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New marine algal records from the Polynesia–Micronesia region of the Pacific Ocean

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The first known collections of marine algae from Santa Rosa Reef, a submerged seamount located 46 km south-south-west of Guam in the Mariana Islands, occurred at 10.0 to 13.7 m depths in 2003 and 2005. Dasycladus vermicularis*, a green alga known predominantly from the Caribbean but also reported from the Philippines in 1976 and the Ryukyus in 1995, and* Cutleria irregularis*, a brown alga first described from the Hawaiian Islands in 2003, represent the first record of* D. vermicularis *in the Polynesia–Micronesia region, and the first record of* C. irregularis *in Micronesia. In total, 8 of the 32 algal species collected at Santa Rosa Reef represent new records for the Mariana Islands.*

Keywords: *Dasycladus vermicularis*, *Cutleria irregularis*, marine algae, Polynesia, Micronesia, Mariana Islands, Santa Rosa Reef, Guam

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INTRODUCTION

Since 2000, the US National Oceanic and Atmospheric Administration (NOAA) Pacific Islands Fisheries Science Center (PIFSC) Coral Reef Ecosystem Division (CRED) has visited all tropical to subtropical Pacific islands that fall under US jurisdiction in order to document biodiversity and gain baseline understanding of reef communities in these locations. Voucher specimens of algae from these Reef Assessment and Monitoring Program (RAMP) research expeditions have improved our understanding of species diversity and abundance for many remote and unpopulated islands (Vroom *et al.*, 2006; Tsuda *et al.*, 2008, 2011; Vroom & Timmers, 2009), and are expanding known species ranges for many taxa. Recently, biologists at the Bishop Museum have begun to examine the thousands of algal specimens collected from the Mariana Islands during the 2003, 2005, and 2007 CRED expeditions, and are in the process of creating detailed species lists for each of the reef systems situated along the island chain.

As part of RAMP expeditions to the Mariana Islands, two unique algal collections were made at Santa Rosa Reef (the southernmost reef in the Mariana Islands) by P.S. Vroom and K.N. Page on 28 September 2003 and 7 October 2005, respectively (Figure 1). Santa Rosa Reef is a flat-topped submerged seamount (shallowest depth, 7 m below sea level) located 46 km south-south-west of Guam. The reef is characterized by moderate relief (Figure 2), scattered corals and few reef fish. Although the benthic communities at Santa Rosa Reef receive few direct anthropogenic impacts, the bank is a popular fishing location for sports fishers travelling from Guam. Subsequently, reduced fish populations may affect benthic communities.

Before the RAMP expeditions, no algae had ever been reported for Santa Rosa Reef. However, given its relatively close geographical proximity to Guam (see Figure 1), it was hypothesized that the marine flora of Santa Rosa Reef would not differ from the algal species composition previously published for the Mariana Islands or for Micronesia as a whole. Guam is the largest (640 km^2), most populated (~183,000 people) and southernmost island in the north–south oriented Mariana Islands with 332 reported species of marine benthic algae (Tsuda, 2003), i.e. 38 blue-green algae (Cyanobacteria), 162 red algae (Rhodophyta), 32 brown algae (Phaeophyceae) and 100 green algae (Chlorophyta). Currently, the marine flora of Micronesia, which encompasses the Mariana Islands, Caroline Islands, Marshall Islands, Gilbert Islands (portion of Kiribati) and Ellice Islands (Tuvalu) is reported to contain 653 species of benthic marine algae (Tsuda & Wray, 1977; Tsuda, 1981; Lobban & Tsuda, 2003).

The primary objective of this study was to document baseline algal species diversity starting in 2003 for Santa Rosa Reef, and compare taxa to the marine flora of Guam (Santa Rosa Reef's closest neighbour).

