



## DETAILED ENVIRONMENTAL DESCRIPTION OF ÚVWÖY SITES

Ten sites were chosen at depths of 5-10m in a range of environments. They are 1) a river delta, 2) a coastal siliciclastic lagoon, 3) and 4) both 5m and 10m depths of a narrow mangrove-fringed inlet, 5) a restricted lagoon in a carbonate cay, 6) a broad carbonate back-reef lagoon floor, 7) a seagrass channel within the same large lagoon, 8) and 9) a reef wall at 5 and 10m, and 10) a channel through a windward reef crest. Original site numbers are used in the description (format YYSB####) to avoid future confusion with work in preparation on other sites. Detailed descriptions follow of the general setting, water characteristics, benthic biological community, and sediment characteristics for each site.

### Rio Agua (95SB055) - coastal embayment, local river mouth

Rio Agua, among other rivers, drains the coastal plain at the western end of the Golfo de San Blas. The drainage basin supports little to no agricultural activity and deforestation, and so anthropogenic increases in sedimentation should be limited. The mouth of Rio Agua has a 1km-wide submerged delta platform (max depth 5m). This platform is elongated parallel to the shore, and abruptly slopes off about 1km offshore going from the delta top at 5m to the floor of the Gulf at 20m. Study site 55 is on the delta slope, directly offshore of the river mouth at a depth of 10 m. The delta plain is flooded,

trapping sediment, and the delta front and abandoned lobes provide topographic highs for carbonate production.

The water column at this site is influenced by the fresh water runoff of Rio Agua. After heavy rains, surface waters (~top 1-2m) have depressed salinity (25 ‰) and increased silica (100  $\mu\text{M}$ ) (Figure 4). Resultant stratification of the water column is observed with a turbid freshwater lens on the surface and relatively clear waters underneath. In addition, high energy fair weather wave base grounds around the depth of the study site, causing the bottom part of the water column (1-3m) to be particularly turbid. Visibility ranges from <1-10m depending on runoff and waves.

The bottom sediments are highly bioturbated. The seafloor has open burrows and *Callianasa* mounds and holothurians, starfish, and strombid gastropods are abundant. Rays are not commonly sighted. *Halophila* seagrass occurs sparsely in discontinuous patches.

Sediments are sandy muds (Figure 5), often showing diagenetic discoloration to orange and black, including on the abundant shells of *Laevicardium*, lucinid and strombid fragments. There is a discontinuous mud drape but no significant development of a nepheloid layer. The coarse fraction (>250 $\mu$ ) has a minor component of iron oxides but is predominantly bioclasts: abundant bivalves, gastropods, crustaceans, and *Halimeda*, with lesser amounts of echinoderms (Figure 6). Wood and leaves are also fairly common.

#### Soledad (95SB054) - coastal siliciclastic embayment, no local river

This 3 km wide lagoon is situated between the mainland and the island of Soledad, to the east of Rio Agua along the mainland coast. There is no large river outlet into the lagoon, but there are several small streams that drain the forested mountainsides that rise from the coast. There is no significant agriculture or deforestation on the mainland (though a Kuna burial ground exists on the hillside). The study site (#54) is on the outer edge of a

semi-restricted bay which was observed to have reduced oxygenation in bottom waters.

There seems to be a submerged fault scarp running across the entrance to the restricted back bay, and this serves to trap sediments and diffuse runoff from local streams.

The lagoon is protected from onshore winds and waves by a belt of islands and reef flats level with Punta Playa. The water is usually stratified, with a significant benthic turbid layer 1-2m deep above the sediment-water interface. The main anomaly in the water analyses is the relatively high phosphate value for the bottom samples. This is probably related to the turbidity, which may result from bottom outflow from the restricted back bay over a 7m sill, or simply to limited bottom disturbance by waves of the clayey sediment. Slightly elevated silica in some surface water samples suggest sporadic fresh water input.

The bottom sediments are highly bioturbated with ~2cm diameter burrow openings and ray pits. Jellyfish and strombid gastropods are common, as are rays. Macroalgae are largely absent, but red bacterial films (*Schizothrix*) were commonly observed on the sediment surface.

The sediment is a moderately sorted sandy clayey mud and has a benthic nepheloid layer approximately 3-4cm thick. Below this layer, cohesive clayey mud contains a bioclastic assemblage (>250 $\mu$ ) of abundant infaunal bivalves such as *Dosinia* and *Laevicardium*, with lesser amounts of gastropods, scaphopods, crustaceans, and echinoids (Figure 6). Other components of the sand fraction include abundant lithic fragments, mafic crystals and quartz that are probably volcanogenic.

