

MULTIVARIATE ANALYSIS OF GORGONIAN HABITATS ON SABA BANK, NETHERLANDS ANTILLES

Peter J Etnoyer
Texas A&M University-Corpus Christi
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INTRODUCTION

Saba Bank is a large submarine platform 4km from the coast of Saba Island in the Netherland Antilles, Caribbean Sea (**Fig. 1**). The Bank is elliptically shaped, with a 40km short axis, and a 60km long axis oriented ENE-WSW (**Fig. 2**). The total surface area above the 200m isobath is 2200 km², much of which is shallow water between 20-30 m, within the limits of recreational scuba diver depths. The rim of the Bank is steep sided in some places, rising up from 1000 m depth. Technically, the feature could be called a seamount because the Bank is an isolated geological feature of volcanic origin with 1000 m relief. However, the geological debate has focused largely on whether the bank is a “remnant coastal plain” (Spencer 1904), an “atoll-lagoon floor, deprived of its original reef” (Davis 1926), or a “remnant tidal marsh environment during Pleistocene or post-Pleistocene” sea level fluctuations (Mcintyre 1975). While the geological origin of Saba Bank remains unclear, many consider the feature an actively growing atoll based on findings and reports from Dutch SCUBA divers and surveyors (Van der Land 1977). If the Saba Bank is a submerged atoll, this would make it “the third largest atoll in the world,” although the feature never breaks the sea surface.

Extensive coral reefs have been identified on the eastern and south-eastern rims of the Saba Bank (Boeke 1907), but only a few recent research expeditions focused on corals (Van der Land 1977, Meesters et al. 1996). Researchers collecting coral specimens focused on scleractinian (hard coral) species, collecting 28 different species in 17 genera. Alcyonarian corals (aka soft corals, gorgonians, or sea fans) are common and conspicuous on the fore-reefs of the southeast rim and the reef-flats that dominate the interior of the Bank. Taxonomic expertise of these recent expeditions was limited for the gorgonian species, because the species list is short (9 spp.) and several commonly observed groups are classified to genus level only (5 genera- *Pseudopterogorgia* spp., *Eunicea* spp., *Muricea* spp., *Plexaurella* spp.).

The recent “October Expedition” strives to improve upon our knowledge of the gorgonacea by generating a comprehensive species list for shallow and deep water species with georeferenced *in-situ* photographs and voucher specimens for each sample taken. The completeness of our surveys will be evaluated using species accumulation curves. We provide separate curves for shallow and deep water collections, because the results of scuba effort differ so greatly from the results of equivalent hours using the ROV to make collections. In addition, the surveys conducted here will characterize benthic habitat *vis a vis* gorgonians. This will be done using multivariate techniques. Principal Components Analysis (PCA), multidimensional scaling (MDS), and hierarchical clustering techniques will be used to identify differences between different survey zones surveyed on the Bank.

METHODS AND MATERIALS

Researchers from Harte Research Institute at Texas A&M University- Corpus Christi, University de los Andes in Bogota, Colombia, and Rostenstiel School for Marine and Atmospheric Sciences (RSMAS) at University of Miami descended upon Saba bank for the October Expedition in Oct 19-30, 2007. The primary objective was to collect marine biological samples using nitrogen enriched air (nitrox) with scuba (on one boat) and a Seabotix remotely operated vehicle (ROV) capable of 200m depth from another. The scuba boat was a 28 ft. vessel powered by twin 115 HP engines. The ROV boat a 35 ft. lobster fishing boat equipped with a winch for hauling traps from deep water. Over the course of the 10 day expedition, 14 scuba dives and 5 ROV dives were completed. The first four dives were dedicated to collecting specimens. All specimens were photographed before clipping 4-6 in. samples from distal tips of branches and preserving these in 95% ethanol. The remaining eight dives were used to conduct quantitative transects to compare different “habitat zones”. We established the zones using high resolution multibeam sonar derived bathymetry (2 m) and Landsat TM satellite imagery.

A general block design was established for a restricted study area on the bank called “Overall Bank”. The research design was based upon a horizontal stratification scheme (XX – Wes Toller) with “front reefs” and “fore reefs” at the rim of the bank, and a series of zones called “reef flat”, “backreef slope”, “patch reefs”, and a “lagoon” as we move towards the bank interior. Five zones were established using criteria for habitat continuity (from Landsat TM), depth, and distance from the rim (from the bathymetry). The zones are labeled A-E, with A representing the “fore reef” environment and E representing the “lagoon environment” (**Fig. 3**). To avoid confusion, the “lagoon” will be referred to hereafter as the “reef flats”. A 100m grid was overlaid on each zone and a random number table was used to select 12 grid cells within the zone. The cells were labeled alphanumerically (A1, A2, etc...). These labels and coordinates were used to identify survey sites used in this and other analyses.

