REPORT: Bonaire National Marine Park—Algal Survey and Inventory

Date: 12 December 2006

To: Ramon de Leon, Manager - Bonaire National Marine Park
P.O. Box 368, Bonaire - Netherlands Antilles

CC: Mike Smith, Conservation International
Larry J. Gorenflo, Conservation International
Paul C. Hoetjes, Senior Policy Advisor, MINA, Netherlands Antilles

From: D.S. Littler & M.M. Littler, Smithsonian Institution, Botany, NMNH

Purpose: **Assess the Current Status of Bonaire's Marine Reefs**

The Littler's team [including Barrett Brooks, Don Hurlbert, Barbara Watanabe and Larry Gorenflo (Conservation International)] traveled to the island of Bonaire, Netherlands Antilles (1 Nov 06 to 14 Nov 06). The purpose of this expedition was to assist the Ministry of Nature Affairs for the Netherlands Antilles (MINA) and the Center for Applied Biodiversity Science at Conservation International to assess the current status of Bonaire's marine flora. The team collected over 300 specimens from the upper reef to a depth of 56 m. This assessment increased the known species reported from Bonaire by 35% (Appendix II, List of Species). The marine flora is typical of many Caribbean reefs with no specific areas of extremely high diversity or unique species composition. Also included in this evaluation are over 100 digital images (Appendix III), properly identified to the species level in most cases. These images may be used by managers in web sites, oral presentation, training manuals, brouchures, etc., to make marine plant identification possible for Bonaire's many divers, volunteers, conservationists or interested agencies.

The team surveyed the health of the reefs using key indicator species (recognized from our >30 continuous years of coral-reef research) in reference to the growing problems associated with eutrophication and overfishing along tropical and subtropical shorelines worldwide. The ecological responses of corals and macroalgae to nutrient enrichment and release from predation have been repeatedly cited as priority areas in need of further research (National Research Council, 2000; Littler & Littler 2006).

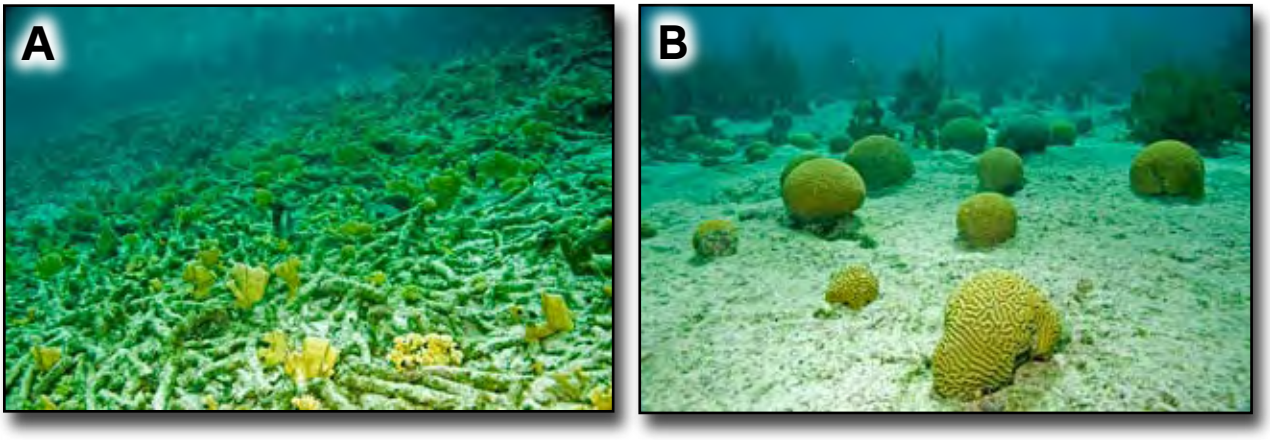


Fig 1. A. *Acropora cervicornis* debris from recent hurricanes showing only *Millipora* recruiting (*Millipora* can develop under elevated nutrient levels). B. Brain coral recruiting on Klein Bonaire.

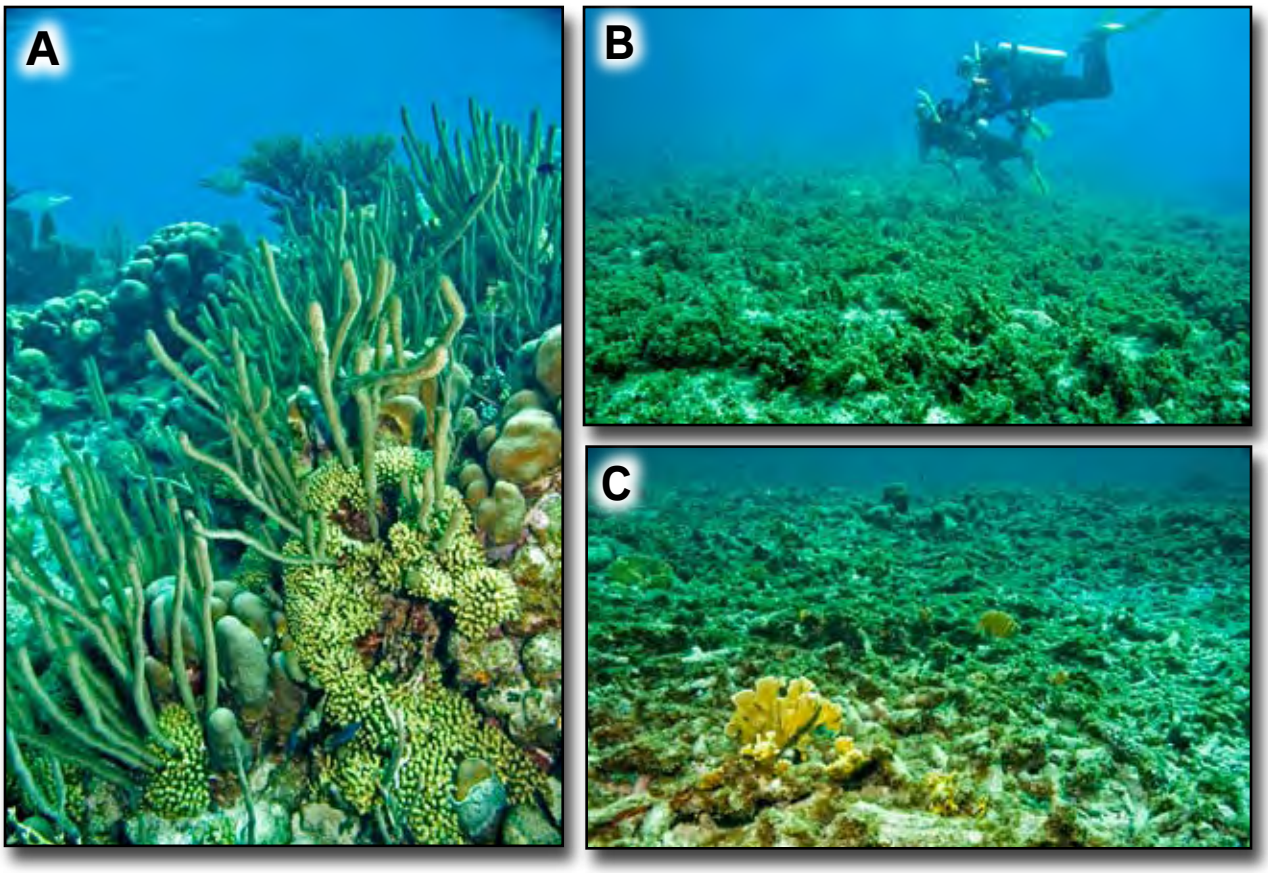


Fig 2. A. Healthy leeward reef community. B. Windward high-energy system dominated by the large rockweed *Sargassum*. C. Cyanobacterial community typical of many shallow disturbed habitats.

