

State of Curaçao's Coral Reefs

1973-2045



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Introduction: What is this report about (and what not)?

In October 2025, the latest information available on the state of and processes affecting coral reefs around Curaçao was presented to various ministries (e.g., VVRP, MEO, GMN) and local organizations involved in the tourism industry (e.g., CHATA, CPA, CTB). These sessions were sparked by the drastic decline of coral reefs around Curaçao and the availability of new information on drivers underlying this decline that in recent year was collected by various, mostly international universities and research organizations. At the same time, Curaçao faces an increase in tourism numbers while it also wants to stay a “paradise above and below the surface”. Especially this latter ambition is difficult to rhyme with the ongoing, largely human-induced decline of reef communities along the majority of Curaçao’s leeward shore. A (relatively) short summary of the existing information on Curaçaoan reefs seems therefore timely.

This summary should concisely overview the knowledge and insights that could be useful to those in positions to take action. Healthy reefs and clean waters benefit locals and visitors, beachgoers and fishers and young and old. While measures to reverse the rapid decline of coral reefs around our island will be challenging and sometimes expensive, decisions on what actions could be taken (or not) should be based on the best information available, of which some can be found in this report. It is important to realize that Curaçao still has some of the best reefs left in the Caribbean which are still growing (and in some other places as well) and that therefore not all is as “gloomy” as commonly presented by many scientists and/ or conservation groups. Curaçao is somewhat unique in this aspect within the region and functional reefs would definitely distinguish Curaçao from many other Caribbean islands, where reefs have all but disappeared already.

This report follows the principle that “information” and “decision making” are two different fields (*Figure 1*). All too often scientists and “conservationists” are unaware of e.g., policy and law making, the inherent workings of government (“the government is not doing anything to stop or reverse this decline!”), whereas, vice versa, many in government simply do not have time (or access) to read the scientific studies that could be relevant to their jobs (“why can’t anyone make a simple overview of all this? I don’t have time to read 100+ scientific studies!”). This report thus provides the main messages arising from the growing number of scientific studies conducted on Curaçaoan reefs, but will steer away from subsequent policy recommendations as this is the area of expertise and responsibility of the Curaçaoan government. Recommendations on technical aspects (e.g., design of water treatment facilities) or financing mechanisms (“how are we going to pay for it all?”) are also not included in this report. Only when clear examples exist from other Caribbean locations or in case work to improve the quality of Curaçaoan reefs has already started, are such cases included here.

During aforementioned presentations, attendees were asked to provide questions relevant to the (decline of) Curaçaoan reefs to ensure that this report catered to the need of those in positions to facilitate actual change rather than “overview” science’s accomplishments, which are often of no interest to policy, management, etc.

Curacao Reefs: Information and Decision-Making

Characteristic	Information	Decision-Making
 Focus	Scientific studies on reef decline	Policy and law implementation
 Expertise	Conservationists and researchers	Government officials and policymakers
 Scope	Overview of reef status and drivers	Actionable strategies for reef conservation
 Content	Scientific findings and data	Policy recommendations and technical aspects
 Purpose	Inform and educate stakeholders	Facilitate change and conservation efforts

Figure 1 Conceptual overviewing the different roles and functions of those providing and using information within the context of this report.

A total of 178 questions were received that were very similar in some cases and we condensed them to the questions starting each paragraph in this report. When questions concerned aspects addressed in existing policy documents (e.g., those resulting from the collaboration with the Wait institute) or are already addressed in local law (e.g., can you still use spearguns in Curaçao?), they were not included in this report, nor were questions concerning specific aspects of government "operations" (e.g., how does one make a new law? Does the Kingdom have a role in operationalizing conservations law in Curaçao?, Which Ministries have "stopped" earlier ambitions to produce effective nature legislation on the island?).

The format of this report obviously does not provide space to address nuances and exceptions. Regardless, since policy or conservation action should not depend on such details, we decided to move forward with this format and hope that the "question driven" format will steer people directly to those sections relevant to them. We have included references to original data sources throughout this report for those seeking more detailed information. This report foremost strives to convey the threads and urgency (and to lesser degree opportunities) relevant to Curaçao's ambition to be "a paradise below the surface". We also welcome feedback so this document could become a "living document" in the future based on the input and concerns of all.

Willemstad, June 2026.

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Curaçao in numbers

Curaçao's surface comprises 77 % vegetation (shrubland (36 %), tree cover (26 %), grassland (13 %)), 19 % built-up areas, and 3 % is classified as bare soil. Only a small portion (<1 %) is identified as agricultural land, although small-scale agricultural activities might be overlooked (Steward et al. 2025). Most built-up areas concentrate around Schottegat bay with Willemstad and oil refinery complex. Approximately 17 % consist of urban areas (12 % dense urban and 5 % sparse urban areas). A large part of eastern Curaçao (~10 %: “Eastpoint”) is privately-owned and inaccessible (*Figure 2*). The most significant land use changes over recent decades include reforestation in the west, driven by the establishment of nature conservation areas and the restriction of livestock grazing (Debrot 2015), and continued urbanization around Willemstad in the east, following rapid population growth (from 34,000 in 1920 to 150,000 in 1970). Over the past 50 years, the total population of Curaçao has remained relatively stable, although decreasing average household sizes and the substantial increase in tourism (stayover tourists: 100,000 in 1970 to ~800,000 in 2024¹) has exerted additional pressure on urbanization rates (Wit et al. 2025). The island harbors 15.7 km² of coral reef habitat along its coasts, mostly along its leeward shore.

Curaçao lacks perennial surface water, except for natural springs and artificial lakes behind dams that fill up during the wet season. The island's catchments are drained by ephemeral streams, locally referred to as ‘rooien’, that flow during extensive rainfall and mostly drain into inland bays that (used to) connect to the open ocean where the island harbors 15.7 km² of fringing coral reef habitat along its coasts, mostly along its leeward shore. These numbers hopefully help with establishing some intuitive understanding on the pressures faced by the island's marine ecosystems. For example, while many believe the island harbors vast areas of coral reefs, built-up areas are 5 times larger than all reef habitats combined. Another example, all the excrement produced by people present in Curaçao in one day weights approximately the same as all fishes swimming on the island's reefs combined. These examples question the commonly held intuitive notion that the “ocean is too large to destroy”.

1 <https://tourismanalytics.com/Curaçao-statistics.html>

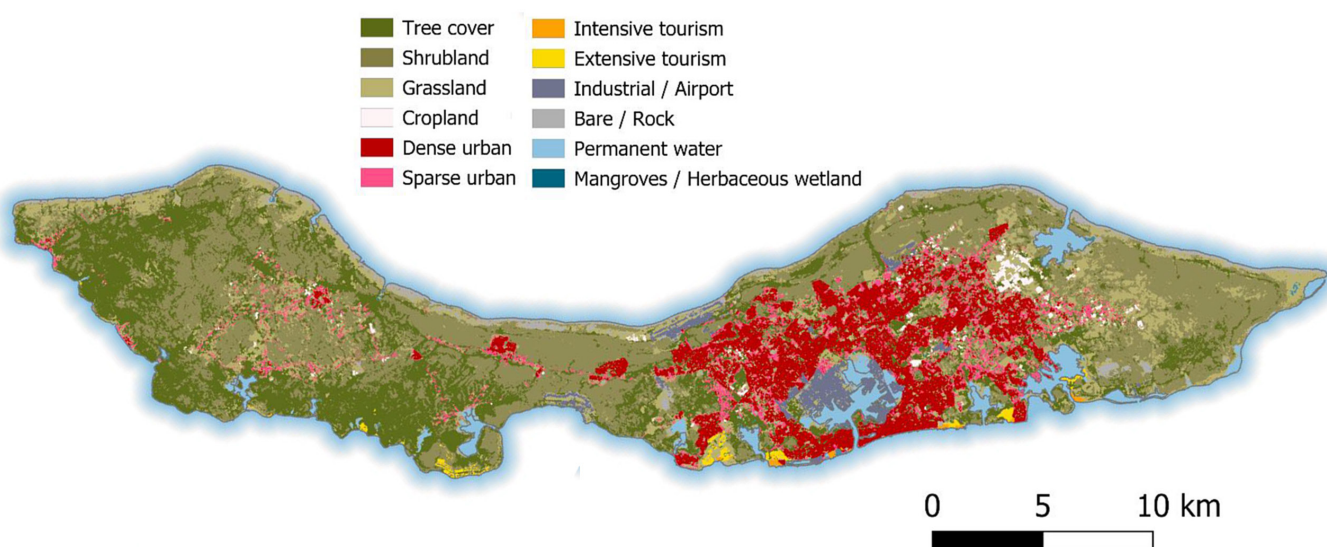


Figure 2 Land use land cover (LULC) map of Curaçao after Steward et al. (2025)

Are coral reefs around Curaçao in decline? Yes

Systematic reef monitoring around Curaçao began in the early 1970s, when live hard coral cover averaged 45 – 55 % on leeward fore reefs at 10 – 20 m depth (Bak 1977, Bak and Nieuwland 1995). This depth range is commonly considered indicative of overall reef health as reefs can extend from ~1m to ~70m in Curaçao. An island wide decline in average coral cover occurred to ~18 % by 2010 followed by a further decline to ~13% in 2015 (and 2023) and then to ~5% in 2025 ([Figure 3](#)). Locally (e.g., Oostpunt, Klein Curaçao) areas with high coral cover (> 25%) remain ([Figure 4](#)).

Major declines in the abundance of reef building corals steps coincided with disease outbreaks (e.g., white band/white plague outbreaks in the late 1970s to mid 1980s and SCTLD in 2023-present), hurricane swells in 1999 (Hurricane Lenny) and 2008 (Omar), and the Caribbean coral bleaching events (e.g., 1998, 2010 and 2023). Furthermore, widespread pollution and overfishing have contributed to the island-wide continuous decline in coral abundance. Nineteen of the 65 reef building coral species in Curaçao are now threatened with extinction according to IUCN's Red List (Gutierrez et al. 2024). Carbonate budgets are positive but marginal, implying vulnerability to storm erosion. Legal frameworks exist but enforcement and sewage infrastructure lag. Without rapid improvement in terms of fisheries management, pollution reduction, enforcement etc., reefs are expected to fall below recovery thresholds within decades.

