Organizational Profiles

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Chapter 1

Reef corals of the northwestern lagoon of Grande-Terre, New Caledonia

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SU MMARY

- The northwestern lagoon area of New Caledonia has a diverse coral fauna. A total of 322 named species were observed during the present survey. This compares well with the total of 310 species reported for all of New Caledonia from all previous studies combined. It also compares well with the 303 species in the Calamianes Islands (Philippines); 315 in the Togian and Bangaai Islands, Sulawesi, Indonesia; 318 in Milne Bay, Papua New Guinea; and 331 in the Raja Ampat Islands of West Papua, Indonesia which the first author has found in similar marine rapid assessment program (RAP) surveys for Conservation International (CI).
- Species numbers at visually sampled sites ranged from 22 to 117, with an average of 63.8 per site. A similar study by the first author in the southwest lagoon of New Caledonia produced an average of 52.7 species per site. Previous CI RAP's with the same method and the first author as identifier have produced 70 species per site at N. Sulawesi, 92 species per site at Calamianes Islands, Philippines, 81 species per site at Milne Bay, Papua New Guinea and 87 species per site at Raja Ampats, Indonesia. The mean of 63.8 species per site compares well with the mean of 38.5 species per site found by Laboute (2006) in the northeast lagoon of New Caledonia. The mean of 54.9 species which the first author recorded is quite similar to the mean of 52.7 species per site which he found in the southwest lagoon in a previous study, providing little support for the suggestion that there is a north-south diversity gradient.
- *Acropora, Montipora*, *Favia*, and *Porites* were dominant genera on New Caledonia reefs, with 77 (including *Isopora*), 24, and 12 species, respectively; the number of *Acropora* species is very high in relation to other areas.
- A total of 61 species that had not been previously reported from New Caledonia were found. Six additional new records were found by the first author on a previous study of the southwest lagoon (Fenner, unpublished). These new records bring the total coral species known from New Caledonia to 377 species, just slightly less that the highest total (411) known from any country (the Philippines) in 1989.
- A total of 43 species were found that extend the known biogeographic range of the species. The most notable was *Acropora pharaonis*, a species described from the Red Sea and known from the Indian Ocean, but not from the Pacific until recently.
- The number of species on the outer slopes of the barrier reef tended to be higher than on other reefs; however, the highest number was recorded on fringing reefs around Yandé Island. The number of species tended to be less in the inshore reefs around the mainland. Reefs with smaller depth ranges tended to have fewer species of coral since deeper habitats were absent, and reefs nearer to shore had smaller depth ranges.
- The number of species tended to increase significantly northwards and away from the mainland which corresponds to a decrease in human impacts such as sediment and nutrient runoff and fishing activity. These trends were statistically significant.
- New Caledonia has the highest total number of coral species known of any similar size area in the southwest Pacific, probably due to more study based on compiled results

including this survey. The numbers of species found in one and 10 dives are similar to other areas in the South Pacific.
- We recommend reducing sediment runoff that is killing near shore reefs by re-vegetating mining areas.

INTRODUCTION

Hard corals are a critical component of coral reefs worldwide. Coral reefs have the highest diversity known in marine ecosystems. Corals contribute to the build-up of the calcium structure of coral reefs (along with certain algae) and are critical to holding them together. Further, corals are a primary constructor of habitat on coral reefs, providing the hiding places needed for fish habitat, living spaces for many commensal species, and the carbonate reef material which is the habitat of large numbers of cryptic species, and the attachment surface for many other sessile organisms. Corals are highly vulnerable to a range of disturbances, many of which are caused by humans, and are undergoing rapid declines in many parts of the world.

Many corals can now be identified alive on coral reefs, due to field identification guidebooks such as Veron (1986, 2000) and taxonomic revisions such as those by Hoeksema (1989) and Wallace (1999). Field identification has the advantage that one is able to see the entire colony, and often many colonies, while identification from collected specimens often must be based on small samples that don't show the range of variation. The number of species is less than that for fish, but the difficulty of identification is greater due to greater variation within species. However, field identification is much easier than groups such as sponges or ascidians, which would require extensive collecting and years of museum work to identify.

The coral reefs and reef fauna of New Caledonia have been the subject of a considerable amount of study. Currently, New Caledonia has the highest known number of marine species (of all types, not just corals) of any coral reef area in the world. Some 8,783 species are currently known from New Caledonia (Payri and Richer de Forges 2006) compared to about 7,000 in Hawaii (including all marine species: Eldredge and Evenhuis 2003), 5,640 species in Guam (Paulay 2003), 4,671 species in Enewetok (Devaney et al. 1987), 2,876 in French Polynesia (Richard 1985), and 2,705 species in American Samoa known so far (Fenner et al. 2008). Even in New Caledonia the number of reef species currently known is almost surely a tiny fraction of the total diversity present (Reaka-Kudla 1995; Bouchet et al. 2002). The total number currently known is likely to be proportional to the total amount of collecting and taxonomic effort and the number of specialists who have studied the area. Hawaii clearly has much less diversity than New Caledonia (seen in individual groups like corals and fish), yet has nearly as many total species known, likely due to a larger amount of total effort there. In fact, Hawaii has a lower diversity than all the other sites mentioned above, yet has a higher total number of species currently known except for New Caledonia.

A considerable amount is known about the diversity of types of reefs in New Caledonia as well (e.g., Laboute and Richer de Forges 2004; Andréfouët et al. 2006; Lasne 2007; Wantiez et al. 2007). New Caledonia has the world's longest continuous barrier reef, plus many other types of reefs such as fringing reefs, patch reefs, double barrier reefs, and so on. Because different species have different habitat requirements, total diversity may be proportional to habitat diversity to some degree, as well as biogeographic location, total area (species-area effect) and so on.

In a review of the reefs and corals of New Caledonia, Lasne (2007) concluded that the diversity of corals decreased with proximity toward the shore of Grande-Terre, due to the sediment coming from that island. In addition, he commented that there was a latitudinal gradient with higher diversity toward the north and lower diversity toward the south. The present data set will be examined for these trends.

Pichon (2006) listed all the coral species known from previous studies of the corals of New Caledonia. A total of 310 species were reported there. Laboute (2006) reported the results for corals from a CI RAP at 44 sites in the northeastern reefs of Grande-Terre, New Caledonia where corals were not collected in compliance with tribal regulations for that survey area. He reported 196 named corals species plus 82 species that were not identified to species. This included three named species not reported in the Pichon (2006) summary. Fenner (unpublished) studied coral species in the southwestern area near Noumea in 10 dives in 2006. A total of 182 named species were recorded, including 28 species not reported in the Pichon (2006) summary. An average of 52.7 coral species were recorded per site in that study. Samples could not be collected for verification.

The following is a report of the reef coral fauna of the 62 sites in the northwestern lagoon of Grande-Terre, New Caledonia based on results of the authors' observations and collections during Conservation International's RAP in November – December 2007.

The principle aim of the coral survey was to provide an inventory of the coral species growing on reefs and associated habitats and to compare the coral fauna at different sites. The primary group of corals is the zooxanthellate scleractinian corals, that is, those that contain single-cell algae and which contribute to building the reef. Also included are a small number of zooxanthellate non-scleractinian corals which also produce large skeletons which contribute to the reef (e.g., *Millepora*: fire coral), a small number of azooxanthellate scleractinian corals (*Tubastraea*), and a small number of azooxanthellate non-scleractinian corals (*Distichopora* and *Stylaster*). All produce calcium carbonate skeletons that contribute to reef building to some degree.

The results of this survey facilitate a comparison of the faunal richness of New Caledonia with parts of southwest Pacific and adjoining regions. However, the list of corals presented below is still incomplete, due to the time restriction of the survey (62 dives), the fact that most of New Caledonia was not studied, the highly patchy distribution of corals and the difficulty in identifying some species in the water. Corals are sufficiently difficult to identify that there are significant differences between leading experts on some identifications.

