Reef Corals of the Eastern Lagoon (Touho-Ponerihouen) of Grande-Terre, New Caledonia

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Chapter 1

Reef corals of the eastern lagoon (Touho-Ponerihouen) of Grande-Terre, New Caledonia

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SUMMARY

- The northeastern lagoon area of New Caledonia has a diverse coral fauna. A total of 333 named coral species was observed during the present survey. This compares well with other similar studies in other areas, including the Coral Triangle.
- The average species diversity per reef site (73.2 species) was higher in this study than in the northwest (63.8) and the southwest (52.7) of New Caledonia, using the same method and recorder (Fenner and Muir 2009). The diversity was similar to that in some areas in the Coral Triangle
- A total of 36 species that had not been previously reported from New Caledonia was found. These new records bring the total coral species known from New Caledonia to 457 species, more that the total of 350 given by Veron et al. (2009) for New Caledonia derived from their large database, "Coral Geographic." The number of *Acropora* species recorded is very high in relation to other areas.
- Five species were listed as endangered according to the IUCN Red List (*Acropora rudis*, *Anacropora spinosa, Alveopora minuta*, *Pectinia maxima* and *Millepora tuberosa*) and 68 were listed as Vulnerable.
- New Caledonia has the highest total number of coral species reported from any similar size area in the southwest Pacific, probably due to more field work in New Caledonia, including this survey. Equating the number of dives indicates diversity is similar to other areas of the southwest Pacific.
- A total of 26 species was found that extends the known biogeographic range of the species. The most notable was *Acropora rudis*, a species only reported from the Indian Ocean. The presence of the rare blue coral, *Heliopora coerulea*, was confirmed and compliments the recent discovery of this species in Fiji. The presence of a rare and cryptic fire coral, *Millepora tuberosa*, was also confirmed.
- Nine new species were collected, consisting of two *Acropora*, two *Goniopora*, one *Alveopora*, one *Porites*, one *Goniastrea*, one *Mycedium*, and one *Psammocora*.
- The number of coral species was highest at sites in the lagoon, next highest on the outer barrier reef, followed by passes, then the back reefs of, and finally fringing reefs. The number of coral species was correlated with the depth range, as it was in the northwestern RAP (Fenner & Muir 2009).
- The sites with the greatest number of coral species (in descending order) were 41, 40, 33 and 45 (tied), and 32. The sites with the highest replenishment index (CI) were (in descending order) sites 41, 36, 19 and 40 (tied), and 9 and 29 (tied). The sites with the highest rarity index (RI) were (in descending order) sites 36, 40, 41, 35, and 29. The sites with the highest combination of CI and RI were sites 41, 36, 40, 29, and 35.

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 contributor of habitat diversity used by many species associated with coral reefs (cryptic, sessile or commensal 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 *in-situ* 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 allows one to see the entire colony, and often times many colonies, while identification from collected specimens often must be based on small samples that don't show the range of morphological variation. Although the number of coral species is less than that for fish, identification difficulty is harder due to greater morphological variation within species. However, field identification is much easier than with groups such as sponges or ascidians, which require extensive collecting and years of museum work to identify.

The combination of the critical role of corals for coral reefs, the high diversity of coral reefs, and the ability to identify most coral species rapidly in underwater visual census makes them a critical component in any rapid assessment of coral reefs.

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 8783 species are currently known from New Caledonia (Payri and Richer de Forges 2006) compared to about 7000 in Hawaii (including all marine species: Eldredge and Evenhuis 2003), 5640 species in Guam (Paulay 2003), 4671 species in Enewetok (Devaney et al. 1987), 2876 in French Polynesia (Richard 1985), and 2705 species in American Samoa (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 of reef species 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 in Hawaii. 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 reef types in New Caledonia as well (e.g., Laboute and Richer de Forges 2004; Andréfouët et al. 2006; Lasne 2007; Wantiez et al. 2007; Andréfouët et al. 2009; Andréfouët and Wantiez 2010). 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 etc. Because different species have different habitat requirements, total diversity may be proportional to habitat diversity to some degree, as well as to 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. However, Fenner and Muir (2009) found just two more species per site in northwestern New Caledonia compared to southwestern New Caledonia, a difference that was not significant. The present data set will be examined for these trends.

Several studies in recent years have reported coral species in New Caledonia. 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), (see Table 1.4 in Fenner and Muir 2009). . Fenner and Muir (2009) reported an additional 28 species in the southwestern lagoon area in November, 2006. One species out of that 28, *Psammocora profundacella*, had been reported by Laboute (2006), though denoted with a "cf." and a question mark. The 2006 data from Fenner had 27 new records for a cumulative total of 346 coral species reported from New Caledonia. Fenner and Muir (2009) also reported finding 61 species that had not been reported in previous publications, (see Table 1.5 in Fenner and Muir, 2009). The new data of Fenner and Muir (2009) added another 32 new records beyond those found earlier in the 2006 Fenner data, for a cumulative total of 384 coral species reported from New Caledonia (Table 1.1). Lasne (2010) reported six additional species, plus a list of 401 species known from the IRD collections, 31 of which had not been previously reported, for a total known of 421 species.