MATERIALS AND METHODS

Algae were collected by SCUBA divers on 28 September 2003 and 7 October 2005 between the depths of 10.0 and 13.7 m. Algae were placed in plastic bags, labelled and frozen immediately after each dive. Prior to examination, the frozen plastic bags from each station were thawed in tap water. Thawed seawater was poured carefully out of the bag and replaced with

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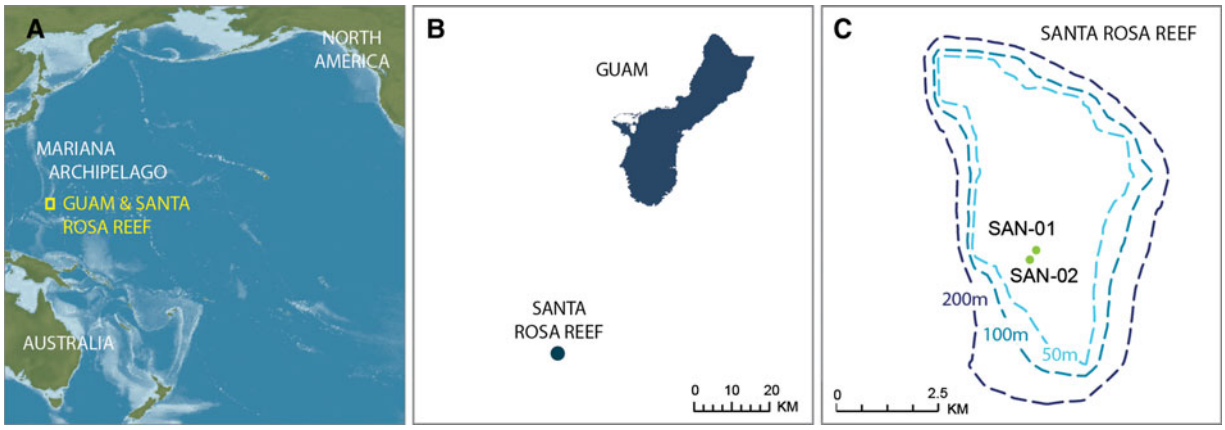

Fig. 1. (A) Guam and Santa Rosa Reef in the Mariana Islands; (B) Santa Rosa Reef in relation to the southernmost island of Guam; (C) bathymetry of Santa Rosa Reef and location of Stations SAN-01 and SAN-02.

80% ethyl alcohol to prevent the delicate turf and epiphytes from decomposing. The collections were examined using a dissecting microscope, and epiphytes were separated. All specimens are deposited in the Herbarium Pacificum (BISH) at the Bishop Museum, Honolulu.

National Oceanic and Atmospheric Administration stations were designated by a code system, e.g. SAN-01-03, which denotes Santa Rosa Reef (SAN), station (01) and year 2003 when the specimens were collected (03). Two stations were sampled in the southern sector of Santa Rosa Reef during both the 2003 and 2005 cruises to the Mariana Islands (see Figure 1). NOAA RAMP dives have not been conducted at Santa Rosa Reef since these initial visits. Station SAN-01 was located north-east of Station SAN-02 and possessed high coral cover (~26%) and diversity, while Station SAN-02 possessed coral cover of ~13% and higher algal cover. The coordinates and collection depths were as follows:

Station SAN-01: 12°48.784′N 144°25.483′E, 10.0–13.1 m deep; and

Station SAN-02: 12°48.685′N 144°25.422′E, 11.6–13.7 m deep.

RESULTS

A total of 32 algal species were collected during the 2003 and 2005 collections (see text and Appendix). Of these, 3 species represented cyanobacteria, 10 species were red algae, 4 species represented brown algae and 15 species represented green algae.