The block design supplemented by additional transects from a random site in the unmapped region (the “Void”) and two transects from a remote site on the “front reef” called Conch Valley (CV). The label Void represents one site in the unmapped interior of the Bank. Not all zones in the block design were realized. In total, 8 dive transects were conducted in five zones. Two transects occurred in the A zone at A7 and A12, and one occurred in the D zone at D9, two occurred in the E zone at E7 and E4, one in the Void, and two on the southeast rim in Conch Valley at CV1 and CV2. No gorgonian transects were conducted in zones B and C.

Survey transects were conducted by 2 divers along a 50m transect tape counting coral colonies by species in one meter square quadrats placed every 5 meters on either side of the tape. The total number of colonies per species was averaged by summing the results from two divers and dividing by 22 m² to achieve density values in units of colonies/m².

The resulting data matrix consisted of eight transects (A7, A12, CV1, CV2, D9, E4, E7, and Void) and 28 species observations (**Table 1**). This should not be confused with the total number of gorgonian species collected, because it includes only those species identified along the survey transects. The species list is shown in **Table 2**. A distance

matrix was calculated from the data matrix shown in Table 1 using the Euclidian distance measure in R software, and a PCA was conducted. The multivariate techniques used in the analysis include hierarchical clustering and MDS. MDS plots were made using species as variables and sites as observations, and vice versa. Finally, species level density estimates were averaged to produce genus level density estimates, and a hierarchical cluster analysis was performed to gauge the influence of species level identifications on the resulting habitat classification exercise.

RESULTS

Gorgonian species were common and conspicuous at all sites surveyed, except perhaps in some deep water (~60m) rubble flats south of Poison Bank. A total of 47 species were collected, including two new species in the genera *Pterogorgia* and *Lytreaia*. *Pterogorgia* n. sp. was collected twice from 20m depth in the D zone. *Lytreaia* n. sp. was collected twice from 50m depth near the A zone. The total number of gorgonian species collected from shallow water was 39. The number of gorgonian species from deep water (>50m) was 12. There was some overlap in the zones, with 4 shallow water species (*Muriceopsis flavida*, *Eunicea clavigera*, *Pseudopterogorgia acerosa*, and *Ps. bipinnata*) occurring below 50m. **Table 2.** The species accumulation curve for shallow water species indicates the slope of the fitted line decreases with effort, but the line shows no clear asymptote (**Fig. 3**). The species accumulation curve for deep water collections is still climbing. The line could be interpreted as a linear rise in deep-water species richness. There is no indication we have collected all the gorgonian species from the Saba Bank.

Principal Components Analysis (PCA) indicates 82% of the variance between sites is captured by two principal components. A bar graph of the components shows no clear change in slope after the first two components, so transects are largely uncorrelated. PCA was used to plot species in two dimensional space, rather than sites (**Fig. 4**). The first component (x-axis of the PCA plot) is interpreted as a gradient in rarity or a gradient in endemism, with endemism defined as occurring in only one zone. Species to the extreme right of the origin (*Briareum abstenium* and *Eunicea knighti*), occurred in low abundance in only one zone, while species to the extreme left occurred in relatively high abundance in many zones (*Pseudopterogorgia acerosa* and *Pterogorgia guadalupensis*). The second component (y-axis of the PCA plot) seems related to endemism as well, the gradient is interpreted as whether gorgonians were “A-zone species” (low on the y-axis) or “not A-zone species” (higher on the y-axis).

Cluster analysis and multidimensional scaling are preferred techniques because the transects are largely uncorrelated. The sample size is low (n=8), so each new transect brought something new. Ordination and clustering techniques are more powerful than the PCA, and yield better interpretation of the results. A dendrogram of sites derived from the hierarchical cluster technique is shown in **Fig. 5**. The cluster technique accurately groups transects together from within zones (e.g. A7 and A12). Reef flat transects in E4 and E7 are also grouped together, along with the one transect from the “Void”, inward of the E zone, and one transect from the D zone, which lies seaward of the E zone. This is expected because each of these transects (E4, E7, Void, and D9) were low in richness (3-5 spp.) and low in abundance (0.18 – 1.50 colonies/m²). Transects in zones A and CV are characterized by high richness (10-17 spp.) and high density (3.5-4.7 colonies/m²).

