

Curaçao Should Adopt Fish Reproduction Zones to Recover Reef Fish Stocks and Improve Coastal Resources

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Photo by Shayna Brody

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Executive Summary

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Curaçao has some of the best coral reefs remaining in the Caribbean. These reefs provide for local fisheries and livelihoods. However, Curaçao's reef fish stocks are facing a rapid decline. To better protect and manage these resources, the Government of Curaçao proposes five fish reproduction zones. The Waitt Institute supports the Government's proposal to adopt fish reproduction zones.

This report summarizes relevant research and provides scientific evidence that fish reproduction zones will provide long-term ecological and economic benefits to Curaçao. These zones will support key fish nurseries, adult habitat and spawning grounds, which will promote recovery of reef fish stocks and allow undisturbed reproduction. Healthy fish populations are critical to enhance coral cover and ecosystem restoration. Implemented correctly, these zones should increase fish stocks inside and outside the dedicated zones, benefit fisheries and tourism economies, and improve long-term ecosystem health.

Curaçao's fishermen have alternatives to fishing in fish reproduction zones by targeting pelagic fish.

- Fishermen mainly fish part-time using small vessels to fish by trolling and with hand lines.
- Most fishermen target pelagic species with a smaller percentage targeting reef fish species.
- More than 85% of fishermen surveyed support the establishment of zones to protect fish and coral reefs.

Centuries of exploitation have led to the significant decline of Curaçao's reef fish stocks.

- Caribbean fishermen have targeted reef fish stocks for hundreds of years.
- Curaçao's reef fish stocks have declined substantially with indications of overfished species and overfishing.
- The biomass of today's reef fish stocks varies by zone with the Westpunt coastal area having the lowest fish biomass.

Habitat loss, invasive species and pollution contribute to fisheries decline.

- Loss of coral reefs, mangroves, and seagrasses have contributed to reductions in fish populations.
- Invasive lionfish prey on reef fish and have few predators in the Caribbean.
- Pollution threatens Curaçao's marine habitats and fisheries.
- Parasites are an additional threat to reef fish species.

Photo by Joe Lepore



Curaçao's marine environment is an interconnected system that relies on reef fish for habitat health and function.

- Healthy coral reefs depend upon algae-eating parrotfish and other herbivorous species.
- Large carnivorous fish like snappers and groupers help keep reef systems in balance.

Fish reproduction zones improve fish stocks inside and outside the zones.

- Fish reproduction zones are a type of marine protected area, which is a widely used tool to manage reef fisheries sustainably.
- Fish reproduction zones will increase fish biomass as they provide a nursery habitat for juvenile reef fish
- As fish migrate, increased fish biomass inside fish reproduction zones results in spillover outside the dedicated zones.

Fish reproduction zones benefit fisheries and tourism economies.

- Reef fish fishermen will endure short-term impact from the fish reproduction zones.
- Reef fish fishermen will experience long-term gains from reef fish recovery.
- The tourism sector will benefit from fish reproduction zones with reef and fish recovery.

Fish reproduction zone success requires effective management, compliance and enforcement.

- Small fish reproduction zones can be effective for species with small home ranges and when designed as an interconnected system.
- Effective fish reproduction zone networks protect areas that are important for all life stages of reef fish.
- An effective management system should include long-term in-situ ecological and fisheries monitoring.
- An effective management system should include a long-term fisheries dependent monitoring system.
- Fish reproduction zones should be designed to maximize biological gains while minimizing impacts to fishermen.
- Fish reproduction zones require compliance to be effective.
- Fisheries managers require adequate funding to support implementation and enforcement of fish reproduction zones



I. The Waitt Institute supports the proposed fish reproduction zone decree

A. The Government of Curaçao proposes five fish reproduction zones.

In 2011, the Government of Curaçao proposed a decree to establish five fish reproduction zones. These fish reproduction zones are designed to protect fish stocks from harvest and to promote the recovery of reef fish stocks on Curaçao's coral reefs through undisturbed reproduction (Figure 1).

This report reconfirms the need for these zones with a synthesis of ecological and fisheries data from 1986 - 2015 that indicate areas with high ecological value of existing fish, coral, seagrass, and mangrove communities as well as areas in need of recovery. Fish reproduction zones are placed in a way to satisfy ecological goals while at the same time reducing conflict with reef fishing use where possible. By providing a diverse range of habitats and ensuring the inclusion of the most pristine habitats in Curaçao, these zones capture important fish nurseries, adult habitats, and spawning grounds.

The zones are designed to halt and reverse the decline of Curaçaoan reef fish species and restore their contribution to coral reef health. Restoring fish abundance and improving habitat should in turn improve tourism and fishing.

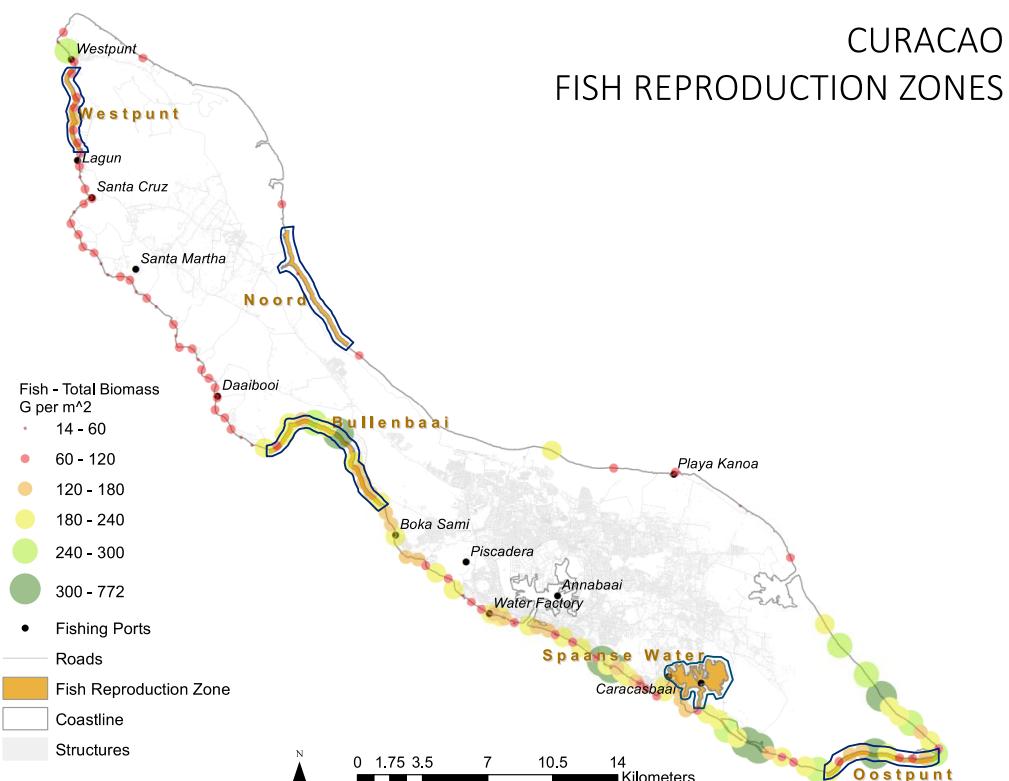


Figure 1. Fish Reproduction Zones (orange and highlighted with black box) proposed by the Government of Curaçao and total fish biomass (circles) based on 2015 science assessment (Waitt Institute 2016b)

B. More than 85% of fishermen surveyed support the establishment of zones to protect fish and coral reefs

In a 2016 survey, the Waitt Institute gathered fishermen's feedback regarding the usefulness of ocean zoning, different zoning goals, and the types of zones that should be created (Waitt Institute, 2016a). Respondents were asked to rate the importance of different ocean zoning goals. Figure 2 shows that almost 90% of fishermen identified protecting coral reefs and allowing fish stocks to increase as "important" or "very important" as an ocean zoning goal. Other important zoning goals include preventing user conflicts, curbing ocean pollution, and improving boating safety.

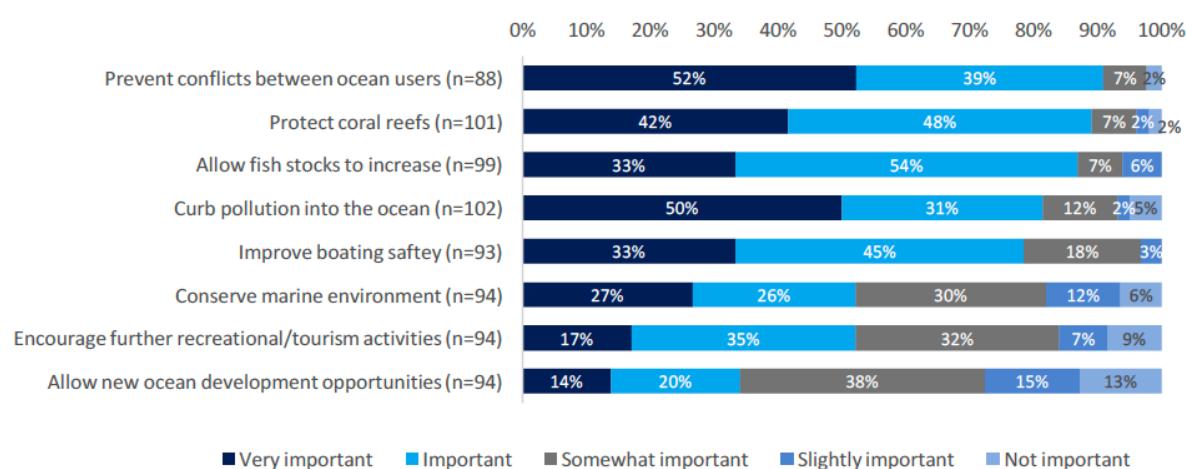


Figure 2. Fishermen's perception on importance of designating ocean zones for different purposes. n = number of fishermen who responded to the question.

In addition to the fisher survey, the Waitt Institute surveyed the general public in Curaçao to gauge their perceptions of ocean management and what measures should be taken to address concerns (Waitt Institute 2016a). Survey findings indicate that the vast majority would support conservation measures, with 87% of the public supporting the creation of marine reserves (which is a term that is equivalent to the term fish reproduction zones) (Table 1).

Measure	All In Support (n=1,078)	Fishers in Support (n=265)
Protect sea turtle nesting beaches	95%	96%
Protect mangroves and lagoons	94%	92%
Coral in danger of being destroyed	92%	91%
Create marine reserves	87%	87% ^A
Protect critically endangered fish	87%	85%

Note A: The number of respondents who answered this questions was n=253.

Table 1. Public indication of support for ocean management measures, including all members of the public (All in Support) and those responding to the public survey who self-identified as "fishers" (Fishers in Support). n = number of respondents to survey question.

II. Curaçao's fishermen have alternatives to fish reproduction zones because they target pelagic fish



Photo by Daryn Deluco

A. Most fishermen surveyed are male, part-time, and over 40 years old.

According to a 2016 survey that surveyed 110 fishermen, Curaçao fishermen are predominantly male and 71% of them fish part-time (Waitt Institute 2016a). Most fishermen indicated that fishing is not their primary source of income (69%). Both full-time and part-time fishermen span a wide age group but are commonly 40 years or older (72%). About two-thirds of those surveyed (71%) own a boat with just over half of them (54%) having a functional vessel.

B. Fishermen mainly use small vessels to fish by trolling and with hand lines.

Curaçao has a small fleet of artisanal vessels with recent estimates of fewer than 300 vessels in the fishery.¹ Of these vessels, a 2016 study classified 238 as 'in use' (Kraan 2016). Based on the type of boat, researchers predict that approximately half of the vessels are mainly used for trolling offshore ("slepen") and the other half mainly for hand line reef fishing. According to Kraan 2016, the ~120 hand line reef fishermen utilize smaller vessels that do not have the ability to travel great distances.

The most commonly used gear types for fishing are hand lines (~85% of the observed total catch), with fish traps ("kanasters") accounting for the remaining ~15% (Debrot et al. 2006). Similarly, a 2016 Waitt Institute survey of fishermen found that almost all fishermen use hook and line (97%) and the majority troll for fish (85%) (Waitt Institute 2016a). Few fishermen identified other types of gear utilized, e.g., spear guns and gill nets. However, usage of spear guns and gill nets may be under-reported given that

¹ The most recent survey of Curaçao's fishing fleet, in 2016, reported 294 fishing vessels. In 2002-2003 there were an estimated 258 fishing vessels participating in Curaçao's reef fisheries (LVV 2003).

their use is illegal (gill net use is illegal in waters <60 meters in depth). Other research finds that both methods are commonly used due to a lack of enforcement (van Buurt 2001).

