

# The current state of Curacao's Coral Reefs

Dr. Mark J.A. Vermeij  
Carmabi Foundation/ University of Amsterdam



## **EXECUTIVE SUMMARY**

The coral reefs of Curaçao represent one of the best reef systems left in the Caribbean at present. However, this does not mean that these reef systems are doing well. On the contrary: increased coastal development has resulted in pollution of near shore waters through the release of (untreated) sewage, nutrients and chemicals and overfishing represent some of the factors that have contributed to a near 20% decrease in the abundance of corals on the island in the last 25 years. Fish communities have been impacted similarly through uncontrolled fishing practices and Curacao presently holds an intermediate rank among Caribbean nations in terms of fish abundance. Coral reef systems provide the foundation for the island's tourism and fishing industry and protect near shore developments against storms. Furthermore, healthy reefs prevent the rise of disease-causing bacteria in near shore waters preventing people, locals and visitors alike, from becoming ill. At the current rate of decline, coral reefs will have virtually disappeared around Curacao around the year 2060. Presently, it is estimated that Curaçaoan reefs bring in at least \$1.6 million per kilometer per year through revenue from tourism, fishing and coastal protection alone. The decline of reefs will thus come with severe economic consequences for a recently formed country that finds itself still in a position to avert such catastrophe.

This report summarizes some of the information currently available to illustrate a potentially dark future for Curaçaoan reefs. Hopefully this report helps to illustrate some of the factors contributing to this decline so directed management strategies can be designed and put in place in order to maintain a unique aspect of Curaçao that makes it stand out in the region: its coral reefs.

## RESÚMEN EHEKUTIVO

E refnan di koral di Kòrsou ta representá un di e mihó sistemanan di ref aún eksistente den Karibe. Sinembargo, esaki no ta nifiká ku ta bayendo bon ku e sistemanan di ref aki. Al kontrario: e kresementu den desaroyo di nos kostanan a bin ta resultá den sobrepeska i polushon di awanan kantu di kosta dor di bashamentu di awa di riol (no tratá), nutriente- i kímikonan. Esakinan ta algun di e faktornan ku a kontribuí na un bahada di kasi 20% den abundansia di koralnan rondó di nos isla den e delaster 25 añanan. Komunidadnan di piská a ser impaktá di forma similar dor di formanan di peska deskontrolá. Aktualmente, Kòrsou ta poseé un rango intermedio entre nashonnan karibense pa loke ta trata abundansia di piská. Sistemanan di refnan di koral ta proveé un fundeshi pa e indústrianan di turismo i peska riba nos isla i na mes momentu ta sòru pa protekshon di edifisionan i otro desaroyonan kantu di kosta kontra tormenta i/o orkan. Mas aleu, refnan salú ta prevení kresementu di bakterianan ku por kousa malesa den awanan kantu di kosta, loke en torno ta prevení hendenan, turistánan i hendenan lokal, ku ta uza nos laman di bira malu. Teniendo na kuenta e velosidat aktual di disminushon, e refnan di koral lo por desaparecé virtualmente rònt Kòrsou pa aña 2060. Aktualmente a ser balotá ku refnan di Kòrsou ta generá por lo menos 1.6 miyon dollar merikano pa kilometer pa aña djis kontando entradanan di turismo, peska i protekshon di kosta so. Disminushon di refnan ta trese pues konsekuenshanan ekonómiko severo pa e país resientemente formá aki ku ahinda ta den e posishon pa evitá un katástrofe di tal índole.

E reportahe aki ta resumí algun di e informashonnan aktualmente disponibel pa ilustrá e futuro potenshalmente skur di e refnan di Kòrsou. Ohalá e raportahe aki yuda ilustrá algun di e faktornan ku ta kontribuí na e disminushon aki di moda ku strategianan di maneho dirigí por ser diseñá i implementá pa di e forma aki mantené un aspekto úniko di Kòrsou ku ta laga e isla sobresalí den region: su refnan di koral.

## Contents

Introduction	5
The coral reefs of Curaçao	7
Historic impacts	8
Stressed reef systems	9
Overview of main local drivers of Caribbean reef decline	10
Purpose of this report	13
Lessons learned elsewhere	14
The state of Curaçao's reefs: comparisons to other Caribbean islands	16
Recent changes in coral reef cover on Curaçaoan reefs	17
Recent changes in the abundance of juvenile corals on Curaçaoan reefs	18
2010: the worst coral bleaching event in Curaçao's history	19
Turf algae: a new group of algae affecting the health of neighboring corals	20
Hopeful news: a possible return of an important herbivore to Curaçao's reefs?	20
The importance of inland bays: new insights	21
The status of reef fish communities	22
The lionfish invasion	23
The die-off of the reef building coral <i>Acropora palmata</i> and its impact on associated fish communities	24
Population explosion of damselfish	25
No coastal development means healthier reef systems	26
Worrisome developments	26
Reef conservation on Curaçao	30

## The current state of Curaçao's Coral Reefs

"I'd never heard of anyone else doing it, so I figured it must be stupid."

— Serge Storms

### Introduction

Coral reefs are an important aspect of Curaçao's identity. Coral reefs are traditionally used for fisheries, recreation, provide coastal protection, prevent beach erosion, support tourism based economies and prevent the emergence of waterborne diseases. Coral reefs are productive and biologically diverse ecosystems that, despite the fact that they globally cover only 0.2% of the ocean floor, support an estimated 25% of all marine life<sup>1</sup>. In a way, coral reefs are like a bank account that when in "good shape" produce "more" through interest. A healthy system whether a reef or a bank account is simply more productive on the long term and should therefore be kept in such "healthy" (i.e.,

---

<sup>1</sup> Spalding, M.D., Ravilious, C., Green, E.P. (2001) World Atlas of Coral Reefs. Prepared by the UNEP-World Conservation Monitoring Centre. University of California Press, Berkeley, USA

productive) state to ensure its long-term contribution to an island's economy and the ability of the system to renew itself.

Unfortunately, coral reefs face worldwide degradation, such that today we have already lost 27% of the world's reefs through a combination of natural and, more importantly, human impacts<sup>2</sup>. If present rates of destruction are allowed to continue, 60% of the world's coral reefs will be destroyed over the next 30 years. Runoff, pollution, tourism overuse, destructive fishing and climate change are among others contributing synergistically to these trends and are, more and more also occurring on Curaçao.

Reefs provide a variety of goods and services, which create economic benefits to society. These economic benefits are often taken for granted, yet if these goods and services were taken away or destroyed, we would be forced to provide other methods to supply these benefits at significant costs. Presently, a kilometer of *healthy* Caribbean reef is estimated to generate

---

<sup>2</sup> Wilkinson, C. (2000) Status of Coral Reefs of the World 2000, Australian Institute of Marine Science (AIMS), Global Coral Reef Monitoring Network (GCRMN), Townsville, Australia

approximately \$1-1.5M annually through coastal protection, fisheries and tourism alone<sup>3</sup>.

Curaçao is no exception to the trends outlined above and coral reefs, as well as the benefits they provide are in a state of decline. From a Caribbean wide perspective, Curaçao still harbors some of the best reefs in the region providing the island a unique opportunity to take advantage of the economic benefits coral reefs provide as well as to protect a unique ecosystem that is becoming increasingly rare elsewhere in the Caribbean. In this document the current state (2012) of Curaçao's reefs is described and recommendations are made to preserve these ecosystems for the future. This document primarily serves to inform stakeholder groups about the current state concerns, opportunities, changes and possibilities that exist to ensure that the uniqueness of Curaçao's marine resources can be guaranteed for the future.