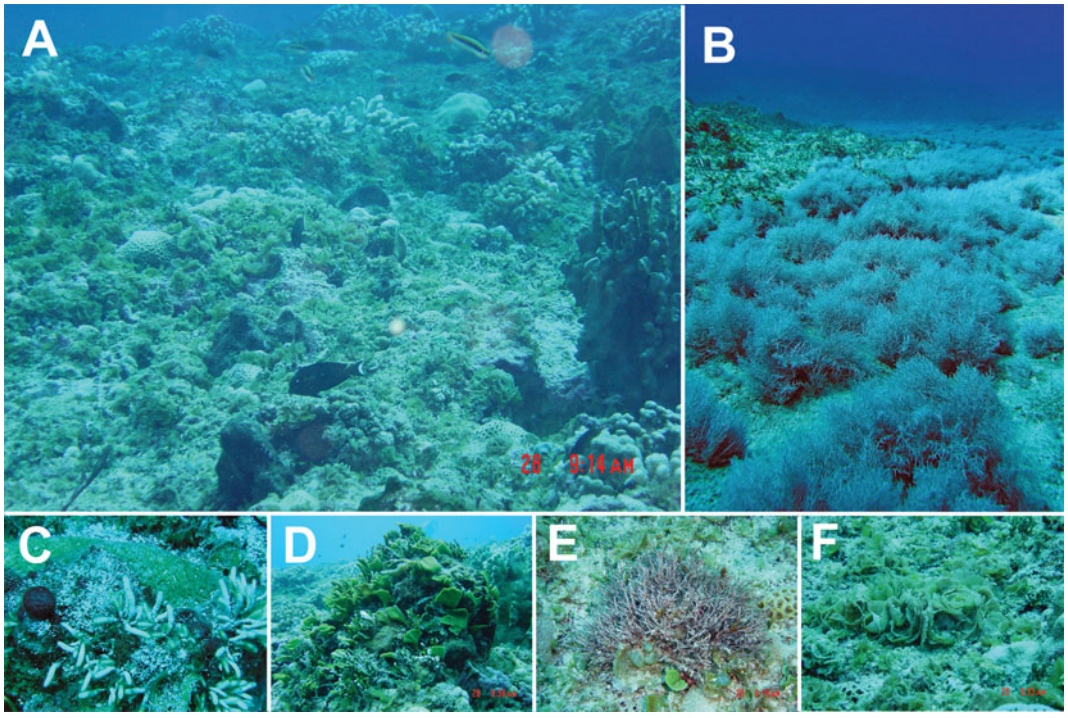

Fig. 2. Santa Rosa Reef: (A) general field shot of Station SAN-01 showing rugosity of reef system, 28 September 2003; (B) *Liagora ceranoides*, Station SAN-02, 7 October 2005; (C) *Neomeris mucosa*, Station SAN-02, 7 October 2005; (D) *Rhipilia micronesica* and *Halimeda taenicola*, Station SAN-01, 28 September 2003; (E) *Laurencia* sp., Station SAN-01, 28 September 2003; (F) *Microdictyon okamurae*, Station SAN-01, 28 September 2003.

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First Polynesia–Micronesia record

Phylum CHLOROPHYTA

Dasycladus vermicularis (Scopoli) Krasser in Beck & Zahlbruckner, 1898, 459, figure 8; Taylor, 1960, 99, pl. 4 (figure 2), pl. 6 (figures 2 & 8); Reyes, 1976, 150, pl. 5 (figure 8);
Ohba, 1995, 25; Littler & Littler, 2000, 436.

REMARKS

Specimens are cylindrical or club-shaped (9–25 mm tall and 3 mm diameter), brown-black, soft, fuzzy, uncalcified and grew in clusters on hard substrata. Transverse sections (BISH 748784) show whorls of branches initiating from a central siphon with each primary branchlet (240 μm diameter, 720 μm long) bearing 3 (occasionally 4) tiers of branchlets (each with single cell), i.e. each of the 3 secondary branchlets (140 μm diameter, 600 μm long) bear 3 tertiary branchlets (80 μm diameter, 320 μm long) with each bearing 2 or 3 terminal branchlets (48 μm diameter, 160 μm long), and occasionally terminating in a hairlike filament (2–4 cells long). The mature terminal branchlets of *Dasycladus vermicularis* are cylindrical and most terminate in a small sharp point (apiculate) unlike the clavate apex of *Dasycladus densus* Womersley and the obovoid apiculate apex of *D. ramosus* Chamberlain. Gilbert (1978) provided photographs of the branchlets of the 3 species of *Dasycladus*, with comparative photographs of *Chlorocladus philippinensis* W.J. Gilbert and *Chlorocladus australasicus* Sonder.