C. Most fishermen target pelagic species with a smaller percentage targeting reef fish species.

When asked, Curaçao's fishermen indicated that they most commonly target pelagic fish (55%) and demersal species (53%), with one-third targeting reef fish species (38%; Waitt Institute 2016a). Notably, only one-quarter of full-time fishermen (24%) said they target reef fish species. The survey does not indicate whether these reef fishermen exclusively target reef fish or target those species as well as pelagic species. However research indicates that today the reef fish fishery in Curaçao accounts for a small portion of the total catch (~10-15%), whereas this value was nearly 70% at the beginning of the 20th century (Boeke 1907). As discussed in Section III, this fishing pressure significantly reduced the abundance of a large number of reef fish species over the last ~100 years.

Curaçao lacks a fisheries monitoring program, so landings data are unavailable. When asked, "which species do you catch most often?" most fishermen responded that they catch pelagic species including tuna and wahoo (Figure 3).

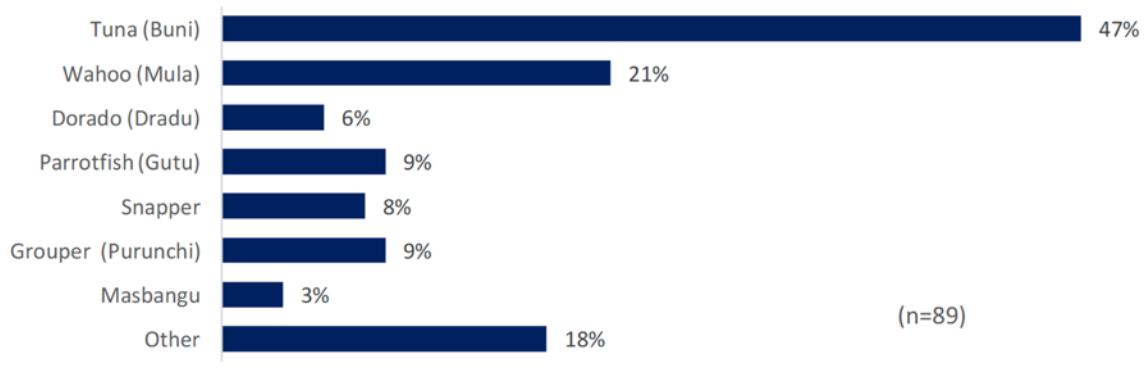


Figure 3. Fishermen's responses ($n = 89$) by percentage to the question "What species do you catch most often?"

D. Most fishermen fish and land catch on Curaçao's south shores.

Fishing occurs mainly along the calmer waters of the south shore due to the limited capacity of the small (<7m) vessels (Kraan 2016). A majority of vessels use Caracasbaai or Piscaderbaai as their harbor, though

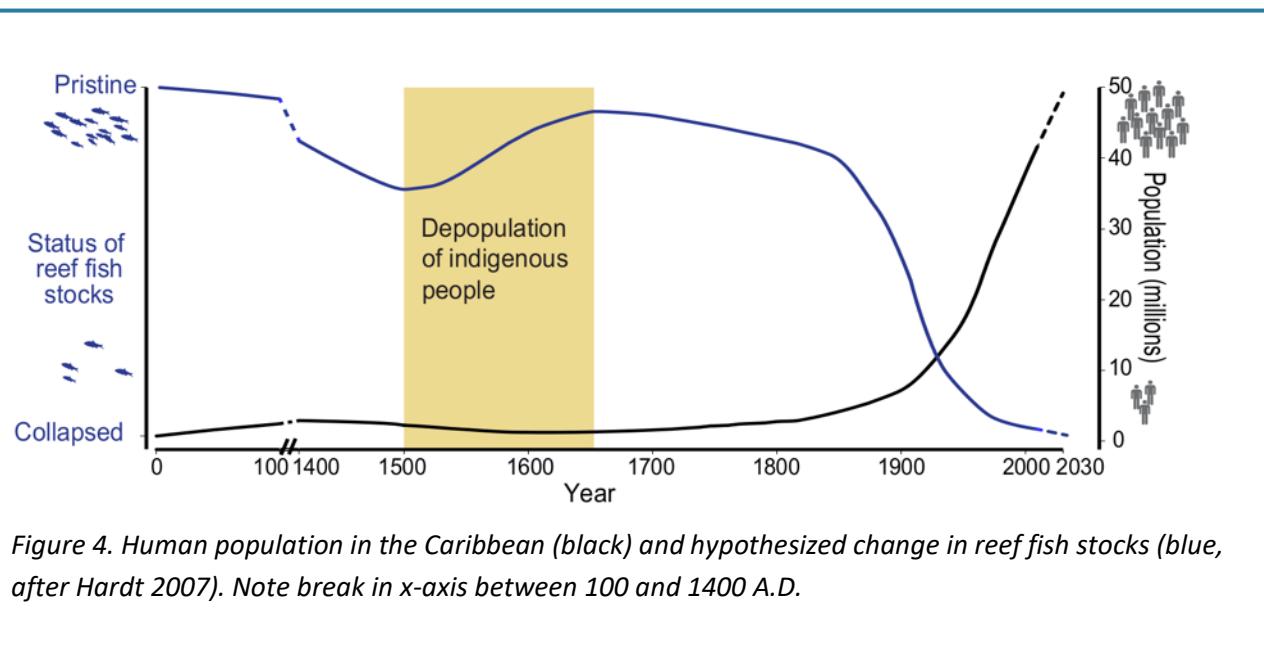
ten other bays and beaches also serve as vessel harbors (Kraan 2016). The largest portion of landings from the reef fishery was landed at Westpunt, followed by Santa Cruz and Boca Sint Michiel (LVV 2003).

III. Centuries of exploitation have led to the significant decline of Curaçao's reef fish stocks.

A. Caribbean fishermen have targeted reef fish stocks for hundreds of years

There has been heavy fishing pressure on Caribbean reefs for over a century, and even long before this, humans were over-exploiting some reef fish stocks (Jackson 1997, McClenachan et al. 2010).

Archaeological evidence from 1500 years ago to 560 years ago strongly suggests that the indigenous peoples of the Caribbean overexploited the easily accessible reef fish populations on some islands (Wing & Wing 2001). After the arrival of Europeans in the Caribbean in the 15th and 16th centuries, the decimation of the indigenous peoples of the Caribbean may have reduced fishing pressure and resulted in the recovery of reef fish populations (Figure 4). However, this reprieve for marine life was short-lived with the increasing human population soon placing more pressure on fish stocks. Subsistence fishing increased rapidly through the 19th and early 20th centuries, and the introduction of new fishing gears, including fish traps, led to the precipitous decline in reef fish stocks. The results are the reef fish populations seen today on Caribbean reefs, which are a shadow of what they once were (Jackson 1997, Hardt 2009, McClenachan et al. 2010; Figure 4).



B. Curaçao's reef fish stocks have declined substantially with indications of overfished species and overfishing

Fisheries data show that the people of Curaçao had overexploited reef fishes by the 1950s. Figure 5 shows the decline in reef fishes over the period 1973 – 2015. Fish species of commercial interest, such as groupers and snappers, have declined in abundance by over 90% in the past 40 years (Figure 6) and are now relatively rare (<5 grams per square meter, Waitt Institute 2016b). Such commercially targeted species represent only 4% of the total fish biomass on Curaçao's reefs (Waitt Institute 2016b). Non-commercially targeted species, such as butterflyfish, are heavily dependent upon well-developed coral communities. These species also have suffered large reductions in abundance over the same time period (Figure 5).

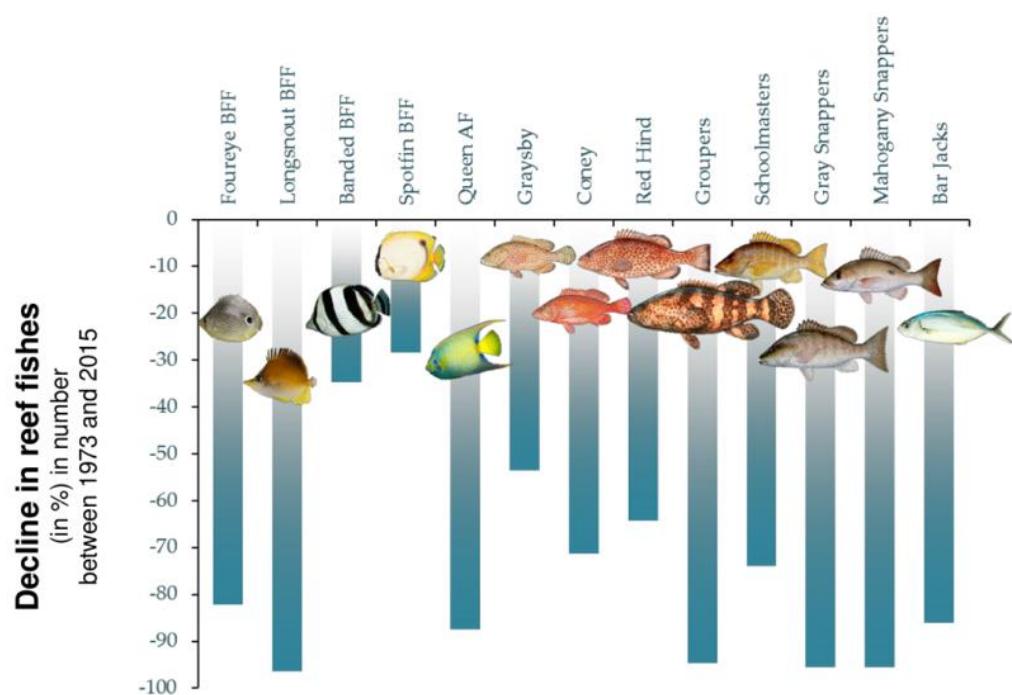


Figure 5. Change in the abundance of coral associated fishes (average number per m²) on shallow reefs of Curaçao between 1973 and 2015 (Carmabi unpublished. data). A decline of 50% means that only half the number of that fish species was observed in 2015 compared to 1973. BFF and AF are abbreviations for butterflyfish and angelfish respectively.

Long-term trends in fish catches can indicate if overfishing is occurring and/or if species are overfished. Such trend data include type of fish caught, size of catch, amount of catch, and catch per unit effort.

Declines in the average size of individual fish species and a shift from larger, high value species to smaller, low value species, are indicators of overexploitation (Graham et al. 2005, McClenachan 2009). Historical data on fish landings indicate that Curaçao's fisheries started experiencing overexploitation in the 1950s (Zaneveld 1961). Large fish species commonly landed in 1904 (Boeke, 1907), such as Nassau grouper, blue marlin, king mackerel, and ocean triggerfish became rare or absent in landings by 1955.

Decline in fish catch over time and increased effort to catch the same or fewer fish are indicators of stock depletion. With the introduction of nylon fishing lines in 1934 and the use of larger and motorized fishing vessels (Boeke 1907; Zaneveld 1961), one would expect the catch in the 1950's to be higher than in 1904. Despite the increased fishing efficiency, the catch decreased, indicating that overfishing was already occurring ~60 years ago. After reef-associated demersal species became rare in the mid 20th century, fishermen started targeting near shore pelagic species (e.g., mula, dradu). More recently, species like mula have decreased in abundance, and fishermen have moved even further offshore to fish for tuna and other pelagic species (including fishing around stationary oil tankers that are waiting to come to port in Sint Annabaai).

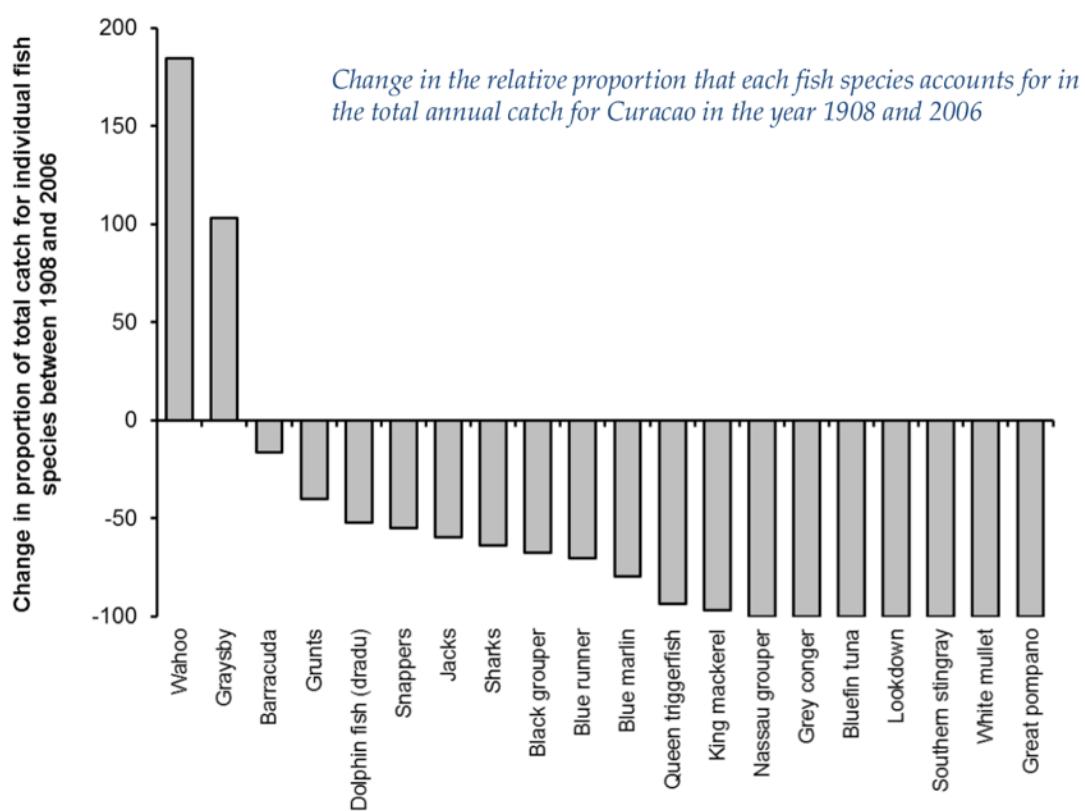


Figure 6. Change in the relative proportion of reef fish (species and families) in the total annual catch for Curaçao, from 1908 to 2006. Negative values indicate that a species was caught less in 2006 compared to 1908. A -100 change indicates that fish species that were commonly caught in 1908 have disappeared from present day catches. (Data (1908) from Dr. P.J. van Breeman in: Zaneveld (1962), and Debrot et al. 2006).

