

Atlas of the Nearshore Shallow Benthic Habitats within the Manell-Geus Habitat Focus Area



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This atlas presents quantitative surveys and GIS-based mapping of three types of biological communities present within the shallow nearshore zone of the Manell-Geus Habitat Focus Area: mangrove forests, seagrass beds and coral-dominated communities. These are described in detail in the succeeding pages in this atlas. In addition, the manual provides a description of the methods used to obtain these data, descriptions of the mangrove species found within the area, details on the types of health impacts affecting corals, and results of a nutrient and bacteria study.

The atlas presents these benthic habitat studies within Global Information Systems (GIS) grids. The location of each grid within the HFA is identified by a yellow square on the base map provided below the habitat grid map. Red dots within the habitat types represent the site of the actual surveys. Grids are organized from south to north, beginning with the southeast seagrass bed and Tonggan Way coral community (which is outside the Manell-Geus boundary), and ending at the northern boundary of the Geus watershed.



Map of the Manell-Geus Habitat Focus Area, showing the location of the survey sites presented in this manual. SG = seagrass; MNG = mangroves; Sites A through O are Cocos Lagoon coral patches; TON = Tonggan Way; AJA = Ajayan River; LIY = Liyog River; LAO = Laolao River; MNS and MNN = Manell Channel South and North.

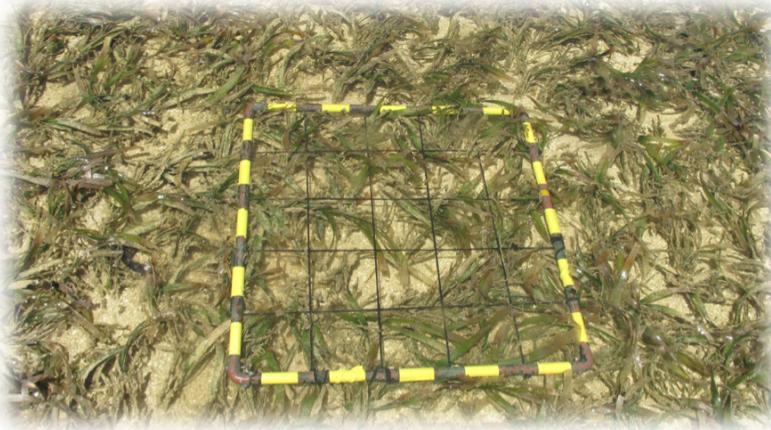
METHODS USED IN THESE SURVEYS

Mangrove surveys



Mangroves were mapped by towing a transect and GPS unit in a kayak, along the periphery of the forests, which line the coast from the Achang Marine Preserve to the village of Malesso. At points along the forest, the number of trees of each species present were counted; the diameter of the trunks of a subset of trees of each species were measured, and the trees per unit of area were counted to determine stand density.

Seagrass surveys



Seagrass beds were mapped by walking the periphery of each bed holding a GPS unit. The density, species, and length of plants were determined within 0.25m² quadrats laid every 10 m across the width of each bed.

Coral community surveys

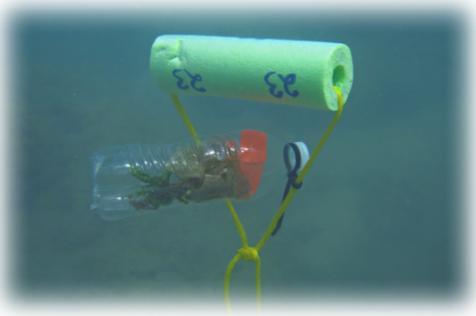


Coral patch reefs and coral communities were mapped using satellite images to trace the boundary of each community. A subset of these patches were surveyed along 10 m - 15 m transects (n=1-3 transects per site, depending on the size of the patch), for the following types of information: benthic composition (percent of live hard coral, dead standing coral, coral rubble, sand, silt, soft coral, macroalgae). All corals within a 10 m by 1 m transect belt were identified to species, their size was estimated by size class, and visually inspected for health impacts (coral diseases, bleaching, silt smothering, predation, overgrowth, physical damage; see Coral health Impacts, pp. 56-61).



Nutrient enrichment experiments

Nitrogen uptake experiment



The macroalga *Padina* sp. was deployed in these bottles for one week at 50 sites within the Manell-Geus HFA, to see how much nitrogen they absorbed at each site. Samples were analyzed for $\delta^{15}\text{N}$ at the University of Hong Kong. $\delta^{15}\text{N}$ is the ratio of stable naturally-occurring isotopes of nitrogen, which can be traced to either fertilizer or fecal sources.

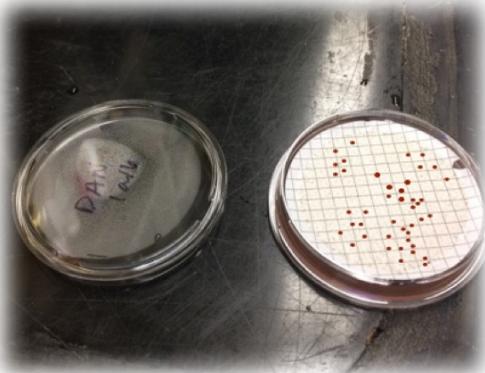
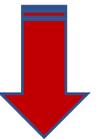
Does the water of the Manell-Geus HFA have too many nutrients? These studies tested water and algae within the HFA to see if the nutrient concentrations were higher than what we would expect from clean nearshore ocean water. This is a way of determining if human activities, such as agriculture and sewage discharge, are enriching or 'fertilizing' our coastal waters. This can cause problems for marine communities, such as overabundant algal growth and certain diseases of corals.

Bacterial contamination survey



Water samples were collected from rivers and along the coast.

They were filtered in the lab....



And the residue was cultured on culture plates. Each red dot on this plate is one colony of *Enterococcus* bacteria.



GRID 1: SEAGRASS BED 1, SITES A,B,C





Seagrass Bed 1 is composed of three connected patches and lies outside the boundary of the Manell-Geus HFA. It was included in this survey due to its proximity to the HFA.

Appearance of *Enhalus acoroides* bed at seagrass bed 1A.

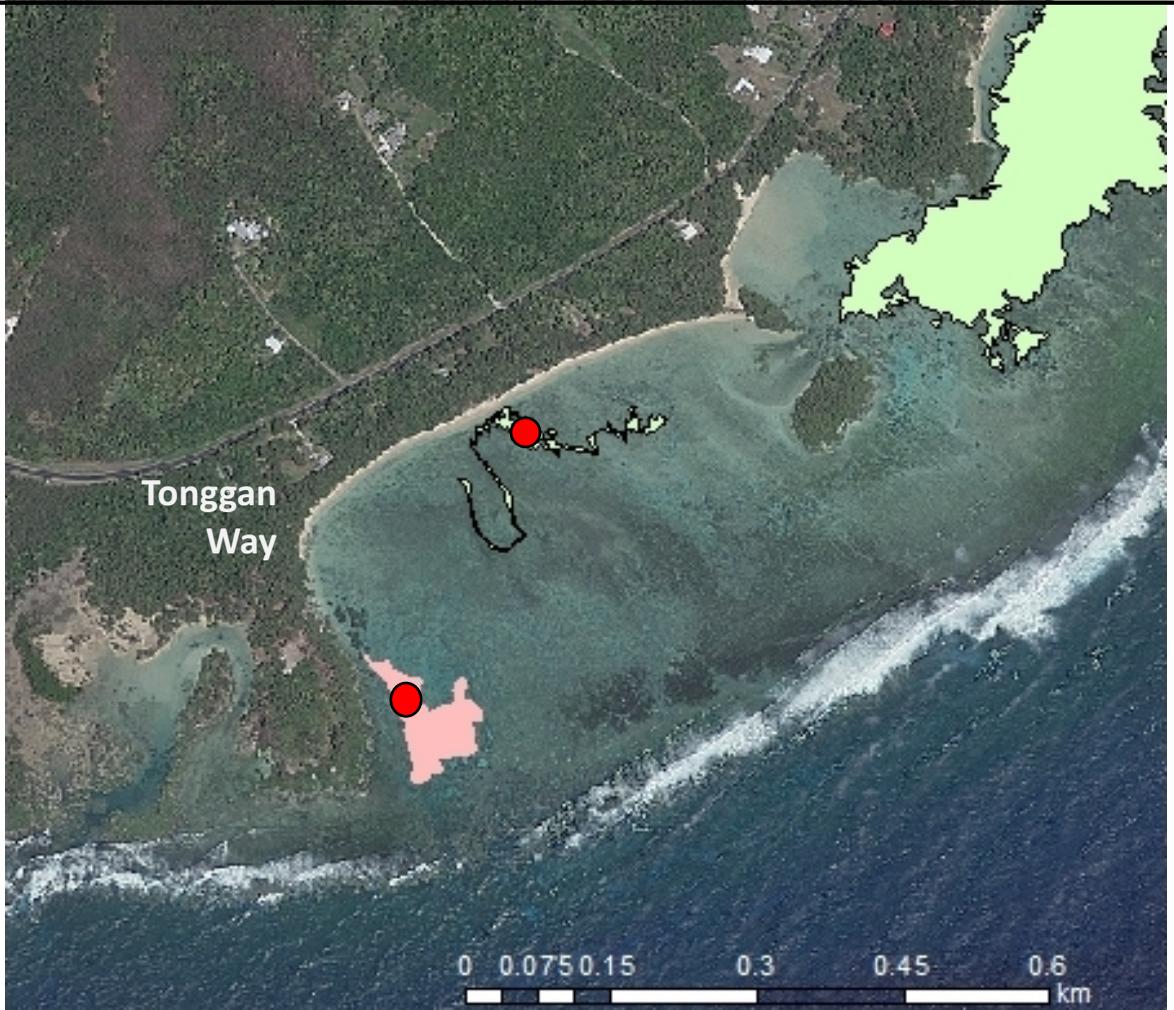
Site	Mean <i>E acoroides</i> shoots/sqm	Mean blade length, cm	Mean % epiphyte cover
1A	233.7 +/- 213.4	14.4 +/- 5.2	1.1 +/- 1.0
1B	272.7 +/- 57.5	12.0 +/- 3.9	0.7 +/- 0.5
1C	387.0 +/- 109.2	28.9 +/- 15.0	1.2 +/- 1.0

Three sites were surveyed within seagrass bed 1 (sites A, B, and C). This bed is composed exclusively of the seagrass species *Enhalus acoroides*. Mean shoot density and epiphyte cover did not vary significantly between different sites. However, site C was characterized by both longer and denser seagrass shoots, possibly explained by increased water depth at this site. Seagrasses at the shallowest sites were exposed at low tide and showed breakage at the top of the blades, which may have occurred during a storm which had recently passed through. Low epiphyte density corresponded with relatively clear water.



Enhalus acoroides in deeper water, seagrass bed 1C.

GRID 2: SEAGRASS BED 2 & TONGGAN WAY OUTCROP CORAL COMMUNITY





Two sites were surveyed within this grid: seagrass bed 2 and the Tonggan Way coral community.

Seagrass bed 2 is a small, dispersed, mixed bed containing both *Enhalus acoroides* & *Halodule pinifolia*, interspersed with a sand-rubble-algae community.

Halodule pinifolia in seagrass bed 2, showing blades covered in epiphytes and silt, and coarse sand substrate.

Seagrass bed 2 species	Mean shoots/sqm	Mean blade length, cm	Mean % epiphyte cover
<i>E. acoroides</i>	174+/- 126	17 +/- 7	9 +/- 13
<i>H. pinifolia</i>	1225 +/- 780	n.a.	n.a.



Surface view of seagrass bed 2 (foreground) and Tonggan Way (background)



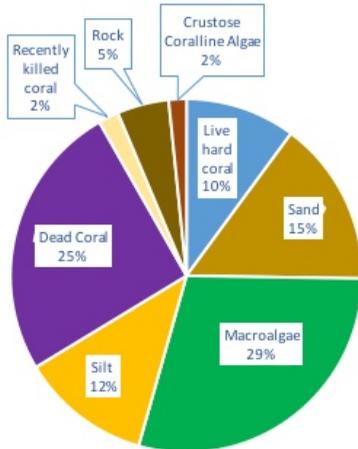
Mixed sand-rubble-algae community with a colony of the coral *Dipsastraea favus*.

The Tonggan Way coral community is composed of patches of limestone platforms interspersed with sand flats. Live coral cover is low and macroalgal cover is correspondingly higher. Corals are scattered and dominated by massive growth forms. Coral disease is very rare and silt smothering is the most common form of coral mortality.



A massive *Porites* sp. colony, the dominant coral growth form in Tonggan Way outcrop

TONGGAN WAY OUTCROP CORAL COMMUNITY BENTHIC COMPOSITION



Macroalgae community at Tonggan Way

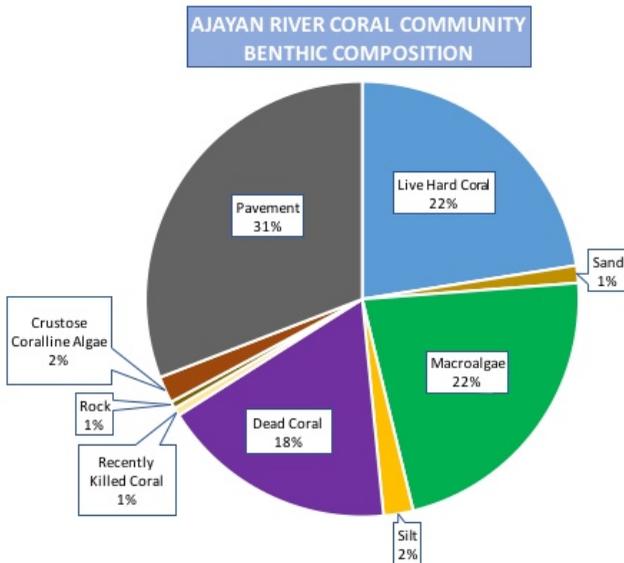
Tonggan Way coral species list
<i>Acanthastrea</i> sp.
<i>Cyphastrea microphthalma</i>
<i>Goniopora fruticosa</i>
<i>Goniastrea retiformis</i>
<i>Heliopora coerulea</i>
<i>Leptastrea purpurea</i>
<i>Pocillopora damicornis</i>
<i>Pocillopora meandrina</i>
<i>Pocillopora</i> sp.
<i>Pocillopora verrucosa</i>
massive <i>Porites</i> sp.
<i>Porites rus</i>
<i>Plesiastrea versipora</i>
<i>Psammocora digitata</i>
<i>Dipsastrea pallida</i>
<i>Dipsastrea stelligera</i>
<i>Pavona venosa</i>

Coral Health Impact	% of colonies with impact (n=231 surveyed)
Damselfish territory	1.8%
Partial mortality	6.6%
Silt smothering	11.1%
Physical damage	1.1%
<i>Terpios</i> overgrowth	0.4%
White syndrome	0.7%

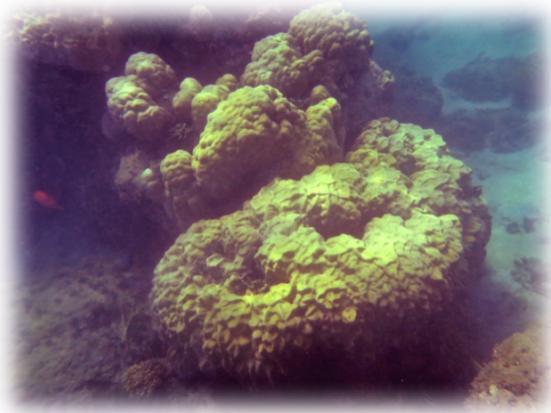
GRID 3: AJAYAN RIVER CORAL COMMUNITY



One site was surveyed within this grid: the Ajayan River coral community. This community exists along a narrow fringe on the southwestern platform border of the river channel and was surveyed along its entire length. Seagrass bed 3 is partly shown in this grid; the assessment of this bed is included in Grid 4.



Ajayan River reef flat, adjacent to the river channel.



Massive *Porites* boulder corals that provide habitat, structure and stability to the Ajayan River channel.

Ajayan River Channel coral species list

<i>Acanthastrea echinata</i>	<i>Plesiastrea versipora</i>
<i>Galaxea fascicularis</i>	<i>Platygyra pini</i>
<i>Heliopora coerulea</i>	<i>Diploastrea heliopora</i>
<i>Pocillopora damicornis</i>	<i>Astraea valenciennesi</i>
<i>Pocillopora meandrina</i>	<i>Dipsastrea sp.</i>
massive <i>Porites sp.</i>	<i>Dipsastrea pallida</i>
<i>Porites rus</i>	<i>Leptoria phrygia</i>
<i>Porites monticulosa</i>	<i>Leptastrea purpurea</i>
<i>Psammocora contigua</i>	<i>Goniastrea retiformis</i>
<i>Pavona venosa</i>	<i>Favites sp.</i>

The coral community is dominated by massive growth forms and is impacted by silt from the river. In addition, a large number of recently killed colonies of the species *Pocillopora damicornis* were observed during the surveys. Mortality is hypothesized to have been caused by the recent bleaching event. Bleaching and related mortality were the most prevalent health impacts.