Of the 37 specimens of *D. vermicularis* in the collections, 10 of the larger specimens were sectioned and found to be sterile. The species was plentiful in October 2005 and was recorded in 2 of 12 photoquadrats sampled at SAN-02-05. *Dasycladus vermicularis*, however, was not among the algal species collected in September 2003.

SPECIMENS EXAMINED

SAN-01-05, BISH 748784, coll. K.N. Page, 10.0–13.1 m deep, 7 October 2005; SAN-02-05, BISH 748819, coll. K.N. Page, 12.8–13.7 m deep, 7 October 2005.

PACIFIC ISLAND DISTRIBUTION

Reyes (1976) and Ohba (1995) previously reported *Dasycladus vermicularis* in the Siquijor Province of the Philippines and Kerama Islands in the Ryukyus, respectively. The specimens from Santa Rosa Reef represent the first record from the Polynesia–Micronesia region. *Dasycladus vermicularis* is predominantly a Caribbean species and is known from Florida, Bahamas, Bermuda, Caicos Islands, Cuba, Jamaica, Trinidad, Greater Antilles, Gulf of Mexico and Brazil (Taylor, 1960; Littler & Littler, 2000).

New Micronesia record

Class PHAEOPHYCEAE

Cutleria irregularis I.A. Abbott & Huisman, 2003, 175, figures 7–15;
Abbott & Huisman, 2004, 226, figure 87A–D.

REMARKS

Specimens consist of fan-shaped fragments less than 5 mm long, brown and 60 μm thick in cross-section. Cross-sections show the distinctive single large medullary cell layer (36 μm thick), rectangular cells (12 μm thick) of the dorsal cortical layer and the elongated cells (12 μm thick) of the ventral cortical layer. The fact that *Cutleria irregularis* looks very similar externally to a thin immature *Lobophora variegata* (Lamouroux) Womersley ex Oliveira may be one reason why this species has not been reported earlier from Guam (Tsuda, 1972a) nor from other Micronesian islands and atolls.

SPECIMEN EXAMINED

SAN-02-05, BISH 748809, coll. K.N. Page, 12.8–13.7 m deep, 7 October 2005.

PACIFIC ISLAND DISTRIBUTION

Oahu and Hawaii in Hawaiian Islands (Abbott & Huisman, 2003); Johnston Atoll (Tsuda *et al.*, 2010a); Wake Atoll (Tsuda *et al.*, 2010b).

New Marianas records

Six of the other 30 algal species collected from Santa Rosa Reef represent new records for the Mariana Islands.

Phylum RHODOPHYTA

Dasya iyengarii Børgesen, 1937, 345, figures 16 & 17; N'Yeurt & Payri,
2010, 127, figures 258–261.

REMARKS

Central axes are predominantly uncorticated with the four pericentral cells clearly visible. A large rounded or angular cell occurs at the base of each lateral branch. The terminal ends of the lateral branches are incurved unlike lateral branches of *Dasya kristeniae* I.A. Abbott which are thrust outward. *Dasya iyengarii* also possesses 5 tetrasporangia per segment with each consisting of 2 cover cells as opposed to *D. kristeniae* with 4 tetrasporangia per segment with 3 cover cells.

SPECIMENS EXAMINED

SAN-02-03, BISH 748773, coll. P.S. Vroom, 11.6–13.4 m deep, 28 September 2003; SAN-01-05, BISH 748800, coll. K.N. Page, 10.0–13.1 m deep, 7 October 2005.

PACIFIC ISLAND DISTRIBUTION

Enewetak Atoll, Marshall Islands (Dawson, 1957; Gilmartin, 1960); Samoa (Skelton & South, 2007); Tahiti, Bora Bora, Austral Islands in French Polynesia (N'Yeurt & Payri, 2010).

Polysiphonia delicatula Hollenberg, 1968a, 62, figure 1F;
Abbott, 1999, 412, figure 120E.

REMARKS

This species is characterized by its predominantly prostrate axes, 30–36 μm diameter, with short erect axes less than 1.0 mm long and 24–32 μm diameter.

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SPECIMEN EXAMINED
SAN-02-03, BISH 748772, coll. P.S. Vroom, 11.6–13.4 m deep, 28 September 2003.

