: fish

The same patterns observed for corals hold for protected and endangered fish species. Less than 0.001% of all fish biomass on Curaçao's shallow water fish communities consists of species that receive some form of international protection indicating wide-spread and severe overfishing and habitat loss (Figure E).

Threatened & endangered species: sharks and rays

In the Dutch Caribbean EEZ, at least 27 shark and ray species have been documented. Elasmobranchs are not a target fishery in the Dutch Caribbean, but do occur as bycatch in artisanal fisheries (Van Beek et al. 2012). The populations' status of most species has unquestionably declined dramatically from former times. In the 1940s-1950 popular writers (Hass 1949; Hakkenberg van Gaasbeek 1955) recount the high abundance of large fishes in the near shore waters surrounding Curaçao and Bonaire. In those times, sharks were observed on practically every snorkeling trip, whereas today sharks are only sporadically encountered during dives (A. Debrot, R. de Leon, H. Meesters, M. Vermeij, pers. obs.).

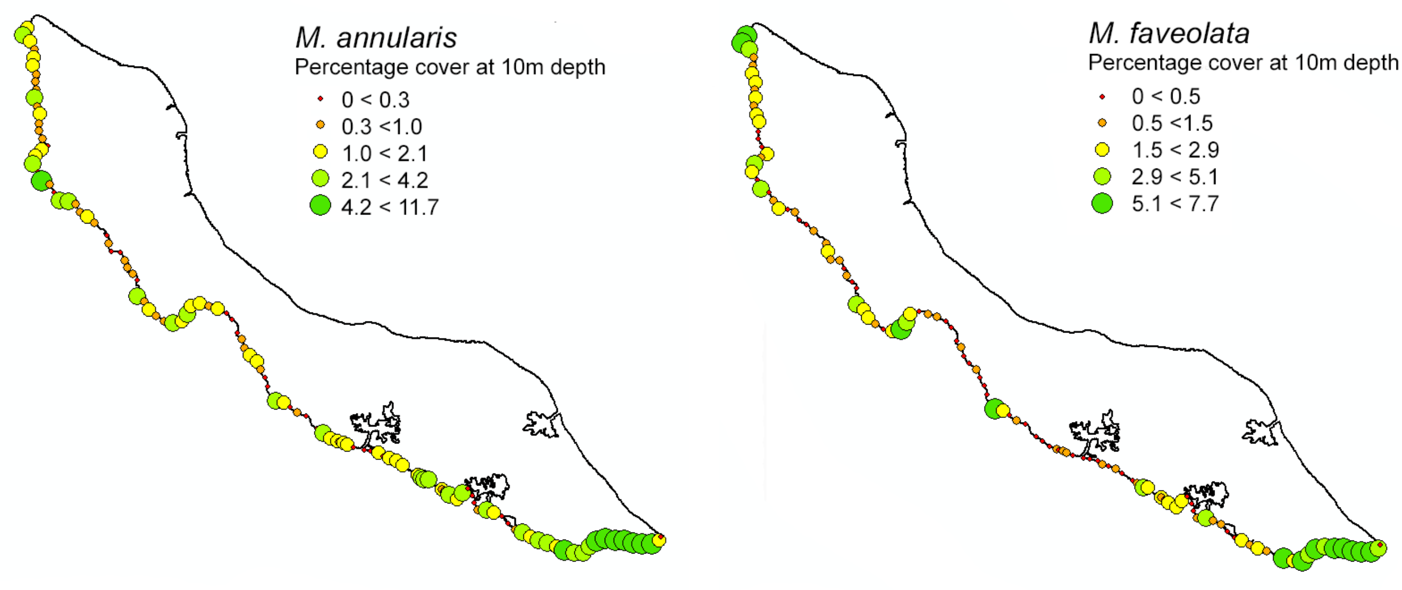


Figure C Distribution and abundance of *Montastraea* spp. along Curacao's leeward coast in 2015