#### Ulagsukun (97SB059 and 95SB053) - 5m and 10m depths towards restricted end of narrow mangrove-fringed inlet

A narrow mangrove lined inlet is located on the leeward side of Punta San Blas. There is limited agriculture on the surrounding relatively arid low hills which may have

increased sedimentation and nutrient runoff to this inlet over recent years (Shulman and Robertson 1996). There is a 5m deep bench along both sides of the mangrove inlet, which merge at the head of the inlet to form silted-in shallows (0.2-3m water depth). The bench sharply slopes down to the inlet floor at (10-15m water depth) which deepens towards the opening of the inlet and then sharply drops off to depths of >50m on the main lagoon floor. Both sites are in the upper part of the inlet, with site #59 at 5m on the edge of the bench and site #53 at 10m on the inlet floor. The sharp sides of the inlet suggest it is a flooded erosive feature such as an incised channel.

The water column is usually greenish and moderately turbid, even during dry (low runoff) periods, which may indicate high planktonic production. This is consistent with the elevated phosphate and nitrate through the water column. Turbid surface layers associated with runoff occur occasionally. Visibility is generally less than 7 m, and reduces to <2m after heavy rains.

With the exception of the bioturbated black muds at the head of the inlet, the shallow bench is colonized by thriving *Thalassia* and/or *Halimeda* communities. Coral communities colonize and possibly maintain a sharp bench edge. These communities attract diverse fish life and in turn dolphins which take shelter in the inlet during storms. The bench slopes sharply from 5m down to the floor of the inlet at 10-15m which is muddy and highly bioturbated, including callianassid burrows.

The sediment along the bench is a coarse sand, composed predominantly *Halimeda* plates with lesser amounts of bivalves, gastropods, echinoids, crustaceans and forams, all in a dark organic rich terrigenous mud. The sediment in the centre of the inlet is fine carbonate sand, again in an organic rich terrigenous mud, and the proportion of bioclasts is similar to the shallow site. Sediment accumulation estimated by experimental shell burial is on the order of 8cm/yr.

Guigalatupo (97SB058) - restricted lagoon in a small carbonate cay <sup>5</sup> ~~AD~~

The small shallow lagoon enclosed by Guigalatupo cay is 100m long, 40m wide and reaches a maximum depth of 3m. The entrance is through a narrow channel (2m deep) which connects the lagoon with a deeper channel draining the Punta San Blas lagoon into the Golfo de San Blas to the south. Even in rough seas, waves have very limited effect on this small lagoon within Guigalatupo Cay. Site #58 is in the centre of the lagoon.

The water in the lagoon is generally warmer than the surrounding Punta San Blas Lagoon, reaching temperatures of 30°C homogeneously through the water column. Visibility is moderate to limited, depending on occasional wind-driven resuspension of bottom sediment, the amount of suspended organic matter from the surrounding mangrove community, and primary production in the water.

Callianassid burrows are common and rare brown algae anchored to wood or shell debris grows above the sediment water interface. Bacterial films cover areas of the sediment surface that are not heavily bioturbated. Rays are occasionally found in the lagoon, feeding on the lucinid-dominated molluscan community. *Bulla* is a common gastropod genus.

The sediment is organic rich carbonate muddy fine sand (bimodal fine sand and clay), with a deep nepheloid layer. Shells placed on the sediment surface were buried beneath 5-7cm of sediment after 1 year. The nitrogen content of the sediment is the highest measured among the study sites at 0.33 wt %. Bioclasts are sparse, and consist mainly of bivalves, gastropods, and *Halimeda*. Wood and mangrove leaves are also present.

Pico Feo (95SB050 and 97SB056) - floor of a large carbonate lagoon and coastal seagrass channel

The lagoon floor to the east of Punta San Blas is up to 10m in depth and approximately 50% of the area is covered with *Thalassia*. Site #56 is at the midpoint of a shallow channel (5m) that runs between the coast of Punta San Blas and the surface breaking reef-fringed Pico Feo Cay, and is predominantly covered with *Thalassia*. Site #50 is located between a surface-breaking, reef-fringed cay (200m to west) and two *Agararicia* and sponge dominated patch reefs at 8-10m depth (40m to east and 30m to north) (see Figure 3).

A moderate current runs N-S through the area, draining the lagoon through a channel to the south between Pico Feo and Guigalatupo and to a lesser extent between the coast and Pico Feo (Coffroth personal communication). The water column is well mixed, with the exception of rare turbid freshwater runoff at surface during strong rains. Phosphate levels are low, nitrate+nitrite levels are low to moderate, possibly due to the *Thalassia* communities.

In Site 50, the sediment surface is punctuated by burrows, but calianassid mounds are only occasionally present in small patches. Patches of sediment are stabilized by filamentous algae. Sparse *Halophila* seagrass is present along with *Halimeda incrassata* and some fleshy algae. Rays are present but not particularly common. Site 56 is colonized by sparse to dense *Thalassia* alternating with *Halimeda incrassata*, and shows intense calianassid bioturbation in all but the densest *Thalassia*. Lucinids and cerithids (+ other herbivorous gastropods) are abundant.