The MDS technique supports the hierarchical cluster. The y axis accurately reflects the ordination of richness within the reef crest sites, with A7 being highest (17 spp.) and CV2 (10 spp.) being lowest (**Fig. 6**). The interpretation of the x axis is less clear. CV sites differ from the rest only by high abundance of common species (*P. acerosa* and *G. mariae*). Therefore the y axis is interpreted as a gradient in richness and the x axis is interpreted as a gradient in the abundance of common species. In order to understand which species were driving these differences, another MDS plot was constructed using the original matrix with sites as variables and species as observations (**Fig. 7**) In this case, the x-axis is interpreted as a gradient between common species (*P. acerosa* and *G. mariae*) that occurred in high abundance on the extreme right of the plot, and rare species that occurred in low numbers in few zones on the extreme left of the plot. The y axis is interpreted as a gradient between those species that occurred in low to medium abundance in many zones at the bottom of the axis (*Pterogorgia guadalupensis*, *Pseudopterogorgia acerosa*) and those that occurred in medium to high abundance in few zones (*Eunicea fusca* and *Pseudopterogorgia americana*) at the top of the axis.

Finally, in order to evaluate the importance of high taxonomic resolution in field surveys to classify habitat vis a vis gorgonians, the species within each genera were added together to produce an average density for each transect in each genus. *Eunicea* (n = 11) and *Pseudopterogorgia* and *Pterogorgia* (n = 4) were the most speciose genera, so the effects of those species should be most dampened. The resulting hierarchical clusters varied little from the species level dendrogram. Reef flat transects clustered together, and the A zone site and CV sites clustered apart.

DISCUSSION

The recent survey results add 38 species to the list of gorgonacea known to occur on Saba bank. This is > 400% increase in our knowledge of species richness on the Bank. Only one species reported previously (Meesters et al 1996) was not documented by this expedition, *Gorgonia flabellum*. This species is generally considered endemic to the Bahamas, so it was ruled out from occurring on the Bank. This may have been an observational bias on the part of the recent study, or an error on the part of the former study. The survey results add XX new genera to the original list.

The discovery of a new species of *Pterogorgia* was surprising because a) the discovery was made in shallow, easily accessible water depths and b) the new species was collected from the relatively depauperate reef flats in the “D zone”. This suggests the reef flat area in the interior of the Bank may be largely unexplored and the true diversity of the reef flat areas may be somewhat underappreciated. There is currently no question about the novelty of the new *Pterogorgia* because this is a distinctive genus characterized by flattened branches with polyps protruding from the edges of the blade. Only three species are known from the genus *Pterogorgia*- *P. guadalupensis*, *P. citrina*, and *P. anceps*, so differences are readily observed in the field. Interestingly, specimens all three *Pterogorgia* spp. were collected from the discovery site. Microscopic observation of the diagnostic calcareous sclerites confirmed the novelty of the finding. New species results will be reported at a later date in a suitable venue, i.e. a peer-reviewed journal.

Regarding the habitat characterization of the Saba Bank *vis a vis* gorgonians, hierarchical cluster techniques and MDS support the hypothesis that there is a gradient in gorgonian diversity and abundance from the “fore-reef” to the reef flats. The A sites and CV sites occur along the fore reef. These are clustered and plotted separately from the four sites in the interior of the Saba Bank. Fore reef sites are rich with gorgonians, with up to 17 spp. occurring in one transect. The sites are characterized by *Eunicea* spp., *Gorgonia* spp., *Plexaura* spp., *Pseudoplexaura* spp., and *Pseudopterogorgia* spp. in high densities. Reef flat sites are relatively depauperate, characterized by *Gorgonia* spp., *Pseudopterogorgia* spp. and *Pterogorgia* spp. in low densities.

Sites in the D zone, E zone, and Void all group tightly together, in support of the idea of higher habitat homogeneity. Conversely, the hierarchical cluster techniques and MDS employed here support the hypothesis of habitat heterogeneity along the rim of the Bank, because CV sites and A sites fall apart as much as they fall together. While sites along reef crest differ from sites in the interior, sites at two different ends of the reef crest differ from each other. This may be an artifact of the low sample size ($n=8$) and the low degree of replication ($df = 1$), but CV sites did differ dramatically from the A sites in terms of the abundance of *Gorgonia* spp. sea fans and *Pseudopterogorgia* spp. The fore-reef on Conch Valley is remarkably rich and abundant with gorgonians, but the total richness is probably not entirely reflected in the two transects performed there.