METHODS

Coral diversity and abundance was surveyed at each of the 62 sites using one SCUBA dive of 50 to 80 minutes duration. A direct descent was made in most cases to the base of the reef, to or beyond the deepest coral visible. The bulk of the dive consisted of a slow ascent along the reef in a zigzag path to the shallowest point of the reef or until further swimming was not possible. Sample areas of all habitats encountered were surveyed, including sandy areas, walls, overhangs, slopes, and shallow reef. Areas typically hosting few or no corals, such as grass beds and mangroves, were not surveyed. Corals were usually identified *in-situ* however, where an identification could not be made rapidly, a photograph or small sample was taken. Coral species and their abundance data were recorded on an underwater slate or printed form. The abundance measures used in the survey were: "R" for rare, "U" for uncommon, "C" for common, "A" for abundant, and "D" for dominant. Many corals can be identified to species with certainty in the water and a few must be identified alive since they cannot be identified without living tissues. In addition, there are some that are easier to identify alive than from skeletons. Several field guides assisted identification (Wallace 1999; Veron 2000). However, there are species that normally require collection for verification. Samples of species that have not been previously reported from New Caledonia, or could represent new species were collected at many sites, within the time limits of the RAP survey. Samples were later bleached in household bleach solution then rinsed in freshwater, dried and returned to the laboratory for identification. Additional references used in identifying corals from skeletons and in the field are listed in references (Boschma 1959; Veron and Pichon 1976, 1980, 1982; Dineson 1980; Veron, Pichon and Wijman-Best 1977; Hodgson and Ross 1981; Moll and Best 1984; Randall and Cheng 1984; Hodgson 1985; Veron 1985, 1986, 1990a, 2000; Nemenzo 1986; Nishihira 1986; Dai 1989; Hoeksema 1989; Claereboudt 1990; Best and Suharsono 1991; Hoeksema and Best 1991, 1992; Sheppard and Sheppard 1991; Dai and Lin 1992; Ogawa and Takamashi 1993; Wallace 1994, 1997a; Veron and Nishihira 1995; Suharsono 1996; Cairns and Zibrowius 1997; Wallace and Wolstenholme 1998; Razak and Hoeksema 2003; Fenner 2005).

Wallace et al. (2007) have found evidence that the subgenus *Isopora* of the genus *Acropora* deserves to be elevated to the level of genus, and the authors have followed this. Differences in nomenclature for a few *Acropora* have been indicated in text tables and the appendix. The species long referred to as *A. formosa* has been designated as type species (*A. muricata*) for the genus *Acropora* by Wallace (1999) and designated as a neotype. A species which Veron (2000) refers to as *A. nobilis* is referred to as *A. intersepta* by Wallace (1999). Veron (2000) treats *A. spathulata* as a junior synonym of *A. millepora*, but Wallace (1999) treats it as valid, in part based on the reproductive incompatibility of these two (Willis et al. 1997). The authors find the distinction clear in the field and treat *A. spathulata* as valid. Veron (2000) considers *A. rosaria* to be valid, but Wallace (1999) considers it to be similar to *A. loripes*. Veron (2000) considers *A. akajimensis* to be valid, but Wallace (1999) considers it to be a junior synonym of *A. donei*. Veron (2000) considers *A. copiosa* to be valid, while Wallace (1999) considers it to be a junior synonym of *A. muricata*. Veron (2000) considers *A. insignis* to be valid, but Wallace (1999) considers it unresolved. The authors have elected to distinguish these species in this report, while noting the possible synonyms. Recording these as separate allows those in the future to maintain those distinctions without data loss, or to consider them as synonyms and lump them as they wish. The nomenclature of Veron (2000) has been followed for Fungiids, though the illustrations and descriptions in Hoeksema (1989) were the primary source for actual identification. The nomenclatures of these two authors differ primarily at the level of genera and sub-genera, not species. One species named after Hoeskema's (1989) publication, *Podabacia motuporensis*, was recognized, as was one species (*Herpolitha weberi*) synonymized (with *H. limax*) by Hoeksema. As with the *Acropora* species, recording these separately allows the distinction of these species from congeners to be continued or discontinued in the future.

Statistical analysis and plotting of results was conducted using the computer packages Microsoft Excel and SPSS. For each site the distance to the mainland was calculated using the computer mapping program C-Map, the distance northwards was calculated in nautical miles from the latitude 20°S, while the distance eastwards was calculated in nautical miles from the longitude 163°E. Cluster analyses were conducted on species presence data using the similarity index:

$$\frac{\text{\# species in sites a and b}}{\text{\# species in sites a or b}}$$

This index is well suited to species presence data where there are many species which only occur in a small proportion of the sites.

RESULTS AND DISCUSSION

A total of 322 named species and 72 genera of stony corals (312 species and 67 genera of zooxanthellate Scleractinia) were found in the northwest New Caledonia RAP, (Appendix 1). Almost all of these species are illustrated in Veron (2000) and *Acropora* are illustrated in Wallace (1999) and

Fungiids are illustrated in Hoeksema (1986). The total of 322 species compares well with the 310 species reported for all of New Caledonia by Pichon (2006), based on all previous studies combined. It also compares well with the 196 named species and 82 unnamed species reported from the northeastern lagoon of Grande-Terre by Laboute (2006). Further, it also compares well with other CI RAP locations using the same methodology: 303 species in the Philippines RAP, 315 sp. in Sulawesi, 318 in Milne Bay, Papua New Guinea (PNG), and 331 in Raja Ampats, even though these sites were in the area of highest diversity, and New Caledonia is considered outside that area.

A mean of 63.8 species per site was found in this study across all sites. This compares well with the mean of 38.5 species per site found by Laboute (2006) in the Mont Panié area or northeastern lagoon of Grande-Terre. This difference may be due any combination of several factors, such as different reef habitats in the two areas, differing identification skills, and the fact that in this study collecting was allowed so species could be verified (whereas no collecting occurred in the Mt. Panié survey of the northeastern lagoon).

The mean of 54.9 species per site found by the first author is very close to the mean of 52.7 species per site found by the same author in 10 dives in the southwest lagoon of Grande-Terre off Noumea in 2006. This difference is not significant ($t = 0.51$, $p = .61$). Seventy-four species were found on the outer barrier reef slope per dive in the southwest, compared to 77 in the northwest, but this is based on only one dive in the southwest and two in the northwest, so the difference is not significant. Lasne (2007) suggested that there is a latitudinal gradient with higher diversity in the north and lower diversity in the south. If so, the differences are too small to be detected reliably in this study.

General faunal composition

The coral fauna consists mainly of Scleractinia. The genera with the largest numbers of species found were *Acropora, Montipora, Porites, Favia, Pavona, Fungia, Goniopora, Goniastrea, Psammocora, and Turbinaria.* These 10 genera account for about 52% of the total observed species (Table 1.1). There were 18 families of corals found, with the largest families being Acroporidae with 107 species, Faviidae with 65 species, Fungiidae with 21 species, Poritidae with 18 species, Agariciidae with 20 species, and Mussidae with 20 species.

The order of the most common genera is fairly typical of Western Pacific reefs, with a few minor differences- *Acropora, Montipora*, and *Porites* are the three most species-rich genera. The farther down the list one moves, the more variable the order becomes, with both the number of species and the differences between genera decreasing.

Most of the corals were zooxanthellate (algae-containing, reef-building) scleractinian corals, with 97% of the coral species in this group. There were two species (*Tubastraea*) that were azooxanthellate (lacking algae) Scleractinia for 0.6% of the total. Also there were seven corals that were not Scleractinia, for 2% of the total. Of those that were not Scleractinia, five were zooxanthellate (*Millepora*) and two were azooxanthellate (*Distichopora* and *Stylaster*).