Herbivory:

Bonaire's reefs seemed in excellent shape with respect to fish populations. Large numbers of herbivorous fishes occur at nearly all of the 21 sites surveyed. Fish population surveys directed by Bonaire National Marine Park personnel, with the many competent volunteers, should be continued and supported by the MINA as an important part of monitoring reef health.

Eutrophication:

The problem of eutrophication is of paramount importance to the economy of Bonaire, since the vast majority of tourists are divers. The Antilles government (presently funding our colleague Dr. Brian E. Lapointe to coordinate nutrient monitoring) and many in the local community are aware of the need to reduce the nutrient load to improve coral recruitment following the last several hurricanes, which destroyed most of the shallow coral populations (Figs. 1A). The devastated reefs are now turf-algal dominated, having lost sufficient levels of resiliency (likely due to cultural eutrophication) and are not likely to recover their former coral populations. Those tourists who only snorkel will be very disappointed, since the shallow reefs (above 10 m) are in extremely poor condition. The only shallow reefs remaining in a healthy condition are on the west side of the small offshore island, Klein Bonaire, with substantial recruitment of coral (Fig. 1B) and a high diversity of other organisms. The west coast of Klein Bonaire is the area most distant from anthropogenic effects of Bonaire proper. The deeper reefs (below 10 m) are still in relatively good health with abundant hard corals and gorgonians (Fig. 2A) dominating the seascape.

However, there is a disturbing abundance of dead and diseased coral (Fig. 3) at these depths, with Black Band (Fig. 3B) and Dark Spot (Fig. 3C) diseases being the most prevalent. These coral diseases are indicative of an overly stressed environment most likely due to high nutrient and/or sediment levels. The windward coast represents a vast wave-shocked habitat dominated by healthy stands of large rockweeds (e.g., *Sargassum, Turbinaria,* Fig. 2B). Most of the other sites surveyed were dominated by noxious Cyanobacteria (blue-green algae). This harmful bloom of unpalatable (chemically-defended) Cyanobacteria is smothering most other organisms (Figs. 4A, 4B) and occupying much of the available space (Fig. 2C), precluding settlement of desirable coral species.

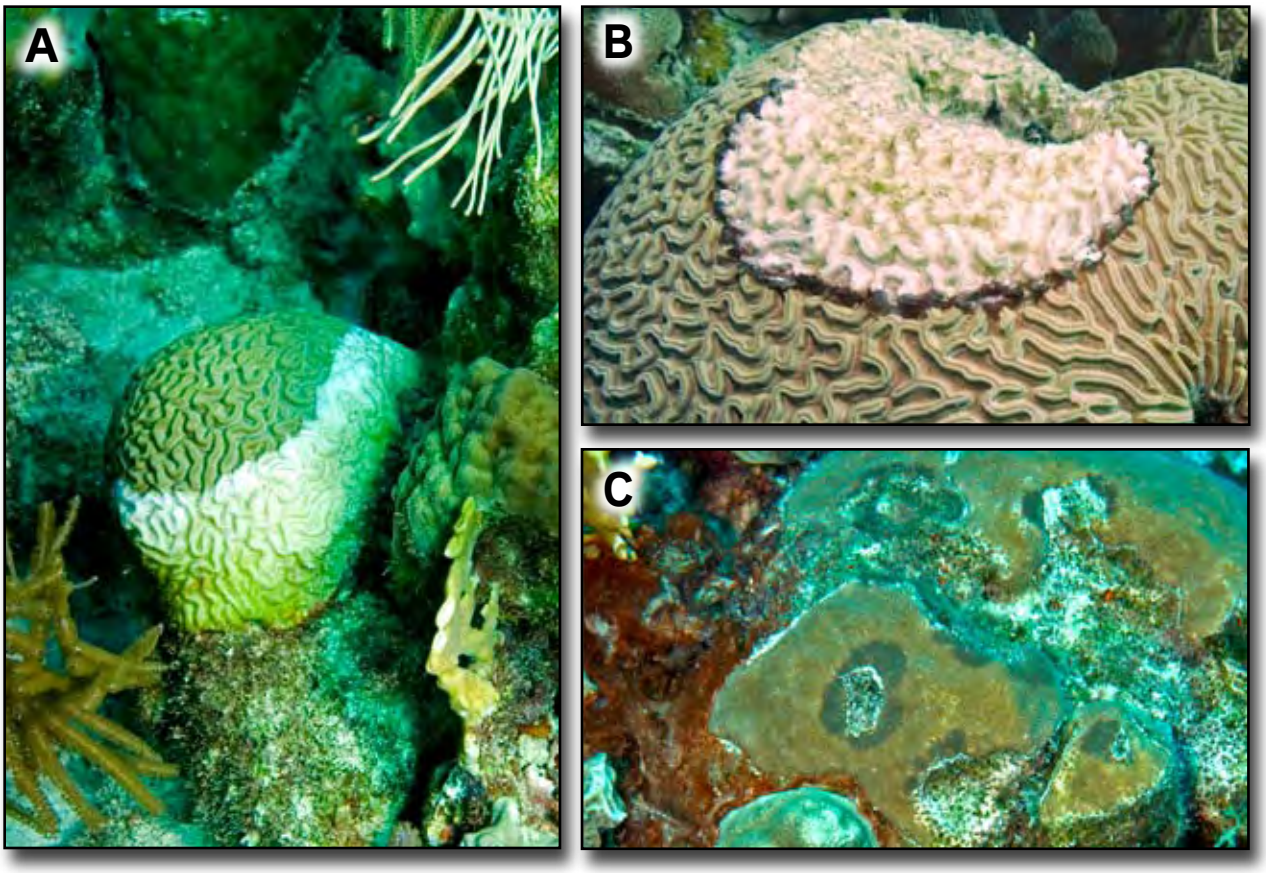


Fig 3. A. White Plague Disease caused by a bacterial pathogen. B. Black Band Disease caused by a consortium of microbial pathogens including Cyanobacteria. C. Dark Spot Disease, cause unknown.

Our own published work in Belize (Littler et al., 2006) found that abundances of blue-green algae (Cyanobacteria) were significantly elevated by SRP (phosphates) in the Carrie Bow Cay Lagoon site, consistent with earlier findings (Miller et al., 1999). Cyanobacteria are considered harmful to coral-reefs and have increased in abundance and importance in association with world-wide coral-reef declines. Many blue-green algal species can fix atmospheric nitrogen and appear to be among the first to bloom when SRP concentrations are elevated above the universal 0.1 µM tipping-point level or when SRP**:**DIN (soluble reactive phosphate**:**dissolved inorganic nitrate) ratios increase in general. Therefore, the dominance of blue-green algae is often an indicator of SRP nutrient levels higher than the above mentioned tipping-point for coral resilence/recoverability. These elevated nutrient levels are most likely caused by groundwater incursions due to the lack of sewage treatment facilities on the island.

