Saba Bank research expedition 2011 – Progress Report

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Summary

The Saba Bank is a large submerged carbonate platform of approximately 2,200 km^2 in the Caribbean Sea which lies partially within the Exclusive Economic Zone of the Netherlands and partially within the territorial waters of Saba and St. Eustatius. It was declared a protected area by the Dutch Government on 15 December 2010 and has been registered as such in the Specially Protected Areas and Wildlife (SPAW) protocol of the Cartagena Convention for the Protection and Development of the Marine Environment of the Wider Caribbean. Applications for a Particularly Sensitive Sea Area (PSSA) at IMO and Ecological or Biological Significant Area (EBSA) at CBD are pending.

As part of the Saba Bank research program 2011-2016, commissioned by the Dutch Ministry of Economic Affairs (EZ), an expedition to the Saba Bank was conducted from 22 to 29 October 2011. The Saba Bank research program aims to obtain information on the biodiversity, key ecological processes and carrying capacity for commercial fisheries to facilitate sustainable management of the area. The primary objectives of the 2011 research expedition were to collect data on benthic and reef fish communities; sponges and nutritional sources of the sponge community; seabirds and marine mammals; water quality, water velocity and other physical parameters. A multidisciplinary team conducted video and visual surveys on benthos, fish and sponges during 10 SCUBA dives at 20-30m depth, while sea birds and marine mammals were surveyed by means of on-board visual surveys and acoustic data loggers. Water velocity and water quality were also measured on-board using an Acoustic Doppler Current Profiler (ADCP) and Conductivity, Temperature and Depth (CTD) device.

During the expedition 8 sponge species were collected and 37 scleractinian coral species and 85 fish species were identified.Fish biomass varied per site between 1.3 kg to 4.4 kg.

Part of the measurements on water velocity, water quality and benthic cover are still in the process of being analysed. Data collected will also be used as baseline for future monitoring and analyses of biodiversity and key ecological processes within the framework of the 2011-2016 research program.

1 Introduction

The Saba Bank in the north-eastern Caribbean Sea (17°25′ N, 63°30′ W) is a large submerged carbonate platform, located 3-5 km Southwest of Saba and 25 km West of St. Eustatius in the Dutch Caribbean (figure 1). It has a roughly rectangular shape with a length of 60-65 km and a width of 30-40 km. The total surface area is approximately 2,200 km^2, as measured to the 200-meter isobath.

The Saba Bank is raised about 1000 meter above the general depths of the surrounding sea floor. The bathymetric map (figure 2) shows the surface slopes gradually from the shallower south-eastern part to the deeper north-western part. On the eastern and south-eastern edges, where a prominent and actively growing coral ridge of 55 km long runs along the platform, depths vary between 7 and 15 m. On its western rim depths are around 50 m and without actively growing coral reef this rim should be considered a drowned fringing reef. The largest part of the Saba Bank is between 20 and 50 m depth, but a substantial eastern part (approximately 225 km^2) is between 10 and 20 m depth (Macintyre et al. 1975; Van der Land 1977).

The Saba Bank lies partially within the Exclusive Economic Zone of the Netherlands. The other part of the Bank is within 12 nautical miles of mainly Saba as well as St. Eustatius for a small part, and falls under their island authorities (figure 1). The Saba Bank has been declared a protected area by the Dutch Government on 15 December 2010 and has been registered as such in the Specially Protected Areas and Wildlife (SPAW) protocol of the Cartagena Convention for the Protection and Development of the Marine Environment of the Wider Caribbean. Two applications for an international special status of the Saba Bank are pending: an IMO request for a Particularly Sensitive Sea Area (PSSA) status and a CBD request for an Ecological or Biological Significant Area (EBSA) status in March 2012.

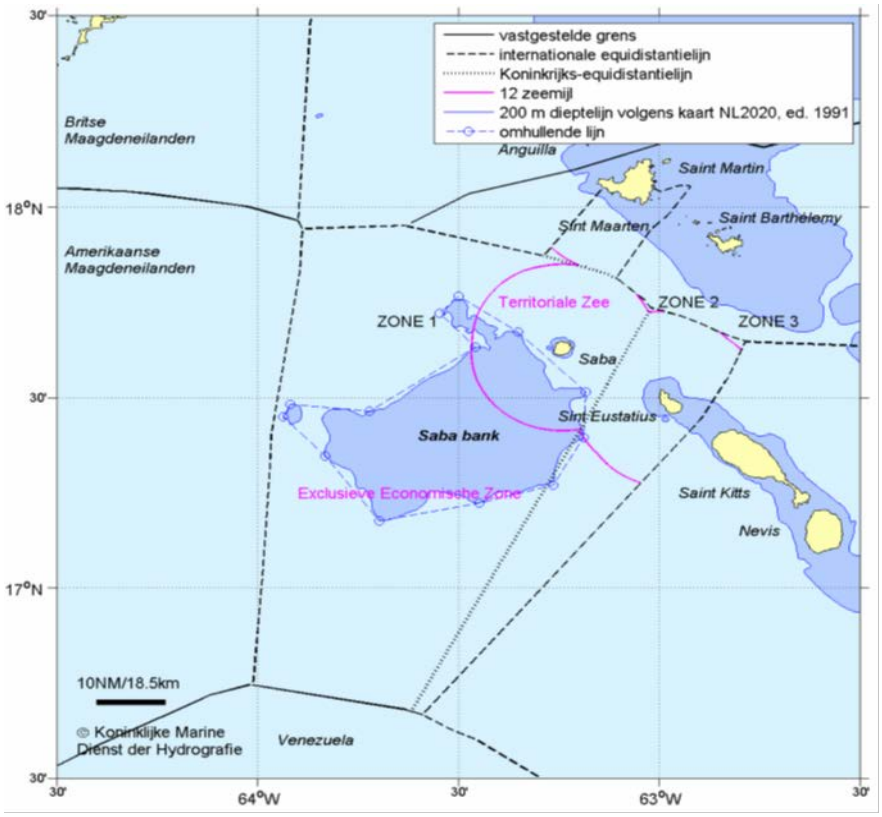


Figure 1. Location and zonation of the Saba Bank, Exclusive Economic Zone and Territorial Sea (Staatscourant 2010 no. 20424).

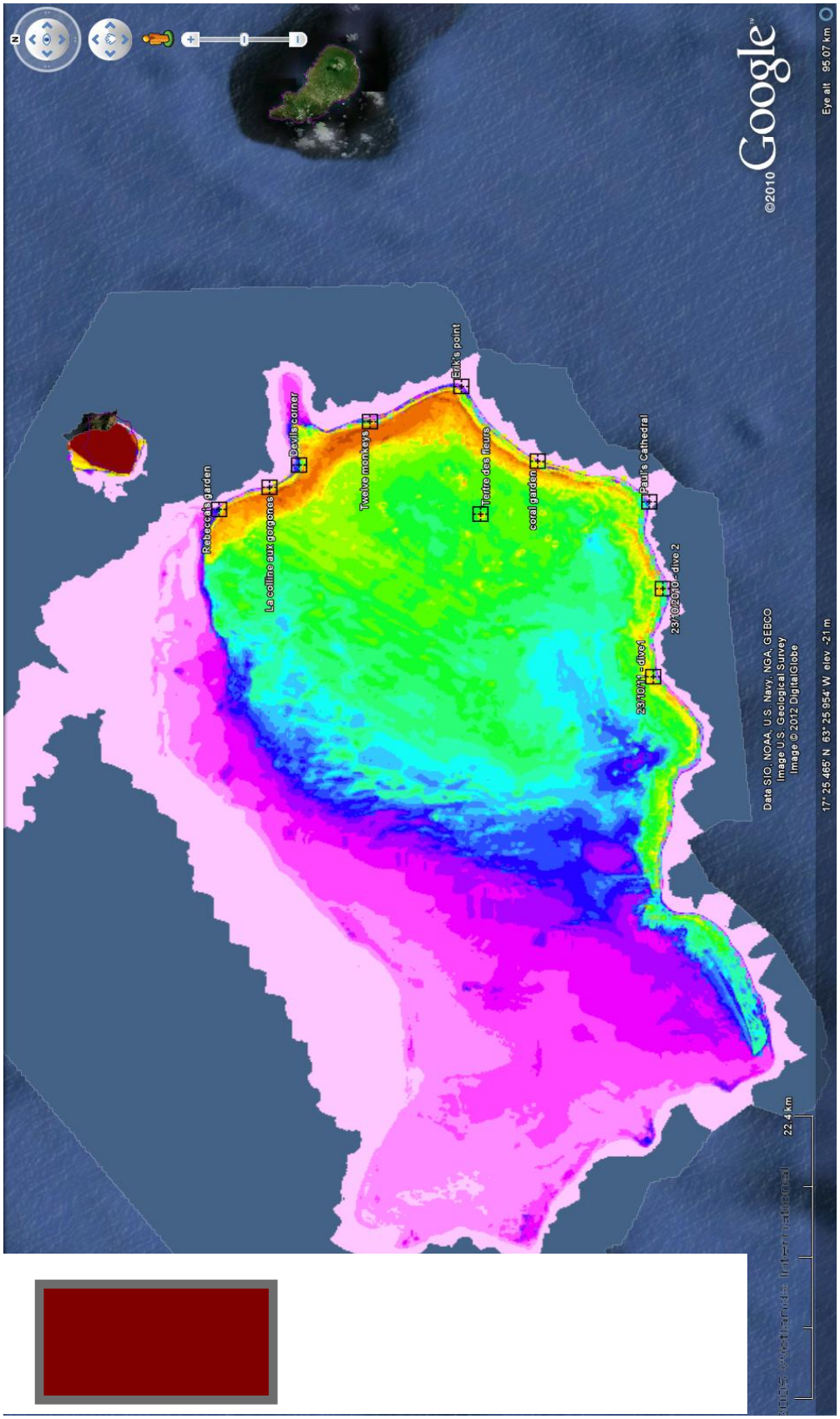


Figure 2. Bathymetry of the Saba Bank with isobath depth contour lines (Netherlands Hydrographic Service).

The first biodiversity studies at the Saba Bank were a quick field survey commissioned by the Netherland Antilles Department of Environment and Nature and completed in 1996 and the Conservation International Rapid Assessment Program in 2006. The first survey concluded the Saba Bank is a regionally unique and relative pristine ecosystem with high biodiversity and productivity (Meesters et al., 1996 in Hoetjes and Carpenter 2010) and the second study demonstrated the richness of its biodiversity with the identification of many species of fishes, corals, sponges and macro-algae (Hoetjes and Carpenter 2010). The present research expedition was performed to check the current status.
Because of the remote location away from densely populated and industrialized regions in the Caribbean we expected to meet relatively pristine conditions characteristic for such open water reefs. Observations from the above studies indicated that the Saba bank had generally healthy corals, compared to other coral reefs, and that it was a good area for fishes to reproduce. However, more recent observations (Meesters and Debrot, pers. comm.) indicate a decline in living coral and in fish population in this area.

1.1 Research question

This research has been commissioned by the Dutch Ministry of Economic Affairs, Agriculture and Innovation (EL&I) as part of the Saba Bank research program 2011-2016. The aim of this research program is to obtain information on the biodiversity, key ecological processes and carrying capacity for commercial fisheries to facilitate sustainable management of the area.

The aim of the Saba Bank research expedition was to:

- Collect data for monitoring of benthic reef communities
- Collect data on fish abundance and fish size for fish density, biomass and biodiversity estimates.
- Improve our understanding of the water quality and nutritional sources of the sponge community.
- Improve our understanding on water velocity and other physical parameters.
- Collect data on seabirds and marine mammals.

1.2 Acknowledgements

We like to thank the following people for their support in making this research expedition possible: Greg van Laake and Kai Wulf of the Saba Conservation foundation for generously providing and employing the Lady Rebecca as additional research vessel; Hayo Haanstra, team coordinator and policy advisor department of Nature and Biodiversity for the Dutch Ministry of Economic Affairs for arranging the funding of this study under grant no. BO-11-011.05-008 and Carel Drijver, head Oceans & Coasts Program of Wereld Natuur Fonds for co-financing this study.

2 Materials and Methods

The Saba Bank expedition 2011 was conducted with the Caribbean Explorer, a 32 m long liveaboard research vessel (Figure 3). We embarked on 22 October and disembarked on 29 October 2011 at St Maarten. We had 6 effective sampling days on the Saba Bank from 23-28 October 2011.

Figure 3. The research vessel the Caribbean Explorer in St Maarten.

During the expedition 10 stations were visited for reef fish and benthic communities surveys, 9 stations along the edge of the bank at the south-eastern site and 1 station (Tertre des Fleurs) on top of the bank, a patch-reef characterized by a calcareous hard bottom outcrop with corals, sponges and benthic macroalgae. Figure 2 shows the locations of survey stations on the map, for exact locations see table 1.

Table 1. Station names and coordinates surveyed during the Saba Bank expedition 2011.

Survey date	Station name	Site ID	Latitude (N)	Longitude (W)	Depth (m)	Reef transect	Sponge dive
23/10/2011	Site 3 (2010 expedition)	S3	17°16.103′	63°24.526′	25	1	1
	Site 4 (2010 expedition)	S4	17°15.716′	63°20.658′	25	2	2
24/10/2011	Paul's Cathedral	PC	17°16.267′	63°16.850′	25	3	3
	Coral Garden	CG	17°20.750′	63°15.067′	24	4	4
25/10/2011	Twelve Monkeys	TM	17°27.500′	63°13.333′	24	5	5
26/10/2011	Erik's Point	EP	17°23.817′	63°11.783′	27	6	6
	Tertre des Fleurs	TDF	17°23.050′	63°17.393′	18	7	7
27/10/2011	La Colline aux Gorgones	LCG	17°31.533′	63°16.217′	31	8	
	Devil's Corner	DC	17°30.350′	63°15.233′	25	9	8
28/10/2011	Rebecca's Garden	RG	17°33.566′	63°17.183′	28	10	9

Besides data of fish and benthic reef communities, data were collected on nutrients, sponges, water flow, seabirds and marine mammals. For the reef transects researchers split in two teams. The first team went in to count fish and coral recruits after rolling out the transect lines. The second team went in after ca. 15 minutes to do video transects, collect sponge and macro algae samples and retrieve to collect the transect line.

2.1 Sponges, macroalgae and nutrients

At 9 of the 10 stations sponges and benthic macroalgae were collected for stable isotope analysis ($\delta^{13}C$ and $\delta^{15}N$) while SCUBA diving with Nitrox. On each site two 2-5 cm^3 sponge pieces of common sponge species were photographed and collected and benthic macroalgae (*Dictyota* sp. and *Lobophora* sp.) were also collected. Sponge and macroalgal samples were again photographed after sampling and wrapped in aluminium foil and stored in a deep freeze for later analysis. Water was collected by hand with a niskin bottle on a steel wire at ca. 2 m and ca. 12-18 m depth at each of the 9 stations. Samples for inorganic nutrients (NH_3, NO_2, NO_3, PO_4), total organic carbon (TOC), total nitrogen (TN), dissolved organic carbon (DOC), total dissolved nitrogen (TDN) were taken after diving. Subsequently 6-15 L water was filtered over combusted 47 mm GFF filters with overpressure from dive tanks for collection of particulate organic matter (POM) with Sweet Fleurs Moonshine Machine (Figure 4). Nutrient and POM samples were stored in the deep freeze and DOC, TDN, TOC and TN were fixed with a few drops of concentrated HCL and stored at 7°C. On several occasions light intensities were measured over depth. Problems with the light meter limited the amount of reliable data obtained.