These species were in 72 genera, including 67 genera of zooxanthellate Scleractinia. These in turn were in 18 families, 16 of which are zooxanthellate Scleractinia.

Diversity at individual sites

Sites 37, 17, and 1 had the highest species richness, with 117, 111 and 109 species, respectively (Table 1.2). Sites 30, 29, and 72 had the lowest species richness, with 22, 27 and 30 species (Table 1.3).

Species were added to the list at a slow but relatively steady rate after about 10 sites, indicating that sufficient sites were surveyed (Figure 1.1).

A total of 77 *Acropora* species (including *Isopora*) were recorded in this study which is high relative to other reef areas of the world. For example, the highest number of *Acropora* species recorded after a world wide analysis by Wallace (2001) was 78 in the Togian Islands, Indonesia which is in the heart of the "coral triangle" of highest coral diversity. However, exact comparison of our results is difficult since this analysis was conducted according to the taxonomic

Table 1.1. Genera with the most species, in order of decreasing number of species per genus. *Acropora* includes one species not identified to species, and does not include *Isopora*.

	Genus	Number of Species
1.	*Acropora*	73
2.	*Montipora*	24
3.	*Favia*	15
4.	*Porites*	12
5.	*Pavona*	11
6.	*Turbinaria*	9
7.	*Goniastrea*	8
8.	*Fungia*	7
9.	*Psammocora*	7

Table 1.2. Most diverse sites surveyed. Site number with corresponding number of species is reported.

Site	Number of Species
37	117
17	111
1	109
7	107
36	105
9	100
59	99
3	99
26	95
38	94

review of Wallace (1999) which recognized 113 valid species in the genus. Since that review, Veron (2001) has introduced a large number of new or previously synonymised (i.e. discarded) species and recognizes a total of 167 valid species. Since the latter scheme has been used in this study, comparison with Wallace's (2001) global maximum is not possible here. Compared with other well known high diversity areas which have been surveyed using Veron's scheme the figures for New Caledonia are still quite high. For example, Veron (2002) reported 95 species in the genus in Raja Ampats of West Papua, Indonesia, and Veron and Turak (2006) reported 124 species in the Solomon Islands.

Table 1.3. Total number of coral species recorded at each site.

Site	Number of Species	Site	Number of Species	Site	Number of Species
1	109	29	27	57	67
2	91	30	22	58	93
3	99	31	34	59	99
4	45	32	61	60	80
6	93	33	76	61	66
7	107	34	45	62	67
9	100	35	64	63	47
10	51	36	105	64	33
11	82	37	117	65	41
12	61	38	94	69	73
13	68	40	37	72	30
14	68	41	63	73	33
16	78	42	60	74	49
17	111	43	63	79	76
18	71	45	69	80	78
19	73	47	53	83	64
20	62	48	53	84	56
22	50	49	72	85	74
24	75	51	54	86	60
26	95	52	49	87	42
28	53	56	60		

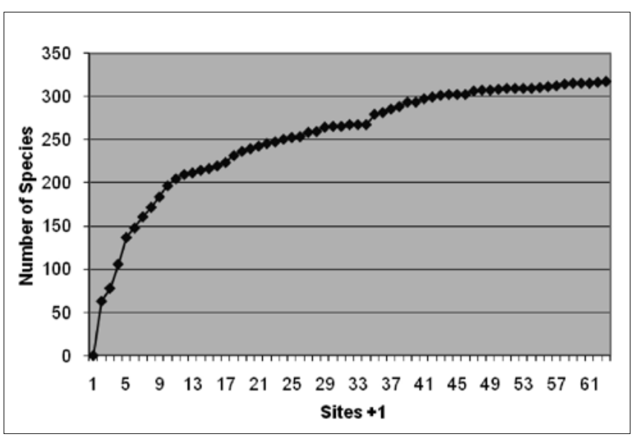

Figure 1.1. Cumulative total number of coral species over the course of the survey. Sites are listed on the x axis in order of time surveyed (sites + 1).

SPECIES OF SPECIAL INTEREST

New records

Pichon (2006) reported that a total of 310 coral species have been reported from all of New Caledonia in all previous studies combined. Laboute (2006) reported nine species not reported by Pichon (2006). They were probably not included in Pichon's list because they were not confirmed by skeleton examination as collection was not permitted. Six of the species were "cf.", indicating that the identification was not certain, and one was identified only to genus (Table 1.4).

In the present study, Fenner found 52 species not reported in Pichon (2006), 44 of which were supported by the identification of samples collected plus photographs (Table 1.5), and eight of which were supported only by photographs. Three of those species were also found by Muir. A total of 22 species were found by Muir that were not reported in Pichon (2006), including eight not found by Fenner. In 10 dives in the southwestern lagoon of Grande-Terre in November 2006, Fenner found a total of 28 species not reported in Pichon (2006), six of which were not found in the present study (Table 1.6). Thus, in the present study a total of 61 species were found that were not reported by Pichon (2006). The previous study by Fenner of the southwest lagoon adds six additional species found in neither Pichon (2006) nor the present study. Laboute (2006) reported three species which have not been reported in any other study. Something resembling *Astreopora moretonensis* was found by Fenner in this study, but a small sample did not confirm the species. Therefore, just two of the Laboute (2006) species are added to the total here making 379 the total number of coral species now known from New Caledonia. Even in areas where a fauna is well-studied, if a new person searches an area that has not been searched before, there is a high probability of finding additional species. Several years ago (Veron and Hodgson 1989), the largest number of coral species known from any country in the world was the 410 species documented in the Philippines. Although over 500 species are now known from Indonesia, the number of species known in New Caledonia

Table 1.4. Species noted by Laboute (2006) during the Mount Panié RAP survey and not reported by Pichon (2006).

1.	*Acropora* cf. *granulosa*
2.	*Astreopora* cf. *moretonensis*
3.	*Dendrophylila* sp.*
4.	*Oulophyhllia* cf. *bennettae*
5.	*Porites* cf. *annae*
6.	*Psammocora* cf. *profundacella?*
7.	*Psammocora* cf. *superficialis*
8.	*Tubastraea micranthus*
9.	*Turbinaria frondens**

* not found in present study

Table 1.5. New records for New Caledonia, confirmed from samples, except as otherwise indicated.

1.	*Stylophora subseriata*^
2.	*Montipora capitata*^
3.	*Montipora malampay*^
4.	*Montipora stellata*^
5.	*Montipora verruculosus*^
6.	*Acropora akajimensis*^ ?(j.s. of *A. donei*)
7.	*Acropora anthocercis**
8.	*Acropora copiosa*^
9.	*Acropora echinata**^
10.	*Acropora granulosa**^+
11.	*Acropora insignis*^
12.	*Acropora nana**^
13.	*Acropora halmaherae*^ (?j.s. of *A. parlis*)
14.	*Acropora pharonis*^
15.	*Acropora retusa*^
16.	*Acropora rosaria*^ (?j.s. of *Acropora loripes*)
17.	*Acropora spathulata*^* (?j.s. of *Acropora millepora)*
18.	*Acropora speciosa**^
19.	*Acropora torresiana*^#
20.	*Isopora crateriformis*^*#
21.	*Astreopora randalli*^
22.	*Euphyllia paraancora*^#
23.	*Galaxea longisepta**#
24.	*Galaxea paucisepta**^
25.	*Pseudosiderastrea tayami*^
26.	*Psammocora profundacella**^+
27.	*Psammocora superficialis**^+
28.	*Pavona bipartita*^
29.	*Pavona chiriquensis*^
30.	*Pavona duerdeni*^
31.	*Leptoseris incrustans*^
32.	*Pachyseris gemmae*^*
33.	*Herpolitha weberi**^#
34.	*Lithophyllon undulatum*^
35.	*Podabacia motuporensis*^
36.	*Echinomorpha nishihirai*^#
37.	*Hydnophora grandis*^*
38.	*Acanthastrea hemprichii*^
39.	*Lobophyllia diminuta**#
40.	*Symphyllia hassi*^
41.	*Lobophyllia robusta*^
42.	*Cyphastrea decadea*^
43.	*Echinopora pacificus*^
44.	*Favia helianthoides*^*#
45.	*Favia truncates*^*#
46.	*Favia veroni**#
47.	*Goniastrea minuta*^
48.	*Leptastrea bottae*^*
49.	*Montastrea salebrosa**
50.	*Oulophyllia bennetae**^#+
51.	*Platygyra* cf. *acuta**#
52.	*Platygyra ryukuensis**#
53.	*Porites annae*?^+
54.	*Tubastraea micranthus*+#
55.	*Turginaria irregularis*^
56.	*Millepora dichotoma*^
57.	*Millepora exaesa*^
58.	*Millepora intricata*^
59.	*Millepora murrayi*^
60.	*Millepora platyphylla*^#
61.	*Stylaster* sp.^