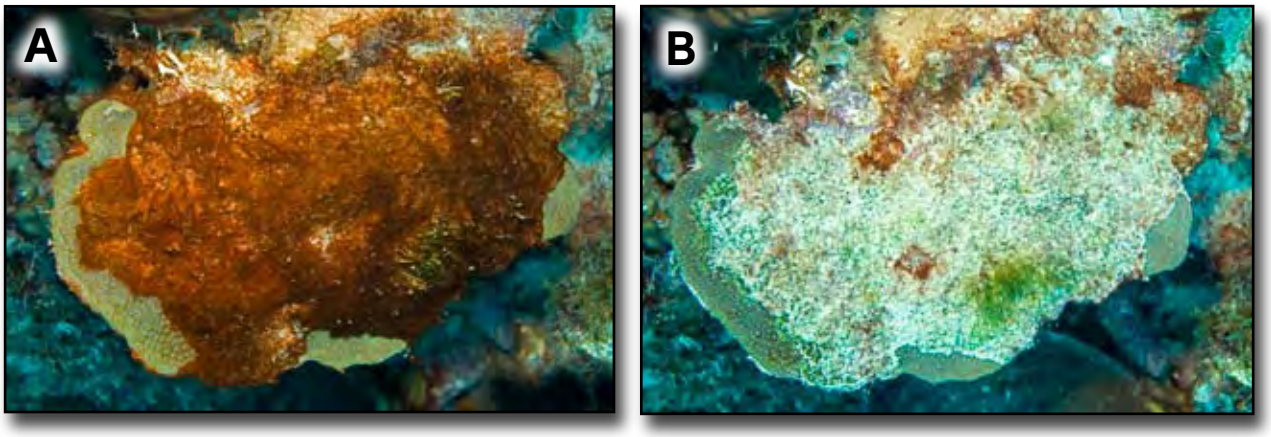


Fig 4. A. Coral being overgrown by Cyanobacteria. B. Cyanobacteria removed to reveal dead coral beneath.

Recommendations:

We recommend immediate change to some form of centralized tertiary treatment facilities that will **remove** phosphates and nitrates before the water is discharged or reused. Since Bonaire is primarily a carbonate island, any nutrients not removed prior to release (e.g., secondary treatment) would again leach back into the shallow-water reef habitats. The effects of secondary treatment release would be little different from the present situation. Therefore, in our opinion, the removal of nutrients is of paramount importance to restoring Bonaire's shallow reef habitats.

References cited:

Littler, M.M. and D.S. Littler. 2006. Assessment and management of coral reefs using herbivory/nutrient assays and functional indicator groups of benthic primary producers: a critical synthesis, proposed protocols, and critique of management strategies. Aquatic Conserv.: Mar. Freshw. Ecosyst. 16(7): 1–21.

Littler, M.M., D.S. Littler and B.L. Brooks. 2006. Harmful algae on tropical coral reefs: bottom-up eutrophication and top-down herbivory. Harmful Algae 5: 1–23.

Littler, M.M., D.S. Littler, B.L. Brooks and B.E. Lapointe. 2006. Nutrient manipulation methods for coral reef studies: a critical review and experimental field data. J. Exp. Mar. Biol. Ecol. 336(2): 242–253.

Miller M.W., M.E. Hay, S.L. Miller, D. Malone, E.E. Sotka and A. Szmant. 1999. Effects of nutrients versus herbivores on reef algae: a new method for manipulating nutrients on coral reefs. Limnol. Oceanogr. 44: 1847–1861.

National Research Council. 2000. Clean coastal waters: understanding and reducing the effects of nutrient pollution. Ocean Studies Board, Water Science and Technology Board. National Academy Press, Washington D.C.

APPENDIX – I
SUGGESTED MANAGEMENT STRATEGIES

See attached pdf files of the following articles

Littler, M.M., D.S. Littler and B.L. Brooks. 2006a. Harmful algae on tropical coral reefs: bottom-up eutrophication and top-down herbivory. Harmful Algae 5(5): 565-585.

Littler, M.M., D.S. Littler, B.L. Brooks and B. E. Lapointe. 2006b. Nutrient manipulation methods for coral reef studies: a critical review and experimental field data. J. Exp. Mar. Biol. Ecol. 336(2): 242-253.

Littler, M.M., and D.S. Littler. 2006c. Assessment and management of coral reefs using herbivory/nutrient assays and functional indicator groups of benthic primary producers: a critical synthesis, proposed protocols, and critique of management strategies. Aquatic Conserv.: Mar. Freshw. Ecosyst. 16(7): 1-21.

APPENDIX – II
LIST OF ALGAL SPECIES FROM BONAIRE BASED ON PAST RECORDS AND THE PRESENT EXPEDITION

APPENDIX – III
IMAGES OF ALGAL SPECIES COMMON LY FOUND ON BONAIRES REEFS

APPENDIX – II

LIST OF ALGAL SPECIES FROM BONAIRE BASED ON PAST RECORDS AND THE PRESENT EXPEDITION

CHLOROPHYTA (Green Algae)

* Bold = new records

Acetabularia crenulata
Acetabularia schenckii
Anadyomene saldanhae
Anadyomene stellata
Avrainvillea asarifolia
Avrainvillea levis f. translucens
Avrainvillea digitata
Avrainvillea longicaulis
Avrainvillea nigricans
Avrainvillea rawsonii
Batophora oerstedii
Boodlea composita
Boodleopsis pusilla
Bryopsis hypnoides
Bryopsis pennata
Bryopsis plumosa
Cladophoropsis membranacea
Caulerpa cupressoides
Caulerpa macrophysa
Caulerpa mexicana
Caulerpa microphysa
Caulerpa peltata
Caulerpa racemosa
Caulerpa racemosa var occidentalis
Caulerpa sertularioides
Caulerpa serrulata
Caulerpa verticillata
Caulerpa vickersiae
Caulerpa webbiana
Chaetomorpha area
Chaetomorpha crassa
Chaetomorpha gracilis
Chaetomorpha linum
Chaetomorpha media
Cladophora cf. brasiliana
Cladophora cf. submarina
Cladophora dalmatica
Cladophora jongiorum
Cladophora laetevirens
Cladophora prolifera
Cladophora socialis
Cladophora vagabunda
Cladophoropsis macromeres
Codium cf. repens
Codium intertextum
Codium isthmocladum
Codium taylorii
Dictyosphaeria cavernosa
Dictyosphaeria vanbosseae
Diplochaete solitaria
Enteromorpha cf. erecta
Enteromorpha chaetomorphoides
Enteromorpha clathrata
Enteromorpha flexuosa
Enteromorpha lingulata
Enteromorpha plumosa
Enteromorpha prolifera
Ernodesmis verticillata
Halimeda copiosa
Halimeda simulans
Halimeda incrassata
Halimeda opuntia
Neomeris annulata
Neomeris mucosa
Penicillus capitatus
Penicillus pyriformis
Penicillus sp.
Phaeophila dendroides
Phyllodictyon anastomosans
Rhizoclonium hookeri
Rhizoclonium kerneri
Rhizoclonium riparium
Rhizoclonium totuosum
Struvea anastomosans
Udotea cyathiformis
Udotea flabellum
Ulva fasciata
Ulva lactuca
Ulva rigida
Ulvella lens
Valonia aegagropila
Valonia macrophysa
Valonia ocellata
Ventricaria ventricosa

PHEAOPHYTA (Brown Algae)

Chnoospora minima
Colpomenia sinuosa
Dictyopteris delicatula
Dictyota bartayresii
Dictyota cervicornis
Dictyota crispata
Dictyota (divaricata) mertensii
Dictyota (jamaicensis) crenulata
Dictyota dichotoma
Dictyota pfaffii
Dictyota pinnatifida
Dictyota (Dilophus) guineensis
Ectocarpus breviarticulatus
Ectocarpus rhodochortonoides
Feldmannia elachistaeformis
Feldmannia indica
Giffordia conifera
Giffordia duchasaingiana
Giffordia mitchelliae
Hydroclathrus clathratus
Lobophora variegata
Padina gymnospora
Padina sanctae-crucis
Padina spp.
Pseudolithoderma extensum
Rosenvingea sanctae-crucis
Sargassum cf. rigidulum
Sargassum hystrix
Sargassum polyceratium
Sargassum vulgare
Spatoglossum schroederi
Sphacelaria furcigera
Sphacelaria novae-hollandiae
Sphacelaria rigidula
Sphacelaria tribuloides
Stypopodium zonale
Taonia abbottiana
Turbinaria tricostata
Turbinaria turbinata

