Habitat diversity and bio-diversity of the benthic seascapes of St. Eustatius

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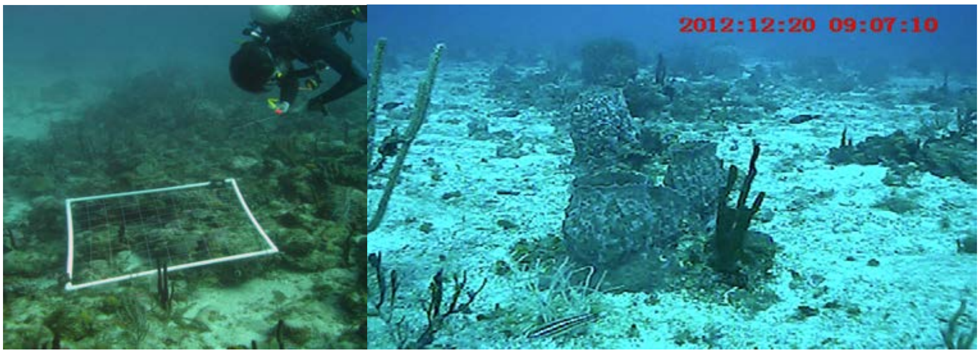

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Summary

Quantitative habitat mapping and description form the basis for understanding the provisioning of ecosystem services and habitat connectivity, and hence provide an essential underpinning for marine spatial planning, management and conservation. Based on 869 video stations in a 150 x 200 m grid, we mapped 25.3 km^2 of the near-shore island shelf of St. Eustatius at depths ranging 5-30 m. This yielded a coarse-grained map of the principal habitat classes of St. Eustatius' seascapes. A total of nine principal seafloor habitats were distinguished. Gorgonian reefs amounted to 22% of the Statia Marine Park habitats sampled and were concentrated in the shallow wave-exposed eastern parts of the island (7.7 m average depths). The densest coral "scapes" and seagrass beds of St. Eustatius were concentrated at depths of about 24 m and only amounted to 4 and 5 percent resp. of the island shelf habitats studied. Whereas coral areas were essentially limited to the southern and south-western island shelf areas, seagrass beds were confined to the northern island shelf area. Including patch reef habitats, total hard coral-scape habitat for the St. Eustatius Marine Park amounted to about 19% of the area surveyed and about 475 ha of habitat. *Sargassum* reef habitat typically occurred at the seaward edge of communities dominated by hard coral growth.

Seagrass beds and coral areas are considered key components of the nearshore ecosystem continuum as they typically play complementary roles in the life-cycle of many key coral reef fishes and endangered species. On St. Eustatius these critical habitats show a strongly disjunct distribution. The intensively used anchorage zone represents a major habitat discontinuity as the substrate is damaged by heavy anchors and chains, as documented previously by White et al. (2007). Given the geographic scale concerned (several kilometers of separation), this may interfere with ecological connectivity and have consequences for ecosystem service provision. The dominant habitat in the anchorage zone is algal fields growing on rubble, which amount to a combined 22% coverage of the surveyed habitat. Survey results show that adult conch appear to be concentrated in this zone (M. de Graaf, unpubl. data.)

More detailed information on the community structure was obtained by sampling belt transects by SCUBA at a total of 24 stations (9 seagrass, 10 coral reef, 5 algal field). The coral reef habitats appeared to be dominated by macroalgal coverage (geom. mean: 12.7%). Next were sponges (6.8%) and finally corals (4.9%). The main hard corals present (in decreasing order of percentage cover) were: *Meandrina meandrites, Siderastrea siderea, Montastrea cavernosa, M. faveolata* and *Diploria strigosa*. Two distinct types of seagrass beds were distinguished. Dense seagrass beds were dominated (45-95% cover) by the invasive *Halophila stipulacea* and sparse seagrass beds were dominated (8-25% cover) by the native *H. decipiens*. A third seagrass species, *Syringodium filiformis,* was documented, but only at densities of 2% or less.

Compared to Klomp and Kooistra (2000), who documented an average coral cover of 20% at 10 reef sites in St. Eustatius, our findings highlight and substantiate other studies referring to coral mortalities and declines over the last 15 years. Concomitantly macroalgal cover appears to have increased. These trends are consistent with coral decline and shifts in community structure observed throughout the region. Two major documented impacts to coral cover in St. Eustatius were the 1999 hurricane Lenny and the 2005 Caribbean-wide bleaching event.

We conclude that marine habitats of St. Eustatius are under stress and have declined significantly in quality in recent decades. This trend threatens a natural resource worth roughly 9% of the annual GDP. Therefore, measures and interventions to actively enhance and protect this resource could make a difference and give long-term economic pay-off.

Hard substrates, suitable to benthic macrofaunal communities in the shallow areas around this island are rare, and unconsolidated sediments predominate. As others before, we suggest that the combination of an erosion-prone geomorphology and overgrazing on land are local stressors that likely play a key role in coral reef declines for St. Eustatius. To protect and enhance the marine quality and ecosystem services, interventions seem possible on both these fronts. We believe that measures to address overgrazing by feral livestock and research into the use of artificial submerged structures ("artificial reefs") to enhance marine biodiversity could both significantly help bolster reef health and productivity.

Our principal findings and recommendations can be summarized as follows:

- The two designated marine reserves within the marine park contain the main concentrations of coral reef and seagrass habitat of the island but other valuable habitats lie principally outside these reserves.
- Ways should be sought to limit anchor damage to areas that have already been severely impacted, following the recommendations from White et al. (2007), and two (but possibly more) isolated small areas of shallow seagrass and gorgonian reef between Oranjestad and the oil terminal should be protected from future anchor damage.
- The possible stepping-stone role of these habitat patches (seagrass and gorgonian reef) in the central, disturbed anchorage section of the island should be assessed.
- More adequate community description than we provide here is needed as a basis for long-term monitoring of habitat state and ecosystem services.
- Use of the various habitats by fauna during different stages of their life-cycle probably differs greatly and should be assessed.
- The marine biodiversity of St. Eustatius likely includes several species that will prove to be new to science and therefore deserves further taxonomic investigation.
- Studies on how to enhance degraded marine benthic habitats by means of artificial submerged structures and other intervention, might help increase ecosystem service provisioning in terms of coastal protection, fish stock enhancement and dive attractions for tourism.

1 Introduction

Quantitative habitat mapping and description form the basis for understanding the provision of ecosystem services and habitat connectivity, and hence provide an essential underpinning for marine spatial planning, management and conservation. This essential background information is either lacking or outdated for most of the Dutch Caribbean (islands of Aruba, Bonaire, Curaçao, Saba, St. Eustatius, St. Maarten and the Saba Bank), particularly with respect to marine habitats (Debrot and Sybesma 2000). The need for baseline descriptive marine resource assessment is highlighted as a priority within the EEZ management plan for the Caribbean Netherlands (Meesters et al. 2010) and forms an essential part of the implementation of the latest Nature Management Plan for the Caribbean Netherlands (MinEZ 2013). Consequently, several studies that quantify habitat diversity and biodiversity throughout the Dutch Caribbean, including the Saba Bank (Toller et al. 2010), Lac Bay Bonaire (Davaasuren and Meesters 2012, Debrot et al. 2012) and Saba (van Beek et al., in prep.) have recently been undertaken. For St. Eustatius, only three studies on marine communities exist to date: a non-quantitative description of the marine algal flora and communities documenting 63 algae for the island waters (Vroman 1968), a quantitative assessment of 10 selected coral reef sites and documentation of large coral losses due to the 1999 hurricane Lenny (Klomp and Kooistra 2003), and a study by Bouchon et al. (2012) which discusses major coral mortalities associated with the 2005 Caribbean-wide coral-bleaching event. A thorough quantitative assessment of habitat diversity and biodiversity of the benthic seascape of St. Eustatia was thus required.

The abundance and quality of productive shallow benthic habitats critically contribute to the total economic value of nature for the island (Tieskens et al. 2014). Bervoets (2010) estimated the economic value of the island's coral reef resources to be roughly USD 11 million per year and concluded that active coral reef conservation and research were a priority for sustainable economic development. More recently, van der Lely et al. (2014) estimated the total economic value of nature (TEV) (both marine and terrestrial) for the island at USD 25.2 million per year but declining in the future. Habitat quality and ecological connectivity are also critical issues for all exploited species of economic importance (e.g. fishes and lobster) that require one or more of these habitats during various phases of their often complex life-cycles. For all these reasons, basic insights into habitat distribution, quality, biotic cover, long-term trends and ecological drivers are critically needed for sustainable management of these vital natural resources.

Habitat mapping and community description can take place at several geographic levels of detail, depending on its intended purpose and the method that is used. In mapping the reefs of Curaçao and Bonaire to depths of 10 m for instance, Van Duyl (1985) was able to use aerial photographs and diver propulsion vehicle-assisted SCUBA to provide a coarse-grained quantitative community assessment of the leeward fringing reefs of these islands. While the belt-transect method was used for detailed community description of the macrobenthic seagrass communities of the Spaanse Water, Curaçao and Lac Bay, Bonaire (Kuenen and Debrot 1995; Debrot et al. 2012), satellite imagery was successfully used for a quantitative assessment of mangrove coverage and principal species composition for mangrove stands in Bonaire (Davaasuren and Meesters 2012). Finally, Toller et al. (2010) used satellite imagery for coarse mapping of 5 habitat zones across a 40 km section of the Saba Bank, combined with more-detailed community description at eight locations in each zone based on SCUBA and belt transects.