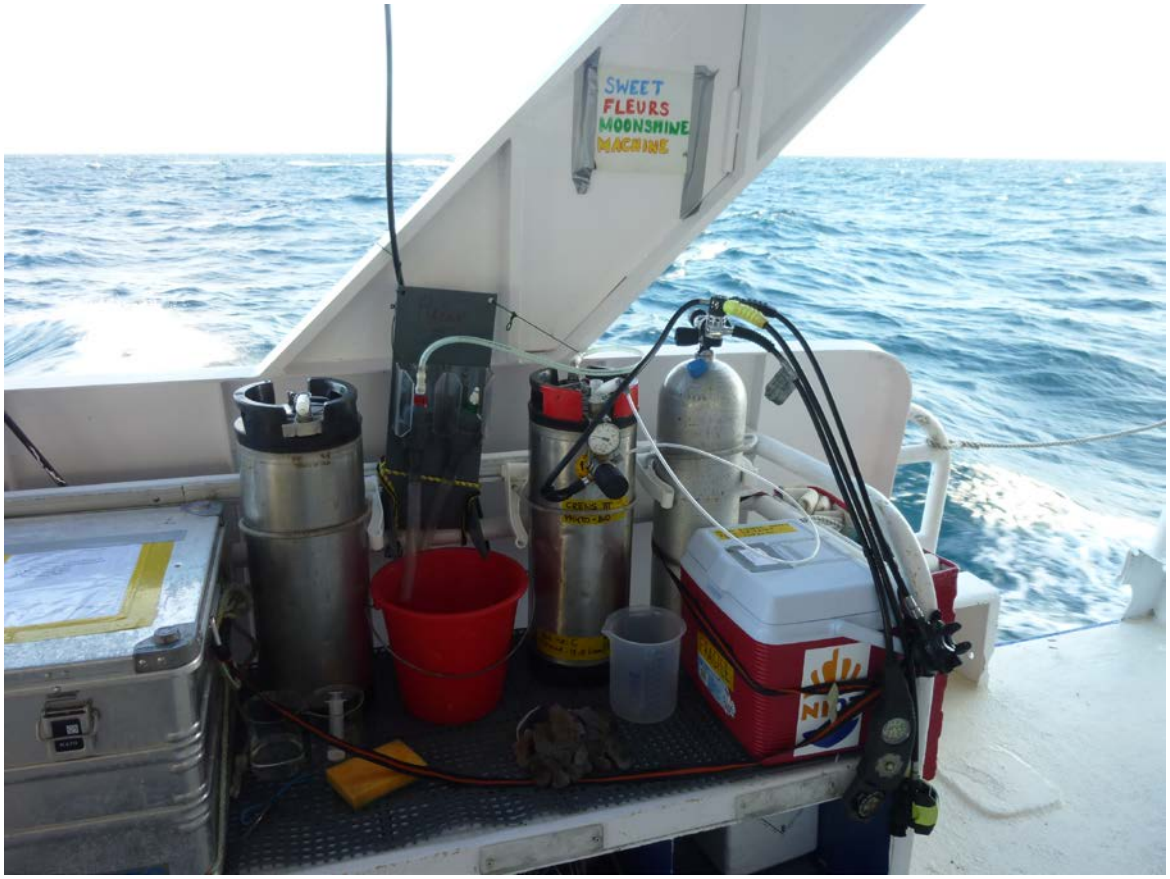


Figure 4. Experimental filtering set up with pressure vials and a dive tank. Filters were placed in the grey PVC filter holder in the middle.

2.2 Fish and benthos

At all 10 stations fish and benthos were monitored along three 50m transect lines. Transects were separated by placing the three lines in opposite directions in a Y shape, with 5m in between the central starting point. The measuring tape was rolled out by the coral recruit surveyors following the fish surveyor to minimize disturbance of the fish. The fish surveyors passed the measuring tape twice (forth and back) while the coral recruit surveyors started their counts at the end of the transect line. The benthic surveyors started filming at the beginning of the transect line after the recruit surveyors had finished and collected the measuring tape on their way back.

2.2.1 Coral recruits

Recruitment is the measure of the number of young individuals entering the adult population. Coral recruits of all scleractinian corals and Millepora spp. of maximum 4cm diameter were counted in 25cm × 25cm quadrats placed at 2m intervals along each transect line. In each quadrat as many recruits as possible were tallied to the genus or species level using two size category (≤ 2 cm or ≤4 cm). The predominant substratum type within each quadrat was also recorded as one of the following types: live coral, dead coral, pavement, rubble, sand. Substratum types of approximately equal abundance were recorded both.
Within each quadrat loosely attached algae and sediment were brushed off the substratum using the hands. In quadrats at area of high topographical complexity all coral recruits were recorded, regardless of its orientation relative to the reef's planar surface.

2.2.2 Fish

Data on fish abundance and fish size were collected for 105 fish species in 50m x 5m belt transects while SCUBA diving with Nitrox. Belt transect is a widely used method for fish abundance and size estimates (Hill and Wilkinson 2004) and the most effective for monitoring small (<20cm TL) and medium sized (20-35cm TL) reef fishes. At each stations three surveyors did one belt transect each of 50m long and 2.5m width on either side of the transect line. In total 30 belt transects of 250m^2 were surveyed.

Each surveyor passed the measuring tape twice. The first pass from the starting point to the end of the transect line was used to count medium to large more mobile fish (parrotfish, surgeonfish, grunt and snapper). The second pass back was used to count small (damselfish) and cryptic (grouper) less mobile species. Fish size was estimated using total length (TL), because it is easier to estimate underwater than standard length (SL). Since the greatest error in the visual census method is underwater size estimation, TL can be considered equal to SL for this purpose (Green and Bellwood 2008). Six size categories were used (0-5cm, 6-10cm, 11-20cm, 21-30cm, 31-40cm and >40cm) following the AGRRA protocol (Lang et al. 2010). Surveyor swimming speed was on average 8 meter per minute, because a constant speed is important as more fish is seen when swimming slowly (Hill and Wilkinson, 2004). Transects were conducted between 8 am and 4 pm, which is within the recommended time for fish transects to avoid spawning aggregations (Hill and Wilkinson 2004), except for one transect at 7 am. Prior to the start of the survey, surveyors calibrated swimming speed, accuracy of the transect width estimates and size estimation of fishes underwater.

Biomass was calculated using known length-weight relationships for each species. If such data did not exist, the length-weight relationship of a closely related species was used. The relationship between total length (L) and total weight (W) for nearly all species of fish is expressed by the equation:

$W = aL^b$

where W is weight in grams, L is length in millimeters and a and b are constants. The value of a and b for each species was derived from Bohnsack and Harper (1988) and for missing species from fishbase (www.fishbase.org). Because fish size was measured in centimeter and Bohnsack and Harper provided the value of log a instead of a, the equation $W = aL^b$ was adapted to $W = 10^{\log a} (L_{\text{in cm}} * 10)^b$. Fishbase notation of the value of a was based on length in cm. This was adapted to the notation of Bohnsack and Harper (log a based on length in mm) with the equation $\log a_{\text{Bohnsack L in mm}} = \log (a_{\text{Fishbase L in cm}} / 10^b)$.

Fish abundance and fish biomass per survey site was standardized to respectively numbers and grams per 100 m^2, a unit commonly used in fish surveys. This was done through the calculation of averages per survey site, by adding up fish abundance and biomass of the three 250 m^2 belt transects and dividing this by 7.5.

Analysis of the standardized dataset of fish abundance and fish biomass proceeded through the following steps. First step was to test the observer effect between the three observers doing fish counts and length estimates. This was done using the linear mixed effects model (LME). By correcting for observer bias the residual error of the final estimate is reduced.
The second step was data exploration to calculate and plot total abundance, total biomass and biodiversity across all study sites. These indicators illustrate basic patterns and differences between study sites. The third step was to calculate and plot biomass distribution per functional group across all study sites.

2.2.3 Benthos

On each site 2-3 50m video transects were filmed using a HD video camera (Sanyo VPC-HD2000EX). From each transect 20 random frames were isolated and these were analyzed for cover by the main benthos groups (corals, algae, sand).

2.3 Sea birds and marine mammals

Data on marine mammals were collected by deploying acoustic data loggers, and by means of visual surveys. The visual surveys to count marine mammals as well as seabirds were conducted while on transit between the diving spots and whenever the other activities permitted it.
Counts were conducted from the bow of the research vessel, were three chairs were secured on the deck in front of the bridge. The eye height of the observers was about 9 m. All birds, marine mammals and particular floating matter (balloons and fishing vessels) were logged at one side of the ship, as it sailed along the random transect lines. To this end, one survey team of two observers detected, identified and counted these object within a strip of 300 m wide. Standardized counting methods from the European Seabirds At Sea (Tasker et al. 1984) were used. All birds seen were logged per 5 minute counts, only those seen within the counting strip, and – in case of flying birds - at the correct snapshot moments (once every minute). The behaviour of observed birds and marine mammals was noted according to Camphuysen and Garthe (2004). GPS positions and environmental conditions were recorded.
Whenever possible observations were made during other activities. These observations were recorded as off-effort observations.

2.4 Water velocity and physical parameters

Measurements on the water velocity and other physical quantities were obtained. The water velocity was measured using an Acoustic Doppler Current Profiler (ADCP) attached to the research vessel (figure 5).

The ADCP measure the water velocity in all directions (x,y,z), for several depth layers (each 0.5 m) in stationary points and transect points. This device has been measuring almost continuously during the whole week. Because the research vessel was not exclusively meant for ADCP-measurements, the locations and conditions were not always optimal for ADCP-measurements. Therefore, some measurements were more useful than others. Most used ADCP settings were:

- Mode 12 (fast pinging), 10 sub-pings
- 1 ping per ensemble
- 1 bottom track ping
- 32 bins (=depth layers) of 0.5 m each
- Beam coordinates
- As fast as possible: on average 0.92 seconds per ping.
- Maximum velocity (ambiguity velocity) varied between 150 and 550 mm/s
- GPS signal
- No external heading (did not function well)

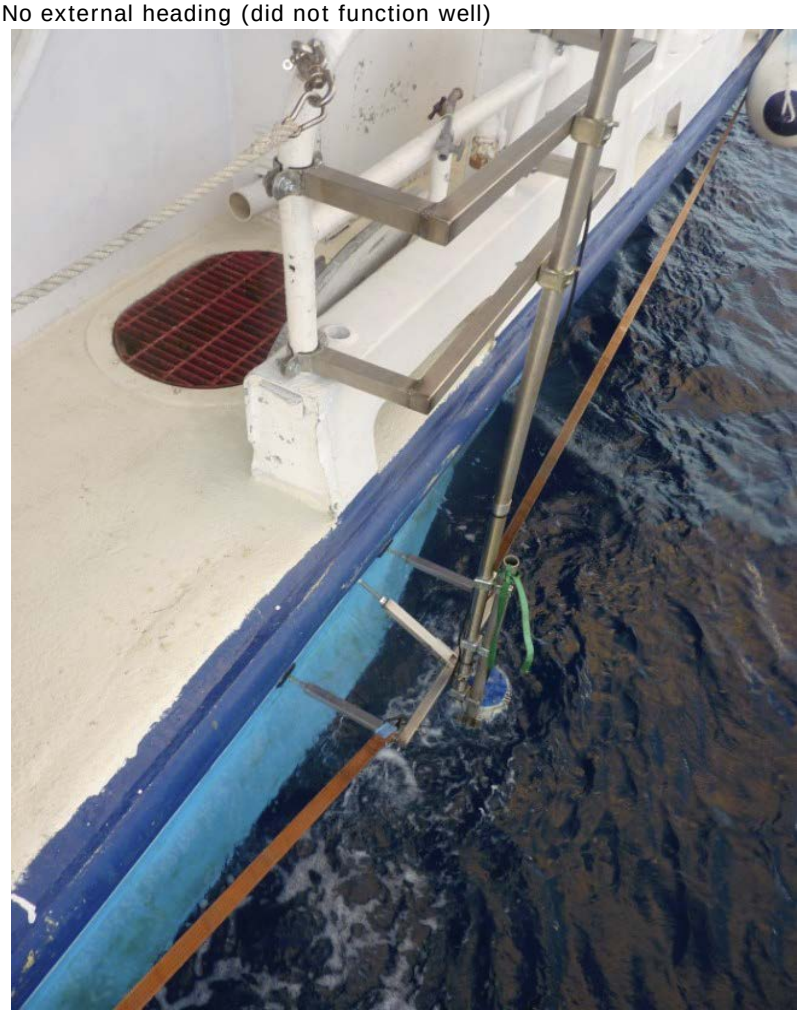


Figure 5. Acoustic Doppler Current Profiler (ADCP) attached to the research vessel.

Several spatial and temporal wind and wave conditions were observed during the expedition and written down in a logbook. Local fishermen at the Saba Bank were interviewed after the expedition about their experience and observations on wind and wave conditions. These fishermen are Ivan Hussel, Rob Hurrel and Arnold (last name unknown, lives across Ivan Hussel).

Profiles of Conductivity, Temperature and Depth (CTD), oxygen and turbidity were measured with a CTD device at some stationary locations to determine essential physical properties of the seawater.

3 Data and results

3.1 Trophic conditions for sponges on the Saba Bank

Author: Fleur C. van Duyl (see appendix A for contact information)

3.1.1 Introduction

The aim is to study the main food sources for several dominant sponges along the reef rim of the Saba Bank (east side and south side) and on a patch reef situated on top of the Saba Bank. It is hypothesized that sponges exposed to the incoming currents mainly feed on plankton and sponges in the lee of the current complement their nutrition with bank derived food (benthic primary production). This may be reflected in consistent changes in the stable isotope signature of sponges with respect to their $\delta^{13}C$ and $\delta^{15}N$ content the further the sponges occur from the reef rim and incoming current. Since benthic primary producers are usually heavier in $\delta^{13}C$ than phyto- and bacterioplankton it is hypothesized that sponges in the lee are heavier in $\delta^{13}C$ and depend more on bank food than the current-exposed fore-reef sponges along the east side. Bank-derived food for sponges comprises DOM, released by corals and benthic macroalgae. Sponges on sheltered reefs rely for a large extent on the DOC produced by the reef itself (van Duyl et al. 2011). The study aims to improve our understanding of the water quality and nutritional sources of the Saba bank sponge community.

3.1.2 Data collected

Table 2 shows which data were collected at each station.

*Table 2. Overview of the different sponge, algal and water samples taken at the 9 dive sites on the Saba Bank in October 2011. Temperature varied between 28 and 29°C. FR=fore-reef, PA=patch reef. *filter leaked. O = Niphates digitalis.*

						Algae			Sponges											
Sponge dive	Site ID	Depth (m)	Date in 2011	Local time (hr:min)	reef zone	*Lobophora sp*	*Dictyota sp*	*Agelas conifera*	*Xestospongia muta*	*Aplysina cauliformis*	*Amphimedon compressa*	*Plakortis halichondrioides*	*Callyspongia plicifera*	*Aiolochoia crassa*	Depth watersamples (m)	Inorganic nutrient sample nrs	DOC/TDN sample nrs	TOC/TN sample nrs	POM (ltrs filtered)
1	S3	25	23-okt	9:45	FR	X	X	X				X	X	X	2	1/2	1	2	8
					FR										18	3/4	3	4	9
2	S4	25		15:15	FR	X	X	X	X	X	X	X	X	X	2	5/6	5	6	14
					FR										18	7/8	7	8	12.5
3	PC	24.9	24-okt		FR	X	X	X		X		X	X		2	9/10	9	10	13.2
					FR										18	11/12	11	12	16.3*
4	CG	23.9			FR	X	X	X	X	X		X	X		2	13/14	13	14	12.3
					FR										18	15/16	15	16	6
5	TM	24	25-okt		FR	X	X	X		X	X	X		X	2	17/18	17	18	11.5
					FR										18	19/20	19	20	13
6	EP	27	26-okt	9:00	FR	X	X	X	X	X		X	X		2	21/22	21	22	12.4
					FR										18	23/24	23	24	9
7	TDF	17.5		13:45	PA		X		X	X				X	2	25/26	25	26	13.2
					PA										12	27/28	27	28	14
8	DC	25		12:00	FR	X	X	X	X	X		X	X	X	2	29/30	29	30	10.5
					FR										18	31/32	31	32	14.1
9	RG	28	28-okt	8:00	FR	X	X	X	X	X		X	O	X	2	33/34	33	34	8

The macroalga Dictyota was sampled at all sponge dive stations (n=9). Lobophora was not collected on the patch reef (sponge dive 7). That it was not readily found is most likely related to the fact that this station was 5-10m shallower than the other stations. Common sponge species collected during the first 2 dives were not always found at the dive sites during the ca. 30 min dives. However most sponge species were collected 6-8 times during the 9 sponge dives. These were *Plakortis halichondrioides, Aiolochroia crassa, Aplysina cauliformis, Xestospongia muta, Amphimedon compressa, Callyspongia plicifera, Agelas conifera* and *Niphates digitalis.*
Watercolumn samples were measured at 9 sites for inorganic nutrients (NH_3, NO_2, NO_3, PO_4), dissolved organic carbon (DOC), total dissolved nitrogen (TDN), total organic carbon (TOC) and total nitrogen (TN) at 2 depths per site. Of 8 different sponge species collected at 8 stations the stable isotope signals were determined. The particulate organic matter (POM) data of the water filtration still need to be analysed for weight and stable isotope signals. Of Devil's corner (sponge dive 9) only water-column data are available.