As can be seen in Table 1.1, the total number of coral species known from New Caledonia has risen rapidly, from 310 species in 2006 to 421 species in 2010, an increase of 111 species, or 35.8%, in just four years. This is probably due to the relatively high number of studies during this short period.

The following is a report of the reef coral fauna of the 48 sites in the Touho-Ponérihouen area in New Caledonia based on results of the author's observations and collections during Conservation International's RAP in November-December 2009. 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 and *Heliopora*: blue coral; *Tubipora*: organ pipe coral), a small number of azooxanthellate scleractinian corals (*Cladopsammia*, *Dendrophyllia*; *Eguchipsammia*, *Rhizopsammia*, *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 other 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 (48 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 were surveyed at each of the 48 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 zig-zag 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 (except one site at the edge of a mangrove forest). 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. Species abundance was recorded on the "DAFOR" scale where "D" stands for dominant, "A" for abundant, "C" for common, "U" for uncommon, and "R" for rare, where rare was defined as only one or two colonies seen (DAFOR being an acronym for the categories; Mumby et al. 1996). Abundance categories were then given a numerical value, by assigning R = 1, U = 2, C = 3, A = 4, and D = 5. 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 some 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. Samples were later bleached in a 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 et al. 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 author has followed this (as did Fenner and Muir, 2009). 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), as examination by the author of the type speciemen of *A. nobilis* suggests it is a junior synonym of *A. robusta*. 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 author finds the distinction clear in the field and considers *A. spathulata* a valid species. Veron (2000) considers *A. rosaria* to be valid, but Wallace (1999) considers it to be

Table 1.1. Numbers of named coral species reported in studies beginning in 2006, additional species records, and the cumulative total number of species known from New Caledonia. "Named species" is the number of species names reported in the study, regardless of whether they had been reported before. Unnamed species (such as "*Acropora* sp. 1") are not included. "Additional records" are species that are included in the first column, but had not been previously reported in any other study. "Cumulative total" is the total number of previously reported species plus any additional species reported in the present study which had not been reported before.

	Named Species	Additional Records	Cumulative Total
Pichon, 2006a	310	310	310
Laboute, 2006	196	9	319
Pichon, 2006b	219	8	327
Fenner unpubl, 2006	184	25	352
Fenner & Muir, 2009	322	32	384
Lasne, 2010	277	6 + 31*	421

*Lasne (2010) reported 13 new records from fieldwork, six of which had not been reported in previous studies. Lasne (2010) also gives a list of 401 species known from the IRD collection of corals from New Caledonia, 31 of which were not reported in previous studies.

similar to *A. loripes*. Veron (2000) considers *A. insignis* to be valid, but Wallace (1999) considers it unresolved. The author has 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.

Coral communities were assessed by two multivariate methods: cluster and non-metric multidimensional analyses using transformed data (log of abundance + 1). Cluster analysis was used to determine hierarchical levels of community structure. For both analyses, a similarity matrix was constructed using Bray-Curtis index. The Bray-Curtis index was used since it is measured towards the dominant species, these species being the indicators of communities. Clustering was conducted using the group average. Non-metric multidimensional scaling was used to determine community structure without any assumption of hierarchical organization among islands and among reef zones. Analysis of similarities (ANOSIM) was then used to test the significance of species groupings with habitat (barrier, exterior barrier, pass, fringing and lagoon) as factor with 999 permutations and significance of groupings set at $p \leq 0.05$. All data analyses were conducted using Primer 5 for Windows.

RESULTS AND DISCUSSION

A total of 333 named species in 72 genera of stony corals (319 species and 64 genera of zooxanthellate Scleractinia) was found in the Touho-Ponerihouen area (Appendix 1). Almost all of these species are illustrated in Veron (2000), *Acropora* are illustrated in Wallace (1999) and Fungiids are illustrated in Hoeksema (1986). The total of 333 species compares well with several other studies. These include: the 310 species reported for all of New Caledonia by Pichon (2006), based on all previous studies combined; the 196 named species and 82 unnamed species reported from Mt. Panié region of Grande-Terre by Laboute (2006); and the 322 species reported in Fenner and Muir (2009) based on 62 sites in NW New Caledonia. Further, it also compares well with other CI RAP locations using the same methodology: 303 species in the Philippines, 315 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 71.6 species per site was found in this study across all sites, and 73.2 species per reef site (that is, excluding the one mangrove site). This compares well with the mean of 38.5 species per site found by Laboute (2006) in the Mont Panié area. This difference may be due to any combination of several factors, such as different reef habitats in the two areas, differing coral 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). The mean of 68.9 species per site was also higher than the 63.8 species per site reported by Fenner and Muir (2009) for northwestern New Caledonia, and higher than the 54.9 species per site recorded by this author in that study.