The sediment at site 50 is carbonate, low organic, well sorted fine sandy silt. Nitrogen content of the sediment is the lowest of all the sites analysed, possibly related to its lack of clay. The sediment is generally rigid due to the high degree of sorting and the

locking nature of the carbonate grains. Bioclasts are *Halimeda*, bivalves, gastropods, corals, with lesser forams, crustaceans, and echinoids. Site 56 has poorly sorted muddy coarse sand, predominantly composed of *Halimeda*, with molluscs common and forams less abundant. It also shows a higher nitrogen content and a higher organic content which is more comparable to the reefal sediments (sites 60 and 51 below) than to site 50.

Korbiski (97SB060 and 95SB051) - reef wall on southern side of Punta San Blas lagoon

Korbiski reef forms a surface breaking flat, then a shallow bench to 5m, and then a steep reef wall that descends to 30-40m before sloping off into the shelf floor (50m). The wall is the south side of a structural platform that creates a ring of cays off Punta San Blas. Site 60 (5m) is at the crest of the reef wall and site 51 (10m) is halfway down the wall. To the east (200m) of the study sites is a channel that drains the Punta San Blas lagoon. While this also acts as a sediment chute, the study sites are laterally removed from direct downslope deposition.

Prevailing winds generally come from the north, leaving the wall in a leeward position, however winds do shift to southerly directions during the rainy season causing storm waves to build up across the archipelago and hit the southern crest full force. Some relative warming of surface waters occurs (30°C, Shulman and Roberston 1996) occurs, perhaps through the influence of the lagoon. Visibility ranges from 9 to >12m, and stratification in the water column is rare. Nutrients show moderate levels of nitrate and phosphate, as well as silicate.

The reef community includes a diverse array of corals, gorgonians, calcareous and non-calcareous algae, sponges, and abundance schooling fish (see Clifton et al. 1996). Sand patches intersperse among abundant live cover of coral and sponges where burrows

are common. The 5m crest of the reef wall has a series of large *Diploria* heads and large gorgonians (Lasker et al. 1984) among abundant abraded coral rubble.

The sediments are very poorly sorted gravelly muddy carbonate sands with the 5m site having 12% more gravel than the 10m site. They are generally resting close to the angle of repose. The nitrogen and the organic carbon are moderate among the sites sampled. Bioclasts are predominantly corals, with molluscs, *Halimeda*, *Homotrema*, echinoids, crustaceans and forams as lesser components.

#### Barrier Channel (95SB052) - through NW barrier off Punta San Blas

This channel through the windward barrier off the northern end of Punta San Blas is a very high energy environment. The reef crest flat (5m) drops sharply off to the channel floor at 13m. The barrier channel may be an ancient drainage channel or groove structure.

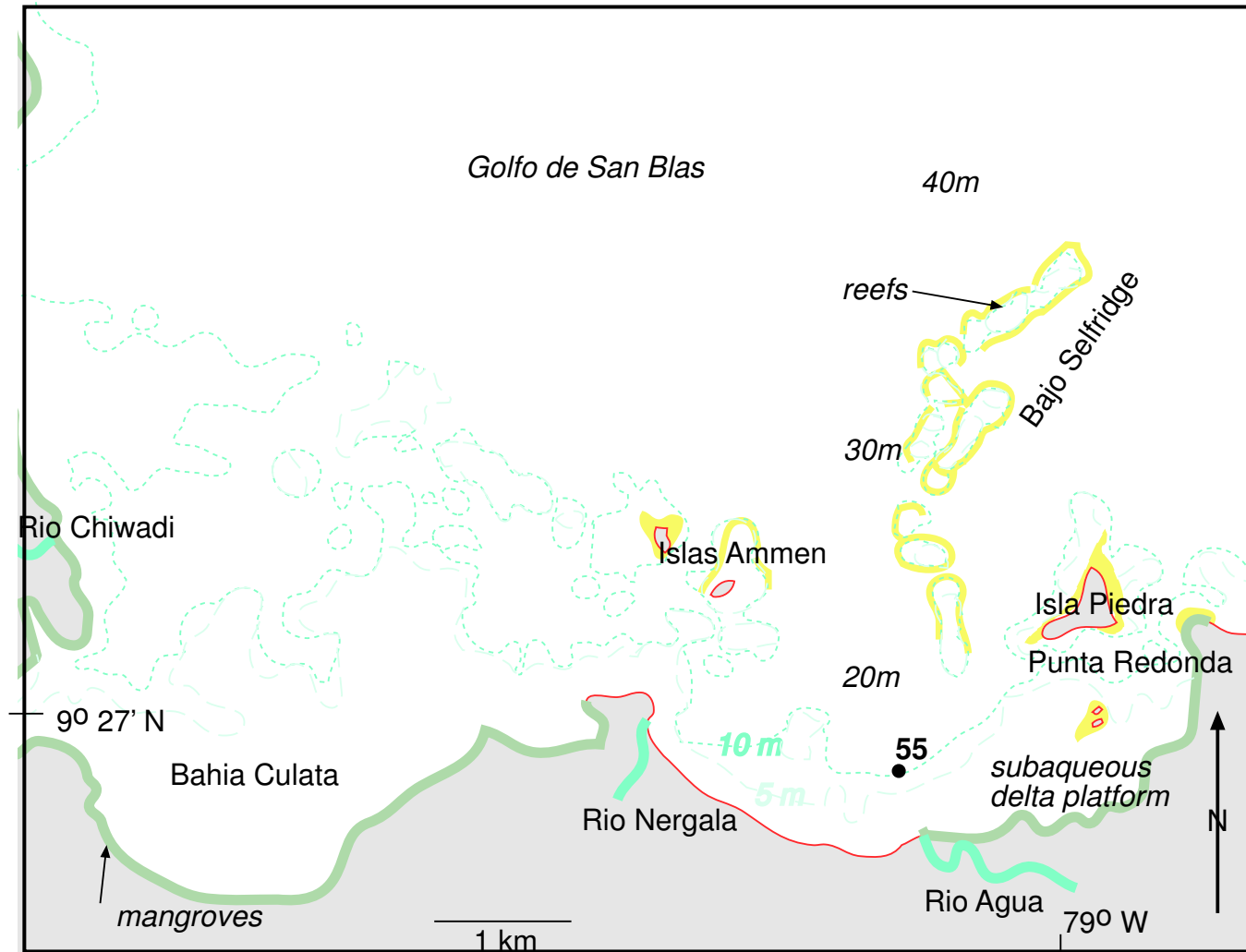
The water column is well mixed by the swell coming in from the Caribbean Sea. Visibility ranges from 7-13m depending on the water energy and resultant suspended sediment. Water analyses show low silicate and nutrient levels.