Underwater light measurements were made several times at the dive sites by SCUBA diving with an underwater light meter. Values still need to be corrected with a calibration factor. In Figure 6 the extinction of the light with depth is shown for Sponge dive 8 at 12:00h on 27 October. The extinction coefficient is 0.12391.

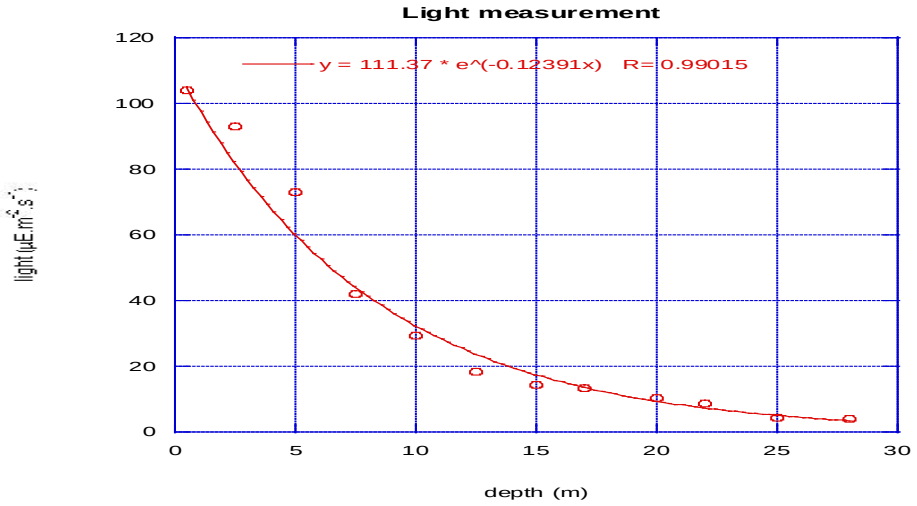


Figure 6. Light absorption with depth at sponge dive station 8.

3.1.3 Results

Inorganic nutrient concentrations were below the eutrophication threshold value of 1 µM at all stations. Dissolved inorganic nitrogen (DIN) values ranged from 0.22-0.70 µM. PO_4 values ranged from 0.010-0.024 µM. Ammonia concentration varied between 0.16-0.29 µM. Stations along the south side of the bank (sponge dives 1-3) had relatively high NO_x (NO_2+NO_3) concentrations (>0.22µM) which exceed those of ammonia compared with NO_x concentrations at the sites along the northeast side of the bank. The molar NP ratio was on average higher along the south side (stations 1-3) and Coral Garden (station 4) with values of 24-69 than at the stations further north on top and along the bank with values 14-24. DOC concentration varied between 79 and 108 µM. The organic particle load in the water was low and was on average 11 µM (st.dev. 14), based on TOC-DOC values. Differences may be related to different origin of water masses passing the Saba Bank or upwellings. This still needs to be verified with the seabird profiles and the current velocity data.

There were no clear differences in concentrations of organic and inorganic nutrients between 2 and 12-18m depth. The “deep” samples were taken in vicinity of the bottom, but exact bottom depth during water sampling was not measured.

Stable isotope signals of sponges vary depending of species. It indicates that the diets of sponges differ only slightly between species. *Xestospongia muta* has the lowest $\delta^{13}C$ value (average -19.9‰) , which may be attributed to its symbiotic cyanobacteria or that it predominantly feeds on plankton. Plankton is usually lighter in $\delta^{13}C$ than organic matter derived from the benthos (benthic primary producers). *Plakortis halochondrioides* may also partly depend on its diet from associated cyanobacteria (-19.23‰), but it may also be a plankton feeder. Its low $\delta^{15}N$ value (average1.56‰) compared to the other sponge species suggest that this sponge harbors N_2 fixing bacteria. Sponges heavier in their $\delta^{13}C$ signal may largely feed on the benthic primary production. The tested benthic macroalgae had SI (stable isotope) signals of $\delta^{13}C$ 14.168‰, $\delta^{15}N$ 0.721‰ for Lobophora and $\delta^{13}C$ -16.544, $\delta^{15}N$ 0.497‰ for Dictyota on average. The heavier sponges may rely more on benthos derived organic matter than on the plankton. Remarkable is the tendency in the sponge SI signals of $\delta^{13}C$ that the diet of the sponges appears to be slightly different between the station in the south (1-4) and the stations in in the northeast (5-9). Going north sponges tend to be lighter in $\delta^{13}C$. This was found in all sponge species. Shift in $\delta^{13}C$ were however small.

3.1.4 Conclusions and recommendations

It is possible that in the northeast part the availability of plankton is larger than in the south. However this was not supported by the TOC-DOC = POC data. It is also possible that the plankton in the northeast has a different composition with regards to species composition than the plankton along the south side.

Hypotheses which need to be tested in future research:
1. Are the apparent differences in diets between sponge species significant?
2. To what extent is the variation in the SI in sponges explained by site, inorganic nutrients (NH_3, NO_2, NO_3, PO_4) and DOC, TOC etc?
3. What is the diet of the sponges (plankton SI data will be ready soon). Which sponges mainly feed on benthic primary production (SI of *Lobophora* and *Dictyota* available) and which species prefer more plankton in their diet? Apply isotope mixing model.
4. Does the diet of sponges at the northeastern stations (5-10) differ from the southern stations (1-4)?

Fleur van Duyl thanks all who helped with sponge data collection, among others Klaus Lucke, Erik Meesters, Tuna, Hans Verdaat, David Vermaas and Ramon de Léon.

3.2 Corals

Authors: Erik Meesters and Ingrid van Beek (see appendix A for contact information)

3.2.1 Introduction

Coral recruitment is the measure of the supply of young coral colonies in the population. It can play a critical role in the resilience of coral populations through the number of individuals and the number of different species that repopulate a reef. The rate, scale, and spatial structure of larval dispersal among populations drive population replenishment, and therefore have significant implications for population dynamics, reserve orientation, and resiliency of a system.

We identified at species level the number of recruits (abundance) and the presence of adults (biodiversity). We also identified the benthic cover of live, dead and diseased corals, coralline algae, macroalgae, gorgonians, zoanthids and sponges. The results of the video are currently being analysed for percentage cover.

3.2.2 Results

Table 3 lists the 37 coral species which were identified during the expedition, 23 species as part of the coral recruit survey and 29 species as part of the coral biodiversity and coral health survey. Combining our findings with that of previous studies in 2006, 2003, 1996 and 1977 (table 3) a total of 46 species have been documented at the Saba Bank, 43 species from previous studies (McKenna and Etnoyer 2010) and 3 not previously documented species (*Agaricia fragilis, Mycetophyllia aliciae* and *Porites porites)* in the present study.
Coral biodiversity between sites ranged from 14 species at Tertre des Fleurs (TDF) and 23 species at Coral Garden (CG). *Acropora cervicornis* was present at just one site, Twelve Monkeys (TM). All other families were present at most sites except for Devil's Corner (DC) with 15 species in 7 families and TDF with 14 species in 6 families. *Eusmilia fastigiata* was absent in DC and TDF and species from the Mussidae family were also absent in TDF (Figure 7).

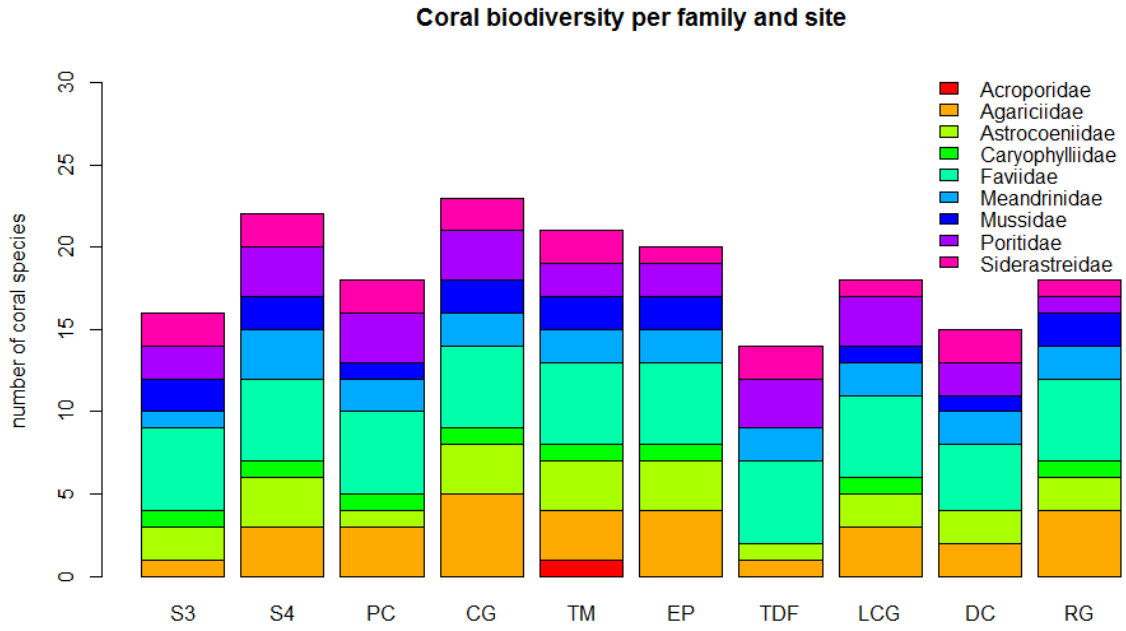


Figure 7. Coral biodiversity in number of species identified at each dive site (see table 1 for Site ID).

Table 3. Overview of the coral families and species identified at the 10 dive sites on the Saba Bank in October 2011. Recruits were identified during the recruitment survey and adults were identified during the coral biodiversity and coral health survey. Coral species documented in previous studies at the Saba Bank are also included (McKenna and Etnoyer 2010).

								2011	
Class	**Order**	**Family**	**Genus-species**	**1977**	**1996**	**2003**	**2006**	**Recruit**	**Adult**
Anthozoa	Scleractinia	Acroporidae	Acropora cervicornis	x	x	x	x		x
		Agaridiidae	Agaricia agaricites	x	x	x	x	x	x
			Agaricia fragilis						x
			Agaricia grahamae				x	x	x
			Agaricia humilis				x	x	x
			Agaricia lamarcki		x		x		x
			Agaricia sp.				x		
		Astrocoeniidae	Leptoseris cucullata/ Helioseris cucullata		x		x		x
		Caryophyllidae	Stephanocoenia intersepta/ Stephanocoenia michelini	x	x	x	x	x	x
		Dendrophylliidae	Eusmilia fastigiata	x	x		x	x	x
		Faviidae	Tubastraea coccinea				x		
			Colpophyllia natans	x	x	x	x	x	x
			Diploria clivosa	x				x	
			Diploria labyrinthiformis	x	x	x	x		x
			Diploria strigosa	x	x	x	x		x
			Favia fragum				x	x	
			Manicina areoata	x			x		x
			Montastrea annularis	x	x		x	x	
			Montastrea cavernosa	x	x	x	x	x	x
			Montastrea faveolata		x	x	x	x	x
			Montastrea franksi		x	x	x	x	
			Montastrea sp.				x		
			Solenstrea bournoni	x					
			Solenstrea sp.				x		
		Meandrinidae	Dendrogyra cylindrus	x	x		x		x
			Dichocoenia stokesi	x	x	x	x	x	x
			Meandrina brasiliensis				x		
			Meandrina meandrites		x		x	x	x
		Mussidae	Isophylia rigida	x	x		x		
			Isophylia sinuosa	x	x		x		x
			Mussa angulosa	x	x		x		x
			Mycetophyllia aliciae						x
			Mycetophyllia danaana		x				
			Mycetophyllia lamarckana	x					
			Mycetophyllia sp.				x		
			Scolymia cubensis					x	
			Scolymia lacera	x					
			Scolymia sp.				x		x
		Pocilloporidae	Madracis asperula	x					
			Madracis auretenra				x		
			Madracis decactis		x	x	x	x	x
			Madracis mirabilis		x			x	x
			Macracis sp.				x		
		Poritidae	Porites astreoides	x	x	x	x	x	x
			Porites divaricata		x		x		x
			Porites porites					x	x
			Porites sp.				x		
		Siderastreidae	Siderastrea radians					x	x
			Siderastrea siderea					x	x
			Siderastrea sp.		x	x	x		
Hydrozoa	Capitata	Milleporidae	Millepora alcicornis	x	x		x	x	
			Millepora complanata		x	x		x	
			Millepora squarrosa						
			Millepora sp.			x			
	Filifera	Stylasteridae	Stylaster roseus				x		
			Stylaster sp.				x		
			Number of species identified					23	29

Coral recruits abundance was counted for individuals smaller than 2cm (Figure 8) and 4cm (Figure 9). Interesting enough the site Tertre des Fleurs with the least coral biodiversity had the highest number of recruits (52) and species (13), after the site S4 with 46 recruits from 10 species and the site Paul's Cathedral (PC) with 32 recruits from 13 species as well.

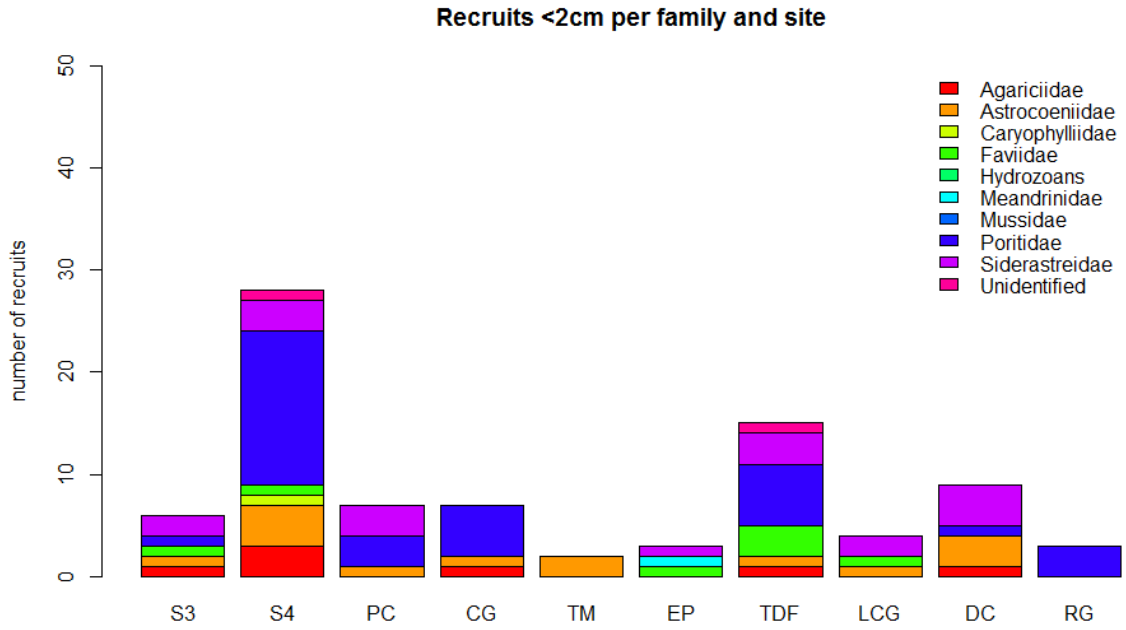


Figure 8. Coral recruitment abundance in number of individuals <2cm at each dive site (see table 1 for Site ID).