The mean of 73.2 species per reef site was much more than the mean of 52.7 species per site found by the same author in 10 dives in the southwest lagoon off Nouméa in 2006. This supports the suggestion by Lasne (2007) that there is a latitudinal gradient with higher diversity in the north and lower diversity in the south. However, it is also much more than the 54.9 species per site found by the author in the study of the reefs on the northwest (Fenner and Muir, 2009), which throws doubt on whether there is a gradient. More information will be required before the gradient question can be answered.

General faunal composition

The coral fauna consists mainly of Scleractinia. The genera with the largest numbers of species found were *Acropora, Montipora, Pavona, Porites, Fungia, Leptoseris, Favia, Psammocora,Turbinaria, Goniastrea, Platygyra.* These 11 genera account for about 50% of the total observed species (Table 1.2). There were 18 families of corals found, with the largest families being Acroporidae with 92 species, Faviidae with 52 species, Fungiidae with 25 species, Agariciidae with 24 species, Mussidae with 20 species, Dendrophyllidae with 14 species, and Poritidae with 13 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 coral species were zooxanthellate (algae-containing, reef-building) scleractinian corals, with 97% of the coral species in this group. There were nine species (in *Cladopsammia*, *Dendrophyllia*, *Eguchipsammia*, *Rhizopsammia*, *Tubastraea,* and an undescribed rhizganiid genus) that were azooxanthellate (lacking algae) Scleractinia for 2.7% of the total. Also there were eight corals that were not Scleractinia, for 2.4% of the total. Of those that were not Scleractinia, six were zooxanthellate (in *Millepora, Tubipora, and Heliopora*) and two were azooxanthellate (*Distichopora* and *Stylaster*).

These species were in 78 genera, including 72 genera of zooxanthellate Scleractinia. These in turn were in 19 families, 15 of which are zooxanthellate Scleractinia.

Diversity at individual sites

Sites 41, 40, 33, and 45 had the highest species richness, with 124, 109, 105 and 105 species, respectively (Table 1.3). Sites 30, 14, 24, 15, and 48 had the lowest species richness, with 0, 1, 27, 33 and 45 species respectively (Table 1.4). Site 30 was a fringing reef along Grande Terre, and although the author found no corals, others in the team found some corals farther up the shore. Site 14 was a mangrove forest with sand in front of it.

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

A total of 75 *Acropora* species (including *Isopora*) were recorded in this study and 77 species in Fenner and Muir (2009) 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 et al. (2000) was 78 in the Gulf of Tomini, Indonesia which has been claimed to be in the heart of the "coral triangle", the region with the highest coral diversity (Wallace 1997). However, Wallace (1999) recognizes fewer species of *Acropora* than Veron (2000). Wallace (1999) recognized 113 valid species in the genus. Veron (2000) introduced a large number of new or previously synonymised (i.e. discarded) species and recognized a total of 167 valid species. In this study, four species were recorded (*A. inermis*, *A. insignis*, *A. plana*, and *A. rosaria*) that are recognized by Veron (2000) but not by Wallace (1999), and one species (*A. spathulata*) were recorded that is recognized by Wallace (1999) but not by Veron (2000), so in effect the present results should be comparable to the Wallace (2001) study. Compared with other well known high diversity areas that have been surveyed using Veron's scheme, the figures for New Caledonia are still quite high. For example, Veron (2002) reported 95 species of *Acropora* in Raja Ampats of West Papua, Indonesia, and Veron and Turak (2006) reported 124 species in the Solomon Islands.

Diverse ecosystems typically have a large number of species, most of which are rare. A Marine RAP survey puts emphasis on recording as many species as possible. If there is a desire to document the rarity of species, either effort must be diverted from recording species, or additional effort (i.e., personnel) are required to make quantitative recordings of species abundances. Thus, quantitative records of species abundances, such as that produced by various transect methods, were not possible in this study. However, there are a number of semi-quantitative measures of abundance that

Table 1.2. Genera with the most species, in order of decreasing number of species per genus. *Acropora* includes three species that have been included in *Acropora* as the subgenus *Isopora*, but which now are placed in genus *Isopora*. That is, for this purpose the three species continue to be counted in genus *Acropora* in order to maintain comparability with earlier studies.

	Genus	Number of Species
1.	*Acropora*	75
2.	*Montipora*	18
3.	*Pavona*	11
4.	*Porites*	10
5.	*Fungia*	10
6.	*Leptoseris*	9
7.	*Favia*	8
8.	*Psammocora*	8
9.	*Turbinaria*	8
10.	*Goniastrea*	7
11.	*Platygyra*	7

Table 1.3. Most diverse sites surveyed. Site number with corresponding number of species is reported.

Site	Number of Species
41	124
40	109
33	105
45	105
32	100
39	97
29	96
31	96
38	94
44.	87
34	87

Table 1.4. Total number of coral species recorded at each site.