Coral health impact	% of colonies with impact (n=269 surveyed)
Bleaching	6.2%
Bleaching death	11.9%
Damselfish territories	2.9%
Silt smothering	3.1%
Partial mortality	6.4%
White syndrome	2.0%

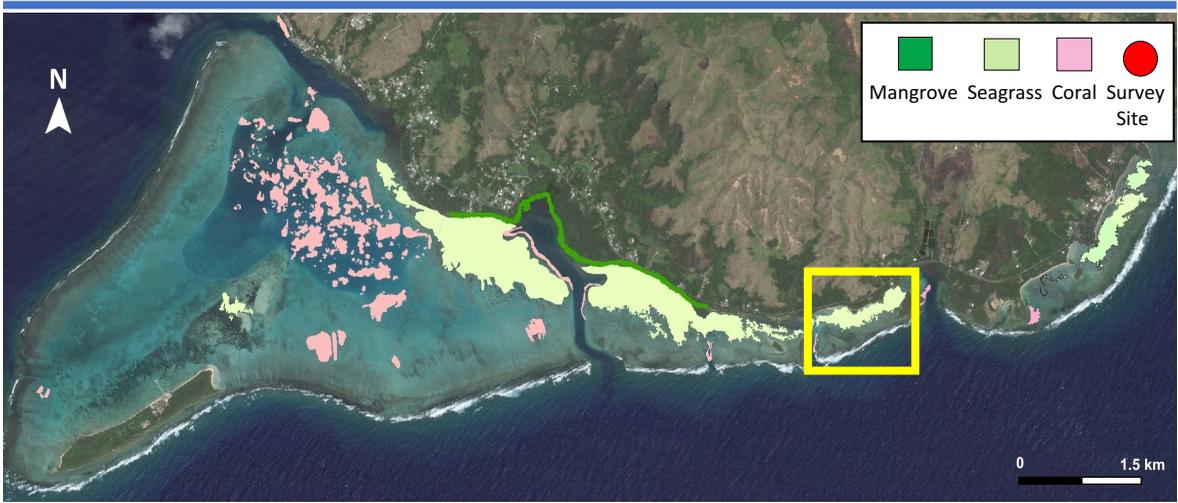
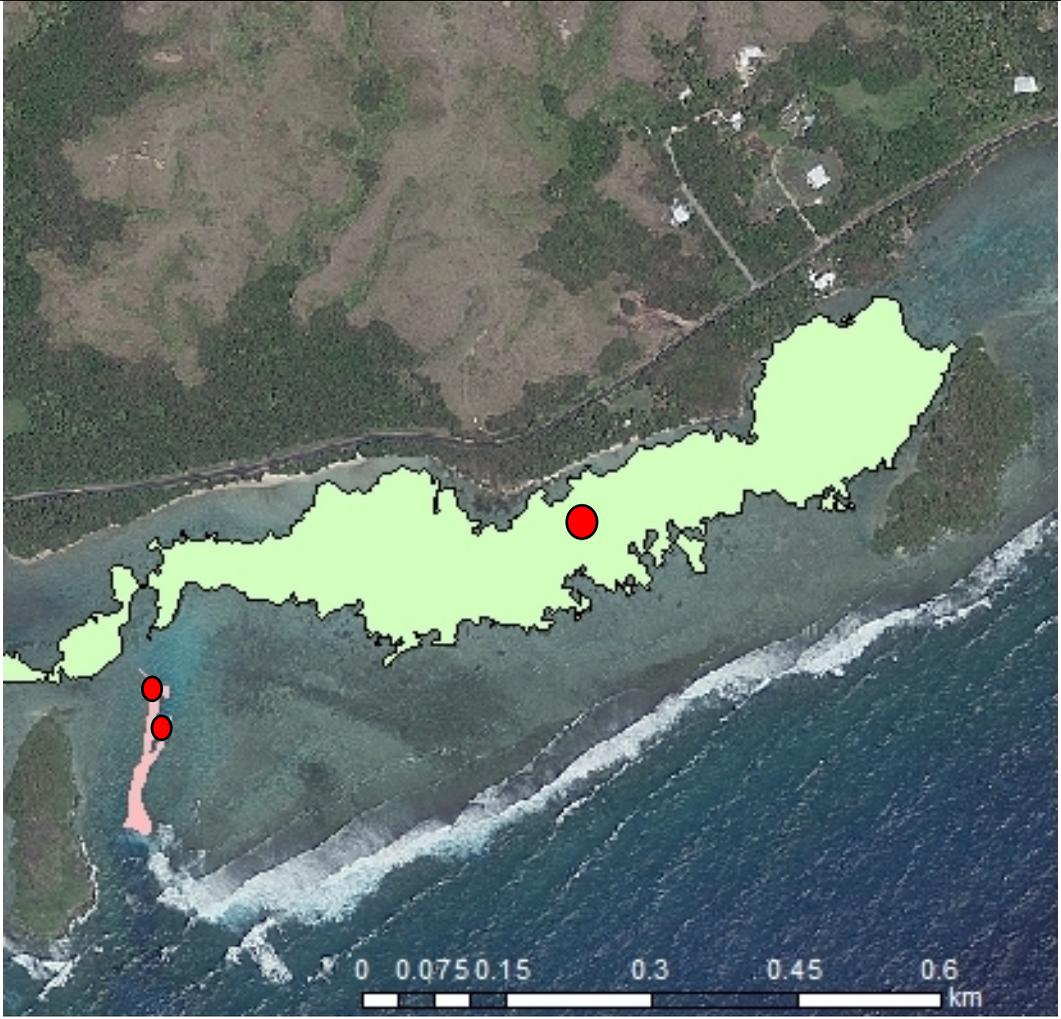


Numerous *Pocillopora damicornis* colonies killed during the previous season's bleaching event. Dead colonies marked with a red star.



Silt smothering (blue circle) and a growth anomaly (at yellow arrow) affecting the health of this massive *Porites* coral colony

GRID 4: SEAGRASS BED 3 & LIYOG RIVER CORAL COMMUNITY



Grid 4 contains Seagrass bed 3 and the small coral community of the Liyog River Channel. The seagrass bed is located nearshore and extends in width midway across the reef flat. The coral community is limited to the offshore section of the river channel. The remainder of the reef flat is a mixed sand-rubble-algae substrate.



Holothuria atra, “balate”, one of the benthic invertebrates found within Seagrass bed 3.

Seagrass bed 3 is a mixed bed dominated by *Enhalus acoroides*, but also containing scattered patches of *Halodule pinifolia* and *Halophila ovale*. Seagrasses are of average density when compared with other sites, though blades are longer than those of other sites, suggesting deeper water. High epiphyte load suggests some siltation, undoubtedly due to proximity to two river channels.

Seagrass bed 3	Mean shoots/sqm	Mean blade length, cm	Mean % epiphyte cover
<i>E. acoroides</i>	271 +/- 88	29 +/- 19	10 +/- 12



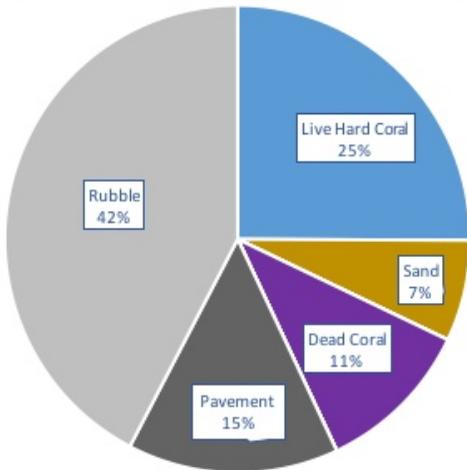
Mixed patch of *Halodule pinifolia* and *Halophila ovale*.



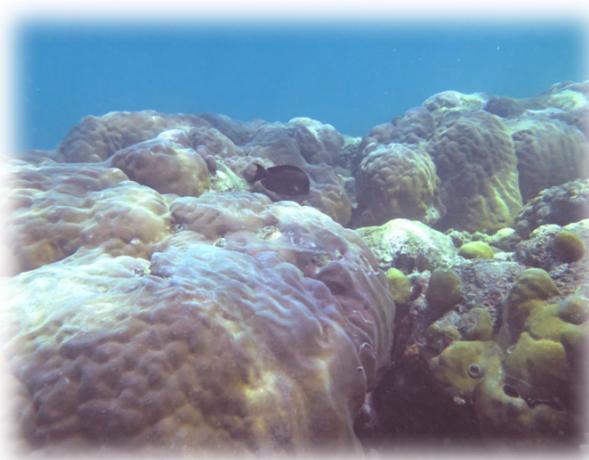
Low density patch of *Enhalus acoroides* at very shallow depth. Blades have been broken off due to exposure at low tide.

The Liyog River channel coral community is composed of a narrow fringe of coral growth along both north and south borders of the channel. The channel is bordered by a limestone platform continuous with the reef flat. Both northern and southern coral communities were surveyed. Species diversity was higher along the northern border but coral cover was similar for both sites, and still dominated by massive growth forms. This site displayed several coral diseases which were absent from other sites (skeletal eroding band, growth anomalies and grey death). Tissue death due to silt smothering was more prevalent on the southern border than on the northern channel, undoubtedly due to current patterns. However, white syndrome was much more common along the northern border.

**LIYOG RIVER NORTH CORAL COMMUNITY
BENTHIC COMPOSITION**

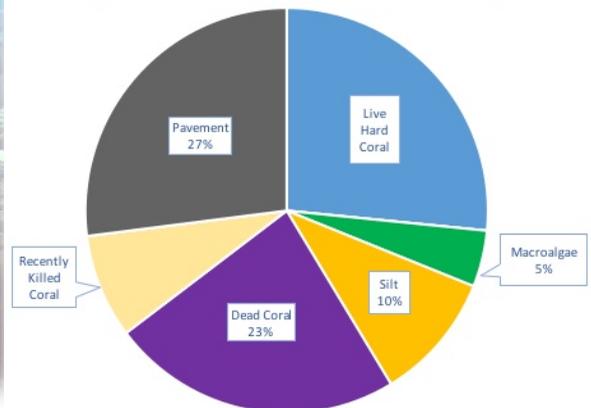


The northern Liyog River channel coral community.



The top border of the southern Liyog River coral community.

**LIYOG RIVER SOUTH CORAL COMMUNITY
BENTHIC COMPOSITION**



Coral Health Impacts	North: % of colonies with impact (n=211 surveyed)	South: % of colonies with impact (n=404 surveyed)
Damselfish territory	3.3%	0.8%
Silt smothering	0.8%	7.6%
Partial mortality	11.1%	8.1%
Grey death disease	0.3%	0.2%
Growth anomaly	0.8%	0.0%
White syndrome disease	5.0%	0.6%
Skeletal eroding band disease	0.0%	0.2%



A massive *Porites* colony infected with the coral disease grey death



A colony of the coral *Goniastrea retiformis* which is severely bleached. This picture was taken after the surveys were conducted. No bleaching was recorded at the time of the surveys.

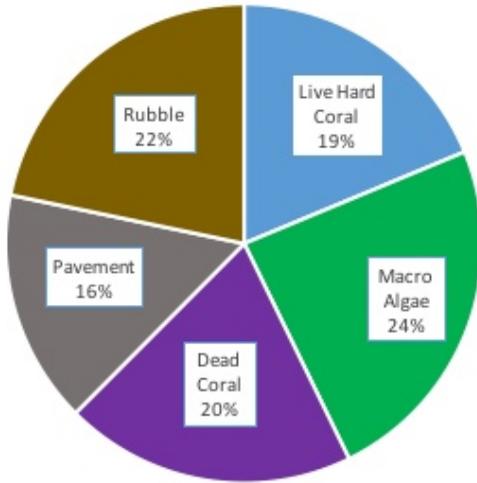
Liyog River Channel coral species list	
North	South
<i>Acanthastrea echinata</i>	digitate <i>Acropora</i> sp.
<i>Acanthastrea</i> sp.	<i>Pocillopora damicornis</i>
<i>Montipora caliculata</i>	<i>Goniastrea edwardsii</i>
<i>Pocillopora damicornis</i>	<i>Goniastrea retiformis</i>
<i>Pocillopora meandrina</i>	<i>Leptastrea purpurea</i>
<i>Goniastrea retiformis</i>	<i>Plesiastrea versipora</i>
<i>Dipsastraea pallida</i>	<i>Platygyra daedalea</i>
<i>Dipsastraea helianthoides</i>	<i>Astraea curta</i>
<i>Plesiastrea versipora</i>	<i>Leptoria phrygia</i>
<i>Astraea curta</i>	<i>Diploastrea rotundata</i>
<i>Astraea valenciennesi</i>	massive <i>Porites</i> sp.
<i>Leptoria phrygia</i>	<i>Lobophyllia hemprichii</i>
<i>Leptastrea purpurea</i>	
<i>Porites annae</i>	
<i>Porites lichen</i>	
massive <i>Porites</i> sp.	

GRID 5: LAOLAO RIVER CORAL COMMUNITY



Grid 5 contains the coral community along the channel formed by the Laoalao River, as well as the southernmost tip of the coastal mangrove forest and the southern half of seagrass bed 4. Data from the Laoalao River quantitative survey is presented in this grid; the other two site surveys are included in Grids 6 and 7.

LAOLAO RIVER CHANNEL CORAL COMMUNITY BENTHIC COMPOSITION



Northern channel rim showing a *Pocillopora damicornis*-dominated coral community.

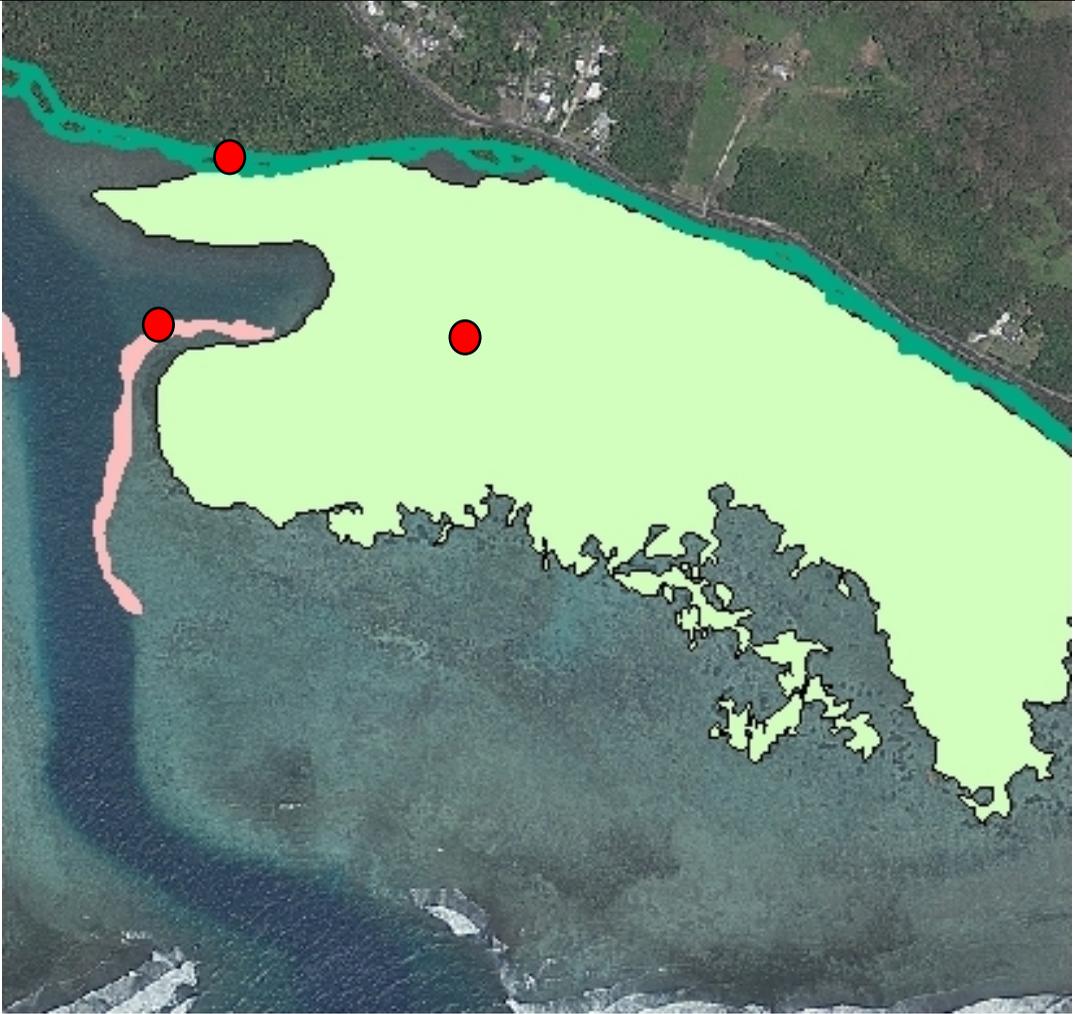


Southern channel rim, showing a substrate dominated by sand, pavement, macroalgae and the seagrass *Halophila pinifolia* and scattered colonies of massive *Porites* sp.