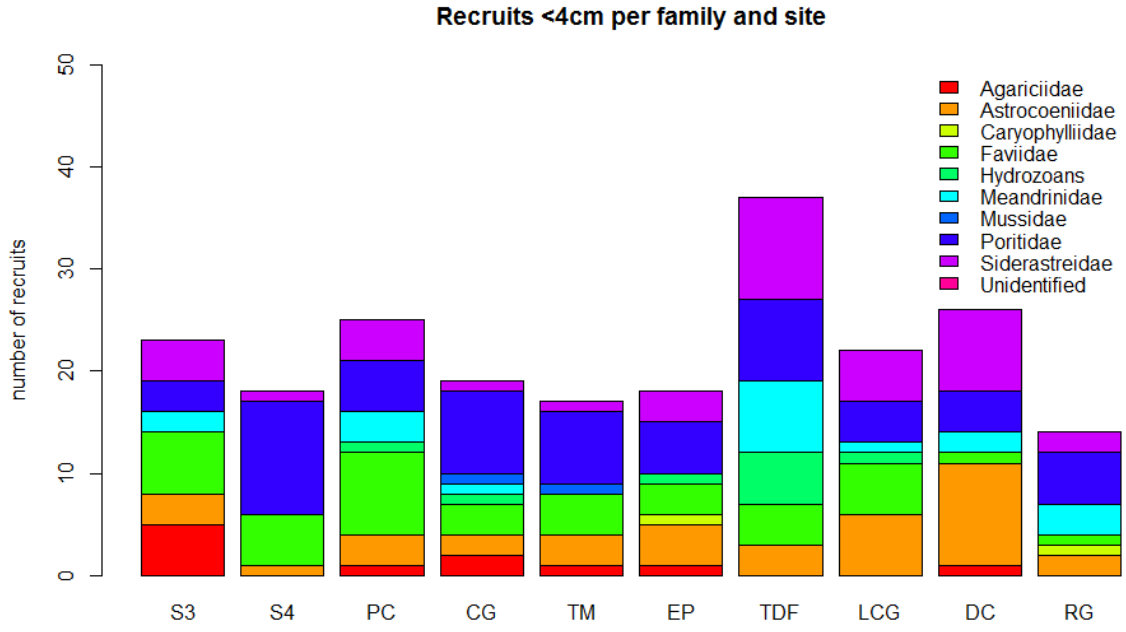


Figure 9. Coral recruitment abundance in number of individuals <4cm at each dive site (see table 1 for Site ID).

Coral health was analysed by observing the common three coral diseases in the area: Caribbean white syndrome, Caribbean yellow band and Dark spots disease. These were observed at respectively 6, 3 and 1 sites, whereby most occurred at site S4 with 6 diseased colonies and Twelve Monkeys (TM) with 5 diseased colonies (figure 10). Other threats to coral health included in the survey were bleaching and predation by fish based on observations of fish bite marks. Presence of flamingo tongue (*Syphoma gibbosum*) and sea urchins (*Diadema spp.*) were included in the survey, because *S. gibbosum* predates on gorgonians and sea urchins cause bioerosion of the coral reef framework.

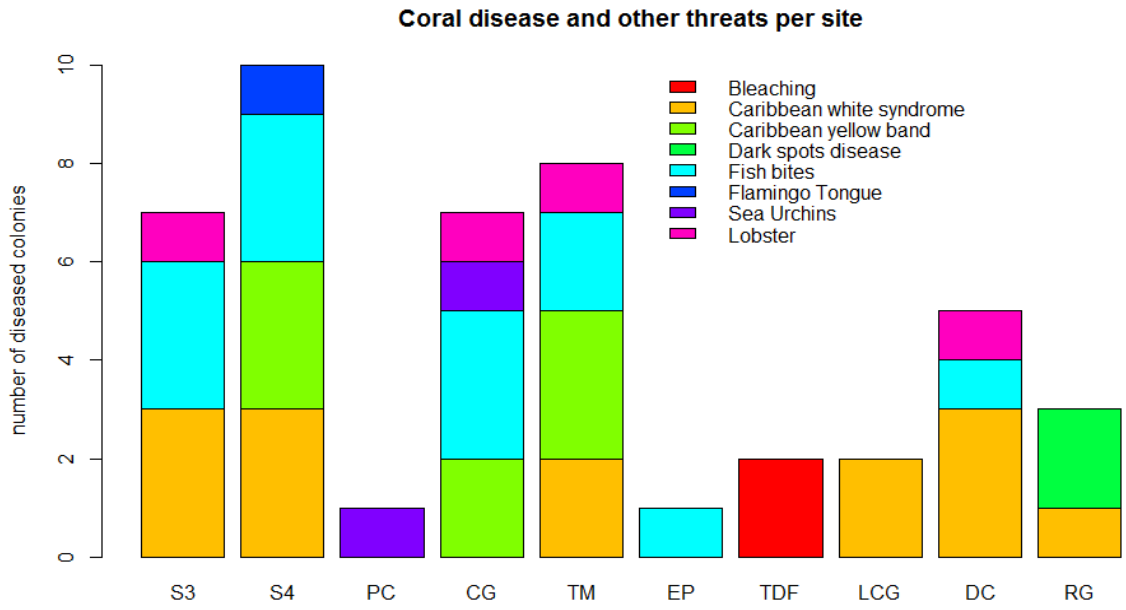


Figure 10. Observations of coral diseases (Caribbean white syndrome, Caribbean yellow band disease and Dark spots disease) and other threats to coral health (bleaching and predation by fish, flamingo tongue and sea urchins).

Erik Meesters thanks the team who collected data on coral recruits, Ramon de Léon, Paul Hoetjes, and Roberto Hensen, as well as Franck Mazeas for data collection on coral biodiversity and coral diseases and Jean-Philippe Marechal for his help with the video transects.

3.3 Reef fish

Author: Ingrid van Beek and Erik Meesters (see appendix A for contact information).

3.3.1 Introduction

The fish survey did not aim to estimate the total species richness of the fish community. Previous studies already documented 270 fish species on the Saba Bank and estimated the total species richness between 320 and 411 species (Williams et al. 2010). The aim of this survey was to estimate biomass and differences between sites for the most common species. Selection of surveyed species was based on a functional group approach. Functional groups are defined as a collection of species that perform a similar function irrespective of their taxonomic affinities (Steneck and Dethier 1994). This functional group approach has been selected for three reasons: First, it is possible to classify functional groups according to the focus and needs of the research, based on either morphological, physiological, behavioural, biochemical or trophic criteria (Steneck, 2001). Second, , it permits an examination of patterns without the need for detailed data collection at species level (Steneck and Dethier 1994). Third, it provides the

basis for managing uncertainty in conservation by maintaining not individual species, but the functional groups that support dynamic ecological processes (Bellwood et al. 2004) and sustain ecosystem services (Hughes et al. 2005). Species included in the sampling were 58 species of the main 7 families:

Herbivores: Scaridae (parrotfish), Acanthuridae (surgeonfish), Pomacentridae (damselfish)

Planktivores: Pomacentridae (chromis)

Omnivores: Haemulidae (grunts), Lutjanidae (snappers)

Piscivores: Serranidae (groupers), Carangidae (jacks)

An additional 8 predatory species from 7 families were distinguished to include in the piscivorous functional group and another 36 species from 20 families were included for the biodiversity assessment. For a list of all species is referred to appendix A.

3.3.2 Results

The models to test for observer effect (difference between the three observers, table 4), heterogeneity effect (difference in variance between transects and sites, table 5) and site effect (difference between sites, table 6) resulted in the following model selection for biodiversity, abundance and biomass:

Table 4. Test for observer effects (=difference between observers) in (A) biodiversity (B) abundance and (C) biomass between transects and sites. There is a significant observer effect (p=0.0302) in biodiversity

(A)

	Model	df	AIC	BIC	logLik	Test	L.Ratio	p-value
nlm1	1	12	148.2814	160.2302	-62.14072			
nlm0	2	11	150.9803	161.9334	-64.49015	1 vs 2	4.698868	0.0302

(B)

	Model	df	AIC	BIC	logLik	Test	L.Ratio	p-value
nlm1.dens	1	12	228.3366	240.2854	-102.1683			
nlm0.dens	2	11	226.3366	237.2896	-102.1683	1 vs 2	2.370905e-08	0.9999

(C)

	Model	df	AIC	BIC	logLik	Test	L.Ratio	p-value
nlm1.biom	1	12	372.9511	384.8999	-174.4756			
nlm0.biom	2	11	374.3660	385.3190	-176.1830	1 vs 2	3.414858	0.0646

Table 5. Test for heterogeneity effects (difference in variance between transects and sites) in (A) biodiversity (B) abundance and (C) biomass, whereby (B) and (C) are modelled with and without observer effect. There is a significant heterogeneity effect in abundance (p=0.015) and biomass (p=0.021 and p=0.0568 resp. with/without observer effect).

(A, with observer effect)

	Model	df	AIC	BIC	logLik	Test	L.Ratio	p-value
nlm1	1	12	148.2814	160.2302	-62.14072			
nlm2	2	21	154.4182	175.3286	-56.20911	1 vs 2	11.86322	0.2211

(B, with observer effect)

	Model	df	AIC	BIC	logLik	Test	L.Ratio	p-value
nlm1.dens	1	12	228.3366	240.2854	-102.1683			
nlm2.dens	2	21	225.8331	246.7435	-91.91656	1 vs 2	20.50347	0.015

(B, without observer effect)

	Model	df	AIC	BIC	logLik	Test	L.Ratio	p-value
Nlm0.dens	1	11	226.3366	237.2896	-102.1683			
nlm2c.dens2	21	223.8332	243.7478	-91.9166	1 vs 2	20.5034	0.015	

(C, with observer effect)

	Model	df	AIC	BIC	logLik	Test	L.Ratio	p-value
nlm1.biom	1	12	372.9511	384.8999	-174.4756			
nlm2.biom	2	21	371.4142	392.3245	-164.7071	1 vs 2	19.53697	0.021

(C, without observer effect)

	Model	df	AIC	BIC	logLik	Test	L.Ratio	p-value
nlm0.biom	2	11	374.3660	385.3190	-176.1830			
nlm2.biom	2	21	375.8468	395.7615	-167.9234	1 vs 2	16.51914	0.0568

Table 6. Test for site effects (difference between transects and sites) in (a) biodiversity (b) abundance and (c) biomas. All are modelled with and without transformation (square root).There is a significant site effect in abundance after transformation (p=0.0224) and biomass (p=0.0132 and p=0.021).

(A, no transformation)

	Model	df	AIC	BIC	logLik	Test	L.Ratio	p-value
nlm2a	1	12	181.779	198.5934	-78.88951			
nlm2b	2	3	177.000	181.2036	-85.50001	1 vs 2	13.22101	0.1529

(A, square root transformation)

	Model	df	AIC	BIC	logLik	Test	L.Ratio	p-value
nlm2a	1	12	53.28865	70.10302	-14.64433			
nlm2b	2	3	48.33861	52.54220	-21.16931	1 vs 2	13.04996	0.1604

(B, no transformation)

	Model	df	AIC	BIC	logLik	Test	L.Ratio	p-value
nlm2a.dens	1	12	301.8618	318.6761	-138.9309			
nlm2b.dens	2	3	300.2735	304.4771	-147.1368	1 vs 2	16.41177	0.0588

(B, square root transformation)

	Model	df	AIC	BIC	logLik	Test	L.Ratio	p-value
nlm2a.dens	1	12	130.5043	147.3187	-53.25217			
nlm2b.dens	2	3	131.8514	136.0550	-62.92570	1 vs 2	19.34708	0.0224

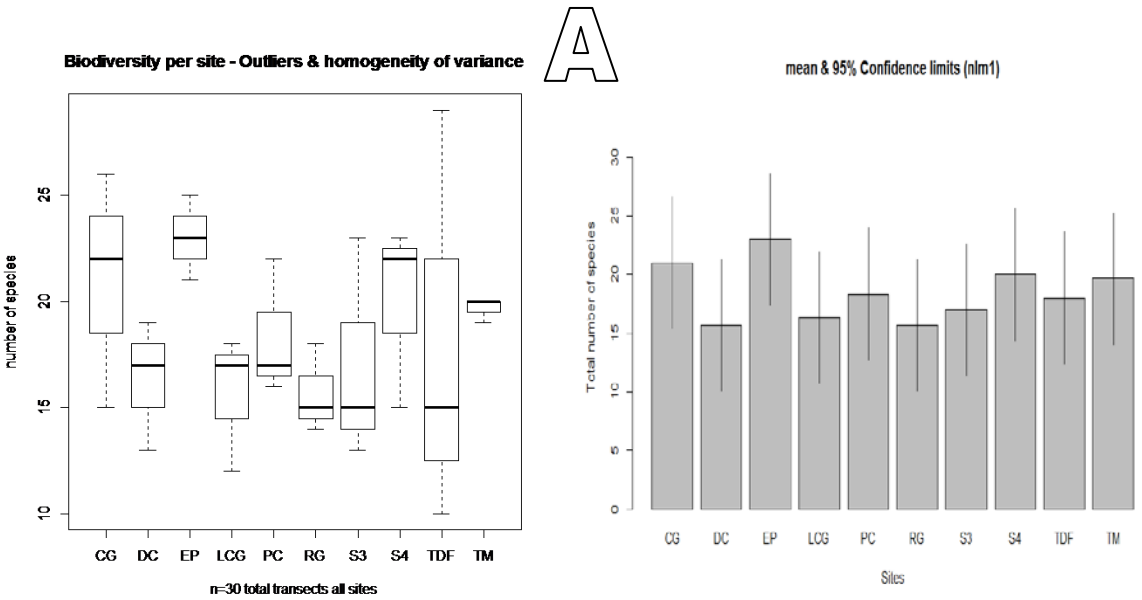
(C, no transformation)

	Model	df	AIC	BIC	logLik	Test	L.Ratio	p-value
nlm2a.biom	1	12	518.7836	535.5979	-247.3918			
nlm2b.biom	2	3	521.6570	525.8606	-257.8285	1 vs 2	20.87345	0.0132

(C, square root transformation)

	Model	df	AIC	BIC	logLik	Test	L.Ratio	p-value
nlm2a.biom	1	12	244.3877	261.2020	-110.1938			
nlm2b.biom	2	3	245.9288	250.1324	-119.9644	1 vs 2	19.54112	0.021

For biodiversity the model nlm1 was applied (figure 11A), because it fits the significant observer effect (p=0.0302, table 4A). There is no significant difference in variance between sites (table 5A), nor a significant difference between sites (table 6A). For density the model nlm2c was applied (figure 11B), because it fits the significant heterogeneity effect (p=0.015, table 5B). There is no observer effect (table 4B) and only a minor difference between sites after square root transformation (table 6B), between sites TDF and TM (figure 11B). For biomass the model nlm2 was applied (figure 11C), because it fits the almost significant observer effect (p=0.0646, table 4C) and heterogeneity effect (p=0.021, table 5C). There is a significant difference between sites (table 6C).