---

<sup>3</sup> Reefs at Risk Revisited (2011) Burke L, Reytar K, Spalding M, and Perry A.  
<http://www.wri.org/publication/reefs-at-risk-revisited>

## The coral reefs of Curaçao

The island of Curaçao is surrounded by a fringing reef with a total surface of 7.85 km<sup>2</sup> situated at a distance from the coast ranging from 20 m to 250 m. Especially the island's undeveloped, north shore and eastern and western sides of the south shore still harbor coral communities reminding one of reef communities that existed 40-50 years ago. Extreme water movement causes the reef communities of the windward and leeward shores of the island to fundamentally differ in terms of reef structure and species abundance. All along the south western shore, a general pattern can be distinguished. From the shore, mostly consisting of steep cliffs and rubble beaches, a submarine terrace gradually slopes to a "drop-off" at 7-12 m depth. Here, the reef slopes steeply at 45°-90°, sometimes interrupted by an inclined terrace at 50-60 m, to a second drop-off at 80-90 m. Coral cover and diversity are highest near the drop-off, and decreases rapidly below 40-50 m as light decreases and the influence of sedimentation is high. Coral cover can be extremely high (>70%) and 65 coral species occur around the island. In addition to its fringing reefs, large inland bays can be found around the island in which mangrove/seagrass communities occur that serve as nursery areas for many species of reef fish. The number of known fish species for Curaçao is

currently 358, which is, like the number of coral species, relatively high for an island the size of Curaçao (444km<sup>2</sup>). It is currently assumed that this large number of fish species is related to the presence of the numerous marine habitat types that are present on the island such as coral reefs, sea grass beds and mangroves. The total number of coral species found in various marine environments of Curaçao is 68, representing more than 70% of all Caribbean species. With regard to hard corals with zooxanthellae, Curaçao, together with the Cayman Islands, Aruba and Bonaire, is by far part of the most species-diverse areas in the Caribbean<sup>4</sup>. Curaçao is not only part of one of the five richest hotspots for biodiversity and endemism on Earth (i.e. the Caribbean), but it represents a hotspot center by itself within its wider ecoregion<sup>5</sup>. As a result, many new organisms have been found and described for the first time on Curaçao, so that the island's name is commonly encountered in taxonomic textbooks. Examples include crustaceans (*Neogonodactylus Curaçaoensis*), sponges (*Haliclona Curaçaoensis*) and corals (*Isopora Curaçaoensis*).

---

<sup>4</sup> Miloslavich P, Dr'az JM, Klein E, Alvarado JJ, Dr'az C, et al. (2010) Marine Biodiversity in the Caribbean: Regional Estimates and Distribution Patterns. PLoS ONE 5(8): e11916. doi:10.1371/journal.pone.0011916

<sup>5</sup> Stehli FG, Wells JW (1971) Diversity and Age Patterns in Hermatypic Corals Syst Biol (1971) 20(2): 115-126

## Historic impacts

The reefs of Curaçao are subjected to a variety of natural and human related stressors that also affect reefs elsewhere on the planet. They currently suffer from overfishing as a result of the uncontrolled use of spear guns, fish traps, and gill-nets<sup>6,7</sup>. Coastal development, underground sewage discharge, chemical pollution and artificial beach construction have caused the decline of the shallow reef<sup>8</sup>. 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 and 2010 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 a few months in late 2010. Several diseases have had detrimental effects on coral reef organisms of Curaçao reefs in the 1980s and

1990s. In 1980, the corals *Acropora palmata* and *A. cervicornis* were affected by white-band disease<sup>9</sup>, and in 1983 the population of the then common sea urchin *Diadema antillarum* was reduced by 98-100% by an unknown cause<sup>10</sup>. Because this sea urchin species is an important herbivore controlling the abundance of undesirable algae on coral reefs, their die-off resulted in a significant increase in algae in combination with a decrease in the abundance of calcifying, i.e., reef forming organisms<sup>11</sup>. In 1999 and unusual west-east moving hurricane (Lenny) caused severe damage to all west facing coral communities on the island<sup>12</sup> toppling many of the larger colonies on Curaçao's reefs. The reefs experienced similar damage during a subsequent storm in 2008 (Omar).

---

6 Van't Hof, T., A. O. Debrot, I. A. Nagelkerken. 1995. Curaçao Marine Management Zone: A Plan for Sustainable Use of Curaçao's Reef Resources. Unpublished report, Curaçao Tourism Development Bureau/Carmabi/STINAPA, 89 pp.

7 LeLoup, M. J., C. Van der Mark. 1984. De dichtheden en grootte samenstelling van de roofvis populaties op de koraalriffen van Curaçao en Bonaire, bepaald volgens verschillende censusmethodes. Unpublished report, Carmabi Foundation-University of Amsterdam, The Netherlands, 68 pp.

8 Bak, R. P. M., G. Nieuwland. 1995. Twenty years of change in coral communities over deep reef slopes along leeward coasts in the Netherlands Antilles. *Bulletin of Marine Science*, 56(2):609-619.

---

9 Bak, R. P. M., S. R. Criens. 1981. Survival after fragmentation of colonies of *Madracis mirabilis*, *Acropora palmata* and *A. cervicornis* (Scleractinia) and the subsequent impact of a coral disease. *Proceedings of the 4th International Coral Reef Symposium*, 2:221-227.

10 Bak, R. P. M., M. J. E. Carpay, E. D. de Ruyter van Steveninck. 1984. Densities of the sea urchin *Diadema antillarum* before and after mass mortalities on the coral reefs of Curaçao. *Marine Ecology Progress Series*, 17:105-108.

11 De Ruyter van Steveninck, E. D., R. P. M. Bak. 1986. Changes in abundance of coral-reef bottom components related to mass mortality of the sea urchin *Diadema antillarum*. *Marine Ecology Progress Series*, 34:87-94.

12 Bries, J.M., A.O. Debrot and D.L. Meyer, 2004. Damage to the leeward reefs of Curaçao and Bonaire, Netherlands Antilles from a rare storm event: Hurricane Lenny, November 1999. *Coral Reefs*, 23: 297-307.

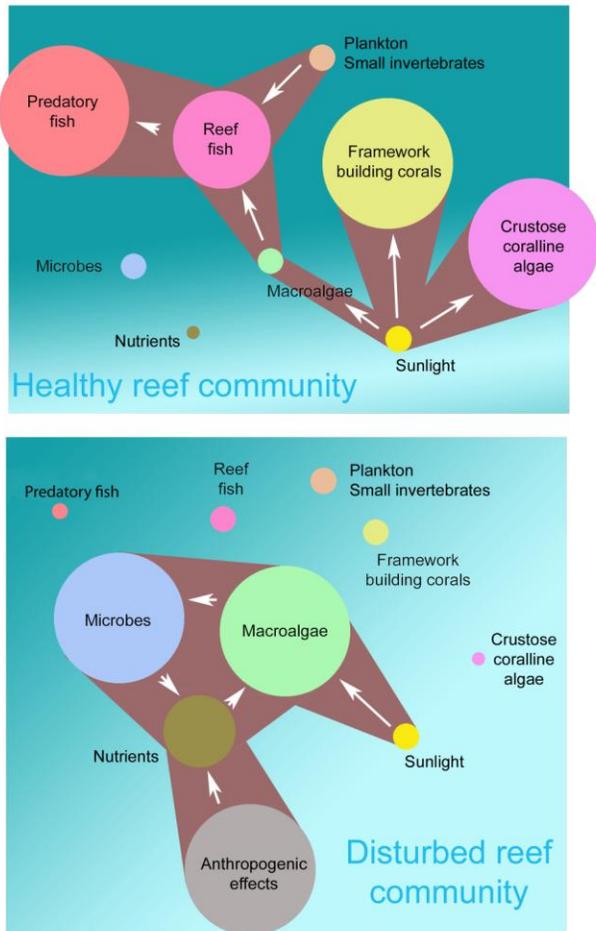


Figure 1. Collapse of trophodynamic relationships between functional groups that dominate(d) past and present day reefs. The shaded area with white arrows indicates the dominant trophic relationships before human disturbance (top) and at present day (bottom).

## Stressed reef systems

Despite the observation that reef decline is generally higher in areas close to coastal urbanization, not much is known about the dynamics that drive reef community decline on Curaçao. Most studies have focused on quantifying the resultant reduction in coral cover, but such approach is largely retrospective, does not provide early warning signs that decline is forthcoming or insight in the dynamics that drive such decline. Furthermore such surveys are often carried out once a year which does not allow for direct quantification of the effects of inputs to the marine system that are episodic and short-lived (e.g. storms, sewage spills, groundwater inputs). Components of the benthic community other than coral, often respond faster to such inputs and might thus be more suitable for the detection of undesirable land-sea interactions (e.g. (macro)algae and microbes).

Recent evidence<sup>13,14</sup> strongly suggests that algal abundance and organic run-off fuel microbial communities in reef waters.

- 
- 13 Dinsdale E.A., Pantos O., Smriga S., Edwards R.A., Angly F., et al. (2008) Microbial ecology of four coral atolls in the Northern Line Islands. PLoS ONE, 3,e1584. doi:10.1371/journal.pone.0001584.  
 14 Rohwer, F., Youle M. (2010) Coral reefs in the microbial seas. Plaid Press, Pennsylvania, USA. 197pp.