Large toppled colonies were observed in the sand channel on the approach to Conch Valley. The area is heavily fished by lobstermen using pots and traps. No similar damage was observed at other sites. In general, gorgonian populations appeared healthy, with only a few instances of fungal infections of *Aspergillosis* on *Gorgonia ventalina*. Hard corals on the fore reef area do not appear to fare as well. Many hard coral colonies are bleached and dead, recently overgrown by calcareous algae.

These extent of these findings are limited to the southeast corner of the Saba Bank, but the results offer some insights towards the character of two different habitats occurring on the Bank. The high diversity/high abundance habitat is the reef crest (i.e. the “A zone”), a fairly heterogeneous habitat that runs at least 40 km along the perimeter of the Bank. The low diversity/low abundance habitat is a broad reef flat area (i.e. the “D zone” and the “E zone”), a fairly homogenous habitat that appears to dominates the interior parts of the Bank within our designated study area. Scenarios for a zoning scheme based on these results would include: 1) an anchor ban on the Bank, or 2) the restriction of tanker anchors from the reef crest perimeter identified in Meesters et al. (1977), and/or 3) the restriction of tanker anchors from the most homogenous parts of the Bank. The latter option assumes habitat loss in a small area would be mitigated by habitat protection in other parts of the interior bank.

Recommendations for further study include: 1) the continued pursuit of greater sample sizes in all zones (especially B and C zones) to confirm these preliminary findings; 2) an expansion of the study area to include more fore reef sites along the southeast rim of the Bank; 3) increased exploration of the heretofore unknown submerged northern parts; and 4) the incorporation of isolated features (e.g. mounds and ridges) into the research design to test the hypothesis of habitat heterogeneity within the reef flat region.

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FIGURES



Fig. 1. The Netherlands Antilles in the Caribbean Sea

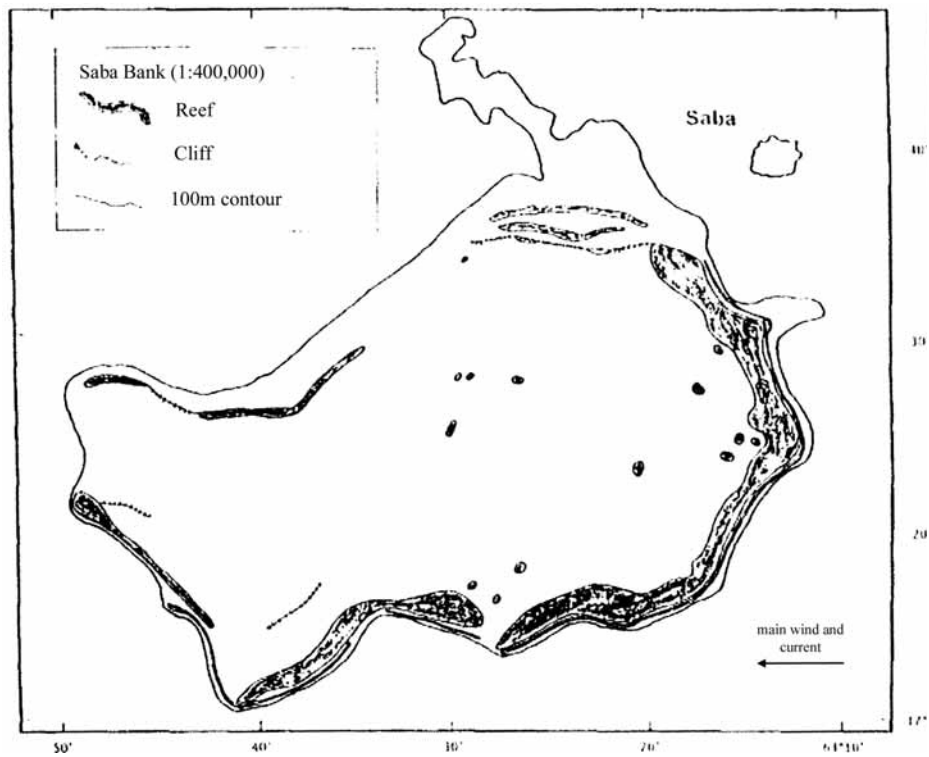


Fig. 2. General topography of Saba Bank from Van der Land (1977)