Rays, sharks, and barracuda are common in the channel, the first feeding on bivalves such as *Glycymeris* and the latter two on abundant schooling fish. Fleshy red algae occasionally grow by attaching to a rhodolith. The surrounding reef crest is predominantly a hardground community with encrusting forms on a relic barrier that shows karstic relief.

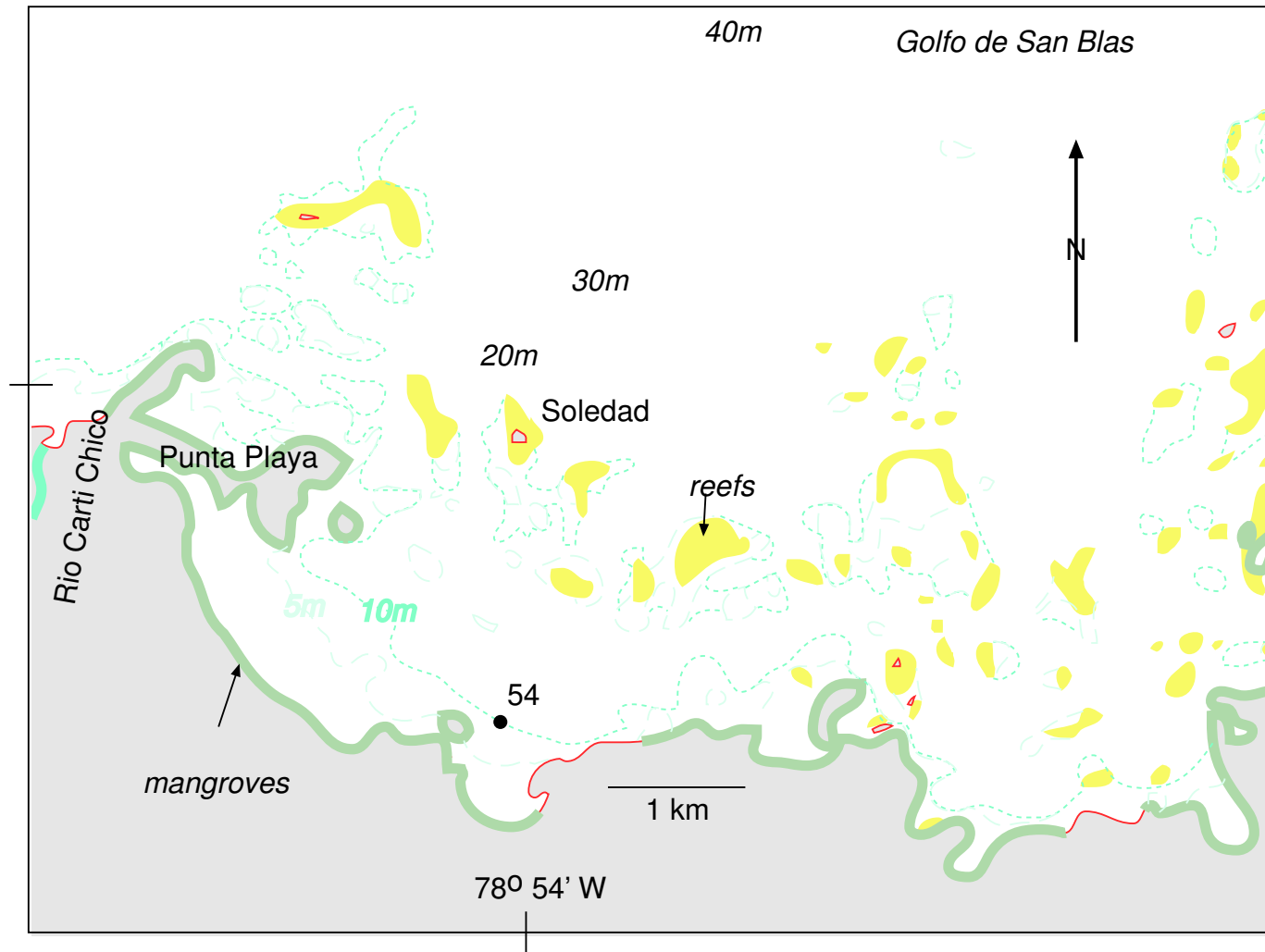
The sediment is a well sorted gravelly very coarse carbonate sand, with abundant rhodoliths that commonly reach 10cm in diameter. Bioclasts are *Halimeda* and corals, with lesser amounts of molluscs, *Homotrema*, and echinoids. Experimental shell arrays were either completely lost or buried under >8cm of sand after 1 year.