Coral Health Impacts	% of colonies with impact (n=396 surveyed)
Damsel fish territories	3.3%
Silt smothering	3.0%
Partial mortality	6.3%
White syndrome	1.0%
Skeletal Eroding Band	1.8%
Endolithic Fungal Infection	0.8%

Laolao River Channel coral species list
<i>Pocillopora damicornis</i>
<i>Pocillopora</i> cf. <i>coniculus</i>
<i>Porites massiva</i>
<i>Heliopora coerulea</i>
<i>Goniastrea retiformis</i>
<i>Dipsastrea favus</i>
<i>Leptoria phrygia</i>
<i>Leptastrea purpurea</i>
<i>Astrea valencienessi</i>
<i>Psammocora contigua</i>
<i>Psammocora</i> sp.

GRID 6: MANELL CHANNEL CORAL SOUTH, SEAGRASS 4, MANGROVE FOREST SOUTH



Grid 6 includes the Manell channel and was bounded nearshore by the southern length of the Achang mangrove stand. Seaward of this stand was Seagrass bed 4. The grid also included a small coral community along the southern rim of the Manell channel.



The mangrove forest of the Manell-Geus HFA begins in the south, in Grid 5, and extends as a narrow fringe along the coastline, ending in Grid 9. Significant portions of this forest are presented in Grids 6 and 8. Spot surveys were conducted at regular intervals along this community and survey data are summarized in Grid 6.

Manell channel margin forest

There are three species of mangrove trees found within the Manell-Geus HFA and the Achang Marine Preserve: *Avicennia marina* ('grey mangrove'), *Bruguiera gymnorhiza* ('black mangrove'), and *Rhizophora apiculata* ('red mangrove'). *R. apiculata* is the most common and the majority of the trees are in the second (10 cm trunk diameter) and third (15 cm trunk diameter) smallest size categories.



Rhizophora apiculata



Avicennia marina



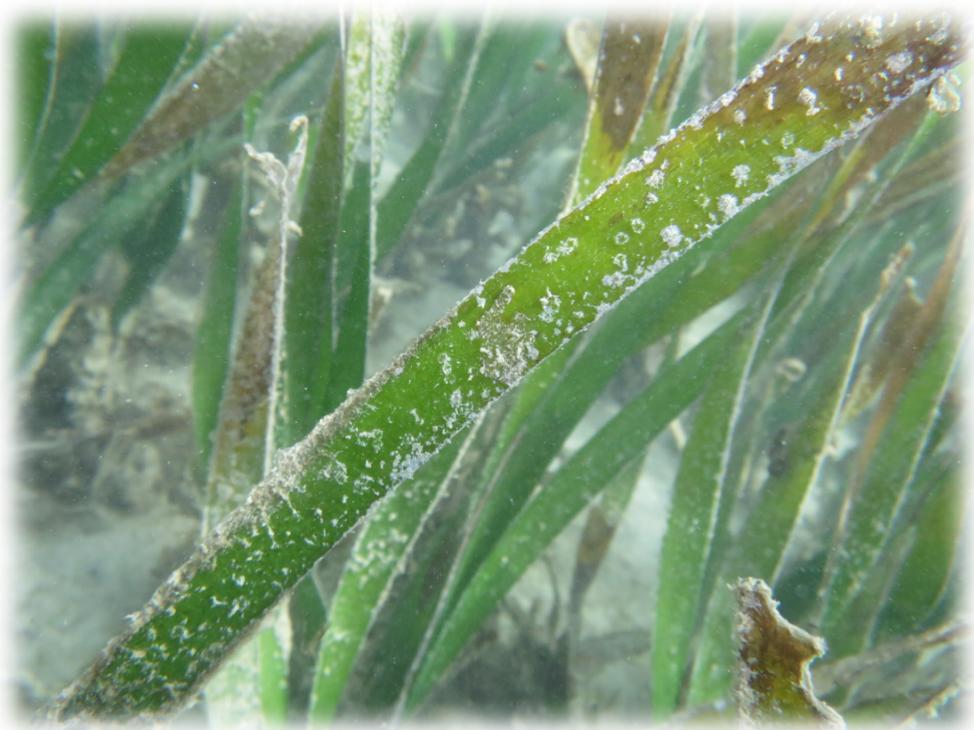
Bruguiera gymnorhiza



Seagrass bed 4 is extensive, beginning close to bed 3 and extending to the Manell Channel. The survey site was positioned in Grid 6 so survey results are presented here. This seagrass bed displayed the highest blade density of all those surveyed. Epiphyte cover was high, suggesting high silt load from the Manell Channell.

Shoot density typical of Seagrass bed 4.

Seagrass bed 4	Mean shoots/sqm	Mean blade length, cm	Mean % epiphyte cover
<i>Enhalus acoroides</i>	403 +/- 250	21 +/- 13	16 +/- 13



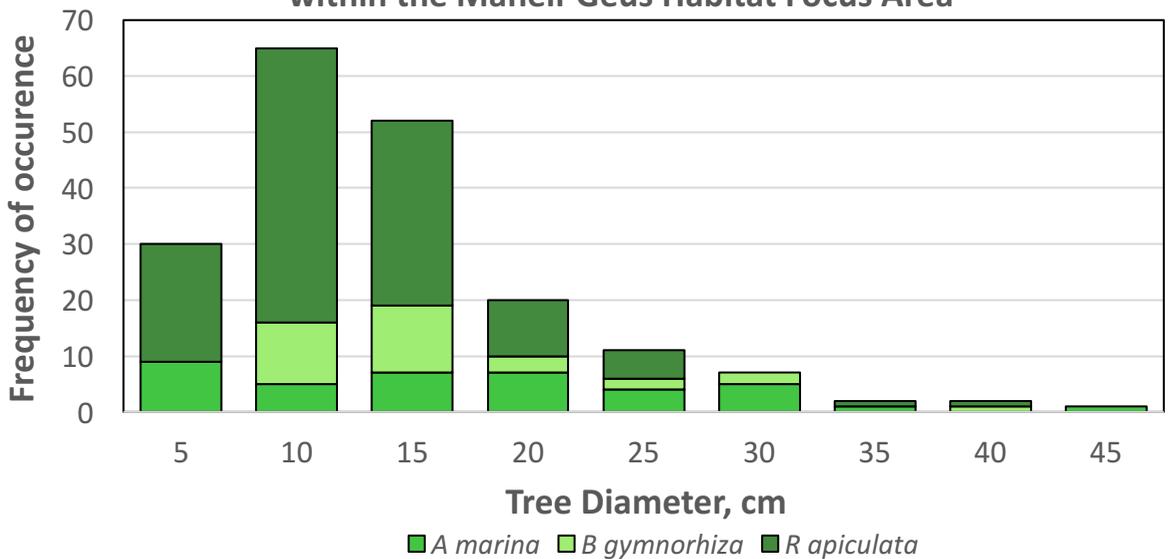
Appearance of an *Enhalus acoroides* seagrass blade with a moderate density of epiphytic growth.

Species	Trees/ ha	Relative Density	Relative Cover	Relative Frequency	Relative Importance
<i>Avecinnia marina</i>	406	0.2	35.5	20.5	28.0
<i>Bruguiera gymnorrhiza</i>	323	0.2	20.3	16.3	18.3
<i>Rhizophora apiculata</i>	1249	0.6	44.2	63.2	53.7

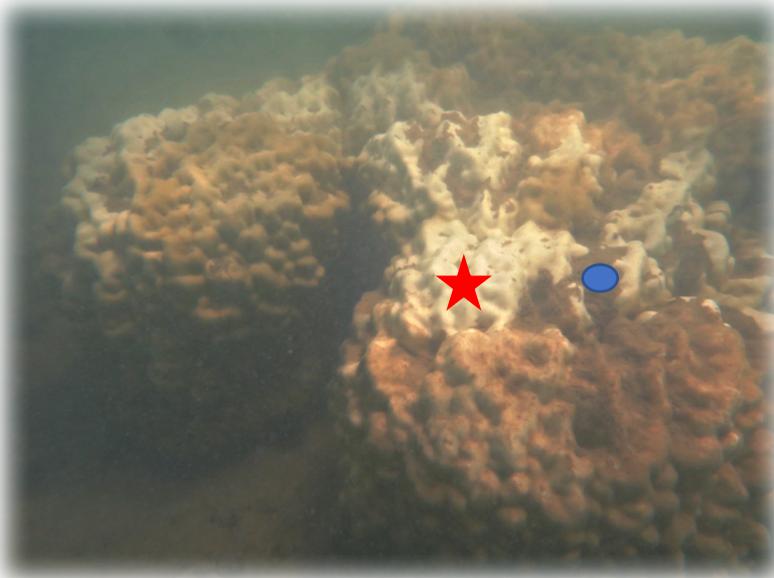


Mixed mangrove forest along the Laolao river channel.

Size-Frequency Distribution Among Mangrove Forest Species within the Manell-Geus Habitat Focus Area



The southern coral community is scattered among patches of seagrass along the southern channel boundary, near the mangrove forest, at 2 to 3 meters depth. It is very silty, due to its proximity to the channel and the mangrove and seagrass beds. A formal survey was not conducted due to poor visibility. The coral community is composed almost exclusively of large massive *Porites* spp, 0.5 m – 1 m in diameter, with scattered colonies of *Pocillopora damicornis*. The larger colonies form dense, consolidated patches which rise almost to the surface of the water at low tide.



Massive *Porites*-dominated coral community along the nearshore southern rim of the Manell Channel. The photos show accumulation of silt on coral heads (indicated by the ●), a partially bleached colony (indicated by the ★), and poor visibility due to very turbid water.

Bleached massive *Porites* colony

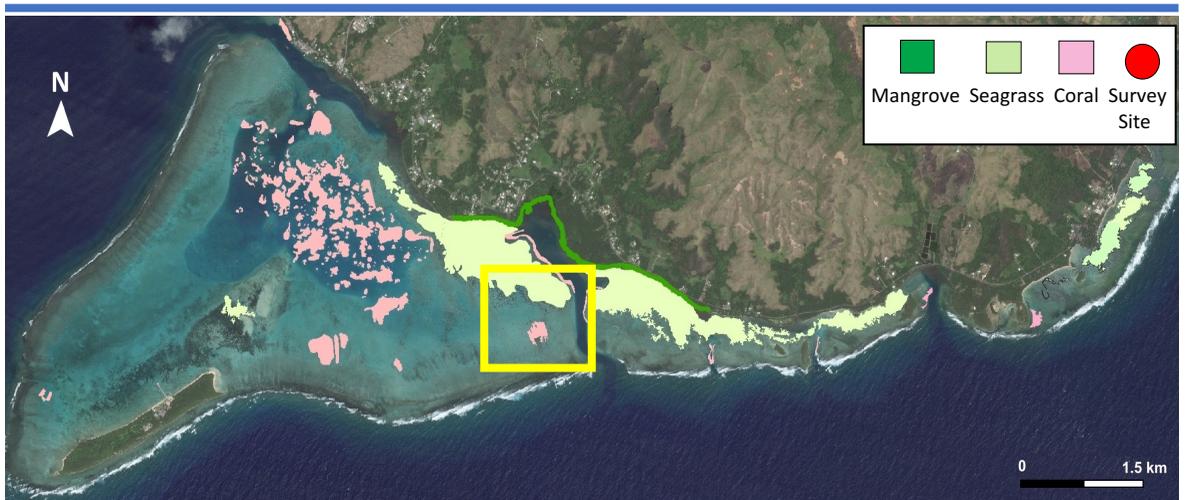


A small massive colony surrounded by silt

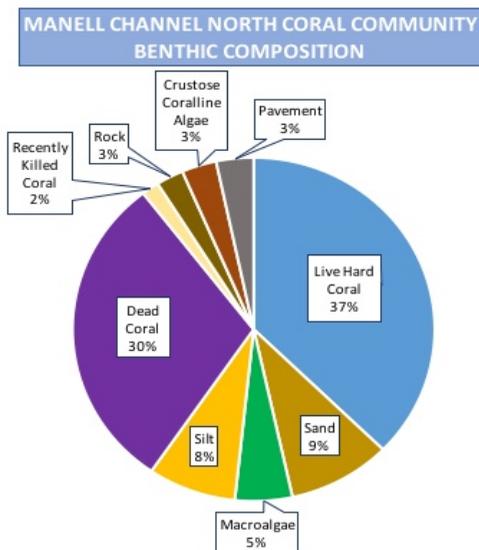


A *Porites* coral ridge growing in very turbid water

GRID 7: MANELL CHANNEL NORTH CORAL COMMUNITY & CORAL PATCH A



Grid 7 contains the southern portion of Seagrass bed 5 (presented in Grid 8), the Manell Channel northern coral community, and Cocos Lagoon Coral Community A. Results of the two coral community surveys are presented here. Manell Channel North has higher species diversity, greater coral cover, and less silt than the south community (see Grid 6, p. 25)



Patchy coral community along the northern edge of the Manell Channel



Manell Channel North coral species list

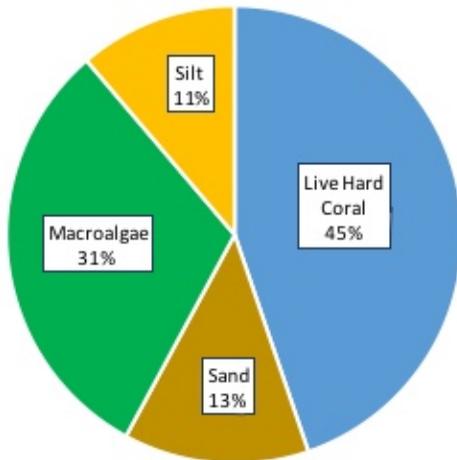
- Acropora muricata*
- Acropora palifera*
- Acropora cf. pulchra* (dead)
- Montipora verrucosa*
- encrusting *Montipora* sp.
- Pocillopora verrucosa*
- Pocillopora damicornis*
- Goniastrea edwardsii*
- Goniastrea retiformis*
- Leptastrea purpurea*
- Platygyra pini*
- Porites cylindrica*
- Porites annae*
- Porites deformis*
- Porites lichen*
- Porites monticulosa*
- massive *Porites* sp.
- Galaxea fascicularis*
- Heliopora coerulea*
- Pavona* sp.

Manell Channel North coral health impacts	% of colonies with impact (n=71 surveyed)
Algal overgrowth	4.5
Damsel territories	4.5
Silt smothering	11.9
<i>Terpios</i> overgrowth	3.0
Bleaching	1.5
Partial mortality	7.5
White syndrome disease	3.0

Cocos Lagoon Coral Community

A – This is an extensive coral thicket composed primarily of the staghorn *Acropora aspera*. Recent surveys indicate that this is the last remaining population of this species on Guam.