RHODOPHYTA (Red Algae)

Acanthophora spicifera
Acrochaetium microscopicum
Acrochaetium pulchellum
Aglaothamnion cf. furcellariae
Amphiroa brasiliana
Amphiroa fragilissima
Amphiroa hancockii
Amphiroa rigida var antillana
Amphiroa tribulus
Anotrichium tenue
Antithamnion antillarum
Antithamnion cruciatum
Asparagopsis taxiformis
Bostrychia binderi
Bostrychia scorpioides
Bostrychia tenella
Botryocladia caraibica
Botryocladia spinulifera
Bryothamnion triquetrum
Callithamnion byssoides
Callithamnion corymbosum
Caloglossa leprieurii
Catenella repens
Catenella caespitosa
Centroceras clavulatum
Ceramium byssoideum
Ceramium codii
Ceramium dawsonii
Ceramium gracillimum
Ceramium leutzelburgii
Ceramium nitens
Ceramium tenerrimum
Champia parvula
Chondria collinsiana
Chondria curvilineata
Chondria dasyphylla
Chondria sedifolia
Chondrophycus gemmifera
Chondrophycus papillosa
Chroodactylon ornatum
Coelothrix irregularis
Colaconema caespitiforme

Colaconema flexuosum
Colaconema netrocarpum
Colaconema seriatum
Cruoriopsis cruciata
Cryptonemia sp.
Dasya cf. corymbifera
Dasya rigidula
Dasya spinuligera
Digenea simplex
Erythrotrichia cornea
Fosliella farinosa
Galaxaura comans
Galaxaura marginata
Galaxaura rugosa
Gametophyte Stage (squalida)
Galaxaura rugosa
Tetrasporophyte Stage
Ganonema farinosum
Gelidiella acerosa
Gelidiella sanctarum
Gelidiopsis intricata
Gelidiopsis planicaulis
Gelidium pusillum
Goniolithon spectabile
Goniolithon strictum
Goniotrichum alsidii
Gracilaria damaecornis
Gracilaria foliifera
Gracilaria mammillaris
Grateloupia filicina
Griffithsia tenuis
Herposiphonia secunda
Herposiphonia tenella
Heterosiphonia crispella
Hydrolithon boergesenii
Hypnea cervicornis
Hypnea cornuta
Hypnea musciformis
Hypnea spinella
Hypneocolax stellaris
Jania adhaerens
Jania capillacea
Jania pumila
Jania rubens
Laurencia gemmifera
Laurencia chondrioides
Laurencia corallopsis
Laurencia intricata
Laurencia obtusa
Laurencia poiteaui
Lejolisia exposita
Liagora ceranoides
Liagora farinosa
Lithophyllum congestum
"Lithothamnion"
Lophosiphonia cristata
Melobesia spp.
Murrayella periclados
Ochtodes secundiramea
Peyssonnelia boergesenii
Peyssonnelia conchicola
Peyssonnelia simulans
Peyssonnelia spp
Pleonosporium caribaeum
Polysiphonia atlantica
Polysiphonia binneyi
Polysiphonia cf. subtilissima
Polysiphonia ferulacea
Polysiphonia havanensis
Polysiphonia macrocarpa
Polysiphonia howei
Polysiphonia scopulorum var. villum
Polysiphonia subtilissima
Polysiphonia sphaerocarpa
Porolithon craspedium ?
Porolithon pachydermum
Pterocladiella capillacea
Pterocladia americana
Pterocladia bartlettii
Pterocladia pinnata
Pterocladiophila hemisphaerica
Spermothamnion investiens
Spyridia aculeata
Spyridia filamentosa
Taenioma perpusillum
Titanoderma sp
Tricleocarpa fragilis
Wrangelia argus
Wrangelia penicillata
Wurdemannia miniata

CYANOBACTERIA (Blue Green Algae)

Calothrix aeruginea
Calothrix confervicola
Chroococcus turgidus
Dichothrix sp.
Entophysalis deusta
Hormothamnion enteromorphoides
Hydrocoleum sp.
Lyngbya aestuarii
Lyngbya majuscula
Lyngbya penicilliformis
Lyngbya sordida
Lyngbya semiplena
Microcoleus chthonoplastes
Microcoleus tenarrimus
Oscillatoria nigro-viridis
Phormidium corallyticum (Black band)
Phormidium crosbyanum
Phormidium hendersonii
Polythrix corymbosa
Symploca sp.

Sea Grasses

Halodule beaudettii
Rhizophora mangle
Thalassia testudinum
Syringodium filiforme

Chlorophyta

Acetabularia crenulata 68517

Anadyomene saldanhae 68319

Avrainvillea digitata 68504 (11)

Avrainvillea levis f

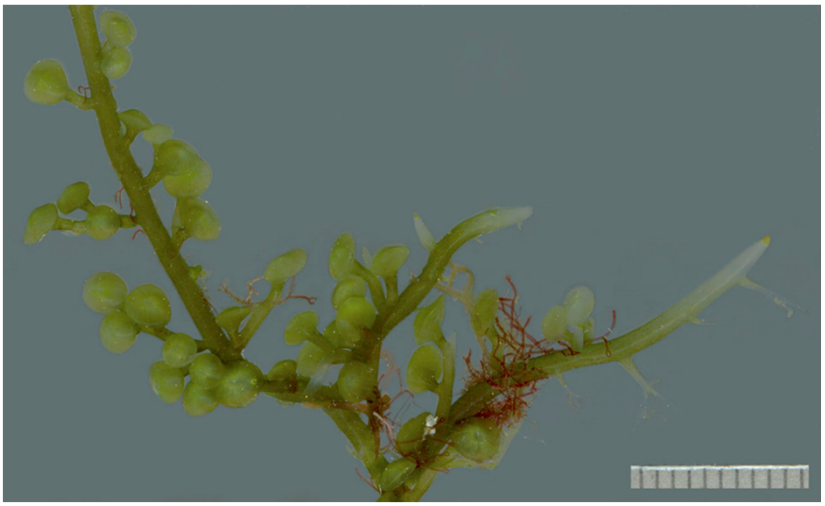
Batophora oerstedii 68523

Bryopsis 68390

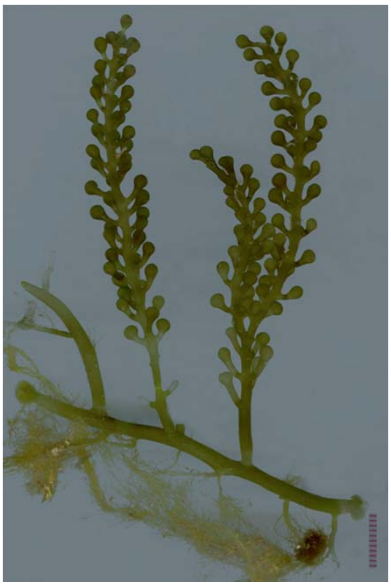
Caulerpa cupressoides 68505

Caulerpa macrophysa (1)

Caulerpa racemosa 68315 (5)