PACIFIC ISLAND DISTRIBUTION
Arno Atoll and Bikini Atoll in Marshall Islands, Yap State in Federated States of Micronesia, Tuamotu Islands in French Polynesia (Hollenberg, 1968a); Oahu, Kauai, French Frigate Shoals, Laysan and Necker in Hawaiian Islands (Abbott, 1999; Vroom *et al.*, 2006); Austral Islands in French Polynesia (N'Yeurt & Payri, 2010).

Polysiphonia homoia Setchell & N.L. Gardner, 1930, 162; Hollenberg, 1968b, 201, figure 2B; Abbott, 1999, 417, figures 122F–G.

REMARKS
Prostrate and erect axes, 100–126 μm diameter, consist of five elongated pericentral cells pit connected to adjacent cells in successive segments.

SPECIMENS EXAMINED
SAN-01-03, BISH 743282, coll. P.S. Vroom, 10.7–13.1 m deep, 28 September 2003; SAN-02-03, BISH 748776, coll. P.S. Vroom, 11.6–13.4 m deep, 28 September 2003.

PACIFIC ISLAND DISTRIBUTION
Hawaiian Islands (Hollenberg, 1968b); Baker Island (Tsuda *et al.*, 2008); Johnston Atoll (Tsuda *et al.*, 2010a); Wake Atoll (Tsuda *et al.*, 2010b).

Phylum CHLOROPHYTA

Neomeris mucosa M. Howe, 1909, 80, pl. 1 (figures 4 & 7), pl. 5 (figures 17–19); Littler & Littler, 2003, 264.

REMARKS
The specimen consists of a cluster of 5 sterile calcified plants, up to 1 cm tall. Upper surface cells possess the characteristic bulbous tips. See Figure 2 for habit of species at Santa Rosa Reef.

SPECIMEN EXAMINED
SAN-02-05, BISH 748818, coll. K.N. Page, 12.8–13.7 m deep, 7 October 2005.

PACIFIC ISLAND DISTRIBUTION
Arno Atoll, Marshall Islands (Dawson, 1956).

Rhipilia micronesica Yamada, 1944, 36, pl. vi (figures 1 & 2); Millar & Kraft, 2001, 23, figures 3, 9–12.

REMARKS
Specimen (BISH 748792) consists of a flat, uncalcified, felty blade, 30 mm long and 23 mm wide, with a 15 mm long and 3 mm wide stipe. Siphons are 16–20 μm diameter and cylindrical with lateral branches (up to 360 μm long) possessing mostly rounded apices or with two-prong or occasionally three-prong apices (tenacular). See Figure 2 for habit of species at Santa Rosa Reef.

SPECIMENS EXAMINED
SAN-01-03, BISH 743285, coll. P.S. Vroom, 10.7–13.1 m deep, 28 September 2003; SAN-02-03, BISH 748774, coll. P.S. Vroom, 11.6–13.4 m deep, 28 September 2003; SAN-01-05, BISH 748818, coll. K.N. Page, 10.0–13.1 m deep, 7 October 2005; SAN-02-05, BISH 748811, coll. K.N. Page, 12.8–13.7 m deep, 7 October 2005.

PACIFIC ISLAND DISTRIBUTION
Ant Atoll, Pohnpei State, Federated States of Micronesia (Yamada, 1944).

Udotea palmetta Decaisne, 1842, 380, pl. 17 (figure 15); Gepp & Gepp, 1911, 122, figures 10, 11 & 54; Dawson, 1956, 41, figure 28.

REMARKS
Flat calcified blade, 18–32 mm long and 22–35 mm wide, possess narrow (2 mm diameter) stipe 7–19 mm long. Siphons, 24–28 μm diameter, have short protuberances (16–20 μm long with rounded tips) on one side and uneven constrictions at the base of dichotomies.

SPECIMENS EXAMINED
SAN-01-03, BISH 743275, coll. P.S. Vroom, 10.7–13.1 m deep, 28 September 2003; SAN-02-03, BISH 748777, coll. P.S. Vroom, 11.6–13.4 m deep, 28 September 2003; SAN-01-05, BISH 748790, coll. K.N. Page, 10.0–13.1 m deep, 7 October 2005; SAN-02-05, BISH 748814, coll. K.N. Page, 12.8–13.7 m deep, 7 October 2005.