The decline of the island's reefs, once mentioned as “among the healthiest in the Caribbean”, has also been noticed by tourists. Overall, public web based opinion has matured from carefree admiration to a nuanced, solution oriented dialogue that balances tourism promotion with urgent calls for coastal management, wastewater treatment, disease response and large scale reef restoration. These sentiments can be summarized as follows: 2000s: “Curaçao looks fantastic—come dive!”, early 2010s:

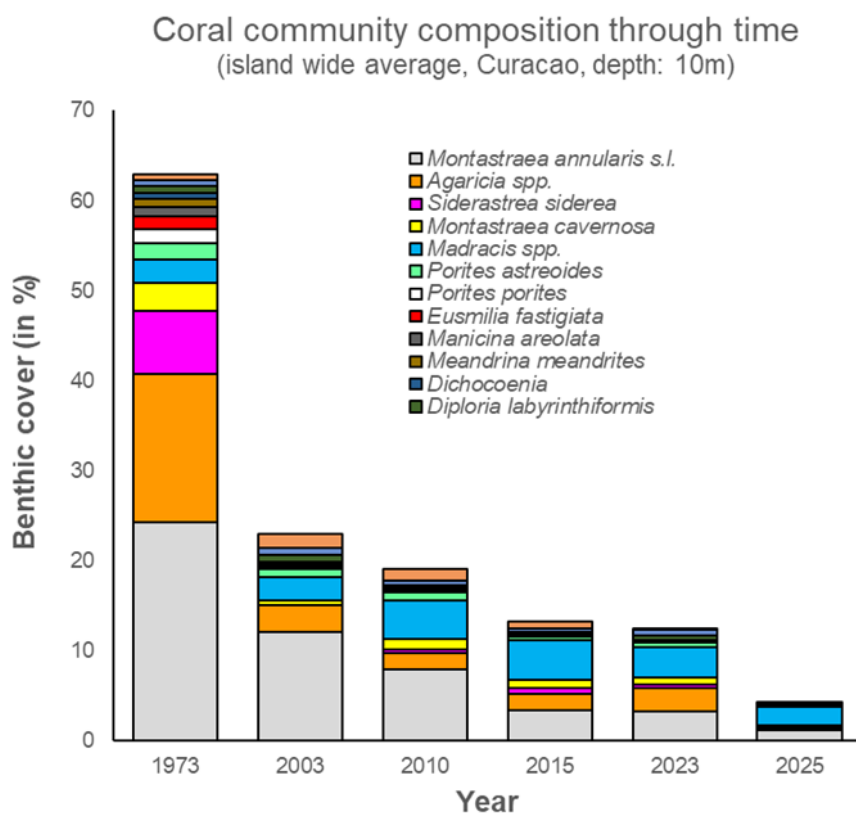


Figure 3 Changes in coral community composition along Curaçao's leeward shore. Note: there are hardly any reefs along the island's windward shore. The different colors indicate different color species and a healthy reef is characterized by coral cover >50%.

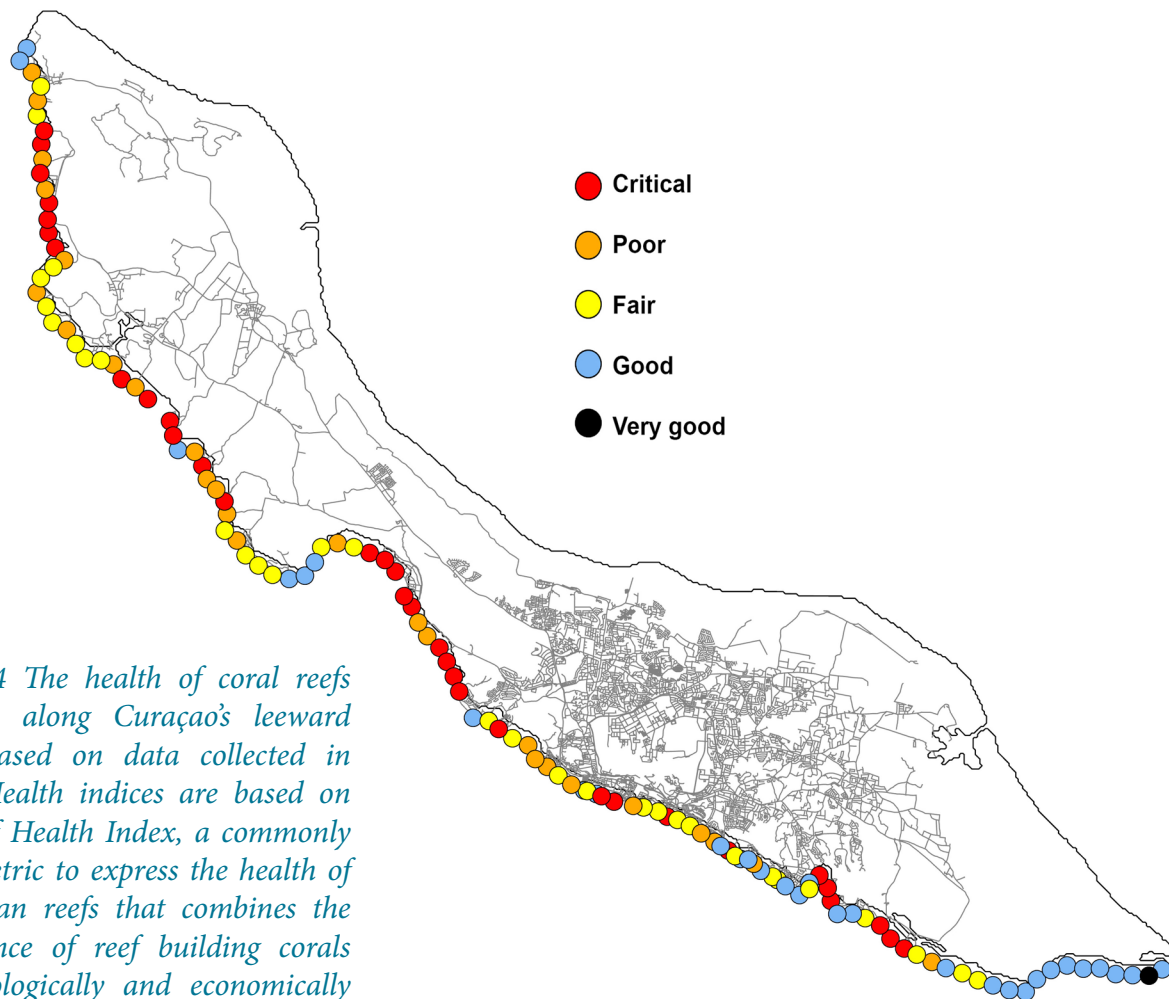


Figure 4 The health of coral reefs at 10m along Curaçao's leeward shore based on data collected in 2023. Health indices are based on the Reef Health Index, a commonly used metric to express the health of Caribbean reefs that combines the abundance of reef building corals and ecologically and economically important fish species..

“Reefs still good but starting to slip—let’s keep an eye.”, mid 2010s: “Some sites hurting; restoration sounds promising.”, 2020 pandemic: “Human break = reef breather—let’s manage pressure better.” and at present “Bleaching & coral disease are here—urgent upgrades and targeted closures needed.”

Has the abundance of reef fishes declined? Yes.

Fish communities changed in parallel with the decline in coral abundance. Historical catch analyses that span 1905 2020 reveal long term “sequential over fishing”, whereby landings of large reef predators (groupers, jacks, reef sharks) collapsed by the 1950s (Vermeij et al. 2019). Fishing efforts then shifted offshore and toward smaller herbivores and pelagics (e.g., dradu, buni, mula). Today, predators constitute <6 % of standing reef fish biomass, and should exceed 20 % for a reef fish community to be considered “healthy” or functional and all important fish groups are currently near or below thresholds associated with healthy or functional reef communities ([Figure 5](#)). In addition to overfishing, habitat destruction in the form of aforementioned declines in framework building coral species, but also the pollution and destruction of nursery areas such as mangroves and seagrass areas (Huijbers et al. 2013) have contributed to the general and enormous decline of reef fishes over the last few decades. Overfishing and habitat destruction are estimated to have equally contributed to the decline in reef fishes around Curaçao (Vermeij et al. 2019).

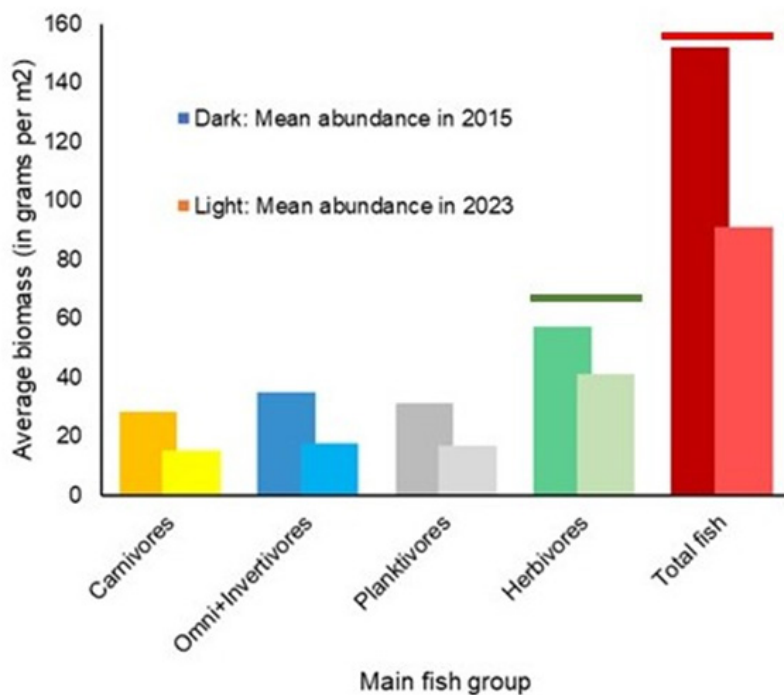


Figure 5 graph showing the decline in all major fish groups around Curaçao over the last ~ 10 years. Especially the decline in herbivorous fishes is worrisome as healthy herbivore communities are essential for proper reef functioning. Bars indicate values associated with functional reefs.

Are Curaçao's reefs still in better condition compared to other Caribbean islands? Yes, but only in a few locations.