^ Found by D. Fenner
* Found by P. Muir
# Photo taken, but no specimen collected
+ Also reported by Laboute (2006)
? j.s. Indicates possible junior synomyn

Table 1.6. New records recorded by Fenner in November, 2006 in the southwest lagoon of Grande Terre, supported by photos.

1.	*Sylophora subseriata*
2.	*Acropora akajimensis* (?j.s. of *A. donei*)
3.	*Acropora insignis*
4.	*Acropora parlis* (?s.s. of *A. halmaherae*)
5.	*Acropora pharaonis*
6.	*Acropora speciosa*
7.	*Astreopora cucculata**
8.	*Astreopora randalli*
9.	*Montipora cactus**
10.	*Montipora capitata*
11.	*Montikpora stellata*
12.	*Psammocora profundacella*+
13.	*Pachyseris gemmae*
14.	*Pavona duerdeni*
15.	*Podabacia motuporensis*
16.	*Sandalolitha dentata**
17.	*Galaxea paucisepta*
18.	*Acanthastrea hemprichi*
19.	*Acanthastrea ishigakiensis**
20.	*Lobophyllia robusta*
21.	*Cyphastrea decadea*
22.	*Goniastrea minuta*
23.	*Hydnophora grandis*
24.	*Rhizopsammia verrilli**
25.	*Tubastraea diaphana**
26.	*Millepora dichotoma*
27.	*Millepora intricata*
28.	*Millepora murrayi*

* not recorded in the present study
? j.s. indicates possible junior synomyn
? s.s. indicates possible senior synomyn

is very high, and the rate at which additional species is being found is very high. It is highly probable that additional searching will reveal more species.

Range extensions

Range extensions were determined by consulting the range maps in Hoeksema (1989), Wallace (1999), and Veron (2000). A range extension was recorded if New Caledonia was outside the indicated range for the species in all three sources. Ranges of possible senior synonyms were not used. A total of 43 range extensions were recorded (Table 1.7).

Table 1.7 Range extensions for coral species of New Caledonia. These are species for which New Caledonia is outside their range as indicated in Veron (2000), Wallace (1999) and Hoeksema (1989).

1.	*Stylophora subseriata*
2.	*Acropora akajimensis* (?j.s. of *A. donei*)
3.	*Acropra halmaherae* (?j.s. of *A. parlis*)
4.	*Acropora pharaonis*
5.	*Acropora retusa*
6.	*Acropora spathulata* (?j.s. of *A. millepora*)
7.	*Acropora tenella*
8.	*Acropora torresiana*
9.	*Anacropora reticulate*
10.	*Astreopora randalli*
11.	*Montipora malampaya*
12.	*Montipora stellata*
13.	*Montipora verruculosus*
14.	*Goniopora fruiticosa*
15.	*Porites* cf. *arnaudi*
16.	*Porites evermanni sensu* Veron 2000
17.	*Coscinaraea monile*
18.	*Psammocora explanulata*
19.	*Psammocora nierstraszi*
20.	*Coeloseris mayeri*
21.	*Leptoseris foliosa*
22.	*Pachyseris gemmae*
23.	*Herpolitha weberi* (?j.s. of *H. limax*)
24.	*Lithophyllon undulatum*
25.	*Galaxea longisepta*
26.	*Galaxea paucisepta*
27.	*Echinomorpha nishihirai*
28.	*Acanthastrea hemprichii*
29.	*Lobophyllia robusta*
30.	*Symphyllia hassi*
31.	*Cyphastrea japonica*
32.	*Favia maxima*
33.	*Favia truncatus*
34.	*Goniastrea minuta*
35.	*Goniastrea palauensis*
36.	*Leptastrea bottae*
37.	*Platygyra acuta*
38.	*Euphyllia ancora*
39.	*Euphyllia divisa*
40.	*Heterocyathus aequicostatus*
41.	*Heteropsammia cochlea*
42.	*Turbinaria irregularis*
43.	*Turbinaria heronensis*

?j.s. indicates possible junior synomyn

Perhaps the most notable range extension is *Acropora pharaonis*. This species was described from the Red Sea. Although there are reports of *A. pharaonis* in the Indian Ocean (Wallace, 1999; Veron, 2000), Wallace (1999) had seen no samples from the Indian Ocean and remarked that it appears to be restricted to the Red Sea. Fenner (2007) reported it first in Fiji where it was found at a number of sites, and samples collected. He has also found and collected *A. pharaonis* in American Samoa. Although it does not display the table form seen in the Red Sea, it does have colonies with a single narrow stem and diverging main branches that show some resemblance to the photograph of a large colony in the Red Sea in Sheppard and Sheppard (1991). Individual branches look exactly like individual branches from the Indian Ocean shown in Veron (2000). All of the details of axial and radial corallites and coenosteum are consistent with the descriptions of *A. pharaonis* in Sheppard and Sheppard (1991), Wallace (1999) and Veron (2000). The most similar species appear to be *A. grandis* which has much shorter radial corallites down the branch and a more indeterminate arborescent form, and *A. echinata*, which has much longer incipient axial corallites forming a more hispidose (i.e. bottle-brush shaped) colony.

Many coral species are threatened to various degrees by human activities as well as natural disturbances. Species in the genera *Acropora*, *Millepora*, and *Pocillopora* are particularly vulnerable to mass coral bleaching, perhaps the greatest threat to corals in the century. In addition, many *Acropora* have relatively fragile branching forms susceptible to damage from hurricanes, are particularly vulnerable to disease, and are one of the preferred prey items of the crown-of-thorns starfish. Two species of *Acropora* in the Western Atlantic which were once dominant on many reefs have declined so precipitously that they are currently listed as endangered species under the United States Endangered Species Act. The genus *Acropora* has more species than any other coral genus, and often is the most abundant genus on a reef. A recent report found that one third of all reef building corals face an elevated risk of extinction (Carpenter et al. 2008). A total of 74 species of *Acropora* were recorded in this study (77 if Isopora is included), a very high number, and at many sites the genus was very common. Thus, the coral communities in northwest New Caledonia are particularly vulnerable to disturbances, including global warming.