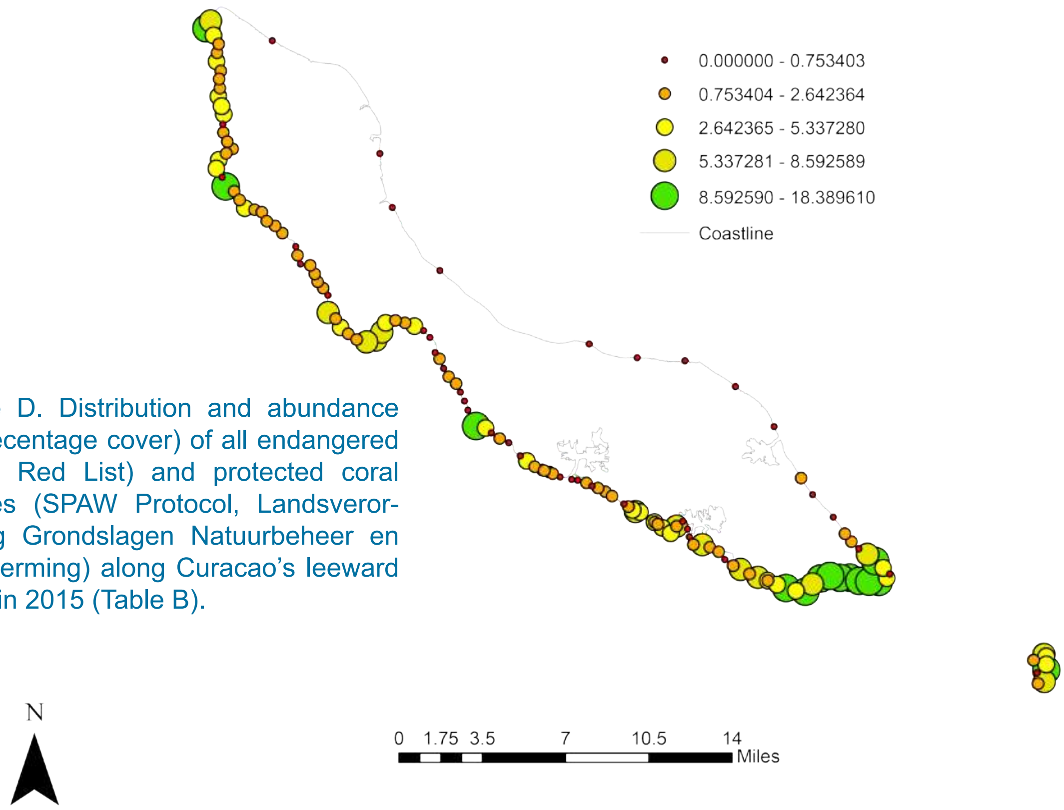


Figure D. Distribution and abundance (in precentage cover) of all endangered (IUCN Red List) and protected coral species (SPAW Protocol, Landsverordening Grondslagen Natuurbeheer en Bescherming) along Curacao's leeward coast in 2015 (Table B).

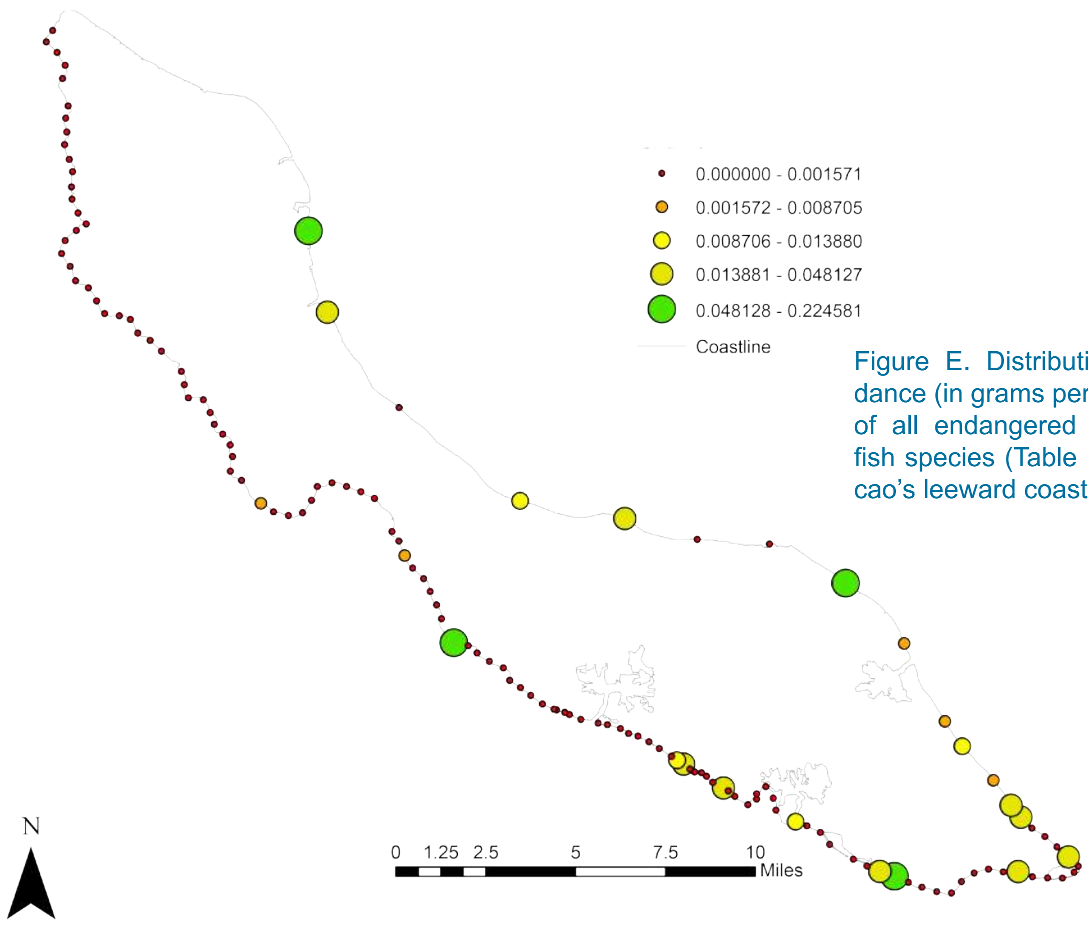


Figure E. Distribution and abundance (in grams per square meter) of all endangered and protected fish species (Table B) along Curacao's leeward coast in 2015