The absence of several historically abundant species from present day catches (Figure 6) is largely attributable to overfishing. Fishing pressure has been so great in the Caribbean that some species (e.g., Nassau grouper) are now classified as ‘Endangered’ on the IUCN Red List of Threatened Species (Cheung et al. 2013).

C. The biomass of today’s reef fish stocks varies by zone with the Westpunt coastal area having the lowest fish biomass

Fish biomass varies considerably around the island with the highest biomass in the southeast and middle parts of the island (Klein Curaçao to East of Willemstad, and Bullenbaai to Rif Marie). Total fish abundance is extremely low in Banda Abou and near Westpunt (Figure 7). Fish biomass for the North side of the island, where coral reefs are less well developed due to the strong trade winds, falls in the middle of these values.

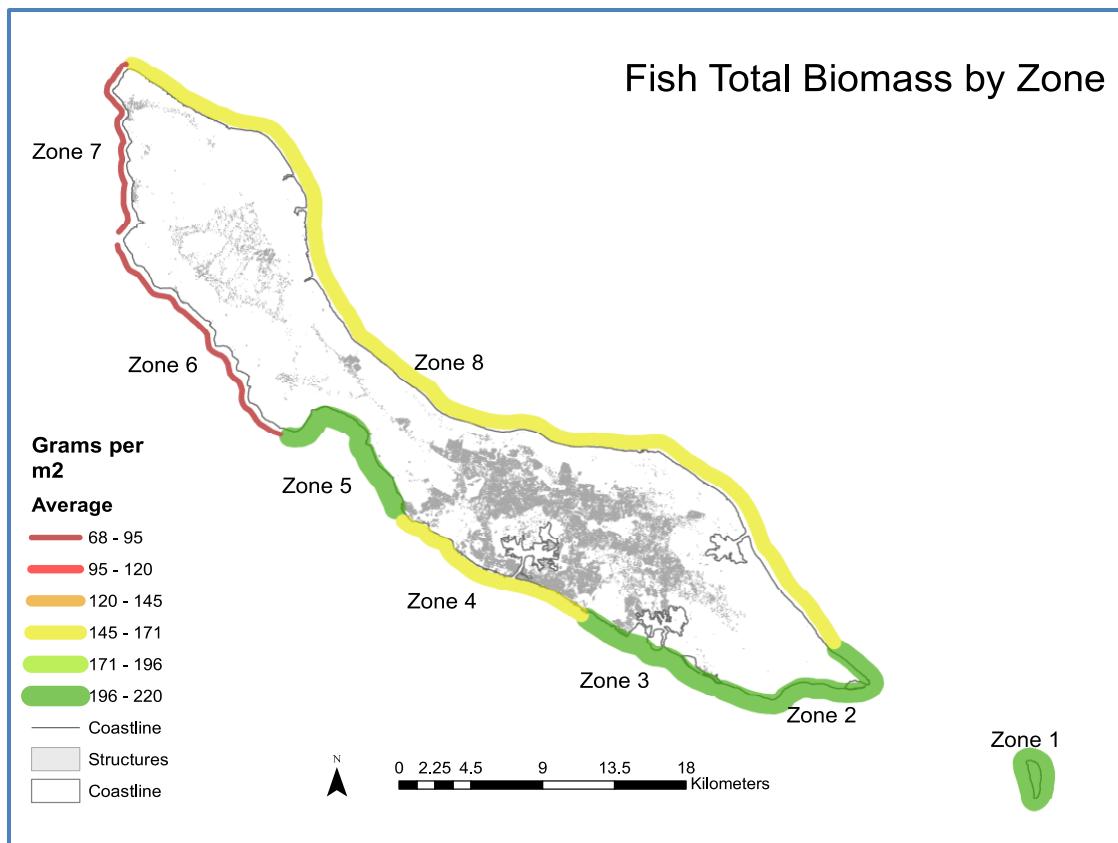


Figure 7. Spatial distribution of total fish biomass around Curaçao (Source: Waitt Institute 2016b). The proposed fish reproduction zones will cover areas with a range of fish biomass, thus allowing recovery in areas where biomass is low (Zones 7 and 8) and maintaining biomass where it is already relatively high (Zones 2 and 5).

The highest average fish biomass ($159 - 219 \text{ g m}^{-2}$) on Curaçao (found at sites from Klein Curaçao to East of Willemstad, Bullenbaai to Rif Marie, Zones 1, 2, and 5, respectively) is relatively high by Caribbean

standards, but much lower average values are found from Rif Marie to Westpunt ($68 - 94 \text{ g m}^{-2}$, Zones 6 and 7).



There is no Caribbean health indicator for *total* coral reef fish biomass, however reefs with intact ecosystems in the Pacific have total fish biomasses between 270 and 510 g m^{-2} (Sandin et al. 2008), considerably higher than the highest values found in Curaçao. Furthermore, high fish biomass on certain sites around Curaçao is often the result of the high abundance of small planktivorous fish (e.g., bicolor damselfish and chromis species) that are of no interest to fishermen. Moreover, higher biomass of such

species can be an indicator of a depletion of reef carnivores (Boaden and Kingsford 2015).

Herbivorous fish play a vital role on coral reefs, grazing on algae that can otherwise reduce the growth and reproduction of corals (McCook et al. 2001, Nugues & Bak 2006, see Section V. A. below). While herbivore biomass is relatively high ($58 - 89 \text{ g m}^{-2}$) in certain areas around Curaçao (Klein Curaçao to Willemstad and near Bullenbaai), herbivore biomass is much lower (as low as 26 g m^{-2}) in most other areas, especially from Rif Marie to Westpunt (Waitt Institute 2016b).

IV. Habitat loss, invasive species and pollution contribute to fisheries decline.

A. Loss of coral reefs, mangroves, and seagrasses have contributed to reductions in fish populations

Principal threats to reef fish in the Caribbean and elsewhere around the world are habitat loss, overfishing, and degraded water quality. Vital habitat for many Curaçaoan reef fish and other marine species are shallow-water coral communities dominated by *Acropora palmata* and *Acropora cervicornis* (elkhorn and staghorn coral; Alvarez-Filip et al. 2009, Roff & Mumby 2012). Due to an unknown pathogen both *Acropora* species suffered a decline of more than 90% in the 1980's and are now listed as endangered species (Jackson et al. 2014). The severe decline of these coral species led to an estimated 67% decline in associated fishes (Vermeij 2012).

Additional habitats that are required to support healthy fish communities on Curaçao are mangrove forests and seagrass beds (Nagelkerken & Van der Velde 2002, Nagelkerken et al. 2002, Nagelkerken 2009). Both habitats serve as important nursery grounds for reef fish species. Caribbean islands lacking

these habitats have very low densities or even an absence of some reef fish species that are common on Curaçao (Dorenbosch et al. 1998, Mumby et al. 2004). As reef fishes grow, they move beyond the nurseries into surrounding waters, sometimes a significant distance from the nursery itself. For example, a study conducted on Curaçao found that up to 80% of individuals of certain snapper species caught at Westpunt were born in the mangrove and seagrass habitats of Spanish Water (Huijbers 2012).

Unfortunately, the nursery function of mangrove forests and seagrass beds on Curaçao is degraded by unsustainable coastal development and pollution. Their abundance has decreased at an annual rate of 0.5% over the last decades (Feller et al. 2017). The reduction of mangrove forests, seagrass beds as well as living coral has significantly contributed to the severe decline in reef fishes around Curaçao.

B. Invasive lionfish prey on reef fish and have few predators in the Caribbean



Photo by Joe Lepore

The invasive lionfish (*Pterois volitans*)—a species native to the Indo-Pacific has posed a significant threat to fish communities. In September 2009, lionfish were first observed in Curaçao's waters. Lionfish quickly spread around the entire island. Lionfish can reduce the abundance of juvenile reef fish (through predation) by 80% (Albins & Hixon 2008, Green et al. 2012), sometimes even 95% (Côté et al. 2013). Because lionfish grow quickly, reproduce longer and have less predators on Caribbean reefs than in their native range (Mumby et al. 2011, Côté et al. 2013), their abundance around Caribbean Islands greatly exceeds their natural abundance in their native range. These animals therefore disproportionately impact native fish communities, especially juveniles. In 2012, Curaçao established the Lionfish Elimination Team to help eradicate lionfish by spearfishing (LET 2011).

C. Pollution threatens Curaçao's marine habitats and fisheries.

Coral reefs thrive in low nutrient environments, so added inputs of nutrient pollution from land-based sources can have devastating effects. Land-based sources of pollution in Curaçao include sewage, animal waste, and fertilizer (Waitt Institute 2016b). Excessive levels of nutrients like nitrogen and phosphorus in shallow coastal waters can encourage blooms of phytoplankton in the water, which block light from reaching the corals and seagrasses, or they can cause vigorous growth of algae and seaweeds on the seabed that out-compete or overgrow corals. In severe cases, eutrophication can lead to “dead zones,” where decomposition of algae and other organisms consumes all of the oxygen in the water. In

both 2009 and 2011 Curaçao experienced such dead zone events. With dead zones comes fish kills and possible nearshore ecosystem collapse. In addition to nutrient runoff, land-based sources of pollution include toxic pollutants and pathogens.

D. Parasites are an additional threat to reef fish species.

A new threat to reef fishes in Curaçao is the high prevalence of parasites found on some reef species (Bernal et al. 2015). Rates of infection of reef fishes in Curaçao were found to be more than 10 times higher than reef fishes in Belize and Mexico. Although the causes and the consequences of this high rate of parasite infection are not known, studies from other regions suggest that this may be a consequence of a breakdown in ecosystem function, for example, due to a lack of predators to remove infected fish from the system (Bernal et al. 2015). Fish Reproduction Zones will help to reestablish trophic structure, including increasing predator abundance.

V. Curaçao's marine environment is an interconnected system that relies on reef fish for habitat health and function.

A. Healthy coral reefs depend upon algae-eating parrotfish and other herbivorous fish species.

The health of a coral reef is tightly linked to the community of fish species present on the reef (Mumby et al. 2007, Cole et al. 2008, Wilson et al. 2009). One important function that herbivorous reef fish serve is grazing of macroalgae (Williams & Polunin 2001). Algae are naturally present on coral reefs. However, when they are not grazed by sufficient numbers of parrotfish and other herbivores, macroalgae can outcompete coral species for space (McCook et al. 2001, Nugues & Bak 2006).



Too little grazing of algae can lead to a negative feedback loop whereby cover of macroalgae (seaweeds) increases, reducing space available for baby corals to settle (coral recruitment). This in turn leads to a reduction in coral cover (Figure 8, left-hand side). As coral cover declines, the 3-dimensional structure of the reef is reduced. In other words, reefs can become 'flattened' (Figure 7, left-hand side), which in turn can lead to reduced fish recruitment. This reduced fish recruitment leads to reduced grazing because there are fewer herbivorous fish, thus completing the negative feedback loop.

A positive feedback loop is also possible if the numbers of herbivores on a reef are increased (Figure 8, right-hand side), for example by banning fishing of parrotfish species, which are the principal

herbivorous species on most Caribbean reefs. One study from a no-take marine reserve in the Bahamas showed that the recovery of parrotfish changed the trend in corals from one of decline to one of recovery (Mumby & Harborne 2010). This is the reason why some Caribbean nations, such as Belize, Bonaire and the Turks and Caicos Islands, have banned the catching of parrotfish altogether (Montero 2009, Government of Bonaire 2010, DECR 2011).