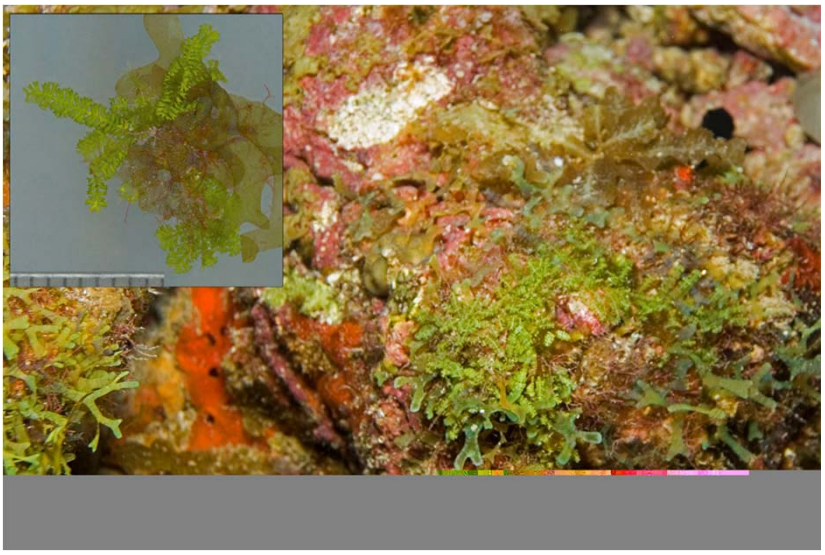
Caulerpa racemosa 68315



Caulerpa racemosa f occidentalis 68508

Caulerpa sertularioides 68459

Caulerpa serulata 68467



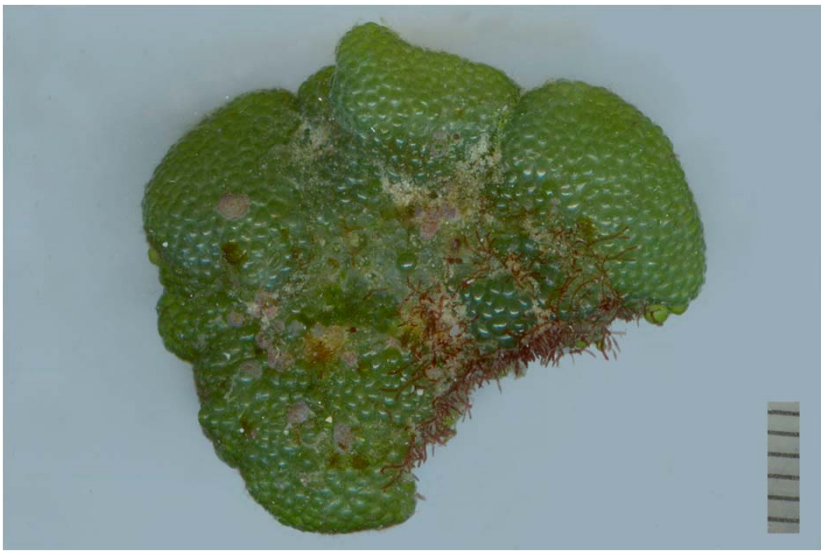
Caulerpa webbiana 68596

Chaetomorpha linum 68333

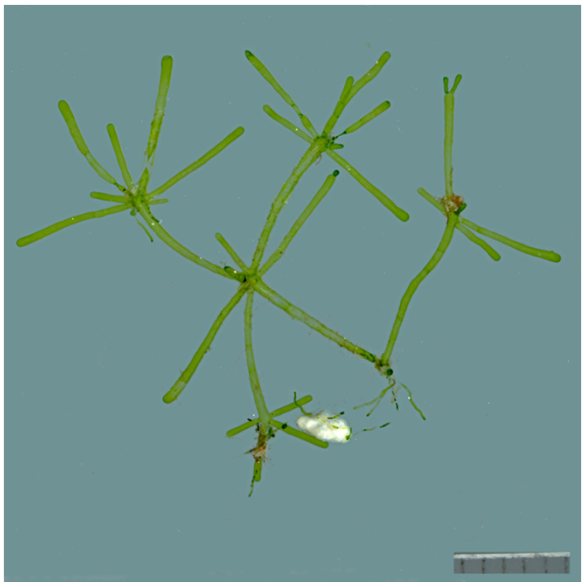
Codium intertextum 68409 b

Codium intertextum 68409

Codium taylorii 68440



Dictyospheria cavernosa 68403



Ernodesmis verticillata 68377

Halimeda copiosa 68606 (4)

Halimeda incressata (1)

Halimeda opuntia

Neomeris annulata 68429

Neomeris annulata 68475 (5)

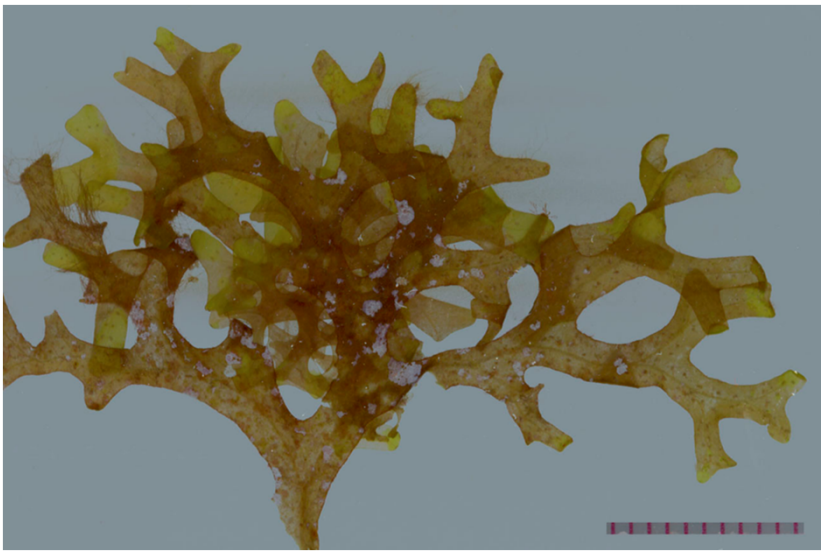
Penicillus capitatus 68528

Phyllodictyon anastomosans 68312

Udotea cyathiformis 68466 (6)

Udotea flabellum 68524

Phaeophyta

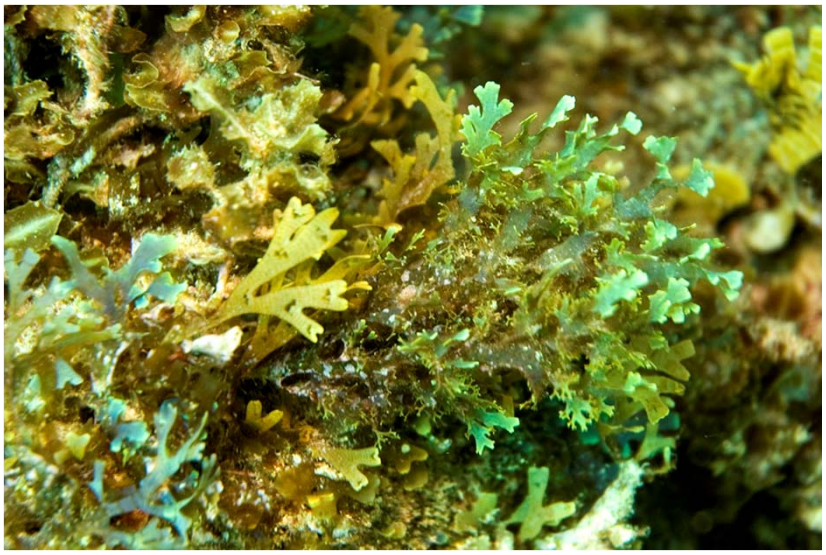


Dictyopteris delicatula 68499

Dictyota bartayresiana 68421

Dictyota bartayresiana

Dictyota crispata 68498



Dictyota martensii 68511 (2)

Dictyota pfaffi 68470

Dictyota pinnatifida 1

Dictyota pulchella 68610 (5)