Based on recent data, published sport diver accounts, and anecdotal accounts, it is clear that shark populations in most areas of the Dutch Caribbean, including Curaçao have been strongly depleted in the last half century (Van Beek et al. 2012). The drastic reduction in reef predators such as sharks is the fingerprint of marine fisheries (Branch et al. 2010), and is inversely related to increased human population density throughout the wider Caribbean (Stallings 2009). An overview of (historic) shark sightings on Curaçao can be found in (Van Beek et al. 2012).

Threatened & endangered species: sea turtles

At least five species of sea turtles have been reported from the waters surrounding Curaçao; however, only three of these five species are known to nest on the island. The three sea turtle species that nest on the island are loggerhead (Caretta caretta), hawksbill (*Eretmochelys imbricate*), and green sea turtles (*Chelonia mydas*). The two species that do not nest on Curaçao but are found in the surrounding waters are leatherback (*Dermochelys coriacea*) and olive ridley (*Lepidochelys oliveacea*) sea turtles. Sea turtles are long-lived species that reach sexual maturity after 20 – 30 years of age and migrate great distances at different stages of their lives. These unique life history features necessitate international cooperation and long-term monitoring programs to best understand and safeguard these endangered species. Once amazingly abundant, Caribbean sea turtles have seen rapid decline since the time of European expansion in the Americas. Scientists estimate that in the 1600's, over 90 million Green Turtles swam the Caribbean seas. Today the number is estimated at 300,000. Hawksbills have plunged 99.7% from 11 million to 30,000. Both Green Turtles and Hawksbills nest on Curaçao. Today, fishing gear entanglement, illegal harvesting, coastal development, marine pollution and climate change are still putting serious pressure on sea turtle populations, which remain threatened with extinction not only in the Caribbean, but across the globe. Presently, sea turtles can be seen along the island's entire coast and use the east side of Klein Curaçao, beaches along Curaçao's northwestern coast and occasionally other locations (e.g., Barbara Beach) for nesting. In 2015, 60 sea turtle nests were found and monitored on Klein Curaçao and Curaçao producing approximately 4400 sea turtle hatchlings. Only one hatchling in a thousand makes it to adulthood (15-25 yrs).

Threatened & endangered species: marine mammals

A recent review established beyond doubt that the Dutch Caribbean has a rich and diverse marine mammal fauna which merits more extensive protection. Even though the fauna is only poorly known, based almost exclusively on incidental sightings and strandings, it amounts to a minimum of 19 marine mammal species, and possibly up to more than 30 (Debrot et al. 2011a). The newly set up marine mammal database for the Dutch Caribbean contains 209 marine mammal records for the leeward islands: 160 sightings and 49 strandings or animals found dead in the water, amounting to 19 confirmed species in total. So far 20 different marine mammals species have been documented for the Dutch Kingdom waters; 15 species for Curaçao (including the West Indian Manatee), 15 for Aruba, and 11 for Bonaire (Debrot et al. 2011a). The largest number of records are for the bottlenose dolphin (41) and spinner dolphin (40) followed by rorqual whales (20 - includ-

ing 10 Bryde's whale records).In terms of number of individuals, the spinner dolphin is much more common (1,379) than the bottlenose dolphin (544), followed by short finned pilot whale (370) and pantropical spotted dolphin (106) (Debrot et

al. 2011a). Bryde's whales, bottlenose dolphins, spinner dolphins, pantropical spotted dolphins, Atlantic spotted dolphins and rough-toothed dolphins appear to be present year-round in the waters of the leeward islands. Humpback whale, sperm whale, Gervais' beaked whale, Cuvier's beaked whale, killer whale and short-finned pilot whales occur here at least part of the year. In the Dutch Caribbean, direct taking of cetaceans is largely illegal and does not form part of the cultural tradition of these islands. Therefore, it is a negligible problem. Marine debris, underwater sounds changes, pollution, ship strikes, habitat degradation, human interactions and diseases are increasingly affecting the health and survival of marine mammals and while data is scarce, populations of all marine mammals appear to be in decline on Curaçao (Debrot et al. 2011a; Simmonds 2011).