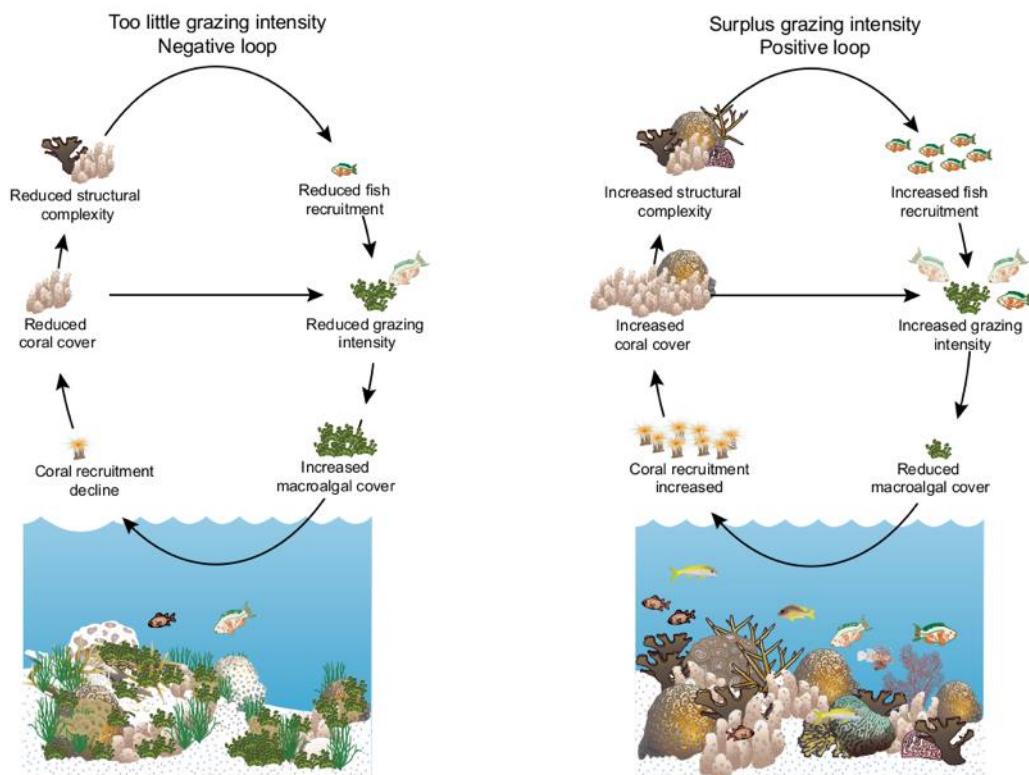


Figure 8. Grazing feedback loop. Maintaining large populations of grazers on a reef is vital to ensuring that it stays in a 'healthy', coral dominated state (right hand side). When too few herbivores are present on the reef (e.g., due to overfishing), an 'unhealthy', algal dominated state will arise (left hand side), in turn contributing to a rise in coral diseases, unnatural microbial growth including that of pathogens, loss of habitat for settling fish and coral larvae and a generally less attractive landscape for coral reef-oriented forms of tourism. Source: Mumby et al. 2014

B. Large carnivorous fish like snappers and groupers help keep reef systems in balance.

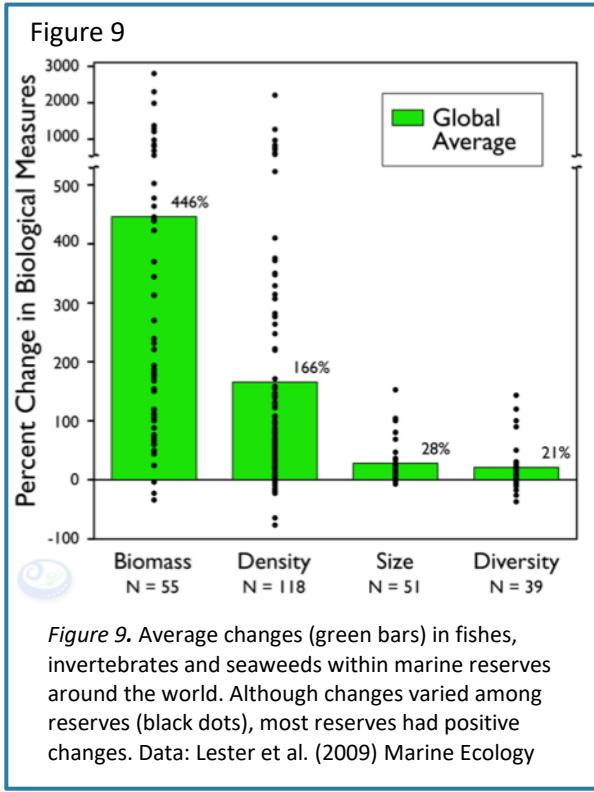
Similar to herbivorous fishes, carnivorous reef fishes play an important role in the ecological functioning of coral reefs. Many larger carnivorous fishes (e.g., snappers, groupers) are commercial fish targets and

have become extremely rare on many Caribbean reefs (McClenachan 2009, Jackson et al. 2014) including Curaçao (Figure 8). Loss of these fish species can have significant impacts on reef health as they regulate fish species that, if overabundant, can destroy corals (Hinds & Ballantine 1987, Vermeij et al. 2015). Carnivorous fish can also prevent the spread of diseases in smaller fish species by specifically targeting diseased or weakened individuals (Sandin et al. 2010; see also: Section IV, above). In addition, high abundance of large-bodied groupers contributes to the suppression of lionfish populations and their negative impact on native fish communities (Mumby & Harborne 2011).

VI. Fish reproduction zones improve fish stocks inside and outside the zones.

A. Fish reproduction zones are a widely used tool to manage fisheries.

Fish Reproduction Zones are a type of marine protected area (MPA). MPAs are widely used to manage fisheries because of their potential to increase fish abundance and thus improve the biological and economic value. In many places, MPAs or fish reproduction zones are effective for a large number of species and are easier and less expensive to implement in comparison to other management tools such as fishing quotas, gear restrictions, seasonal closures, and size limits (Dahlgren 2014).

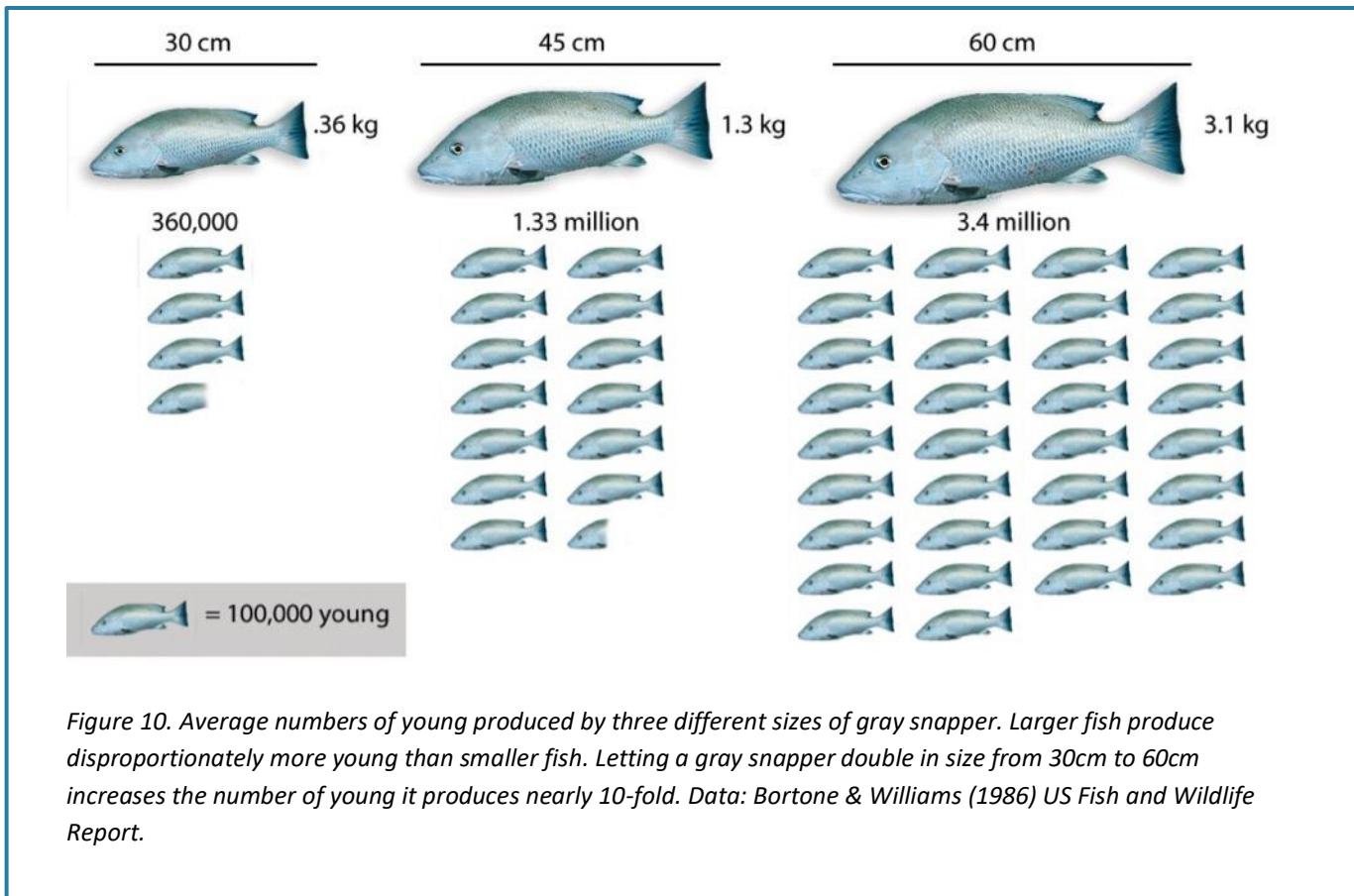


Designed correctly, fish reproduction zones increase abundance and size of fish within and outside their boundaries. Around the world, the formation of no-take zones resulted (on average) in a 446% increase in biomass, a 166% increase in density, a 21% increase in diversity, and a 28% increase in size of fishes, invertebrates and seaweeds within marine reserves (Figure 9, Lester et al. 2009).

Increased size of fish within fish reproduction zones benefits fish recovery both within and outside the zone, as large fish produce disproportionately more babies than smaller fish (PISCO 2008). For example, a 60 cm gray snapper produces nearly 10 times more offspring than a 30 cm snapper (Figure 10). When these offspring move outside the zones, they contribute to the replenishment of surrounding fish stocks.

B. Increased fish biomass inside zones results in spillover outside the dedicated zones.

Furthermore, as the density of juvenile and adult fish inside the zones increases, some of these fish migrate outside the zones (the ‘spillover’ effect), further contributing to the replenishment of fish stocks in the areas surrounding the zones (Abesamis and Russ, 2005, Stamoulis and Friedlander, 2013).



VII. Fish reproduction zones benefit fisheries and tourism economies

A. Reef fishermen will endure short-term impact from the fish reproduction zones.

The fishermen that target reef fish will experience the greatest short-term impact from the designation of fish reproduction zones. Most of Curaçao’s artisanal fishermen sell some of their catch at local markets and retain a portion for home consumption (Johnson 2010). The small-scale coastal fishing industry of Curaçao is valued at \$12 million per year, which includes the value of fishing for subsistence

purposes (Figure 11). Local for-sale fisheries account for 85% of the total value, with the remaining value from subsistence fishing (7%), local recreational fishing (4%), and processing and cleaning (4%) (SFG 2016).

Reef fish fishing makes up a segment of this fishing industry. While \$12 million makes up a very small part of Curaçao's overall economy, local fishing is an important source of food for many, is an important cultural activity, and financially supports some Curaçaoan individuals and families (Waitt Institute 2016a).

B. Reef fishermen will experience long-term gains from reef fish recovery.

Well-designed and enforced fish reproduction zones have been proven to increase fish stocks. Spillover effect improves fishing grounds adjacent to fish reproduction zones through the export (spillover effect) of both larval and adult fish (see Section VI). For example, in the Bahamas, groupers increased in abundance inside a marine reserve and then moved into surrounding waters (Figure 12). Such benefits of fish reproduction zones are heavily dependent upon their design and enforcement, whereby fisheries benefits are greatest when well enforced zones are placed to protect both spawning and nursery habitats (PISCO 2008).