“Microbialization” of reef communities could hence be part of their degradation trajectory with subsequent consequences for corals (increases in pathogens) and potentially humans that use the water for recreational purposes. Under increasing human disturbance, coral reef ecosystems start to “leak” energy to trophic levels dominated by opportunistic organisms (e.g. microbes and algae) as longer lived organisms such as corals and fish are no longer capable of “holding on” to the energy available in a certain area. These predictions are visualized in Figure 1, where the size of each circle indicates the relative abundance of various functional groups in undisturbed (top) and disturbed (bottom) reef communities. While many studies primarily focus on the disappearance of key-stone species such as large fish and corals, this figure clearly illustrates that the appearance of less conspicuous functional groups such as microbes and (turf)algae should be taken as seriously.

The degradation of reef systems does not follow a trajectory of steady linear decline evidenced by the gradual disappearance of certain organisms. In contrast, systems literally reach a point where "one additional straw (i.e. a new or intensified anthropogenic stressor) breaks the camel's back (i.e. the reef)" which then collapses. This has occurred in many locations

around the world, especially the Caribbean. It would be good if Curaçao took this information more seriously as it clearly shows that stressed reef systems eventually collapse over a very short period of time (< 20-30 yrs) and no evidence currently exists showing that such collapse can be predicted beforehand or reversed afterwards. This fact clearly shows that prevention of reef decline is probably more successful and economically more feasible than reef restoration to guarantee healthy reefs in the future.

#### **Overview of main local drivers of Caribbean reef decline**

Below an overview is given of the factors believed to be most responsible for the decline of Caribbean reefs which is based on a report of the World Resources Institute<sup>15</sup>. This overview concerns only local stressors and does not consider stressors related to global climate change such as rising sea water temperatures, ocean acidification etc. For an overview of such factors see the publication referred to above. They are left out here as it seems unpractical to think that Curaçao itself could

---

<sup>15</sup> Reefs at Risk Revisited (2011) Laretta B, Reyta K, Spalding M, and Perry A.  
<http://www.wri.org/publication/reefs-at-risk-revisited>

change such factors in the near future. It is however possible to increase the ability of local reefs to withstand such global stressors by relieving the reefs of local stressors such as those overviewed below. One can increase the ability of a reef to withstand increasing global stressors by reducing local stressors that can be managed locally.

**Coastal development.** 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 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 some cases, tourism can also threaten reefs. Hotels can bring coastal development to new and remote locations, with associated higher levels of construction, sewage, and waste.

**Watershed-based pollution.** 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”, fish kills (Figure 2) and eventually complete near shore ecosystem collapse. 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.

**Overfishing.** Reef fisheries have long sustained coastal communities by providing sources of both food and livelihoods. However, over 275 million people currently live within 10 km of the coast and fishing pressure is high on many reefs. 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, fishermen move to smaller, often herbivorous fish as the numbers of larger fish



*Figure 2. Example of a massive fish die-off likely caused by polluted water at Playa Canoa in 2008.*

decline rapidly (in a process known as “fishing down the food chain”). Heavily fished reefs are thus left with low numbers of mostly small fish and, without herbivores, become prone to algal overgrowth. Such overfished reefs appear to be generally less resilient to (global) stressors, and may be more vulnerable to disease and slower to recover from other human impacts.

## **Purpose of this report**

Now that Curaçao reefs degrade at an increasingly faster pace, it is time to decide whether or not we let these reefs degrade beyond a point from which recovery is no longer possible. When coral reefs are gone, the foundation for the island's (fishing) culture, beach sand production, recreation, tourism and coastal protection will also disappear and new problems will arise. One of the best examples of such new problems constitutes human health issues as people entering the water are increasingly more likely to contract waterborne diseases.

Coral reefs will always look attractive to people that see them for the first time, even when they are severely degraded. What is lost when reefs degraded is their ability to sustain themselves and provide the functions that we are often unaware of and take for granted:

1. Creation of habitat for fishes that are recreationally/economically important
2. Production of the type of sand that forms Curaçao's beaches
3. Sustaining the island's tourism industry
4. Provide coastal protection during storms
5. Keep the near shore water clean of (disease-causing) bacteria

6. It provides Curaçao with a unique asset in the Caribbean region.

Because we will lose the aforementioned services that coral reefs provide, the discussion on whether or not to save coral reefs on Curaçao is about more than corals. It is about economics, local culture and the protection of the island itself in a time where storms are expected to increase due global climate change.

This report is intended to shortly overview the current state of the reefs on Curaçao. One will see that Curaçao still has one of the "best" reef systems in the Caribbean. To prevent that such comparison leads to the notion that "all is ok", the dramatic changes that have occurred on Curaçaoan reefs in the last 2-3 decades are overviewed. After reading this report, readers will hopefully understand that despite the fact that the underwater world around the island (still) looks attractive, much of this is about to change and decisions need to be made should Curaçao want to remain an island harboring one of the best coral reefs in the Caribbean. This report is not intended to provide a technical or complete report as to what is currently happening to Curaçao's reefs. It merely is intended to provide those that are interested with (1) a global overview of what state the island's reefs are in, (2) provide some context to what that means for the

island and (3) overview which factors are mainly responsible for the ongoing degradation.

### **Lessons learned elsewhere**

The dramatic future painted for coral reef is often dismissed and considered as “unrealistic” or “unlikely to occur”. However, several Caribbean locations have now experienced the consequences of sudden reef degradation (i.e., “collapse”) and found out three things. First, when reefs collapse, they often do so unexpectedly as factors till then believed to be unimportant, turn out to be crucially important to maintain the functioning of coral reef systems. A precautionary approach to reef protection is hence crucial. Secondly, once reefs degrade and one realizes what is lost, it is generally too late to reverse the downward spiral of reef degradation and lastly, the services provided by reefs (e.g., tourism, coastal protection) are lost and therefore reef degradation turns out to be costly as such services need somehow be replaced. Below are a few examples<sup>16,17,18</sup> of

---

16 Wielgus, J., Cooper, E., Torres, R., Burke, L. (2010) Coastal Capital: Economic Valuation of Coral Reefs in the Dominican Republic. World Resources Institute.

17 Best, B., A. Bornbusch (2001) Global Trade and Consumer Choices: Coral Reefs in Crisis. American Association for the Advancement of Science.

18 Waite, R., E. Cooper, N. Zenny, and L. Burke. 2011. Coastal Capital: Jamaica. The Economic Value of Jamaica's Coral Reef-Related Fisheries. Working Paper. Washington, DC: World Resources Institute and The Nature Conservancy.

scenario's that have occurred elsewhere and are not unlikely for Curaçao should the island's reefs degrade further in the future.

In northern Jamaica, it is estimated that almost all of the reefs are dead or severely degraded from overfishing and coastal runoff. Fish stocks have declined to a point where local fishers are now straining fish larvae out of the sea for fish soup.

In the Philippines, degraded reefs and fish populations have led to an 18% decrease in the amount of protein in the average diet.

The Dominican Republic depends on its beaches to attract tourists, but it's the reefs that keep the shoreline from eroding. Without reefs, the beaches disappear which has a huge impact on tourism. Researchers found that for each meter of beach a resort loses the average per-person hotel room rate drops by about \$1.50 per night. So if beaches continue to erode at the current rate, the Dominican tourism industry stands to lose \$52-100 million in revenue over the next decade.

A 2003 study found that overfishing at landing sites on Jamaica's north coast led to a 13 percent decline in total fish catch volume and a 17.3 percent decline in fish catch value between 1968 and 2001. Scaling this up to the national level suggests that Jamaica's

failure to effectively manage its fisheries cost the country US\$1.6 billion in lost revenues over the period from 1975 to 2000.

The fact that healthy ecosystems provide more substantial tourism revenue than other “tourism branches” (e.g., mass tourism, cruise tourism) is probably best illustrated by a recent study from Belize<sup>19</sup>. In 2007, reef- and mangrove-associated tourists spent an estimated US\$176 to \$265 million on accommodation, reef recreation (e.g., diving), and other expenses in Belize. Combined, these result in a total economic contribution of US\$205–\$299 million from coral reef- and mangrove-associated tourism in 2007 which corresponds to approximately US\$1M per kilometer of reef per year. Belize’s cruise industry, by comparison, brings a high volume of tourists—620,000 in 2007—but has a very small economic impact (i.e., US\$5.3 to \$6.4 million) compared to the overnight sector. Hence, while the negative impacts of cruise tourism affect coastal and marine areas disproportionately, these areas reap very little economic benefit from the industry.