Site	Number of Species	Site	Number of Species	Site	Number of Species
1	56	17	78	33	105
2	75	18	47	34	89
3	60	19	85	35	79
4	72	20	83	36	85
5	79	21	-	37	76
6	52	22	80	38	94
7	51	23	70	39	97
8	59	24	27	40	109
9	75	25	58	41	124
10	83	26	78	42	71
11	49	27	84	43	52
12	77	28	65	44	87
13	64	29	96	45	105
14	1	30	0	46	63
15	33	31	96	47	85
16	81	32	100	48	45

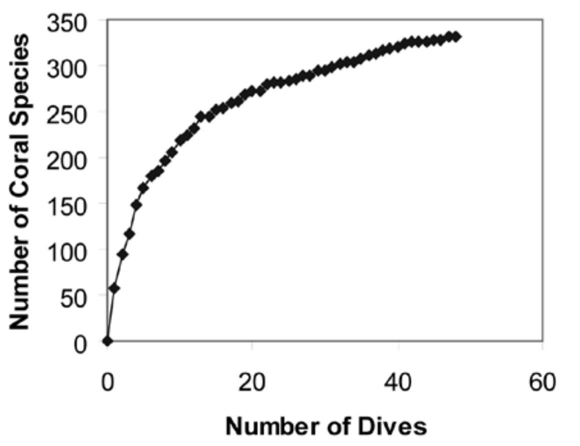

Figure 1.1. Total number of species recorded as it accumulated over the 48 dives of this study, with the sites in the order in which they were assessed.

Table 1.5. Coral species with the highest incidence, showing the number and percentage of sites in which they were found.

	Species	No. sites	% of sites
1.	*Pocillopora damicornis*	38	81%
2.	*Pocillopora verrucosa*	38	81%
3.	*Acropora florida*	37	79%
4.	*Pachyseris speciosa*	36	77%
5.	*Pavona varians*	34	72%
6.	*Leptoria phrygia*	34	72%
7.	*Acropora humilis*	32	68%
8.	*Goniastrea pectinata*	32	68%
9.	*Platygyra dadalea*	32	68%

Table 1.6. The total abundance rating for the nine most abundant species of coral.

	Species	Total Abundance Rating
1.	*Pocillopora verrucosa*	82
2.	*Pachyseris speciosa*	73
3.	*Acropora florida*	64
4.	*Stylophora pistillata*	57
5.	*Acropora hyacinthus*	57
6.	*Pocillopora damicornis*	56
7.	*Merulina scabricula*	56
8.	*Diploastrea heliopora*	58

were recorded. The first such measure was that of "incidence," that is, the proportion of sites that had at least one sighting of a species. Table 1.5 gives the incidence of the nine most prevalent species.

Abundance estimates were also taken for each species at each site, using the "DAFOR" scale with a conversion to a numerical scale as explained in the Methods section. For each species, the numerical value on the abundance scale recorded for each species was added up for all 47 sites to produce a total abundance rating. The eight species with the highest abundance ratings are presented in Table 1.6. Comparison with Table 1.5 reveals that some of the same species are present, but the list is not the same.

Incidence and abundance are not the same. One species could be present at every site but be rare at all sites, while another species could be present at only one site, which it might dominate. The former is likely to be a species that does not reproduce by fragmentation, while the later is very likely to be a species that reproduces by fragmentation. While that is possible, it is not clear how often that happens, and it may be that species that are found at more sites are also usually more abundant at those sites. This was tested by running a correlation between the total abundance ratings and incidences of the most common species, seen in Tables 1.5 and 1.6. The result was not significant, $r = 0.4893$, $p < .1$. Although this correlation was not significant, it is fairly large, suggesting that if the N were larger, it might well be significant (though that is not guaranteed). When all species were used, the correlation was large and significant, $r = 0.9459$, $p < .0001$. Similar results have been found in American Samoa (Fenner 2008). Thus, although it is possible for one species to have high incidence but be rare and another species to have low incidence but be abundant, that is quite uncommon, and for most species, incidence and abundance are strongly correlated. Thus, incidence is a good proxy for abundance.

Turak and DeVantier (2005) use an index for evaluating reef sites for conservation, called the "coral replenishment" index. The presence of high diversity, abundance and cover of coral can provide an ability to replenish or restock local area reefs in the case of a major disturbance. Their index, CI, is based on the abundance of each species and the total cover at a site, to get a measure of the local population of the species at the site. The index is

$$CI = \sum A_i H_i / 100$$

Where A_i is the abundance score of each species at the site on the 0 to 5 scale used in this study, and H_i is the rank coral cover at the site. They assign ranks to coral cover such that 0% cover = 0, 1–10% cover = 1, 11–30% cover = 2, 31–50% cover = 3, 51–75% cover = 4, and 76–100% = 5. The mean site coral cover from the chapter 5 by Sheila McKenna was used for this purpose. The results for all sites are shown in Figure 1.2. The sites with the highest CI index were (in order) sites 41, 19 and 40 (tied), and 9 and 29 (tied).