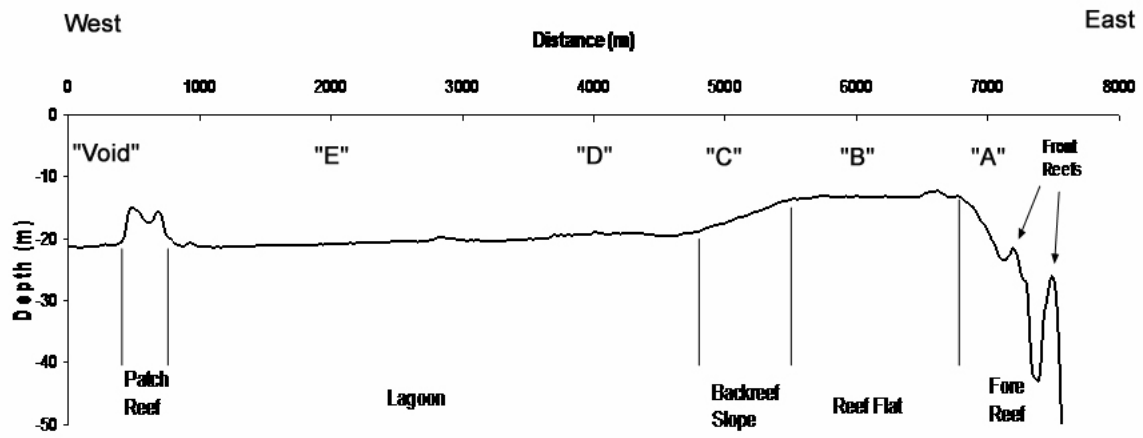


Fig.3. Profile view of Saba Bank indicating depth, direction, and nomenclature.

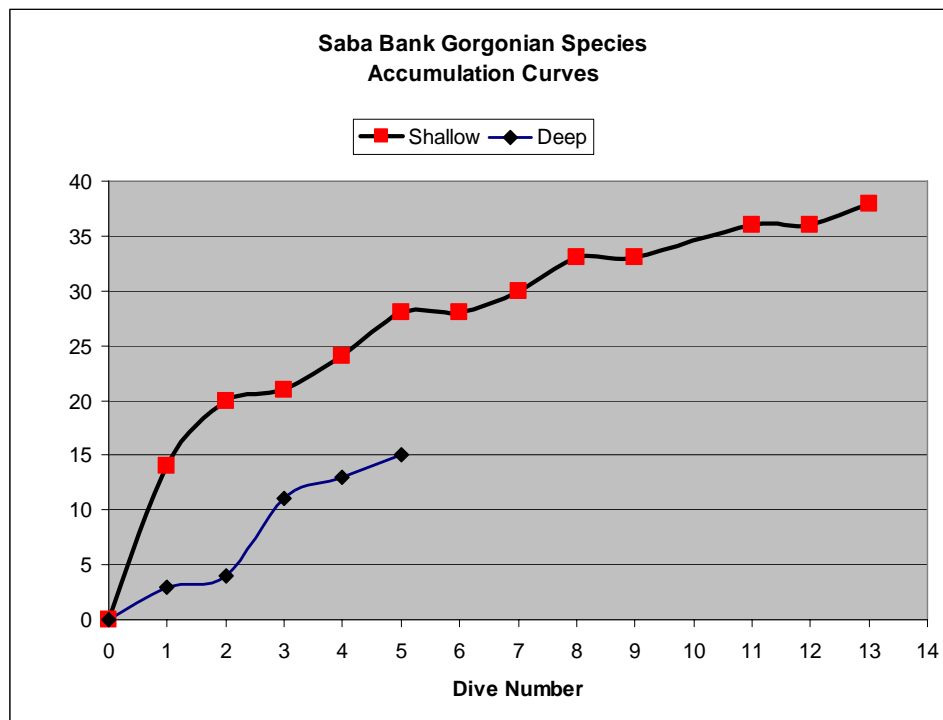


Fig. 4. Cumulative species per dive from Saba Bank in October 2007.