---

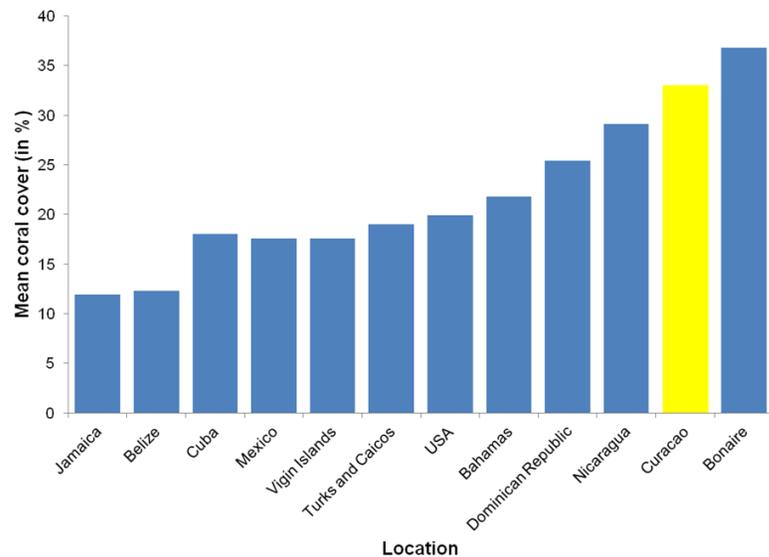
19 Cooper, E., L. Burke and N. Bood. 2008. Coastal Capital: Economic Contribution of Coral Reefs and Mangroves to Belize. Washington DC: World Resources Institute.

Improvement in the collection and treatment of wastewater from coastal settlements benefits both reefs and people through improved water quality and reduced risk of bacterial infections, algal blooms, and toxic fish. Estimates show that for every US\$1 invested in sanitation, the net benefit is US\$3 to US\$34 in economic, environmental, and social improvement for the nearby community<sup>20</sup>.

There are many more examples of the associated costs and benefits that coral reef systems provide to small Caribbean islands. The ones above only show that what might happen once reefs degrade has become reality in localities where protection efforts were begun too late. It is also evident that a failure to protect one’s marine resources comes with substantial economic losses.

---

20 Jeftic, L. and United Nations Environment Programme. 2006. The State of the Marine Environment : Trends and Processes. The Hague: UNEP/GPA Coordination Office.



*Figure 3. Based on the AGGRA dataset that was mainly collected during the 1980's, one can see that Curaçao has relatively "healthy" reefs compared to many other locations in the region. However, such relative measure by no way means that reefs on the island do not degrade, but just that they likely degrade slower.*

### **The state of Curaçao's reefs: comparisons to other Caribbean islands**

When various commonly used measurements of reef health are considered, such as the percentage of the bottom that is covered by reef building corals, Curaçaoan reefs, like those of other islands in its vicinity (i.e., Bonaire, Aves Islands) are in relatively good condition (Figure 3). While the actual number varies slightly depending on the methodology used, a Caribbean wide monitoring protocol revealed that Curaçaoan reefs harbor approximately twice as much coral than other reefs in the region. Similar observations exist for the amount of fish and other metrics of reef health<sup>21</sup>. The absence of mountain slopes and year-round rainfall likely contributes to relatively better reef health on islands in the Southern Caribbean as terrestrial run-off is increased by these two factors. However, when one realizes that average coral cover was close to 60%<sup>22</sup> when serious surveys were started near the end of the 1970's, one quickly realizes that reefs on Curaçao have simply degraded less than most others in the Caribbean. Curaçao therefore still has a

<sup>21</sup> Reefs at Risk Revisited (2011) Laretta B, Reytar K, Spalding M, and Perry A. <http://www.wri.org/publication/reefs-at-risk-revisited>

<sup>22</sup> Gardner, T. A., I. M. Coate, J. A. Gill, A. Grant, and A. R. Watkinson. 2003. Long-term region-wide declines in Caribbean corals. *Science* 301:958–960.

unique asset comparative to other islands in the Caribbean, i.e., reefs that are in better condition than most others in the Caribbean, but its reefs are, like basically all other locations in the Caribbean, in decline as well as the island's possibilities for fishing, tourisms etc.. If the degradation of these resources is halted or, even better, reversed, it will provide the island with unique opportunities rarely found elsewhere in the Caribbean.

### Recent changes in coral reef cover on Curaçaoan reefs

At the beginning of the early 1980's reef building corals covered approximately 40% of the reef<sup>23</sup>. In 2010, that number had decreased to 23.2%<sup>24</sup>, indicating that coral cover has decreased by 42% in only three decades. The decrease in coral cover has consequences for the wider reef system as the topographical complexity provided by living corals sustains larger fish communities, provides better coastal protection, generates sand to supply the island's beaches and attracts more tourists. Only the reefs near Kalki (Westpunt) and the reefs near Oostpunt

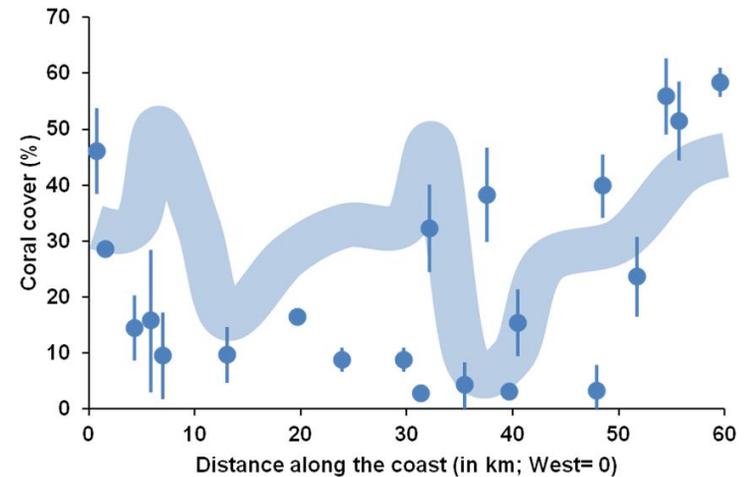


Figure 4. The change in coral abundance (expressed as the percentage of the bottom covered by corals) between 1980 (the light blue band) and 2011 (dark blue dots). One can see that except for the most Eastern and western parts of the island, coral cover has declined severely in only 3 decades.

(which are not coincidentally both far removed from coastal development) show growth relative to 1980 (Figure 4). The fact that growing reefs still exist on Curaçao makes the island unique in the Caribbean. All other reefs along the islands southwestern coast degraded. Some (e.g., rif and Slangenbaai) showed

23 Van Duyl, F.C. Atlas of the Living Reefs of Curaçao and Bonaire (Netherlands Antilles); Naturwetenschappelijke Studiekkring voor Suriname en de Nederlandse Antillen: Utrecht, The Netherlands, 1985, 117, 1–38.

24 Van Alfen, M. Van Vooren J. (2010) Een inventarisatie van de koraalriffen van Curaçao Onderzoek naar de staat van het rif langs de zuidkust van Curaçao. Carmabi onderzoeks rapport.

relatively minor changes compared to the early '80's, most probably because they occur in areas with relatively high water movement that flushes the reef "clean" with oceanic water. Regardless, when reefs occur near coastal development, their conditions worsens considerably (Figure). Vice versa, when they are located far away (> ~30 km) from human influences (i.e., coastal development) they are in surprising good health and among the best in the Caribbean region.

#### **Recent changes in the abundance of juvenile corals on Curaçaoan reefs**

A comparison of the community structure of juvenile corals between 1975 and 2005 shows a decline of 54.7% in juvenile coral abundance<sup>25</sup>. Because the maintenance and recovery of coral communities depends on the successful establishment, early survival and subsequent growth of coral larvae, these observations are worrisome. In addition to the observed decline, a shift in species composition has occurred. *Agaricia* species and *Helioseris cucullata*, the most common juveniles in 1975, showed the largest decline in juvenile abundance (a 9 and 120 fold