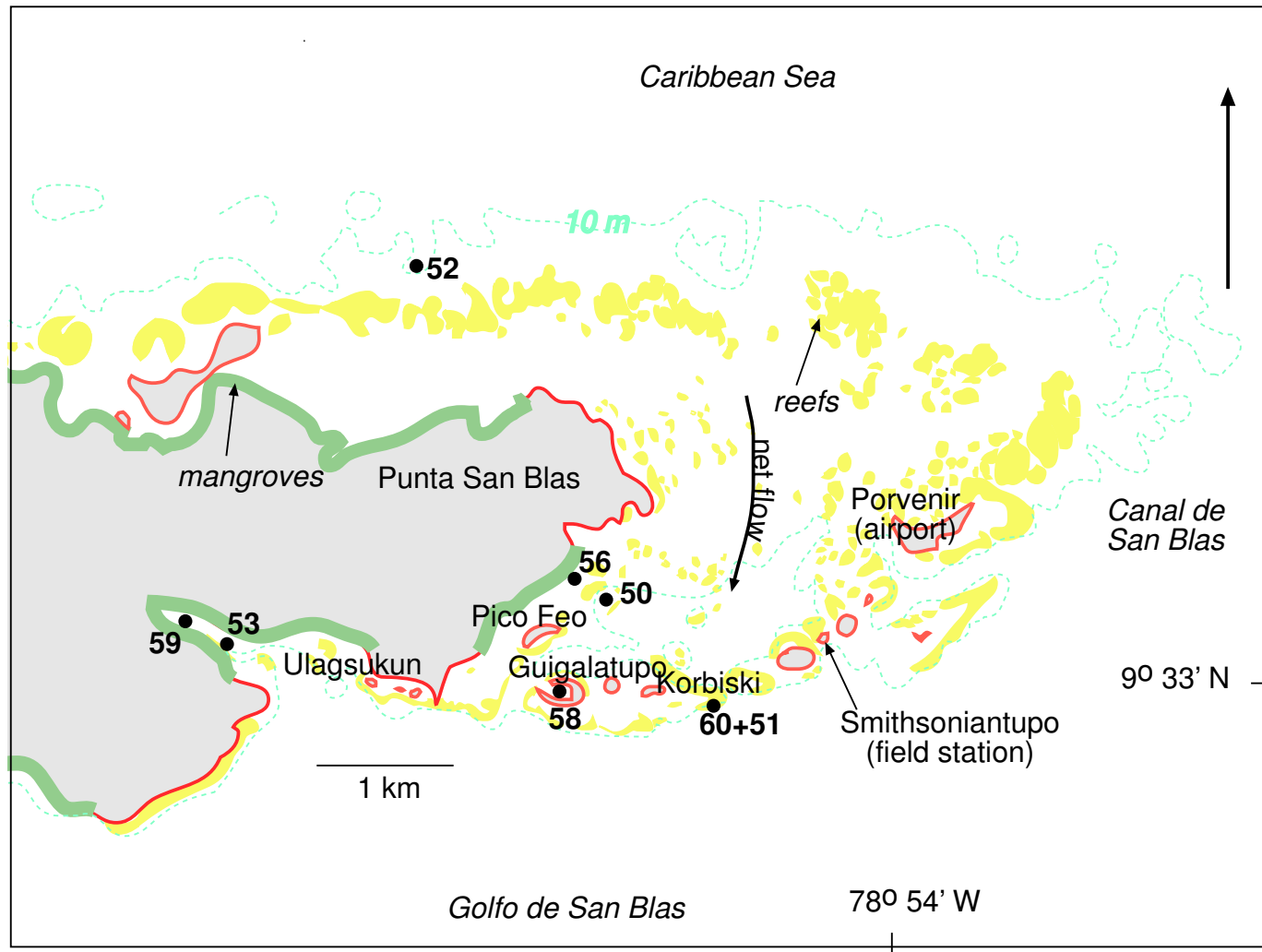
Supplementary Data 1, Figure 1. Map of mainland coast by outlet of Rio Agua, including location of study site 55.