COCOS LAGOON CORAL COMMUNITY A BENTHIC COMPOSITION



Cocos Lagoon coral patch A coral species list

<i>Acropora aspera</i>
<i>Acropora cf. pulchra</i>
<i>Porites cylindrica</i>
massive <i>Porites</i> sp.
<i>Porites lichen</i>
<i>Pocillopora verrucosa</i>
<i>Pocillopora damicornis</i>
<i>Leptastrea purpurea</i>
<i>Heliopora coerulea</i>
<i>Goniastrea retiformis</i>
<i>Goniastrea edwardsii</i>
<i>Pavona decussata</i>
<i>Pavona varians</i>



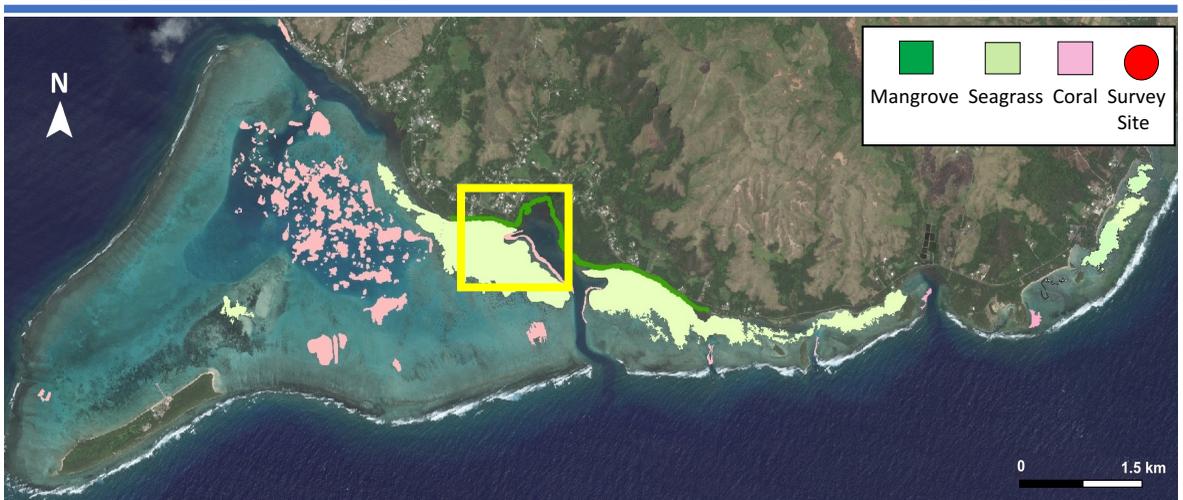
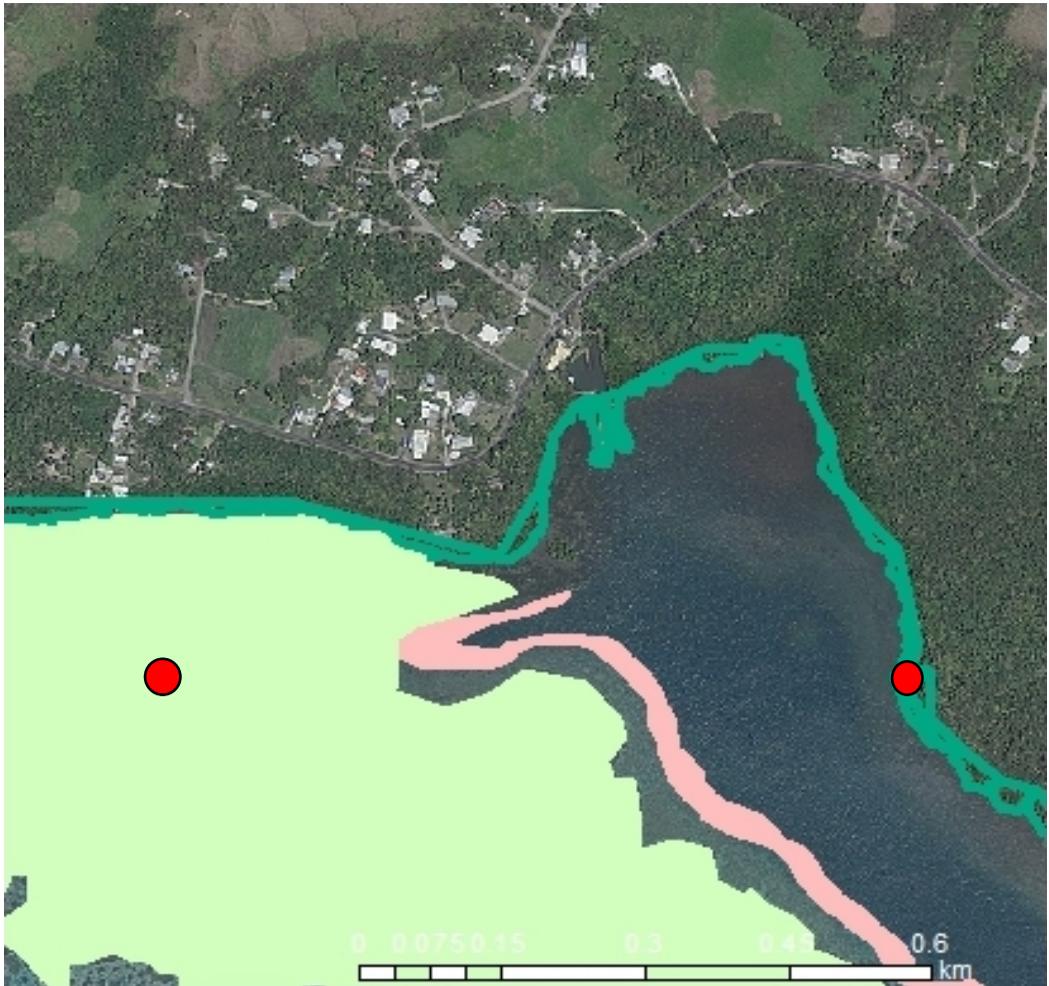
Acropora aspera within coral patch A



Acropora cf. pulchra along the nearshore edge of coral patch A

Staghorn <i>Acropora</i> health impacts	% of colonies with impact (n=98 surveyed)
Bleaching mortality	12%
Damselfish territories	49%
Dead/Rubble	2%
Partial mortality	7%
<i>Terpios</i> overgrowth	19%

GRID 8: MANGROVE FOREST NORTH & SEAGRASS BED 5



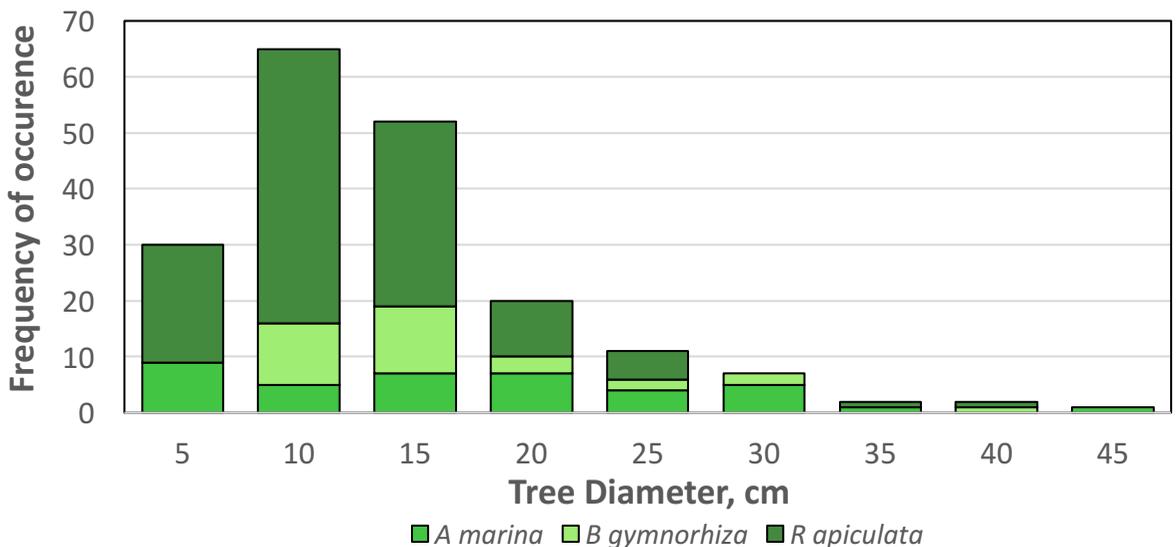
Grid 8 contains a diverse collection of ecosystems: the northern fringe of the mangrove forest, the majority of seagrass bed 5, and the nearshore coral community along the northern Manell Channel. The coral community was described in Grid 7, and will not be presented again here. Mangrove community data presented in Grid 6 are reproduced here, as data were pooled for these two survey sites. The mangrove forest is a mixed stand composed of the species *Avecinnia marina*, *Bruguiera gymnorhiza*, and *Rhizophora apiculata*, with *R. apiculata* the most common.



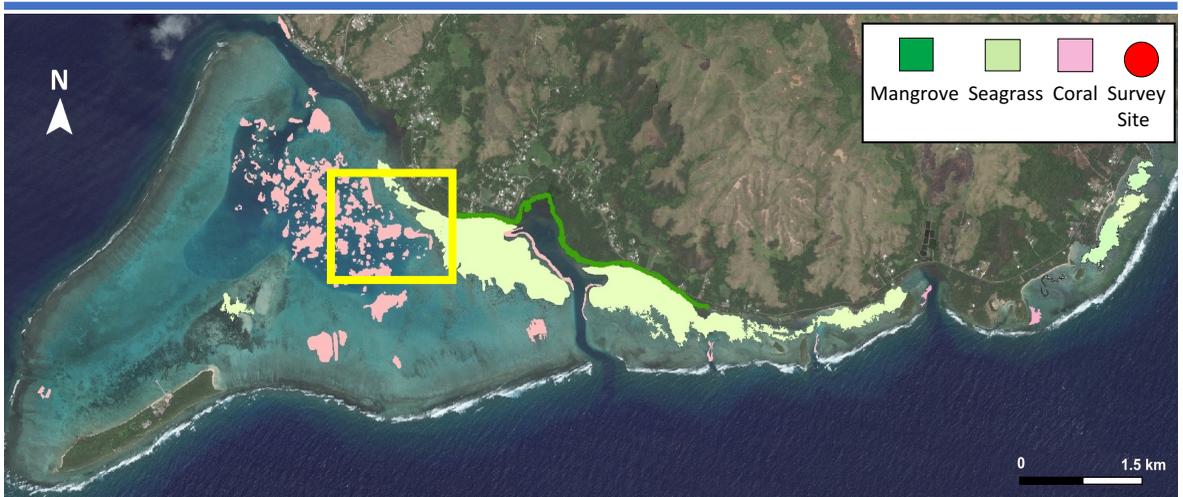
The seaward border of the Manell mangrove forest fringe.

Species	Trees/ ha	Relative Density	Relative Cover	Relative Frequency	Relative Importance
<i>Avecinnia marina</i>	406	0.2	35.5	20.5	28.0
<i>Bruguiera gymnorhiza</i>	323	0.2	20.3	16.3	18.3
<i>Rhizophora apiculata</i>	1249	0.6	44.2	63.2	53.7

Size-Frequency Distribution Among Mangrove Forest Species within the Manell-Geus Habitat Focus Area



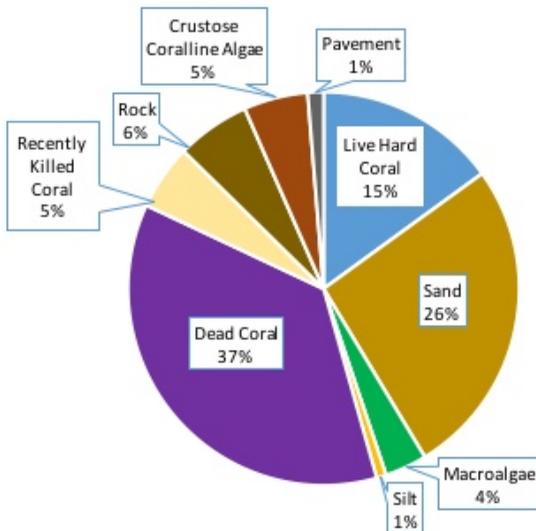
GRID 9: COCOS LAGOON CORAL PATCHES B, C, D AND E



Grid 9 contains the northwestern tip of the mangrove forest fringe and the northern end of Seagrass bed 5. In addition, it is dominated by numerous coral community patches within Cocos Lagoon. Three of these patches: B, C, and D were quantitatively surveyed and patch E was photographed. Seagrass bed 5 is reported in Grid 8.

Cocos Lagoon Coral Community B – this is a large nearshore coral community seaward of Seagrass bed 5. Though its proximity to shore results in higher physical damage and more land-based silt in the water than in more offshore sites, species diversity is high. The coral community is patchy and interspersed with sand and mixed algal assemblages.

**COCOS LAGOON CORAL COMMUNITY PATCH B
BENTHIC COMPOSITION**



A large bommie of the coral *Porites cylindrica*. The yellow star denotes a dead area on the top of the colony caused by extreme low tide events in 2015.

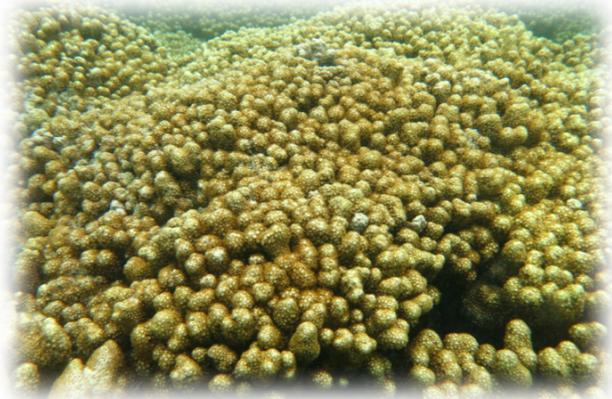
Cocos Lagoon Site B coral species list

<i>Acropora abrotanoides</i>	<i>Porites monticulosa</i>
<i>Acropora muricata</i>	<i>Porites rus</i>
staghorn <i>Acropora</i> (dead)	<i>Porites vaughani</i>
<i>Astreopora myriophthalma</i>	massive <i>Porites</i> sp.
<i>Montipora caliculata</i>	<i>Goniopora fruticosa</i>
encrusting <i>Montipora</i> sp.	<i>Pavona decussata</i>
<i>Montipora verrucosa</i>	<i>Pavona venosa</i>
<i>Goniastrea edwardsii</i>	<i>Pavona frondifera</i>
<i>Goniastrea retiformis</i>	<i>Stylocoeniella armata</i>
<i>Leptastrea purpurea</i>	<i>Millepora platyphylla</i>
<i>Leptastrea transversa</i>	<i>Galaxea fascicularis</i>
<i>Dipsastrea pallida</i>	<i>Galaxea</i> sp.
<i>Pocillopora damicornis</i>	<i>Psammocora contigua</i>
<i>Porites cylindrica</i>	unkown coral species

Coral health impact	% of colonies with impact (n=214 surveyed)
<i>Terpios</i> overgrowth	2.3%
Damselfish territory	4.7%
White syndrome disease	3.3%
Partial mortality	1.9%
Physical damage	7.5%

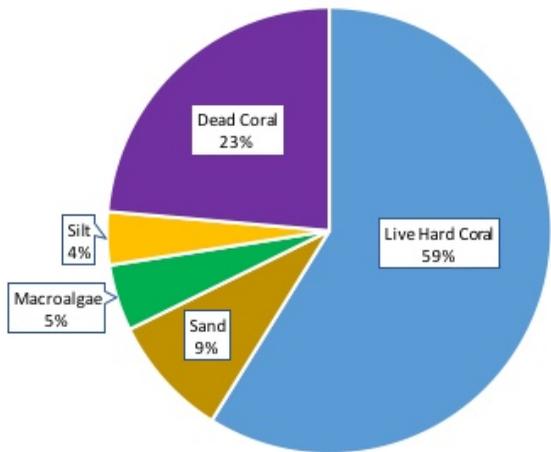
Cocos Lagoon Coral Community C

This community is marked by an extensive contiguous patch of *Goniopora fruticosa*, and evidence of a previous staghorn *Acropora* thicket, which is now largely rubble. Remaining corals include pocilloporids and poritids.



A portion of the extensive stand of the coral *Goniopora fruticosa* within community C

COCOS LAGOON CORAL COMMUNITY PATCH C BENTHIC COMPOSITION



Dead staghorn coral patch, now turned to rubble, within community C

Cocos Lagoon C coral species list

- Acropora surculosa*
- Staghorn *Acropora* (dead)
- encrusting *Montipora* sp.
- Pocillopora acuta*
- Pocillopora damicornis*
- Porites rus*
- Porites cylindrica*
- Porites monticulosa*
- Goniopora fruticosa*
- Pavona venosa*

Coral health impact	% of colonies with impact (n=121 surveyed)
White syndrome disease	1.7%
Black band disease	1.7%
Partial mortality	4.1%

Cocos Lagoon Coral Community

D – This community is dominated by medium to large bommies of the coral *Porites cylindrica*, interspersed with coarse rubble and silty sand. Species diversity is high, though the majority of colonies were small and of the family Merulinidae. Extensive rubble may have been generated by bleaching mortality and storm energy.