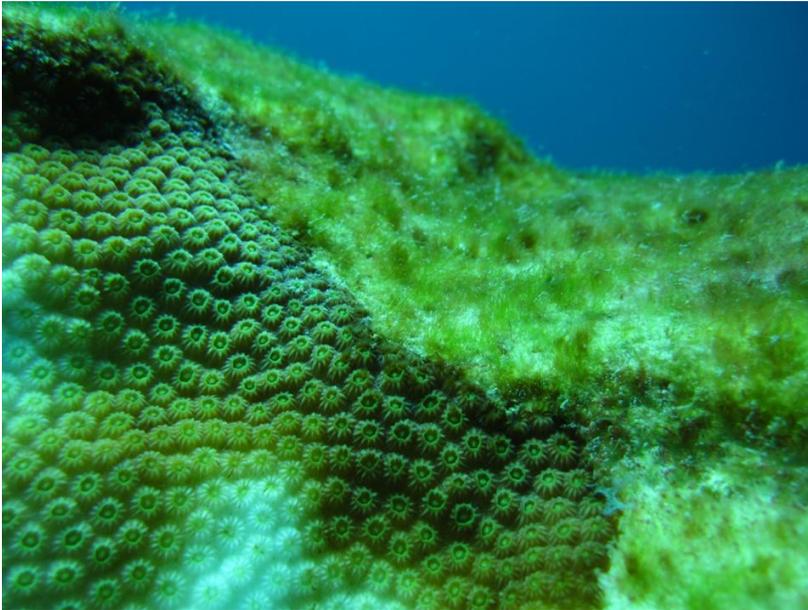
*Figure 5. The reef at Watamula in December 2010. The "bleached" corals can clearly be seen. While corals survive such events if they don't last long, the 2010 bleaching event killed nearly 10% of all affected corals.*

decrease in density respectively) with *H. cucullata* being nearly extirpated locally. These data illustrate the magnitude of the changes that have occurred in only three decades in the composition of juvenile coral communities. While the 54.7% decline in juvenile abundance observed between 1975 and 2005 can both be a cause and a consequence of the decline in adult

---

<sup>25</sup> Vermeij M.J.A., Bakker J., Hal N., Bak R.P.M. Juvenile coral abundance has decreased by more than 50% in only three decades on a small Caribbean island. *Diversity*. 2011; 3(3):296-307. Available online at: <http://www.mdpi.com/1424-2818/3/3/296/>

coral cover on these reefs, it indicates that fundamental processes required for population maintenance and recovery are operating at rates well below their historic baselines.



*Figure 6. At first turfalgae are relatively inconspicuous, but slowly but surely they overgrow corals around Curaçao as can be seen on this picture taken at Watamula.*

### **2010: the worst coral bleaching event in Curaçao's history**

The rising temperature of the world's oceans has become a major threat to coral reefs globally as the severity and frequency of mass coral bleaching and mortality events increase. During

bleaching events corals lose their endosymbiotic algae that are crucial to their survival (Figure 5). In 2005, high ocean temperatures in the tropical Atlantic and Caribbean resulted in the most severe bleaching event ever recorded in the basin. Another severe bleaching event occurred in 2010 when a second bout of extremely strong thermal stress struck the Caribbean, this time centered on the southern Caribbean (including Curaçao) where little bleaching has been seen in the past. A regional average of 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. It caused major stress to reefs in the southern Caribbean, including some sites that had not previously experienced thermal stress of this magnitude. 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 under a warming climate. 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%).

### **Turf algae: a new group of algae affecting the health of neighboring corals**

Turf algae are multispecies communities of small marine algae (Figure 6) that are becoming a dominant component of coral reef communities around the world. To assess the impact of turf algae on corals, the effects of increased nutrients (eutrophication) on the interaction between corals and turf algae was investigated<sup>26</sup>. It was found that turf algae which cover 48.3% of the reef bottom on Curaçao (i.e., all bottom not covered by sand) cause visible (overgrowth) and invisible negative effects (reduced fitness) on neighboring corals. Corals can overgrow neighboring turf algae very slowly (at a rate of 0.12 mm 3 wk<sup>-1</sup>) at ambient nutrient concentrations, but when increased nutrients are present in the water turf algae rapidly overgrew corals (at a rate of 0.34 mm 3 wk<sup>-1</sup>). Herbivores had no measurable effect on the rate by which turf algae overgrew corals. The findings that herbivores are not

capable of controlling the abundance of turf algae and that nutrient enrichment gives turf algae an overall competitive advantage over corals together have serious implications for the health of Curaçao's coral reef systems. At ambient nutrient levels, traditional conservation measures aimed at reversing coral-to-algae phase shifts by reducing algal abundance (i.e., increasing herbivore populations by establishing Marine Protected Areas or tightening fishing regulations) will not necessarily 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 need to be designed to mitigate their negative impact on coral communities.

### **Hopeful news: a possible return of an important herbivore to Curaçao's reefs?**

Not all news related to coral reefs on Curaçao is worrisome. The long-spined sea urchin *Diadema antillarum* used to be a common species that occurred in high densities (i.e., 3–20 ind m<sup>-2</sup>) on the shallow fore-reef along the leeward coast of Curaçao<sup>27</sup>. In 1983,

---

26 Vermeij MJA, van Moorselaar I, Engelhard S, Hornlein C, Vonk SM, et al. (2010) The effects of nutrient enrichment and herbivore abundance on the ability of turf algae to overgrow coral in the Caribbean. PLoS ONE 5(12): e14312. doi:10.1371/journal.pone.0014312

---

27 M. J. E. Carpay, and D. E. De Ruyter van Steveninck. 1984. Densities of the sea urchin *Diadema antillarum* before and after mass mortalities on the coral reefs of Curaçao. Mar. Ecol. Prog. Ser. 17: 105–108.

an unidentified disease caused *Diadema* to become almost extinct on Curaçao and elsewhere in the Caribbean. Mass mortality was first observed on Curaçao in October 1983 and locally 97.3%–100% of all urchins died. *Diadema antillarum* was an important benthic herbivore and turf/macroalgae increased in abundance after the *Diadema* die-off. 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. Recruitment of *Diadema antillarum* on artificial recruitment panels along the leeward coast of Curaçao and showed that present recruitment rates were equal to 2.2 times lower compared to those observed before the *D. antillarum* die-off and 56.5 times higher than those observed directly after the die-off. This suggests that despite similar recovery of the species' adult population, increasing recruitment rates of this important reef herbivore indicate that its populations might be recovering.

### **The importance of inland bays: new insights**

On Curaçao, the ecological importance of these bays has been well studied by Nagelkerken et al. They have shown that the

juveniles of at least 17 Caribbean reef-fish species are highly associated with bays containing mangroves and seagrass beds as nurseries, and that juveniles of these species are absent in bays lacking such habitats. On reefs of islands lacking these habitats, complete absence or low densities were observed for 11 of the 17 species, several of which are of commercial importance to fisheries. This finding suggests a very important nursery function of such habitats and implies that the densities of several fish species on coral reefs are a function of the presence of nearby bays containing mangroves and sea grass beds as nurseries. Coral reef populations of a variety of fish and invertebrate species are replenished by individuals that use inshore coastal ecosystems (i.e., mangroves and sea grass beds) as juvenile habitats. These habitats vary greatly in their architecture, and different characteristics of structure could play a role in their selection and utilization by resident fauna. Researchers<sup>28</sup> tested whether fish prefer the structurally most complex microhabitat and that such structure is more important to their habitat choices than the bays themselves. They found that fish prefer distinct lagoonal microhabitats irrespective of their structural

---

28 Grol, M.G.G., Nagelkerken, I., Bosch, N. Meesters, E.H. (2011) Preference of early juveniles of a coral reef fish for distinct lagoonal microhabitats is not related to common measures of structural complexity. *Mar. Ecol. Prog. Ser.*: 432: 221–233.

complexity indicating that the bay habitat provides certain benefits to juvenile fish other than e.g., hiding opportunities. In this light, continuing loss of coral and seagrass habitats in lagoonal environments due to anthropogenic effects is alarming as it affects preferential habitat of certain stages of the life cycle of fishes. These same researchers also found that fish do generally not disperse far from the inland bays in which they were born. A notable exception is Spaanse Water that contributes disproportionately large amounts of fish to the reef communities around the island and is as such crucially important in maintaining healthy fish stocks around the island. Sixty percent of all individuals belonging to certain fish species that are found on the reef (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)<sup>29</sup>.