PACIFIC ISLAND DISTRIBUTION
Arno Atoll, Enewetak Atoll, Kwajalein Atoll, Majuro Atoll in Marshall Islands (Dawson, 1956, 1957); Chuuk State, Federated States of Micronesia (Tsuda, 1972b); Baker Island (Tsuda *et al.*, 2008). There is one report of *Udotea palmetta* from Agat Bay in Guam (Chernin *et al.*, 1977); the specimen, if collected, is not present in the GUAM Herbarium (Tom Schils, personal communication, 14 July 2011).

DISCUSSION

This study represents the second report of marine benthic algae from the submerged Santa Rosa Reef. Kolinski *et al.* (2005) listed 10 putative field-identified algal species (i.e. 9 green algae and 1 red alga) and at least 3 additional taxa identified only to genus that were observed by one of us (P.S.V.) on the submerged reef during the September NOAA–RAMP expedition in 2003. None of the 10 algal species reported represented new records for the Mariana Islands. Laboratory-based analyses completed during the study presented here on the voucher specimens collected during 2003 and 2005 NOAA–RAMP cruises confirmed field identifications of 6 species (i.e. *Caulerpa urvilleana* Setchell, *Dictyosphaeria cavernosa* (Forsskål) Børgesen, *D. versluysii* Weber-van Bosse, *Halimeda taenicola* W.R. Taylor, *Microdictyon okamurae* Setchell and *Liagora ceranoides* Lamouroux), but refuted the identifications of *Avrainvillea nigricans* Decaisne, *Boodlea composita* (Harvey) Brand, *Halimeda cylindracea* Decaisne and *Udotea argentea* Zanardini. Although the species of *Halimeda* and *Neomeris*

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left unidentified by Kolinski *et al.* (2005) were identified (see text and Appendix), the unidentified species of *Caulerpa* was not present among the voucher specimens.

The isolated and completely submerged nature of Santa Rosa Reef suggests that it is less likely to suffer from introduced species than islands with sustained high anthropogenic marine activities (e.g. harbour traffic and aquarium dumping). However, because recreational fishing boats are known to frequent the reef (PIFSC, 2010), it is possible that alien species could arrive via anchoring activities (Acosta & Forrest, 2009). Despite this possibility, the eight newly reported species discussed here have not been documented from Guam or other islands in the Mariana Islands, so the possibility of these species arriving with boats travelling from Guam is unlikely. Instead, it is hypothesized that these new records are naturally occurring species on Santa Rosa Reef, and possibly reflect a deeper water flora that may exist on other islands within the Mariana Islands that have not yet been extensively studied. Recent studies of deep-water habitats in the Hawaiian Islands have revealed a suite of newly reported algal species (Vroom, 2005; McDermid & Abbott, 2006; Bailey-Brock & Magalhães, 2010), and it is expected that many new taxa will be reported from other isolated islands in the Pacific once deeper water surveys are conducted.

The four newly reported green macroalgae (*Rhipilia micronesica*, *Udotea palmetta*, *Dasycladus vermicularis* and *Neomeris mucosa*) and the brown alga *Cutleria irregularis*, all of which grow on hard substrata, are not considered to be potentially invasive species that could harm reef ecosystems. In other areas of Micronesia or the Pacific where these species have been reported, they are not common components of most reef systems. The other 3 species, i.e. *Dasya iyengarii*, *Polysiphonia delicatula* and *P. homoia*, are small species that typically occur as epiphytes on larger algae such as *Halimeda*. The genus *Halimeda*, represented by *Halimeda taenicola* (Figure 2) and 4 other species at Santa Rosa Reef (Appendix), was the predominant algal genus in all collections made in 2003 and 2005. *Liagora ceranoides*, *Caulerpa urvilleana*, *Microdictyon okamurae* and an unidentified species of *Laurencia* (see Appendix and Figure 2) were among the predominant macroalgal species at Santa Rosa Reef.