Dictyota sp

Lobophora variegata

Padina sp

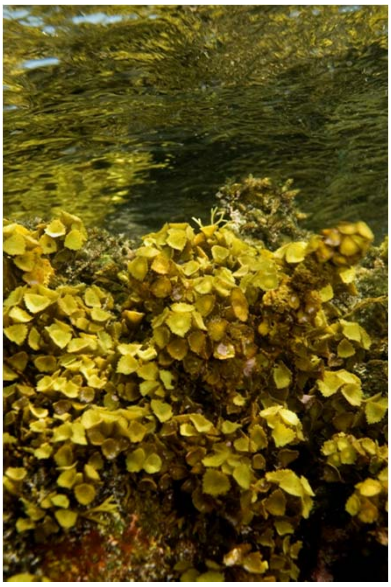
Pseudolithoderma extensum 68593 (3)

Sargassum hystrix

Sargassum sp drift 3 (1)

Taonia abbottiana 68492

Turbinaria tricostata 68417

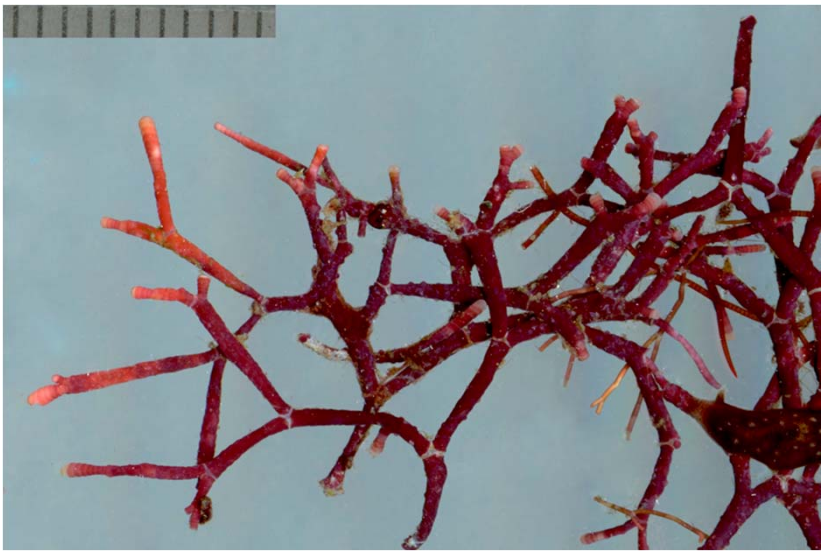


Turbinaria turbinata 68445

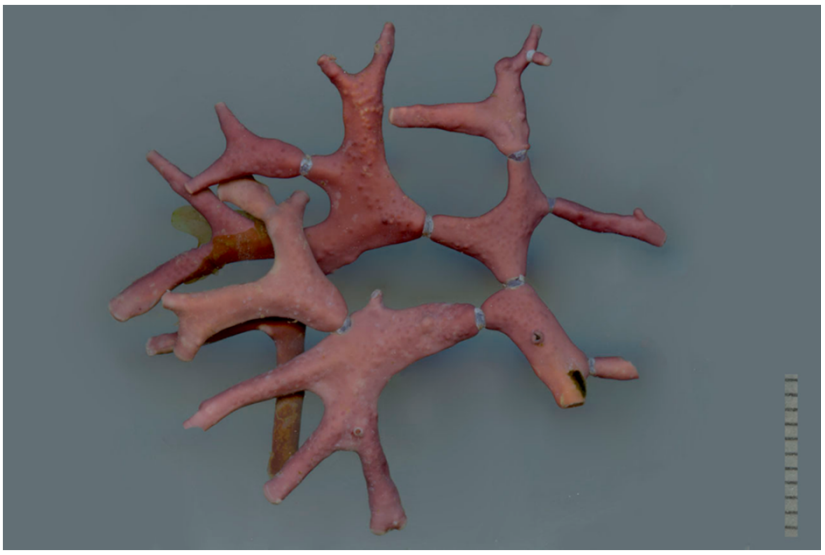
Turbinaria turbinata 68602

Rhodophyta

Acanthophora spicifera 68379



Amphiroa brasiliana 68385



Amphiroa hancockii 68603

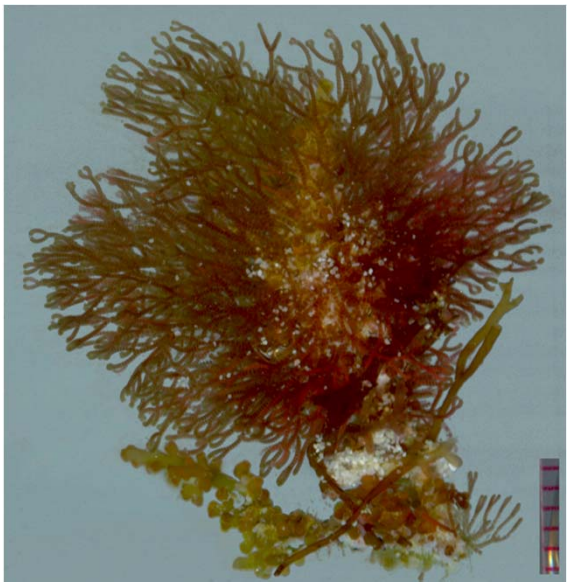
Amphiroa tribulus 68490

Amphiroa tribulus 68614 (7)

Bostrychia sp 68533 (4)