### The status of reef fish communities

On average a square meter of reef harbors 67 grams of fish on Curaçao. The highest observed biomass of reef associated species (i.e excluding species that occur > 2 m above the reef bottom)

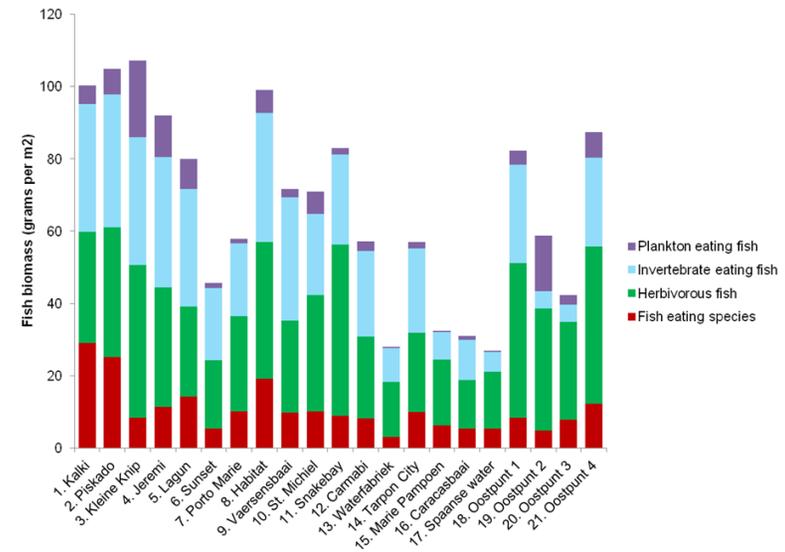


Figure 7. Overview of reef fish community composition around the island of Curaçao.

was found near Westpunt, Rif St. Marie (Habitat) and Oostpunt, whereas the lowest fish abundance was recorded on reefs near Willemstad (Figure 7). The abundance of piscivorous fish (i.e., fish eating other fish) is lowest near towns and likely

29 Huijbers CM et al (submitted) Movement across ecosystem boundaries: source-sink population dynamics of a coral reef fish

attributable to local fishing efforts. Herbivorous fish that are important in controlling algal growth are most abundant in the Oostpunt area. The abundance of herbivorous fishes, again a very important group of fish that keep reefs free of excess algal growth, increases when the abundance of corals increases indicating a tight relationship between the two groups: when coral is present, there are more herbivores around that feed on algae which then provides more space for additional coral growth. Commercially interesting species (e.g., large snappers, groupers, barracuda's) are relatively rare and only represent 4% of the total fish biomass on Curaçaoan reefs and are found at 3.2 grams per square meter. To illustrate, this latter value corresponds to one 1m long grouper in an area of 1000 x 5m or one 1m long barracuda in a 1000 x 2m large area. In comparison to other locations in the Caribbean, Curaçao has decent though not high abundance of fishes on its reefs (Figure 8), though the actual numbers vary greatly among sites along the island's southwest coast.

### The lionfish invasion

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. Results of the

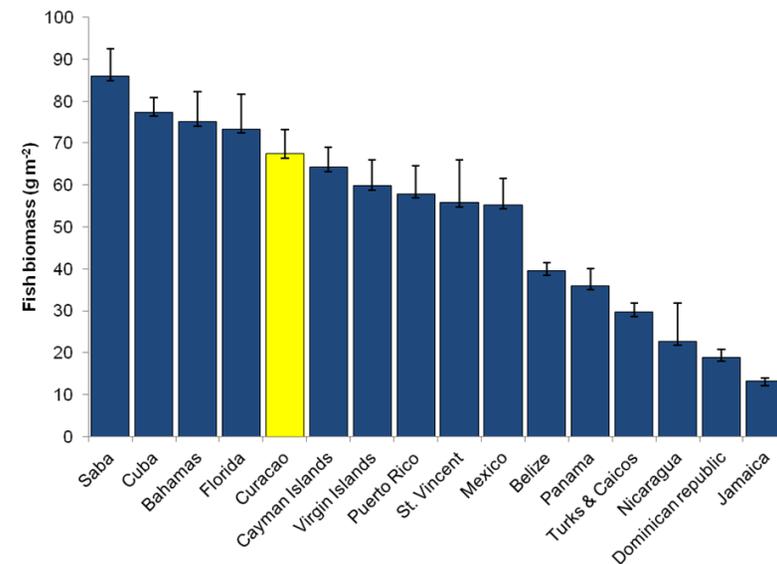


Figure 8. Based on AGGRA data, Curaçao ranks intermediate among various Caribbean islands and countries if it comes to fish abundance on its reefs.

experiment show that lionfish significantly reduce the net recruitment of coral reef fishes. The huge reduction in recruitment is due to predation and may eventually result in substantial, negative ecosystem-wide consequences. It is also

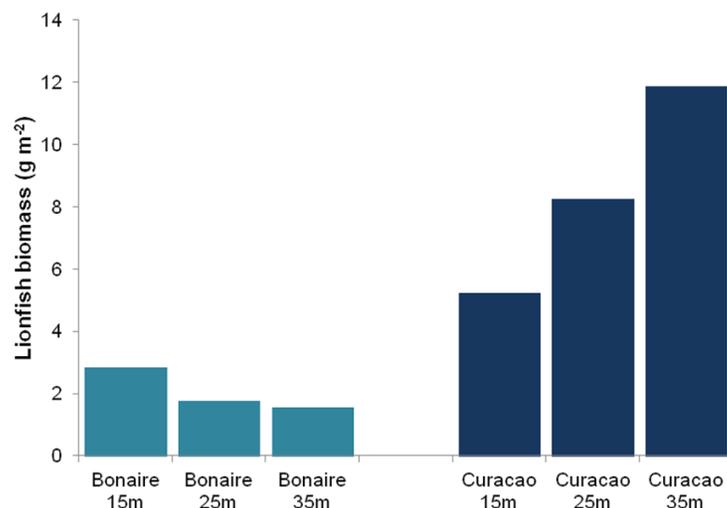


Figure 9. Lionfish abundance on Bonaire and Curaçao. One can clearly see the effect of the eradication efforts on Bonaire after only one year.

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 Atlantic coral reefs. While complete eradication does not seem realistic, Curaçao now has a lionfish elimination program similar to that of Bonaire where it has been in effect for more than 1 year. 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 (Figure 9). 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.

### The die-off of the reef building coral *Acropora palmata* and its impact on associated fish communities

Prior to the 1980's, large *Acropora palmata* (Elkhorn coral) colonies dominated coral communities in shallow reefs (> 4 m depth) across the Caribbean. Due to its abundance and branching morphology, *A. palmata* fulfills an essential role in the maintenance of healthy and productive reefs by providing shelter to an enormous amount of other reef organisms. Dense populations of this branching species also yield important

physical benefit as they are known for their great wave energy dissipation capacity and thus protection of coastal areas. Due to a disease outbreak, the abundance of *A. palmata* has severely decreased throughout the Caribbean during the last 30 years and declines in abundance are estimated to more than 97%. As in the wider Caribbean, the shallow reefs of Curaçao have impoverished considerably in the past four decades. Data from 1969 indicates that the south coast of the island used to harbor large (tens of meters length) and continuous areas of *A. palmata*. Back then, it covered up to 75% of the shallow reef bottom and formed aggregations of large stands measuring more than 4 m<sup>2</sup>. Nowadays, *A. palmata* is mostly found in scarce patches along the south coast of Curaçao and does no longer dominate shallow reefs. A new study quantified long-term shifts in fish community structure following the demise of these framework-building species. Preliminary results indicate that the decline of *A. palmata* has negatively affected local fish abundances. It was estimated that the shallow fish biomass was reduced by 67% and that one third of the species diversity was lost. The demise of this dominant structural framework builder has likely caused a corresponding reduction of their ecosystem functions, e.g., as a provider of habitat structure and complexity to other reef organisms.

### **Population explosion of damselfish**

Another worrying trend is a recent explosive numerical increase of coral-destroying damselfish (*Stegastes planifrons*). These small territorial fish garden turf algal 'yards' which they use as food sources and zealously protect them against invaders. However, they kill live coral to maintain and expand their yards, and as such cause a lot of damage on Curaçao's reefs. Predatory fish are likely important for regulating the number of destructive damselfish suggesting that overfishing of predatory fish will eventually cause declines in coral cover as numbers of *S. planifrons* increase as they are no longer predated upon. In Curaçao, the return of the once abundant staghorn coral (*Acropora cervicornis*) is completely halted by damselfish that create their algal gardens within the three-dimensional structure of this coral which subsequently dies. The decline of *Acropora* species (see above) has resulted in a near 70% reduction in fish biomass on shallow reefs with obvious implications for fishing and tourism. These findings illustrate the tight (and often cross-linked) relationships that exist between the fish and bottom community on reefs that need to be in a "pristine" state to ensure a reef's long term survival.