The aerial photographs and satellite imagery available to us proved to be of limited use for habitat mapping. While Nieto et al. (2013) evaluated satellite imagery and found that it could be used to establish bathymetry, because 50% of stations still remained wrongly classified, it was of limited use for habitat-classification purposes. Because the reef communities around St. Eustatius are distributed over a wide range of depths (down to 30 m), and island shelf areas are (relatively) wide, it was clear that diver propulsion vehicle-assisted SCUBA was also not feasible for mapping. We therefore chose to develop a mapping approach based on rapid camera video assessments using video drops from a boat and working from a GPS grid. A similar approach has recently been used to map the marine habitats of St. Kitts and Nevis (Agostini et al. 2010) for use in marine zoning compatibility evaluation. There, 425 camera drops were used to map 12 benthic classes across 326 km^2 of shallow bank waters (Agostini et al. 2010) In our study, we camera dropping combined mapping with a belt-transect sampling by means of SCUBA to allow quantification of macrobenthic community structure and key habitat classes.

The objectives of this study were to:

- Chart a coarse-grained GIS habitat map for the island shelf areas of the St. Eustatius Marine Park as a baseline for further biological, ecosystem and marine spatial planning studies.
- Use this to provide semi-quantitative insight into the range of benthic habitats around the island of St. Eustatius, their surficial coverage, and spatial distribution.
- Provide a preliminary biodiversity status assessment of three key habitats: seagrass beds, coral reefs and algal fields.
- Discuss the distribution of these habitats and communities around the island in relation to patterns in physical regimes of waves, currents, substrate, sedimentation, and depth.
- In context of faunal significance and connectivity, discuss their distribution in relation to what is known about habitat dependencies and different life-stages of key exploitable resources (such as reef fishes, the West-Indian spiny lobsters and endangered sea turtles).
- Assess long-term trends, principal driving forces and potential management interventions.

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Author contributions: Conceived and designed the survey: AOD, EHM, MG. Conducted the fieldwork: EH, TT, EB, IvB. Analysed the data: EH, EHM, ED. Identified species and confirmed species identifications: ERH, DLB. Coordinated the project: AOD. Wrote the report: AOD, EHM, EH, ERH, IvB, TT.

2 Study Area and Methods

2.1 St. Eustatius

Geography

The island of St. Eustatius lies in the north-eastern Caribbean between 17°28' and 17°32' N latitude and 62°56' and 63°0' W longitude. Its nearest neighbouring islands are Saba (27 km to the northwest) and St. Kitts (12 km to the east). The surface area of the island is 21 km^2 and the island is part of the inner arc of the Lesser Antilles (Freitas et al. 2014). The highest point is the 600 m dormant Quill Strato Volcano which has not erupted for about 1600 years (Roobol and Smith 2004).

The island can be divided into three principal landscape areas: a) the Quill volcano, b) the central, formerly agricultural plains on which the town of Oranjestad is situated, and 3) the north-western hills collectively named the "Northern Hills". The population of the island is about 3600 people while government and the oil transhipment industry (NUSTAR) are the two largest employers. Annual average rainfall on St. Eustatius is 986 mm (1971-2000; Meteorological Service of the Netherlands Antilles & Aruba). Rainfall is strongly seasonal, with the months of August, September, October and November accounting for 47% of the long-term annual average (Freitas et al. 2014).

Climate and weather

The island is situated in the zone of the north-eastern trade winds and in the hurricane belt. The most frequently-occurring wind directions are NE, ENE and E; together they account for 80% of the wind direction frequency (Augustinus et al. 1985). The average wind speed at 10 m height is 4.8 m/s (Freitas et al. 2014) for an average force of 2 to 3 Beauforts (Kateman and Bos 2010). The Atlantic hurricane season extends from June 1 through November 30. Once every 4-5 years hurricane conditions are experienced (Meteorological Service of the Netherlands Antilles & Aruba 2010). Recent major hurricanes which affected the island include Hugo (1989), Marilyn (1995), Georges (1998) and José and Lenny (1999).

2.2 Shores and the shallow sublittoral zone

The shore zones of the island vary. Wide sandy beaches are found along the Zeelandia and Concordia eastern shores of the central plain. Elsewhere, most beaches are dominated by cobble and boulders. Most sand and cobble is of volcanic origin and owe the dark colour to the abundance of magnetite and ilmenite. Where the Quill volcano borders the sea, at White Wall, a steep cliff has been formed showing horizontal stratification of agglomerates and tuffs. The beach below the cliff consists largely of pebbles. Wide, shallow-water *Acropora palmata* forests used to be found at many places along the shores of St. Eustatius (e.g. Corre Corre Bay, Schildpadden Bay; Vroman 1968) but these have since disappeared. The eastern shore of the island is exposed to heavy surf. The western shore and generally also the southern and northern coasts are much less exposed (Vroman 1968). Along the north-west coast from Jenkins Bay up to the north tip there is a small strip of boulders close to shore on which corals are growing, protected by the island from wind and waves. At approximately 15 m depth the habitat changes to sand with seagrass patches from 20 m depth onwards. The shallow benthic communities of the whole south side of the island are located at the base of the Quill volcano and this is reflected in the benthic habitat in terms of lava fingers which are a dominant feature in this area. These lava fingers along the east side of the coast are populated by a gorgonian reef up to approximately 25 m depth. From 25 m onwards, the lava fingers are overgrown principally by algae, including *Sargassum* sp. In front of the calcareous White Wall area (south) more sand is found in the subtidal areas. The island is situated on a relatively wide island shelf (Fig. 1) that forms part of the St. Kitts Bank. Maximum marine sill depths between St. Eustatius and St. Kitts are less than 50 m (Roobol and Smith 2004).

2.3 Sea state

The average day-temperature throughout the year varies between 29 and 31 ^{0}C and the average night-temperature varies between 23 and 25 ^{0}C. The average sea temperature varies between 26 and 29 ^{0}C. Along the leeward central Lower Town beach-front area of Oranjestad, sea conditions are generally calm. However, regular swell waves (with a period of 10-20 seconds) generated further away, do reach the harbour area. For about 80% of the time, the swell on St. Eustatius comes from the southwest while about 20% of the time it comes from the northeast and southeast (Kateman and Bos 2010). Two conditions exist during which significant wave heights occur on the central western coast: during winter storms (December-April) and during the hurricane season (July-October) (Slijkerman et al. 2011). Beaches on the west central coast of the island are highly seasonal in occurrence.

According to Kateman and Bos (2010) 'brown seas' (turbidity due to volcanic silt) occur once or twice per month during the period December-April. These are apparently generated by cold fronts in Florida during winter storms. On such occasions, heavy swell (waves of 3 to 4 m, but occasionally up to 5 m) comes from the north to northwest with strong currents and undertow. Such 'brown seas' usually last one or two days but sometimes last a week. Sediment resuspension caused by wave-action, frequently reduces water transparency in the near-shore environment of St. Eustatius (Slijkerman et al. 2011).

Very little information is available on currents around St. Eustatius (Slijkerman et al. 2011). These are likely dominated by the Caribbean Current, transporting South Atlantic water through the Caribbean. Freshwater from the Amazon and Orinoco rivers is also partly directed into the Caribbean Sea. Model simulations (Cherubin and Richardson 2007) suggest that near St. Eustatius, the flow velocity on the westward sides of the island will be low (in the order of 10 cm/s). According to Slijkerman et al. (2011), on the eastward side of the island, the flow is largely directed northward.

2.4 The St. Eustatius Marine Park

All marine habitat from the low tide level out to the depth of 30 m is legally designated as the St. Eustatius Marine Park by means of the St. Eustatius Marine Environmental Ordinance (AB 1996, No. 3) (McRae and Esteban 2007). The total surface area of the marine park is 27.5 km^2. The park is managed by STENAPA (St. Eustatius National Parks Foundation, which also manages two terrestrial parks on the island). Inside the St. Eustatius Marine Park two reserves have been designated in which no fishing or anchoring is allowed (Fig. 1). Habitats include coral reefs (drop off walls, volcanic 'fingers' and 'bombs'), 18th century shipwrecks and artificial reefs. The island's marine environment is home, to, and migratory stop-over or breeding site for 4 IUCN Red List Species, 10 CITES Appendix I species and 98 Appendix II species (McRae and Esteban 2007). These include among others, Boulder Star Coral, *Montastrea annularis*, the Caribbean Reef Shark, *Carcharhinus perezi*, the Queen Triggerfish, *Balistes vetula*, and the Green Turtle, *Chelonia mydas*.