Inland bays: mangroves and seagrasses

Caribbean coral reef habitats, seagrass beds and mangrove stands provide many important ecosystem goods and services such as coastal defence, sediment production, primary production, fisheries and the maintenance of high species diversity (Moberg and Folke 1999).The mangroves of Curaçao are restricted to a few isolated areas of well-developed intertidal fringe forests in drowned coastal valleys, and in small areas along the coast where a barrier protects the trees from wave action and erosion. Ongoing destruction of mangrove habitat has led to a dramatic decrease in coverage. Curaçao has 55 ha of mangroves remaining (0.12% of the island's surface area), of which a significant portion is threatened by coastal development (Debrot and Freitas 1991). This is less than half of the mangrove coverage of a century ago. Mangrove stands in the vicinity of Willemstad are despite of the high level of eutrophication and pollution in that area in good health (Snedaker 1988). Mangroves near the St. Jorisbaai also appear to be in good shape. Thirteen different seagrass and algal assemblages are known for Curaçao (Kuenen and Debrot 1995). These shallow-water ecosystems play an important role as nursery areas and habitats for coral reef fishes, conch and lobsters (Sierra 1994; Nagelkerken et al. 2000; Nagelkerken and Van Der Velde 2002; Verweij et al. 2008). Many snapper, grunts and parrotfish species, for example, undertake ontogenetic shifts in habitat use from seagrass beds or mangroves to their adult coral reef habitat. For a complete overview how Caribbean fish species use mangrove and seagrass habitats, see: Harborne et al. 2006. Fish can disperse far from the inland bays in which they were born. For example, sixty percent of all individuals belonging to certain fish species that are found on the reef along the entire island (and are often commercially important, such as yellowtail snappers; *grastelchi piedra*) are "born" in Spaanse Water or in the other Eastern Bays (i.e., Fuik, Awa di Oostpunt).

Seagrass beds on Curaçao are threatened by eutrophication (Govers et al. 2014). While nutrient levels in most bays do not raise any concern, high leaf % Phosphorus values of Thalassia in Piscadera Bay (0.31%) and Spanish Water Bay (0.21%) showed that seagrasses in these locations are currently suffering from eutrophication, due to emergency overflow of waste water and coastal housing. In contrast to T. *testudinum*, the fast growing *S. filiforme* did not accumulate nutrients in the eutrophic bay, but seem to have used the extra nutrients for growth (Govers et al. 2014). The seagrasses of Piscadera Bay have already retreated to the shallowest areas (<1 m) of the murky waters and are under threat of complete disappearance with a further increase of nutrient loads. Moreover, *T. testudinum* in Spanish Water Bay has been declining for some time (Kuenen and Debrot 1995) due to excess anthropogenic nutrient input by coastal residencies (Govers et al. 2014). This bay, with the largest seagrass area of Curaçao (Kuenen and Debrot 1995) highly contributes to coral reef fish populations by functioning as a nursery habitat (Verweij et al. 2008; Huijbers et al. 2013; Sheaves et al. 2015). Possible disappearance of seagrasses (but also mangroves) due to eutrophication may therefore have serious consequences for the ecological and economical values of the coastal ecosystems of Curaçao. An overview of the island's main mangrove and seagrass areas and their ecological functions is shown in Table C.

Information about coral health and disease

Several diseases have had detrimental effects on coral reef organisms of Curaçao reefs in the 1980s and 1990s. In 1980,

Table C. An overview of the island's main mangrove and seagrass areas and their ecological functions

	Nursery function	Seagrass abundance	Mangrove abundance	Human impacts
Awa di Oostpunt	high	high	low	low
Bartolbaai	medium	medium	low	low
Boka Ascencion	medium	medium	nihil	high
Fuikbaai	high	high	high	high
Piscaderabaai	high	medium	high	high
Playa Grandi	medium	low	medium	low
Saliña St. Michiel	nihil	nihil	low	medium
San Juanbaai	low	nihil	medium	low
Spaanse Water	high	high	high	high
St. Jorisbaai	high	high	high	medium
Sta. Cruz	low	nihil	high	medium
Sta. Marthabaai	low	nihil	low	medium
Zakitó lagune	nihil	nihil	high	high

From: (Nagelkerken 2000)

the corals *Acropora palmata* and *A. cervicornis* that dominated shallow water reefs were affected by white-band disease (Bak and Criens 1981), and in 1983 the population of the sea urchin Diadema antillarum, the most important species preventing corals from being overgrown by algae, was reduced by 98-100% by an unknown cause (Bak et al. 1984). The latter resulted in a significant increase in cover of fleshy and filamentous algae in combination with a general decrease in coral, crustose corallines (i.e., the preferred settlement habitat for coral larvae), and/or loose sediment cover. In 1995, widespread mortality was observed in Caribbean sea fans (Gorgonia spp.), and in Curaçao the sea fan *Gorgonia ventalina* was foremost affected resulting in mass mortalities of this species (Nagelkerken et al. 1997). Massive "coral bleaching" whereby corals lose their symbiotic algae in response to elevated sea water temperatures has been documented for Curaçao reefs: in 1987, 1990, 1995, 1998, 2010 and 2014 whereby large coral species that contribute most to reef framework were most heavily affected. For example, almost 1% of the living corals around Curaçao died when seawater temperatures were higher than normal for just two months in late 2010.It is important to note that while the cause for bleaching (higher CO2 levels resulting in warmer waters) cannot be managed effectively by small islands such as Curaçao. However, the conditions under which recovery can occur after diseases or bleaching "hit" the island's coral communities are manageable on an island scale so local actions (partially) offset the consequences of global phenomena.