While average island-wide coral abundance is declining as in many other Caribbean nations, Curaçao's coral reefs reflected the Caribbean average for coral cover in 2023, i.e., ~13% coral cover ([Figure 6](#)). Some of Curaçao's reefs (e.g., reefs along the east coast of Klein Curaçao, the reefs near Oostpunt and Kaap Marie, [Figure 4](#)) remain among the better performing systems in the wider Caribbean ([Figure 6](#)). Curaçao's reefs left the "coral dominated" state as average coral cover is now ~5 %, (in 2025) which

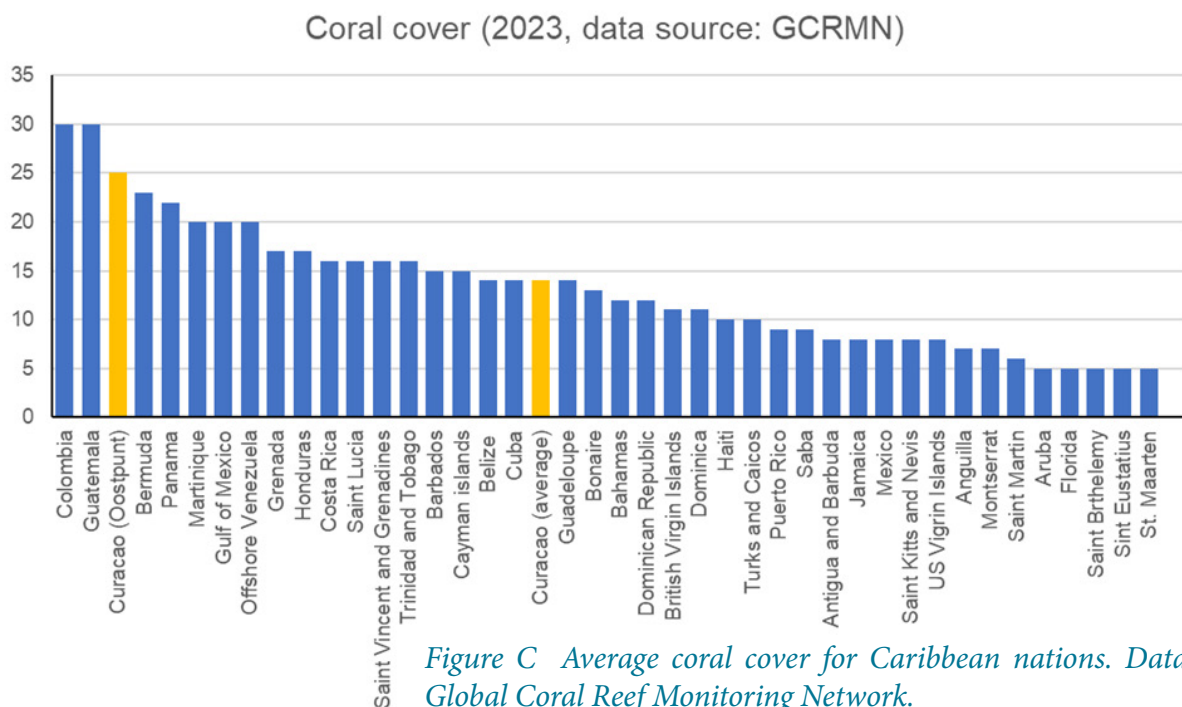


Figure C Average coral cover for Caribbean nations. Data source: Global Coral Reef Monitoring Network.

is below the 20 % threshold commonly used to denote functional coral reefs. Macro /turf algae now dominate the reef bottom in many sites.

Are coral reefs common along the island's windward shore? No

A 2015 survey along the island's windward shore found only a few reefs (e.g., near St. Joris and Boka Patrick) and most of the reef in this area has been historically dominated by algae (Sargassum, [Figure 7](#)). This is a different Sargassum species than the one that sometimes washes ashore in large amounts.

Does Curaçao taper off with increasing depth ? No

This commonly heard “concern” arose when some of the first researchers using SCUBA in the ‘50’s tried to describe to local fishers what they had seen underwater. Unable to speak Papiamentu, they used their arms to describe the large “mushroom looking” coral colonies (*O. faveolata*) they had seen. These arm gestures were then assumed to refer to the island itself which led to the perception that Curaçao is shaped like a mushroom underwater, i.e., it has a small stem on which the island sits. Recent surveys show that Curaçao sits on top of a mountain that extends underwater ([Figure 8](#)) and concerns about the island's solid connection to the Earth are unwarranted.



Figure 7 Fields of Sargassum dominate much of the bottom along Curaçao's windward shore.

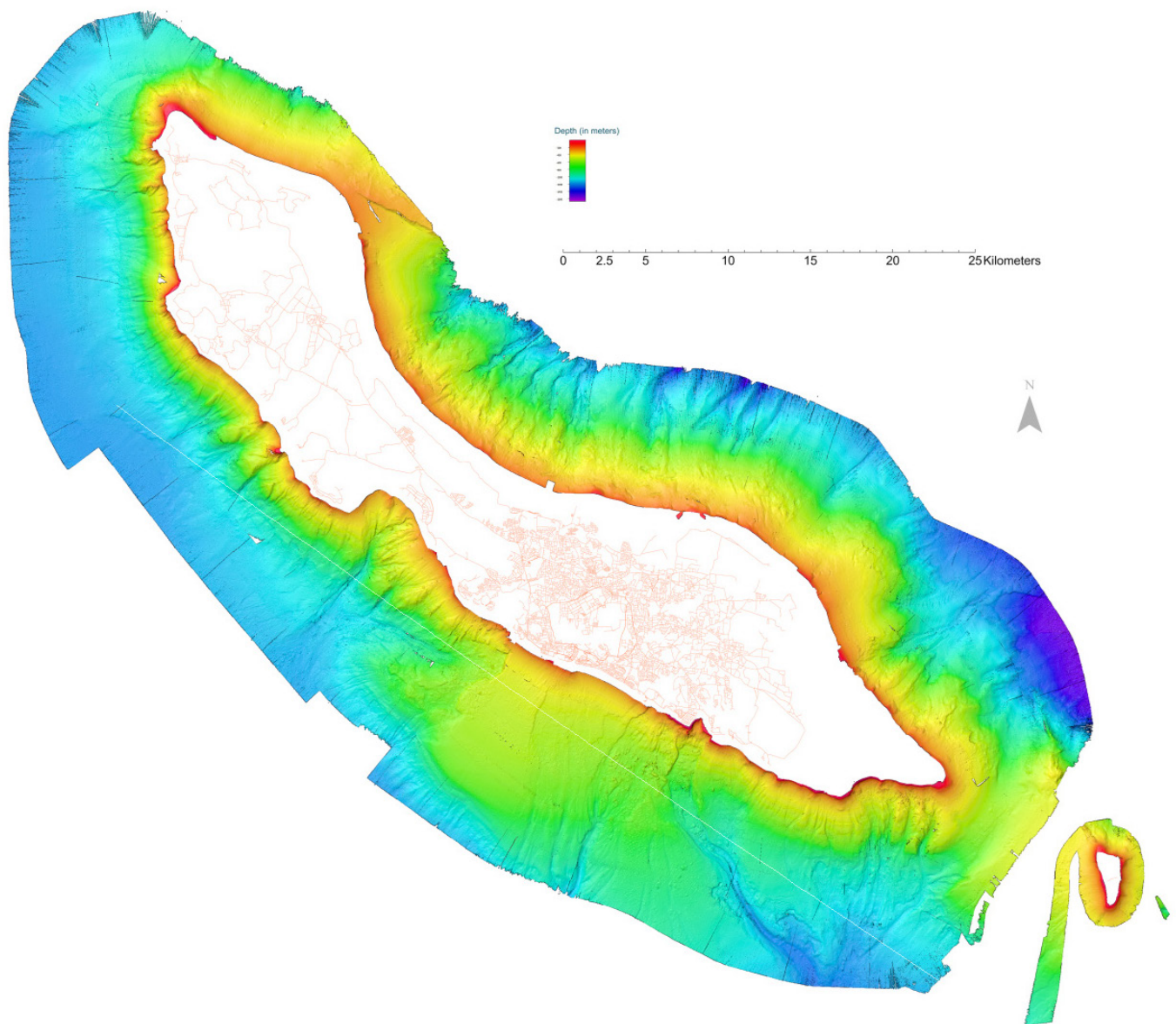


Figure 8. Depth map (in meters) of the waters around Curaçao.

Do Curaçaoan reefs harbor threatened and endangered species? Yes

Curaçao is located in a biodiversity hotspot within the Caribbean that is already a biodiversity hotspot in itself (Spalding et al. 2007, Miloslavich et al. 2010). At least 12,046 marine species occur in Curaçao of which ~70 only occur in the ABC islands (Debrot et al. 2017). Approximately half of the ~ 68 coral species found in Curaçao are threatened with extinction (Gutierrez et al. 2024) and all reef building corals, gorgonians, marine mammals, parrotfishes, karko and sea turtle species are in some form protected under local and international law. While less common, certain fish species (e.g., Nassau groupers, Caribbean reef sharks, all parrotfishes) also receive some form of protection.

Do Curaçaoan reefs harbor species that are protected by local law? Yes

Curaçaoan law protects numerous marine species through various laws, such as the “Rifbeheersverordening (RBV)” and the “landsverordening Grondslagen Natuurbeheer en -bescherming (LvGNBB)”. Indirect protection through fisheries laws arises from a ban on illegal hunting methods such as the use of spearguns and gill nets. All coral species, including gorgonians and hydrozoans, are protected under the RBV and can only be damaged or collected with special permits provided by the Ministry of GMN. The LvGNBB dynamically refers to the SPAW Protocol¹, making rules in this international treaty local law in Curaçao. The SPAW Protocol extends strict protection for certain plant and animal species (indicated on SPAW annexes I and II, respectively). Species on these lists can change through time, though species are mostly added, rather than removed. No SPAW I species occur in Curaçao, but there are many SPAW II species, such as four common coral species (*A. palmata*, *A. cervicornis*, *O. annularis* and *O. faveolata*), all sea turtles, all marine mammals, whale sharks, oceanic whitetip sharks, mantas and the karko. Species listed on Annex III are protected unless one can show that their harvest can take place “sustainably”, though no specific rules are provided to assess this criterion. Species listed on SPAW Annex III, include all stony corals of the order Scleractinia (other than those already listed above), all gorgonians/sea fans (Order Gorgonacea), all black corals (Order Antipatharia), and all fire corals (Family Milleporidae). Furthermore, Caribbean reef sharks, Nassau groupers, all parrotfishes (Family Scaridae), Queen conch (Karko), as well as all mangrove and seagrass species are listed on Annex III and hence receive protection under both international (SPAW) and local (LvGNBB) law. See: Vermeij and Chamberland (2013)² for a general overview of other potentially relevant laws and regulations.

Have Curaçaoan reefs stopped growing altogether? No

Relatively healthy reefs can still be found around Curaçao such as near the north-western tip of the island, Kaap Marie, the eastern side of Klein Curaçao and within the Curaçao Underwater Park which is ranked among the best three reef systems left in the Caribbean (Jackson et al. 2014). While the average abundance of corals in Curaçao is declining through time, local increases occur pretty much everywhere as species forming small to medium sized colonies increase in abundance. These increases are however not large enough to offset the decline of coral species (such as *Orbicella* spp.) that dominated reef communities in the past and formed large colonies. Nonetheless, the fact that growth does occur contrasts with the wide held belief that all coral species are in decline when “total coral cover” decreases through time. Even historically dominant species that have largely disappeared near developed coasts (e.g., *A. agaricites*, *Orbicella* spp.) are locally still abundant (CARMABI, unpubl. data 2025, Figure 4) such as near Oostpunt, Kaap Marie and the east side of Klein Curaçao. In other locations, certain species, especially the yellow pencil coral (*M. mirabilis*), but also *S. siderea* and *M. cavernosa*, are increasing in abundance compared to historical baselines along ~25% of the coast, mostly near Willemstad, whereas general decline occurs along ~60% of the coast (mostly near Banda Abao) and ~15% of reefs still have (declining) communities of historically dominant species (mostly near Oostpunt, Alcantar et al. in prep.). While coral communities could change in composition as a consequence, the observation that certain species appear capable of acclimatizing/ adapting to today's

1 <https://www.car-spaw-rac.org/?MAMMIFERES-MARINS-TEST>

2 <https://rsis.ramsar.org/RISapp/files/RISrep/NL2119RISformer.pdf>

conditions differs from predictions where algae generally take the place of corals that succumbed and suggests that reef communities, albeit different than those in the past, could still form in certain, disturbed locations. This phenomenon is somewhat unusual and has not been reported from other Caribbean locations, other than maybe Bonaire. Species like *M. mirabilis* harbor an enormous variety of microbes and viruses (more than all other coral species combined) that likely allow them to thrive under disturbed and/ or polluted conditions typifying reefs near Willemstad (Wallace et al. 2025).