Botryocladia caraibica 68501

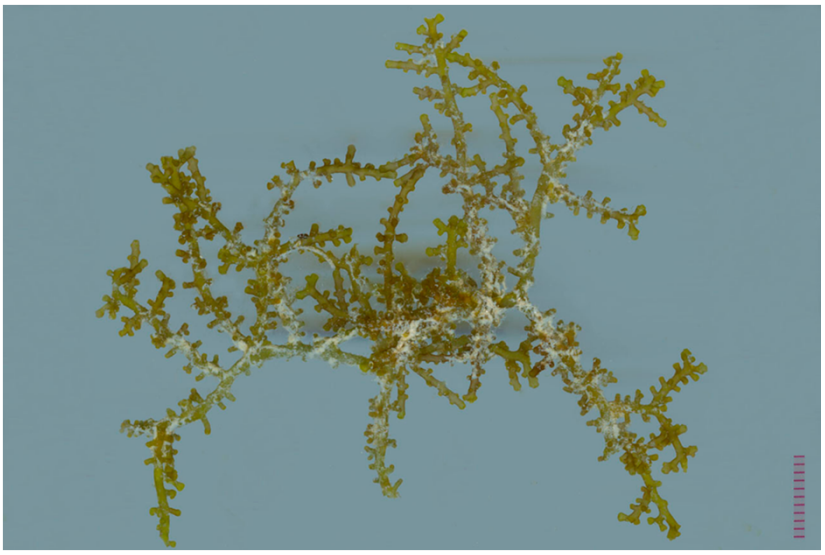
Botryocladia spinulifera 68350



Ceramium 68355

Ceramium nitens 2

Ceramium nitens

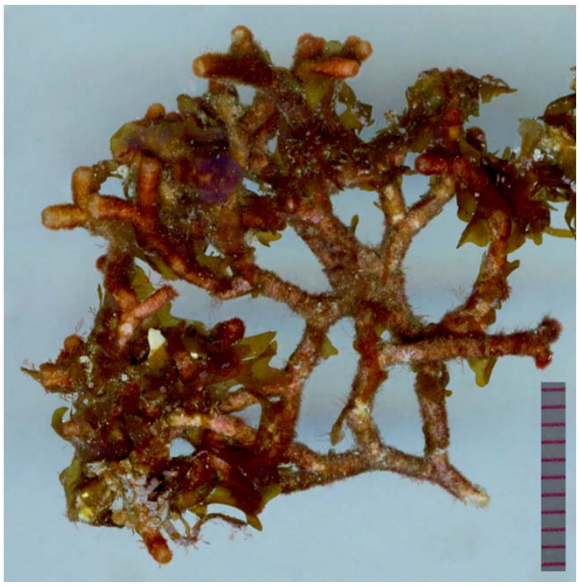


Chondrophycus gemmifera 68530

Chondrophycus papillosa 68392

Coelothrix irregularis

Copy of Galaxaura rugosa gametophyte 68412 b



Copy of Galaxaura rugosa tetrasporophyte 68414

Copy of Ganonema farinosum 68423 b

Copy of Ganonema farinosum 68423

Copy of Hypnea musciformia 68358

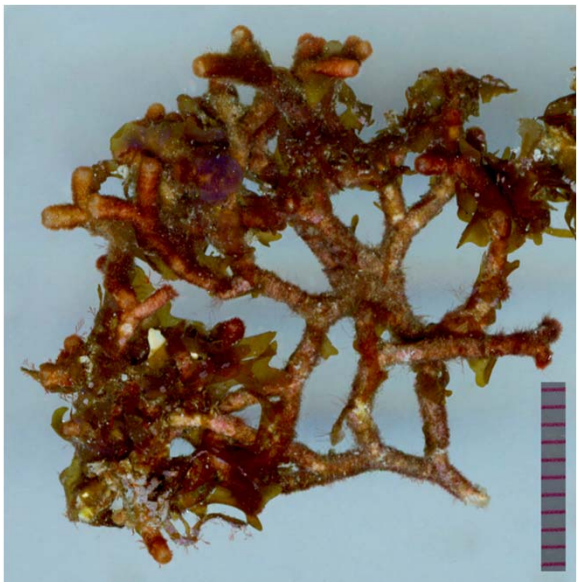
Cryptonemia sp 68553

Dasya spinuligera 68552

Galaxaura comans 68413

Galaxaura marginata 68329

Galaxaura rugosa gametophyte 68412 b



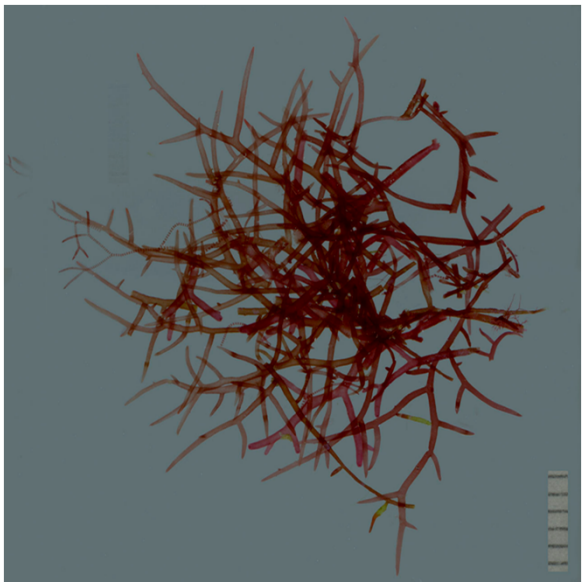
Galaxaura rugosa tetrasporophyte 68414

Ganonema farinosum 68423 b

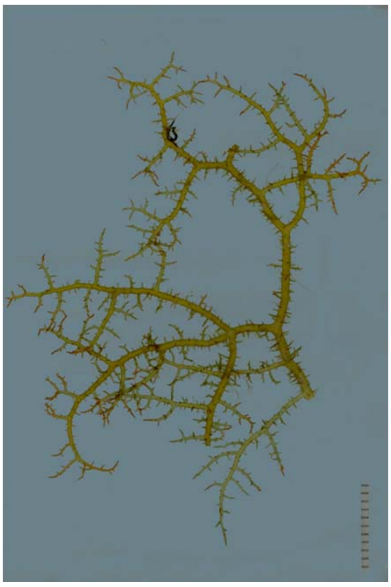
Ganonema farinosum 68423

Hydrolithon boergesenii 68604

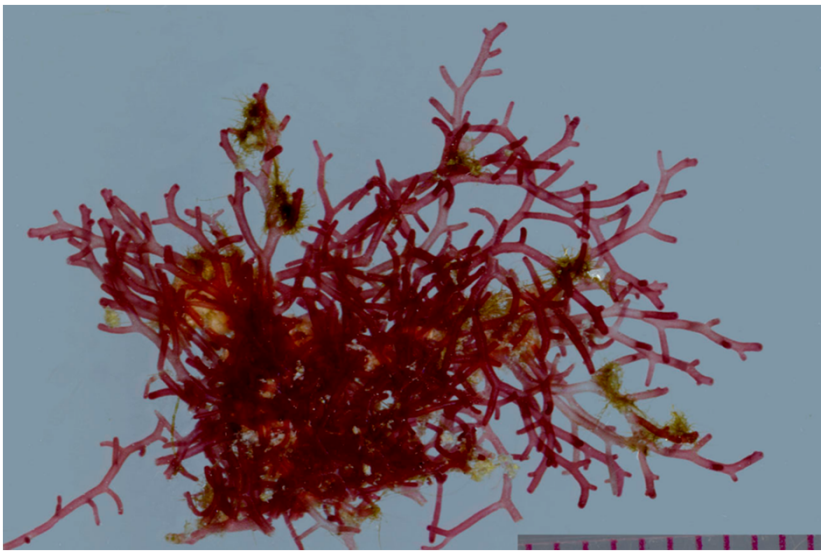
Hypnea musciformia 68358



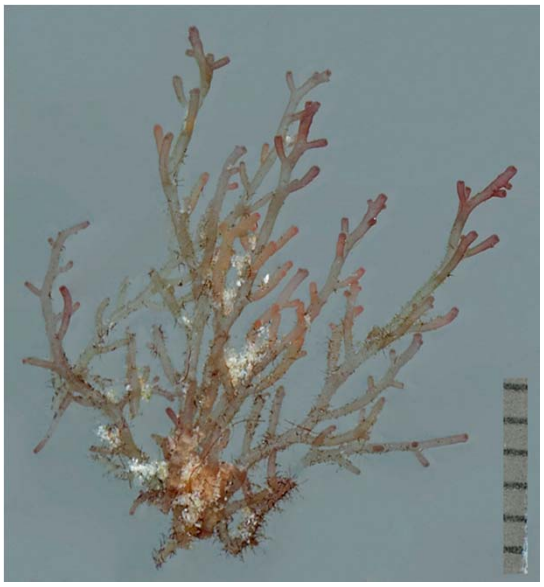
Hypnea spinella (cervicornis) 68370



Hypnea spinella 68419