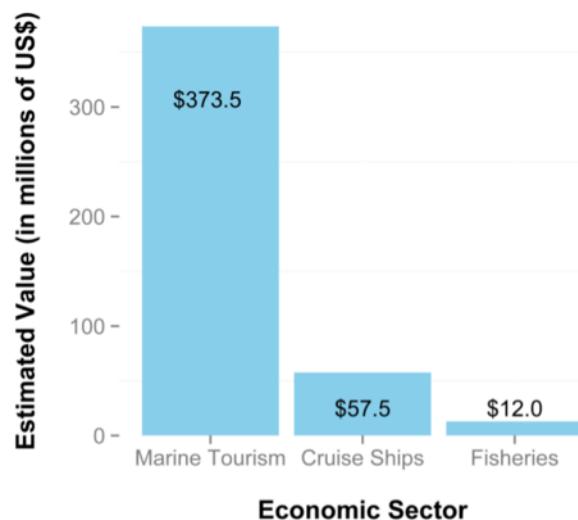


Figure 11. Estimated values of economic sectors relying on marine and coastal resources, including marine tourism and associated expenditures in the hotel sector; cruise tourism; and fisheries (SFG 2016).

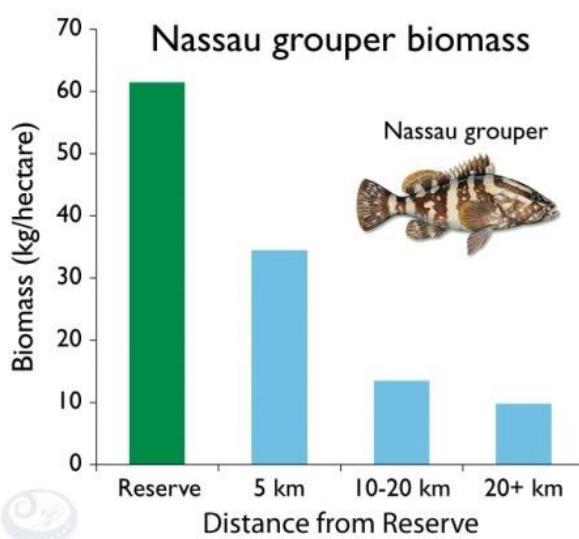


Figure 12. Biomass of Nassau grouper was highest in the marine reserve and decreased with distance from the reserve. This pattern strongly suggests that grouper from the reserve move into adjacent fished areas. Data: Sluka et al. (1997) Proceedings of the 8th Annual International Coral Reef Symposium

C. The tourism sector will benefit from fish reproduction zones.

The positive impacts of fish reproduction zones on the abundance of fishes and other marine organisms result in economic benefits through tourism and fishing. Tourists, especially scuba divers and snorkelers, are attracted to locations where fishes are large and numerous (Uyarra et al. 2005, Gill et al. 2015). Given that marine tourism contributes an estimated US\$373.5 million annually to Curaçao's economy (SFG 2016), maintaining or enhancing reef fish communities is needed to ensure and possibly increase this significant source of revenue.



Photo by Shayna Brody

VIII. Fish reproduction zone success requires effective design, management, compliance and enforcement.

A. Small fish reproduction zones can be effective for species with small home ranges and when designed as an interconnected system.

Wide ranges of fish reproduction zone (i.e. MPAs) types and sizes exist, with varying levels of protection and enforcement (Lester et al. 2009, Gill et al. 2017). Smaller protected areas may be effective for species with small home ranges or when they are placed in areas harboring healthy coral and fish communities that are more productive than communities at degraded sites (Hartmann et al. 2017). For example, in Barbados a relatively small 2.3 km² fish reproduction zone led to an overall 68% increase in fish density and a 14% increase in average size (Rakitin & Kramer 1996, Chapman & Kramer 1999, Tupper & Juanes 1999; see Lester et al. 2009).

When creating smaller protected areas, it is important to establish a protected area network that is ecologically connected, so that young fish (larvae) and adults can move between the protected areas (PISCO 2008, Gaines et al. 2010). This is accomplished by ensuring that protected areas are located within a minimum distance of one another.

Specific conservation objectives of target species determine minimum distance needed and is highly dependent on the spatial scale of larval and adult movement patterns (Gaines et al. 2010). For most marine species, larvae move further than adults. The Government of Curaçao has designed a network of five fish reproduction zones that are closely spaced that will help ensure adults and larvae can move between the reserves, therefore protecting a greater fraction of species through movement patterns of the young (PISCO 2008).

B. Effective fish reproduction zone networks protect areas that are important for all life stages of reef fish.

In designing the proposed network of fish reproduction zones, the Government of Curaçao has ensured a network with adequate habitat representation, replication, and spacing.

Successful fish reproductive zones contain ecologically important or biologically critical areas for fish species such as nursery grounds, spawning aggregation areas, and areas of high species diversity (Green et al. 2014). Areas that contain rare habitat or rare species should also be included. Studies evaluating effective parameters and characteristics of effective protected areas suggest allocating at least 20-30% of each habitat type (Bohnsack et al. 2000; Airame et al. 2003) and at least three representative locations of each marine habitat type (Fernandes et al. 2005; Salm et al. 2006; Green et al. 2014) into the protected area networks.

The proposed fish reproduction zones do not meet all of these criteria. However, they include many of the features that are known to result in protected networks that adequately protect reef fish. These include protecting coral reefs, protecting important seagrass and mangrove nursery habitat, reducing impact to fishers, and creating a network of reserves to allow flow between them. Designation of these zones is an important step in the development of an effective fisheries management system for Curaçao.

C. An effective management system should include long-term in-situ ecological and fisheries monitoring.

To determine the positive effects of a fish reproduction zone, it is important to monitor the status of fish and benthic communities both before and after implementation to determine if designation of the zone results in increased fish abundance. Preferably, scientists should conduct monitoring at least every two years, especially during the first 10 years after implementation so progress can be tracked. Monitoring at a representative number of sites should be done both inside and outside the fish reproduction zones and at increasing distances from the zones to determine if conservation benefits are occurring.

Scientists from Carmabi Research Station, as well as many visiting scientists, have conducted extensive reef surveys around Curaçao. In 2015-2016 the Waitt Institute partnered with Carmabi and others to

conduct marine surveys at 148 locations around Curaçao and Klein Curaçao (Waitt Institute 2016b). These data provide a baseline for the proposed fish reproduction zones.²

Moving forward, Curaçao should build upon past studies to establish more robust baselines for Spaanse Waters and the north shore; and it should monitor all sites using the same methods that have been employed in the past. The preferred method for Caribbean coral reef monitoring comes from the Global Coral Reef Monitoring Network (GCRMN 2016), which includes regionally standardized guidelines for surveying Caribbean coral reefs. GCRMN Caribbean monitoring elements include benthic substrates, reef fish, mobile macro invertebrates, juvenile corals, coral disease, and water quality.

D. An effective management system should include a long-term fisheries-dependent monitoring system.

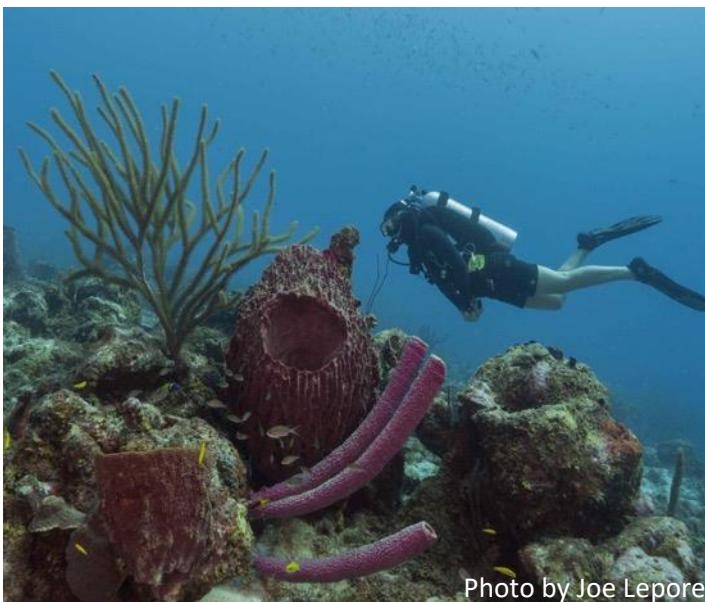


Photo by Joe Lepore

Fisheries-dependent data can inform on numerous aspects fisheries management and their effectiveness over time. This type of monitoring characterizes fishing fleets, fishing effort, and composition of species landed (including their size and weight). Fisheries monitoring data are important because they indicate the condition of fish stocks, and the sustainability of fishing activities. Managers can also use fisheries-dependent data to determine the effectiveness of management and regulations. With this information, managers can design and implement adaptive management strategies.

In the case of fish reproduction zones, fisheries-dependent monitoring data can be used to measure the impact of the zones on catch per unit effort (CPUE) of fishermen by comparing CPUE data before and after implementation. A well-designed and enforced network of fish reproduction zones should result in an increase in CPUE as target fish biomass and abundance within zones, as well as increased spillover into adjacent fishing grounds.

Curaçao currently does not consistently conduct fisheries-dependent monitoring. Without data on CPUE, it is difficult to know the current condition of the fishery and the baseline status of CPUE in the

² During the 2015-2016 expeditions, scientists did not conduct extensive surveys in the proposed fish reproduction zones for the north zone or Spannse Waters. WI surveys did reveal that north shore habitats are very similar ($n = 13$, Waitt Institute 2016a). Studies of Spannse Waters over the past and recent times were used to rank its importance amongst other bays in Curaçao.

fishery prior to implementation of the fish reproduction zones. We recommend that the Government establish a long-term fisheries monitoring program to evaluate changes over time. This program should include monitoring the fishing fleet, catch, and effort. These data will ensure that Curaçao's fisheries are operating sustainably through effective and adaptive management. A fisheries monitoring program will also help track the impacts of the fishery reproduction zones over time. Later this year, the Waitt Institute and Sustainable Fisheries Group will provide fisheries monitoring options and associated resources that may be suitable for Curaçao's reef fishery.

E. Fish reproduction zones should be designed to maximize biological gains while minimizing impacts to fishermen.

For maximum ecological benefit, managers should not allow extractive activities within a fish reproduction zone, including for example, fishing, mining, aquaculture development. A global study investigated protected areas effectiveness based on varying levels of restrictions. Sites that allowed multiple gear types of fishing had the same total fish biomass as sites that were open to all types of fishing. However, sites that allowed only hook and line fishing had higher biomass of many reef fish families relative to both the open sites and those that allowed fishing with multiple gear types, such as nets and traps (Campbell et al. 2017). Another global study also found positive effects of partial protection on fish biomass relative to no-protection (Gill et al. 2017).

In Curaçao, the principal reason for designating fish reproduction zones is to reverse the decline in the abundance of reef-associated fish around the island. As proposed, these zones will allow trolling for pelagic species such as mula, marlins, dradu and tunas. Allowing these limited activities should still result in the positive benefits to reef fish sought by the designation of fish reproduction zones.

Typically allowing some types of fishing in a fish reproduction zone makes enforcement more difficult. However, determining if a boat is trolling can be relatively simple as boats that are trolling should be moving along the outer edge of the reef with lines cast behind the boat. Other types of fishing that is typical in Curaçao require a fishing vessel to be drifting and/or anchored making them easily distinguished from sanctioned trolling activities.

F. Fish reproduction zones require compliance to be effective.

The biological and economic benefits from fish reproduction zones can only be realized if fishermen comply with the regulations for the zones, which normally requires enforcement capacity. A global study of marine protected areas found that having adequate staff and financial stability can be more significant predictors of ecological outcomes than whether the area is fully or partially protected (Gill et al. 2017).

Principles for effective enforcement of a fish reproduction zone are summarized in Table 2 (ELI, 2016). These principles were developed by a group of legal, technical, and enforcement experts convened in

2016 by the Environmental Law Institute in Washington, DC. The expert panel included Curaçao's Head of Law Enforcement and Liaison at the Dutch Coast Guard.

Effective MPA Enforcement ...	
1	Begins with sound, adaptive MPA design and public education.
2	Is fair, consistent, transparent, and governed by the rule of law.
3	Is carried out by trained enforcement officers with clear legal mandates and broad enforcement powers who possess robust maritime domain awareness.
4	Leads to timely legal action, supported by admissible evidence to prove violations, and the imposition of appropriate penalties by neutral decision-makers.
5	Deters would-be violators and increases overall compliance with the law by establishing a high likelihood of detection. It relies on a highly visible enforcement presence as a component of an effective enforcement posture.
6	Is prioritized and adequately funded by government.
7	Is cooperative, within and among government ministries and enforcement agencies, and with the public. It also makes full use of regional and international cooperation, collaboration, partnerships, and institutions.
8	Uses available data, information, and intelligence to anticipate shifting and emerging threats and to plan countering operations, rather than solely responding to observed violations.
9	Ensures that the results of enforcement activities are communicated to the public, information about ensuing proceedings and penalties is shared in a transparent manner, and enforcement authorities are responsive to public input and concerns.
10	Employs modern technologies and approaches without becoming overly dependent on them.