Are Curaçaoan corals impacted by diseases and “coral bleaching”? Yes

In general, it is somewhat challenging to distill the importance of historic events such as disease outbreaks, storms, ship groundings etc. from factors that currently drive changes in the abundance of corals and reef fishes. Nonetheless, bleaching events and disease outbreaks have significantly reduced the abundance of many coral species over the last five decades. Dramatic examples include the outbreak of white band disease that in the early 1980's decimated (> 90%) the well-developed shallow water coral communities formed by two *Acropora* species (Goreau et al. 1998) that occurred along pretty much the entire leeward coast (Van Duyl 1985). Recently, the arrival of Stony Coral Tissue Loss Disease (SCTLD) in 2023 has caused the ecological extinction of certain coral species (e.g., pillar coral (*D. cylindrus*)) and caused the decline of ~ 20 others (Cróquer et al. 2021, Pepe et al. 2025).

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, 2014, 2018 and 2024 whereby large coral species that contribute most to reef framework were most heavily affected between 2 to ~ 80 m. Thermal stress during the 2024 event exceeded any observed from the Caribbean in the prior 40 years of satellite records and 150 years of analyzed temperatures suggesting we may now be moving into conditions predicted by climate models where severe bleaching in the Caribbean becomes a regular event. While they will not solve the consequences of climate change altogether, improving water quality through reduced nutrient and sediment pollution, controlling overfishing, and managing local human impacts are known to contribute to reefs that are better able to withstand or recover from climate impacts like coral bleaching (e.g., Anthony et al. 2015, Donovan et al. 2021).

Can climate change also affect tourism? Yes

Temperature is the most important climate variable in the analysis of nations' tourism demand because beyond a certain range it affects comfort. Warm temperatures, clear waters and low health risks are the main environmental attributes important to tourists, in addition to marine wildlife attributes (Bonaire) and beaches (Barbados) (Uyarra et al. 2005), but 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 (e.g., Mather et al. 2005) resulting in millions lost in tourism revenue (Moore 2010).

Are inland bays, mangroves and seagrass beds important?

Yes

Caribbean coral reef habitats, seagrass beds and mangrove stands provide many important ecosystem goods and services such as coastal defense, sediment production, primary production, fisheries and the maintenance of high species diversity (Moberg and Folke 1999). Approximately 0.55 km² of Curaçao's surface (i.e., ~ 0.1%) is covered by mangroves which is less than half of the mangroves existing a century ago (Debrot and Freitas 1991, Pors and Nagelkerken 1998). Similar to seagrass beds, mangroves serve as an essential nursery and juvenile feeding habitat for many commercially important reef species, among which snappers, grunts, barracuda and the West-Indian spiny lobster (Nagelkerken and Van Der Velde 2002, Sustainable Fisheries Group 2015).

Fish can disperse far from the inland bays in which they grew up. 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) (Huijbers et al. 2013). This example clearly illustrates that managing marine resources such as fish species that are dependent on inland ecosystems as nursery habitats requires a spatial management scales that spans the entire island.

Bays also represent major areas in which pollutants aggregate. In Curaçao, approximately 36% of the island's groundwater is comprised of sewage water (Wit et al. 2025). Half of the island's groundwater (including an enormous variety and amount of pollutants) flows out into the inland bays impacting their nursery functions. Bays therefore act as nutrient and substance reservoirs in dry seasons, releasing them during wet periods (Sanchez Baranco et al. 2025). Simultaneously, the bays act as “natural filters” to some degree for some of these pollutants, especially during the dry season when exchange with the open ocean is minimal (Sanchez Baranco et al. 2025). Seagrass beds on Curaçao (especially in Piscaderabaai and Spaanse Water) are threatened by eutrophication (Govers et al. 2014a). The seagrasses of Piscaderabaai 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. 2014a). Spaanse Water, with the largest seagrass area of Curaçao (Kuenen and Debrot 1995) highly contributes to coral reef fish populations around the entire island by functioning as an important nursery habitat for many fish species that spent their adult life on reefs (Verweij et al. 2008, Huijbers et al. 2013, Sheaves et al. 2015).

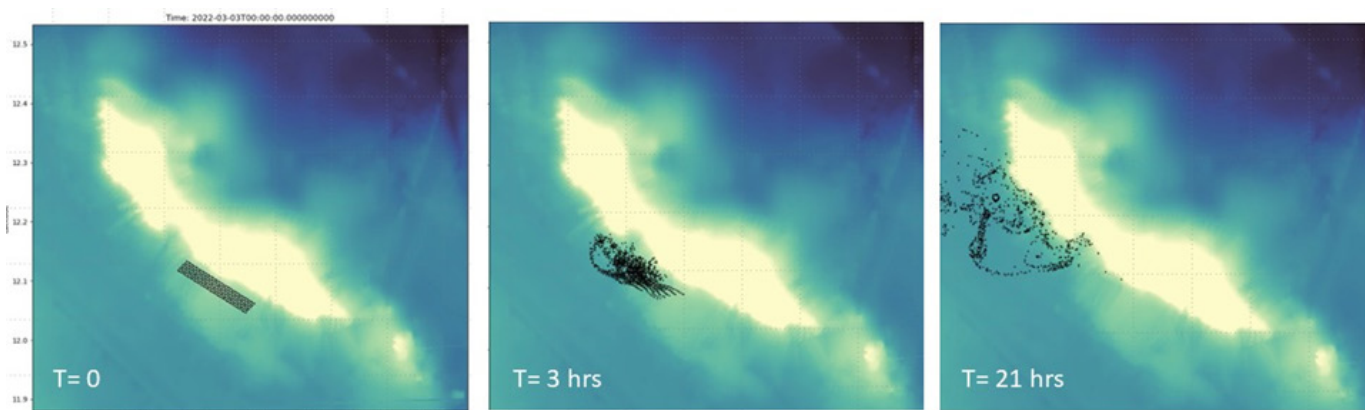


Figure 9 Spread of particles representing pollutants released into Curaçao's coastal waters near Willemstad and their location after 3 and 21 hrs, illustrating how rapidly pollutants spread along the island.

Are invasive species driving the decline of Curaçaoan reefs? Yes

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. 2011)). 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 (e.g., long-spined sea urchin disease). The latter example is often associated with the onset of Caribbean reef decline as sea urchins were the only grazers left in many overfished localities that prevented algae from overgrowing neighboring corals. In addition to such documented species, 76 other exotic species that have already been observed elsewhere in the Caribbean (e.g., *Unomia stolonifera*) and 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, whose impacts can 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. Invasive seagrasses (*Halophila*) are one of the more pressing concerns in this regard as they already have displaced many local sea grass beds. 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. Establishment of marine invasive species (but also diseases such as SCTLD) is 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.

Are Curaçao's coastal waters polluted? Yes

There are many forms of pollution that affect the survival of reef species and the functioning of coral reef communities. Below is an overview of some of the major pollutants that have impacted the proper functioning of Curaçaoan reef communities. All forms of pollution are highest close to Willemstad, probably due to presence of ~50 sewage overflows that spill sewage and other pollutants into coastal waters especially after heavy rainfall. While many pollutants (e.g., sewage, nutrients, chemicals and heavy metals) originate in densely populated or industrialized areas (such as the general Willemstad

area) west flowing currents transport such pollutants withing a day towards Westpunt (Bertoncelj et al. 2025). In other words, while pollutants often have very localized sources where they enter coastal waters, they rapidly spread out across the entire island (including the windward coast) so that their negative impacts on the island's coral reefs are widespread (**Figure 9**). Run-off, especially during rain, groundwater flow towards the ocean and direct release (e.g., sewage overflows) are the prime mechanisms by which pollutants move from land to the ocean. There are ~50 sewage overflow locations in Willemstad dumping raw sewage directly into coastal waters used for recreation etc. (**Figure 10**). Only 30 % of households connected to sewer, municipal sewage treatment plants treat <50 % of incoming flow (Adshead et al. 2018, Erdoğan 2021, Leiser 2022).

It is extremely important to note that pollutants that enter Curaçao's coastal waters at one locations often spread across the entire island due to the island's relatively small size and local current regimes (**Figure 9**, Bertoncelj et al. 2025) as managing only sections or zones within the coastline (e.g., near Westpunt) will have little effect when negative impacts (such as pollutants originating from Willemstad) are not also mitigated or addressed.