Turak and DeVantier (2005) also use an index for evaluating reef sites for conservation, called the "rarity index." This is an index of how many relatively rare species are found on a site and how abundant they are. It is

$$RI = \sum A_i / 100P_i$$

Where A_i is the abundance rank and P_i is the proportion of sites in which the species was present. Figure 1.3 gives the values of the index calculated for each site.

The two indices, CI and RI, can be combined to produce a single score for each site, which would provide a ranking of sites by both of these scores. Figure 1.4 presents the combined score for each site. The sites with the highest scores, starting with the highest, were 29, 35, 19 and 21 which were tied, and 17.

Species of Special Interest

New records

The present study reports a total of 333 species including 35 species that have not been previously reported in New Caledonia in any other study. This brings the total number of species known from New Caledonia to 456, when the additional species are added to the previous totals given in Table 1.1. One species (*Millepora tuberosa*) that was recognized by Fenner from photos taken during the rap survey from Yandé to Koumac (Fenner and Muir 2009) raises the total known to 457 species. Those 36 new records are presented in Table 1.7. Samples were collected for most of the 36 species to verify the identifications, and for all of the 36 species, one or more photographs of the living colony were taken. The *Acropora plana* sample matched Veron (2000) exactly, with tubular axials and incipient axials, and appressed radial corallites. His photo of a skeletal sample does not show prominent septa. Nemenzo (1986) indicates that some corallites have extended lips, and that corallites have large directive septa, neither of which were found on this sample. Veron (2000) may have decided based on seeing more samples that Nemenzo's sample did not have the

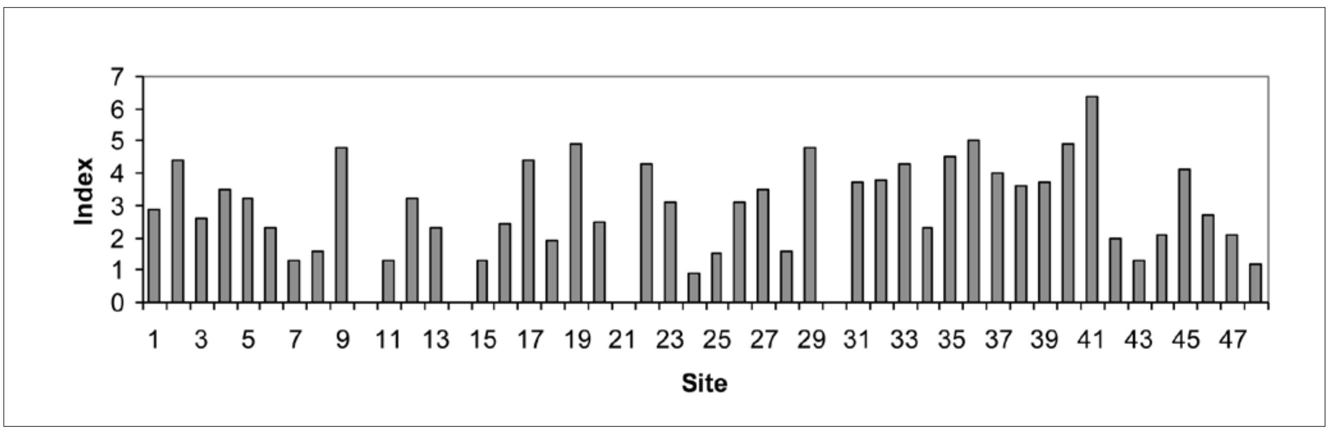

Figure 1.2. The coral replenishment index for each site. Sites with a zero value did not have data available for calculating the index.