No coral species are known to be endemic to New Caledonia and most coral species found there have wide ranges. Two species were found that have smaller ranges than most coral species. *Acropora torresiana* is known only from the northern Great Barrier Reef (GBR), but a photo of a single colony in this survey matches the description. No sample was taken, as only a single colony was sighted. New Caledonia is the type locality for *Cantharellus noumeae*, and the range for this species extends to the Great Barrier Reef and

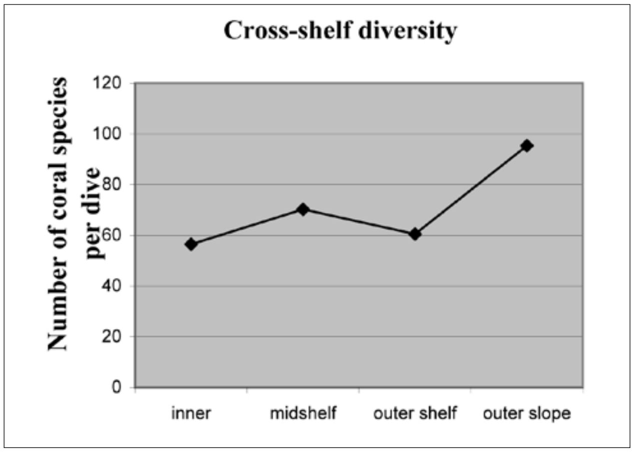

Figure 1.2. Average number of coral species per dive with increasing distance from Grande-Terre. For inner reefs, n = 13, for midshelf n = 23, for outer shelf n = 17, and for outer slope n = 8. Site 64 was excluded because it was a pass in the outer reef with a low diversity unlike all outer reef slope sites.

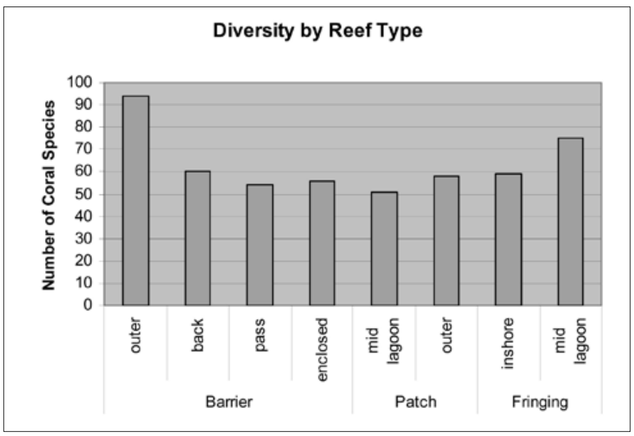

Figure 1.3. The number of coral species by reef types based on the geomorphology (Andréfouët and Torres-Pulliza 2004). Number of coral species are an average of 9 sites for outer barrier, 8 for back, 5 for pass, 3 for enclosed, 3 for mid lagoon patch, one for outer lagoon patch, 19 for inshore fringing, and 14 for mid lagoon fringing.

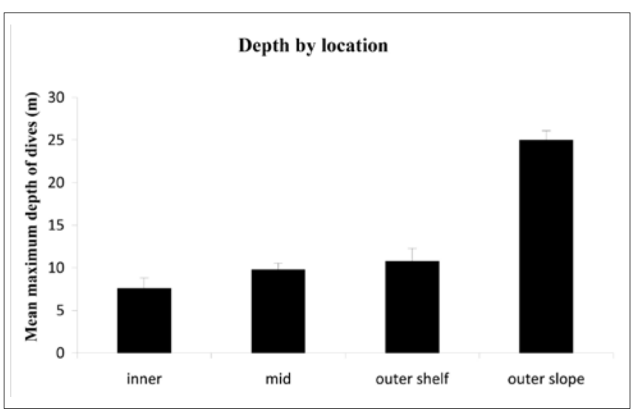

Figure 1.4. Location of sites with the mean maximum depth of dives in meters (m) reported with standard error. For inner lagoon (inner), n = 14; mid lagoon (mid) n = 22; outer shelf n = 18; for outer slope n = 8 with total n = 62.

northern New Guinea. On the west coast of Australia and in the Red Sea there are corals that appear to be in this species but have some differences.

Habitat Effects and Spatial Patterning

Lasne (2007) reported that coral diversity is lower near the shore of Grand-Terre than farther from the shore. He also suggested that this may be due to the higher sedimentation near shore. The sites in this study are located in different areas of the northwestern lagoon of Grande-Terre. Some were located at fringing reefs near the shores of Grande-Terre. Others were located in the lagoon between Grande-Terre and the outer barrier reef. Still others were located just inside the barrier reef, and finally a few were located on the outer slope of the barrier reef. The average number of coral species per dive found on reefs close to Grande-Terre was 56.5 compared to 95.4 on the outer slopes of the barrier reef, (Figure 1.2).

In Figure 1.3, finer distinctions between different reef types were made based on geomorphological data of the area provided by Andréfouët. Once again, the outer barrier reefs have higher diversity than most other types of reefs. Among fringing reefs, diversity increases with distance from Grande-Terre, with outer fringing reefs having the highest diversity of all reefs. This is consistent with the view that diversity increases with distance from Grande-Terre.

Reefs near Grande-Terre have smaller depth ranges than farther from land (Figure 1.4). Some coral species have depth preferences with certain coral species only found in deeper water. It could be that reefs that have a very narrow depth range and do not extend into deep water, have fewer corals because those deepwater habitats are not present. To examine this possibility, the relationship between the depth range and number of coral species was plotted for all sites (Figure 1.5).

The correlation between depth range and number of species was moderate, $r = 0.44$, but highly significant, $p < 0.0001$. Thus, the depth range at the reefs helps determine the number of species present and since the depth ranges of reefs near shore are less than farther offshore, there are fewer species near shore.

Another variable that could influence diversity is sedimentation. Near shore sites appeared to have high sedimentation levels and some sites had many dead colonies and other colonies that appeared stressed.

Turbidity was significantly correlated with coral species richness (Figure 1.6) such that as turbidity went down (and visibility went up), the number of coral species increased ($r = 0.52$, $p < 0.0001$). Sedimentation can kill corals and dead corals were observed at some fringing reefs along Grande-Terre during the survey. Water turbidity reduces light that the corals require and sedimentation acts as a stressor on corals that can impair growth and reproduction. Eventually this can lead to local extinction of some coral species. Quantitative diversity measures like Shannon-Wiener Index H’ are likely to show this even more clearly, as they are sensitive to the numbers of individuals of each species present. Site spe-

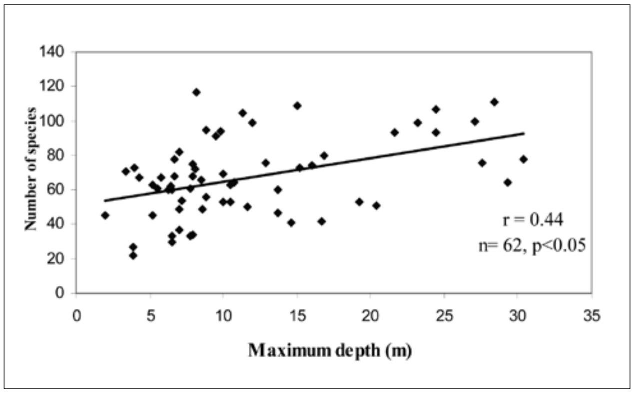

Figure 1.5. Scattergram of correlation ($r = 0.44$, $p < 0.05$) between maximum depth in meters (m) and number of species per site ($n = 62$).

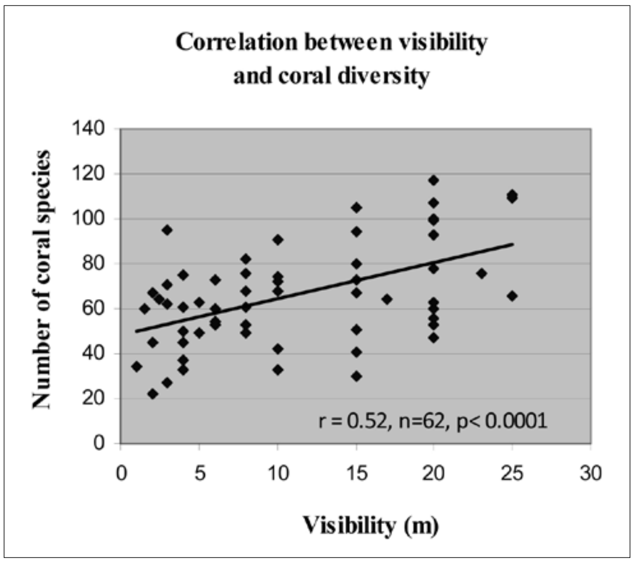

Figure 1.6. Scattergram of the correlation ($r = 0.52, p < 0.0001$ between visibility in meters (m) and corresponding number of coral species recorded by site where $n = 62$.