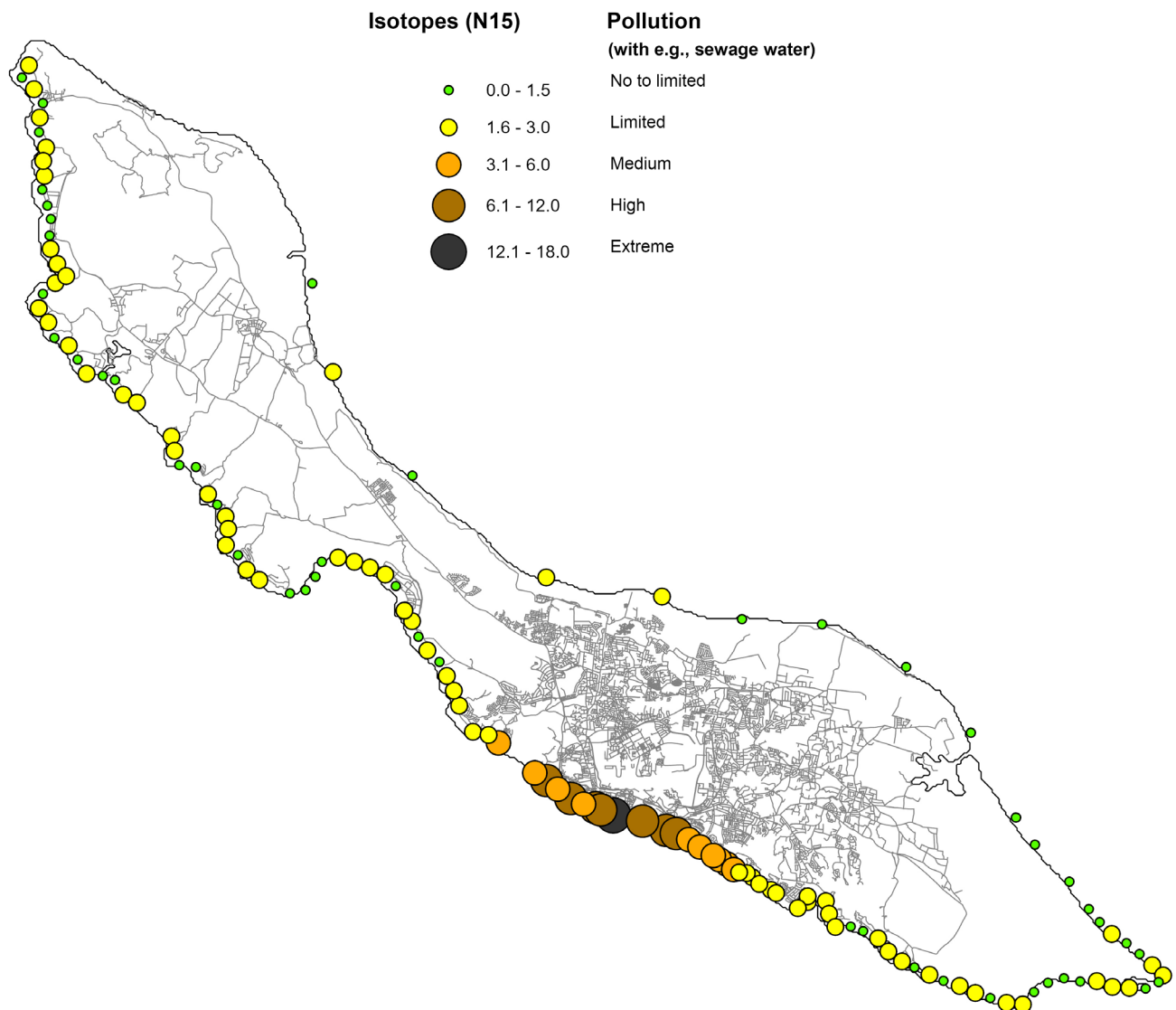


Figure 10. Map indicating areas where sewage water enters the ocean resulting in pollution and eutrophication of nearby water bodies.

Pollutant type 1: Eutrophication

Tropical waters, especially those near coral reefs, are highly susceptible to nutrient pollution. Persistent enrichment with land derived nitrogen and other nutrients (“eutrophication”) of the island’s coastal waters elevates planktonic productivity (resulting in “green water”) and lead to algal blooms, which can smother and kill coral. Therefore, standards often aim for very low concentrations of nitrogen and phosphorus, typically lower than those used for human health standards.

For example, the management authority of the Great Barrier Reef Marine Park (GBRMP) in Australia recommends that chlorophyll a concentrations in coastal waters should be below 0.0005 mg/L in tropical environments. Coastal waters in Curaçao exceeds this threshold frequently (~30% of all measurements taken between 2007 and now, n= 106 sampling locations). They also recommend safe limits for nitrate ($<1.6 \mu\text{mol L}^{-1}$) and phosphate ($<0.10 \mu\text{mol L}^{-1}$) and equivalent values are used by other governments and management bodies for tropical coastal waters such as Malaysia’s Marine Water Quality Criteria & Standard (MMWQS, 2016), aforementioned Great Barrier Reef Marine Park Water-Quality Guidelines for Australia’s GBRMP (2010), Brazil’s CONAMA Resolution 357/2005 for water quality standards for saline coastal waters etc.

Such safe limits for water quality in terms of nutrient availability have been frequently and constantly exceeded for decades in Curaçao’s coastal waters ([Figure 11](#)) indicating wide-spread nutrient pollution is contributing to planktonic productivity (resulting in “green water”) and algal blooms (van Duyl et al. 2024).

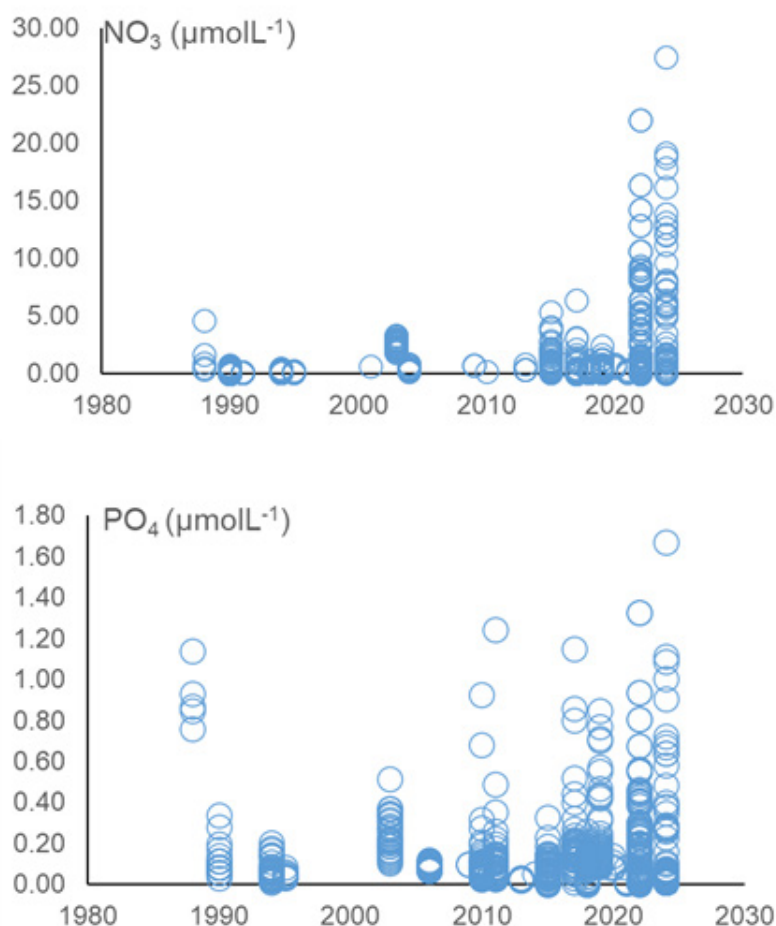


Figure 11 Overview of the abundance of nutrients (nitrate and phosphate) in Curaçao’s coastal waters through time.

Pollutant type 2: Microbialization

Nutrients and organic compounds released by algae growing on the bottom favor the growth of microbial communities and fast growing cyanobacteria (Silveira et al. 2019). The release of untreated sewage and terrestrial run-off during rain events also promotes the growth and abundance of (pathogenic) microbes in the island's coastal waters. The general increase in microbe abundances in Curaçao coincides with increased disease occurrences in fishes (e.g., de Wit and Johnson 2024), corals (e.g., Cróquer et al. 2021) and people (e.g., Steingrover et al. 2016). Coral associated bacterial communities near Willemstad differ significantly from reference reefs, and host higher abundances of opportunistic/pathogenic taxa. Antibiotic resistant *Enterobacteriaceae* are frequently found in recreational waters (e.g., near Willemstad, but also e.g., Porto Marie) and raise exposure risks for residents and tourists. Antibiotic resistant microbes often transfer resistance and pathogenic genes to natural coral and fish microbiomes. The detection of microbes with resistance to carbapenems and colistin indicates that Curaçao's coastal waters are a reservoir harboring resistance to many antibiotics including last resort options (Steingrover et al. 2016). Measurements of microbial communities before, during and after the COVID lockdowns show that pathogenic microbes responsible for human diseases are extremely abundant in waters used for recreation and tourism. Such areas frequently lack or are located close to insufficient sewage infrastructure, which release untreated sewage water harboring (amongst others) pathogenic microbes into the island's coastal waters. When tourism and recreation stopped during the COVID locks downs in 2020 microbial communities in such areas returned to "normal" in ~3 months (Netherlands Institute for Sea Research, unpubl. data, [Figure 12](#)).

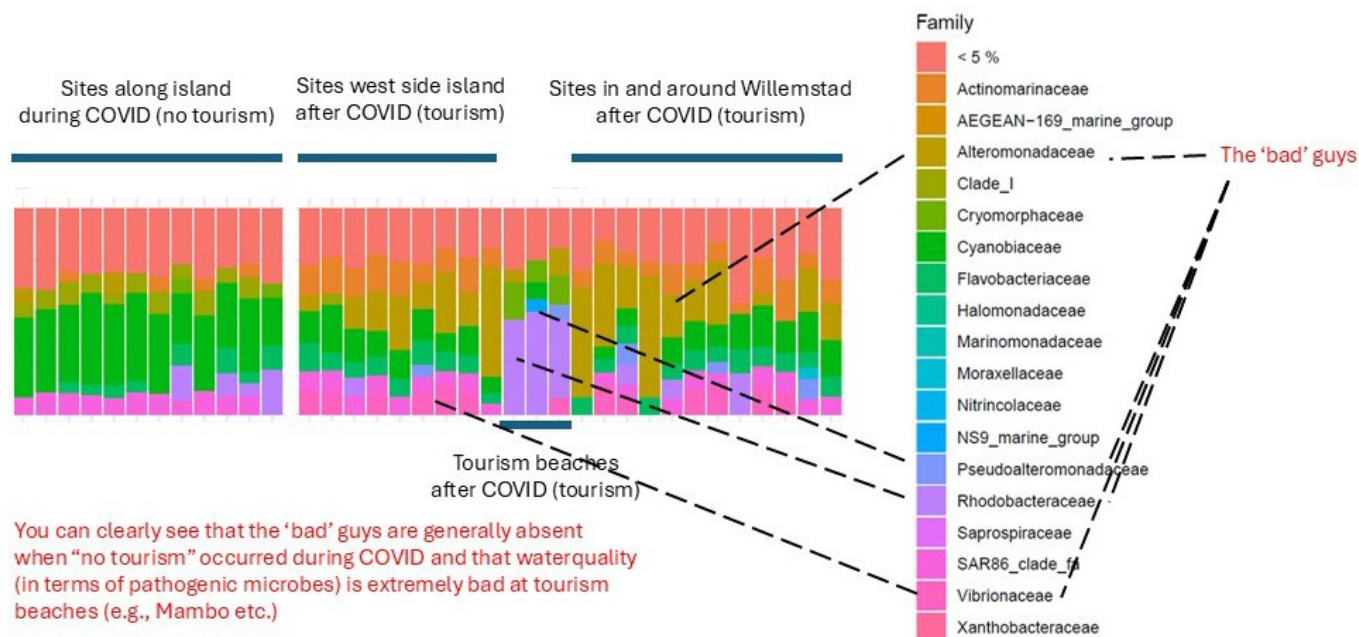


Figure 12. Pathogenic microbes become very abundant in coastal waters in areas used for tourism and recreation. When such areas are not used (such as during the COVID lockdowns), microbial communities return rapidly to their "natural state".