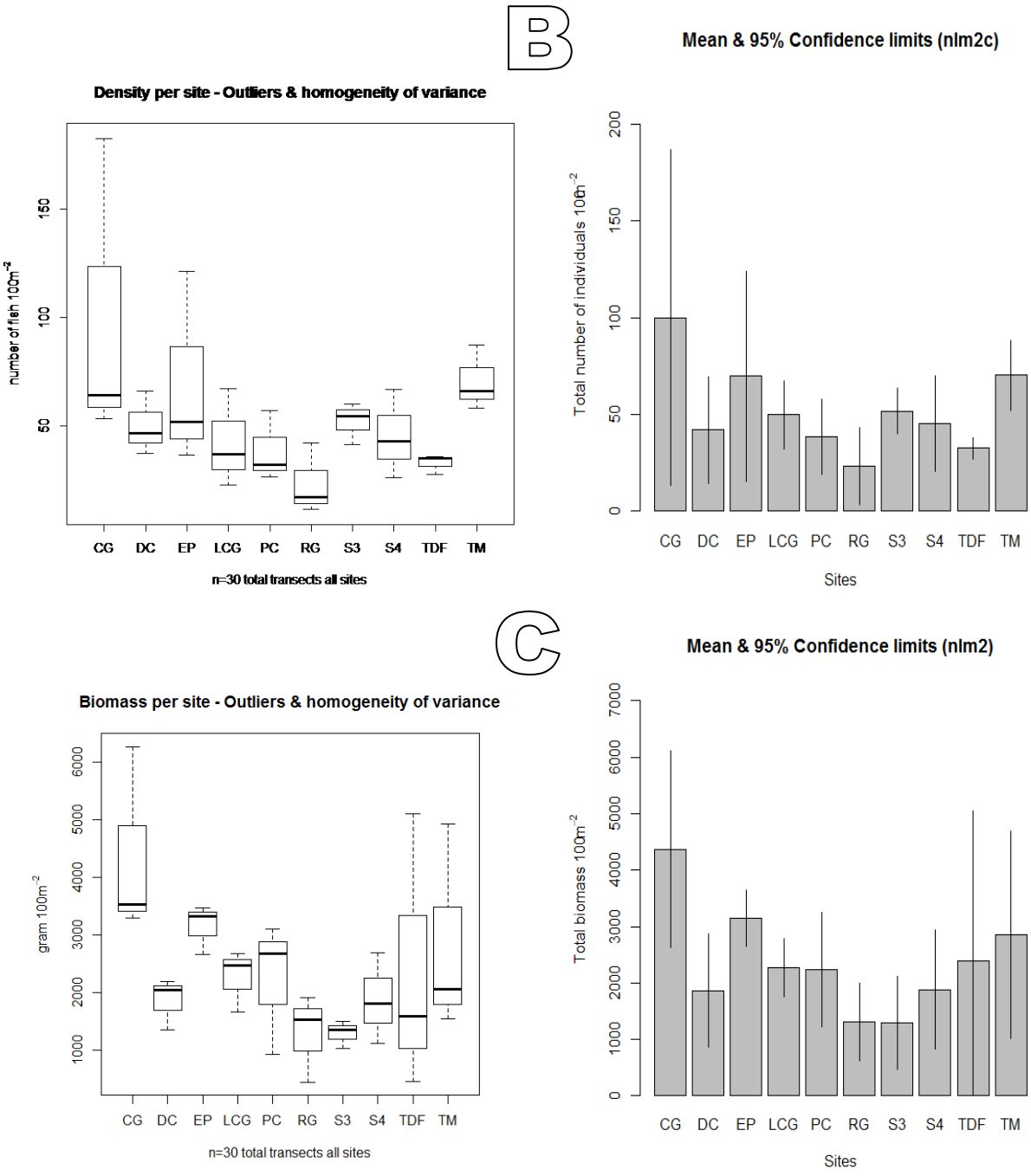


Figure 11. Differences in the mean and variance between sites for (A) biodiversity (B) abundance and (C) biomass. Left: before model fit to observer and/or heterogeneity effects. Right: after model fit to observer effect (A) heterogeneity effect (B) and both observer and heterogeneity effects (C).

Fish abundance and fish biomass varied per site between 23 and 100 fish and 1.3 kg to 4.4 kg (figure 12 and figure 13). Highest fish abundance and biomass was recorded at Coral Garden(CG) , Twelve Monkeys (TM) and Erik's Point (EP). Herbivore biomass, an important indicator for reef health because herbivory is one of the most important processes in maintaining ecological balance in the Caribbean, was not the highest at these three sites. Site S4 and La Colline aux Gorgones (LDG) have the highest herbivore biomass (table 7) which is still poor in the Healthy Reefs SIRHI index for ecosystem health (table 8). Commercial fish biomass is another indicator in the SIRHI index including Serranidae and

Lutjanidae. All sites except Erik's Point (EP) and Tertre des Fleurs (TDF) also had a poor to critical score on this indicator (table 7 and 8).

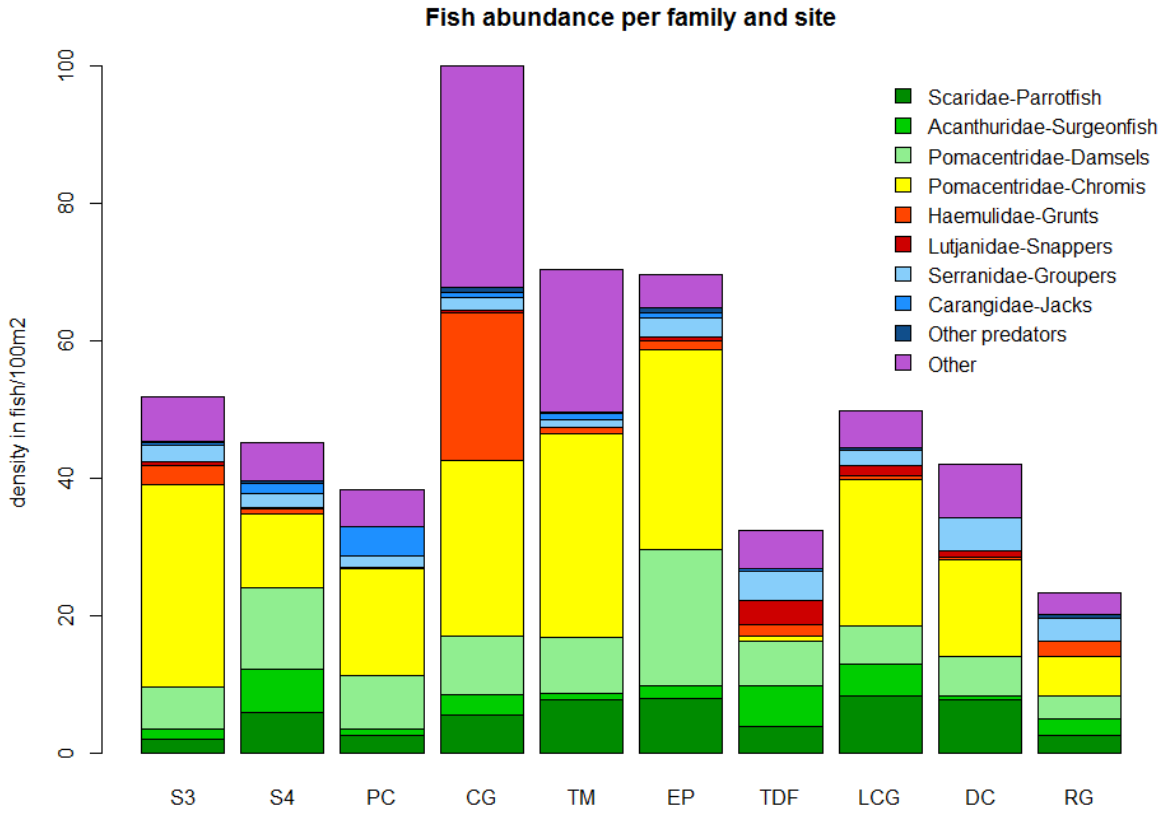


Figure 12. Fish abundance in number of fish per 100m^2 at each dive site (see table 1 for Site ID). Green are herbivores, red are omnivores and blue are predators.

Table 7. Fish biomass per functional group in grams per 100m^2 at each dive site (see table 1 for Site ID).

Biomass g/100m2	S3	S4	PC	CG	TM	EP	TDF	LCG	DC	RG
Scaridae	321.3	714.5	162.8	585.8	510.0	596.7	270.3	820.4	425.0	205.5
Acanthuridae	64.8	160.9	73.4	243.7	57.6	130.0	158.5	274.5	53.8	139.1
Pomacentridae	29.8	51.7	59.7	5.0	4.7	28.2	3.7	16.6	3.3	2.0
Herbivores	**415.8**	**927.0**	**295.9**	**834.5**	**572.3**	**754.9**	**432.5**	**1111.6**	**482.1**	**346.6**
Haemulidae	53.1	55.6	9.0	1277.0	86.4	273.3	385.9	144.6	51.4	279.2
Lutjanidae	7.7	17.0	8.5	68.0	0.0	70.4	178.5	91.4	213.5	0.0
Omnivores	**60.8**	**72.6**	**17.5**	**1345.0**	**86.4**	**343.7**	**564.5**	**236.0**	**264.9**	**279.2**
Serranidae	321.8	381.6	229.3	231.2	167.1	831.4	896.1	374.4	396.7	355.5
Carangidae	74.1	162.8	1280.3	139.9	308.3	163.5	49.0	0.0	0.0	0.0
Other predators	0.0	89.3	20.6	157.1	4.5	119.6	0.0	6.4	0.0	33.8
Predators	**395.9**	**633.7**	**1530.2**	**528.2**	**479.8**	**1114.5**	**945.0**	**380.9**	**396.7**	**389.4**
Other	426.8	250.5	395.7	1659.0	1709.7	939.9	447.9	549.6	724.6	288.5
Total biomass	**1299.3**	**1883.8**	**2239.3**	**4366.7**	**2848.3**	**3152.9**	**2389.9**	**2278.1**	**1868.2**	**1303.7**

Table 8. The SIRHI index for the evaluation of ecosystem health of coral reefs [1].

SIRHI INDICATORS	VERY GOOD (5)	GOOD (4)	FAIR (3)	POOR (2)	CRITICAL (1)
Coral cover (%)	≥40	20.0-39.9	10.0-19.9	5.0-9.9	<5
Fleshy macroalgae cover (%)	0-0.9	1.0-5.0	5.1-12.0	12.1-25	>25.0
Key herbivorous fish (g•100 m²) note: only parrotfish and surgeonfish	≥3480	2880-3479	1920-2879	960-1919	<960
Key commercial fish (g•100 m²) note: only snapper and grouper	≥1680	1260-1679	840-1259	420-839	<420

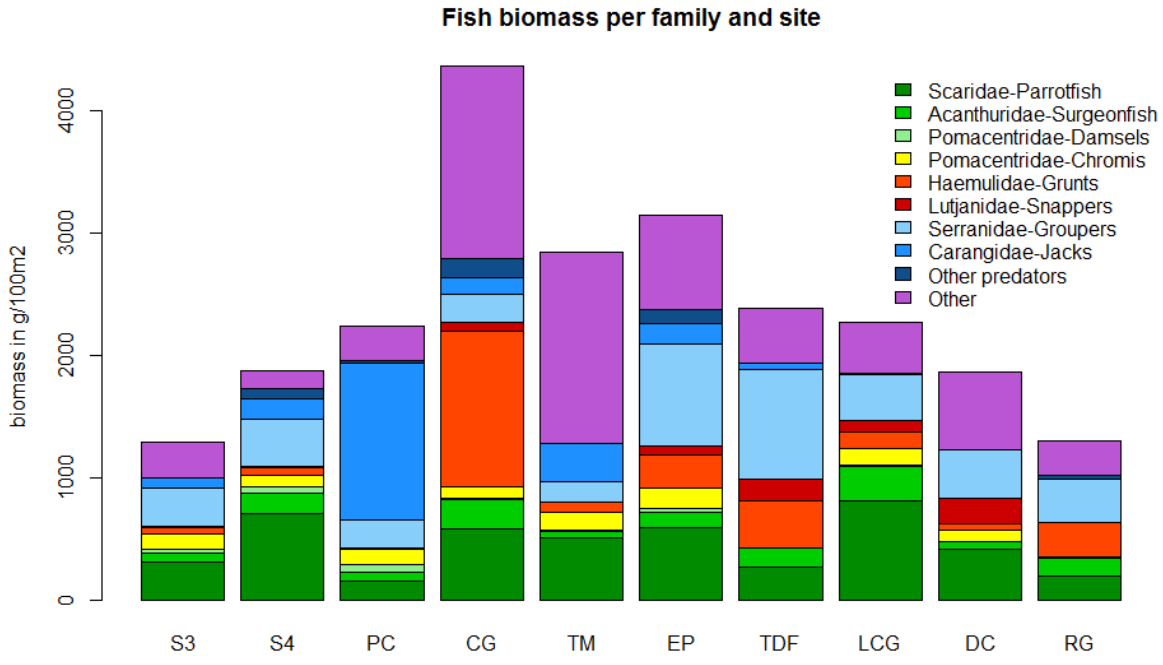


Figure 13. Fish biomass in grams per 100m² at each dive site (see table 1 for Site ID). Green are herbivores, red are omnivores and blue are predators.

3.3.3 Conclusions and recommendations

Length-weight relationships for each species are not always accurately calculated in literature. This relationship varies for the same species between locations, for example in Bohnsack and Harper (1988) the estimated values of a and b are different for the same species in Florida, Puerto Rico, St. Thomas and St. Croix. In fishbase there are also multiple recordings and the median record is taken, irrespective of whether this is the median value of a or b. In our analysis we calculated biomass based on data from Bohnsack and Harper and when species were not included there, we used Fishbase. If species were not

included in either of these sources we used data from a closely related species. This may all influence the accuracy of the biomass calculation.
In our observations we included pelagic fish passing through the transect, such as certain species of jacks (*Carangidae*). We also included three observations of large schools of fish, resulting in a higher density and higher biomass at two sites where they were observed. This concerned a school of 150 Tomtates (*Haemulon aurolineatum*) of 8.8 kb biomass in Coral Garden and two groups of 79 and 150 Creole wrasse (*Clepticus parrae*) in Twelve Monkeys and Coral Garden accounting for 2.4kg and 8.4kg biomass respectively. In addition we included many observations of small fish in size category 0-5cm of the family *Pomacentridae*, such as bicolor damselfish (*Stegastes partitus*), blue chromis (*Chromis cyanea*) and brown chromis (*Chromis multilineata*). Because of their small size this had a minor impact on the biomass and because of their presence on most sites it also did not influence differences between sites.
We did not find significant differences between the 10 sites. This can be due to the small sample size of 3 transects per site. It can also be true that there are no significant differences between sites, because we sampled similar habitats at the fore reefs of the Southeastern edge of the Saba bank.

Data collected of can also be used to analyze size structure, which is important for the role of herbivores in coral reef resilience, which varies depending on their size (Green and Bellwood 2008).

Ingrid van Beek thanks Greg van Laake and Tadzio Bervoets who were part of the team to collect data on fish communities.

3.4 Seabirds and marine mammals

Authors: Steve C.V. Geelhoed, Hans J.P. Verdaat and Klaus Lucke (see appendix A for contact information).

3.4.1 Introduction

The waters of the Caribbean Netherlands are populated by numerous marine mammal species, most of them belonging to the cetaceans (whales & dolphins). However, information on occurrence and distribution of species is scarce as shown by a review compiled by Debrot et al. (2011). The primary aim of the studies conducted by IMARES on marine mammals in these waters is an inventory of the species occurring. This included the ship-based visual pilot study and the pilot deployment of a noise logger at the Saba bank.
Besides ship-based and aerial visual surveys, passive acoustic techniques can be used to detect the presence of marine mammals. Different strategies can be employed in order to detect the vocal of echolocation signals of cetaceans, static acoustic detectors such as noise loggers or CPOD and towed hydrophones used on mobile platforms such as a survey vessel. These techniques allow to detect the presence of a cetacean, to identify the species and ideally also to conclude on the number of animals calling.

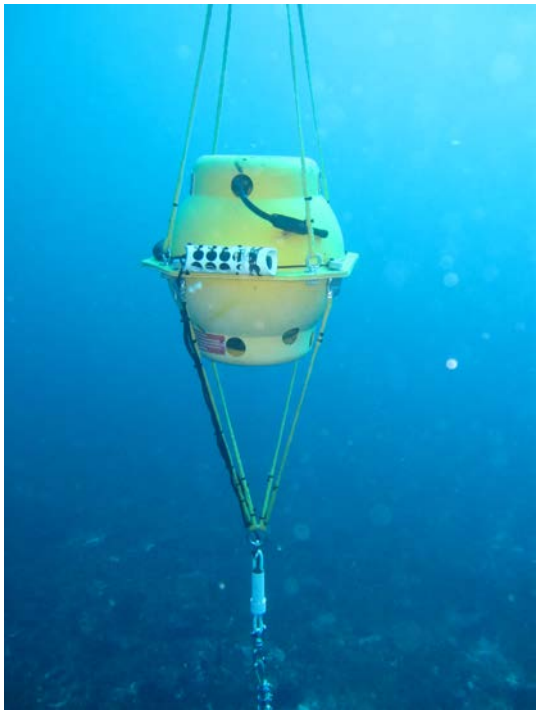


Figure 14. Noise logger deployment.