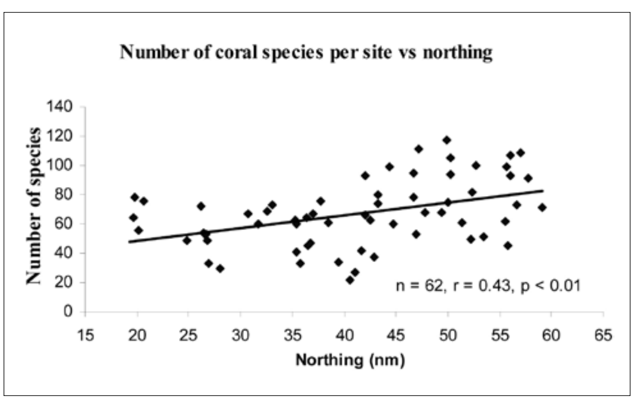

Figure 1.7. Plot of coral diversity (number of species per site) vs distance northwards for each site sampled ($n = 62$). Distance in nautical miles(nm) northwards was calculated from latitude 21°S using the GPS derived site latitudes. There was a significant trend ($p < 0.01$) of increasing diversity northwards.

cies lists as in the present study do not record a decrease in diversity until the last individual of a species dies. Thus, the present correlation is consistent with the view that sediment not only is killing corals near the shore but also can reduce coral diversity farther out from shore.

The results of this study concur with the report by Lasne (2007) that coral diversity is lower near the shore of Grand-Terre than farther away and that the highest diversity is on the outer barrier reef slope. Lasne (2007) indicates that this is most likely due to the smaller depth range of reefs near Grande-Terre than outer reefs, not to the higher sediment levels near Grande-Terre. One of the highest diversity sites was a fringing reef site at Yandé Island located in the mid-lagoon area. However, Yandé Island is a much smaller island with very few inhabitants compared to Grande-Terre. Further, no mining has taken place in Yandé. Even though the reef is close to the shore of Yandé, it is not subject to heavy sedimentation levels.

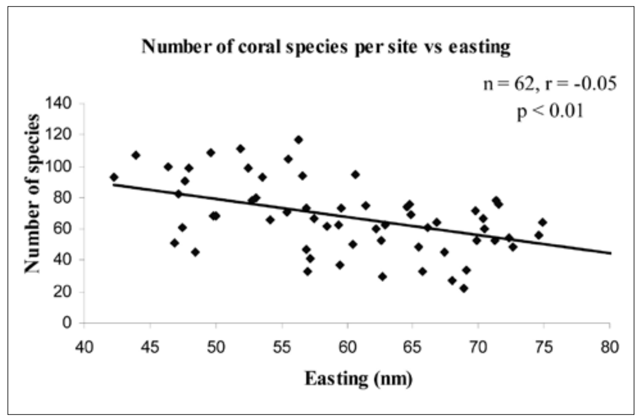

Figure 1.8. Plot of coral diversity (number of species per site) vs distance eastwards for each site sampled ($n = 62$). Distance in nautical miles (nm) eastwards was calculated from longitude 163°E using the GPS derived site longitudes. There was a significant trend ($p < 0.01$) of decreasing diversity eastwards.

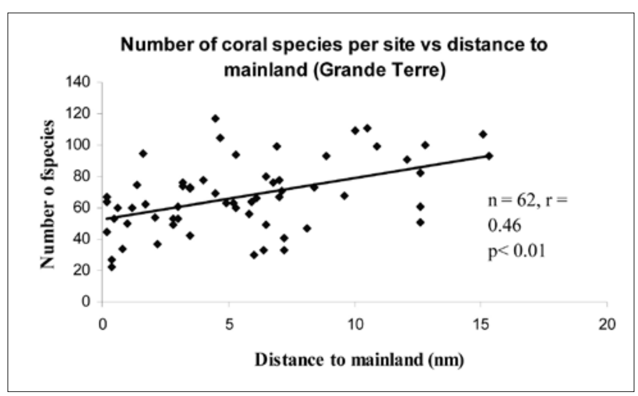

Figure 1.9. Plot of coral diversity (number of species per site) *vs* distance from the mainland for each site sampled ($n = 62$). For each site the distance in nautical miles (nm) to the closest point on the mainland (Grande Terre) was estimated using the C-Map electronic chart system. There was a significant trend ($p < 0.01$) of increasing diversity away from the mainland.

Trends for increasing coral diversity towards the northwest and away from the mainland are evident. Statistical analysis confirmed that these trends were significant: the total number of coral species was significantly correlated with the distance to the north (Figure 1.7, $F = 13.65$, $DF = 1$ by 60, $p < 0.01$) and was also significantly negatively correlated with the distance to the east (Figure 1.8, $F = 17.65$, $DF = 1$ by 60, $p < 0.01$). In addition, the distance to the mainland was also significantly correlated with the total number of coral species (Figure 1.9, $F = 19.27$, $DF = 1$ by 60, $p < 0.01$). The increase in coral diversity westward is most likely due to the presence of the outer barrier reefs which are often considered sites of optimal coral growth and highest coral diversity. However, it is worth noting that some of the highest diversity reefs in the world are nearshore, fringing reefs. The trend of increasing coral diversity northward cannot be explained by natural processes. Globally, coral diversity does tend to increase towards the equator, however, the distances between sites in this study (39.8 nm latitudinal range and 35.33 nm longitudinal range) are too small for this to be a factor. The most likely explanation is that these trends reflect a decrease in human impacts towards the northwards and away from the mainland.

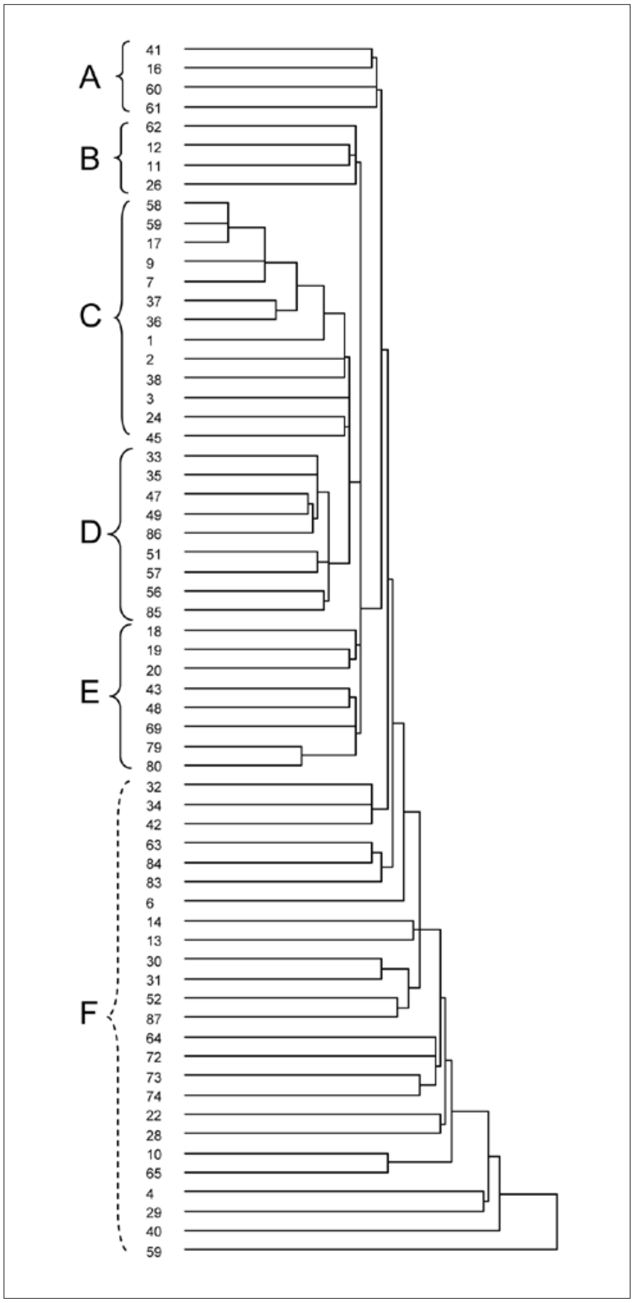

Figure 1.10. Cladogram showing the results of a cluster analysis of sites based upon coral species presence/absence data. A number of broad habitat types are distinct including: (A) inside the northern, Poum pass, (B) inner barrier, northern section, (C) outer barrier, northern section with island of Neba (D) inner lagoon, middle section, (E) odd grouping including the inshore reefs of the far north combined with the outer reefs of the Koumac pass, (F) assorted sites with no clear clustering.