The relatively low algal species diversity (i.e. 32 species) found on Santa Rosa Reef when compared to Guam (i.e. 332 species) is not surprising given the great disparity in their sizes (Losos & Ricklefs, 2009), differences in sampling effort and the significantly greater amount of habitat variability found on Guam as compared to Santa Rosa Reef. Nevertheless, Santa Rosa Reef represents one of many submerged banks and seamounts scattered across the Pacific Ocean that serve as crucial stepping stones allowing marine organisms to naturally, albeit slowly, disperse to new geographical locations.

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APPENDIX

Listing of 24 other marine algal species documented by voucher specimens collected on 28 September 2003 and 7 October 2005 by P.S. Vroom and K.N. Page, respectively, from submerged Santa Rosa Reef (located 46 km south-south-west of Guam)

Cyanobacteria

Calothrix confervicola (Dillwyn) C. Agardh. SAN-02-05, BISH 748815

Lyngbya sordida Gomont. SAN-02-03, BISH 748780

Scytonematopsis pilosa (Harvey ex Bornet & Flahault) I. Umezaki & M. Watanabe. SAN-01-05, BISH 748788; SAN-02-05, BISH 748817

Rhodophyta

Hypnea spinella (C. Agardh) Kützing. SAN-01-05, BISH 748798; SAN-02-05, BISH 748810

Jania capillacea Harvey. SAN-01-05, BISH 748785; San-02-05, BISH 748821

Laurencia cf. *majuscula* (Harvey) A.H.S. Lucas. SAN-01-05, BISH 748802

Laurencia sp. SAN-01-03, BISH 743272; SAN-02-03, BISH 748771; SAN-01-05, BISH 748787; SAN-02-05, BISH 748808

Liagora ceranoides Lamouroux. SAN-01-03, BISH 743277; SAN-01-05, BISH 748786; SAN-02-05, BISH 748886
Liagora sp. SAN-02-05, BISH 748805
Tolypiocladia glomerulata (C. Agardh) F. Schmitz. SAN-01-03, BISH 743283; SAN-02-05, BISH 748806 on *Halimeda opuntia*

Phaeophyceae

Dictyota ceylanica Kützing. SAN-01-05, BISH 748799; SAN-02-05, BISH 748820
Lobophora variegata (Lamouroux) Womersley ex Oliveira. SAN-02-03, BISH 748775; SAN-01-05, BISH 748794
Sphacelaria rigidula Kützing. SAN-02-05, BISH 748816

Chlorophyta

Anadyomene wrightii Harvey ex J.E. Gray. SAN-01-05, BISH 748801
Avrainvillea mazei Murray & Boodle. SAN-01-03, BISH 743280; SAN-01-05, BISH 749303
Caulerpa urvilleana Montagne. SAN-01-03, BISH 743274; SAN-02-03, BISH 748778; SAN-01-05, BISH 748791; SAN-02-05, BISH 748803
Dictyosphaeria cavernosa (Forsskål) Børgesen. SAN-01-03, BISH 743279; SAN-01-05, BISH 748783; SAN-02-05, BISH 748812
Dictyosphaeria versluysii Weber-van Bosse. SAN-01-03, BISH 743284; San-02-03, BISH 743287
Halimeda borneensis W.R. Taylor. SAN-02-03, BISH 748781; SAN-02-05, BISH 749304
Halimeda fragilis W.R. Taylor. SAN-02-03, BISH 743288; SAN-01-05, BISH 748795; SAN-02-05, BISH 748813
Halimeda opuntia Lamouroux. SAN-02-03, BISH 748799; SAN-02-05, BISH 748797
Halimeda taenicola W.R. Taylor. SAN-01-03, BISH 743273; SAN-02-03, BISH 743289; SAN-01-05, BISH 748789; SAN-02-05, BISH 748804
Halimeda tuna (Ellis & Solander) Lamouroux. SAN-02-03, BISH 748782
Microdictyon okamurae Setchell. SAN-01-03, BISH 743278; SAN-02-03, BISH 743286; SAN-01-05, BISH 748796; SAN-02-05, BISH 748807

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