The noise logger from MARU, Cornell University, U.S.A. (figure 14) which IMARES deployed north-east of Saba Bank at a water depth of 40 m in October 2011 was supposed to be retrieved in April 2012. Despite repeated attempts to trigger the acoustic release mechanism the logger didn't float to the surface and could also not be located underwater by a diver. Initially the logger was considered being lost due to unknown reasons. In fall 2012, however, the logger was found drifting in Puerto Rico. The device has now been safely returned to Cornell University. IMARES is awaiting the download and transfer of the acoustic data to conduct an analysis of the recorded sounds.

3.4.2 Data collected

Data collected in the visual survey are presented here as a day to day report with a full list of all birds, mammals and particular pieces of floating matter seen (table 9) and a brief presentation of the results. The full cruise report of this survey has been completed as IMARES rept C062/12 (Geelhoed and Verdaat, 2012).

The survey was conducted in good to windy conditions. Due to rolling of the ship and the spray, surveys were only be conducted in sea states of 4 Beaufort or less, depending on swell height and the sailing- and wind direction. In total 51.7 km were surveyed, with a strip width of 300 m representing a surveyed area of 15.5 km^2.

On effort four bird species were seen, whereas no marine mammals were observed. Off effort, six bird species were recorded.

Table 9. Survey effort and observations of birds and marine mammals. Numbers of off effort observations are presented in classes: A = 1; B = 2-5; C = 5-25; D = > 25.

		22-oct	23-oct	24-oct	25-oct	26-oct
Total counts		21	18	7	16	7
Area (km^2)		5.0	3.8	1.0	2.8	2.9
Length (km)		16.8	12.7	3.3	9.3	9.6
Counts with no observations		8	9	3	15	6
Unidentified shearwater	*Puffinus spec.*		1			
Brown Booby	*Sula leucogaster*	5		1		
Magnificent Frigatebird	*Fregata magnificens*	1	5	1		
Peregrine Falcon	*Falco peregrinus*					1
Cliff Swallow	*Hirundo pyrrhonota*		1			
Unidentified flying fish		19	13	8	2	
Off effort						
Audubons Shearwater	*Puffinus lherminieri*				A	
Red-billed Tropicbird	*Phaethon aethereus*					A
Brown Booby	*Sula leucogaster*	B			C	C
Magnificent Frigatebird	*Fregata magnificens*	B	B	B	B	C
Lesser Yellowlegs	*Tringa flavipes*			A		
Barn Swallow	*Hirundo rustica*			A		

Audubon's Shearwater

At sea one Audubon's Shearwater was seen, off effort, on the Saba bank (17.347 W, 63.252 S) on 25 October. In the evening of 27 October, while anchoring on the southwest side of Saba opposite the cliffs of Great Hill between Ladder Point and Cape Point (17.624 W, 63.26 S), several calling individuals (ca. 5)

were heard and seen flying overhead. Birds were heard calling during flight, and apparently from the land surface, indicating the presence of prospecting or breeding birds at this site. This constitutes the first observation of shearwaters with nest indicating behaviour at this site (Kai Wulf, pers. comm.). On the east side of Great Hill, near The Bottom, vocal responses of shearwaters to nocturnal call-playback were reported in April (1) and May (3) 2004 (Collier and Brown, 2009). Thus rendering the area around Great Hill the only known site with nest indicating behaviour outside Rainforest Ravine, the only site where nesting of this species has been confirmed in recent decades.

Red-billed Tropicbird
Observations of Red-Billed Tropicbirds were restricted to the near-shore waters of Saba on 28 October. Further offshore, only one observation was made, off effort, on the Saba Bank on 26 October.

Brown Booby
During the survey Brown Boobies were restricted to areas between the Saba bank and the island of St. Eustatius. On the crossing from Saba to St. Maarten on 28 October at least 8 individuals accompanied the ship, hunting for flying fish.

Figure 15. Left: Adult Brown Booby; right: flying fish. (Pictures: Hans Verdaat).

3.4.3 Conclusions and recommendations

The vessel used was not suited for dedicated seabird and cetacean surveys; the observation height was too low, and the ship rolled too much even with low swell. Ship speed during surveying was lower than the prescribed 10 knots; in theory leading to an over-estimation of the density of flying birds. Nevertheless, the gathered data fit the seasonal pattern observed in seabird species and densities described for Guadeloupe, which shows a distinct dip from August-October (Levesque and Yésou, 2005). The lack of cetaceans records reflects the findings of the review of cetacean records in the EEZ of the Windward islands by Debrot et al. (in press), who described only two records of cetaceans in October, both on the Saba bank. Since it is known that the waters of the Caribbean Netherlands are populated by numerous marine mammal species, more research is needed to collect information on occurrence and distribution of species. The analysis of the acoustic data of the noise logger will be an important initial step forward.

3.5 Water velocity

Authors: David Vermaas (see appendix A for contact information) and Niels de Graaf, MSc Hydrology and Quantitative Water Management, under supervision of Ton Hoitink of Wageningen University.

3.5.1 Introduction

The objective of the research with the Acoustic Doppler Current Profiler (ADCP) was to get a first impression of wave characteristics on the Saba Bank. The data obtained were used and analysed as part of a study by De Graaf (2012) to investigate the spatial and temporal wind and wave conditions on the Saba Bank.
An ADCP could be applied for velocity and discharge measurements in rivers, as well as for current measurements in ocean and estuary. Measurements could be obtained with fixed-vessel measurements (stationary) or with moving-vessel measurements (transects). The best way to quantify the velocity and current profiles is with stationary measurements as boat velocity and occurring non-homogeneity of the flow could affect measurements (Muste et al., 2003a; Muste et al., 2003b in De Graaf, 2012) and because the measurements are relative to the GPS position of the ADCP, which is easier to determine if the device is fixed. Measurements are obtained with the aid of sound signals. The ADCP transmits sound signals through the water column, which will be reflected by small particles. Due to the small size of these particles the assumption is made that their velocity is the same as the water velocity. The reflected sound has a slightly different frequency; this received shift is used for calculating the velocity. The difference in frequency of a periodic event is known as the Doppler Effect.

3.5.2 Data collected

ADCP measurements on the water velocity resulted in a number of useful data. See figure 16 for the measurement locations.

- Transects during 13 hours (with an interval of 1 hour) between location A and B (ca. 1 km) and back. An additional 2 measurements were performed on this same transect, with more time in between, to stretch this data set to 24 hours.
- Time series of at minimum 7 hours (overnight), on a relatively stationary location, at locations B, C, D, and E. These locations are somewhat more on the reef flat than on the reef crest.
- Time series of ca. 2 hours, on a relatively stationary location, at locations F to N. At these locations a dive was performed too.
- A transect through the deep channel between the Saba bank and the island Saba. This transect was done 4 times, but unfortunately only one of them is recorded with a proper GPS signal. Additionally in two of these transects, Klaus Lucke recorded the GPS-signal at the same time.
- Various transects between the locations. Most of them are not useful because the waves were too high, the boat was sailing too fast or the track was not interesting. However, some of them are useful. In particular, the transect between location L and M can be useful.

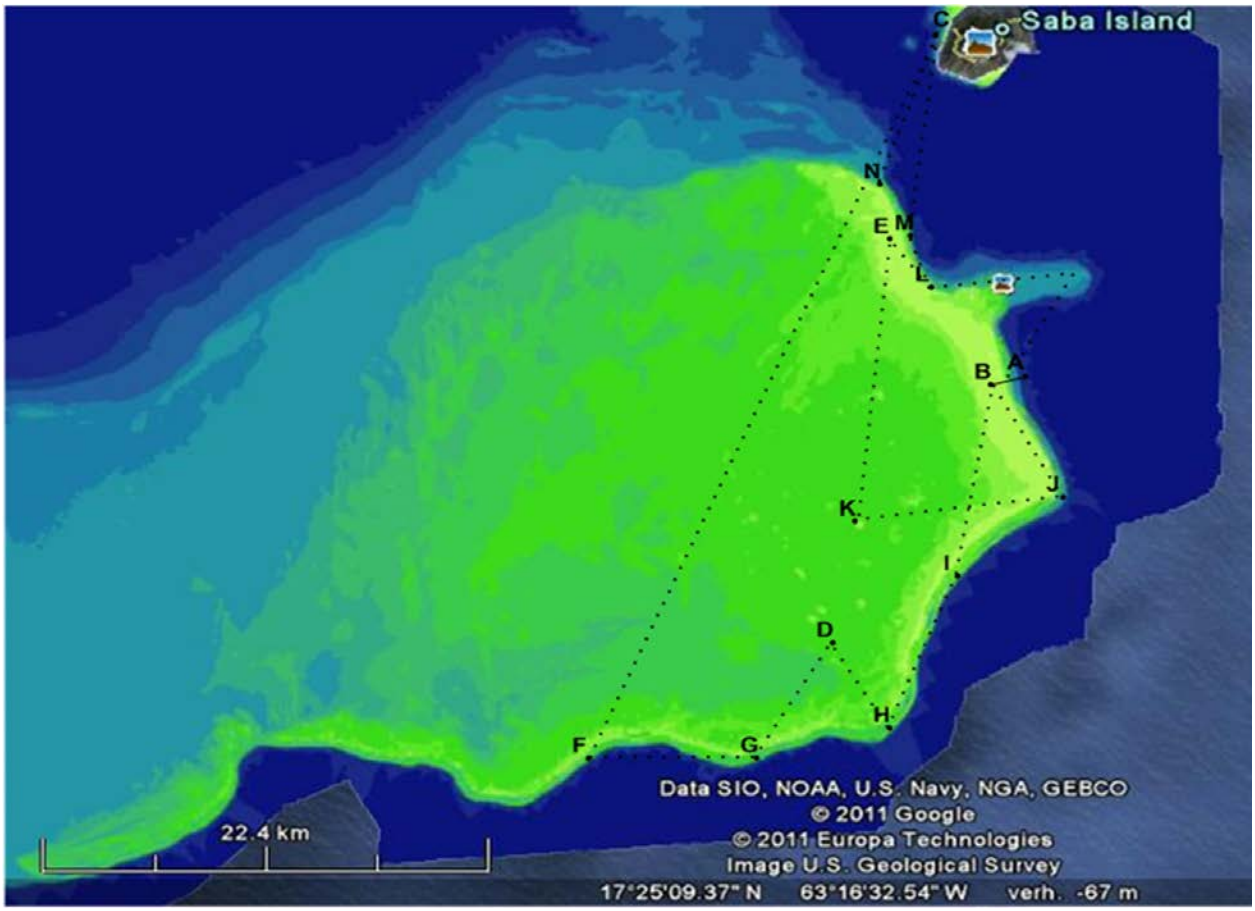


Figure 16. Measurement locations and transects with the Acoustic Doppler Current Profiler (ADCP).

Observations during ADCP measurements were made under differing weather and sea state conditions. The direction of waves and the wind was in general from the east. The direction of the currents was not so consistent as it was for wind and waves. Observed current directions were northward, eastward, southward and west-south westward. The wave height were in the order of 1.0 and 1.2 metre, with a period of 5 seconds. Currents were occasionally over 1 m/s. Some say this is caused by tidal effects (John, engineer on Caribbean Explorer, pers.comm.), others say these high currents occur during long wavelength swell and of course under hurricane conditions (Roberto Hensen, pers.comm.). Autumn is hurricane season and during this period sea state conditions are more variable. This year there was almost no harm from hurricanes. During winter, a steady quite strong wind (and thus waves) is present (Jean-Francois Chabot, pers. comm).

According to fishermen who know the entire Saba Bank well, but in particular fish north or south of the Poison Bank close to Coral Garden (dive 4 of this expedition) and on the west side of the bank, reveal that in general the current is towards the north-east (northern part of the bank), south-east (southern part of the Bank), towards the north and towards the north-east (Arnold, pers.comm.). The wind comes from the north-east or south-east. According to them, from May to August the currents are strong but the wind is calm. At the end of November, the 'northern swell' comes in, waves with a long wave length (in the order of 5-50 metre). After winter time the currents and sea calm down, from May on, the strong currents will come in again.
The velocity magnitude could be high, GPS measurements showed that the boat could drift over 3 knots (ca. 1.5 m/s) by the current (Rob Hurrel, pers.comm.). A clear relation between wind and current is absent.

3.5.3 Results

Preliminary results of the study by De Graaf (2012) indicate that the currents on the Saba Bank are wave driven instead of tidal current driven. Tides probably do not influence the velocity profile on the Saba Bank due to an amphidromic system (Figure17) centered south of St. Croix and the Dominica (Kjerve, 1981 in De Graaf, 2012). An amphidromic system is a wave pattern which rotates around an amphidromic point without tidal influences. An amphidromic point is the point where cotidal lines, simultaneously occurring lines of high tides, intersect. At the center of an amphidromic point the tidal range approaches zero and with increasing distance from the amphidromic point the tidal range increases as well.

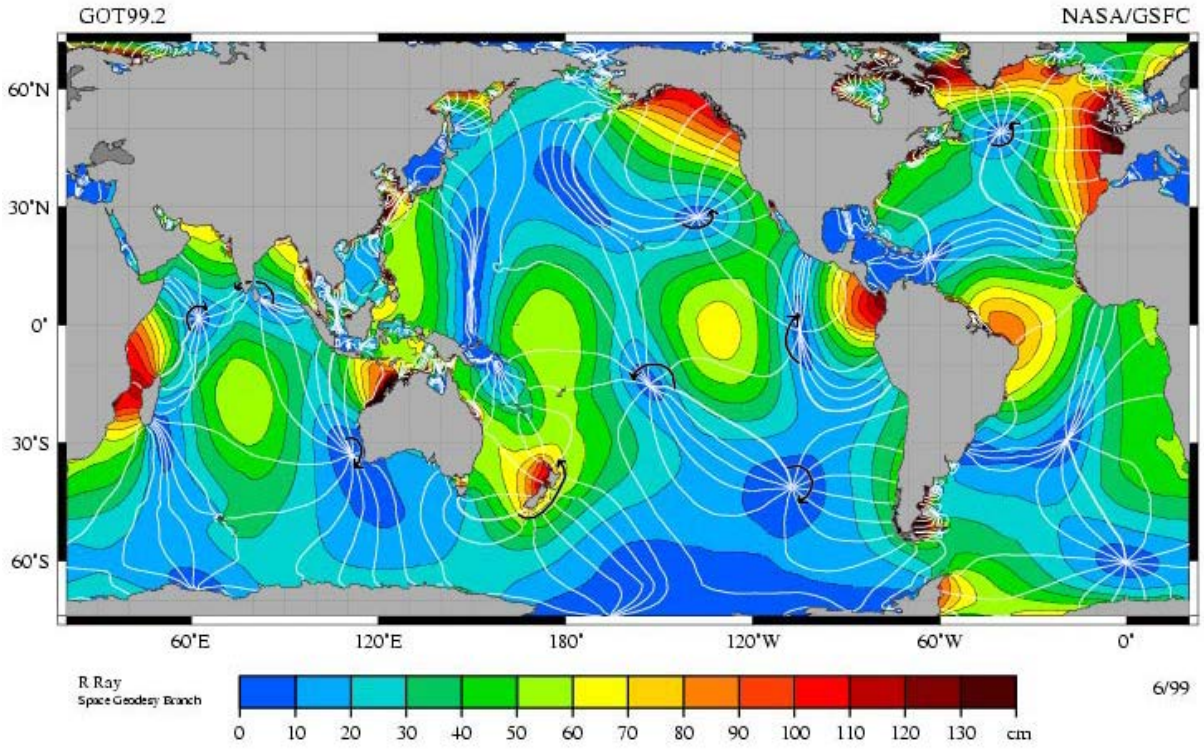


Figure17. Amphridomic systems in the world, cotidal lines and amprhidomic points are schematized on the tidal range (from http://www.iupui.edu/~g115/mod12/lecture07.html, October 2012 in De Graaf, 2012).