Cluster analysis of species lists for sites indicated that there was a large degree of diversity of coral communities surveyed with no closely clustering groups of sites evident in the results (Figure 1.10). There were some broad clusters evident however that corresponded mostly to obvious geographical areas such as the northern pass and outer lagoon (group A), the inner northern barrier (group B), the northern islands and outer barrier (group C), the inner lagoon (group D) and the inshore areas (group E). There were a large number of sites which did not cluster closely at all (group F).

Regional Comparisons

In the Indo-Pacific, there is a well-known diversity pattern in which the highest diversity is found in an area that includes the Philippines and eastern Indonesia (Stehli and Wells, 1971; Veron, 2000; Hughes et al. 2002; Roberts et al. 2002; Karlson et al. 2004), with some evidence indicating that the area extends to Papua New Guinea (Hoeksema 1992; Fenner 2003; Karlson et al. 2004) and the Solomons (Veron and Turak 2006). Diversity decreases in all directions from this area, reaching low diversities in the Eastern Pacific, Japan, and southern Australia. Diversity decreases somewhat in the Indian Ocean and Red Sea, but not nearly as much as in the Eastern Pacific (Veron, 2000). The area of highest diversity is often called the "Coral Triangle." The north-south gradients

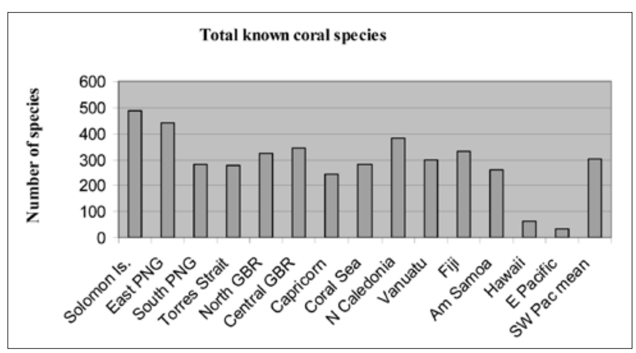

Figure 1.11. The total number of coral species known from different areas of the Southwest Pacific, with comparison figures for Hawaii and the East Pacific. Abbreviations for localities are: Is. = islands, PNG = Papua New Guinea, GBR = Great Barrier Reef, N = north, Am = American, E = east, SW Pac = Southwest Pacific.

are called "latitudinal gradients" and the east-west gradient is called a "longitudinal gradient."

New Caledonia lies outside the Coral Triangle, but fairly near to the eastern end which may be as far east as the Solomon Islands. Thus, the coral diversity in New Caledonia might be anticipated to be high, but not as high as in the Coral Triangle areas.

Figure 1.11 presents the total number of currently known species at locations in the southwest Pacific adjoining New Caledonia, plus Hawaii and the Eastern Pacific for comparison. Eastern Papua New Guinea and the Solomon Islands, which may be considered part of the Coral Triangle, are seen to have the highest total known diversity, and the Eastern Pacific the least among the sites shown, illustrating the strong longitudinal diversity gradient.

Data sources are: Solomon Islands: Veron and Turak (2006); East Papua New Guinea (PNG), South PNG, Torres Strait, North Great Barrier Reef (GBR), Central GBR and Capricorn & Bunker: Veron (1993); Coral Sea (Fenner and Ley 2008); New Caledonia: present study; Vanuatu: Veron (1990b); Fiji: Fenner (2007); Hawaii: Fenner (2005); Eastern Pacific: Glynn (1997). The SW Pacific mean excludes the Solomon Is., East PNG, Hawaii and Eastern Pacific modified after Fenner and Ley (2008).

From the Great Barrier Reef to American Samoa, however, there is no clear longitudinal diversity gradient evident (Figure 1.11). The cause for the lack of gradient within this area is not immediately apparent. Within the southwest Pacific, New Caledonia stands out as having the highest total number of coral species now known. One possible cause for this is the amount and time of study. The numbers for the Great Barrier Reef, southern Papua New Guinea, and Vanuatu come from studies Veron conducted some time ago, before many other species present in Japan and the Coral Triangle became known to him. Coral Sea reefs have received relatively little study (Fenner and Ley 2008), as have Fiji (Fenner 2007) and American Samoa. New Caledonia may now be slightly better studied than other regional reef systems. Additional studies always reveal additional species, so the total number of coral species known is highly dependent on the amount of study, how recent the studies are, and who conducted the studies. Thus, the total number of species currently known from an area is not a very accurate measure of the total diversity that will eventually be found there.

Many of these variables can be controlled for by using more standardized measures of these variables. Comparing the diversity found in a fixed number of dives such as one dive or 10 dives, controls for the amount of effort. Comparing between studies done by the same person controls for the observer variable and comparing between studies done close together in time helps control for the temporal variable. Figure 1.12 shows the mean number of species found in one dive and in 10 dives at several locations. At each location, the recorder was the same (D. Fenner). As always, additional searching effort finds additional species so 10 dives always produce larger numbers of species than one dive. Since the area searched in 10 dives is larger, this is also due to the species-area effect, where larger areas have larger numbers of species.

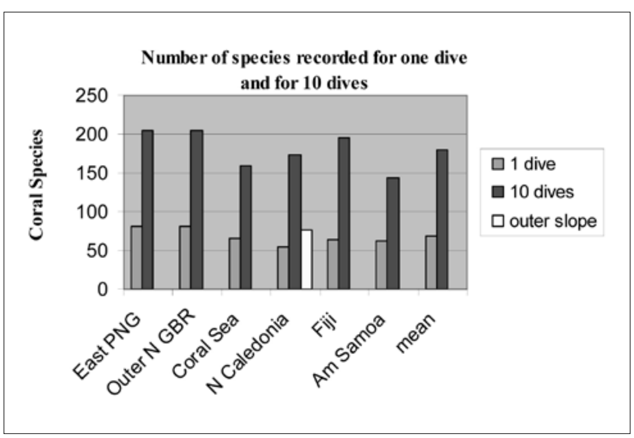

Figure 1.12. The number of coral species found in different areas of the Southwest Pacific by D. Fenner on one dive and 10 dives. Included for New Caledonia are the number of species found in one dive on the outer slope. Abbreviations for localities are: PNG = Papua New Guinea, N Caledonia = New Caledonia, N GBR = North Great Barrier Reef, and Am = American.