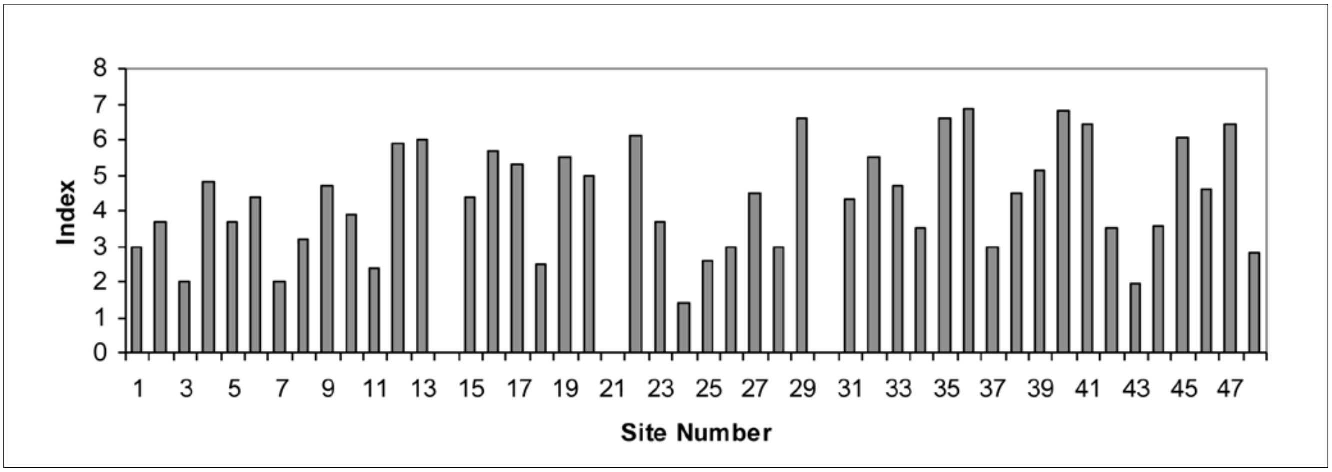

Figure 1.3. The coral rarity index for each site. Sites with a zero value did not have data available for calculating the index.

most common features. Table 1.8 indicates that 26 of those species also represent an extension of the known range for the species, based on range maps of species in Veron (2000), Wallace (1999), and Hoeksema (1989).

All reef-building corals worldwide have been evaluated for status using the IUCN Red List methods (Carpenter et al. 2008). Five species in the present study were given Endangered status (EN), and another 64 were assigned to Vulnerable (VU) status (Table 1.9).

Sites with endangered species have value for conservation. No one site has more than one red-listed species. *Anacropora spinosa* was common at site 13, and uncommon at site 15. *Acropora rudis* was rare at sites 12 and 48, *Goniopora minuta* was rare at site 18, and *Pectina maxima* was rare at sites 4, 22, and 23. *Heliopora coerulea* (blue coral) while only listed as vulnerable, is very rare in New Caledonia. It was found only at site 1, and only one colony was found.

The blue coral, *Heliopora coerulea*, was an especially surprising find. Only one colony was found, and it was both photographed (Figure 1.5) and a very small sample taken (Figure 1.6). The sample clearly showed the blue skeleton that is a signature of the species. This species is actually an Ocotocoral, the group dominated by soft corals, not a Hexacoral like the Sclearactinia which comprise most reef corals. *Heliopora coerulea* is known from the western Pacific to as far east as Olosega Island in American Samoa (Zann and Bolton 1985). It is fairly common in some areas of its range, and forms whole reefs in some of the southern islands of Japan. Until recently it was not known from either Fiji or New Caledonia. A few years ago it was found in Fiji (E. Lovell, personal comm.). Laboute and Magnier (1979), Laboute and Richer de Forges (2004) and Pichon 2006b all state that *Heliopora coerulea* does not exist in New Caledonia. Zann and Bolton (1985) in their review of what is known about this species, present a map of its distribution in the Pacific, which includes New Caledonia, but not Fiji. The inclusion of New Caledonia was based on reports of Wells (1954) and Bouillon and Houvenaghe-Crèvecoeur (1970). It is surely not common in New Caledonia, as P. Laboute has not seen it is his many years of experience there, and only one colony has been found by the author in a total of 87 dives. Zann and Bolton (1985) report that a single sighting of this species at Palm Islands in the Great Barrier Reef (18 degrees South) by J.E.N. Veron is the southernmost record of this species. However, New Caledonia is south of 18 degrees and thus is the southernmost known location in the Pacific for this species. Veron (2000) shows the range in the Indian Ocean as extending south to Madagascar, but the exact location is not shown.

Another species of interest is *Acropora rudis*. This is a coral that is only known from the northeastern Indian Ocean (Veron, 2000), and the Seychelles (Wallace, 1999). The author has collected a sample from American Samoa, but does not have a photograph of the living coral from American Samoa. It was found at one site in this study, photographed alive (Figure 1.7), and a sample collected (Figure 1.8). It is quite distinctive, with very rounded fat radial corallites that have very small calices (openings) and very thick walls. There is no other species quite like it.

Montipora stilosa is only known from the Red Sea. The sample from New Caledonia clearly shows the tall, tapering papillae which the name comes from. *M. stilosa* is the only species which has such tall papillae. Veron (2000) states that corallites are surrounded by papillae, and the drawing of the skeleton shows short papillae surrounding the corallites. However, several of the photos of living colonies (all taken in the Red Sea) clearly do not have small papillae around corallites. The New Caledonia sample does not have short papillae surrounding the corallites.