Supplementary Data 1, Figure 2. Map of coastal embayment by Soledad, including location of study site 54.



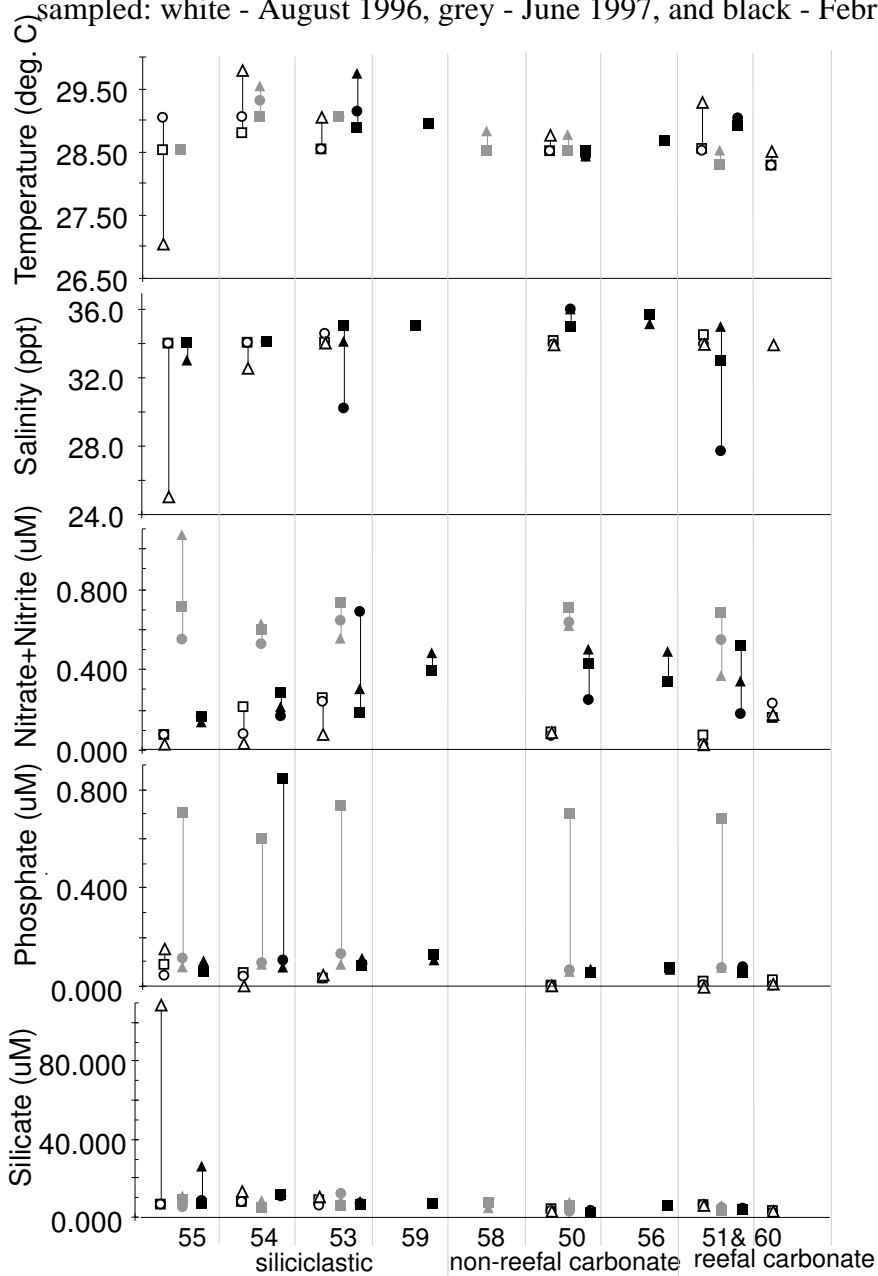
Supplementary Data 1, Figure 3. Map of Punta San Blas, including location of study sites 50, 51, 52, 53, 56, 58, 59, 60.