Recent evidence (reviewed in: Rohwer et al. 2010) shows that algal abundance and organic run-off fuel microbial communities in reef waters. This increase in microbes in coastal water due to increased algal abundance, adds to other pathways whereby microbes can increase in coral reef water such as the dumping of sewage water. The "Microbialization" of reef communities is a fundamental part their degradation trajectory with subsequent consequences for corals (e.g., increases in pathogens, diseases) and likely humans that use the water for recreational purposes. As coral reefs degrade, opportunistic organisms (e.g. microbes and algae) start replacing longer lived organisms such as corals and fish. These long lived organisms that historically dominated on Caribbean coral reefs are simply not capable of surviving in the disturbed and polluted marine environments that have emerged along large parts of the island's coast in the recent past.

Point vs non-point source pollution (septic seepage through groundwater vs sewage outfalls)

Impacts of coastal development on the reef can occur either through direct physical damage such as dredging or land filling, or indirectly through increased runoff of sediment, pollution, and sewage. The removal of coastal vegetation, such as mangroves, also takes away a critical sediment trap that might otherwise prevent damage to near shore ecosystems. Where coastal areas are developed, pollution of near shore waters often follows. Sewage is the most widespread pollutant, and elevated nutrient levels present in sewage encourage blooms of plankton that block light and encourage growth of seaweeds that compete for space on the reef. Many countries with coral reefs have little to no sewage treatment; the Caribbean region discharges an estimated 80 to 90 percent of their wastewater untreated. Toxic chemicals and sewage bacteria also are a problem. Sources of toxic chemicals in coastal runoff include industries and agriculture, as well as households, parking lots, gardens, and golf courses. Direct construction within the marine environment can have even more profound effects. In many cases, tourism itself threatens reefs. Hotels can bring coastal development to new and remote locations, with associated higher levels of construction, sewage, trampling and waste.

Human activities far inland can impact coastal waters and coral reefs. At the coast, sediments, nutrients, and pollutants disperse into adjacent waters. Such impacts can be reduced where mangrove forests or sea grass beds lie between land and the reefs. In high quantities, sediments can smother, weaken, and kill corals and other benthic organisms. Excessive levels of nutrients like nitrogen and phosphorus in shallow coastal waters (i.e., eutrophication) can encourage blooms of phytoplankton in the water, which block light from reaching the corals, or they can cause vigorous growth of algae and seaweeds on the sea bed that out-compete or overgrow corals. In severe cases (which have occurred on Curaçao in 2009 and 2011), eutrophication can lead to hypoxia, where decomposition of algae and other organisms consumes all of the oxygen in the water, leading to "dead zones" and fish kills. In addition to nutrients, coral reefs change when carbon-based compounds ("sugars") enter the water. Addition of carbon compounds fuels local microbial communities that feed on these compounds. As a result microbes increase in abundance and become increasingly more pathogenic. Therefore, in addition to nutrients, unnatural carbon sources (e.g., sewage, terrestrial run off) should be minimized in order to prevent the rise of pathogens (i.e., "microbialization") of Curaçao's coral reefs.

There are over 30 points along the South Coast where sewage is disposed of at marine outfalls. One outfall can discharge up to 1000 m3 of untreated sewage per day. Most of these points are located in Willemstad, where the population density is at its highest. Less urbanized areas (but e.g., also al houses around Spanish Waters) have septic tanks or outdoor sedimentation pits that are not connected to the island's sewage system. Septic tanks near the shore often leach directly into groundwater, that together with water contaminated with excrements from animals on land flows towards the ocean (reviewed in: Wear and Thurber 2015). Natural groundwater flow is always present, though easier to detect after rain events. After rain falls on land, it enters the bottom and eventually part of it flows underground to the ocean where it exits the reef bottom in areas that are not capped by e.g. limestone structures.

Partially treated sewage water is being sold and used as 'grey water' in irrigation systems for agriculture and gardening. Coastal waters experience increases in fecal bacteria after rainfall when water from sewage, septic and grey water systems leaks or spills into lower lying coastal waters resulting in increased abundances of fecal and potentially pathogenic or antibiotic resistant bacteria in recreational waters. Sewage water is often being dumped or leaks from sewer lines along the South Coast of the Caribbean island of Curaçao so that (pathogenic) microbes are found in the island's nearshore waters. Nearshore waters are being visited by many locals and tourists that consequently risk infections caused by pathogenic microbes. Water quality deteriorates especially after rainfall due to runoff and overflowing sewage infrastructure which have resulted in an increase of pathogenic gram-negative bacteria containing antimicrobial resistance genes along the coast of especially Willemstad (Carmabi/

ADC, unpubl. data). Snake bay is often being used by divers and locals in the area. The fact that an ESBL *E. coli* had been found is an indication of resistant coliform bacteria in the water. This means that sewage from neighboring homes are dumped in the water. Recreational coastal waters on Curacao more and more serve as an environmental reservoir for pathogenic antibiotic resistant bacteria, when more sewage enters the island's coastal waters. *E. coli* and enterococci, concentrations can fluctuate heavily in coastal waters (Jonkers, unpubl. data). Constant monitoring of recreational waters on the south coast of Curacao would be advised in order to protect and guarantee the health of swimmers and coastal ecosystems.