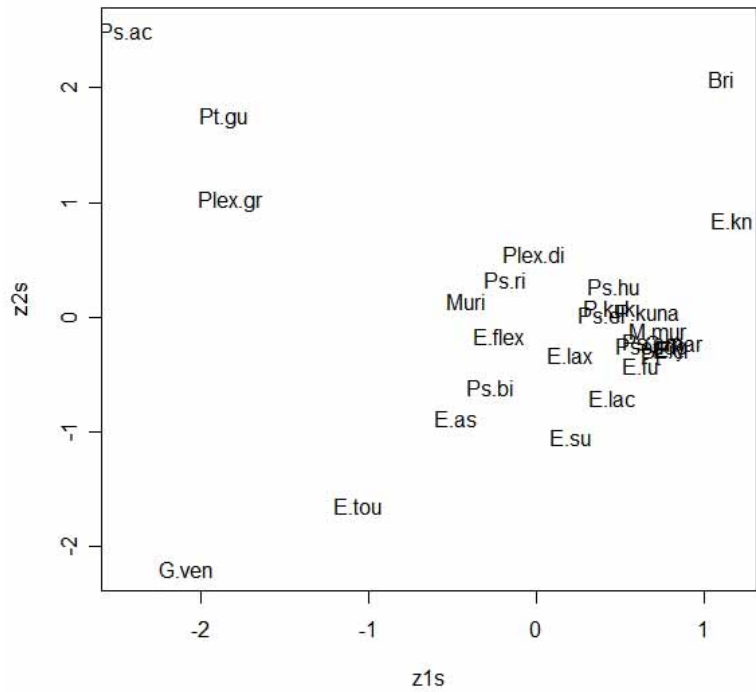


Fig.4. Principal Component Analysis using sites as variables and species as observations. Explanations of abbreviations provided in Table 2.

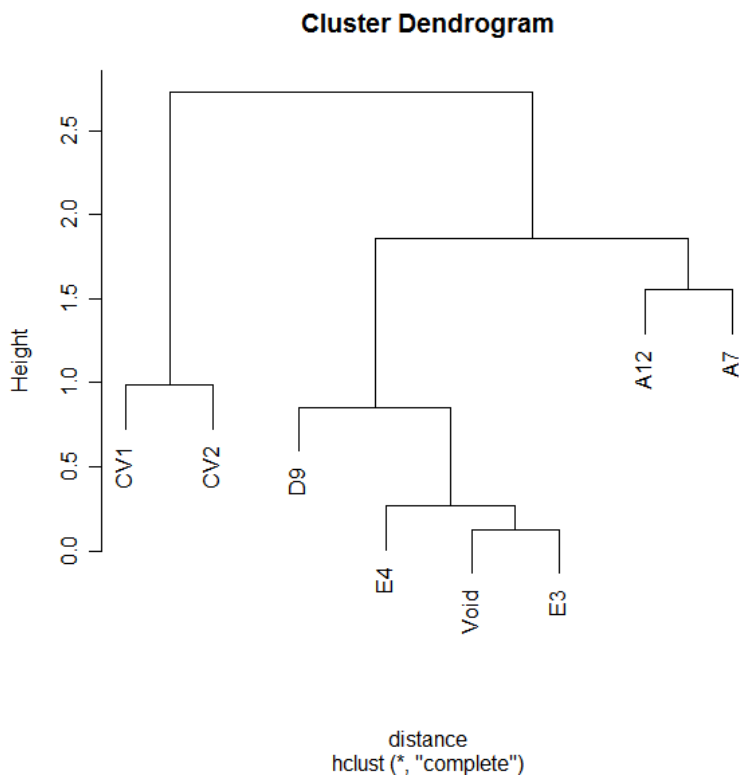


Fig.5. A hierarchical clustering of Saba Bank zones using Euclidian distance.

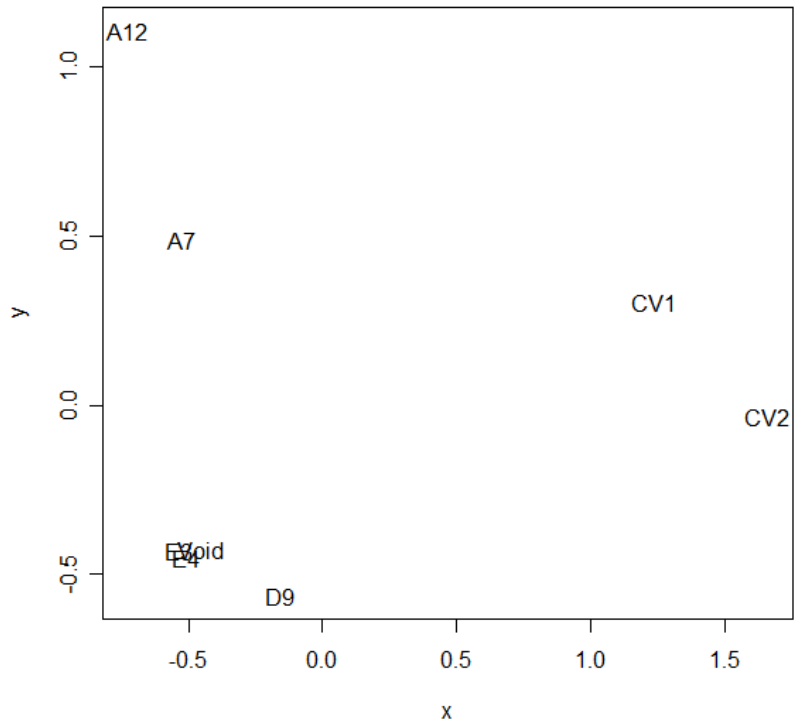


Fig.6. Metric multidimensional scaling of transects and zones on Saba Bank.