### **No coastal development means healthier reef systems**

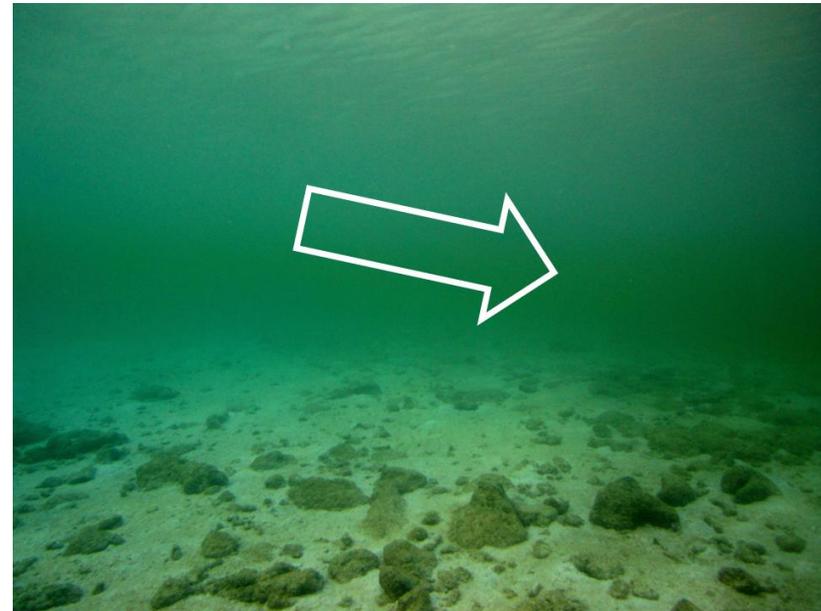
Curaçao boasts some of the most abundant living coral in the Caribbean Sea, yet it experiences intense coastal development and subsequent reef decline. Of all the island's reefs, some of the highest coral abundance occurs near the Eastern tip of the island. By comparing the energy content of East Point corals to those near the urban centre we can determine whether the health of each reef can be linked to parent health as well as offspring health and survival. The presence of these relationships should generate even greater impetus for reef conservation measures because the "fitter" offspring produced by healthy reefs has the capacity to repopulate damaged and degraded reefs. Storage lipids act as energy reserves and can allow corals to survive during times of stress, such as bleaching. Therefore greater storage lipid content is advantageous for a coral's survival. Using this technique, new data confirmed that corals growing at East Point colonies are more fit than conspecifics near Willemstad. Different coral species were observed to produce 3-5 times more larvae when they grew near Eastpoint (i.e., in unpolluted waters) compared to corals growing near developed coasts near Willemstad. Corals near Eastpoint produced also larvae that survived better and had more energy available to start calcification and growth. Combined these findings show that

"healthy" reefs (i.e., those at Eastpoint, Watamula and probably the North Coast) contribute a large fraction of the juvenile pool, i.e., the reefs of the future, on Curaçaoan reefs.

### **Worrisome developments**

Several warning signs exist that signal that certain (and often unknown) processes on the island contribute to the decline of the island's marine resources. Two examples: increased signs of disease in Curaçaoan reef fish communities and the unnaturally high abundance of certain (pathogenic) microbes in Curaçao's near shore waters. While the exact mechanism underlying these observations is presently unclear, they show that the earlier mentioned "microbialization" of reef waters as well as the rise of pathogenic microbes has already started on the island. The fact that people frequenting polluted reef areas (e.g., Spanish Water, Marie Pompoen) contract diseases, most likely from waterborne pathogens further illustrates the point. Various tests have been conducted to assess whether coastal waters contain unusually high abundances of microbes, including human pathogens (e.g., cholera, dysentery, typhus, hepatitis A). All tests showed that especially near populated areas, reef waters were enriched in bacteria occurring in sewage water and bacteria associated with ecosystem decline. It also looks like fish are vulnerable to this

increased abundance of microbes in the water column. The input of sewage waters (but also other forms of pollution) is likely in large part attributable to subterranean 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. The influx of subterranean groundwater on reefs can be observed by eye (Figure 10), but comprehensive studies to the extent of this problem have so far not been conducted despite these worrying observations. The seriousness and extend of subterranean delivery of microbes and pollutants to near shore reef communities has recently (2011) been illustrated in Mexico<sup>30</sup> 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



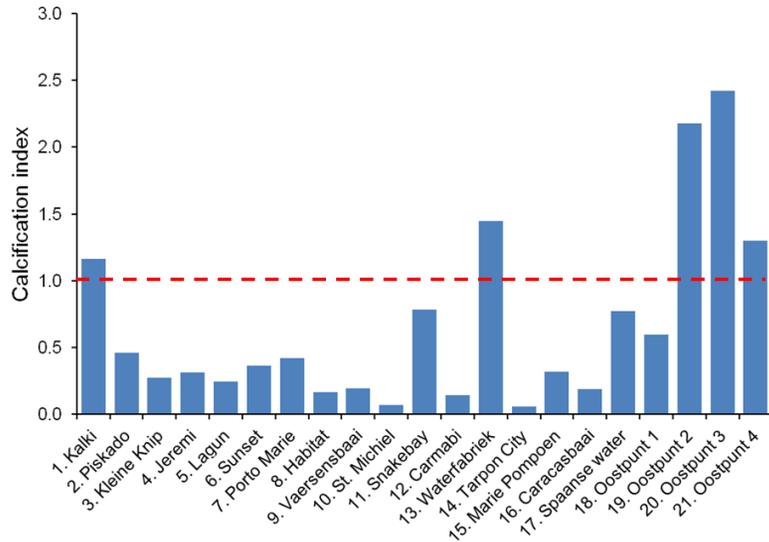
*Figure 10. The influx of groundwater (with possibly pollutants and nutrients) to nearshore communities can sometimes even be seen with the naked eye such as here after heavy rainfall at Blauwbaai.*

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

---

<sup>30</sup> Metcalfe CD et al (2011) Contaminants in the coastal karst aquifer system along the Caribbean coast of the Yucatan Peninsula, Mexico. *Environmental Pollution* 159: 991-997

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



*Figure 11. Overview of various sites along the island's southern shore. All sites with a calcification index of less than 1 are basically no longer forming or renewing the existing reef structure.*

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”.

In addition to the microbialization of coral reef communities, a previously underappreciated dynamic presently contributes to higher than usual bioerosion rates of Curaçaoan reef communities, basically causing these systems to become “eaten from the inside out”. Coral-excavating sponges invade dead and life corals and make excavations in the limestone to create themselves a shelter. While doing this they are killing the coral they are living in and they also weaken the structure of the reef framework. Declining cover by corals causes surfaces to be colonized by fast growing turf algae and filamentous cyanobacteria. These algal types produce dissolved sugars (dissolved organic carbon aka. DOC) that fuel microbes residing in the water column and the aforementioned bioeroding sponges. Higher DOC release by mainly algae (but also other reef organisms) thus causes an increased abundance of microbes and bioeroders which in turn lead to coral diseases and flattening of the reef landscape. The fact that many reefs around Curaçao are presently in a state where active reef growth (through calcification by corals and coralline algae) no longer occurs can

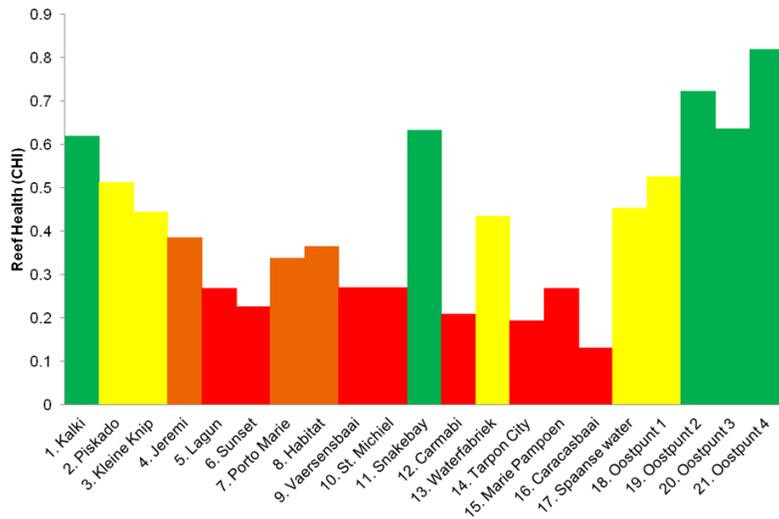


Figure 12. Overview of the current state of Curaçaoan reefs (in 2012). Green indicates healthy areas and these reefs rank among the best left in the Caribbean. Red areas have experienced severe degradation in the last 3 decades, whereas orange and yellow indicate areas where decline is currently ongoing at fast (orange) or moderate (yellow) rates.

be visualized by graphing the relative proportion of calcifying vs non-calcifying organisms. If the abundance of the former exceeds that of the latter, a reef “grows” and will be able to maintain its three dimensional structure. As can be seen in Figure 11, only

the reefs at the East and West sides of the island are currently capable of growth, whereas all other no longer actively grow through calcification and are likely to degrade on the mid to long term.