Pollutant type 3: Chemical pollution

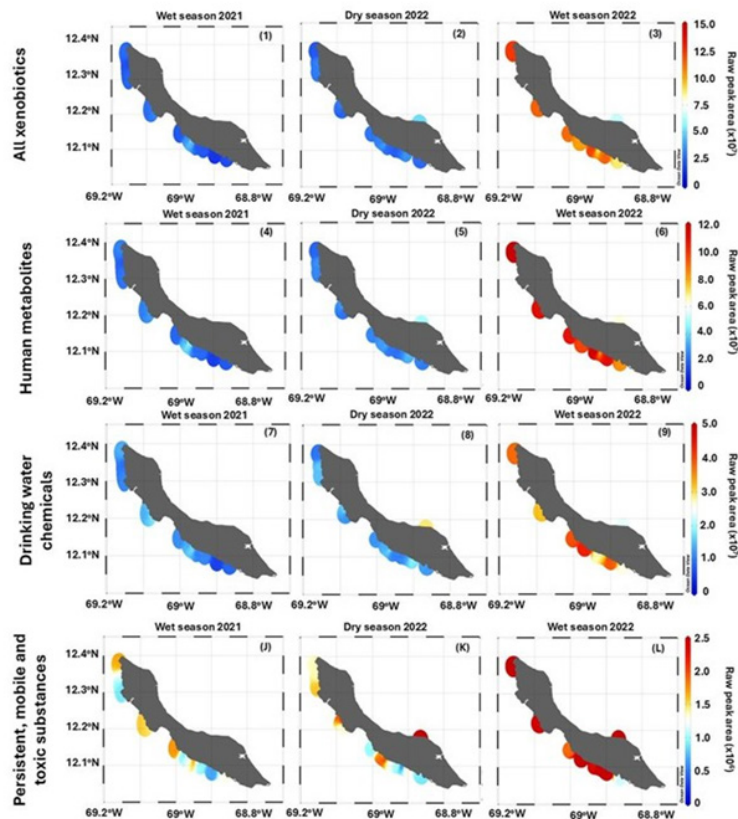


Figure 13. Spatial Heatmap of Curaçao displaying seasonal intensity of some groups of xenobiotics in summed raw peak area per subgroup. Pannel A-C displays the total xenobiotic in wet season 2021 (A), dry season 2022 (B) and wet season 2022 (C). Other xenobiotic groups follow similar widespread distributions and increases in abundance after rainfall.

While safe limits for many chemicals are not available, a large variety of non-natural compounds (xenobiotics) are present in Curaçao's coastal waters such as biocides, drinking water chemicals, drugs of abuse, food contact chemicals, human metabolites, human neurotoxins, indoor environment substances, natural toxins, persistent, mobile and toxic substances, personal care products, pharmaceuticals, plant protection products, plastic additives, smoke compounds, surfactants. All these chemicals increase in abundance after rainfall and their abundance is constantly high in areas with relatively low waterflow such as near Banda Abao (Netherlands Institute for Sea Research, unpubl, data, [Figure 13](#)). Land derived organic pollutants are not locally confined to specific discharge locations, but propagated around the entire island making xenobiotic pollutants a concern across broader spatial scale than their specific discharge point or location of origin.

Pollutant type 4: Heavy metals

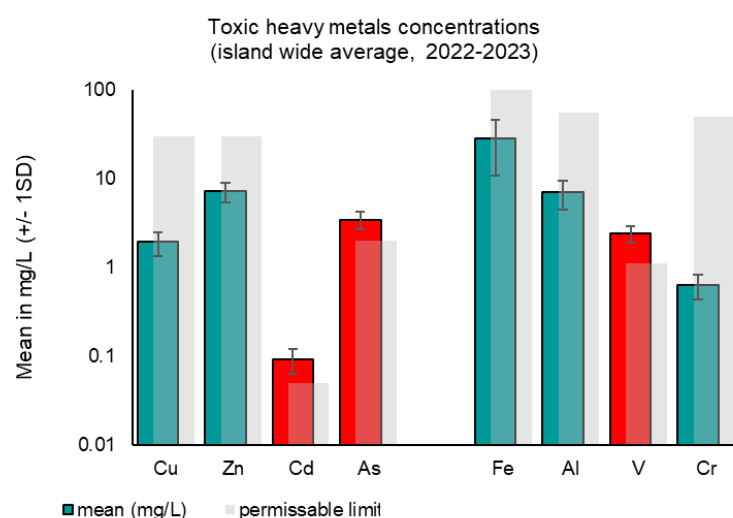


Figure 14. Concentrations of heavy metals measured in sponges and algae along the island's leeward shore (12 locations) frequently exceed safety limits (shown in red).

Similar to chemical and nutrient pollution, heavy metal concentrations are high along the entire leeward coast of Curaçao ([Figure 14](#)) and no clear relationship with e.g., Willemstad are obvious in most cases. In contrast to chemical substances, safety limits exist for heavy metal concentrations and these are frequently exceeded (e.g., for cadmium, arsenic and vanadium) in Curaçao's coastal waters raising concerns about food safety (e.g., fishes that are locally caught and eaten) and environmental impacts on e.g., mangroves, seagrass beds and coral reefs (Govers et al. 2014b).

Does coastal development always result in the decline of nearby reefs? No

Coastal development does not always result cause neighboring coral reefs to decline, but this happens only under specific conditions (Alcantar et al. in prep.). Historic reef communities dominated by *Orbicella* spp. and *A. agaricites* are very sensitive to coastal development and have as such largely disappeared near densely developed coasts (e.g., Willemstad, Coral Estate, Boka Sami). Only when eastward flowing waters that are (relatively) devoid of various pollutants (see “Are Curaçao’s coastal waters polluted? Yes”) encounter build up shores (e.g., Caracasbaai area) are the negative impacts of such developed shores somewhat mitigated. Vice versa, this also means that pollutants originating from e.g., Willemstad are also carried westward to areas without coastal development. In such areas, reefs are in worse condition based than would be expected from the “condition” of the neighboring coast alone, which is often minimally developed (see also: “Are Curaçao’s coastal waters polluted? Yes”). Furthermore, a few coral species such as the yellow pencil coral (*M. mirabilis*) are capable of overtaking the space that has become available once historic communities disappeared. As a consequence, coral cover (mostly dominated by *M. mirabilis*) can still be high near some well developed coasts, though this phenomenon is certainly not occurring in all such places.

Does most pollution foremost come from “outside” Curaçao? No

Certain pollutants (e.g., certain plastics, tar) foremost originate from sources outside Curaçao (Debrot et al. 1995). While such pollutants likely have some negative impact on the island’s marine ecosystems, these are foremost impacted by pollutants of local origin such as chemical waste, sewage, excess nutrients and sediments, heavy metals etc. (see: “Are Curaçao’s coastal waters polluted? Yes”). While the relative importance of both is difficult to estimate precisely. However, genetic analyses of e.g., corals (including those in Curaçao) show that >99% of their offspring (which like plastics etc. also move with prevailing current regimes) are retained within an island (e.g., Foster et al. 2012, Rippe et al. 2017). This degree of retention is surprising to many, but is caused by the fact that nearshore and oceanic waters do not mix very well, a phenomenon known as “the sticky water effect” (Andutta et al. 2012), which creates a band of water overlying islands’ fringing reefs in which e.g., larvae, but also water-soluble pollutants become largely retained so they no longer mix “freely” with offshore waters and currents. So in short, a large share of the beached litter especially along Curaçao’s windward shore clearly arrives from elsewhere, but on the leeward coast and for most forms of “water-quality pollution” (e.g., sewage, nutrients, chemicals), the dominant sources are local. Recent citizen-science monitoring¹ also showed that on the leeward beaches most “litter” items (e.g., bottles, cigarette butts, beer caps) are left by consumers on Curaçao.

1 <https://www.youtube.com/watch?v=4194jMToOWc>

Does groundwater pollution transport pollutants to the island's reefs? Yes

The Curaçao Lava Formation, Knip Group and Midden Curaçao Formation have experienced extensive folding and faulting in response to tectonic activity in the Palaeogene/Neogene (Beets 1972). Fracture zones and networks in these formations serve as hydraulic conduits that transport groundwater (and everything in it, including sewage and pollutants) across the island and to the ocean (Kruijssen et al. 2024). Similarly, karst features in the Seroe Domi and other limestone deposits will function as groundwater flow routes. Springs emerge from the middle Quaternary limestone terrace unit at two locations, at the boundary between the limestones and the underlying Curaçao Lava Formation. These springs form the only natural year-round surface water streams on the island (Kruijssen et al. 2024), but human induced streams are also abundant that serve as “underground conveyer belts” (as can seawater intrusion) for a variety of land-derived pollutants. For example, 36% of the volume of Curaçao's groundwater consists of raw sewage from leaking cesspits (used in 77.1% of all Curaçaoan households) and other dysfunctional sewage infrastructure (Wit et al. 2025). Between 2021 and 2023, *E. coli* was detected in 78 % of sampled wells, making this water unsuitable for consumption (Wit et al. 2025). Because Curaçao has a relatively high average population density (~ 340 people per km²) and a high evaporation to precipitation ratio, its groundwater system is highly susceptible to depletion and pollution from residential, industrial and touristic infrastructure (Wit et al. 2025). Densely populated areas on fractured basalts are particularly vulnerable to contamination due to rapid wastewater infiltration and short residence times.

The diffuse leakage of cesspits into the groundwater on Curaçao has led to elevated nutrient concentrations, especially in the densely urbanized, permeable coastal limestone areas, where sewage leakage undergoes minimal attenuation before reaching the ocean. The direct discharge of (untreated) wastewater further intensifies these concerns, not only contributing to eutrophication but also introducing pathogens and organic micropollutants that may threaten marine ecosystems and public health. Together, these challenges in wastewater management increase the risk of environmental degradation and human health risks (Wit et al. 2025).

Are Curaçao's reef contributing to the economy? Yes

Tourism – Reef related tourism in Curaçao contributes US\$ 373 M yr⁻¹ (38 % of total visitor spending) which corresponds to reefs' direct and indirect benefits of ~US\$ 57500 ha⁻¹ yr⁻¹ (tourism, fisheries)¹. The Caribbean average lies around ~US\$ 87000 ha⁻¹ yr⁻¹ (and can be as high as ~US\$ 300000 ha⁻¹ yr⁻¹ in certain locations (e.g., national parks) through mainly increased tourism revenue, suggesting the economic value of Curaçaoan reef systems is currently underestimated (Compilation 2008, Waite et al. 2014). Indirect benefits in the form of coastal protection, and sand production are not included in these estimates, so the actual economic value would even be higher when such contributions are included.