One coral sample is an exact match for what Veron (2000) presents as *Psammocora vaughani*. Veron (2000) remarks that it has the septa of *Coscinaraea* but has small corallites like *Psammocora*. Sizes of some skeletal elements in corals can be quite variable, and there are often a wide range of corallite sizes within a genus, such as *Goniopora*, *Alveopora* and indeed *Coscinaraea*. Surely the nature of the septa, which are obviously *Coscinaraea*, is more important than the size of the corallites in determining the genus. This species actually

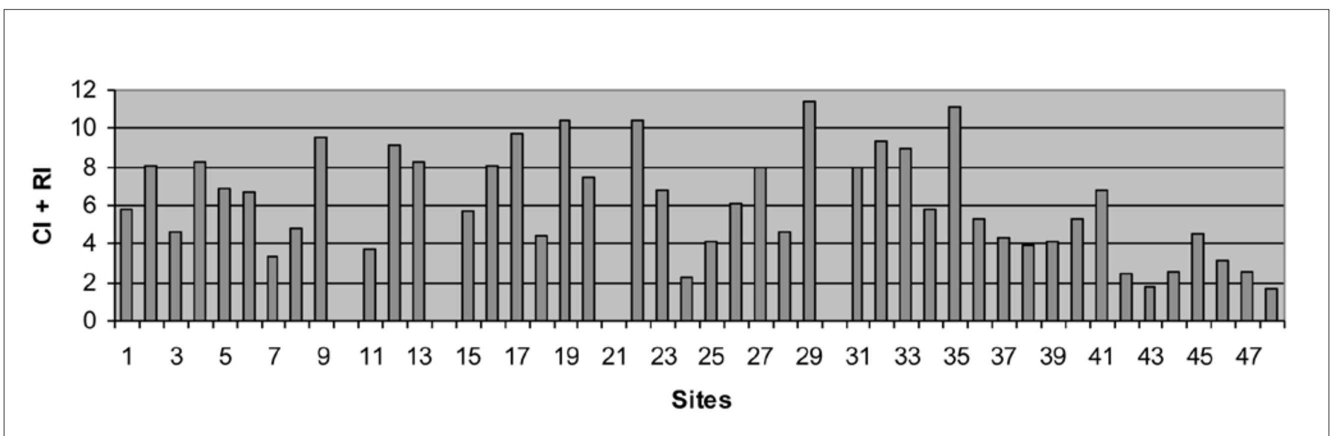

Figure 1.4. The sum of the two indices (CI and RI) for each site. Sites with a zero value did not have data for one or both indices.

Table 1.7. New records and range extensions for New Caledonia, confirmed from samples, except as otherwise indicated.

	Espèce
1.	*Seriatopora guttatus*
2.	*Acropora batunai*
3.	*Acropora* cf. *inermis*
4.	*Acropora jacquelineae*
5.	*Acropora loisettae*
6.	*Acropora pectinata*
7.	*Acropora plana*
8.	*Acropora prostrata**
9.	*Acropora rudis*
10.	*Acropora teres*
11.	*Anacropora spinosa*
12.	*Anacropora reticulata*
13.	*Astreopora suggesta*
14.	*Coscinaraea* sp. per *Psammocora vaughani* in Veron (2000)
15.	*Montipora gaimardi*
16.	*Montipora "orientalis"* per Veron, 2000
17.	*Montipora stilosa*
18.	*Montipora* cf *vietnamensis**
19.	*Porites horizontallata*
20.	*Porites monticulosa*
21.	*Leptoseris striata*
22.	*Pavona gigantea*
23.	*Cantharellus jebbi**
24.	*Oxypora crassispinosa*
25.	*Pectinia maxima*
26.	*Favites paraflexuosa**
27.	*Platygyra yaeyamaensis*
28.	*Leptastrea bewickensis*
29.	*Alveopora minuta*
30.	*Goniopora* cf. *eclipsensis*
31.	*Dendrophyllia* cf. *coccinea*
32.	*Dendrophyllia* cf. *gracilis*
33.	*Enallopsammia* sp.
34.	azooxanthellate rhizganiid
35.	*Heliopora coerulea*
36.	*Millepora tuberosa*

* not confirmed with a sample

Table 1.8. 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).

	Species
1.	*Seriatopora guttatus*
2.	*Acropora batunai*
3.	*Acropora jacquelineae*
4.	*Acropora loisettae*
5.	*Acropora pectinata*
6.	*Acropora plana*
7.	*Acropora prostrata*
8.	*Acropora rudis*
9.	*Acropora teres*
10.	*Anacropora spinosa*
11.	*Anacropora reticulata*
12.	*Coscinaraea* sp. per *Psammocora vaughani* inVeron (2000)
13.	*Montipora gaimardi*
14.	*Montipora "orientalis"* per Veron, 2000
15.	*Montipora stilosa*
16.	*Montipora* cf *vietnamensis*
17.	*Leptoseris striata*
18.	*Pavona gigantea*
19.	*Cantharellus jebbi*
20.	*Oxypora crassispinosa*
21.	*Pectinia maxima*
22.	*Favites paraflexuosa*
23.	*Platygyra yaeyamaensis*
24.	*Leptastrea bewickensis*
25.	*Alveopora minuta*
26.	*Goniopora cf. eclipsensis*

has corallites as large, or larger than, *Coscinaraea hahazimaensis*, as can be seen in Veron (2000), and thus is within the range of variation of the genus *Coscinaraea*. Hence, this species is here placed in *Coscinaraea*. Interestingly, the living colony looked very much like *Psammocora haimaeana*, which it clearly is not. This ("*Psammocora vaughani*") is a rarely reported species, which was reported from Pohnepei (Turak and DeVantier 2005) but not the Solomon Islands, E. Papua New Guinea, or West Papua, Indonesia (Veron and Turak 2006). Benzoni et al. (2007) report that Veron's (2000) drawing and figure 3 do not match either the original descriptions or the clear illustrations in it. They say it is a *Cosinaraea* sp. Thus, it is treated here as an unidentified or undescribed species of *Coscinaraea*, and to indicate that this

Table 1.9. Coral species found in this study assigned elevated levels of threat according to the IUCN Red List criteria (Carpenter, et al. 2008).