It also looks like fish, in addition to corals, are also vulnerable to the increased abundance of microbes in the water column. A large number of fish infected with dermal parasites (trematodes, turbellarians, and protozoans) is currently observed on Curaçaoan reefs (Bernal et al. 2015), possibly due polluted water or reduced resistance as a consequence of increased microbial loads of the same water. The input of sewage waters (but also other forms of pollution) is likely in large part attributable to subterraneous groundwater transport, whereby substances (i.e., bacteria, chemicals, oil etc) that earlier ended up in the island's soil are transported underground to the near shore environment where reef communities are exposed to these unnatural substances, toxins and bacteria. Septic systems or sewage holding tanks will operate effectively if, and only if, they are designed properly, situated in areas that allow proper operation, used only for the purposes for which they were designed, and given periodic maintenance. The US EPA estimates that 10-25% of all individual sewage systems are failing at any one time, introducing feces, detergents, endocrine disruptors, and chlorine into the environment. The influx of subterraneous groundwater on reefs can be observed by eye on many locations along the island's southern shore, but comprehensive studies to the extent of this problem have so far not been conducted despite these worrying observations. The seriousness and extend of subterraneous delivery of microbes and pollutants to near shore reef communities has recently been illustrated in Mexico (Metcalfe et al. 2011) where an enormous variety of products used on land were observed in near shore waters where they were transported through groundwater flow. The study concluded "that planned growth of urban and tourism development will benefit from the adoption of mitigation strategies and Beneficial Management Practices (BMPs) to ensure that pollution does not pose a serious threat to the coastal ecosystems and human health, and thereby affect the economy. To avoid contamination from the domestic sewage produced by cities, towns and resorts, it is essential to develop and maintain adequate wastewater treatment infrastructure. Care must be taken to avoid contamination of the aquifer as a result of runoff from highways, roads, parking lots and the tarmac at airports. Protection of the remaining mangrove ecosystems is necessary to provide an additional buffer against coastal pollution. Integrated approaches to water management are required that are built upon participation by all stakeholders, including the private sector, government and the communities. The stakeholders can help to define problems, identify appropriate BMPs and monitor the effectiveness of management strategies. Without these integrated approaches, a tourism-based economy will not be sustainable over the medium to long term".

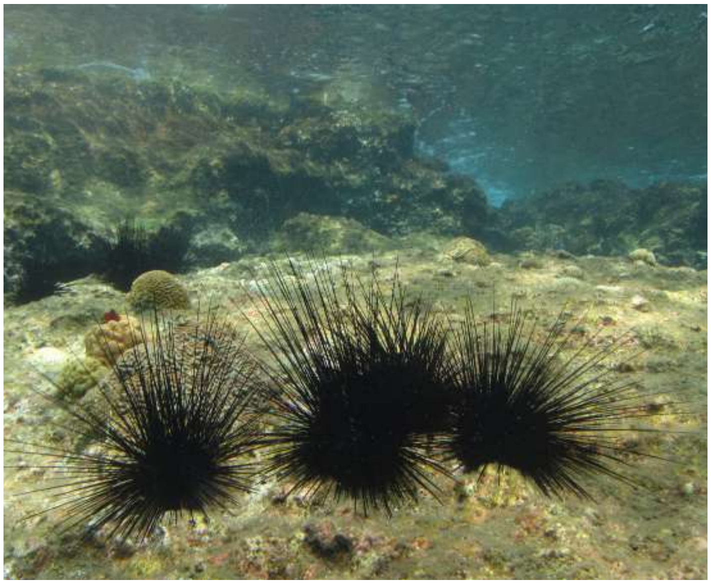
Pro and cons of coastal fortification (seawalls, breakwaters, etc.)

Structures placed in moving water have the capability to, in addition to destroying marine life in its footprint or during construction activities. They disrupt the water's flow and may cause increased flow and sediment rates immediately around their base leading to scour and erosion (Tyrrell 2005). Structures built in the ocean may also lead to a general slowing of flow (especially on their leeward side), resulting in settling out of sediments carried by the current. The resulting changes in sediments caused by scour or deposition may affect marine life in the area and/or coastal morphology due to changes in near shore water flow. Hence pier designs where piers are placed on pilings are generally preferred to allow the water to flow "trough" the structure. Massive structures made out of large limestone boulders (> 1m) are common on Curaçao and appear excellent substrates for settlement and growth of various forms of marine life. Some of these structures consisting of smaller boulders or boulders that are not "fixed" and therefore still mobile, can damage the surrounding marine life during storms when breakwaters break apart and limestone boulders are dispersed across the surrounding landscape where they obviously impact all that is present.