Table 2. Principles for Effective MPA Enforcement.

G. Fisheries managers require adequate funding to support implementation and enforcement of fish reproduction zones

Creating a system of sustainable financing for ocean management planning, development, implementation, monitoring and adaptation is crucial for ocean management success (Marine Ecosystem and Management 2016). It also is one of the most challenging aspects of ocean management. Key approaches to overcoming the challenge include user fees and other payments for ecosystem services to support management, domestic budget allocation, and development assistance, among others (Spergel & Moye 2004). In addition to creating an appropriate funding stream, it is important to ensure a dedicated source of funding so that ocean management moves beyond planning to include implementation, monitoring and adaptation.

Waitt Institute is currently working with a fellow from the Center for Blue Economy to evaluate sustainable finance options to support ocean management. Particularly promising is the potential to impose a dive fee for visiting divers.

IX. Conclusion

Applying these principles to Curaçao's fish reproduction zones demonstrates that the Government of Curaçao has created a network of fish reproduction zones where the design principles are met: these zones were designed using the best available scientific data to maximize their potential to support improved reef ecosystems and improved fisheries while at the same time minimizing impact to fishermen. Once designated, it will be incumbent upon the Government of Curaçao to ensure appropriate outreach and education so that fishermen have due notice of the zones. It will also be essential to have a robust enforcement system in place, which is itself dependent upon effective cooperation among ministries, agents and the public; effective compliance/enforcement monitoring; and adequate funding.

Based on our socioeconomic & scientific research, Waitt Institute supports the Government of Curaçao's proposal to adopt fish reproduction zones.



X. Data Summaries of Proposed Fish Reproduction Zones

This section provides a brief overview of the features and status of each of the proposed fish reproduction zones. For each FRZ, it summarizes location, size, total fish biomass, coral cover, juvenile coral, sewage pollution, trash index, algal cover, fishing value, and diving value. Data come from 2015-2016 scientific and community assessments (Waitt Institute, 2016a, 2016b), unless otherwise stated.

Total fish biomass, coral cover, juvenile coral, sewage pollution, and algal cover are all indicators of coral reef ecosystem and fish stock health. Table 1 provides a summary of the status of each FRZ as it relates to them.

Indicator	Healthy	Westpunt	Bullnbaai	Spaanse Waters	Oostpunt	North shore ³
Total fish biomass	>270 g m ⁻²	103 g/m ²	214 g/m ²	n/a	205 g/m ²	35 g/m ²
Total fish biomass combines #s of fish plus size to estimate the total biomass of fish in an area. Higher total fish biomass is typically an indicator of healthier coral reef systems, though types of species are also relevant.						
Coral cover	40%	8%	10%	n/a	29%	1%
Coral cover is a measure of the average percent of benthic habitat in a given area that is made up of living hard corals. Higher percent coral cover means a healthier reef system.						
1980s coral cover ⁴	40%	40%	35%	n/a	58%	n/a
Coral decline	0%	80%	250%	n/a	66%	n/a
Coral decline is the percent of coral cover decline based on comparison of coral cover in 1982 compared to 2015 surveys.						
Juvenile coral	n/a	4.4/m ²	4.4/m ²	n/a	8.9/m ²	0
The presence of juvenile coral is an indicator coral reef health and the conditions necessary to allow new coral growth. Therefore, the greater the number of juvenile corals the healthier the habitat.						
Sewage pollution	1.40	1.48	1.41	n/a	1.4	1.61
Sewage pollution is measured by the ratio of Nitrogen isotopes (N ₁₅ ratio). ⁵ The higher the number, the worse the sewage pollution. In Curaçao, low pollution levels score an N ₁₅ ratio of 1.4 with the most polluted areas scoring a 12.0.						
Algal cover	Turf:< 5% Macro: < 5%	Turf: 37% Macro: 15%	Turf: 32% Macro: 12%	n/a	Turf: 20% Macro: 13%	Turf: 8% Macro: 88
Algal cover is a measure of the amount of benthic cover that is turf algae or macroalgae. Low levels of algae on the reef is natural. However, higher levels indicate of reef decline. In other words, high algal cover typically means lower coral reef ecosystem health.						

³ North shore is a macroalgal-dominant environment, a condition that is believed to be a product of oceanographic factors rather than human-caused changes. Since this is not a substantial coral reef environment in the shallow water environment, numbers do not necessarily indicate poor ecosystem health.

⁴ DeFleur, 2017

⁵ N₁₅ measurements indicate the level of sewage stress on the reef (Risk et al. 2009; Umezawa et al. 2002)

Table 3. Coral reef health indices for Curaçao.

In addition to measuring coral reef health, each summary includes an overview of fishing value and diving overlap. These values are based on ocean surveys conducted with fishers and divers where ocean users indicated areas they used. Fishing and diving overlap are spatial averages of the sum of overlap per pixel fishing or diving grounds identified. For fishing values, these numbers serve as an indicator of potential adverse impact to reef fishermen, as reef fishermen may be excluded from some fishing areas as part of the fish recovery process. For divers, diving value numbers serve as an indicator of potential benefits, as divers will benefit from reduced fishing pressure—more fish and healthier reefs. However, divers also impact reefs, and too many divers or snorkelers may adversely impact coral reef habitat.

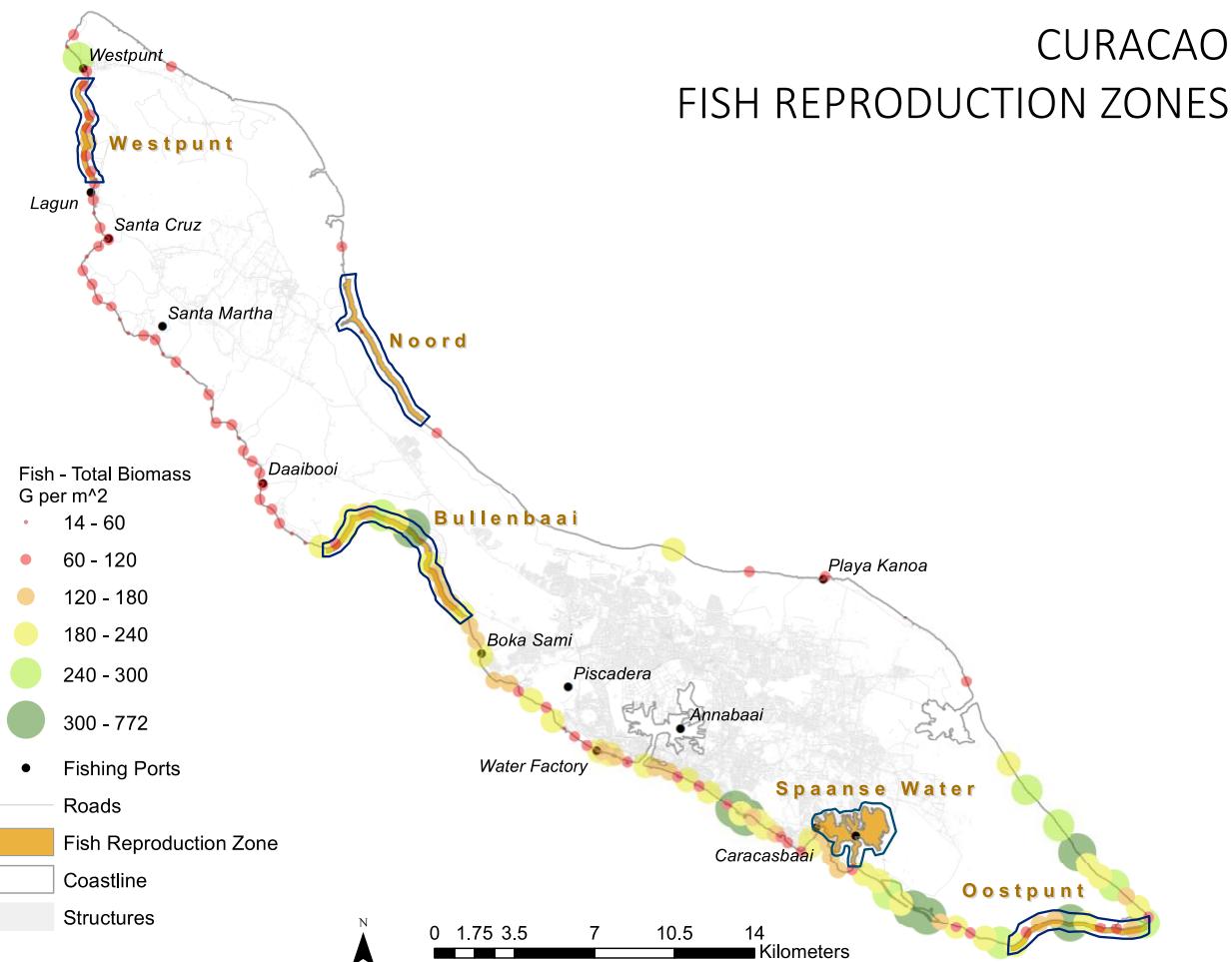


Figure 13. Map of Proposed Fish Reproduction Zones with Total Fish Biomass. Proposed FRZs shown as orange polygons outlined in blue (Westpunt, Bullenbaai, Spaanse Water, Oostpunt, and Noord).

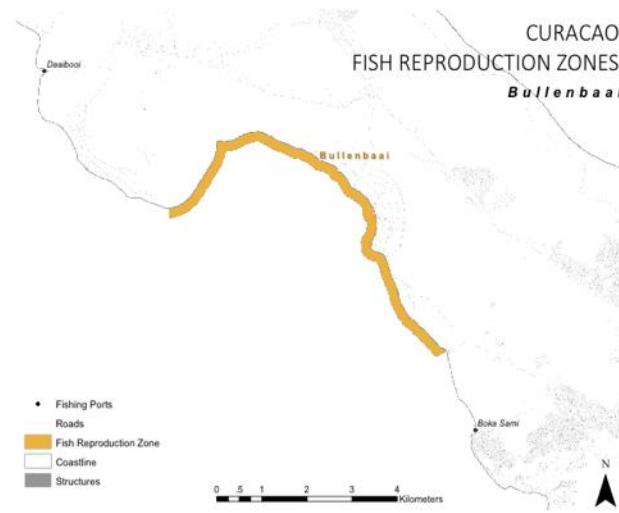
The proposed fish reproduction zones will help rebuild Curaçao's reef fish population. The zones have been chosen with different purposes in mind:

- **Westpunt FRZ and Noord FRZ** – have relatively low numbers of reef fish. Protecting these areas will allow the fish stocks to recover, growing to a larger size and becoming more fecund.
- **Bullenbaai FRZ and Oostpunt FRZ** – have high numbers of reef fish when compared to other places in Curaçao. Protecting these stocks will help enhance recovery around the island, ensuring there are fish to reproduce and export their larvae and juveniles to other areas.
- **Spaanse Waters FRZ** – is an inland bay with extensive mangrove forest and seagrass beds that are key habitat for juvenile reef fish and other marine life. These habitats act as nurseries and are vital to recovery of the reef fish populations.

1: Westpunt FRZ

This section briefly summarizes key attributes of the proposed Westpunt FRZ.

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



KEY FINDINGS

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

CONSERVATION OPPORTUNITIES

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

Additional details include:

- Location:** Zjeremi (GPS code 12°19'43.03"N, 69°09'08.62"W) to Playa Forti (GPS code 12°21'59.36"N, 69°09'19.70"W) along the coast and extending 200m from shore
- Size:** 1.0 km²

- **Total fish biomass:**⁶ 103 g/m² (range = 70 to 160 fish g/m²)
- **Coral cover:**⁷ Average 13% cover with cover as high as 17%
- **Juvenile coral:** 4.4/m² average (range = 1-8)
- **Sewage pollution:** 1.48 average (range = 0.89 to 1.78)
- **Trash Index:** 0.38 average (range = 0-1)
- **Algal cover:**
 - “Turf” 36.9% average (range = 27-46%)
 - Macroalgae: 14.5% average (range = 8-25%)
- **Fishing Value:** This FRZ sits between valued fishing areas at Playa Kalki and Playa Lagun, without overlapping those important fishing grounds. Based on the Blue Halo Listening Tour participatory mapping survey data, the zone overlaps with 1.3% of Curacao’s fishing value.
- **Diver value:** Based on the Blue Halo Listening Tour participatory mapping survey data, the zone overlaps with 0.7% of Curacao’s dive value.