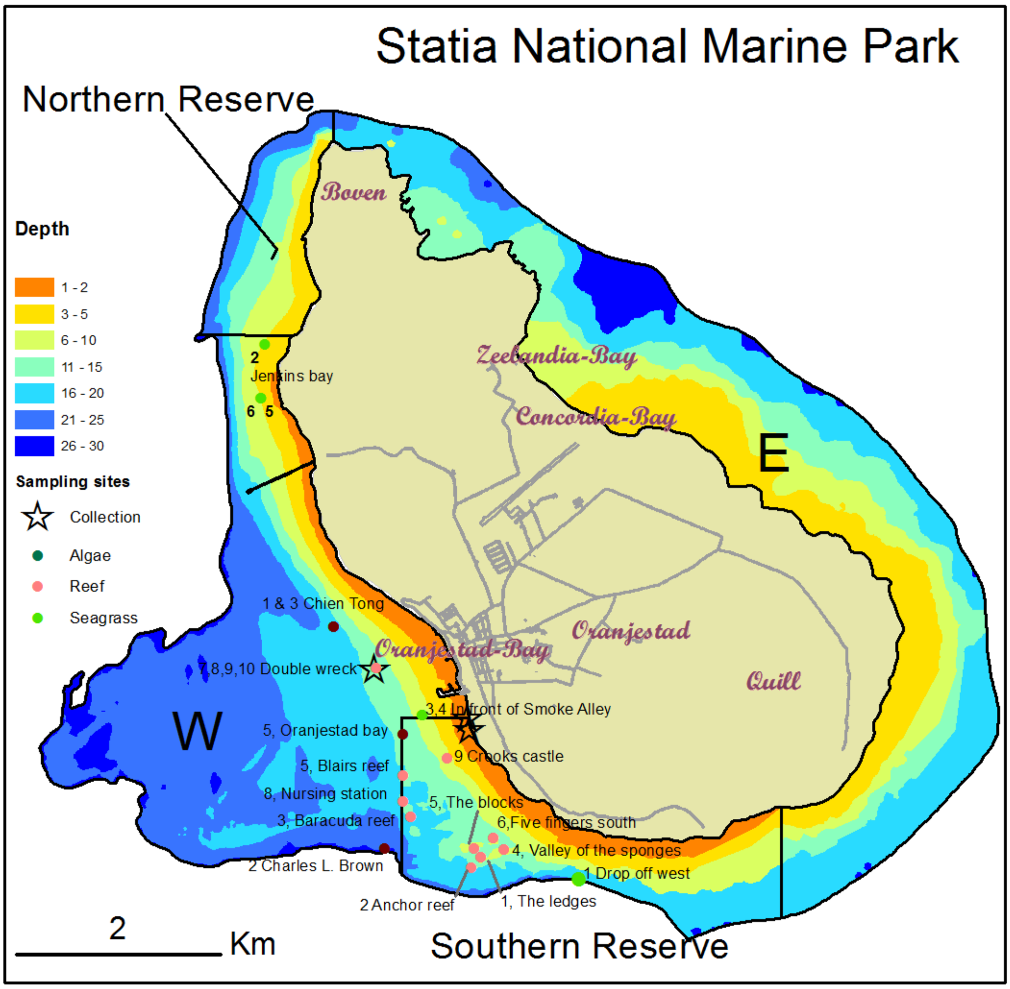


Figure 1. Bathymetric map of the St. Eustatius Marine Park, showing key landmarks and benthic belt transect SCUB sampling sites and algal sampling sites.

2.5 Seascape mapping

Data for this study was collected during October 2012 - August 2013. Video assessments for the benthic map and seascape assessment were done using the SEA-DROP 950 Underwater Video Camera of SeaViewer. The Eyetop LCD (liquid crystal display) sunglasses were connected to the camera as well as the 4k recording DVR. With the footage that was seen on the Eyetop, the recording could start when there was good footage. To prevent the electronics box from getting wet from splash water, the box was covered with a plastic bag and a towel. The camera was always deployed from the boat. To secure the camera and relieve the tension on the cable of the camera, a rope was attached to the cable. The rope was attached to the camera with steel wire loops. A drop weight of 2 kg was attached to the rope allowing the camera to hang straight down to the sea floor, even under heavier currents. The weights were attached to the rope under the camera (Fig. 2). After every use the camera was rinsed with fresh water and the batteries of the camera and DVR were recharged. (Full instructions can be found in Appendix D).

Figure 2. Attachment of the rope to the camera. The red arrow points to the safety line, the blue arrow points to the weighted line.

Video sampling was conducted along predetermined gridlines. Every 150 meters the camera was dropped manually along a transect line, running from the coastline at approximately 5 m depth to approximately 30 m. The transect lines were approximately 100 and 200 m apart. This gave a rough 150 x 200 m grid covering the entire St. Eustatius Marine Park (with exception of the near-shore shallows and a zone around the NUSTAR piers). Every point at which the camera was dropped, a GPS-waypoint was made and specific footage was recorded, in order to be able to judge the footage afterwards. The depth, waypoint name and first rough assessment of habitat were noted after every drop. To measure depth, the sonar fish finder of the boat was used. Our coarse-grid map is based on a total of 869 drop recordings and used to classify and map the equivalent of 2533 hectares (25,33 km^2) of seafloor at depths of 5 - 30 m.

2.6 Analysis

After drops were completed, the videos were reassessed for their habitat type using a laptop computer in the lab. This had to be done since the video feed from the LCD glasses was difficult to judge during the fieldwork. From every recording a screenshot was also made. This screenshot was judged based on three different characteristics. First, the substrate-type was determined as being ether sand, rock or rubble. Second, the dominant species composition was determined in radius of roughly 3 m around the drop point. These were either algae, *Sargassum* sp., seagrass, corals or gorgonians. Last, the coverage percentage of the dominant species composition was determined. These were ranked in rough classes as either 0%, 0-33%, 33-66% or 66-100%. This stepwise categorization of the video screen shots resulted in the distinction of 9 seascape-level habitat classes. These were: sand, bare rubble, diffuse patch reef, dense patch reef, coral reef, gorgonian reef, algal fields, seagrass and *Sargassum* field. Hence, the habitat classification of this study (Table 1) was principally based on the systematic classification of marine habitats in the Caribbean by Mumby and Harborne (1999).

Table 1. Habitat classifications as applied in this study and as based on Mumby and Harborne (1999).

		Classification based on the following indicators (substrate and benthos percentages coverage)				
Habitats St. Eustatius			***Benthos cover***			
Name	***Definition***	***Substrate cover***	***Seagrass***	***Algae field***	***Gorgonian***	***Hard coral***
Bare sand	Sandy bottom (macro) benthos negligible	Bare sand >90%	no	sparse algal cover possible (<10%)	no	no
Bare rubble	Rubble bottom (macro) benthos neglible	Bare rubble >90%	no	sparse algal cover possible (<10%)	no	no
Bare rock	Rocky/hard bottom (macro) benthos neglible	Bare rock >90%	no	sparse algal cover possible (<10%)	no	no
Macro algae field	Rubble/rock bottom (mainly) macro algae	Bare sand+rubble+rock <50% Rubble/rock underneath (not bare)	no	algal cover dominated (>50%)	sparse gorgonian possible (<3/m^2)	no
Sargassum field	Rubble bottom (mainly) sargassum	Bare sand+rubble+rock <50% Rubble/rock underneath (not bare)		sargassum dominated (>50%)	sparse gorgonian possible (<3/m^2)	no
Seagrass bed	Sandy bottom (mainly) seagrass	Bare sand around and sand underneath (not bare)	dense (>50%) sparse (<50%)	no	no	no
Diffuse patch reef	Sandy/rubble bottom with dispersed (living or dead) coral colonies, mixed with algae, gorgonians and sponges	Bare sand/rubble % > reef %	no	macro algae present as part of mixed reef	gorgonian present as part of mixed reef	(living or dead) hard coral between 1-10% (may be more)
Dense patch reef	Sandy/rubble bottom with aggregated (living or dead) coral colonies, mixed with algae, gorgonians and sponges	Bare sand/rubble % < reef %	no	macro algae present as part of mixed reef	gorgonian present as part of mixed reef	(living or dead) hard coral between 1-10% (may be more)
Coral reef	Mainly hard substrate covered with (mainly) hard corals, mixed with algae, gorgonians and sponges	Reef >90%	no	macro algae present as part of mixed reef	gorgonian present as part of mixed reef	(living or dead) hard coral between 1-10% (may be more)
Gorgonian reef	Rubble/hard substrate covered with (mainly) soft corals	Rubble/rock underneath/ around (bare and not bare)	no	algal cover possible (10-30%)	number of gorgonian: dense (>3/m^2 usually >8/m^2) sparse (<3/m^2)	<1%

Figs. 3-11 provide a representative photographic sample of each of the nine different seascape habitats distinguished. The locations of the drops were uploaded into Google Earth for ultimate production of a geo-referenced habitat map. As biotic density estimates are typically highly variable and log-normally distributed, the geometric mean is a statistically more robust measure of central tendency than the arithmetic mean. Therefore, we expressed density estimates in terms of geometric means ± 1 SD based on the log-normal distribution.