It seems inevitable that a pier will change near shore currents and sediment regimes, especially for massive designs, especially during storm events or when large ships are moored to the structure. When selecting a pier design that is capable of withstanding the impacts of storm events, it is important (in addition to the adequate design of the above water section) to determine the elevation at which storm waves propagate. This expectation is largely based on experiences with structures built near the shore line on Bonaire and Curaçao that were all largely destroyed during severe weather events in the last two decades (examples include: the Hilton hotel's concrete pier (1998, 2016), the Octopus Bar (1998, 2008, 2016), Karel's Beach Bar (2008), Habitat Piers (2008), houses along shore at St. Michiel (1998, 2016) etc.). Though mostly anecdotal, the fact that the destruction of such establishments caused a large amount of debris to become scattered across the sea bottom has been confirmed underwater by Debrot (Carmabi, unpubl. data) on Curaçao after the passing of storm Omar: "In areas with coastal construction much fresh man-made material has been deposited on the reefs such as litter, bags, clothing and building debris".

It should be noted that the interactions of seawalls and beaches are not completely understood at this time. Artificial beach creation has generally been unsuccessful in the region and generally results in excessive sedimentation on nearby reefs. Alongshore sediment transport may also be affected in the near shore environment if material placed on the beach is not compatible with natural or historic material. In addition, near shore rock groins are sometimes constructed in order to reduce erosion of the nourished beach, which alters the down drift of sediment and may starve adjacent beaches of sand.
It needs to be noted that a coral reef (or mangroves and seagrass) are efficient buffers against storm surge and waves (Wells and Ravilious 2006; Barbier et al. 2008). Reefs can absorb up to 80% of the energy making them ideal natural solutions against storm impacts.

There are no reliable surveys on the abundance of lobsters or conch on Curaçao. Both species are relatively rare and appear heavily overfished when present numbers are compared against historic information from older islanders. Queen Conch *Strombus gigas* is distributed throughout the Caribbean, from Florida (US) to the northern coast of Latin America. They primarily inhabit sandy seafloors in clean, shallow waters, but also occur in depths of up to 100 m. The species has been included in Appendix II of CITES since November 1992 and although it was classified as Commercially Threatened in the 1994 IUCN Red List of Threatened Animals, it is not currently classified as threatened by IUCN. Over the past few decades, intensive fishing pressure has led to population declines, stock collapses and consequently the total or temporary closure of the fishery in a number of locations, for example in Bermuda (GB), Cuba, Colombia, Florida (US), Mexico, the former Netherlands Antilles (NL), the Virgin Islands (US) and Venezuela. Available information suggests that the majority of *S. gigas* populations have continued to decline since the species was listed in the Appendices, and in some areas, population densities are so low that recruitment failure is a risk to local fisheries. Queen Conch stocks are considered severely depleted in Curacao. Both the populations of Bonaire and Curacao have been affected by illegal fishing that is seen as the principal cause for the observed declines (Van Buurt 2002).



The last survey of lobster (*Panulirus argus*) populations on Curaçao dates from 1985 and already found that this species was overharvested. On the reef, reserachers found on average 1.12 lobsters per hectare during the day and 2.23 at night (Sybesma et al. 1986). Elsewhere in the Caribbean, those values are 3.9 and 7.7 per ha, respectively. In the inland bays, young lobsters were found on slopes of channels with small rocks and holes. The muddy bottom was avoided. Based on these surveys the authors conclude that lobsters are overfished (Sybesma et al. 1986), though harvestable populations might still be present along the island's nother shore.

The long-spined sea urchin *Diadema antillarum* also used to be a common species that occurred in mean densities of 3–20 individuals m^{-2} on the shallow fore-reef along the leeward coast of Curaçao (Bak et al. 1984). In 1983, an unidentified disease caused Diadema to become almost extinct on Curaçao (Bak et al. 1984) and elsewhere in the Caribbean (Lessios 1988). Mass mortality was first observed in October 1983 and locally 97.3%–100% of all urchins died. Available data for 2002 show that adult densities remained low, ranging between 0.08–0.28 individuals m^{-2} (Debrot and Nagelkerken 2006) with no signs of recovery of adult populations since (Vermeij et al. 2010). Presently, *Diadema* are mostly found in shallow, wave-sheltered rocky habitat, and are significantly associated with coastal lagoons, whether natural or man-

made. The highest densities are found particularly on rocky substrate at the entrances of such lagoonal habitat. Size-class distributions at such sites show the full range of urchin sizes, which indicate on-going recruitment and successful survival in recent years (Debrot and Nagelkerken 2006). Diadema antillarum was an important benthic herbivore (Hughes 1994) and turf/macroalgae increased in abundance after the Diadema die-off (Bak et al. 1984; Hughes 1994). Because algae compete for space with juvenile corals, the *D. antillarum* die-off indirectly caused a reduction in the number of juvenile corals once algae had become more abundant. Therefore, many researchers consider the *D. antillarum* die-off as one of the main factors contributing to the overall decline of Caribbean reef ecosystems.