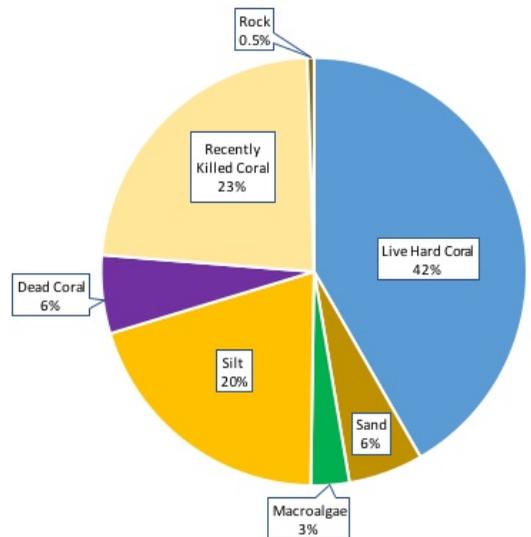


Landscape view of live hard coral and dead coral within coral community D



Close-up view of the hard coral *Porites cylindrica* and a feeding Crown-of-Thorns seastar

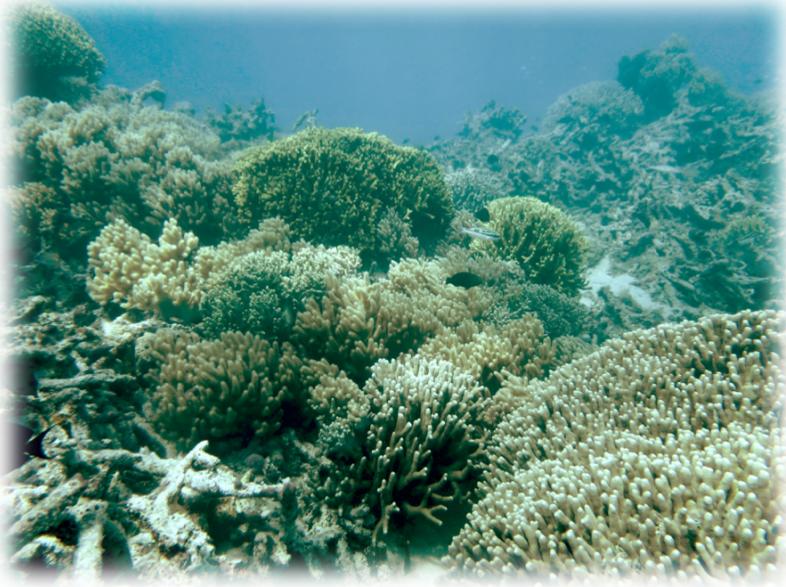
COCOS LAGOON CORAL COMMUNITY PATCH D
BENTHIC COMPOSITION



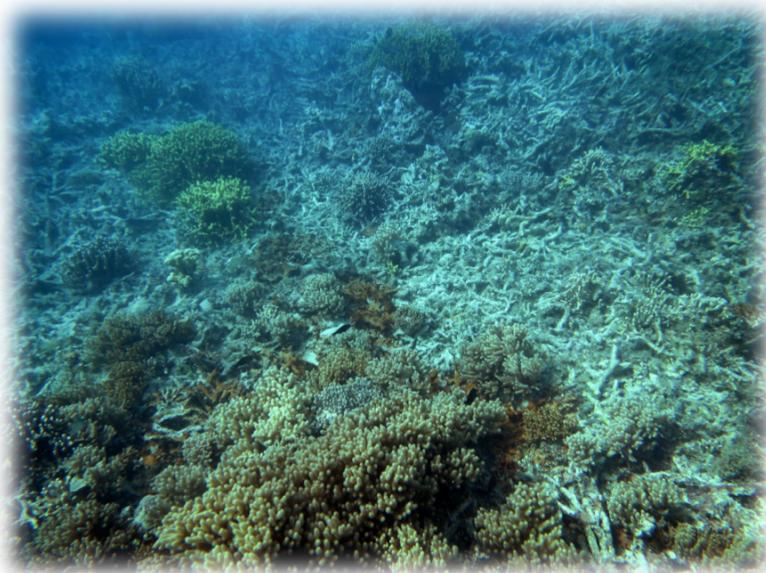
Cocos Lagoon Site D Coral Species List
<i>Montipora caliculata</i>
<i>Montipora verrucosa</i>
encrusting <i>Montipora</i> sp.
<i>Pocillopora damicornis</i>
<i>Stylocoeniella armata</i>
<i>Porites cylindrica</i>
<i>Porites vaughani</i>
<i>Porites rus</i>
<i>Cyphastrea microphthalma</i>
<i>Goniastrea edwardsi</i>
<i>Goniastrea pectinata</i>
<i>Leptastrea purpurea</i>
<i>Acanthastrea echinata</i>
<i>Fungia fungites</i>
<i>Fungia</i> sp.
<i>Psammocora contigua</i>

Coral health impact	% of colonies with impact (n=85 surveyed)
Algal overgrowth	1.2%
Crown-of-Thorns predation	1.2%
Damsel fish territory	2.4%
Skeletal eroding band disease	5.8%
White syndrome disease	1.2%
Partial mortality	2.4%

Coral Community E – This community was photographed but not quantitatively surveyed. It resembles nearby patches, being dominated by the hard coral *Porites cylindrica*, the soft coral *Sinularia polydactyla*, staghorn coral rubble and recently-killed staghorn corals.

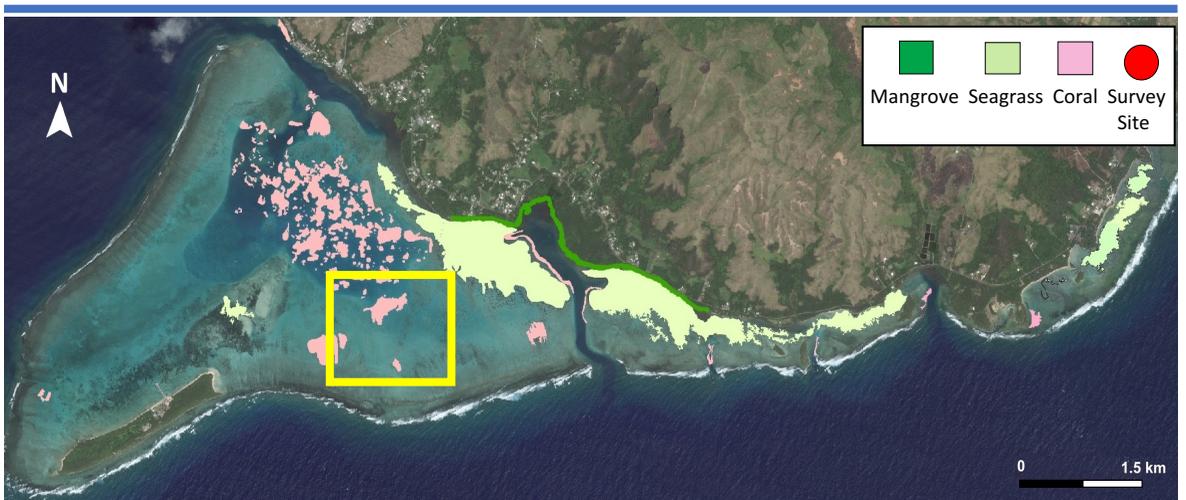
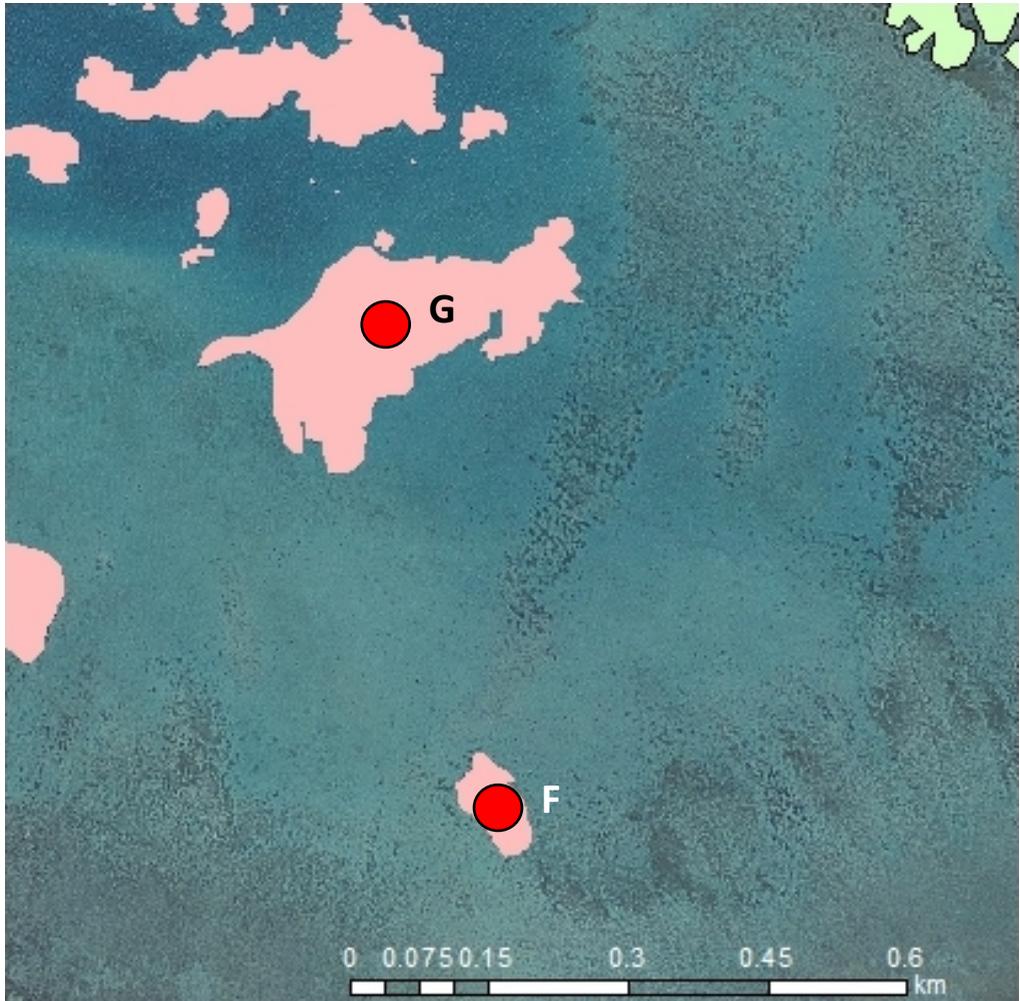


Coral community E, showing a mixture of the live hard coral, *Porites cylindrica*, and the soft coral *Sinularia polydactyla*, intermixed with coral rubble.



A large rubble field with small remnants of the live hard coral, *Porites cylindrica*, and an expanding patch of soft coral, *Sinularia polydactyla*.

GRID 10: COCOS LAGOON CORAL PATCHES F & G



Grid 10 contains several coral patches within the central Cocos Lagoon; two were surveyed within this grid: coral patch F, north of Babi Island, which lies along the southern margin of the lagoon, and coral patch G. Patch F was quantitatively surveyed and patch G was photographed.

Cocos Lagoon Coral Community F

This scattered, yet diverse community is located north of Babi Island, along its inner lagoon border. It contained several thickets of staghorn *Acropora*, as well as several other *Acropora* and *Pocillopora* species. Sand and macroalgal assemblages were interspersed with coral patches.

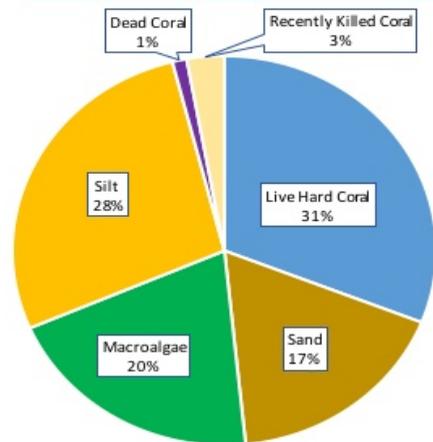


A mixed coral community near Babi Island, composed of *Acropora muricata*, *Pocillopora damicornis* and *Porites cylindrica*.



A staghorn *Acropora* thicket showing high densities of damselfish territories and recruitment of other fish.

COCOS LAGOON CORAL COMMUNITY F BENTHIC COMPOSITION



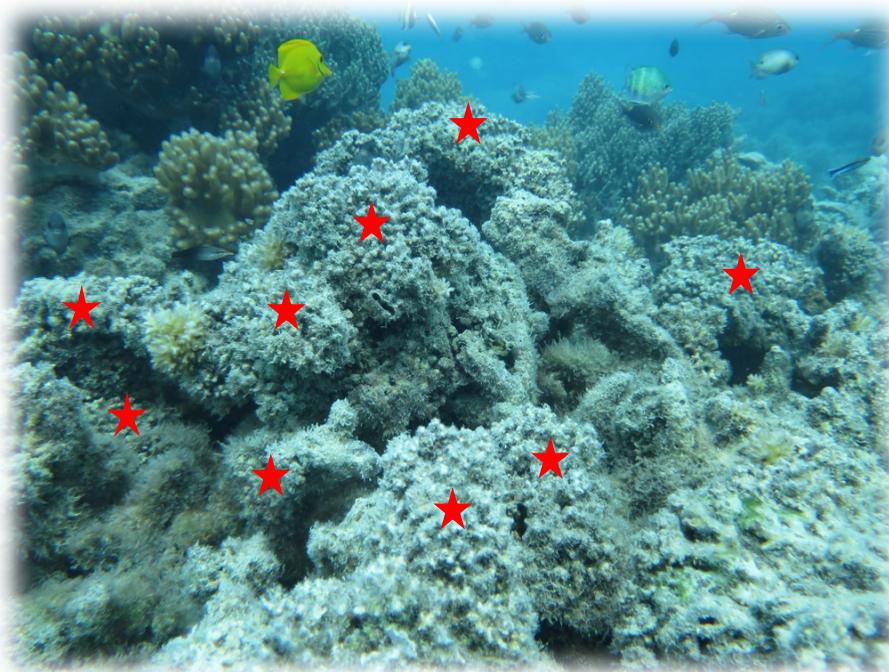
Cocos Lagoon F Coral Species List
<i>Acropora cf. pulchra</i>
<i>Acropora muricata</i>
<i>Acropora surculosa</i>
<i>Acropora nasuta</i>
<i>Acropora sp.</i>
<i>Pocillopora acuta</i>
<i>Pocillopora damicornis</i>
<i>Pocillopora sp.</i>
<i>Porites cylindrica</i>
<i>Leptastrea purpurea</i>

Coral health impact	% of colonies with impact (n=265 surveyed)
Algal overgrowth	7.2%
Damselfish territory	19.6%
<i>Terpios</i> overgrowth	11.3%
White syndrome disease	4.2%
Partial mortality	15.5%

Coral patch G was photographed but not quantitatively surveyed. It resembles patch C, being dominated by the hard coral *Porites cylindrica*, the soft corals *Sinularia polydactyla* and *Sarcophyton* sp., and recently-killed pocilloporid corals. It is probable that the pocilloporid colonies died during previous bleaching events.

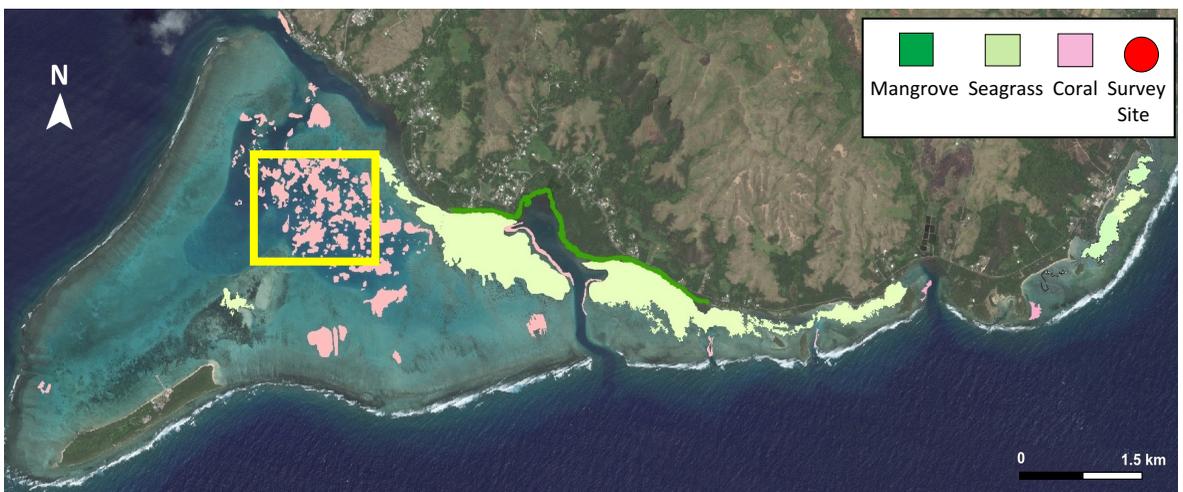
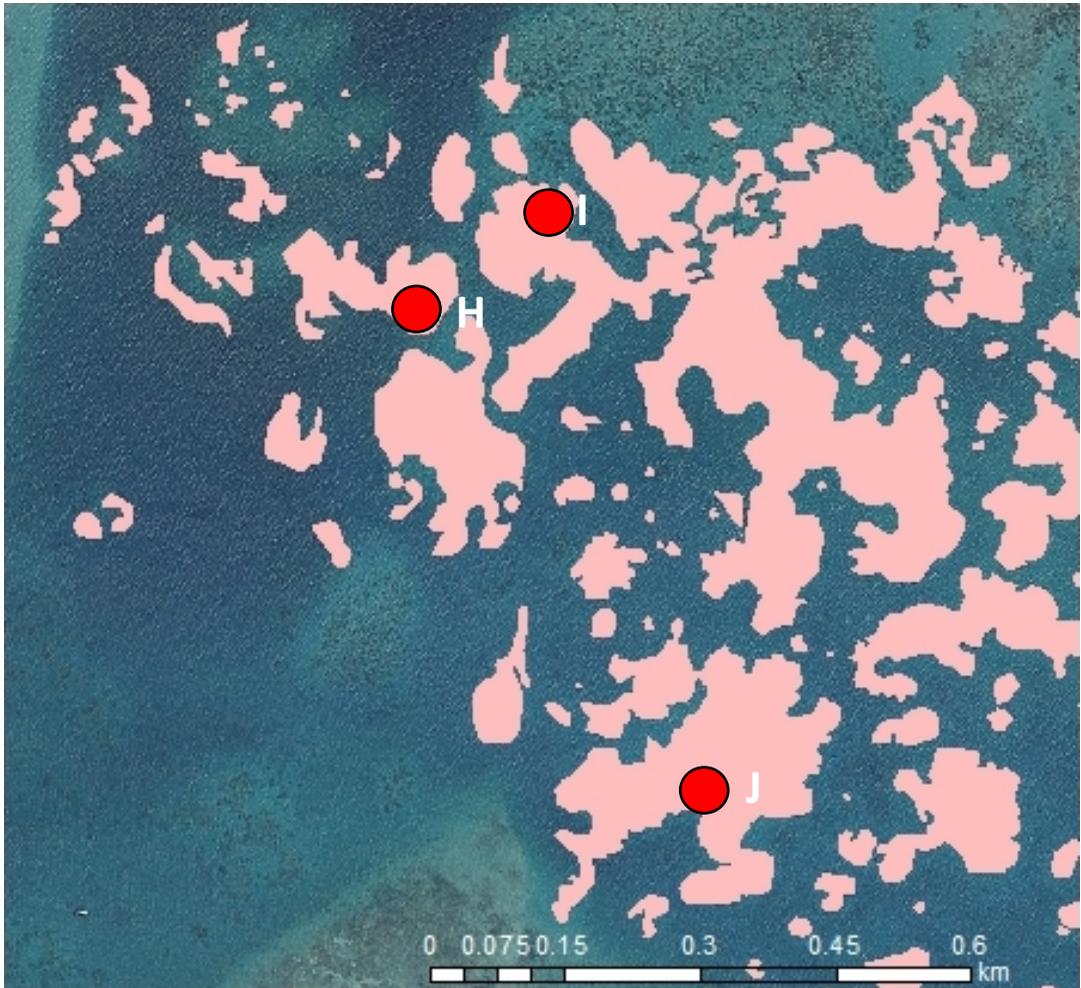


Coral patch G, showing high structure and large colonies of the mushroom soft coral *Sarcophyton*



A patch of dead *Pocillopora* spp. colonies killed during recent bleaching events. Dead colonies are marked with (★).