When all preceding information is combined the current state of Curaçao’s reefs along its southern shore can be visualized as follows (Figure 12) where different colors indicate the severity or absence of reef degradation in the last 3 decades is shown.

## **Reef conservation on Curaçao**

Many organizations exist on Curaçao that strive to improve the quality of its near shore reef systems. While such organizations take the form of local action groups, NGO's and local volunteers, less delineated social groups also express concern about downward trajectory of reef development on Curaçao. The latter includes the local community and commercial fishermen as well as corporations that depend on reefs to generate revenue: the water sport-, hotel- and tourism industry. In general, uncontrolled development leading to overuse, pollution and overharvesting are perceived as the main drivers of reef degradation and while many disagree on the way in which improvement and change should be pursued, they all agree that action is required. It needs to be understood that without clear measures that make "reef management" a reality, many who showed involvement and engagement in the past, no longer believe that endless gatherings will eventually lead to action. This has led others to underestimate the current engagement and motivation that exists on the island to improve the state of the island's reefs. Secondly, it will be impossible to design solutions that will please or benefit everybody equally. It is therefore important to understand that the search for a "Golden

Recipe" will be fruitless and delay meaningful and effective action.

On a more positive note, it helps to realize that Curaçao is not the first to face these problems and locations around the world have gone through the same problems in the past. While initial underestimation of the problem has characterized nearly every nation, group or island that faced them, solutions and better understanding of how to mitigate anthropogenic stress to reef systems are now available. Again, it is advisable that one looks for these lessons learned elsewhere in order to prevent further delays and reinvention of the proverbial wheel. Many of those solutions mitigate a local problem and might not necessarily be applicable to the Curaçao situation; however, they can serve as an initial suite of possibilities that are used in an adaptive management framework. Under such scenario, solutions are being tried and their effect is measured. If no effect is observed, the measure will be deemed ineffective and another is tried. Through trial- and-error, an effective solution will emerge over time. It is required that potential mitigation scenarios are thoroughly tested and all involved take a humble stand by acknowledging that suggested measures can be ineffective. Much of these protective measures will be relatively simple:

enforcement of existing regulations as well as technological advances already provide possibilities to reduce the existing stress on Curaçao's reefs and represent a low hanging fruit through which progress can be achieved.

Secondly, it is now understood that restricting harvesting is probably one of two ways by which reefs can be relieved (the other being more strict fishing regulations). While this approach often takes the form of relatively small protected areas many marine resource managers around the world now acknowledge that at least 30% of an island's shore should be set aside for this purpose in order to be effective. Small reserves simply "drown" in the wider island dynamic where mobile life-stages of all marine organisms (e.g. fish, coral larvae) simply cross its boundary to be killed or harvested. While small protected areas create an appearance that action is indeed undertaken, degradation within their boundaries is merely slowed down, but not reversed.

While many other reefs around the island remain in relatively good health, recent observations show that once decline starts, there is little to nothing that can be done to stop it. Prevention rather than restoration is therefore a more productive, successful and cheaper route by which the existence of reefs can

be guaranteed for the future. It cannot be stressed enough that reef decline does not follow a linear trajectory during which the situation gradually worsens, but that they collapse and basically disappear in a very short period of time. While it took millions of years for reef organisms to evolve and form the communities we now call coral reefs, their degradation occurs on much shorter time scales. It is no surprise that delicate natural systems possess no capacity to withstand the intensification of external stressors related to human activities on land and in the ocean. While they can withstand "some stress for some period of time", , some minute additional stress factor will eventually (and often unexpectedly) cause the entire system to collapse. Long-lived organisms such as large fish and corals quickly disappear and are taken over by more opportunistic species such as algae and microbes that due to their shorter life-spans can cope with the now rapidly changing environment. Reef restoration would then require the removal of such opportunists as well as the reintroduction of fish and corals. Obviously, waiting for reef decline to progress to the point that opportunists have become dominant simply reduces the chances for success.

Management efforts on Curaçao should focus on the following main stressors (1) overfishing, which reduces the ability of the

wider reef ecosystem to oppose replacement of coral and other reef building species by algae; (2) the reduction in the quality of water overlying reefs due to increased dissolved inorganic nutrients, enrichment with particulate organic matter, light reduction from turbidity and increased sedimentation. These two main “problems” are basically an unanticipated side-effect of (1) coastal urbanization resulting from an ever increasing population of residents and tourists, (2) influxes of nutrients (incl. fertilizers and chemicals) into Curaçao’s near-shore waters leading to eutrophic conditions of marine systems historically characterized by near-absence of nutrients.

While many reef stressors have been characterized for Curaçao (e.g. eutrophication, overfishing), it would be naïve to think that such inventory represents a complete description of the local situation. For example, on Curaçao, nutrient additions are considered as increases in nitrogen and phosphate, but there is more to this. Inorganic nutrients, particulate material, pesticides, heavy metals, hydrocarbons or other human-made pollutants, although not classical pollutants, are arguably the most important contaminants driving reef decline at national and regional levels. For example, heavy metals such as copper and zinc and some hydrocarbons have been linked to reduced

fertilization, fecundity and growth in adult corals, while some herbicides (e.g., diuron and atrazin) cause rapid photo-physiological stress in corals after short-term exposure at environmentally relevant concentrations of <1ug per liter. The effects at chronic low-level exposures of all these pollutants are still largely unknown and again stress that a conservative approach is required when deciding which degree of stress a reef can be subjected to.

To start effective management strategies aimed at reversing the degradation of Curaçao’s reefs it is imperative that this issue should be addressed at various spatial and organizational levels. Successful management efforts are generally characterized by the fact that they are started by local communities that have long-term interest in a certain locale, that they are flexible and often do not know beforehand what it is that should be done to guarantee success. Rather than debating the issue, action is simply undertaken and adjusted when the facts show that a change in course is required. Local cooperation for such efforts is often surprisingly large, and contrasts with a more top-down organizational structures that aim to tackle the same issue in a more organized way. It seems advisable that the government directly promotes such community groups while also discussing

this topic with more organized structures such as corporations, fishermen and representatives of the construction and tourism industry. It needs no explaining that the revenue on which many of these groups thrive, directly or indirectly, depend on the persistence of healthy reef systems so all should be involved in reducing the anthropogenic impact on these systems. The willingness to start such conversations seems again underestimated on Curaçao. This false perception and the unwillingness to start dialogues between different usergroups that are traditionally believed to represent different sides of the conservation spectrum, greatly hamper the speed by which progress can be made. As for much of the information that exists on reef decline, potential solutions can also be found outside Curaçao and again, can be applied immediately. For example, Management strategies developed in Florida, a US state with abundant coral reefs, deserve critical attention in the future. While it would be naïve to think that such strategies can be deployed without local fine-tuning, much can be learned from earlier progress and mistakes made elsewhere.

The many small changes that can be made will add up and reef health will improve. While it is probably advisable to take a conservative stand when determining what the effects of certain

actions will be for reef health, there is no need to be overly dramatic either. Reef collapse has not occurred on an island wide level and an apocalyptic perspective on the future of Curaçao's reefs will be interpreted by many that it is too late to reverse reef decline, thus reducing local willingness to contribute to accomplishing such reversal. Several factors will likely contribute to rapid recovery once protective measures are put in place: (1) corals on Curaçao grow relatively fast so coral cover could rapidly increase when algae are no longer competitively superior due e.g. low abundance of herbivores or nutrient inputs, (2) coral recruitment is high suggesting that the next generation of corals would arrive once habitat quality is improved, (3) Curaçao is relatively rich, so money should be generated (e.g. (tourist) taxes), for resources used and to dispose of what's left on the island; such revenue could be used to enforce existing regulations, upgrade sewage treatment facilities or even buy out local fishermen; (4) coral disease are relatively rare at present, preventing additional die-off of the main reef builders, (6) bioerosion can be locally high but has not yet reached a point where the reef framework is actively broken down at an island wide scale.

In conclusion, reef degradation on Curaçao is an omnipresent result of recent development on the island. Support to reverse this decline is great, but action is hardly undertaken at present. Through trial-and-error and dialogue between traditionally non-communicating entities, local management strategies can be devised that could quickly reverse the ongoing degradation. This

document was intended to overview some of the aspects of Curaçaoan reefs that are often unknown by people other than divers and fishermen. I hope that more people will become convinced that saving these island treasures for the future is worth the effort.

Mark Vermeij, Willemstad February 22<sup>nd</sup>, 2012