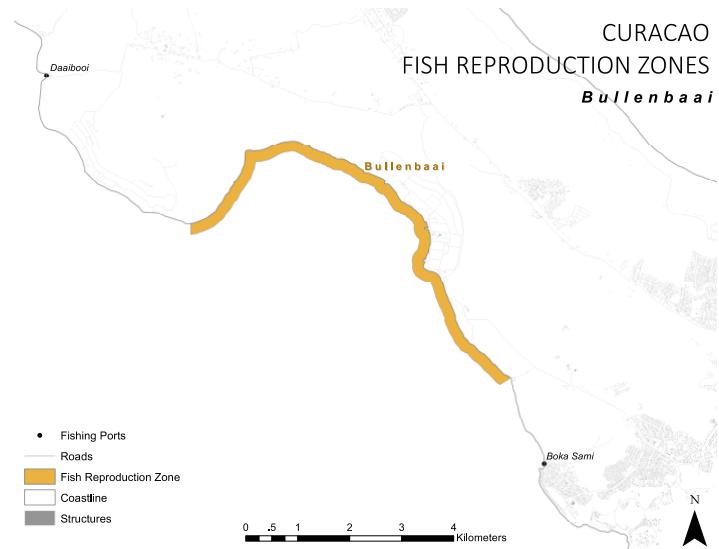
⁶ Values found around Curacao ranged from 14 to 773 fish g/m². See Table 1 for min, max and mean biomass values by trophic group.

⁷ In 1982, coral cover was estimated to have averaged 40%, with values up to 60%, (Van Duyl 1985). Estimates presented here come from the 2015 Science; 40% coral cover level indicates a healthy reef ecosystem (Burke et al. 2011; Jackson et al. 2013).

2: Bullenbaai FRZ

This section briefly summarizes key attributes of the proposed Bullenbaai FRZ.

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



KEY FINDINGS

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

CONSERVATION OPPORTUNITIES

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

Additonal details include:

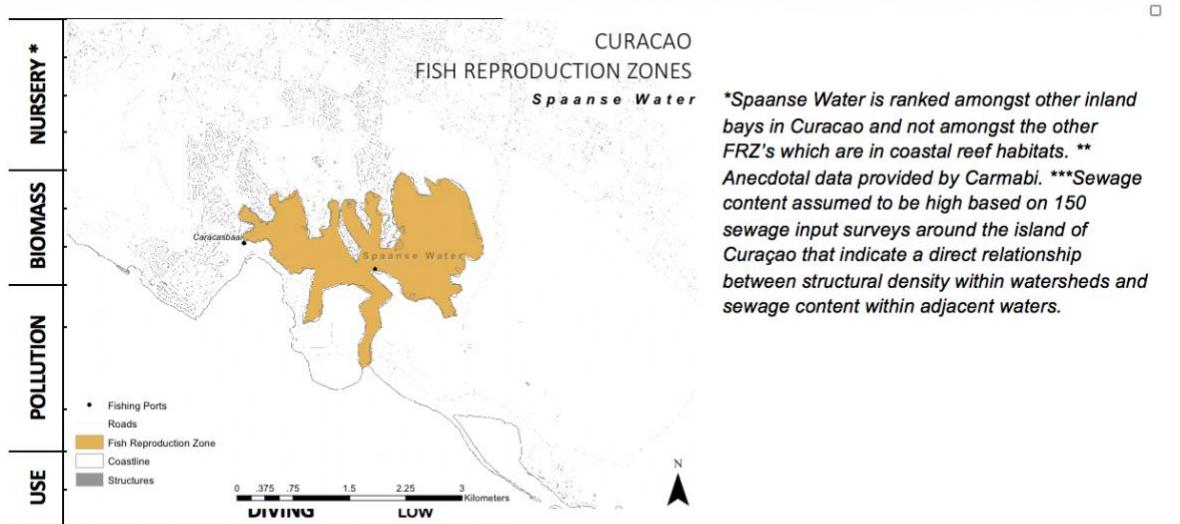
- Location:** Vaersenbaai (GPS code 12°09'36.72"N, 69°00'21.67"W) to Punt Kaap St. Marie (GPS code 12°11'11.65"N, 69°03'35.75"W) along the coast and extending 200m from shore
- Size:** 2.0 km²
- Total fish biomass:** mean of 214 fish g/m² mean (range = 14 to 773 fish g/m²)
- Coral cover:** 10%

- **Juvenile coral:** 4.4/m² (range = 0 and 9 juvenile corals per m²)
- **Sewage pollution:** 1.41 average (range = 0.88 to 1.94)
- **Trash Index:** 0.35 (range = 0-1)
- **Algal cover:**
 - Turf: 32% (range = 19-45%)
 - Macroalgae: 12% (range = 2-25%)
- **Fishing Value:** Based on the Blue Halo Listening Tour participatory mapping survey data, the zone overlaps with **0.3%** of Curacao's fishing value. It is north of valued fishing grounds around Boca Sint Michiel.
- **Diver value:** Based on the Blue Halo Listening Tour participatory mapping survey data, the zone overlaps with **0.7%** of Curacao's dive value.



3: Spaanse Waters FRZ

This section briefly summarizes key attributes of the proposed Spaanse Waters FRZ.



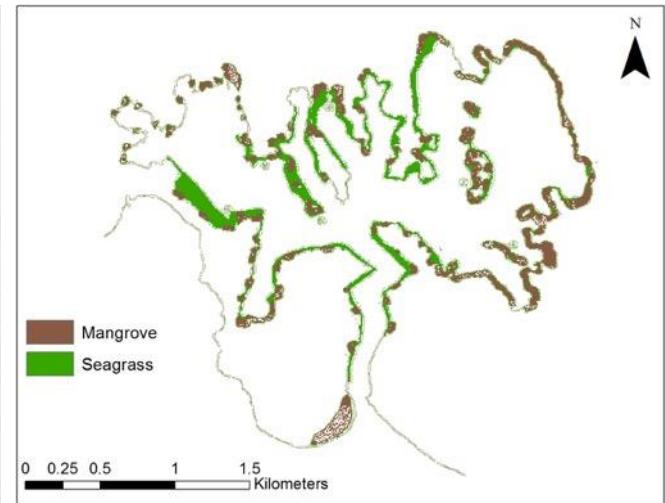
KEY FINDINGS

- Spaanse Waters is the largest and most productive nursery habitat in all of Curaçao and is an invaluable marine resource both ecologically and economically.
 - The largest areas of mangroves and seagrasses in Curacao are found in Spaanse Waters.
 - Use the bay is diverse with a significant amount of recreational and fishing vessels utilizing its protected waters to harbor their boats
 - Infrastructure density is high in adjacent watersheds and likely contributes high amounts of sewage and nutrients into the bay.
-
- Establishing a Fish Reproduction Zone in Spaanse Waters provides an area for juvenile fish to grow and replenish adult habitats on Coral Reefs in the most suitable of all bays in Curacao. Juvenile fish tagged in Spaanse Waters have later been caught as adult fish in Westpunt.

CONSERVATION OPPORTUNITIES



Satellite image of Spaanse Water



Map of mangrove and seagrass cover in Spaanse Water

Additional details include the following:

- **Location:** Bay of Spaanse Waters
- **Size:** 3 km²
- **Total fish biomass:** Unknown
- **Nursery grounds:** The bay is an important nursery area for several fish species.⁶ Up to 80% of individuals of certain snapper species caught at Westpunt were born in the mangrove and seagrass habitats of Spaanse Water.⁷
- **Other species:** Spaanse Water acts as an important feeding area for the threatened (appendix 1 of the CITES Convention) and legally protected (Island Decree protection sea turtles AB 1996 no. 8) Green turtle (soepschildpad)
- **Coral cover:** The coral populations within the bay suffered large declines over a 30 year period, which is linked to increasing coastal development.¹³
- **Mangrove cover:** The shoreline of the bay is fringed with *Rhizophora mangle* mangrove trees, and seagrass beds (*Thalassia testudinum*) are located in front of the mangroves in depths of 0.4 to 3m¹. Spaanse Water has the largest areas of mangroves in the whole of Curacao² Mangroves and seagrasses help prevent erosion and dampen storm surge,^{3,4} filter pollution and nutrients,⁴ and can be an important carbon sink.⁵
- **Seagrass cover:** Between ~3 and 6 m depth the bay consists of a muddy/ sandy seabed, with some algal cover, with a deep channel extending from 6m depth down to a maximum of 18 m¹ Spaanse Water has the largest areas of seagrass beds found in the whole of Curacao² Seagrass beds cover 15% of the seabed within the bay²

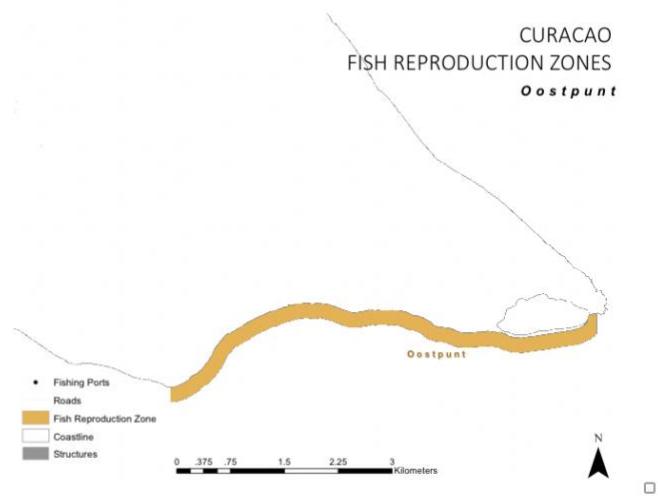
- **Sewage pollution:** The bay has considerable human impacts from boating and sewage. Some areas in the bay have elevated levels of phosphate, heavy metals and human feces^{9–11}, which may be a threat to the seagrasses¹²
- **Trash Index:**
- **Algal cover:**
 - Turf
 - Macroalgae
- **Fishing Value:** The bay has two fisheries landing sites which harbour 100 fishing vessels⁸.
- **Diver value:**
- **Human activities:** Many of the houses around the bay have private boat jetties, and there is a yacht club and windsurfing the bay is popular for watersports activities.



4: Oostpunt FRZ

This section briefly summarizes key attributes about the proposed Oostpunt FRZ

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



KEY FINDINGS

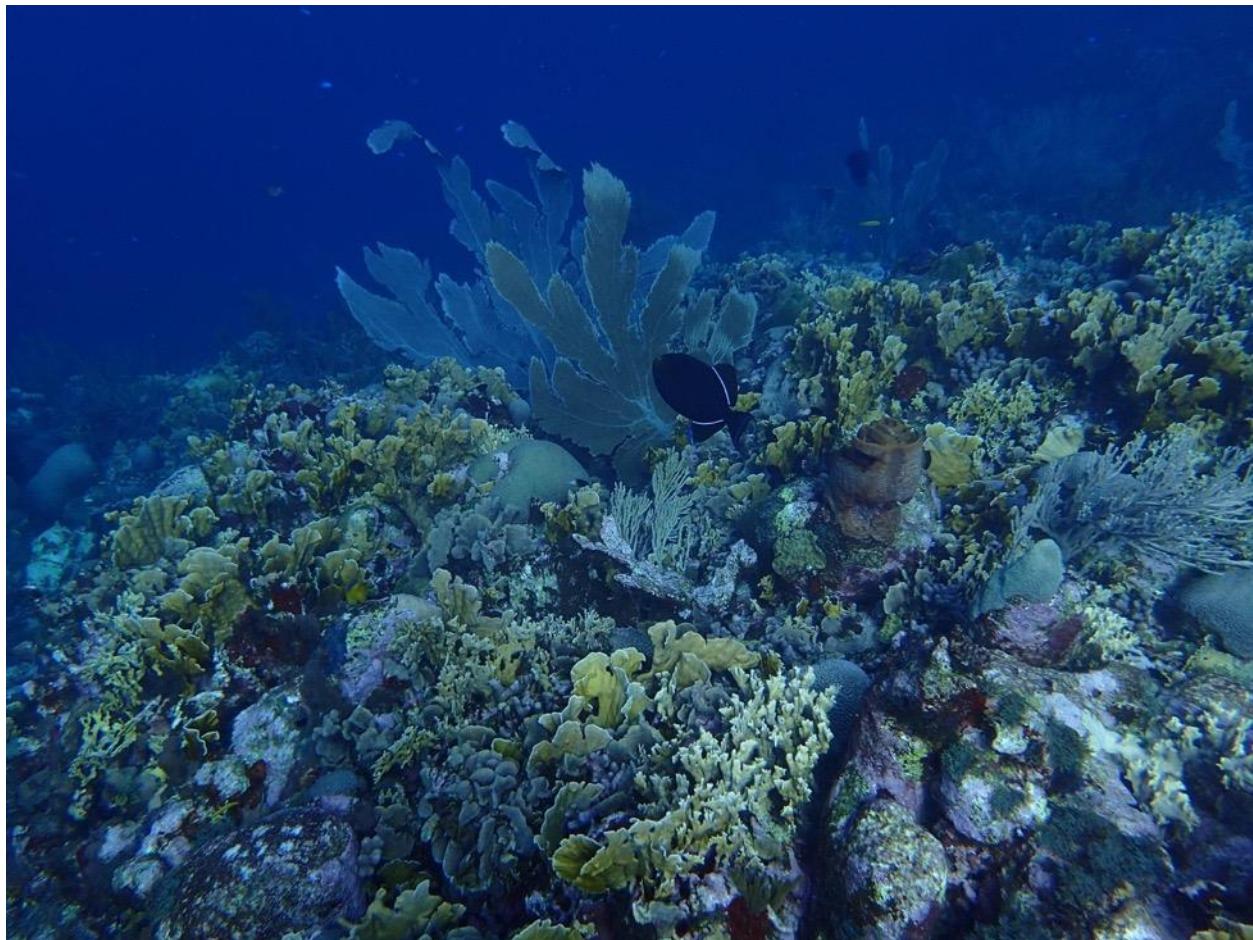
- Oostpunt FRZ has a high percentage of live corals. It also has the second highest density of juvenile corals, being two times higher than other zones.
- This zone has above average fish biomass.
- Use from fishers and divers is low, as is water pollution from trash and sewage.
- Oostpunt is another excellent candidate for protection to preserve this area of high coral recruitment that is important to the long-term survival of coral reefs in Curaçao. Other biological and physical characteristics that support the creation of a protected area in Zone 2 include high fish biomass, already low use from fishers or divers, and the lack of development as well as its up-current location from significant infrastructure.