Figure 3. Bare sand. No coverage of benthic species found. Habitat mostly found close to shore, but also between coral and gorgonian patches.

Figure 4. Bare rubble. Almost no living coverage found. When the rubble is overgrown, the location is classified as that of the covering organisms.

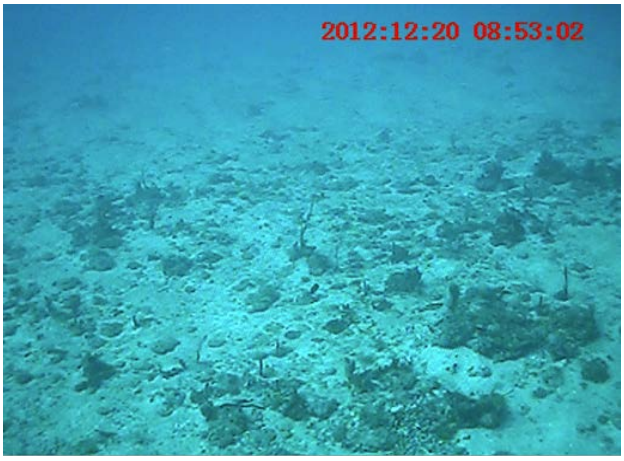


Figure 5. Diffuse patch reefs. Found in sand, rock and rubble patches. Many different sponges, corals and algae are found in this habitat.

Figure 6. Dense patch reefs. Found in rubble and rock fields, often sand between the coral patches. Many different sponges, corals and algae are found in this habitat.

Figure 7. Coral reefs. Found on lava fingers and rock. Many different sponges, corals and algae are found in this habitat.

Figure 8. Gorgonian reef. Dominated by different gorgonian species, including sea fans, wire coral, sea plumes and sea fingers.

Figure 9. Algal fields. Benthic habitats that are overgrown by different algae species. Often a transition phase between sand and reef regions.

Figure 10. Seagrass fields. Sand patches that are covered by different seagrasses. Not often found on St. Eustatius, probably because of the frequent tropical storms and hurricanes.

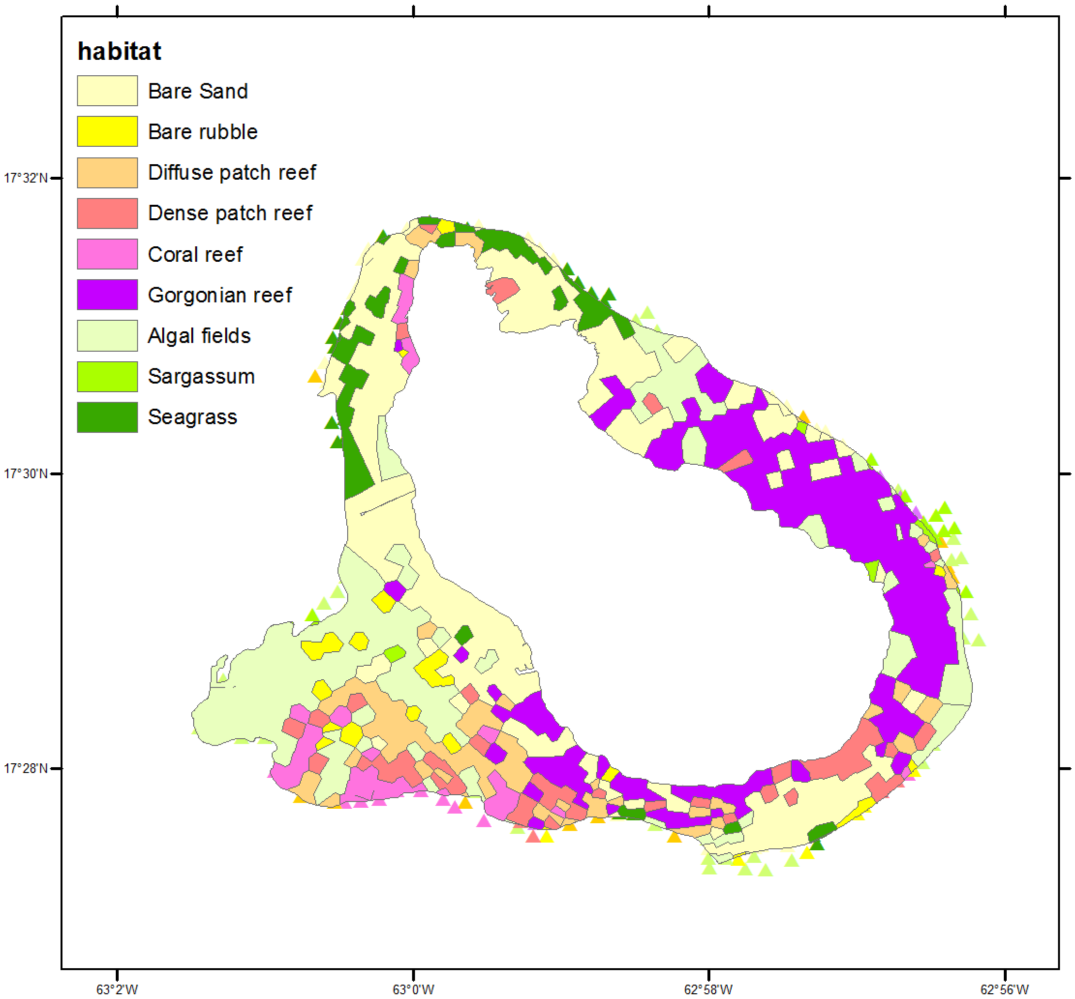
Figure 11. Sargassum fields. It is a species of algae, which is found on rubble. It differs from most algae because it has flotation organs. The strands are lifted up and clearly move with the waves.

2.7 Macrobenthic community description based on quadrant sampling

The coarse-grained map allowing rough distinction of different seascapes, was augmented by more detailed and quantitative description of three key macrobenthic communities using quadrant sampling of coral reefs, seagrass beds and algal fields using SCUBA (Locations provided in Appendix A). A one square meter PVC quadrant divided into 10 x 10 cm grid sections was used to measure species coverage. Within the quadrant all benthic species (coral, sponges, algae) and the substrate composition were determined. An estimation of the coverage percentage per species was made as well. Area sampled per station was affected by depth and faunal diversity. Deeper stations were sampled for less area, while species-poor communities (eg seagrass beds) were sampled across larger surface areas for the equivalent of one dive. Consequently, the total surface sampled per station varied between 4 and 31 m^2. On average, station size was 12.2 m^2 for coral reef stations, 17.1 m^2 for seagrass stations and 7.6 m^2 for algae field stations. Initial identification of species was done using available field guides. Corals could be determined with great certainty in the field without collection based on Humann and DeLoach (1994). The Mussidae were recently revised and we therefore applied the new name for the corals formerly known as (Budd et al. 2012). Most algae and sponges could not be determined with certainty and voucher specimens (collected under island government consent) were collected for definitive expert determination (Appendix C). All algal voucher specimens have been deposited in the collections of the US National Museum of Natural History (Appendix C) while all sponge species found in this study were already present in the collections of Naturalis, The Netherlands.

To start a new station a quadrant was dropped haphazardly around a marine park dive site mooring or the GPS location from the benthic map. Increasing depth greatly reduces maximum allowable bottom time for a dive. Consequently, allowable dive time limited total effort per site. Sampled surface area was less at deeper and more-diverse stations (e.g. coral habitat) but greater in habitats with low diversity (seagrass beds). For every station, GPS coordinates, depth, bottom temperature, vertical Secchi disc depth and rugosity were recorded. Rugosity was measured by means of Risk's chain-and-tape method (Risk 1972) whereby the real surface area (as measured using the chain) was divided by the geometric (straight line) surface area. Additional sampling for algae was done by IvB at three locations on 23 and 24 April, 2013 (Fig. 1).

3 Results



3.1 Benthic seascape map

Figure 12. Map of main the benthic seascapes of St. Eustatius.Triangles indicate stations sampled outside the St. Eustatius Marine Park (30 m isobath).

The benthic map of St. Eustatius shows the distribution of main benthic seascape habitats around the island (Fig. 12), while the relative abundance and average depth distribution of these habitats is given in table 1. The predominant East North East winds result in a large contrast in wave exposure between the eastern and western sides of the island. Gorgonians are flexible and well able to withstand heavy surf and water movement. Gorgonian reefs amounted to 22% of the Statia Marine Park habitats sampled and were concentrated in the shallow wave-exposed eastern parts of the island. The average depths of the stations represented by this habitat was 7.7 m. Key sources of sand on the east coast come from the eroding cliffs of Zeelandia and Concordia (Fig. 1) which also are the most important sea turtle nesting beaches of the island. On the west coast cliffs of Lower Town seem to be an important source of sand.