Information on pelagic fisheries

The fishing industry of Curaçao mainly consists of traditional artisanal fisheries. The fisheries can be broadly categorized into two classes: reef fisheries that primarily target demersal reef-associated species, trolling fisheries that target pelagic species. Hand-line and trolling fishing are, and always have been, the most common form of fishing on Curaçao, accounting for the majority (~85%) of demersal and pelagic fish landings (Boeke 1907; Zanenveld 1961; Lindop et al. 2015). The first hand-line fishermen started operating in 1824, catching mainly demersal fish species (Zanenveld 1961). This method remained unchanged until the introduction of nylon fishing lines in ~1934 (Munro 1977), which allowed fishermen to haul in larger fish. In the late 1800's, fish traps (Kanasters) were introduced as a new method for demersal (reef) fishing (Boeke 1907). The shape and size of kanasters remained unchanged from the late 1800's until 2012, which is when fishermen were by law obligated to equip their kanaster with an escape gap to reduce bycatch in the traps (Dilrosun, pers. comm.). In the 1940's, spear guns were introduced to Curaçao. Due to its efficiency, spearfishing became a very popular fishing method in the late 1940's. Already in the late 60's, it became evident that spearfishing had led to over-fishing of especially big predatory fish species (Van Buurt 2002), which is why the Curaçaoan government prohibited spearfishing in 1976. Nonetheless, illegal spearfishing continues until today as fishermen consider the chances of being apprehended minimal. Due to its illegal nature, it is complicated to attain a precise image of how spearfishing affects the local fishing industry (Dilrosun & Van Buurt, pers. comm.).

While fisheries contributed ~4% to the Curaçaoan national GDP in 1904, this contribution has decreased to less than 1% in 2003 (LVV, 2003). This is partially caused by the low import prices of fish, resulting in relative higher market prices for local fish species compared to foreign fish species (Dilrosun 2002). Secondly, because local fish stocks have decreased, more effort is required to generate the same catch through time. Because the catch per unit of effort (CPUE) is decreasing (local fishermen, pers. comm.), it is becoming increasingly complicated for fishermen to land a catch sufficient to maintain themselves, and their families. In an attempt to help the fishermen increase their catches, the Curaçaoan government funded the installation of 5 fish aggregation devices (FAD's) along the southern coast of Curaçao (Van Buurt 2002). However, the effectiveness of these FAD's is currently unknown. The combination of low import prices for foreign fishes and a decreasing CPUE, causes many fishermen to stop fishing altogether, resulting in the decreasing contribution of fishing to the Curaçaoan economy.

A 25% decline in total fish landings occurred on Curaçao from the early twentieth century to the mid-twentieth century, which is a relatively small decrease compared to the 90% decline in total landings that occurred between the mid 1900's to the early 2000's (Figure 14) (Latijnhouwers and Vermeij 2015). One fisherman in 2006 landed an average total of 12 kg of fish per month, compared to 90 kg in 1958, and 122 kg in 1904 (Latijnhouwers and Vermeij 2015). Because the introduction of nylon fishing lines in 1934 and the use of larger and faster fishing vessels allowed fishermen to catch more and larger fishes, one would expect the catch in 1958 to be higher than in 1904. Nevertheless and despite the increased fishing effort, the catch has decreased with 25% over this 50 year period, suggesting that the first effects of (over)fishing were already evident in the mid twentieth century. From 1904 onward, there was a large decrease in the landings of large fish (e.g, blue marlins, sharks, nassau groupers) and new species have emerged in the catches in 2006 that were not targeted by fishermen in 1900 such as rainbow runners, blackfin tunas and graysby's. While demersal and pelagic catches in 1908 contributed in similar amounts to the total catch (47% and 45% respectively), in 2006 pelagic species accounted for 77% of the landings (kg) compared to 17% demersal catches (kg) indicating a 63% increase in pelagic fish catches (kg) in 2006 compared to 1908. Simultaneously, demersal catches (kg) have decreased with 61% indicating that fishermen moved away from coastal areas and started fishing the open sea (Latijnhouwers and Vermeij 2015). Moreover, the severe decline in coral cover over the last decades caused by pollution, eutrophication, physical destruction of habitats, outbreaks of disease, invasions of introduced species, and human induced climate change also contributed to the decline of reef fish abundance, warning against simplistic views whereby fishermen alone are held responsible for the current depauperate status of Curaçaoan fish communities. Nevertheless, (1) reduced average sizes of numerous target species below the minimum sizes set by FAO for sustainable fishing (Schultink and Lindenbergh 2006), (2) the disappearance of species (e.g., groupers) targeted > 50 years ago from present day catches (Schultink and Lindenbergh 2006; Latijnhouwers and Vermeij 2015) and (3) a 90% reduction in catches over the last century all indicate that severe overfishing has and is taking place on Curaçao.

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