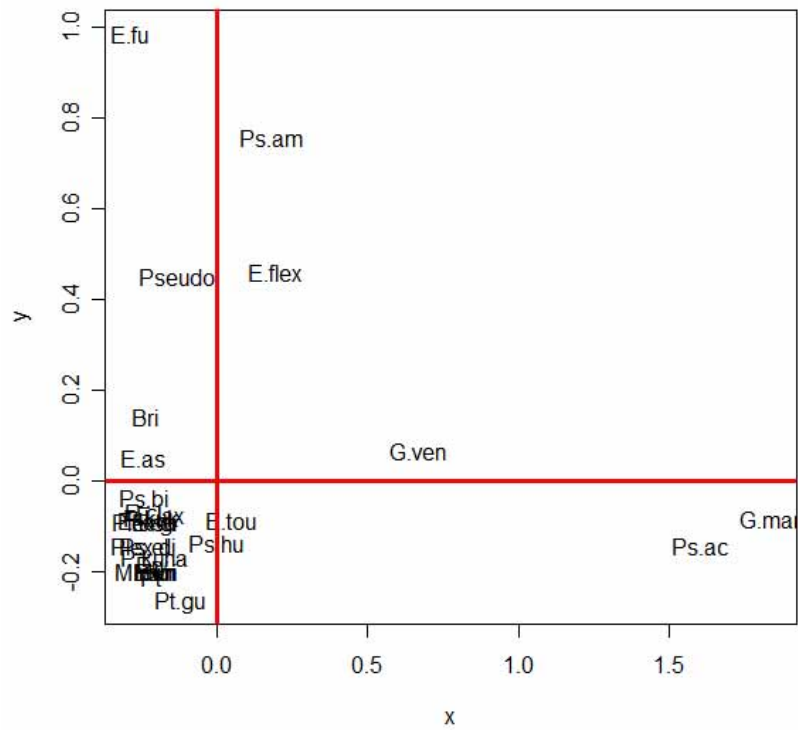


Fig.7. Metric multidimensional scaling of sea fan species on transects from Saba Bank

TABLES

Table 1. Gorgonian density in number of colonies/m² from transects at eight random sites in five zones (A-E) on Saba Bank. CV=Conch Valley, Void = Unmapped region.

	<i>abbreviated</i>	A12	A7	CV1	CV2	D9	E4	E3	Void
<i>Briareum asbestinum</i>	Bri	0.125	0.500	0.000	0.000	0.000	0.000	0.000	0.000
<i>Erythropodium</i>	Eryth	0.000	0.000	0.046	0.000	0.000	0.000	0.000	0.000
<i>Eunicea asperula</i>	E. asp	0.188	0.182	0.000	0.000	0.000	0.000	0.000	0.000
<i>Eunicea clavigera</i>	E.clav	0.125	0.046	0.000	0.000	0.000	0.000	0.000	0.000
<i>Eunicea flexuosa</i>	E. flex	0.250	0.955	0.182	0.409	0.000	0.046	0.000	0.000
<i>Eunicea fusca</i>	E.fu	1.250	0.227	0.000	0.000	0.000	0.000	0.000	0.000
<i>Eunicea knighti</i>	E.kn	0.000	0.000	0.000	0.046	0.000	0.000	0.000	0.000
<i>Eunicea laciniata</i>	E.lac	0.125	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<i>Eunicea laxispica</i>	E.lac	0.125	0.000	0.091	0.000	0.000	0.000	0.000	0.000
<i>Eunicea succinea</i>	E.su	0.125	0.000	0.000	0.046	0.000	0.000	0.046	0.000
<i>Eunicea tourneforti</i>	E.tour	0.000	0.182	0.227	0.182	0.000	0.000	0.000	0.000
<i>Gorgonia mariae</i>	G.mar	0.000	0.000	1.409	1.546	0.046	0.046	0.000	0.046
<i>Gorgonia ventalina</i>	G.ven	0.125	0.273	0.500	0.773	0.000	0.000	0.000	0.000
<i>Muricea muricata</i>	M.mur	0.000	0.000	0.000	0.000	0.000	0.091	0.000	0.000
<i>Muriceides sp</i>	Mur.sp	0.000	0.000	0.000	0.046	0.000	0.000	0.000	0.000
<i>Plexaura hom. Kukenthalii</i>	P.kuk	0.125	0.000	0.046	0.000	0.000	0.000	0.000	0.000
<i>Plexaura kuna</i>	P.kuna	0.000	0.046	0.046	0.000	0.000	0.000	0.000	0.000
<i>Plexaurella dichotoma</i>	Pl.di	0.063	0.000	0.000	0.000	0.000	0.000	0.046	0.000
<i>Plexaurella grisea</i>	Pl.gris	0.125	0.000	0.000	0.000	0.046	0.000	0.000	0.000
<i>Pseudoplexaura spp.</i>	Ps.sp	0.375	0.636	0.182	0.000	0.000	0.000	0.000	0.000
<i>Pseudopterogorgia acerosa</i>	Ps.ac	0.063	0.046	1.000	1.455	0.682	0.046	0.046	0.136
<i>Pseudopterogorgia americana</i>	Ps.am	0.875	0.182	0.727	0.000	0.000	0.000	0.000	0.000
<i>Pseudopterogorgia bipinnata</i>	Ps.bi	0.063	0.227	0.000	0.000	0.000	0.000	0.000	0.000
<i>Pseudopterogorgia elisabethae</i>	Ps.el	0.063	0.000	0.000	0.000	0.000	0.000	0.000	0.000
<i>Pseudopterogorgia hummelincki</i>	Ps.hum	0.000	0.046	0.273	0.091	0.000	0.000	0.000	0.000
<i>Pseudopterogorgia rigida</i>	Ps.ri	0.000	0.000	0.000	0.046	0.000	0.000	0.000	0.000
<i>Pterogorgia guadalupensis</i>	Pt.guad	0.000	0.000	0.046	0.000	0.591	0.227	0.046	0.000
<i>Pterogorgia sp</i>	Pt.so	0.000	0.000	0.000	0.000	0.136	0.000	0.000	0.000