Shallow bare sand habitat amounted to 29% of all habitat and was concentrated down-stream from these important source-beaches

The coral reefs and seagrass beds of St. Eustatius were concentrated at depths of about 24 meters and only amounted to respectively 4 and 5 percent of the island shelf habitats studied. Whereas coral scapes were practically limited to the southern and south-western island shelf areas, seagrass beds were almost limited to the northern island shelf area. Moving landwards in the southern and south-western island shelf area, the reef zone was followed by zones of dense and then sparse patch reefs found growing on shallower zones of lava ridges. *Sargassum* field habitat was largely limited to the outer reef edge of exposed coasts of the eastern and southern island shelf areas (Fig. 12).

Bare rubble (3%) and rubble overgrown by algae (22%, referred to by us as algal fields) were largely concentrated in the anchorage zone on the west side of the island in an area running abruptly straight offshore from the Oranjestad harbour northwards to the NUSTAR oil terminal. The bare rubble largely showed signs of rigorous and recent disturbance. This is probably because this area is an active tanker (and yacht) anchorage zone. White et al. (2007) have quantified tanker anchor damage and impact for St. Eustatius.

T*able 2. Summary of coverage and depth distribution of the various seascape habitat-classes found in the St. Eustatius Marine Park, zoned by depth (5-30 m). SD + standard deviation*

Seascape Habitat Type	Number of drop-recordings (N)	Estimated total surface area 5-30 m (ha)	Relative contribution to total habitat coverage (%)	Mean depth ± 1 SD (m)
Gorgonian reef	165	552	22	7.7 ± 7.8
Sand	235	738	29	15.2 ± 9.0
Dense patch reef	61	173	7	18.0 ± 8.5
Diffuse patch reef	73	204	8	21.9 ± 6.6
Coral reef	35	98	4	24.2 ± 7.9
Bare rubble	24	66	3	24.8 ± 7.7
Sargassum	14	11	0	19.0 ± 14.0
Algal fields	212	567	22	21.9 ± 11.7
Seagrass	50	124	5	24.2 ± 6.2
Total	869	2533	100	

3.2 Community composition

Benthic community description based on quadrant sampling using SCUBA took place at 24 stations as plotted in Fig. 1. The main characteristics of the stations are given in Table 3, whereas GPS locations and detailed descriptors per individual station are provided in Appendix A and B.

Table 3. Key biotic (geometric mean ± SD) and abiotic (arithmetic mean ± SD) characteristics of coral reef, algae field and seagrass bed habitats based on belt-transect community sampling.

	Coral reefs	Algal fields	Seagrass
	n = 10	n = 5	n = 9
Depth (m)	18.5 (2.9)	25.3 (2.9)	21.0 (3.9)
Biotic cover (%)			
Coral	4.9 (0.34)	0.1 (5.5)	0 (0.0)
Gorgonian	1.2 (0.8)	0 (0.0)	0 (0.0)
Algae	12.7 (0.73)	11.7 (1.2)	.3 (3.4)
Sponge	6.8 (0.28)	2.8 (0.4)	0 (0.0)
Seagrass	0 (0.0)	0 (0.0)	30.0 (1.0)
total	27.8 (0.3)	15.4 (1.0)	32.3 (0.9)
Substrate			
rock	74.0 (8.7)	2.0 (3.8)	0 (0.0)
rubble	5.1 (2.5)	85.8 (12.6)	0 (0.0)
sand	20.9 (7.6)	12.2 (13.6)	100 (0.0)
rugosity	1.3 (0.1)	1.1 (0.1)	1 (0.0)

3.2.1 Coral reefs

The reef habitat sampled in St. Eustatius showed low levels of rugosity, low levels of coral cover (4.9%) and algae-dominated biotic cover (12.7%). Reef habitat was the most speciose habitat sampled and a total of 60 species were distinguished. Sponges and corals were equally important in terms of both cover (Table 2) and species richness (Table 4). The main hard corals represented were: *Meandrina meandrites*, *Montastrea annularis, M. cavernosa,* and *M. faveolata*, *Porites astreoides* and *Siderastrea siderea*. Of the algae, *Dictyota sp.* was by far the dominant species and present at all stations while *Lobophora variegata* was also present at all stations (Table 4).

3.2.2 Algae fields

Algae fields were found principally in rubble. Algae dominated in cover as well as in number of species (Table 3, 4) but a variety of sponges and coral species were also found (Table 4). *Dictyota sp.* was found all four stations and *Lobophora variegata* was regularly found as well. This habitat had the highest concentration of adult conch (M. de Graaf, unpubl. data)

3.2.3 Seagrass beds

Seagrass was exclusively found in sand (Table 3). Two different seagrass beds were distinguished: Dense seagrass beds dominated by the invasive *Halophila stipulacea* (between 45-95% cover) and sparse seagrass beds dominated by the native *H. decipiens* (between 8-25% cover). A third seagrass species was *Syringodium filiformis,* which was only found at densities of 2% or less. *H. decipiens* seagrass beds were more diverse than *H. stipulacea* seagrass beds with regards to associated algae. Seagrass beds of the invasive *H. stipulacea* showed the highest biotic cover of all benthic habitats. Seagrass beds of *Thalassia*, reported as being important in St. Eustatius by McRae and Esteban (2007), were found nowhere.

Table 4. Species list and (arithmetic) mean for comparison of relative cover (%) in each of three sampled habitats. Species names in bold have been confirmed based on collected specimens.

	Coral reef	Rubble algal fields	Sea grass beds
Hard corals			
Agaricia agaricites	0.20	0.01	-
A. humilis	0.09	-	-
A. lamarcki	0.05	-	-
Colpophyllia natans	0.12	-	-
Dendrogyra cylindrus	0.01	-	-
Diploria clivosa	0.15	-	-
D. labyrinthiformis	0.16	-	-
D. strigosa	0.34	-	-
Eusmilia fastigiata	0.03	-	-
Favia fragum	0.02	-	-
Helioseris cucullata	0.03	-	-
Madracis auretenra	0.03	-	-
M. formosa	0.06	-	-
M. decactis	0.01	-	-
Meandrina meandrites	0.62	-	-
Montastrea annularis	0.41	-	-
M. cavernosa	0.51	-	-
M. faveolata	0.36	-	-
M. franksi	0.26	0.08	-
Millepora alcicornis	0.32	0.05	-
Porites astreoides	0.48	-	-
P. porites	0.29	0.10	-
Scolymia sp.	0.01	-	-
Siderastrea siderea	0.52	0.02	-
Stephanocoenia intersepta	0.03	-	-
Total coral spp.	25	5	0

Gorgonians			
Eunicea sp.	0.40	-	-
Gorgonian sp.	0.34	-	-
Plexaura	0.46	-	-
Plexaurella	0.01	-	-
Pseudopterogorgia sp.	0.14	-	-
Pterogorgia sp.	0.16	-	-
Total gorgonian spp.	6	0	0

Sponges			
Aiolochroia crassa	0.22	-	-
Aplysina archeri	0.01	-	-
A. cauliformis	0.04	0.34	-
A. fulva	0.27	0.34	-
A. lacunosa	0.04	-	-
Callyspongia plicifera	0.37	0.12	-
C. vaginalis	0.02	-	-
Cliona caribbaea	0.45	-	-
C. varians	1.19	0.11	-
Ectyoplasia ferox	0.06	-	-
Haliclona twincayensis	0.27	-	-
Halisarca sp.	0.08	0.23	-
Ircinia felix	0.47	0.16	-
I. strobilina	0.45	0.21	-
Neopetrosia proxima	0.44	0.27	-
orange encrusting sponge	0.18	0.19	-
Phorbas amaranthus	0.45	-	-
pink bumpy sponge	0.05	-	-
Plakortis halichondrioides	0.66	0.57	-
purple ball sponge	0.01	-	-
purple encrusting sponge	0.10	0.14	-
purple tube sponge	0.15	-	-
Verongula rigida	0.04	-	-
Xestospongia muta	1.00	-	-
Xestospongia sp.	-	0.16	-
yellow encrusting sponge	-	0.17	-
Total sponge spp.	24	13	0
Algae			
Anadyomene stellata	-	0.01	-
Caulerpa cupressoides	-	-	0.11
C. mexicana	-	-	0.01
Dasya spinuligera	0.01	0.42	0.06
Dasya sp.	-	-	0.61
Dictyota sp.	12.81	3.66	0.05
Halimeda cf. goreaui	0.01	0.23	0.11
H. cf. incrassata	0.01	-	0.03
H. cf. tuna	-	0.07	-
Lobophora variegata	2.35	5.30	0.01
Penicillus capitatus	-	0.70	0.68
Sargassum sp.	-	3.18	-
Udotea cyathiformis	-	4.25	0.31
U. spinulosa	-	-	0.01
Total algal spp.	5	9	11

Seagrasses			
Halophila decipiens	-	-	8.52
H. stipulacea	-	-	34.30
Syringodium filiforme	-	-	0.46
Total sea grass spp.	0	0	3
Biota documented:	60	26	14

4 Discussion

4.1 Distribution of seascape habitats in relation to environmental factors

The distribution of marine plant and animal communities is governed by a combination of biotic and abiotic factors, including depth, temperature, salinity, substrate and sedimentation. In present day St. Eustatius, coral formations appear concentrated in a relatively narrow zone at depths of roughly 24 m. This is deep compared to the reefs of the other Dutch Caribbean islands such as Bonaire and Curaçao. Most corals rely on phototrophic symbionts and therefore coral communities are ultimately confined to shallow waters, in which distributions are dictated by light penetration and availability of hard substrates that facilitate recruitment. In very shallow areas, however, corals appear to be limited by higher levels of sedimentation, turbidity, predominance of soft substrates and the frequency of hurricane damage. Suspended sediment concentrations, which are often limiting to autotrophic macrobenthos (Fabricius 2005), are often highest along the reef flat and much lower in deeper water (Rogers et al. 2013). Coralline communities were especially found in the southern marine park reserve, where predominant currents and wave direction flush away sediments. This side of the island also has extensive shallow bank areas towards St. Kitts. These shallow banks were not included in this survey, yet likely host diverse and valuable benthic communities that deserve further study and mapping.