GRID 11: COCOS LAGOON CORAL PATCHES H, I AND J



Grid 11 encompasses dense patches of coral-dominated communities in the center of Cocos Lagoon. Three of these patches were quantitatively surveyed and described: H, I, and J.

Cocos Lagoon Coral Community H – This community shows very sparse coral, though relatively high diversity, with much recently killed coral. Most of the dead skeleton is that of staghorn *Acropora*, suggesting that a large thicket may have suffered complete mortality during recent bleaching episodes.

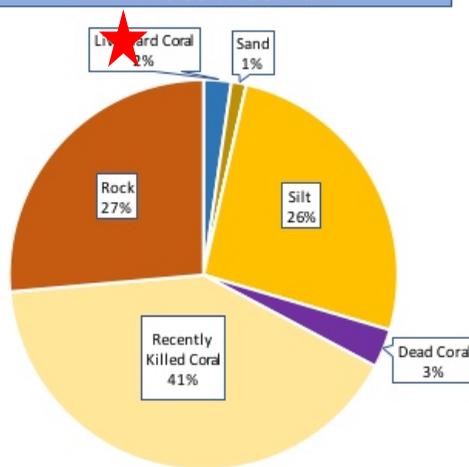


Landscape of coral patch L, showing a low-relief patch reef dominated by the soft coral *Sinularia polydactyla*



Dead staghorn *Acropora* skeletons and rubble, as a result of bleaching events.

**COCOS LAGOON CORAL COMMUNITY PATCH H
BENTHIC COMPOSITION**



Cocos Lagoon H coral species list
staghorn <i>Acropora</i> (dead)
<i>Montipora verrucosa</i>
<i>Pocillopora damicornis</i>
<i>Fungia</i> sp. 1
<i>Fungia</i> sp. 2
<i>Galaxea fascicularis</i>
<i>Goniastrea retiformis</i>
<i>Leptastrea purpurea</i>
<i>Montastraea curta</i>
<i>Cyphastrea serailia</i>
<i>Porites cylindrica</i>
<i>Porites rus</i>
<i>Porites vaughani</i>
<i>Pavona decussata</i>
<i>Lobophyllia corymbosa</i>

Coral health impacts	% of colonies with impact (n=189 surveyed)
<i>Drupella</i> predation	1.6%
Damselfish territory	1.6%
Bleaching	14.8%
Pigmentation response	5.3%
Silt smothering	5.3%
<i>Terpios</i> overgrowth	2.1%
White syndrome disease	1.1%
Partial mortality	17.9%

Cocos Lagoon Coral Community I

This community constitutes a very small patch with large coral colonies, surrounded by sand patches.

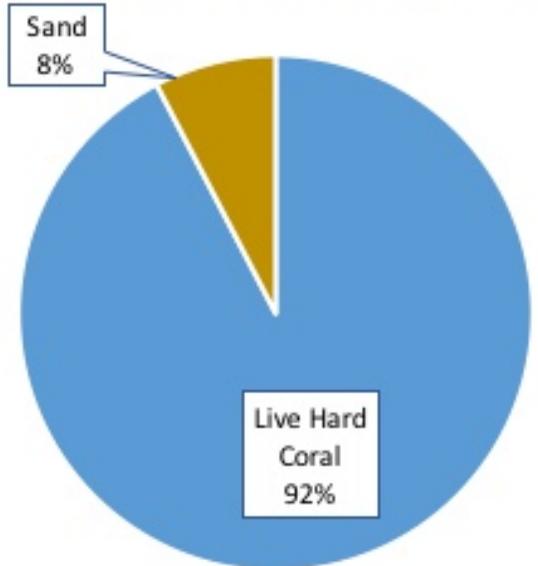


A large bommie, or colony, of the massive coral *Porites* sp.



A large colony of the blue coral *Heliopora coerulea*, showing the complex structure that provides valuable fish habitat.

COCOS LAGOON CORAL PATCH I BENTHIC COMPOSITION



Cocos Lagoon I coral species list
<i>Acropora nasuta</i>
staghorn <i>Acropora</i> (dead)
encrusting <i>Montipora</i> sp.
<i>Pocillopora damicornis</i>
<i>Porites monticulosa</i>
<i>Porites cylindrica</i>
massive <i>Porites</i> sp.
<i>Heliopora coerulea</i>

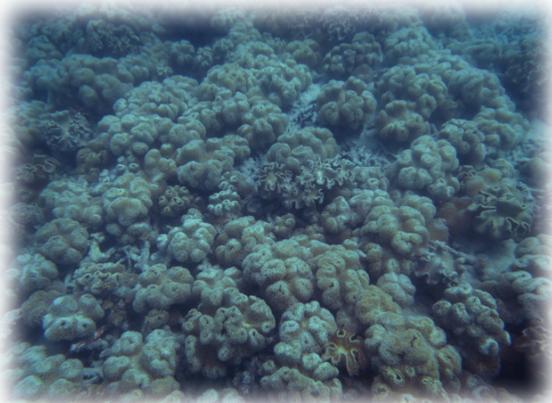
Coral health impact	% of colonies with impact (n=20 surveyed)
Damselfish territory	5%
Skeletal eroding band disease	15%
White syndrome disease	40%
Partial mortality	5%

Cocos Lagoon Coral Community

J – Coral patch J is a high topography, diverse community, with high coral cover dominated by *Porites rus* and *P. cylindrica*. An extensive bed of the mushroom soft coral *Sarcophyton* sp. Is a unique feature of this site.

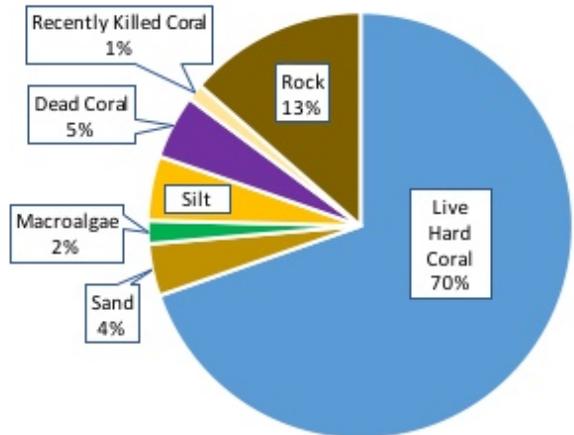


Landscape view of a mixed coral community within coral patch J, with staghorn *Acropora* and *Porites rus* bommies



A large field of the mushroom soft coral, *Sarcophyton* within coral patch J

COCOS LAGOON CORAL PATCH J BENTHIC COMPOSITION

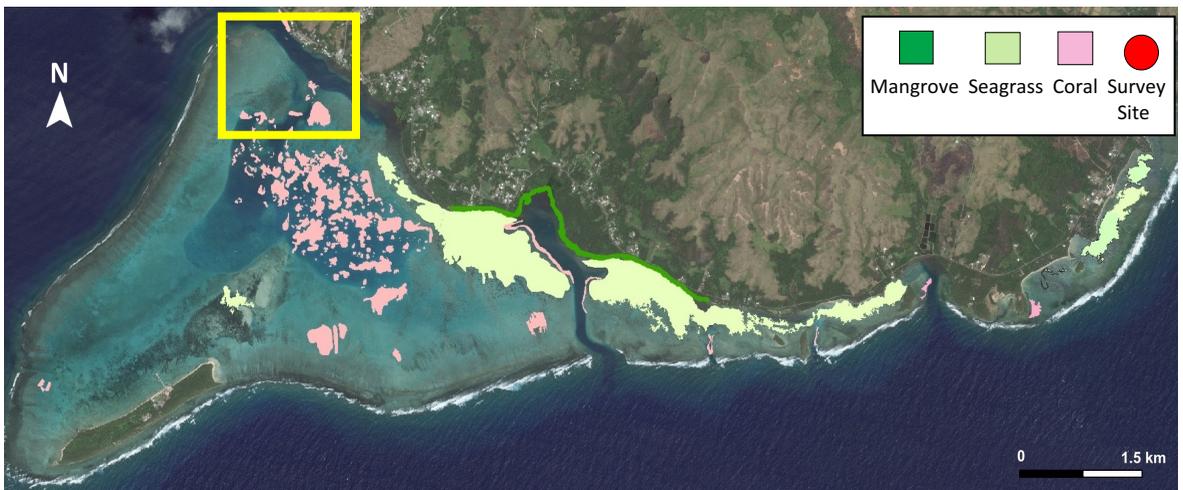
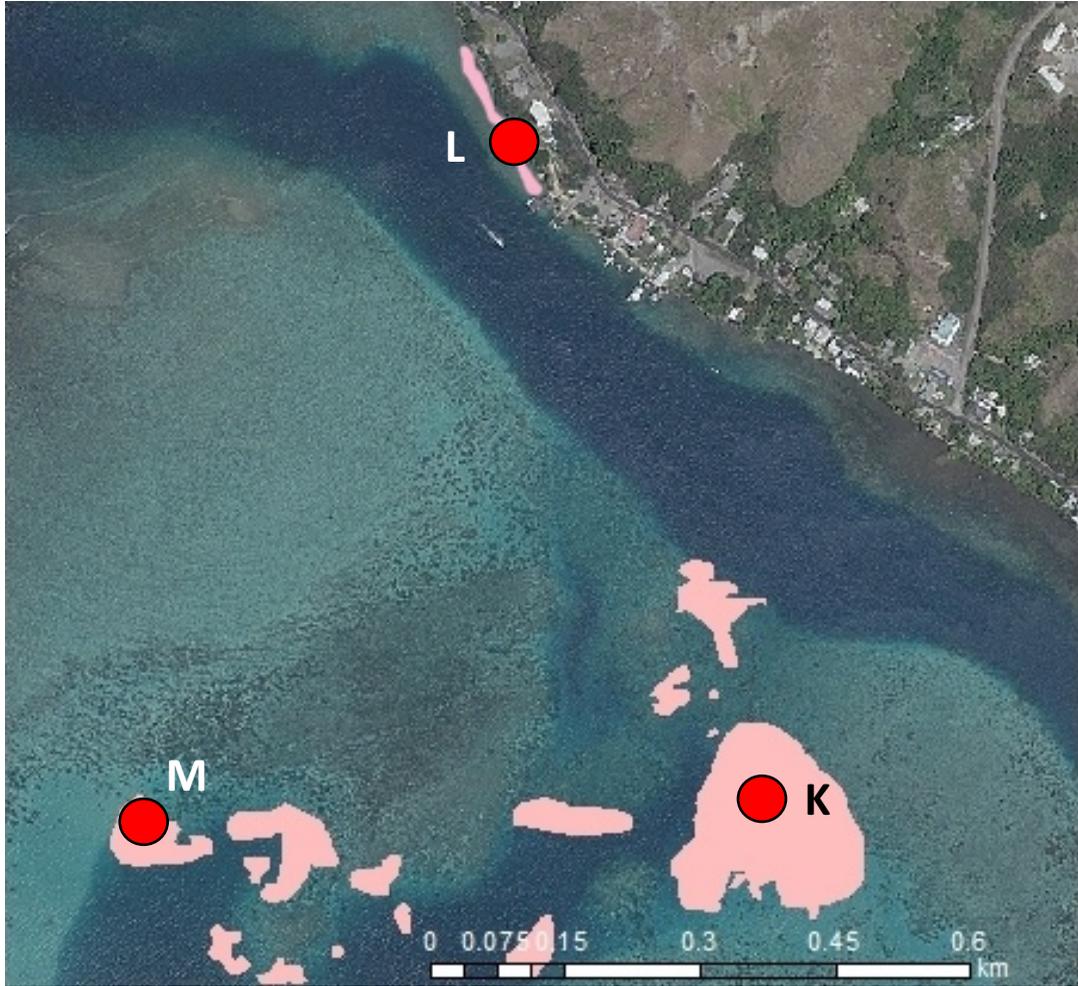


Cocos Lagoon J coral species list

<i>Acropora surculosa</i>
<i>Acropora muricata</i>
encrusting <i>Montipora</i> sp.
<i>Pocillopora damicornis</i>
<i>Porites monticulosa</i>
<i>Porites rus</i>
<i>Porites cylindrica</i>
<i>Pavona cactus</i>
<i>Pavona venosa</i>
<i>Galaxea</i> sp.
<i>Leptastrea purpurea</i>
<i>Astraea valenciennesi</i>

Coral health impact	% pf colonies with impact (n=98 surveyed)
Breakage/physical injury	1.02%
Damselfish territory	15.3%
<i>Terpios</i> overgrowth	2.04%
White syndrome disease	6.1%
Partial mortality	2.04%

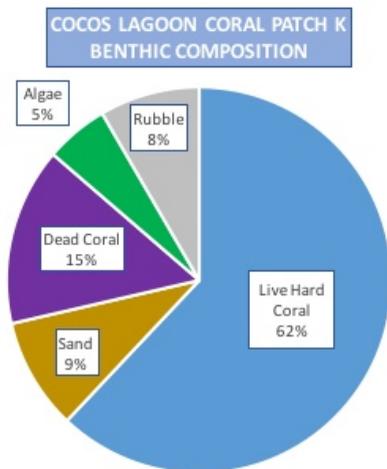
GRID 12: COCOS LAGOON CORAL PATCHES K, L, AND M



Grid 12 encompasses coral patches near the navigation channel from the Malesso Pier. Three sites were surveyed: K, L and M.

Cocos Lagoon Coral Community K -

This community is composed of coral patches dominated by poritids and interspersed with the soft coral *Sinularia polydactyla* (not recorded on transects). Dead standing coral and coral rubble were also abundant.



Coral community of Patch K showing high topographic structure, interspersed with soft coral and sand/rubble.



A rubble patch adjacent to *Sinularia* colonies.

Cocos Lagoon K coral species list

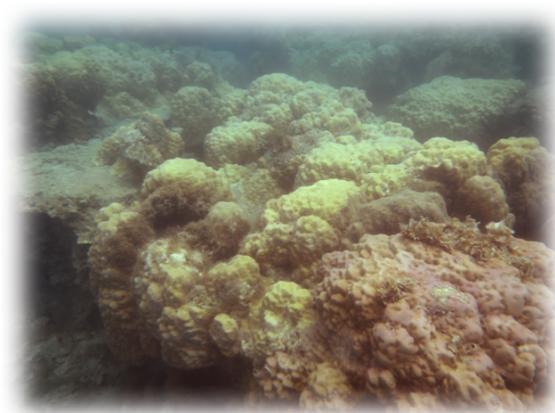
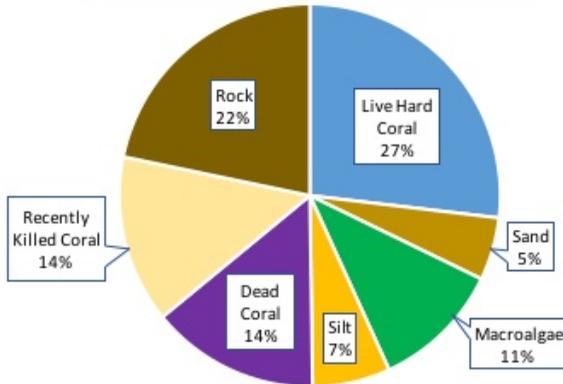
- Acropora pulchra*
- Goniastrea edwardsii*
- Goniastrea retiformis*
- Leptastrea purpurea*
- Porites annae*
- Porites cylindrica*
- Porites rus*
- massive *Porites*
- Porites monticulosa*
- Pocillopora damicornis*
- Pocillopora meandrina*
- Pocillopora* sp.
- Psammocora contigua*
- Pavona varians*

Coral health impact	% of colonies with impact (n=182 surveyed)
Damselfish territory	4.9%
Drupella predation	3.8%
Silt smothering	1.6%
<i>Terpios</i> overgrowth	1.6%
Skeletal eroding band disease	0.5%
White syndrome disease	7.1%
Endolithic fungal infection	0.5%
Partial mortality	16.5%

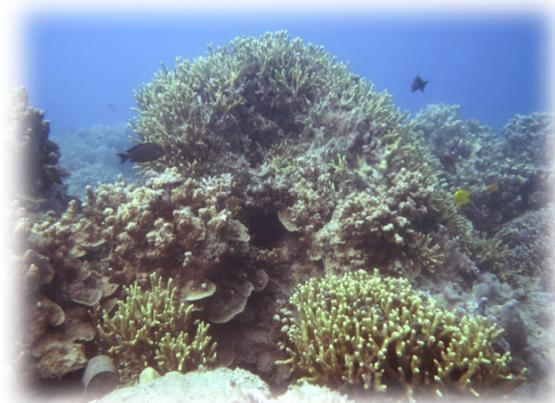
Cocos Lagoon Coral Community L -

This is a narrow strip of coral-dominated biota growing along the narrow shelf of coastline, starting at the Malesso Pier. The community is diverse, dominated by massive growth forms with large *Porites* spp. bommies.