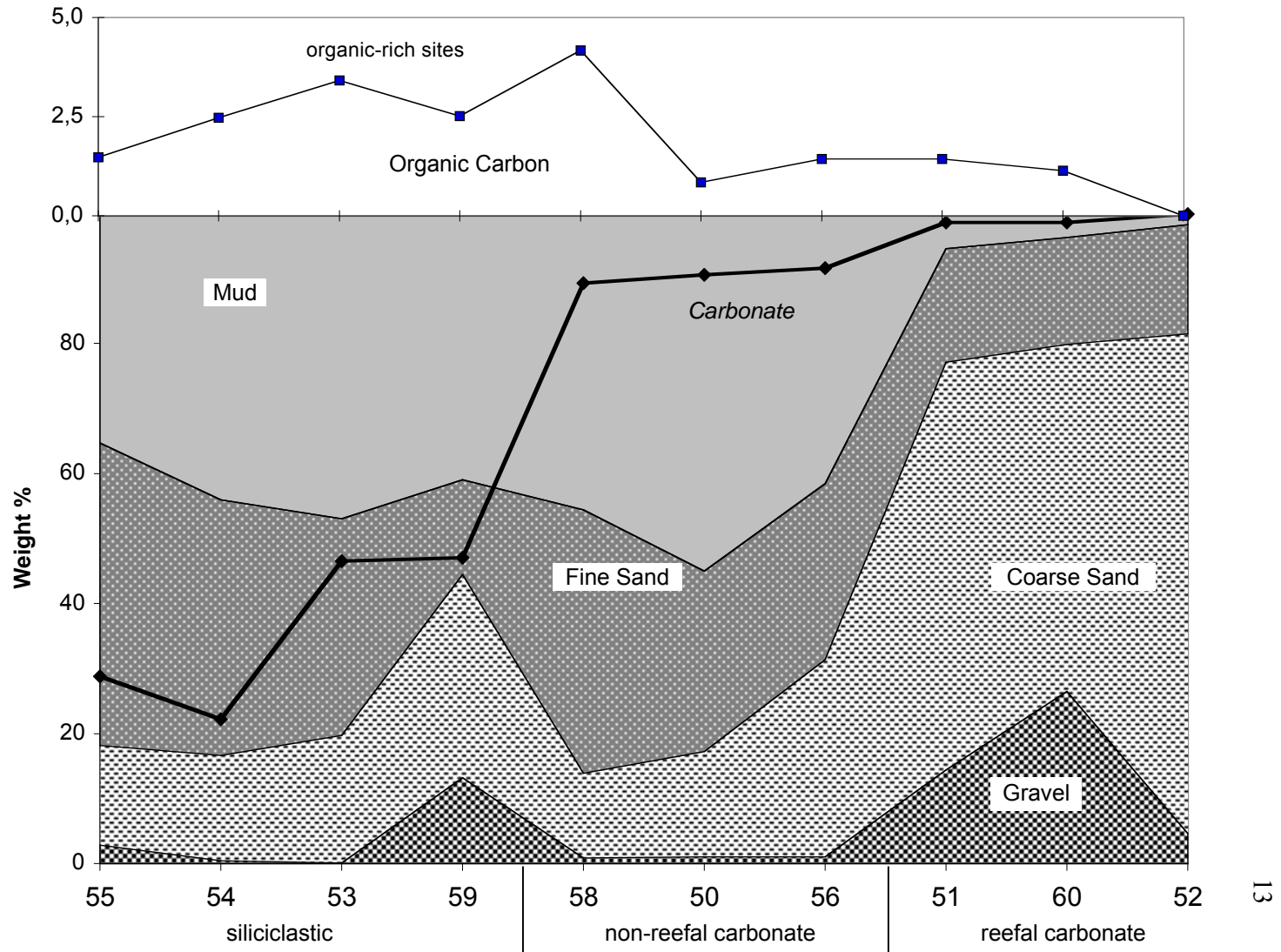
## Supplementary Data 1, Figure 4. San Blas Study Sites, Water Analyses.

Shape of symbols indicates location in water column: triangles - surface, circles - midpoint (5m), squares - bottom.