Due to their flexible skeleton, gorgonian soft corals flex due to water movement and orient their growth towards maximum water flow to extract planktonic food (Grigg 1972). Gorgonians are therefore often concentrated in areas with strong water movement (e.g. van Duyl 1985). This was clearly the case in St. Eustatius as well. Not surprisingly, most of the “gorgonian reef” habitat was concentrated along the wave and current-exposed eastern side of the island. For St. Kitts and Nevis, Agostini et al. (2010) describe a similar pattern of distribution for the habitat-class referred to as “flat gorgonian hard-grounds” and “rugose gorgonian slopes”.

Algae fields were principally concentrated in areas of unconsolidated rubble in the historically and presently active anchorage zone of St. Eustatius. We speculate that two decades of dropping of large anchors in the Oranjestad anchorage zone, after establishment of the oil terminal, resulted in the unconsolidated state of the seabed in this area, and that current human disturbance is likely limiting to the development of important benthic communities (e.g. reefs and seagrass beds). White et al. (2007) have documented massive impact of anchors on the benthos in the anchorage zone and have made recommendations to reduce this impact.

The main distribution of seagrass beds was found at the northern promontory of the island, where fine sediment, originating from the centrally-located eroding beach areas of the island, accumulates due to wave and current transport. The northern end of the island is subject to moderate wave intensity, which likely explains why seagrass formations are confined to relatively deep waters. This is in contrast to several islands in the vicinity (eg. St. Kitts, St. Maarten) where dense seagrass formations of *Thalassia* are found in shallow, relatively wave-protected areas (e.g. Agostini et al. 2010). In St. Eustatius, we found no *Thalassia* beds. Instead, we observed dense beds of the invasive seagrass *H. stipulacea*; a species only recently introduced from the Mediterranean but spreading rapidly throughout the eastern Caribbean (Willette et al. 2013).

4.2 Faunal significance and connectivity

Seagrass beds and coral reefs are considered key components of the near-shore ecosystem continuum as they typically play complementary roles in the life-cycle of many key fishery and endangered species. A critical condition for these habitats to fulfil these roles is for the organisms to be able to move safely from one habitat to the other when this becomes necessary. Therefore, ecological connectivity between habitats is important. Studies show that where ecological connectivity is disrupted, either due to distance (Huibers et al. 2013), water depth or absence of critical habitat, fish species community compositions are negatively affected (Nagelkerken et al. 2002). On St. Eustatius, these critical habitats show a disjunct distribution. On the eastern side of the island, the subsiding and eroding cliffs of Zeelandia and Concordia bay represent the main break between seagrass beds in the north and the shallow gorgonian reefs in the south. On the sheltered western side of the island, the anchorage zone for tankers represents the main discontinuity between seagrass in the north and the best reef habitats of the islands in the south. While this area was likely also subject to much anchorage during the “golden age” of St. Eustatius (which ended in 1776, more than 200 years ago) today the area is subject to anchoring by massive tankers that visit NUSTAR. We speculate that renewed use of the west central portion of the island for anchorage purposes by tankers may be the principal cause of this habitat discontinuity and degradation of what otherwise might have been seagrass and patch reef communities to algae-dominated rubble. These areas amount to 29% of the mapped habitat coverage and this sizable area therefore might have a profound influence on island-scale ecological processes. These areas possess the principal concentrations of adult conch, *Strombus gigas*, of St. Eustatius (M. de Graaf, unpubl. data). While these densities also appear to be at or above threshold levels needed for successful reproduction, they are not high compared to densities commonly observed in pristine or unharvested populations. Conch may aggregate in this central lee area of the island for a number of reasons and limiting factors to conch abundance in Statia (recruitment, mortality, food or otherwise) remain unknown. Therefore, no causal relationship between seafloor destruction (by anchors) and conch abundance should be inferred. Towards the shallow end of the anchorage zone there are a few patches of gorgonian reef and seagrass beds. This suggest a possibly important role for these habitat patches in ecologically connecting the seagrass beds of the northern marine reserve to the reef-scapes of the southern marine reserve. The presence of thes habitat patches also suggests the potential for habitat recovery in this zone, should disturbance by anchoring be reduced or better controlled.

Shallow seagrass beds in particular are known as important nursery areas for many commercially important coral reef fishes, including groupers, grunts, snappers, barracuda and even the West-Indian spiny lobster, *Panulirus argus*. However, because of their deep distribution on St. Eustatius and their quite sparse biotic coverage, the relative importance of these seagrass beds needs to be assessed. To that end, a study of fish distribution around the island has been conducted and will be reported separately (van Kuik 2013). Seagrass beds also typically fulfil an important habitat function for the Green Turtle, *Chelonia mydas*, which abounds in the waters of St. Eustatius (J. Berkel, N. Esteban, pers. obs.). Most work on seagrass beds and sea turtles concerns studies of shallow seagrass beds. Therefore, the significance of the deeper and sparser seagrass beds of St. Eustatius to sea turtle feeding also requires further investigation.

4.3 Long-term trends

The average hard coral cover on Caribbean reefs has been reduced by 80% (from 50% to 10% surface area coverage) in the past thirty years. The global rate of coral loss has slowed in the past decade compared to the 1980s, however, significant declines persist (Gardner et al. 2003). Major causes of coral loss include coral disease (Gardner et al. 2003), coral bleaching (Hoegh-Guldberg 1999) and hurricane damage to corals (Gardner et al. 2005). In the Caribbean, on average coral cover is reduced by 17% in the year following a hurricane, whereas recovery to a pre-hurricane state takes at least eight years (Gardner et al. 2005). Hurricane intensity and frequency are thus important factors explaining states of coral communities in the Caribbean. The most recent major hurricanes affecting St. Eustatius date back to the 1990s: Hugo (1989), Marilyn (1995), Georges (1998) and José and Lenny (1999). The apparent absence of post-hurricane recovery since the 1990s suggests that other stressors are currently affecting coral communities in St. Eustatius. For instance, the reefs of St. Eustatius were especially hard hit by the 2005 Caribbean bleaching event, resulting in a loss of the original coral cover of 30% to less than 15 % in 2008 while macro-algal cover increased from about 40% in 2005 to almost 60% (Bouchon et al. 2012).

The collapse of Caribbean coral reefs and the transition from coral- to algal-dominated states on many Caribbean reefs was preceded by reduced fish stocks and increased nutrient and sediment runoff from land. The die-off of the important grazing urchin *Diadema* throughout the Caribbean, after a disease outbreak in 1983, led to dominance of marco-algae on Caribbean coral reefs (Bellwood et al. 2004).

Our SCUBA survey of 10 coral reef, 9 seagrass, and 5 algae field stations suggests that coral community dynamics in St. Eustatius reflect the region-wide decline of corals. Compared to a previous survey in St. Eustatius (Klomp and Kooistra 2000), which documented an average coral cover of 20% at 10 similar reef locations, our findings suggests that coral cover has declined in the last 15 years, while macroalgae cover has increased from an (arithmetic) average of 10% to about 17% (geometric mean of 13%). These trends are consistent with patterns of reef decline throughout the region (Jackson et al. 2012). Declining trends for seagrass beds and reefs of St. Eustatius were discussed previously by MacRae and Esteban (2007). These authors documented up to 78% mortality of corals during the 2005 Caribbean-wide (Donner et al. 2007) bleaching event. Thus, although more studies are required to better understand the temporal dynamics of coral reefs of St. Eustatius, our current study shows that coral cover appears to be low and communities seem to be deteriorating. Loss of coral reefs represents a loss of sustainable economic potential for the island. Bervoets (2010) estimated the value of coral reef associated tourism and fishery at approximately USD $11 million per year. This amounts to about 9% of the island GDP (of 2003; van de Raadt 2007). This is very high compared to many more-diversified economies and underscores the local importance of this resource.

This study also revealed considerable sponge cover on the reefs of St. Eustatius. Species composition reflects species compositions throughout the Caribbean (e.g. van Soest 1978, 1980, 1884). However, since specimens were not collected from more cryptic parts of the reef (e.g. in caves and overhangs), the number of species reported likely underestimates the actual diversity of sponges in St. Eustatius. More importantly, besides this survey, there is no prior documentation on sponge communities in St. Eustatius, thereby preventing analysis of long-term dynamics of sponge communities. Sponges are important components of Caribbean reefs and increasingly considered to be of major importance to the functioning of ecosystems (De Goeij et al. 2013, Hunting et al. 2013). This thus highlights the necessity of future efforts to survey and quantify the benthic biodiversity of St. Eustatius sponges.