CONSERVATION OPPORTUNITIES

Additional details about the FRZ include the following:

- Location:** This proposed zone extends from Awa di Oostpunt (GPS code 12°02'30.19'' N, 68°44'15.71'' W) to Hambraak (GPS code 12°02'01.81''N, 68°47'27.81''W) along the coast, out to 200m from the tide line,
- Size:** 1.4 km²
- Total fish biomass:** 205 g/m (range = 87 to 635 fish g/m²),
- Coral cover:** 35%

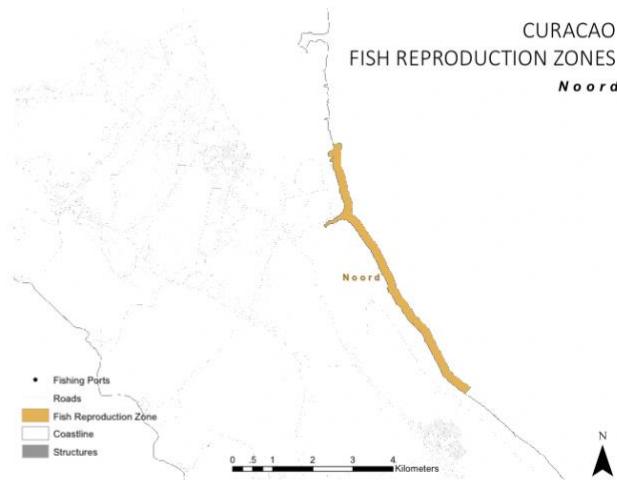
- **Juvenile coral:** 8.9/m² average (range = 1 and 19 juvenile corals per m²)
- **Sewage pollution:** 1.40 (range = 1.00 to 1.67)
- **Trash Index:** 0.03 (range = 0.0 – 0.33)
- **Algal cover:**
 - Turf: 20% (range = 11.3% to 31.2%)
 - Macroalgae: 13% (range = 2.9% to 21.9%)
- **Fishing Value:** Based on the Blue Halo Listening Tour participatory mapping survey data, the zone overlaps with **0.4%** of Curacao's fishing value, south of the valued fishing grounds identified at Caracasbaai.
- **Diver value:** Based on the Blue Halo Listening Tour participatory mapping survey data, the zone overlaps with **1.0%** of Curacao's dive value.



5: Noord FRZ

This section briefly summarizes key attributes of the proposed Noord FRZ.

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



KEY FINDINGS

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

CONSERVATION OPPORTUNITIES

- The Noord FRZ is a good candidate for protection due to its unique habitats and limited human activity from diving or fishing.
- This FRZ also presents an excellent opportunity for continued research to better understand if these habitats play a critical role in conserving the coral and fish communities of Curaçao due to their inaccessibility from human impact.

- **Location:** Windmolenpark San Pedro Hatovlakte (GPS code 12°14'12.44"N, 69°01'18.41"W) to Boka Patrick (GPS code 12°17'25.51"N, 69°03'06.71"W) along the coast and extending 200m from shore
- **Size:** 1.6 km²
- **Total fish biomass:** 35g/m² (range = 14 to 773 fish g/m²)
- **Coral cover:** 0%
- **Juvenile coral:** 0/m²
- **Sewage pollution:** 1.61
- **Trash Index:** High (value of 1 on a scale of 0 to 1 within the proposed boundaries)
- **Algal cover:**
 - Turf: 8.5%
 - Macroalgae: 88.1% (*primarily Sargassum spp*)
- **Fishing Value:** Based on the Blue Halo Listening Tour participatory mapping survey data, the zone overlaps with 0.2% of Curacao's fishing value.
- **Diver value:** Based on the Blue Halo Listening Tour participatory mapping survey data, the zone overlaps with 0.1% of Curacao's dive value.



This section provides an overview of key data by site.

Table 4. Fish Biomass by Site

		WESTPUNT	
TROPHIC GROUP (fish g/m2)	MIN	MEAN	MAX
HERBIVORE (H)	20.87262	31.17465	41.93165
PLANKTIVORE (P)	13.28587	20.73449833	32.27622
CARNIVORE (Car+Pisci)	6.486808	21.06832567	44.279779
FISH OTHER (Inv+Omni)	11.114906	29.95155583	49.998398
FISH (TOTAL)	69.914232	102.9290298	160.60847
		BULLENBAAI	
TROPHIC GROUP (fish g/m2)	MIN	MEAN	MAX
HERBIVORE (H)	7.873057	88.99778208	259.1462
PLANKTIVORE (P)	2.0652	23.34807277	90.56084
CARNIVORE (Car+Pisci)	2.17725	43.31143831	168.241531
FISH OTHER (Inv+Omni)	1.913905	58.15094662	310.31032
FISH (TOTAL)	14.029412	213.8082398	772.953091
		OOSTPUNT	
TROPHIC GROUP (fish g/m2)	MIN	MEAN	MAX
HERBIVORE (H)	34.55235	53.575607	126.4659
PLANKTIVORE (P)	12.18183	69.141812	352.7531
CARNIVORE (Car+Pisci)	9.234077	38.5562218	102.27542
FISH OTHER (Inv+Omni)	11.265071	43.3322232	113.59063
FISH (TOTAL)	87.191111	204.605864	635.43879

		NOORD	
TROPHIC GROUP (fish g/m2)		VALUE	
HERBIVORE (H)		7.527723	
PLANKTIVORE (P)		2.376629	
CARNIVORE (Car+Pisci)		10.309995	
FISH OTHER (Inv+Omni)		15.064065	
FISH (TOTAL)		35.278412	

Table 4. Fish biomass values from Curacao Scientific Assessment (2015) by trophic group within FRZ's Westpunt, Noord, Bullenbaai, and Oostpunt. Data were not collected in Spanish Waters. Min, mean and max values were calculated across sites sampled within the proposed boundaries of each FRZ. Noord shows a single value, as the proposed boundaries overlap with only one survey site sampled.

Table 5. Ecosystem Health Indicators

GROUPING	INDICATOR	RATING	METRIC
CORAL	COVER	Below Average	Percent coral cover
	JUVENILE CORALS	Below Average	Juvenile corals per m ⁻²
	CORAL HEALTH	24%	Progress to 40% coral cover
	DECLINE	32%	Percent coral cover lost since 1982
FISH	TOTAL FISH	High	Biomass in g m ⁻²
	HERBIVORES	Highest	Biomass in g m ⁻²
	CARNIVORES	Very High	Biomass in g m ⁻²

POLLUTION	INFRASTRUCTURE	Below Average	Watershed development per unit area
	SEWAGE	Below Average	N15:N14 ratio (sewage indicator)
	TRASH	Very High	Index
USE	FISHING	Above Average	Pressure (fishing areas indicated per unit area)
	DIVING	Low	Pressure (diving areas indicated per unit area)

Table 5. Ecosystem Health Indicators

Table 6. Scientific Assessment Data by Zone

Fish Reproduction Zone (FRZ)	Westpunt	Bullenbaai	Oostpunt	Noord	Spaanse Water
Fishing pressure (unknown unit [MEAN_OverlapSum])	7.7	5.4	3.9	3.0	NA
Diving pressure (unknown unit [MEAN_OverlapSum])	3.7	1.4	2.1	0.0	NA
Inhabited surface (surface of all homes divided by watershed surface; proportion)	0.008	0.002	0.000	0.014	NA
Altered surface (all structures and road surfaces divided by watershed surface; proportion)	0.035	0.050	0.000	0.036	NA
Carnivore (fish g/m2)	18.5	35.4	25.4	9.3	NA
Herbivore (fish g/m2)	31.2	89.0	53.6	7.5	NA
Invertivore (fish g/m2)	28.2	53.9	26.6	6.1	NA
Omnivore (fish g/m2)	1.7	4.3	16.7	8.9	NA
Piscivore (fish g/m2)	2.5	7.9	13.2	1.0	NA
Planktivore (fish g/m2)	20.7	23.3	69.1	2.4	NA

Fish Reproduction Zone (FRZ)	Westpunt	Bullenbaai	Oostpunt	Noord	Spaanse Water
HERBIVORE (H) (fish g/m2)	31.2	89.0	53.6	7.5	NA
PLANKTIVORE (P) (fish g/m2)	20.7	23.3	69.1	2.4	NA
CARNIVORE (Car+Pisci) (fish g/m2)	21.1	43.3	38.6	10.3	NA
FISH OTHER (Inv+Omni) (fish g/m2)	30.0	58.2	43.3	15.1	NA
FISH (TOTAL) (fish g/m2)	102.9	213.8	204.6	35.3	NA
Hard Coral (% cover; sand corrected)	9.1	13.2	30.3	0.9	NA
Fl Inverts (% cover; sand corrected)	1.3	1.1	0.6	0.0	NA
Gorgonian (% cover; sand corrected)	2.6	3.2	11.4	0.0	NA
CCA (% cover; sand corrected)	4.8	0.8	4.6	0.1	NA
Cyano (% cover; sand corrected)	21.4	8.2	15.4	1.9	NA
Turf (% cover; sand corrected)	45.6	61.5	21.3	9.0	NA
Calc Macro (% cover; sand corrected)	0.7	0.2	2.8	0.1	NA
Fl Macro (% cover; sand corrected)	14.5	11.8	13.6	88.1	NA
Hard Coral (% cover; <u>not</u> sand corrected)	7.9	9.5	28.9	0.8	NA
Fl Inverts (% cover; not sand corrected)	1.0	0.6	0.5	0.0	NA
Gorgonian (% cover; not sand corrected)	2.2	2.0	10.6	0.0	NA
CCA (% cover; not sand corrected)	4.4	0.7	4.5	0.1	NA
Cyano (% cover; not sand corrected)	18.4	5.2	14.5	1.7	NA
Turf (% cover; not sand corrected)	36.9	32.0	20.0	8.5	NA
Calc Macro (% cover; not sand corrected)	0.6	0.2	2.7	0.1	NA
Fl Macro (% cover; not sand corrected)	12.2	7.7	12.8	81.1	NA
Other (% cover; not sand corrected)	16.4	42.2	5.6	7.7	NA
<i>Coral cover (2015 CSA estimated data)</i>	12.6	9.8	35.6	0.0	NA
<i>Coral cover (1982 vDuyl estimated data)</i>	40.1	34.6	58.0	n/a	NA
<i>Sand cover (1982 vDuyl estimated data)</i>	37.1	39.6	8.5	40.0	NA
Recruit density (n/ 0.06m2)	0.3	0.3	0.6	0.0	NA

Fish Reproduction Zone (FRZ)	Westpunt	Bullenbaai	Oostpunt	Noord	Spaanse Water
Turfagal height (mm)	6.4	3.5	2.6	1.9	NA
Average relief (m)	1.0	0.7	1.5	0.2	NA
N	3.0	3.2	3.0	3.0	NA
Mean X15.N	1.5	1.4	1.4	1.6	NA
SD X15.N	0.2	0.3	0.3	0.2	NA
mean_N	2.3	1.8	2.1	2.4	NA
SD_N	0.2	0.3	0.2	0.3	NA
Mean C:N	14.7	16.2	15.6	14.4	NA
SD C:N	0.7	1.0	1.0	1.3	NA
Coral Cover Decline (% decline 1982-2015)	0.7	0.7	0.4	NA	NA

Table 6. Waitt Institute 2015 Scientific Assessment data for five FRZ's. No diver surveys were conducted in bays during the SA and, thus, no values are unavailable for the Spaanse Water FRZ.



Photo by Shayna Brody

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