Table 2. Gorgonian species collected from Saba Bank on the October Expedition, 2007.

No.	Gorgonian Species	Shallow	Deep (> 50m)
1	<i>Eunicea clavigera</i>	X	X
2	<i>Muriceopsis flavida</i>	X	X
3	<i>Pseudopterogorgia acerosa</i>	X	X
4	<i>Pseudopterogorgia bipinnata</i>	X	X
5	<i>Ctenocella</i> sp.		X
6	<i>Ctenocella (Ellisella) cf. elongata</i>		X
7	<i>Ctenocella (Ellisella) sp.</i>		X
8	<i>Eunicea pinta</i>		X
9	<i>Iciligorgia schrammi</i>		X
10	<i>Lytrea</i> sp.		X
11	<i>Muricea laxa</i>		X
12	<i>Pseudopterogorgia albatrossae</i>		X
13	<i>Briareum asbestinum</i>	X	
14	<i>Erythropodium</i> sp.	X	
15	<i>Eunicea asperula</i>	X	
16	<i>Eunicea calyculata</i>	X	
17	<i>Eunicea flexuosa</i>	X	
18	<i>Eunicea fusca</i>	X	
19	<i>Eunicea knighti</i>	X	
20	<i>Eunicea laciniata</i>	X	
21	<i>Eunicea laxispica</i>	X	
22	<i>Eunicea mammosa</i>	X	
23	<i>Eunicea sp. (tayrona)</i>	X	
24	<i>Eunicea succinea</i>	X	
25	<i>Eunicea tourneforti</i>	X	
26	<i>Gorgonia mariae</i>	X	
27	<i>Gorgonia ventalina</i>	X	
28	<i>Muricea elongata</i>	X	
29	<i>Muricea muricata</i>	X	
30	<i>Plexaura cf. nina</i>	X	
31	<i>Plexaura kukenthali</i>	X	
32	<i>Plexaura kuna</i>	X	
33	<i>Plexaurella dichotoma</i>	X	
34	<i>Plexaurella grisea</i>	X	
35	<i>Plexaurella nutans</i>	X	
36	<i>Pseudoplexaura crucis</i>	X	
37	<i>Pseudoplexaura flagellosa</i>	X	
38	<i>Pseudoplexaura porosa</i>	X	
39	<i>Pseudoplexaura wagnaari</i>	X	
40	<i>Pseudopterogorgia americana</i>	X	
41	<i>Pseudopterogorgia elisabethae</i>	X	
42	<i>Pseudopterogorgia hummelincki</i>	X	
43	<i>Pseudopterogorgia rigida</i>	X	
44	<i>Pterogorgia cf. anceps</i>	X	
45	<i>Pterogorgia citrina</i>	X	
46	<i>Pterogorgia guadalupensis</i>	X	
47	<i>Pterogorgia n. sp.</i>	X	