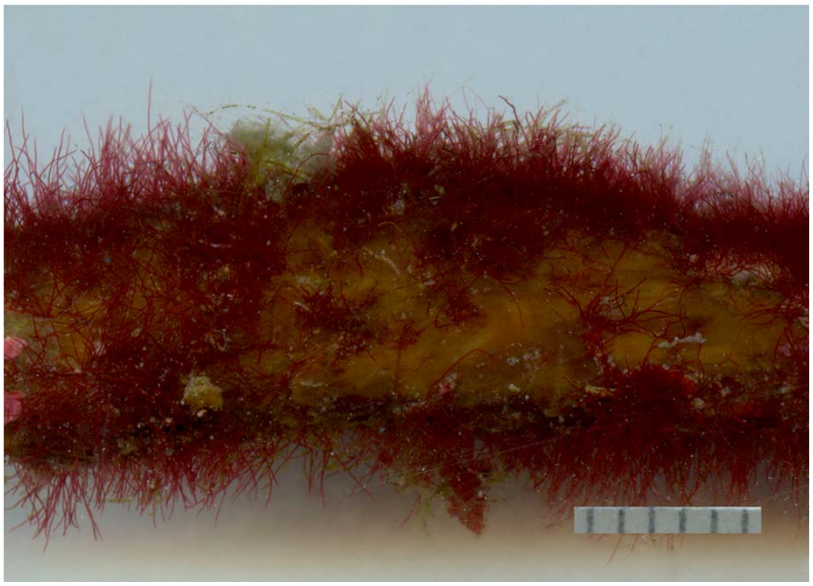


Laurencia cf intricata 68476

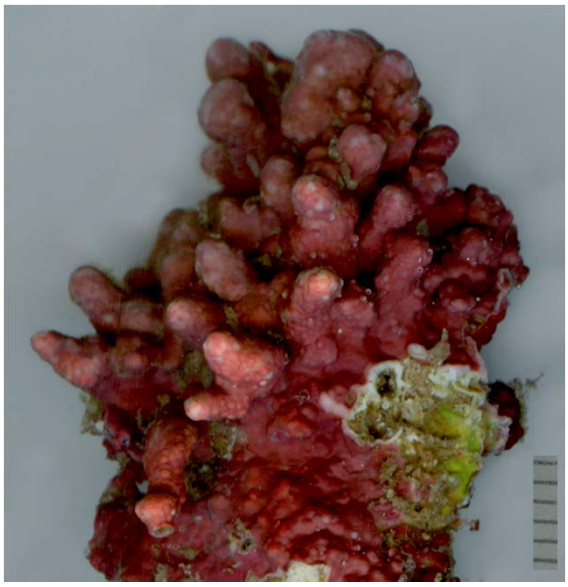


Laurencia chondrioides 68581 a

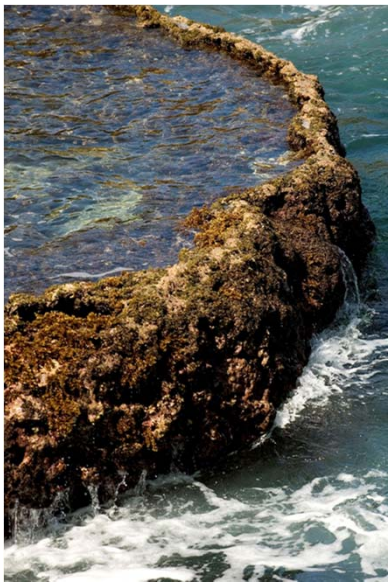
Laurencia obtusa 36



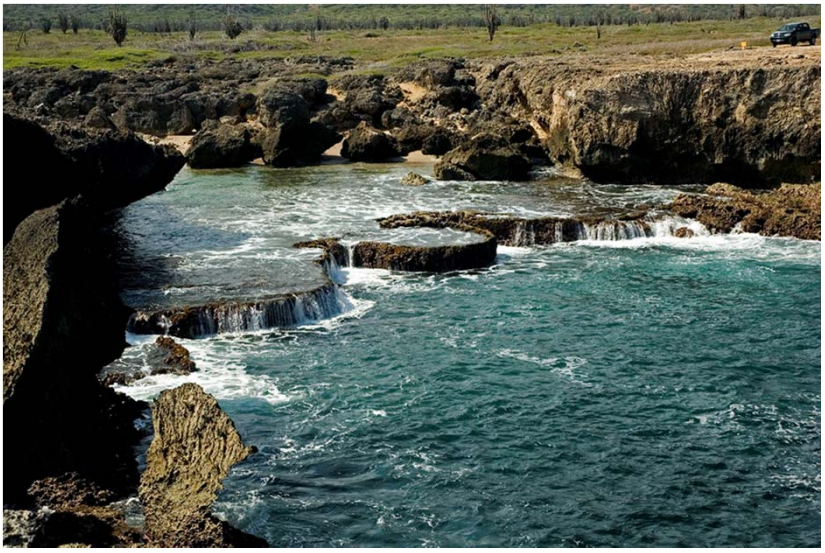
Lejolisia exposita 68585



Lithophylum congestum 68599



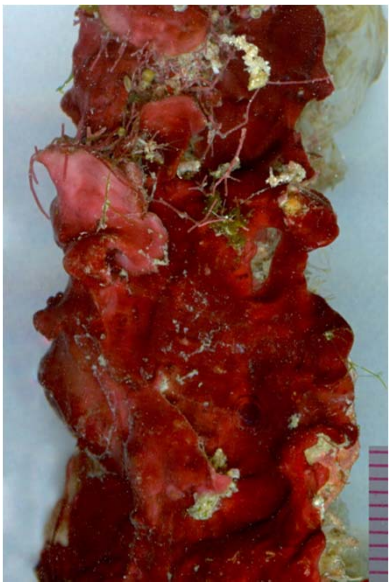
-Lithothamnion- ridge 1



-Lithothamnion- ridge 2

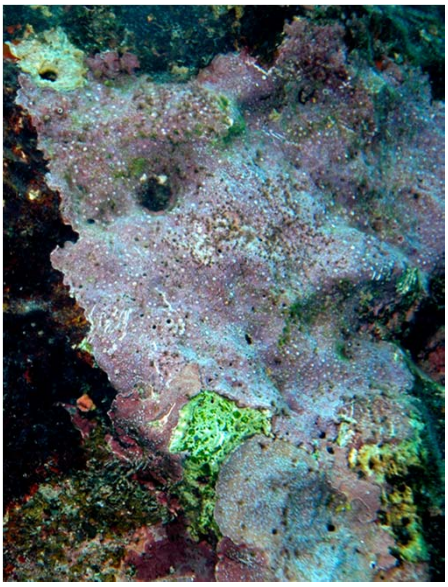
Mixed turf mainly Amphiroa fragilissima

Peyssonnelia boergesenii



Peyssonnelia conchicola 68461

Peyssonnelia simulans

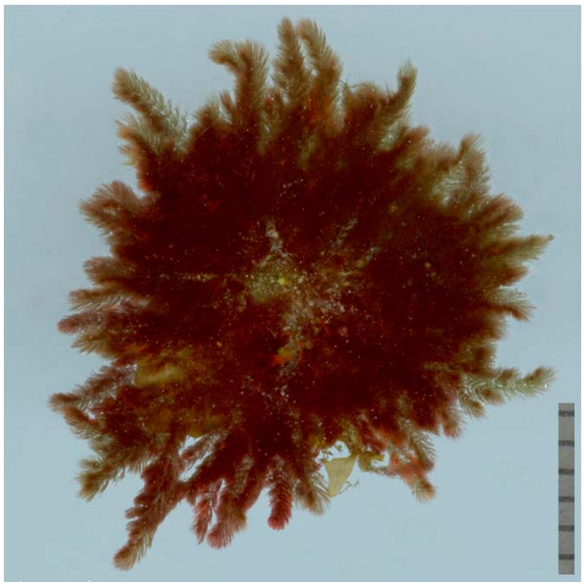


Porolithon pachydermum

Pterocladiella capillacea 68380

Titanoderma sp with CLOD patch

Tricleocarpa fragilis 68487



Wrangelia argus 68391

Wrangelia penicillata

Cyanobacteria

Hydrocoleum 68454 maybe

Lyngbya penicilliformis 2

Lyngbya penicilliformis

Phormidium corallyticum - black band - 1

Phormidium corallyticum - black band - 3

Phormidium hendersonii 68453

Symploca sp

Seagrasses

Thalassia testudinum