Vroman (1968) referred to luxuriant reef growth (and clear waters) which formerly existed at Corre Corre and near Concordia Bay (Turtle Bay). These reefs were largely based on dense *Acropora palmata* stands that provided protective buttresses to the erosion-prone shores. These have died and largely eroded and disappeared since the early 1980s when the new White-Band Disease had in a few short years killed 85% of *Acropora* stands throughout the region (Aronson and Precht 2001, Gladfelter 1991, Green and Bruckner 2000). As a consequence of the demise of *Acropora* stands in various parts of the island, today the beaches and shores of the island are likely much more vulnerable to wave and wind-exposure, particularly during extreme weather events. This likely contributes to the higher turbidity and sediment loads that, in turn, negatively impact and limit near-shore corals. In this way, documented coral declines in St. Eustatius can be seen to have further exacerbated vulnerability of surviving corals. On land, sediment loads in run-off are also contributed to by overgrazing and erosion due to extensive roaming livestock (Debrot and Sybesma 2000).

4.4 Main drivers of change and potential management interventions

This survey identifies habitat degradation as a major driver affecting the diversity of habitats and organisms of the benthic community of St. Eustatius. Bouchon et al. (2012) indicate sediment run-off as a likely main culprit in coral reef declines for volcanic islands throughout the Lesser Antilles, including St. Eustatius. While many factors driving degradation are not local but global, and while several local factors (such as fishing, nutrient contamination or coastal development) play lesser roles for St. Eustatius, one key local factor is erosion. Debrot and Sybema (2000) previously highlighted the special vulnerability of St. Eustatius to erosion due to the combined effect of geomorphology and overgrazing. This leads to sediment stress, turbidity and lack of hard substrates, particularly in shallow areas around the island. Fortunately, at present efforts to limit uncontrolled livestock grazing are already underway (MinEZ 2013).

In many tropical areas that suffer low biotic cover or lack of hard substrate (such as is the case in St. Eustatius), artificial structures have been found to be an effective way of augmenting ecosystem services. While man-made structures in the sea are often criticised for not being able to fulfil all ecological function of natural reef structures, they can help protect vulnerable habitats, shores and beaches, provide habitat for improved fish and shellfish concentrations (Bohnsack 1989, Bonhsack and Sutherland Bohnsack and Sutherland 1985, Bohnsack 1989, Quinn and Kojis 1995) and even help restore endangered keystone species (like *Diadema*) (Debrot and Nagelkerken 2006). Implementing artificial submerged structures could even partially fulfil the protective role of the vanished *Acropora* stands. Trials for use of artificial reefs to help compensate the loss of the formerly protective natural reef structures has been proposed before (MacRae and Esteban 2007), but are yet to be conducted. At present, a small man-made artificial reef (amounting to no more than a modest pile of rocks), is the most important dive attraction and concentration of reef fauna in the Oranjestad harbor. (Fig. 13).

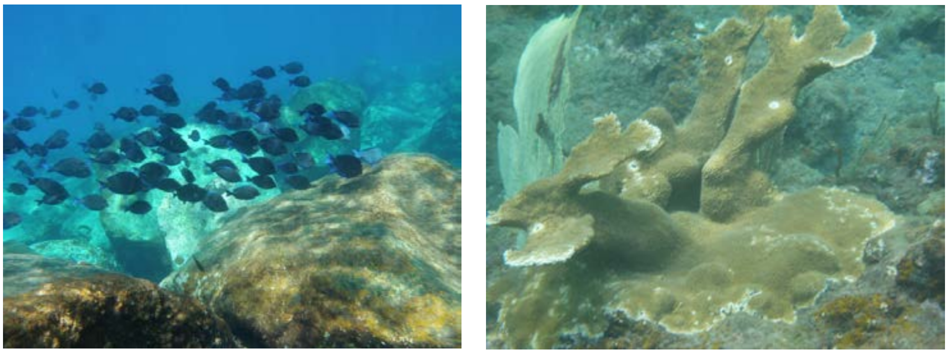


Figure 13. School of Blue Tang (left) and IUCN redlist coral (elkhorn coral) (right) growing on an artificial reef made of natural rock in Oranjestad harbor. (Photos © J. Berkel, STENAPA).

5 Conclusions and recommendations

Our study concludes that marine habitats of St. Eustatius are under stress and have declined greatly in quality in recent decades. In particular, live coral cover is now much lower than formerly. This trend threatens the integrity of a natural resource estimated at an annual value of USD 11 million (even under current conditions) and worth about 9% of the annual GDP. Therefore, measures and interventions to actively enhance and protect this resource could result in long-term economic pay-off.

Key marine habitats show a disjunct distribution with seagrass beds in the north and coral habitat in the south. The intensively used anchorage zone represents a major habitat discontinuity as the substrate is damaged by heavy anchors and chains (White et al. 2007). Given the geographic scale concerned (several km of separation) this may interfere with ecological connectivity and have consequences for ecosystem services. Hard substrates, suitable to benthic coral communities in the shallow areas around this island are rare and unconsolidated sediments predominate.

While several typical local sources of reef degradation are likely unimportant (e.g. overfishing and coastal development), the combination of an erosion-prone geomorphology and overgrazing on land are stressors that likely do play a key role in exacerbating coral reef declines for St. Eustatius. Therefore, to protect and enhance the marine quality and ecosystem services we recommend further measures to address overgrazing as well as research into the use of artificial submerged structures (“artificial reefs”) to enhance marine biodiversity.

Our principal findings and recommendations can be summarized as follows:

- The two designated marine reserves within the marine park contain the main concentrations of coral reef and seagrass habitat of the island but other valuable habitats lie principally outside these reserves.
- Ways should be sought to limit anchor damage to areas that have already been severely impacted, following the recommendations from White et al. (2007), and two (but possibly more) isolated small areas of shallow seagrass and gorgonian reef between Oranjestad and the oil terminal should be protected from future anchor damage.
- The possible stepping-stone role of these habitat patches (seagrass and gorgonian reef) in the central, disturbed anchorage section of the island should be assessed.
- More adequate community description than we provide here is needed as a basis for long-term monitoring of habitat state and ecosystem services.
- Use of the various habitats by fauna during different stages of their life-cycle probably differs greatly and should be assessed.
- The marine biodiversity of St. Eustatius likely includes several species that will prove to be new to science and therefore deserves further taxonomic investigation.
- Studies on how to enhance degraded marine benthic habitats by means of artificial submerged structures and other intervention, might help increase ecosystem service provisioning in terms of coastal protection, fish stock enhancement and dive attractions for tourism.

6 Quality Assurance

IMARES utilises an ISO 9001:2008 certified quality management system (certificate number: 124296-2012-AQ-NLD-RvA). This certificate is valid until 15 December 2015. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Fish Division has NEN-EN-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 27 March 2017 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation.

7 References

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8 Justification

Report number : C078/14

Project number : 4308711013

The scientific quality of this report has been peer reviewed by a colleague scientist and the head of the department of IMARES.

Approved: Dr. Oscar G. Bos
Researcher

Signature:

Date: 13 June 2014

Approved: Drs. F.C. Groenendijk
Head Department Maritime

Signature:

Date: 13 June 2014

Appendix A: GPS locations of sampling stations

Station number	Sample date	Name dive site	N°	N´	W°	W´
Algae						
1	11/12/2012	Chien Tong	17	29.011	62	59.875
2	18/12/2015	Charles L. Brown	17	27.84	62	59.598
3	09/01/2013	Chien Tong	17	29.011	62	59.875
4	10/01/2013	Oranjestad bay	17	28.468	62	0.074
5	15/01/2013	Oranjestad bay	17	28.442	62	59.497
Seagrass						
1	19/12/2012	Drop off west	17	27.676	62	58.527
2	20/12/2012	Jenkins bay	17	30.504	63	0.257
3	03/01/2013	In front of Smoke Alley	17	28.544	62	59.392
4	03/01/2013	In front of Smoke Alley	17	28.544	62	59.392
5	04/01/2013	Jenkins bay	17	30.221	63	0.276
6	04/01/2013	Jenkins bay	17	30.221	63	0.276
7	15/01/2013	Double wreck	17	28.792	62	59.641
8	15/01/2013	Double wreck	17	28.792	62	59.641
9	15/01/2013	Double wreck	17	28.792	62	59.641
Reef						
1	04/12/2012	The ledges	17	27.793	62	59.069
2	06/12/2012	Anchor reef	17	27.738	62	59.118
3	19/12/2012	Barracuda reef	17	28.006	62	59.455
4	21/12/2012	Valley of the sponges	17	27.835	62	58.938
5	21/12/2012	The blocks	17	27.84	62	59.105
6	28/12/2012	Five fingers south	17	27.898	62	58.996
7	05/01/2013	Blairs reef	17	28.227	62	59.493
8	06/01/2013	Nursing station	17	28.088	62	59.495
9	06/01/2013	Crooks castle	17	28.315	62	59.254
10	14/01/2013	Double wreck	17	28.792	62	59.641

Appendix B: Station characteristics for benthic community sampling

Detailed station characteristics for benthic community description using belt transects.