Tides are highly periodic and could be simulated as the summation of several tidal constituents. Research in these fundamental partial constituents in the Caribbean was done by Kjerve (1981). The fundamental tidal constituents of the Caribbean are listed in Table 10.

Table 10. List of fundamental tides where the number 1 stands for diurnal (daily) constituents and number 2 stands for semi-diurnal (half day) constituents (from Kjerve, 1981; Masselink et al., 2010 in De Graaf, 2012).

Constituent	Frequency in hr^{-1} (period in hr:min:sec)	Description	Amplitude (mean in cm.)
M2	0.081 (12:25:12)	Principal lunar	10.4
S2	0.083 (12:00:00)	Principal solar	3.1
N2	0.079 (12:39:28)	Elliptical lunar	2.8
K2	0.084 (11:58:33)	Lunar/solor declinations	-
K1	0.042 (23:55:40)	Principle lunar/solar	8.0
O1	0.039 (25:49:26)	Principle lunar	5.7
P1	0.042 (24:04:32)	Principal solar	2.7

Kjerve (1981) concluded that the mean tidal component amplitudes, diurnal and semi-diurnal averaged out over the entire Caribbean, are less than 15 cm. Local conditions may at times entirely mask the tidal response due to the small range of Caribbean tides.

In theory the above indicates that tides do not influence the velocity profile on the Saba Bank because of its location near the center of an amphidromic system. The data of the ADCP measurements were analyzed to confirm this for the Saba Bank. The analysis of ADCP transect measurements is still in progress and is more complicated as it needs to be corrected for the movement of the vessel. The analysis of ADCP stationary measurements was limited to measurements with a minimum exposure time of at least six hours. Most measurements at the dive sites had a duration of less than three hours, therefor only three measurements (with a duration of 7, 8 and 9 hours) were analyzed (figure 18).

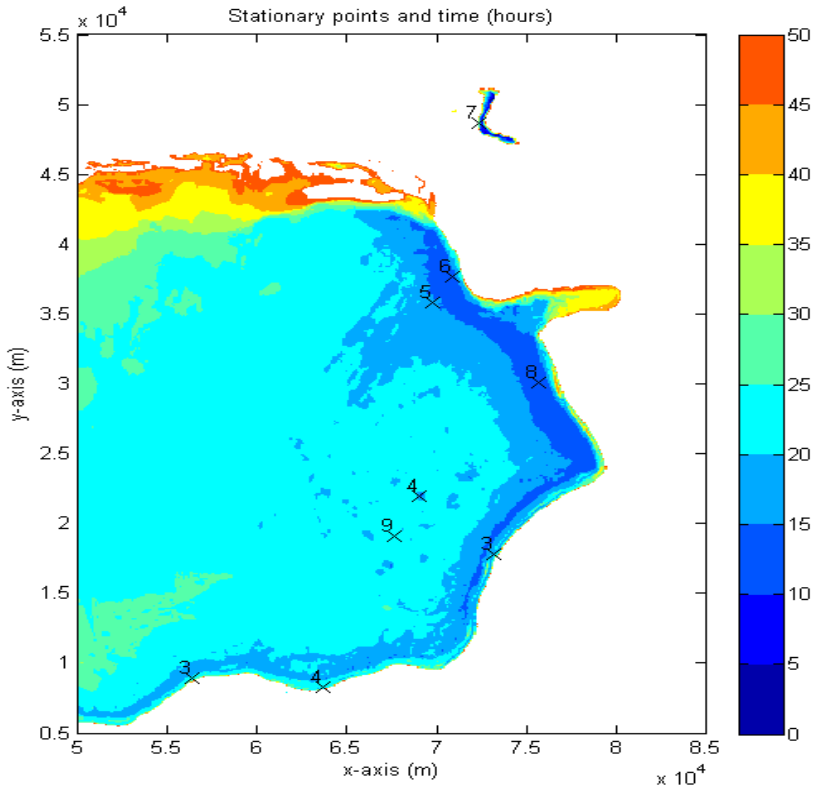


Figure 18. Stationary ADCP measurement locations with duration longer than 3 hours (from De Graaf, 2012).

A Progressive Vector Diagram (PVD) and the direction of the flow were analysed for these three locations. The PVD shows the track which a water particle would have been moved when currents are uniform (Carlson et al., 2010 in De Graaf, 2012).
The three locations show a different track for each point, also the magnitude of the vectors differs in size (Figure 20). From the PVDs it appears that the flow comes from the north-east and south-east and travelled combined in western direction. This is only in contrast with the PVD of the 8 hours measured location. At first the track of this diagram travels to the east and after a while it is bending back to west, which could be occurred due to turbulence.
Looking at the vector diagrams (figure 19) the remarkable fact appears that the magnitude decreases from north (7-hour measure point) to south (9-hour measure point) with intermediate magnitude at the 8-hour measure point (left hand. The direction of the vectors represents the velocity components averaged out over the entire depth. These vectors were split up into two components, one from surface

until halfway the bottom and the other one from halfway the bottom until the bottom. The vector diagrams of these two components shows minor deviation in the direction.

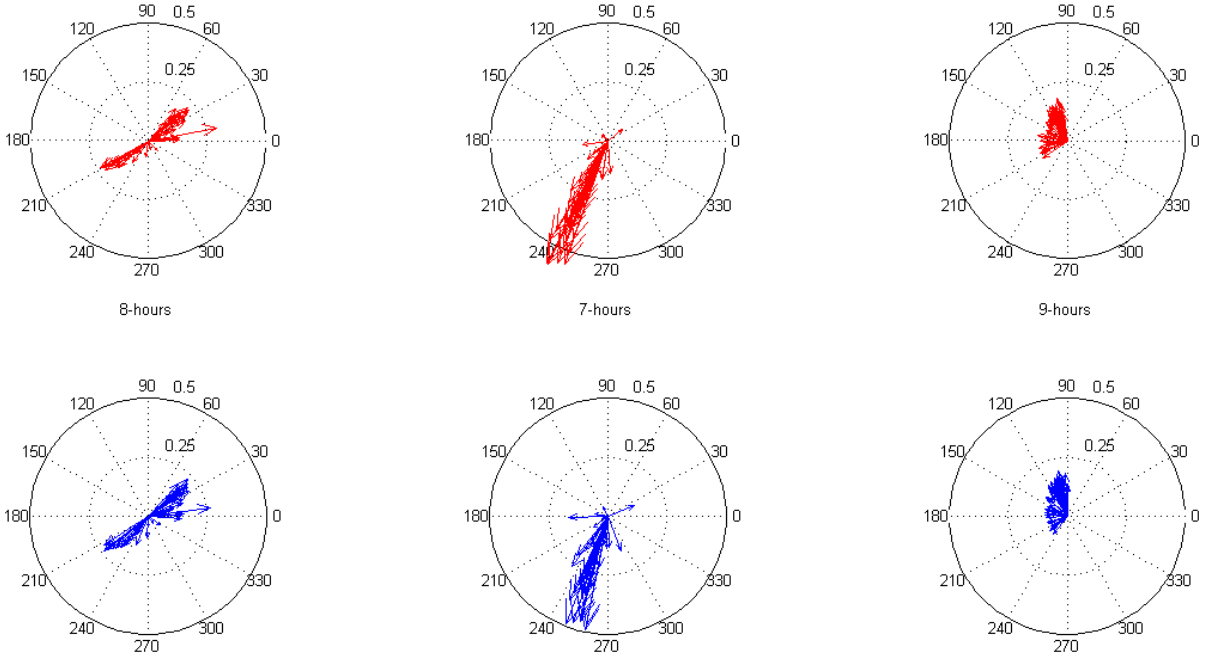


Figure 19. Vector diagrams of velocity components at the 8-hour (left), 7-hour (middle) and 9-hour (right) measuring points. Top: the red color represents the velocity vector for the surface until halfway the bottom. Bottom: the blue color represents the vector from halfway the bottom until the bottom. The length of the arrows indicates the magnitude of the current velocity (from De Graaf, 2012).

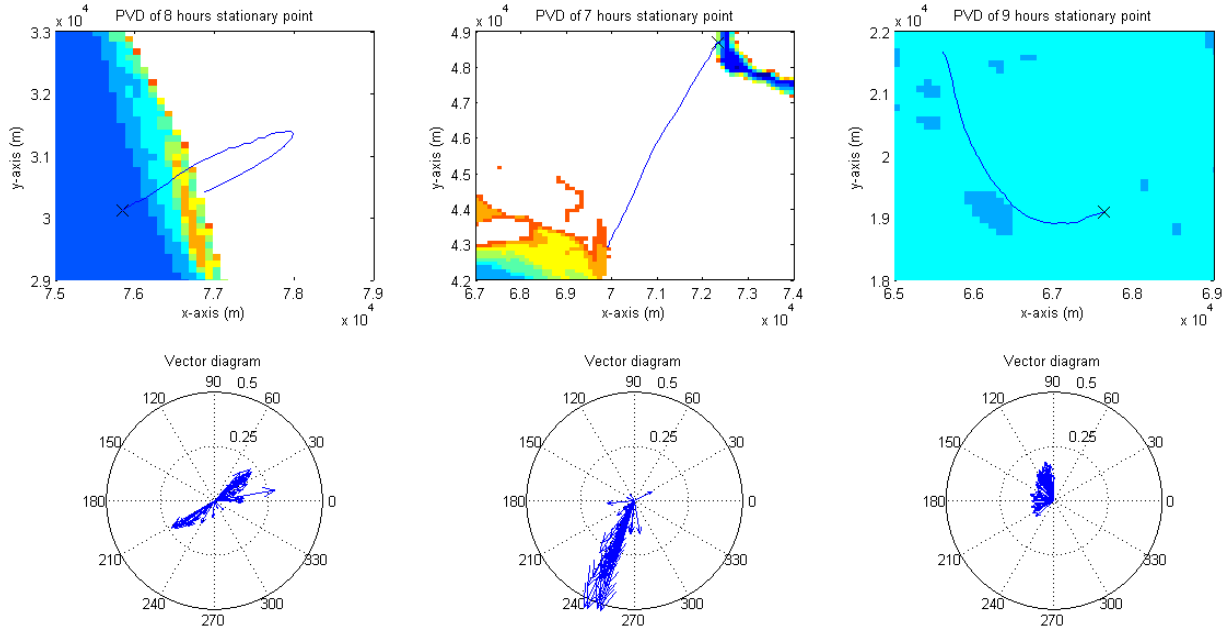


Figure 20. Top: Projective Vector Diagrams (PVD) of the 3 stationary locations were plotted, the black cross represents the start location of each stationary point. Bottom: Vector diagrams of the velocity components were plotted (from De Graaf, 2012).

3.5.4 Conclusions and recommendations

Based on the data collected the following hypotheses were made:

1. Coral reefs are limited by strong currents, there is only coral growth in deeper water.
2. Waves (swell and hurricanes), caused by wind, prevent growth coral in shallower places.
3. Direction of waves and direction of current are often conflicting, causing sometimes a turn in current direction over depth.
4. There is probably no stratification. Maybe extra turbidity on the first day occurred due to algae and other bio-organisms in the top layer (Fleur van Duyl, pers.comm.).
5. Salinity is quite high and is uniform in depth.
6. Tidal effects are relatively small.
7. Tidal current flows around the bank, not over the bank (lowest current on shallow parts).

It is hard to provide representative output for the entire reef based on these three measurement locations. Therefore more and longer field measurements are required to give a representative overview about the flow profiles and currents. It is recommended to employ a fixed ADCP measurement device which is attached to the bottom to collect a longer time series of current velocity.

4 Conclusions and recommendations

Although some of the data are still in the process of being analysed (ADCP transect measurements of water velocity, Particulate Organic Matter (POM) data of the water filtration, films of the benthic cover and acoustic data of the marine mammal noise logger) some preliminary conclusions can be drawn from the results of the various area of research.

The sponges and water quality research concluded that inorganic nutrient concentrations were below the eutrophication threshold value of 1 µM at all stations and that there were no differences in concentrations of organic and inorganic nutrients between 2 and 12-18m depth. Stable isotope signals of sponges varied between species, indicating that the diet of sponges differs only slightly between species. Furthermore, results indicate there is a possibility that the plankton in the northeast has a different species composition and is available in higher quantities than on the south side.

Preliminary results of the ADCP research indicate that the magnitude of the water velocity decreases from the most northern measurement point (near Saba, point 7 in figure 18) to the most southern measurement point (at the reef plateau, point 9 in figure 18). Furthermore literature indicates that tides do not influence the velocity profile on the Saba Bank due to its position relative to an amphidromic system. This implies that the currents on the Saba Bank are wave driven instead of tidal driven. The latter might mean that there are upwellings which might explain the possibly higher plankton concentrations in the northeast.

In total 36 coral species were identified, increasing the total number of coral species which have been documented from the Saba Bank from 43 species to 45 species. Coral biodiversity between sites ranged from 14 species at the one site sampled on the reef platform to 23 species at a site named Coral Garden located at the fore reef. We did not find significant differences in the fish communities between the 10 sites. This can be due to the small sample size of 3 transects per site. It can also be true that there are no significant differences between sites, because we sampled similar habitats at the fore reefs of the south-eastern edge of the Saba bank. Data collected on the fish communities can also be used to analyse size structure, which is important for the role of herbivores in coral reef resilience, which varies depending on their size.

The visual survey of seabirds and marine mammals resulted in a limited number of seabird observations and no marine mammal observations. The first fits our expectations based on the seasonal pattern of observed seabird species and densities in Guadeloupe, where a a distinct dip in abundance occurs from August to October. The latter reflects the findings of a review of cetacean observations in the Dutch EEZ which described only two cetacean records during October. Since the waters of the Caribbean Netherlands are populated by numerous marine mammal species, more research is needed to collect information on occurrence and distribution of species. For dedicated visual surveys for seabird and cetaceans with a more suitable vessel is required with a proper observation height and ship speed.

We recommend further research into the sponges community to test for possible differences in diet between sponge species, depending on the location and the potential difference in food source from planktonic or benthic primary production. More research into the current velocity is required based on more and longer field measurements to yield a representative overview of the flow profiles and currents. This can best be done by employing a fixed ADCP measurement device which is attached to the bottom to collect a longer time series of current velocity.

5 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 1th of April 2017 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation.

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7 Justification

Rapport number C018/13
Project Number: 4308201109

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

Approved: Dr. A. Debrot
Researcher

Signature:

Date: May 14th 2013

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

Signature:

Date: May 14th 2013

Appendices

Appendix A: Research expedition members

	Name	Role	Organisation and function	Contact information
1	Erik Meesters	Expedition leader, video transects and CTD	Researcher IMARES	erik.meesters@wur.nl
2	Fleur van Duyl	Nutrients, sponges and light measurements	Researcher Royal Netherlands Institute for Sea Research (NIOZ)	Fleur.van.Duyl@nioz.nl
3	David Vermaas	Currents, support for CTD and light measurements	Researcher WETSUS centre of excellence for sustainable water technology	david.vermaas@wetsus.nl 06-14310197
4	Klaus Lucke	Acoustics of marine mammals, diving support	Researcher IMARES	klaus.lucke@wur.nl
5	Hans Verdaat	Expedition logistics, seabirds and marine mammals	Researcher IMARES	hans.verdaat@wur.nl
6	Steve Geelhoed	Seabirds and marine mammals	Researcher IMARES	steve.geelhoed@wur.nl
7	Ramon de Léon	Coral recruits	Marine Park manager STINAPA Bonaire	marinepark@stinapa.org
8	Roberto Hensen	Coral recruits	Head of department LVV St. Eustatius	rrhensen@ymail.com
9	Paul Hoetjes	Coral recruits	Ministry of Economic Affairs Rijksdienst Caribisch Nederland Bonaire	paul.hoetjes@rijksdienstCN.com
10	Ingrid van Beek	Fish communities	IMARES	ingrid.vanbeek@wur.nl
11	Greg van Laake	Fish communities	Marine Park ranger Saba Conservation Foundation	sabapark.ranger@gmail.com
12	Tadzio Bervoets	Fish communities	Marine Park manager St. Maarten Nature Foundation	manager@naturefoundationsxm.org
13	Kai Wulf	Cruise film maker	Marine Park manager Saba Conservation Foundation	sabapark.manager@gmail.com
14	Franck Mazeas	Coral diseases and coral biodiversity	Initiative Française pour les Récifs Coralliens (IFRECOR) Guadeloupe	f.mazeas971@orange.fr
15	Jean-Philippe Marechal	Video transects	Director of l'Observatoire du Milieu Marin (OMM) Martinique	marechal.jean@gmail.com
	Jean-Francois Chabot	Captain of the boat	Explorer Ventures	jfchabot@explorerventures.com

Appendix B: Common sponges of the Saba Bank

Figure 1. Agelas conifera (Brown tube sponge).