Do all initiatives aimed at “saving Caribbean reefs” work? No

The “big four” factors contributing to Caribbean reef decline are (1) marine heatwaves, (2) coral

1 <https://www.waittinstitute.org/blue-halo-Curaçao>

diseases, (3) loss of herbivory (overfishing + *Diadema* die-offs), and (4) land-based pollution. Coastal construction and dredging (and maybe Sargassum influxes) follow behind. While the first two factors cannot be addressed at scale in Curaçao, addressing factors 3 (e.g., improved fishing legislation, bans, no take zones etc.) and 4 (e.g., improved sewage treatment capacity, enforcement, regulations on pollutant disposal) has shown to increase reefs' ability to withstand and recover from impacts caused by factors 1 and 2 (e.g., Anthony et al. 2015, Donovan et al. 2021). Other “stressors” that are manageable (e.g., sunscreen bans, coral restoration, lionfish eradication), there is no proof at the moment that such measures (sunscreen bans, lionfish removal) significantly contribute to increases in coral cover or fish biomass. Coral restoration through active outplanting of e.g., lab-raised recruits, would cost approximately ~US\$ 400000 ha⁻¹ yr⁻¹ (e.g., Anthony et al. 2015), making such efforts astronomically expensive at the scale at which degradation occurs, i.e., island wide. Healthy reefs (i.e., those near Oostpunt or Kaap Marie) produce ~200 times more larvae per cm² than degraded ones which makes the protection of even small “healthy reefs” economically more viable than manually restoring reef communities, especially since active restoration efforts focus on only a small number of the 68 coral species comprising Curaçaoan reef communities. Just to be clear: this does not mean that coral restoration efforts should be halted, but just that, at present, they do not focus on sufficient species to actually restore an entire reef community, are too expensive and hard to execute at the scale of the actual problem to aim to remedy. Furthermore, sufficient numbers of coral recruits do still occur on Curaçao's reefs (UvA, unpubl. data) indicating that low survival rather than influx of new individuals prevents the growth of new colonies of many coral species. Survival rates of young corals can be increased through increased herbivory and improved water quality (e.g., Vermeij et al. 2010, Butler IV et al. 2024, Edmunds et al. 2024) making factors 1 and 2 mentioned above the prime candidates for local management interventions in the forms of e.g., banning fishing on all parrotfishes and improvements to the island's wastewater facilities.

Has Curaçao currently exceeded its carrying capacity for the number of visitors it can receive? Yes

Curaçao invites people to “experience the island above and below the surface” (*Figure 15*). Given the island's economic dependency on coral reefs through especially tourism (see: Are Curaçao's reef contributing to the economy? Yes) maintaining functional reef systems will contribute to securing such revenue in the future. However, given the large number of local factors (many related to tourism and the growing number of visitors to Curaçao) contributing to the decline of the island's reefs described in this report the future of reefs (and the income they generate) will be uncertain under a “business as usual scenario”. This decline and reduced “attractiveness” of the island is also noted by visitors (see next paragraph).

Do people notice the ongoing decline of Curaçao's reefs? Yes

Below is a chronologically ordered “sentiment scan” of what tourists, divers, NGOs, scientists, journalists and local media have been saying on publicly available websites about Curaçao's coral reefs over the past two decades. The quotes are deliberately short and illustrative (*Figure 16*). Overall, public web based opinion has matured from carefree admiration to a nuanced, solution oriented remarks that balance tourism promotion with urgent calls for coastal management, wastewater treatment, and

disease responses. The Caribbean tourism industry presently sits at a crossroad where destinations have to decide how to address tourists’ increased focus on diversified “products” that go beyond "sun and beach" and include more nature, cultural, and historical tourism (e.g., Gross et al. 2023, Parra et al. 2024). Furthermore, European and some Caribbean cities are discussing the need to attract the "right" visitors (those seeking sustainable, authentic experiences) rather than simply more people, to alleviate pressure on infrastructure and local life (e.g., Morrison and Buhalis 2023, Akadiri et al. 2025).



Figure 15. Advertisements inviting tourists to enjoy Curaçao’s underwater world.

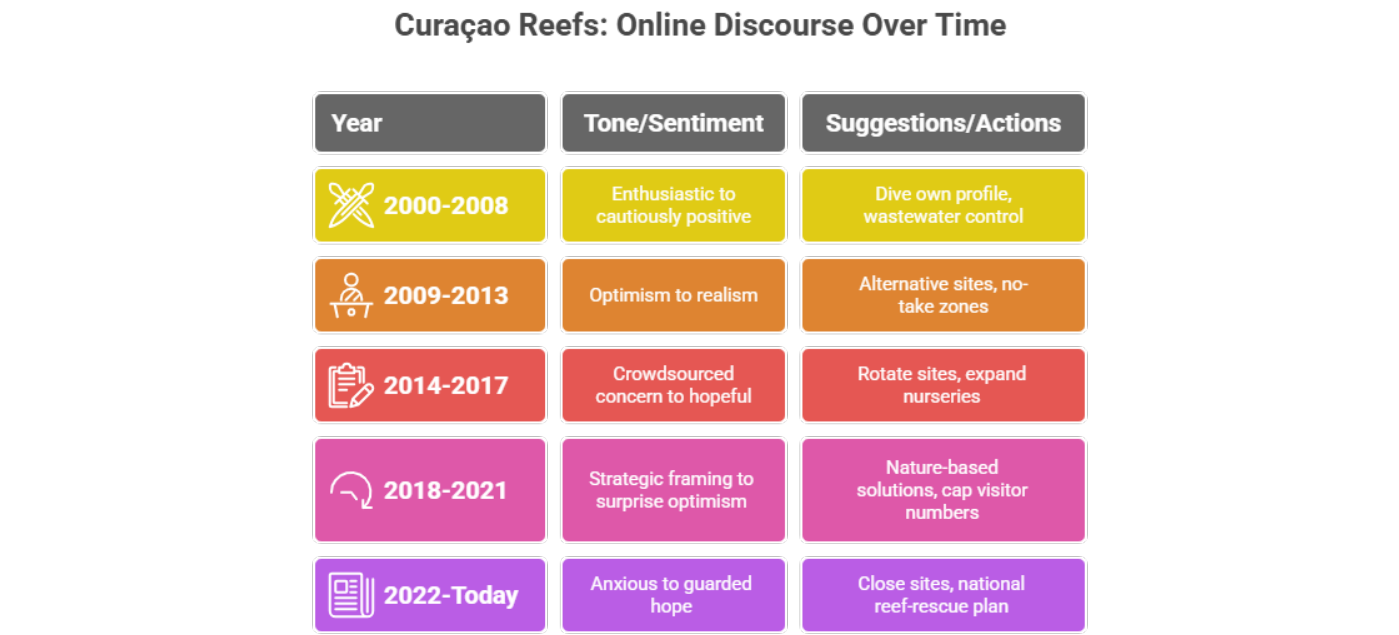


Figure 16. Impressions of Curaçaoan reefs by tourists shifted from “optimistic” in the early 2000’s to “concerned” in recent years.

Have management interventions aimed at halting (or reversing) the decline of Caribbean reefs been successful elsewhere? Yes, but not always

There are many examples of management interventions in the Caribbean that were successful at halting and reversing the decline of coral and reef fish communities in countries such as Cuba, USVI, Belize, Cayman Islands, St. Lucia, Dominican Republic etc (Figure 17). These “success stories” all have in common that they have clear rules in how marine resources can be utilized, strict and functional enforcement and have often been started a while ago. Measurable increases in fish biomass can start as soon as 3 to 5 years after protection was established for fishes and takes longer for corals (e.g., Polunin and Roberts 1993, Dalton et al. 2015). Protection of coral reefs often benefits local fish communities and vice versa, pointing towards the necessity (and benefits) of protecting systems “as a whole”, rather than by focusing on individual species. Protection of species capable of algal removal (parrot fishes, surgeon fishes, but also grazing sea urchin species) foremost benefit the wider reef community (Mumby 2006, Mumby et al. 2006). Management interventions through e.g., regulation of fishing, but also outplanting reared corals show the best results where local stressors (e.g., anchors, sewage, destructive gear) are controlled (Cortés-Useche et al. 2021). Improved grazing on reefs even proved capable of mitigating some of the effects of climate change on coral communities (Mumby et al. 2006, Jackson et al. 2014). While new challenges have arisen due to climate change, aforementioned examples and principles clearly show that interventions aimed at increasing the abundance of corals and reef fishes can work, especially when large areas are protected, enforcement is well organized and capacity in terms of people and financial support are available (Gill et al. 2017, Hargreaves-Allen et al. 2017).

Are Caribbean water quality standards and legislation already available? Yes

There is no single, uniform coastal water quality standard that applies to all Caribbean nations. Instead, standards and monitoring frameworks are typically set at the national level, although regional agreements and initiatives provide a framework for cooperation and general guidelines. Caribbean nations often work within the framework of the Cartagena Convention (Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region), the only regional,

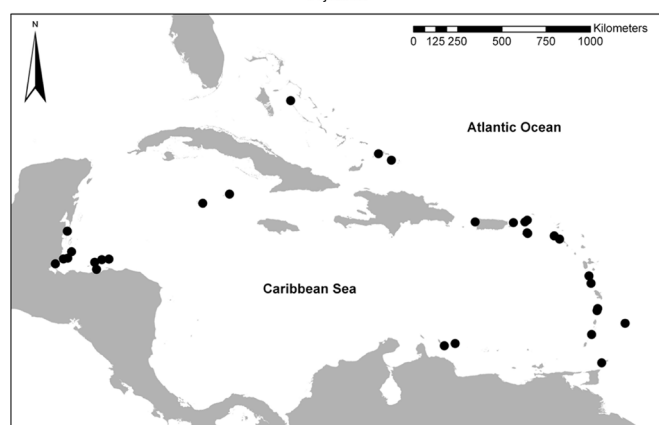
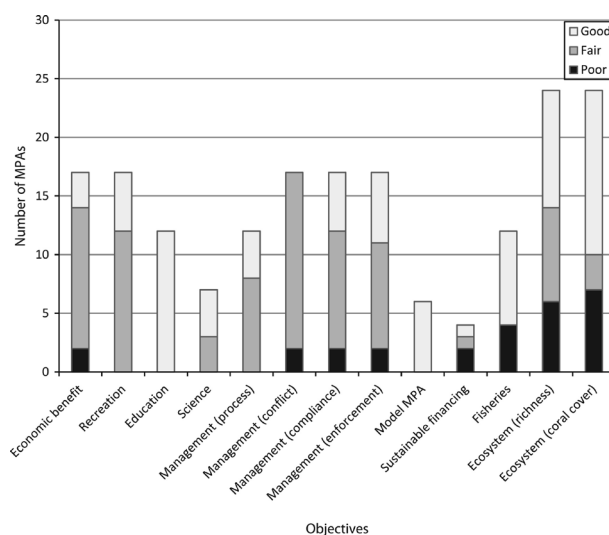


Figure 17. Number of MPAs making progress (poor/fair/good) toward specific stated objectives. From Dalton et al (2015) Are Caribbean MPAs making progress toward their goals and objectives?

legally binding environmental treaty. This Convention includes the Land-Based Sources (LBS) of Pollution Protocol which was never ratified by Curaçao. This protocol is the primary mechanism for addressing marine pollution from activities on land (e.g., sewage, industrial waste, agricultural runoff). It encourages countries to develop and implement legislation and regulations, including effluent limitation guidelines and water classification systems, consistent with the regional framework. Secondly, the UNEP Caribbean Environment Program (CEP) supports nations in developing water quality monitoring programs and strategies, such as a Regional Nutrient Pollution Reduction Strategy and Action Plan.