Station number	Sample size per station (m^2)	Depth (m)	Temperature (°C)	Secchi Disk Depth (m)	Rugosity (m)	Bottom composition		
						Sand (%)	Rubble (%)	Rock (%)
Algae								
1	4	24.4	28	14	-	6	93	1
2	4	30.5	28	14	-	4	88	9
3	7	24.4	27	14	1.06	18	82	0
4	9	24.1	27	12	1.17	1	99	0
5	14	23.2	26	12	1	39	61	0
Seagrass								
1	25	23.5	28	19	1	100	0	0
2	31	22.9	27	19	1	100	0	0
3	14	16.8	27	11	1	100	0	0
4	14	16.8	27	11	1	100	0	0
5	14	26.5	27	11	1	100	0	0
6	14	26.5	27	11	1	100	0	0
7	14	18.6	26	12	1	100	0	0
8	14	18.6	26	12	1	100	0	0
9	14	18.6	26	12	1	100	0	0
Reef								
1	11	20.4	29	-	-	26	9	65
2	11	21.0	28	15	-	20	4	76
3	10	22.3	28	17	1.18	26	4	71
4	16	15.9	28	16	1.21	32	5	63
5	12	17.1	28	16	1.28	26	8	66
6	12	17.4	27	16	1.33	15	7	78
7	12	21.0	27	14	1.15	21	6	73
8	12	20.1	27	17	1.29	16	5	78
9	14	12.8	28	17	1.29	5	3	92

Appendix C: Species identification lists algae and sponges

Algae: identified by Dr. David Ballantine

Sample number, Genus/species, DLB number

3.	*Halimeda* cfr. *goreaui*	8513
13.	*Lobophora variegata*	8509
17.	*Halimeda* cfr. *tuna*	8514
19.	*Dictyota* sp.	8510
21.	*Caulerpa cupressoides* v. *lycopodium*	8498
22.	*Dasya spinuligera*	8495
24.	*Penicillus capitatus*	8496
30.	*Udotea cyathiformis*	8497
31.	*Caulerpa cupressoides*	8500
33.	*Halophila stipulacea*	8499
34.	*Syringodium filiforme*	8501
35.	*Halophila* 8502 (specimen too small to determine)	
36.	*Halimeda* cfr. *incrassata*	8503
37.	*Udotea spinulosa*	8504
38.	*Udotea spinulosa*	8504
39.	*Dasya* sp. (could be *D. pedicellata* but too slender)	8506
40.	*Caulerpa mexicana* (*C. taxifolia* ?)	8507
44.	*Halophila stipulacea*	8508

DLB number, Genus / species.

(Station 3.3) Genus/Species

8515 *Lobophora variegata* (Lamouroux) Womersley

8516 *Canistrocarpus cervicornis* (Kutzing) De Paula & De Clerck

8517 *Sargassum* sp.

8518 *Udotea flabellum* (J. Ellis & Solander) M.A. Howe

8519 *Martensia fragilis* Harvy

8520 *Caulerpa serrulata* (Forsskal) J. Agardh

8521 *Halophila decipiens* Forsskal) Ascherson

8522 *Penicillus capitatus* Lamarck

8523 *Caulerpa cupressoides* (Vahl) C. Agardh

Syringodium filiforme Kützing

8524 *Sargassum polyceratium* Montagne

8525 *Gracilaria cfr. damaecornis* J. Agardh

8526 *Udotea spinulosa* M.A. Howe

8527 *Udotea abbottiorum* D.S. Littler & M.M. Littler

8528 *Digenia simplex* (Wulfen) C. Agardh

8529 *Dasya* sp.

8530 *Halimeda goreauii* W.R. Taylor

8531 *Amphiroa rigida* J.V. Lamouroux

8532 *Amphiroa fragillisima* (Linnaeus) J.V. Lamouroux

8533 *Halimeda incrassata* (J. Ellis) J.V. Lamouroux

Dasya spinuligera F.S. Collins & Hervey

8534 *Cryptonemia crenulata* (J. Agardh) J. Agardh

(Station 3.1)

8535 *Udotea flabellum* (J. Ellis & Solander) M.A. Howe

Sargassum sp.

Dictyota sp.

8536 *Hypoglossum tenuifolium* (Harvey) J. Agardh

8537 cfr. *Naccaria*

8538 *Sargassum* sp.

8539 *Lobophora variegata* (Lamouroux) Womersley

8540 *Padina* sp.

8541 *Symploca hydnoides* Gomont

8542 *Halimeda goreaui* W.R. Taylor

8543 *Martensia fragilis* Harvy

(Station 3.2)

8544 *Dasya spinuligera* F.S. Collins & Hervey

8546 *Lobophora variegata* (Lamouroux) Womersley

8547 *Udotea caribaea* D.S. Littler $ M.M. Littler

8548 *Jania cfr. capillacea* Harvey

8549 *Udotea flabellum* (J. Ellis & Solander) M.A. Howe

8550 *Halimeda incrassata* (J. Ellis) J.V. Lamouroux

8551 *Halodictyon* sp.

Dictyota sp.

8552 *Sargassum hystrix* J. Agardh

8553 *Digenia simplex* (Wulfen) C. Agardh

8554a *Halophila decipiens* Ostenfeld

(H2)

8555 Chondria sp.

8556 Cladophoropsis membranacea (Hoffman Bang) Børgesen

8557 Amphiroa rigida J.V. Lamouroux

8558 Polysiphonia ferulacea Suhr

8559 Dictyota guineensis (Kutzing) P. Crouan & H. Crouan

8560 Dictyopteris delicatula J.V. Lamouroux

(Site 1)

8561 Calothrix sp.

8562 Laurencia microcladia Kützing

8563 Laurencia obtusa (Hudson) J.V. Lamouroux

8564 Padina sanctae-crucis Børgesen

Liagora sp.

8565 Ganonema sp.

8566 Amphiroa rigida J.V. Lamouroux

8567 Dictyota guineensis (Kutzing) P. Crouan & H. Crouan

Sponges, identified by Ellard Hunting!

1: *Verongula rigida* (Esper, 1794)

2: *Amphimedon compressa* (Duchassaing & Michelotti, 1864)

4: *Cliona caribbaea* (Carter, 1882)

5: *Ircinia strobilina* (Lamarck, 1816)

6: *Callyspongia* (Cladochalina) *plicifera* (Lamarck, 1814)

7: *Desmapsamma anchorata* (Carter, 1882)

8: *Cliona varians* (Duchassaing & Michelotti, 1864)

9: *Niphates amorpha* (Wiedenmayer, 1977)

10*:* *Clathria* (Microciona) *spinosa* (Wilson, 1902)

11: *Cliona varians* (Duchassaing & Michelotti, 1864)

12: *Aiolochroia crassa* (Hyatt, 1875)

14: *Haliclona* (*Soestella*) *twincayensis* (de Weerdt,Rützler & Smith, 1991)

15: *Phorbas amaranthus* (Duchassaing & Michelotti, 1864)

16: *Neopetrosia proxima* (Duchassaing & Michelotti, 1864)

20: *Ircinia felix* (Duchassaing & Michelotti, 1864)

23: *Aiolochroia crassa* (Hyatt, 1875)

25: *Plakortis halichondrioides* (Wilson, 1902)

26: put. *Dictyonella funicularis* (Rützler, 1981)

27: *Agelas conifera* (Schmidt, 1870)

28: *Aiolochroia crassa* (Hyatt, 1875)

29: *Aplysina fistularis* (Pallas, 1766)

31: *Clathria* (*Thalysias*) *schoenus* (de Laubenfels, 1936)

41: *Spirastrella hartmani* (Boury-Esnault, Klautau, Bézac, Wulff & Solé-Cava, 1999)

Appendix D: User guide for the drop camera

The day before:

1. Make sure that the batteries for the sunglasses, DVR, the GPS and of the drop camera are charging overnight so that you have enough battery power.
2. Make sure that the memory card is empty so that you have enough storage space for the videos.
3. Prepare on a waterproof paper, that you fasten on a slate with rubber bands, a table for noting the data. The table should include waypoint name, habitat type and depth for each sample site

The day itself:

4. Make sure that everything is on the boat: drop camera, video case, GPS, memory card, towel, plastic bag, back-up batteries, waterproof paper, slate, pencil, snacks and drinks. For the person using the sunglasses, a hat is recommended.
5. Drop the camera on transects 200 meters apart; points in one transect should be approximately 150 meters apart. Mark every point in the GPS, write down the depth, the habitat as judged through the sunglasses and the name of the waypoint made with the GPS. Make sure that the video case and the connections stays dry by using the towel and plastic bag.
6. Rinse the camera with fresh water after every use; make sure that the video case and the connections stay dry.
7. Charge the batteries for the next drop session and take the memory card home to analyze the drop videos.