These data show only a hint of a longitudinal gradient, with East PNG and Outer North GBR slightly higher than other locations. Thus, it confirms the impression from the previous graph (Figure 1.12) of the total number of species that there is little or no longitudinal diversity gradient across the southwest Pacific. New Caledonia has the lowest number of species for one dive, but not for 10 dives. One powerful variable that is not controlled in this analysis is the reef zone being sampled. Reef crests, reef flats, and lagoons generally have many fewer species than on outer reef slopes (Karlson et al. 2004). Reef crests and reef flats have very small depth ranges, which may contribute to their low diversity. In New Caledonia, most of the sites were in the lagoon, and had small depth ranges as seen earlier. Figure 1.12 also includes a bar for New Caledonia which presents the average number of coral species found on the two outer slope dives of Fenner in this study, plus the one outer reef slope dive in the southwest by the same author. The result is a number more comparable to that in American Samoa, for instance, where all dives were on the outer reef slope.

Zoogeographic affinities of the coral fauna

The reef corals of the northwest lagoon of Grande-Terre and New Caledonia in general belong to the overall Indo-West Pacific faunal province. A few species span the entire range of the province, but most do not. Most coral species found in this area have fairly wide distributions within the Indo-Pacific. A majority of corals have a pelagic larval stage, with a minimum of a few days pelagic development for broadcast spawners (a majority of species) and larval settling competency lasting for at least a few weeks. A minority of species release brooded larvae that may be capable of anything from immediate settlement to a long pelagic dispersal period. All are potentially capable of settling on floating objects and rafting great distances, though some such as *Pocillopora* are much more common on floating objects than others (Jokiel 1989; 1990). Most species found in New Caledonia in this RAP have broad geographic ranges that extend from the Pacific into the Indian Ocean and are considered Indo-Pacific (Figure 1.13). A few have ranges restricted to the west Pacific, but very few have ranges that cover most of the Pacific without extending to the Indian Ocean, or ranges known primarily in the East Pacific, or ranges restricted to the southwest Pacific, or ranges known only from the Indian Ocean. The dividing line between the Pacific and Indian Oceans used in Figure 1.14 was just west of the Andaman Islands, as this is where Veron (2000) shows the deepest division between Pacific and Indian Ocean coral faunas. However, if the dividing line is taken at the geographical division between Pacific and Indian Oceans, then the dominance of the Indo-Pacific species in Figure 1.14 becomes even greater.

Most of the species in New Caledonia have broad distributions that extend in all directions from New Caledonia (Figure 1.14). The most common exceptions are species that do not extend south from New Caledonia. This is no doubt because of the southern location of the island, near the southern limits of well-developed coral reefs. The distributions in both these figures are primarily due to the very large ranges of most coral species.

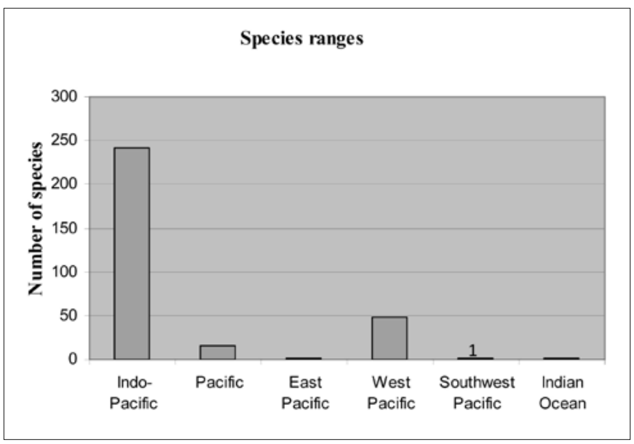

Figure 1.13. Biogeographic ranges for coral species found in New Caledonia.

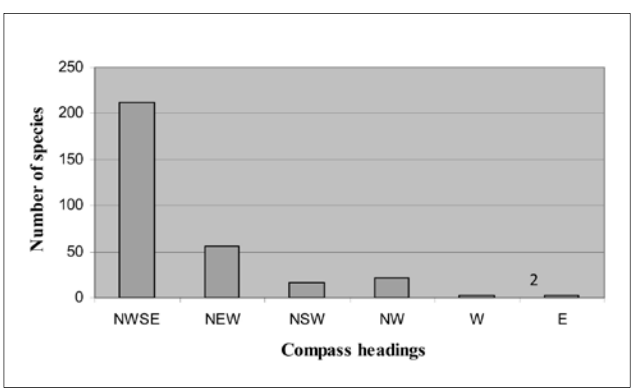

Figure 1.14. Compass headings away from New Caledonia and corresponding number of species known.

CONSERVATION RECOMMENDATIONS

New Caledonia has the world's longest continuous barrier reef system, with a huge variety of different kinds of reefs, such as fringing reefs, patch reefs, double barrier reefs, and so on. This study sampled only a tiny fraction of New Caledonia's reefs. Further, it sampled only a tiny fraction of the variation in New Caledonia's reefs. Because some species are restricted to particular types of habitats or are more common in particular types of habitats, the number of species found is likely to depend heavily on the habitats sampled. Thus, New Caledonia is likely to have many species not yet found. Many colonies could not easily be identified, so there may be a significant number of local variations of species or new species. We recommend further studies to better elucidate this diversity.

Most of the world's reefs have already been significantly impacted by human activities (e.g., Pandolfi et al. 2003; Bellwood et al. 2004). Impacted reefs often have reduced resiliency to the many natural and human-caused disturbance events that impact reefs. The northern reefs of New Caledonia may be some of the least impacted of New Caledonia's reefs. However, two impacts appear to be significant in the northwest reefs of New Caledonia and their impacts are likely to be growing rapidly. One is from sediment that has been eroded off of the hills due to the removal of vegetation and top soils during mining activities. Many coral colonies were observed that had been killed by sediments on the coral reefs that were studied near the shore of Grande-Terre. The water was turbid with silt, and a heavy blanket of mud covered all non-living surfaces. These reefs are already heavily impacted, even though the impact does not yet show up in the total number of coral species seen, probably because all individuals of a species must be killed before a change will show up in a species list. Quantitative diversity measures derived from transects may show lower diversity already; they would most likely show decreased live coral cover and increased dead coral on some near shore reefs. It appears that the corals on these reefs are very close to the limits of what they are able to withstand, and on some of those reefs many colonies have already been exposed to more than they can survive. Runoff of silt from naturally vegetated hillsides is minute, and corals are adapted to withstand it and still flourish (Hodgson and Dixon 1988; Rogers 1990). But if the present trends continue, it appears that the near shore reefs of NW Grande-Terre will be dead in a matter of years to at most a few decades. Some of these reefs have a high diversity of *Acropora* species, many of which could not be identified, and that may contain several or many new species. The need to reduce sediment runoff from mining scars cannot be stressed enough. All mining scars need to be re-vegetated, preferably with native species. This needs to be considered a cost of doing business. If sediment runoff is not reduced soon, sediment will begin to kill more and more reefs, beginning along the shore and extending farther and farther out into the lagoon. Mining and healthy reefs are compatible, but require effective measures to reduce sediment runoff, including re-vegetation of mined areas. Coral cover and quantitative coral diversity on the near-shore reefs need to be surveyed in transects with separate measures for live and dead coral, and the surveys repeated annually, so the health of these near-shore reefs can be monitored. This needs to begin soon, before the near-shore reefs are completely dead.

The results of this study also indicate where marine protected areas or high preservation zones could be sited in this region, at least in terms of coral diversity and reef health. The reefs in the far northern section, particularly around the island of Yandé, contained the highest diversity of corals and a wide range of coral reef community types in a relatively small geographic area. Many unusual coral species were only found in this area and some quite unusual communities were present. This area is certainly worthy of high protection in the future, it is presently relatively remote from large human populations and relatively pristine.

Perhaps the greatest single future threat to individual coral species and to coral reefs is global climate change. The primary defense for this threat is to maximize the resilience of the reefs. To do that, the reefs need to be minimally stressed and have as intact an ecosystem as possible. Sediment stresses reefs and will make it harder for reefs to recover from mass coral bleaching. The loss of coral reefs will mean the loss of shoreline protection, loss of reef fisheries, loss of reef tourism, and a reduced quality of life for residents.

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