COCOS LAGOON CORAL COMMUNITY L BENTHIC COMPOSITION



Reef flat community of large massive colonies of *Porites* spp. along the Malesso Pier



Shallow reef slope community showing branching *Porites* spp. colonies

Cocos Lagoon L coral species list

staghorn <i>Acropora</i> (dead)
<i>Montipora calculata</i>
<i>Montipora verrucosa</i>
encrusting <i>Montipora</i> sp.
<i>Stylocoeniella armata</i>
<i>Dipsastrea pallida</i>
<i>Goniastrea edwardsii</i>
<i>Leptastrea purpurea</i>
<i>Goniastrea retiformis</i>
<i>Porites monticulosa</i>
<i>Porites cylindrica</i>
<i>Porites vaughani</i>
massive <i>Porites</i> sp.
<i>Pavona venosa</i>
<i>Pavona varians</i>
<i>Pavona</i> sp.
<i>Millepora tuberosa</i>

Coral health impacts	% of colonies with impact (n=139 surveyed)
Algal overgrowth	2.9%
Terpios overgrowth	1.4%
Damsel fish territory	1.4%
Crown-of-Thorns predation	0.7%
Drupella predation	0.7%
Breakage/Toppling	1.4%
Bleaching	2.2%
Skeletal eroding band disease	0.7%
White syndrome disease	2.9%
Partial mortality	1.4%

Cocos Lagoon Coral Community

M — This is an extensive mixed community of high diversity. It contains one of the few (possibly the only) remaining populations of the staghorn coral *Acropora cf. virgata*.

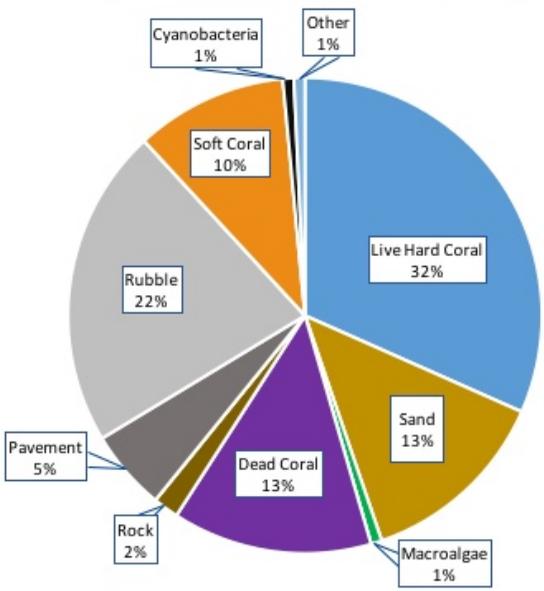


Transect 4 of Site M, showing coral patches dominated by *Porites* and *Sinularia*



A small thicket of the staghorn coral *Acropora cf. virgata*

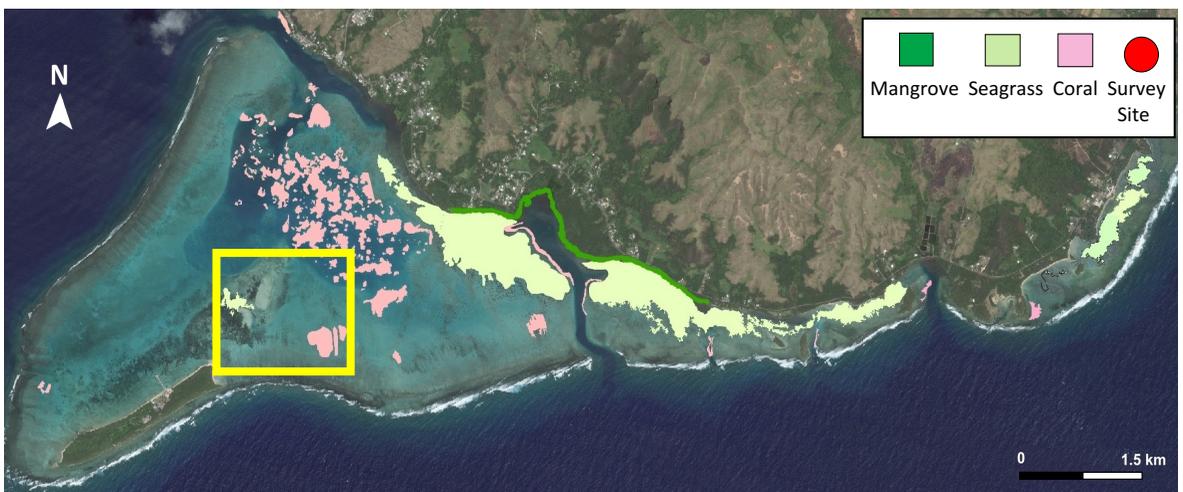
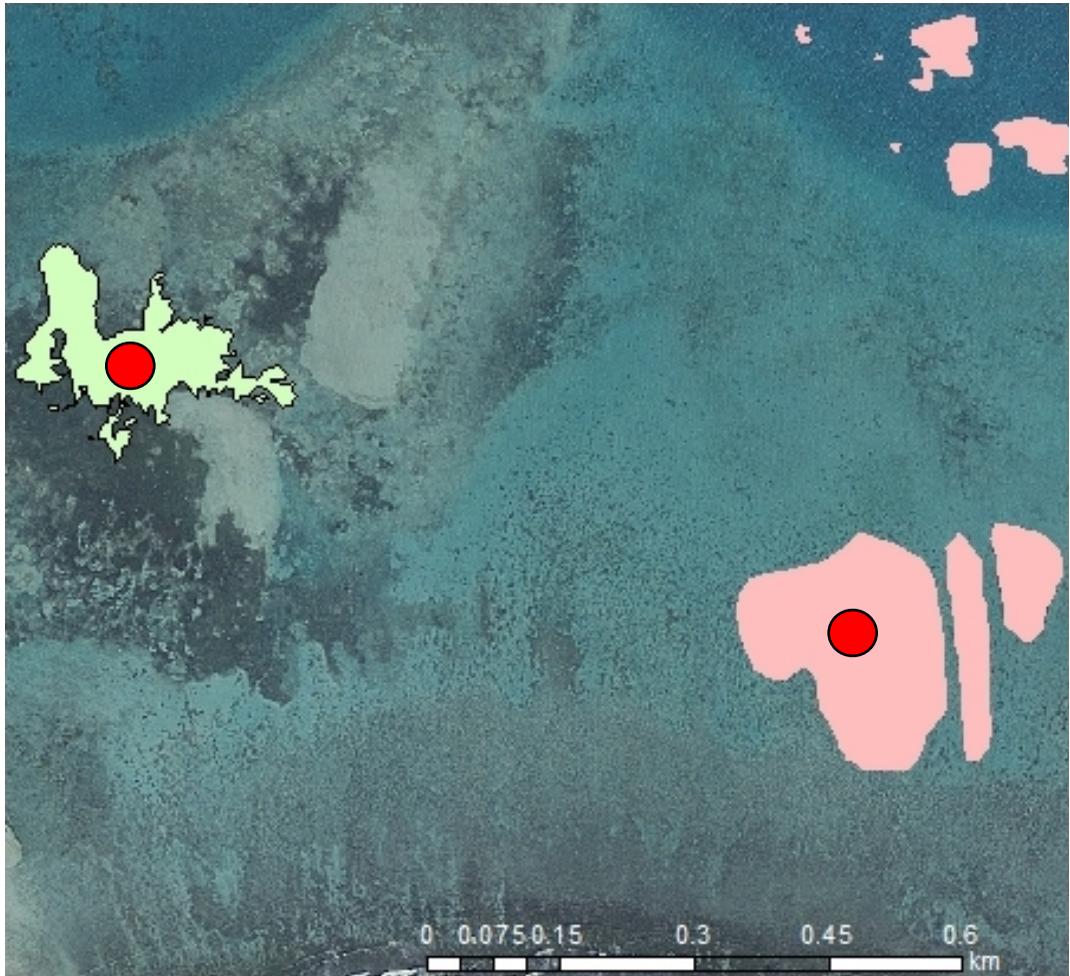
COCOS LAGOON CORAL COMMUNITY M
BENTHIC COMPOSITION



Cocos Lagoon M coral species list
<i>Acropora virgata</i>
<i>Montipora cf. acanthella</i>
<i>Montipora sp.</i>
<i>Goniopora fruticosa</i>
<i>Stylocoeniella armata</i>
<i>Pocillopora acuta</i>
<i>Pocillopora damicornis</i>
<i>Porites monticulosa</i>
<i>Porites cylindrica</i>
<i>Porites mammalata</i>
<i>Porites rus</i>
massive <i>Porites sp.</i>
<i>Leptastrea purpurea</i>
<i>Pavona varians</i>
<i>Pavona frondens</i>

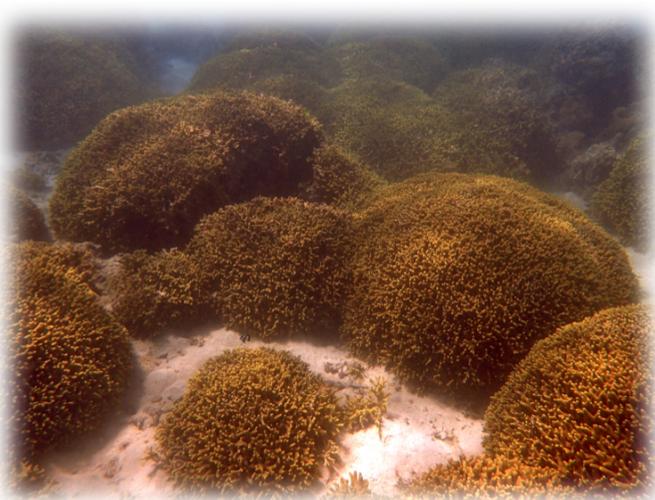
Coral health impact	% of colonies with impact (n=182 surveyed)
Damselfish territory	4.9%
<i>Drupella</i> predation	3.8%
Silt smothering	1.6%
<i>Terpios</i> overgrowth	1.6%
Skeletal eroding band disease	0.5%
Endolithic fungal infection	0.5%
White syndrome disease	7.1%
Partial mortality	16.4%

GRID 13: COCOS LAGOON CORAL PATCH N AND SEAGRASS BED 6



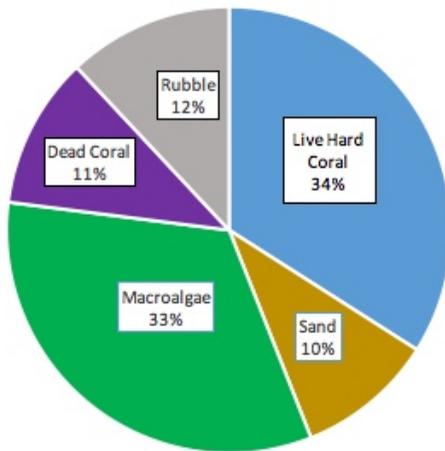
Cocos Lagoon Coral

Community N – This community is dominated by large bommies of the coral *Porites cylindrica*, interspersed with sand and rubble. Seasonally, it accumulates large quantities of the nuisance macroalgal species *Chaetomorpha vieillardii*. This alga has the ability to smother and foul benthic organisms, due to its high densities.



Coral community in Site O showing large bommies of the coral *Porites cylindrica*.

COCOS LAGOON CORAL COMMUNITY N BENTHIC COMPOSITION



Fouling of a *Porites cylindrica* colony (middle of the photograph) by the nuisance alga *Chaetomorpha vieillardii*.

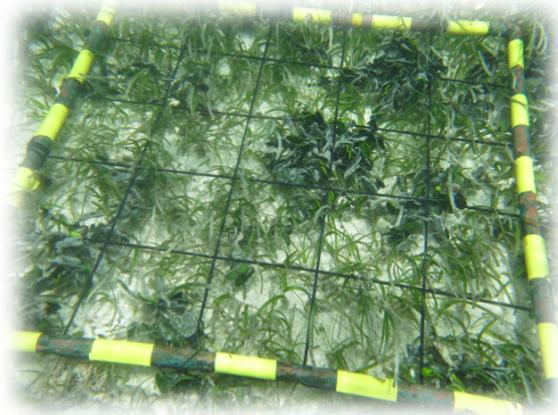
Cocos Lagoon N coral species list
<i>Acropora globiceps</i>
<i>Montipora tuberculosa</i>
<i>Pocillopora damicornis</i>
<i>Pocillopora acuta</i>
<i>Porites cylindrica</i>
<i>Porites annae</i>
<i>Porites monticulosa</i>
<i>Porites lobata</i>
<i>Porites rus</i>
<i>Porites lutea</i>
<i>Platygyra daedaelea</i>
<i>Psammocora digitifera</i>

Coral health impact	% of colonies with impact (n=165 surveyed)
Damselfish territory	4.2%
White syndrome disease	23.6%
Partial mortality	17.6%

Seagrass bed 6 is located in close proximity to Cocos Island, and was composed almost exclusively of *Halodule pinifolia*, with a few scattered *Enhalus acoroides* plants. Shoot density was variable, as can be seen in the photographs below. The graph below compares plant density in seagrass beds 4 and 6; the two beds which contained significant patches of *H. pinifolia*.

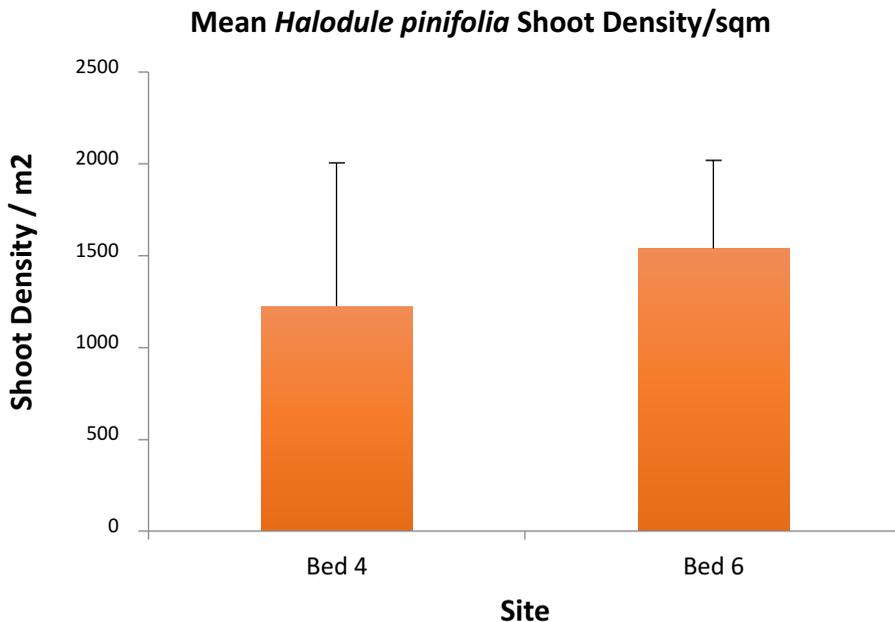


Close up of *Halodule pinifolia* shoots in Seagrass bed 6.



High shoot density within the *H. pinifolia* bed.