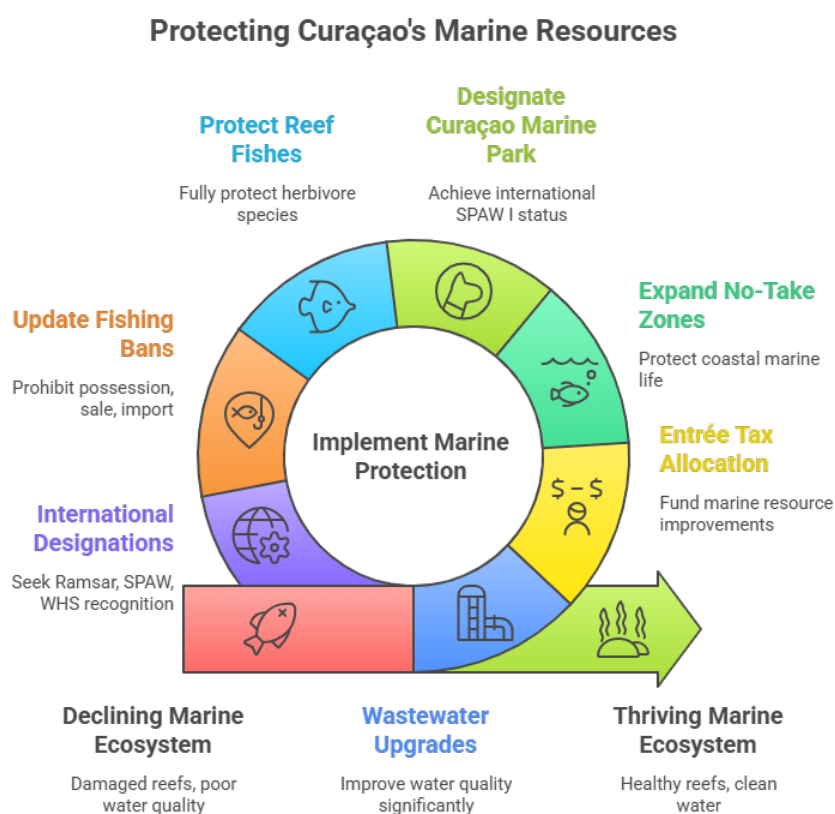


Figure 18. Overview of possible actions can be considered to halt and reverse the ongoing degradation of Curaçao's coral reefs

Individual countries establish their own specific standards, which vary based on local conditions, priorities, and capacity. These standards often aim to protect marine ecosystems, support tourism, and ensure the safety of recreational waters. For example, Jamaica has specific national standards for ambient freshwater and marine water quality developed by the Bureau of Standards Jamaica. The Caribbean Netherlands (Bonaire, St. Eustatius, Saba) established a Nature and Environment Policy Plan (NEPP) which includes specific thresholds for nutrients in coastal waters to protect coral reefs and Barbados has a robust groundwater protection policy to prevent contamination of its primary water sources, which indirectly impacts coastal water quality by managing land-based runoff. There are many more of such examples, and should Curaçao decide to, similar to air quality standards, decide to set water quality standards, such standards could easily be copied from existing, legal equivalents in other nations.

What are possible actions can be considered to halt and reverse the ongoing degradation of Curaçao's coral reefs?

As mentioned in the introduction of this report, it focuses foremost on the urgency to address and underlying causes of reef decline in Curaçao. There are several options to achieve such goal and they have been shortly summarized (*Figure 18*) to inspire future action amongst decision makes and government.

- Accelerate wastewater upgrades – Full secondary/tertiary treatment for Willemstad and resort clusters. Money and plans are already (partly) available.

- Consider a proportion of the proposed “entrée tax” to be spent on solving marine related issues to improve the attractiveness of the island’s marine resources and lower health risks for residents and tourists.

- Expand effective no take zones – Laws have been drafted for certain sections of the island’s coast and only await formal approval. Consider making the entire island a marine park similar to Bonaire. Consider these changes in an extension of the EOP for marine areas that currently are not included.

- Establish a new fisheries management law to require a fisheries management plan, monitoring, and adaptive management (which would require long-term ecological and fisheries monitoring programs).

- Legally designate the existing Curaçao Marine Park as a SPAW I area (documents for filing already exist).

- Fully protect ecologically important reef fishes (i.e., herbivores) and ecosystems (e.g., mangroves) – Laws have been drafted to fully protect all parrotfishes and only await formal approval. Update and pass the 2011 “draft no-fishing zone decree” in accordance with the National Fishing Ordinance. Also designate fishing zones and exclude conflicting recreational use.

- Update spearfishing and gillnet bans to prohibit possession, sale or import.

- For any existing and future locations that satisfies the Ramsar Treaty (e.g., Klein Curaçao, Jan Kok area, Northwestern

Curaçao), SPAW Protocol (e.g., the CMP), or Marine World Heritage Site criteria (e.g., the CMP), in addition to legal designation, such sites should be submitted for international designation and recognition.

- Consider ratifying the LBS Protocol.

- Improve enforcement of existing rules and laws.

- Improving functional reef fish communities (especially of herbivores) and improving water quality will increase the ability of Curaçao’s reef to withstand the impacts of climate change. Reefs with effective fish communities and clean waters elsewhere in the Caribbean were found to suffer less from e.g., heatwaves and recovered faster after e.g., coral bleaching events (Jackson et al., unpubl. data).

- Manage the island’s marine ecosystem as one unit and avoid zoning due to the island’s small size which makes all areas along its coast highly connected and dependent on each other.

- Attract international attention (and funding) to the island’s marine resources by (1) submitting the existing nomination to establish the Curaçao Marine Park (CMP) a UNESCO World heritage Site (WHS) together with the Bonaire Marine Park and (2) finish the nomination of the CMP as a special area under the international SPAW Protocol.

- Consider reef-to-ridge planning and realize that many local stakeholder groups approve development within the current boundaries of the EOP and warn against expansion of e.g., tourism infrastructure outside allocated areas (Steward et al. 2024, 2025).

If these measures are implemented in concert, experiences from other Caribbean locations suggests Curaçao could stabilize coral cover in the high teens and retain positive carbonate budgets through mid century, buying time for global emission reductions. Conversely, failure to curb land based pollution and fishing pressure will amplify disease and bleaching impacts, risking an island wide shift to permanently algal dominated state within the next two decades, hence the inclusion of 2045 in the title of this report. Sites characterized by such degraded communities are already increasing in abundance in Curaçao (*Figure 19*), but other sites could maintain (reasonably) functional Caribbean reef communities beyond this date if appropriate measures are taken.

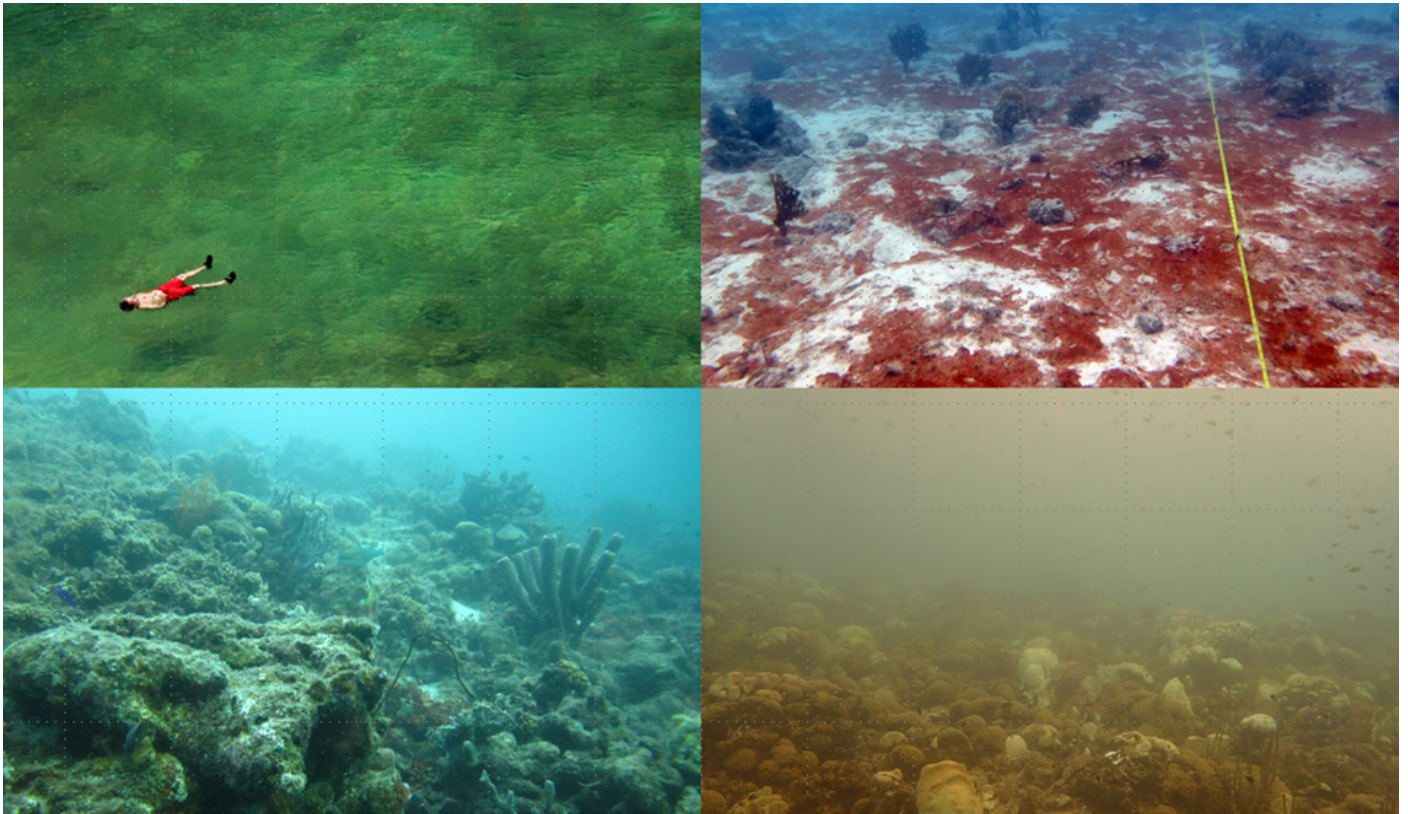


Figure 19. The consequences of land-based pollution, overfishing and climate impacts on Curaçaoan reefs systems are increasingly widespread and results in the disappearance of fishes and corals that are becoming replaced by microbes (including pathogenic ones, especially in tourism areas), phytoplankton (resulting in murky or green water), and algae that smother corals.

Which background documents are already available in Curaçao?

Through [this link](#) a (by far non-exhaustive) overview (in no particular order of importance) is provided of existing documents that could be useful in providing context for possible actions to address some of the issues listed in this report.

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