Figure 2. Aplysina cauliformis (Row pore rope sponge).

Figure 3. Aiolochroia crassa (Yellow throated tube sp).

Figure 4. *Callyspongia plicifera* (Azure vase sponge).

Figure 5. *Xestospongia muta* (Barrel sponge).

Figure 6. Amphimedon compressa? (Erect rope sponge)
Sponge taxonomist is being consulted for verification.

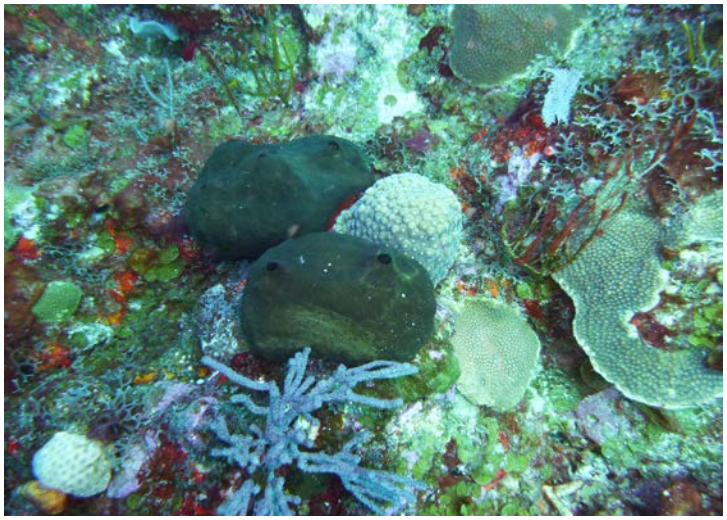

Figure 7. Plakortis halichondrioides? (Dark mound sponge) Sponge taxonomist is being consulted for verification.

Figure 8. Niphates digitalis (Pink vase sponge).

Appendix C: Common coral recruits

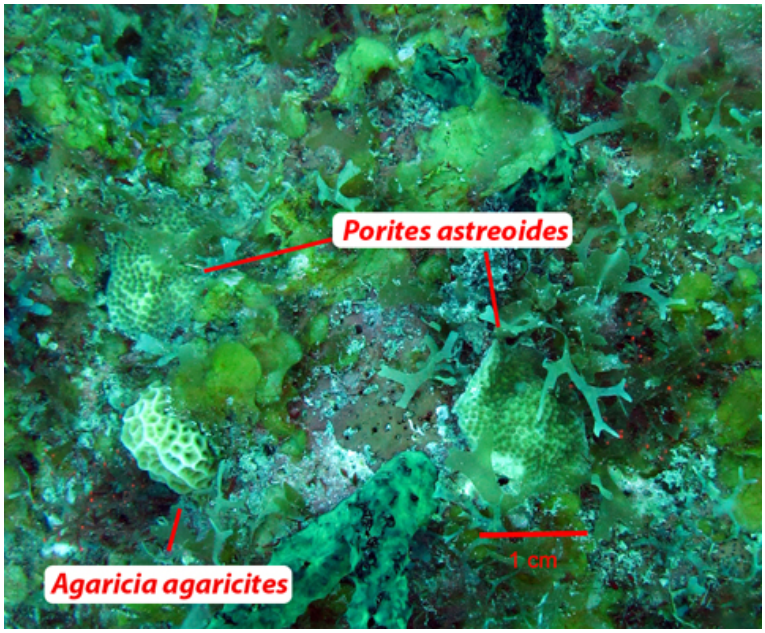

Figure 1. Agaricia agaricites and Agaricia astreoides.

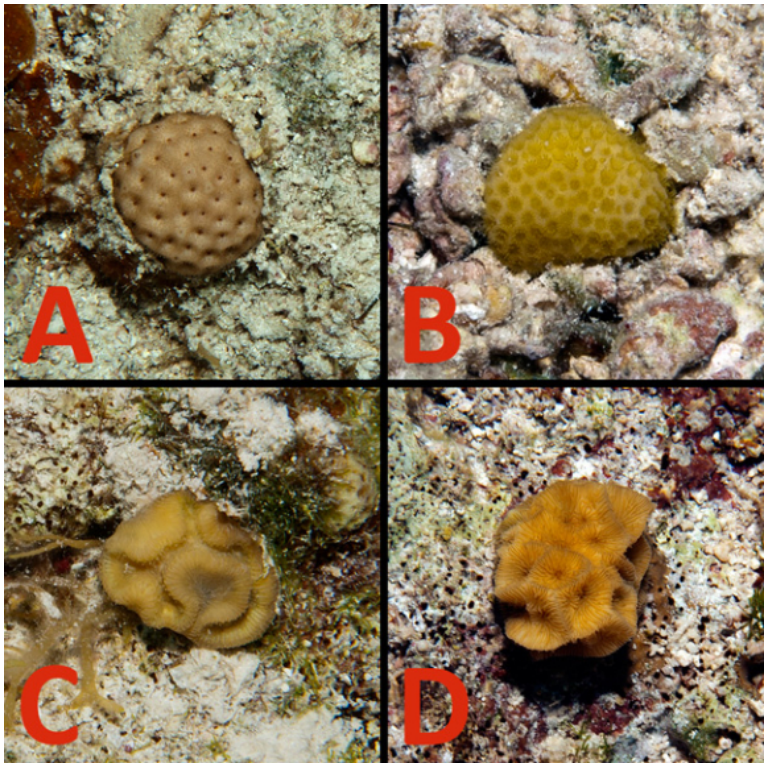

Figure 2. A) Siderastrea B) Porites C) Diploria D) Agaricia.

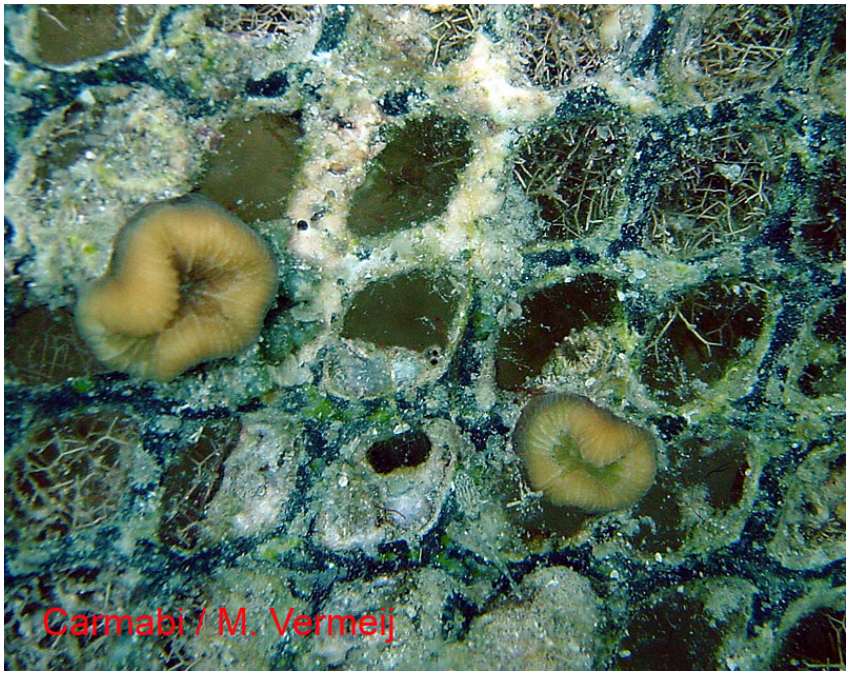

Figure 3. Diploria clivosa.

Appendix D: Fish species included in the monitoring

No.	Code	Common name	Scientific name
	PARROT		
1	S_STOP	Stoplight parrotfish	*Sparisoma viride*
2	S_QUEE	Queen parrotfish	*Scarus vetula*
3	S_PRIN	Princess parrotfish	*Scarus taeniopterus*
4	S_STRIP	Striped parrotfish	*Scarus iserti/croicensis*
5	S_RAIN	Rainbow parrotfish	*Scarus guacamaia*
6	S_REDB	Redband parrotfish	*Sparisoma aurofrenatum*
7	S_REDT	Redtail parrotfish	*Sparisoma chrysopterum*
8	S_REDF	Redfin parrotfish	*Sparisoma rubripinne*
9	S_MIDN	Midnight parrotfish	*Scarus coelestinus*
	SURGEON		
10	A_OCEA	Ocean surgeonfish	*Acanthurus bahianus*
11	A_DOCT	Doctorfish	*Acanthurus chirurgus*
12	A_BLUE	Blue Tang	*Acanthurus coeruleus*
	DAMSEL		
13	D_SPOT	Three spot damselfish	*Stegastes/Pomacentrus planifrons*
14	D_BEAU	Beaugregory	*Stegastes/Pomacentrus leucostictus*
15	D_LONG	Longfin damselfish	*Stegastes/Pomacentrus diencaeus*
16	D_DUSK	Dusky damselfish	*Stegastes adustus/Pomacentrus fuscus*
17	D_BICO	Bicolor damselfish	*Stegastes/Pomacentrus partitus*
18	D_YELL	Yellowtail - *Microspathodon chrysurus*	*Microspathodon chrysurus*
	CHROMIS		
19	C_BLUE	Blue Chromis	*Chromis cyanea*
20	C_BROW	Brown Chromis	*Chromis multilineata*
	GRUNT		
21	H_CAES	Caesar grunt	*Haemulon carbonarium*
22	H_SMAL	Smallmouth grunt	*Haemulon chrysargyreum*
23	H_FREN	French grunt	*Haemulon flavolineatum*
24	H_SPAN	Spanisch grunt	*Haemulon macrostomum*
25	H_BLUE	Bluestriped Grunt	*Haemulon sciurus*
26	H_WHIT	White grunt	*Haemulon plumieri*
27	H-WHMAR	White margate	*Haemulon album*
28	H_BLMAR	Black margate	*Anisotremus surinamensis*
29	H_SAIL	Sailors choice	*Haemulon parra*
30	H-TOMT	Tomtate	*Haemulon aurolineatum*
31	H_COTW	Cottonwick	*Haemulon melanurum*
	SNAPPER		
32	L_SCHO	Schoolmaster	*Lutjanus apodus*
33	L_CUBE	Cubera snapper	*Lutjanus cyanopterus*
34	L_GREY	Grey snapper	*Lutjanus griseus*
35	L_MAHO	Mahogany snapper	*Lutjanus mahogoni*
36	L_DOGS	Dog snapper	*Lutjanus jocu*
37	L_MUTT	Mutton snapper	*Lutjanus synagris/analis*
38	L_YELL	Yellow-tail snapper	*Ocyurus chrysurus*
	GROUPER		
39	G_NASS	Nassua grouper	*Epinephelus striatus*
40	G_BLAC	Black grouper	*Mycteroperca bonaci*
41	G_TIGE	Tiger grouper	*Mycteroperca tigris*
42	G_YELL	Yellowfin grouper	*Mycteroperca venenosa*
43	G_GRAY	Graysby	*Epinephelus cruentatus/Cephalopholis cruentata*
44	G_CONE	Coney	*Epinephelus fulvus/Cephalopholis fulva*
45	G_REDH	Red hind	*Epinephelus guttatus*
46	G_ROCK	Rock hind	*Epinephelus adscensionis*
47	G_HARL	Harlequin bass	*Serranus tigrinus*
48	G_HAML	Hamlets	*Hypoplectrus spp.*

No.	Code	Common name	Scientific name
	JACK		
49	J_HORS	Horse eye jack	*Caranx latus*
50	J_BARJ	Bar jack	*Caranx ruber*
51	J_PALO	Palometa	*Trachinotus goodei*
52	J_BLAC	Black jack	*Caranx lugubris*
53	J_CREV	Crevalle	*Caranx hippos*
54	J_PERM	Permit	*Trachinotus falcatus*
55	J_POMP	African Pompano	*Alectis ciliaris*
56	J_RAINB	Rainbow runner	*Elegatis bipinnulata*
57	J_BLUE	Blue Runner	*Caranx crysos*
58	J_ALMAC	Almaco jack/Longfin yellowtail	*Seriola rivoliana*
	PREDATOR		
59	P_TRUM	Trumpetfish	*Aulostomus maculatus*
60	P_HOGF	Spanish hogfish	*Bodianus rufus*
61	P_FLOU	Peacock flounder	*Bothus lunatus*
62	P_MORA	Moray	*Gymnothorax spp.*
63	P_SCOR	Spotted scorpionfish	*Scorpaena plumieri*
64	P_LION	Lionfish	*Pterois volitans*
65	P_BARR	Great Barracuda	*Sphyraena barracuda*
66	P_LIZA	Sand diver / lizardfish	*Synodus intermedius*
	OTHER		
67	SERG_MAJ	Sergeant major	*Abudefduf saxatilis*
68	GOAT_YELL	Yellow goatfish	*Mulloidichthys martinicus*
69	GOAT_SPOT	Spotted goatfish	*Pseudupeneus maculatus*
70	ANGE_ROCK	Rockbeauty	*Holacanthus tricolor*
71	ANGE_FREN	French angelfish	*Pomacanthus paru*
72	ANGE_QUEE	Queen angelfish	*Holacanthus ciliaris*
73	ANGE_GRAY	Gray angelfish	*Pomacanthus arcuatus*
74	BALL_TRUN	Trunkfish	*Lactophrys spp.*
75	BALL_COWF	Cowfish	*Acanthostracion spp.*
76	BALL_BURR	Burrfish	*Chilomycterus spp.*
77	BALL_PORC	Porcupine	*Diodon spp.*
78	BUTT_LONG	Longsnout butterflyfish	*Chaetodon aculeatus*
79	BUTT_BAND	Banded butterflyfish	*Chaetodon striatus*
80	BUTT_4EYE	4 eye butterflyfish	*Chaetodon capistratus*
81	BUTT_REEF	Reef butterflyfish	*Chaetodon sedentarius*
82	WRAS_BLUE	Bluehead wrasse	*Thalassoma bifasciatum*
83	WRAS_YELL	Yellowhead wrasse	*Halichoeres garnoti*
84	WRAS_PUDD	Puddingwife	*Halichoeres radiatus*
85	WRAS_CREO	Creole wrasse	*Clepticus parrae*
86	TRIG_BLAC	Black durgon	*Melichthys niger*
87	TRIG_OCEA	Ocean triggerfish	*Canthidermis sufflamen*
88	TRIG_QUEE	Queen triggerfish	*Balistes vetula*
89	CHUB_SPP	Bermuda chub	*Kyphosus sectatrix*
90	SOLD_SPP	Squirrelfish	*holocentridae spp.*
91	FILE	Filefish	*Monacanthidae spp.*
92	CREO	Atlantic Creolefish	*Paranthias furcifer*
93	SOAP	Greater soapfish	*Rypticus saponaceus*
94	MAJO	Yellowfin mojarra	*Gerres cinereus*
95	BONE	Bonefish	*Albula vulpes*
96	WAHO	Wahoo	*Acanthocybium solandri*
97	TARP	Tarpon	*Megalops atlanticus*
98	TURT	Turtle	
99	SHARK	Shark	
100	RAY	Southern stingray	*Dasyatis americana*
101	DRUM_SPOT	Spotted drum	*Equetus punctatus*
102	DRUM_HIGH	Highhat drum	*Equetus acuminatus*