Seagrass Bed 6	Mean shoots / sqm
<i>Halodule pinifolia</i>	1540 +/- 479

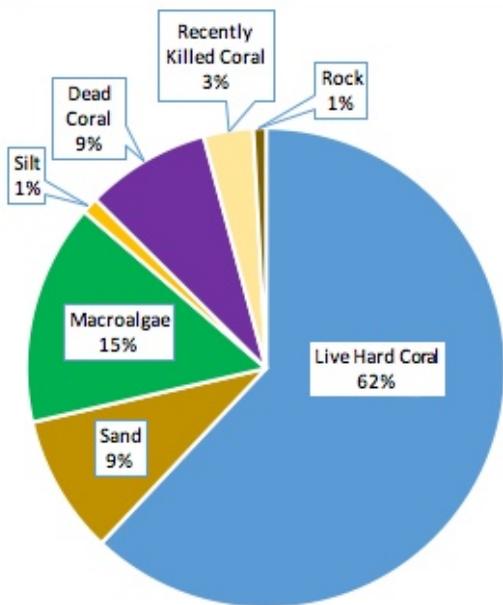


GRID 14: COCOS LAGOON CORAL PATCH O



Cocos Lagoon Coral Community O – This coral community is positioned along the northwestern corner of Cocos Island, remote from other coral patches in the lagoon.

**COCOS LAGOON CORAL COMMUNITY O
BENTHIC COMPOSITION**



Landscape view of the shallow, topographically complex coral community in Site P.

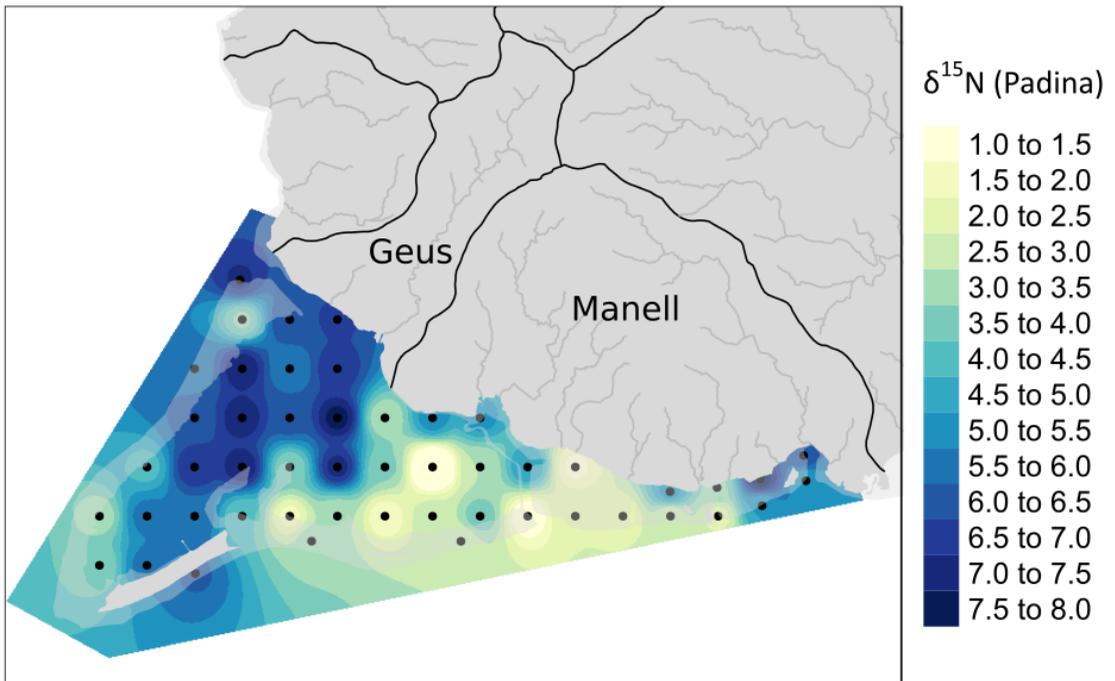


A large colony of *Lobophyllia hemprichii* with macroalgal overgrowth.

Cocos Lagoon Site O coral species list
<i>Acropora cf. pulchra</i>
<i>Acropora abrotanoides</i>
<i>Goniastrea edwardsii</i>
<i>Goniastrea retiformis</i>
<i>Leptastrea purpurea</i>
<i>Porites annae</i>
<i>Porites cylindrica</i>
<i>Porites monticulosa</i>
massive <i>Porites</i> sp.
<i>Porites rus</i>
<i>Pocillopora damicornis</i>
<i>Pocillopora meandrina</i>
<i>Pocillopora</i> sp.
<i>Psammocora contigua</i>
<i>Pavona varians</i>
<i>Heliopora coerulea</i>
<i>Lobophyllia hemprichii</i>

Coral health impact	% of colonies with impact (n=281 surveyed)
Algal overgrowth	4.3%
<i>Terpios</i> overgrowth	1.8%
Damselfish territory	35.2%
<i>Drupella</i> predation	0.4%
Pigmentation response	2.1%
Skeletal eroding band disease	0.4%
White syndrome disease	6.8%
Partial mortality	8.9%

Nutrient Enrichment Study



The results of the study on levels of sewage nutrient enrichment in the Manell-Geus HFA coastal waters are presented in this graphic. The dots on the map correspond to the positions of the algae (*Padina* sp.) that were deployed throughout the HFA shallow coastal waters to be later analyzed for nutrient content. The darkest blue colors on the map pertain to areas with the highest nutrient concentrations. These areas are the deepest waters in the center of the lagoon and are close to the Geus River mouth and Malesso town. The southeastern portion of the M-G HFA, represented by the light green colors, is influenced by coastal currents that bring in nitrogen from the open ocean. These waters show very low enrichment by sewage, as they come from offshore. Note also that river mouths along this coast are sites of nutrient input close to shore. This can be seen by the darker colors near the river mouths. This is consistent with the results of the *Enterococcus* bacteria study that is presented on the following page.

Enterococcus Contamination Study



Enterococcus is a bacterium of mammalian digestive tracts and can, therefore, be used to test for fecal contamination of water. The test does not distinguish between human vs. other mammalian fecal waste. Sampling for *Enterococcus* bacterial contamination of shorelines and rivers was undertaken on January 27, 2017 and samples were processed immediately at the University of Guam Marine Laboratory. Red dots correspond to sampling locations. Upstream samples were taken upstream of the road or bridge in each case, while the downstream or river mouth samples were taken at the mouth of each river as it emptied into coastal water.

Sampling sites were as follows: PUG = Pugua River; GEU = Geus River; MAN = Manell River; LAO = Laolao River; SIT 4 = unnamed stream; REF = non-river coastal reference site; LIY = Liyog River; AJA = Ajayan River; LAG = Lagoon reference site; COREF = Cocos reference site, remote from resort. Filtered drinking water was also tested, as a negative control. Results are presented in the table on the following page. The US EPA maximum acceptable limit for *Enterococcus* contamination is 35 CFUs/100ml. Numbers in red indicate values higher than the current US EPA limits. Nine out of 17 sites tested higher than the EPA limit. All of the upstream river sites showed *Enterococcus* contamination above EPA maximum limits.

Enterococcus bacterial counts for tested rivers within the Manell-Geus HFA

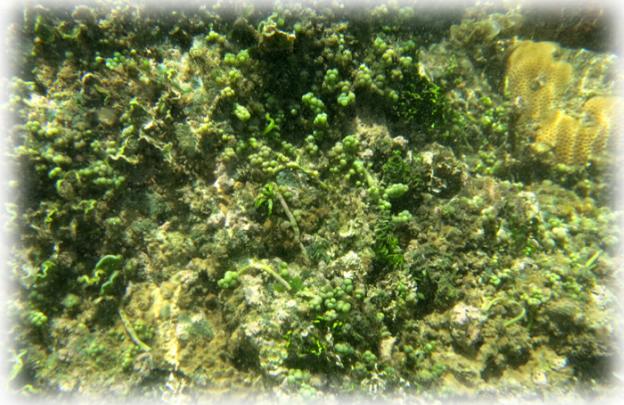
Sample Sites	Site Code	ENT CFU counts/100ml
Ajayan River upstream	AJA	53.4
Ajayan River mouth	AJA	58
Liyog River upstream	LIY	38
Liyog River mouth	LIY	43.8
Site 8 beach reference site (negative control 1)	REF	24.2
Unnamed stream, upstream	Site4	56.2
Unnamed stream, mouth	Site4	22.6
Laolao River upstream	LAO	62
Laolao River mouth	LAO	24.2
Manell River upstream	MAN	88.4
Manell River mouth	MAN	4.4
Geus River upstream	GEU	50.2
Geus River mouth	GEU	22.4
Pugua River upstream	PUG	68.8
Pugua River mouth	PUG	113.2
Cocos Resort	CORST	0.2
Cocos Resort downstream reference site	COREF	1.4
Cocos Lagoon center, near anchor buoy (negative control 2)	LAG	0
Filtered drinking water (negative control 3)	not applicable	0

OTHER COMMUNITY TYPES

The remainder of shallow reef flat and nearshore zones, not described in detail in this atlas, consisted of substrate with mixed sand, coral rubble, algal assemblages, and coral (1-2% cover). These areas were not mapped or surveyed, but the photos below show representative examples of these types of substrate and where they are found within the Manell-Geus HFA.



Mixed sand-coral rubble and brown algae, Cocos Lagoon



Mixed limestone pavement, green algae and coral, Achang reef flat



Mixed fleshy algal assemblages and sand, seaward of Seagrass bed 5.

MANGROVE FOREST ZONATION



Landward mangrove forest margin



Middle mangrove forest stand



Seaward mangrove forest margin

CORAL HEALTH IMPACTS: Non-Disease Impacts



Damselfish territories – several species of damselfish, *fohmo'*, make their homes in coral colonies. They remove living tissue from coral skeletons to create a substrate on which their food algae settles and grows. Thus, they use coral skeletons as surfaces on which to farm their preferred food algae, creating territories within coral colonies that they defend from competitors. These territories create patches of white skeleton devoid of tissue, and are recorded as a source of mortality. On certain reefs, these territories can be very abundant.



Silt smothering – shallow, nearshore corals are often at risk of partial or total mortality from being smothered by silt from land. Silt is composed of very fine soil and organic particles that settle on static surfaces and can smother small living organisms, such as coral polyps.



Bleaching and bleaching mortality

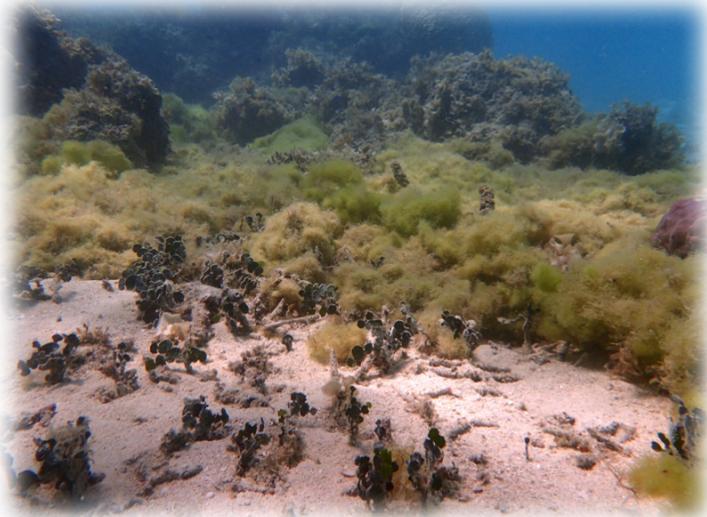
– Corals bleach in response to several stressors, but bleaching due to a combination of very warm water and intense sunlight is the most common reason in Guam. While bleaching is not always fatal to corals, it can be. The upper photo shows a coral that is completely and severely bleached; the lower photo shows corals that have died after they have severely bleached.

Partial mortality

– many corals show signs of dead, exposed skeleton on a portion of their colony that is the result of some past stress event, rather than a current or ongoing stress. These observations are grouped together into a single category: “partial mortality of unknown cause”. For example, the upper photograph shows dead skeleton on the top of the colony that was caused by exposure to air during an extremely low tide (at red star). The lower photograph shows a loss of tissue that could have been caused by either predation or disease, but it is unclear what the original cause was, as the coral is recovering and overgrowing dead skeleton.



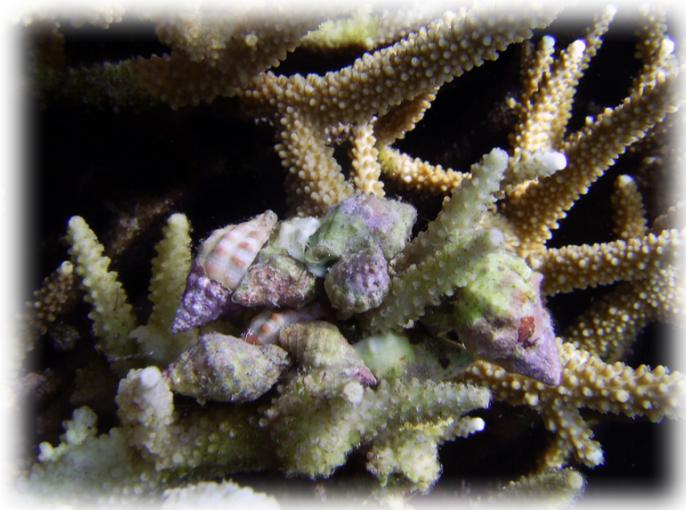
Physical damage – many activities can break corals, making them more susceptible to disease and predation, and reducing their effectiveness in providing habitat to fish and other marine organisms. Severe storms, anchor damage, and trampling are all causes of physical damage.



Algal overgrowth – certain species of algae, such as *Chaetomorpha viellardii* become seasonally very abundant, and can overgrow, smother, and compete with corals. Such species are considered nuisance species because they can affect the health of other species.



Competitive overgrowth - certain organisms, such as the encrusting sponge *Terpios hoshianota*, can aggressively overgrow corals, killing them so rapidly that their skeletal features are still discernible. When this sponge invades an area it can be a major cause of coral mortality.



Drupella predation –

This gastropod snail consumes coral tissue and can occur in very high numbers, causing significant mortality. Its preferred coral food species are the *Acropora*, but it feeds on other species as well.



Crown-of-Thorns predation –

This seastar feeds on living coral tissue and can consume up to 155 cm² of coral tissue per day. In large numbers, an outbreak of this seastar has the capacity to wipe out an entire community. While its food preference is, again, for acroporid corals, it is known to feed on other species as well, when acroporids are absent.

CORAL HEALTH IMPACTS: Coral Diseases



White syndromes – the most common diseases of Guam corals. They are thought to be caused by several bacteria. Many coral species are affected, showing different patterns of mortality on different growth forms. It is identified by a stark white band or patch of newly-exposed skeleton clearly distinguishable from healthy tissue, and an absence from the colony of known coral predators such as snails and sea stars.



Growth anomalies – these are patches of growth on a colony that are uncharacteristic for a particular coral species. The corallites that house the living animals (the coral 'polyps') may be misshapen and unevenly distributed. These anomalous growths may also show unusual pigmentation, dead patches of tissue, and excess mucous production. The cause is unknown, but they are seen in many species.



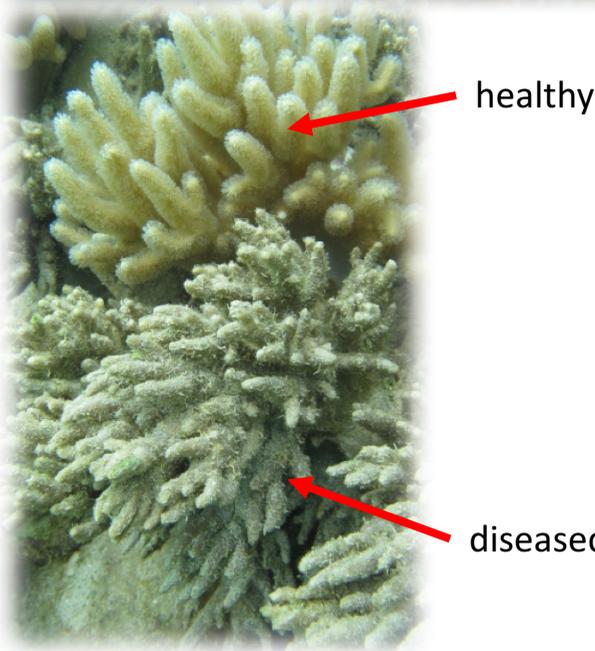
Skeletal eroding band – this disease is marked by a band that is a speckled dark green in color. The band starts at the base of a branch and precedes healthy tissue, leaving behind dead skeleton that is rapidly colonized by algae. The band is composed of a mass of tiny organisms called ciliates, which bore into the coral skeleton and kill the coral tissue. It affects mostly acroporids and pocilloporids on Guam.



Grey death – this is a newly-discovered disease, the causation of which is still being investigated. It appears to be a fungal - bacterial mat which attaches and grows over coral skeleton, killing the underlying tissue (at ★). It affects massive and encrusting corals but does not appear to affect branching species.



Endolithic fungal infection– this is a fungal infection of the internal tissues and skeleton of the coral (indicated by the red coloration of the tissue). It does not appear to be highly infectious and spreads very slowly. It does not cause extensive mortality of host corals, but does appear to show preference for staghorn *Acropora*.



Soft coral disease – this unnamed disease affects soft corals of the genus *Sinularia*, causing polyps to retract, accumulate silt, and secrete excess mucous. The branches lose their turgidity, becoming soft and necrotic. The coral may die as a result.

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