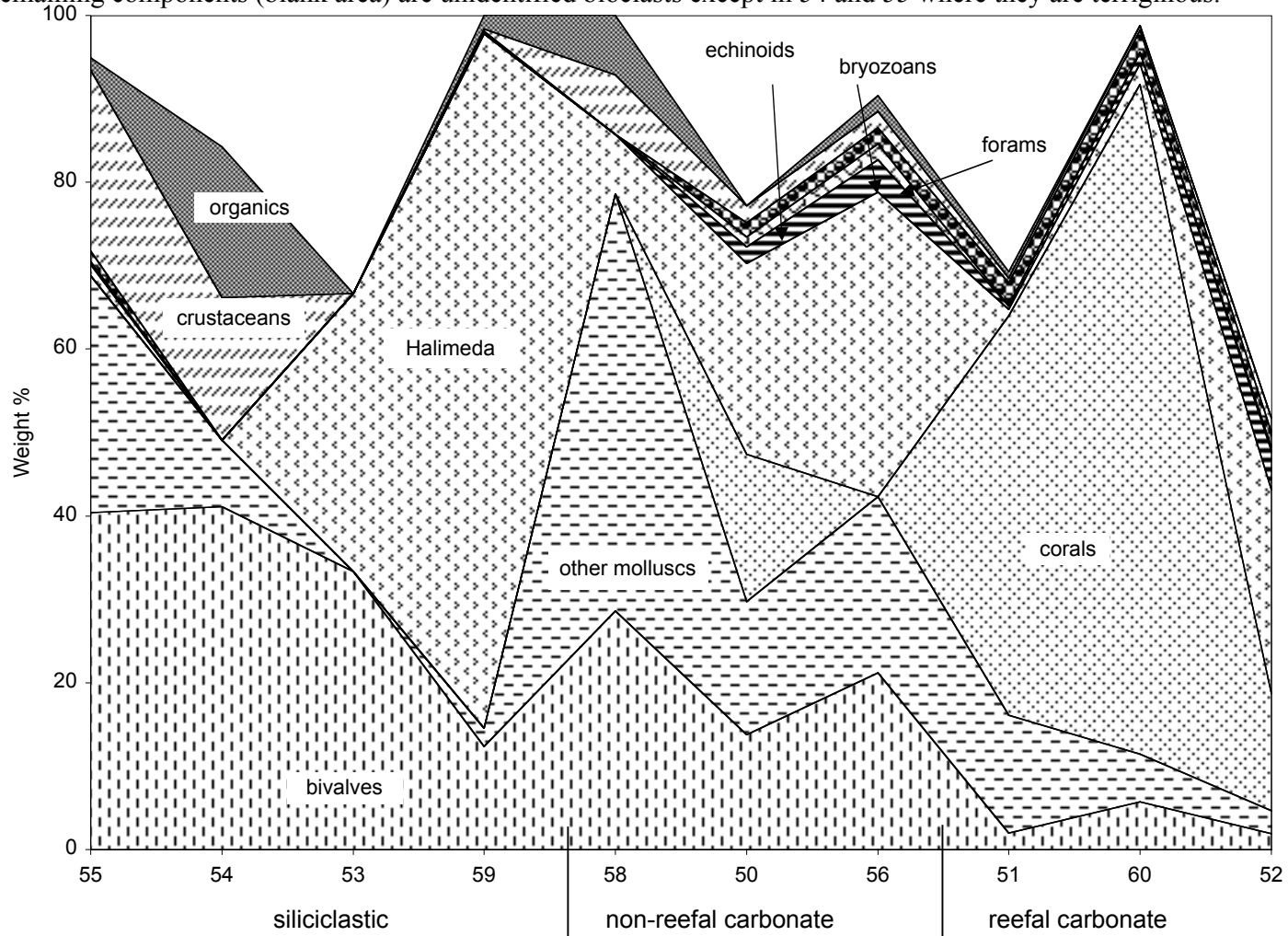
Colour of symbols indicates when sampled: white - August 1996, grey - June 1997, and black - February 1998.



Supplementary Data 1, Figure 5. Sediment grain size, bulk carbonate and organic carbon of mud.



Supplementary Data 1, Figure 6. Weight percent bioclastic groups in >2mm size fraction. Remaining components (blank area) are unidentified bioclasts except in 54 and 55 where they are terrigenous.



Supplementary Data 1, Table 1. Sampling at study sites.

Site	Depth (m)	Latitude		Longitude		Scoop Samples	Cores				Box Cores	Water Samples
		deg. min.		deg. min.			2.5cm x 50cm	2.5cm x 10cm	7.5cm x 10cm	7.5cm x 100cm		
95SB050	9	9	33,22	78	58,08	20	3	12	1	2	2	9
95SB051	11	9	32,84	78	57,60	13	3	9	1	-	-	9
95SB052	12	9	34,44	78	58,78	7	3	3	1	-	-	3
95SB053	9	9	33,02	78	59,73	15	3	12	1	2	2	9
95SB054	9	9	25,78	78	54,11	10	3	12	1	8	2	9
95SB055	9	9	27,01	79	0,21	9	3	12	1	4	2	9
95SB056	5	9	33,23	78	58,18	11	-	3	1	2	2	2
95SB058	3	9	32,78	78	58,18	14	-	3	1	6	2	1
95SB059	5	9	32,98	78	59,85	7	-	3	1	2	2	2
95SB060	5	9	32,78	78	57,61	8	-	3	1	-	-	see 95SB051