	Species	IUCN Red List Status
1.	*Acropora aculeus*	Vulnerable
2.	*Acropora acuminata*	Vulnerable
3.	*Acropora anthocercis*	Vulnerable
4.	*Acropora aspera*	Vulnerable
5.	*Acropora batunai*	Vulnerable
6.	*Acropora dendrum*	Vulnerable
7.	*Acropora echinata*	Vulnerable
8.	*Acropora globiceps*	Vulnerable
9.	*Acropora jacquilinae*	Vulnerable
10.	*Acropora kirstyae*	Vulnerable
11.	*Acropora loisettae*	Vulnerable
12.	*Acropora microclados*	Vulnerable
13.	*Acropora paniculata*	Vulnerable
14.	*Acropora pharaonis*	Vulnerable
15.	*Acropora polystoma*	Vulnerable
16.	*Acropora retusa*	Vulnerable
17.	*Acropora rudis*	Endangered
18.	*Acropora speciosa*	Vulnerable
19.	*Acropora spicifera*	Vulnerable
20.	*Acropora tenella*	Vulnerable
21.	*Acropora vaughani*	Vulnerable
22.	*Acropora verweyi*	Vulnerable
23.	*Acropora willisae*	Vulnerable
24.	*Anacropora puertogalerae*	Vulnerable
25.	*Anacropora reticulata*	Vulnerable
26.	*Anacroproa spinosa*	Endangered
27.	*Isopora crateriformis*	Vulnerable
28.	*Montipora altasepta*	Vulnerable
29.	*Montipora caliculata*	Vulnerable
30.	*Montipora cebuensis*	Vulnerable
31.	*Montipora gaimardi*	Vulnerable
32.	*Montipora malampaya*	Vulnerable
33.	*Montipora meandrina*	Vulnerable
34.	*Montipora orientalis*	Vulnerable
35.	*Montipora stilosa*	Vulnerable
36.	*Montipora verruculosus*	Vulnerable
37.	*Montipora vietnamensis*	Vulnerable
38.	*Alveopora fenestrata*	Vulnerable
39.	*Alveopora minuta*	Endangered
40.	*Porites horizontallata*	Vulnerable
41.	*Leptoseris incrustans*	Vulnerable
42.	*Leptoseris yabei*	Vulnerable
43.	*Pachyseris rugosa*	Vulnerable
44.	*Pavona bipartita*	Vulnerable
45.	*Pavona cactus*	Vulnerable
46.	*Pavona decussata*	Vulnerable
47.	*Pavona venosa*	Vulnerable
48.	*Heliofungia actiniformis*	Vulnerable
49.	*Galaxea astreata*	Vulnerable
50.	*Pectinia alcicornis*	Vulnerable
51.	*Pectinia lactuca*	Vulnerable
52.	*Pectinia maxima*	Endangered
53.	*Acanthastrea brevis*	Vulnerable
54.	*Acanthastrea hemprichii*	Vulnerable
55.	*Acanthastrea ishigakiensis*	Vulnerable
56.	*Lobophyllia diminuta*	Vulnerable
57.	*Symphyllia* cf. *hassi*	Vulnerable
58.	*Caulastrea curvata*	Vulnerable
59.	*Caulastrea echinulata*	Vulnerable
60.	*Montastrea salebrosa*	Vulnerable
61.	*Platygyra yaeyamaensis*	Vulnerable
62.	*Catalphyllia jardeni*	Vulnerable
63.	*Euphyllia ancora*	Vulnerable
64.	*Euphyllia cristata*	Vulnerable
65.	*Physogyra lichtensteini*	Vulnerable
66.	*Turbinaria heronensis*	Vulnerable
67.	*Turbinaria mesenterina*	Vulnerable
68.	*Turbinaria patula*	Vulnerable
69.	*Turbinaria peltata*	Vulnerable
70.	*Turbinaria reniformis*	Vulnerable
71.	*Turbinaria stellulata*	Vulnerable
72.	*Heliopora coerulea*	Vulnerable
73.	*Millepora tuberosa*	Endangered

species of *Coscinaraea* is the same as shown in Veron (2000), it is referred to as "*Coscinaraea* sp. per *Psammacora vaughani* in Veron (2000)."

Colonies reported as *Montipora* cf. *vietnamensis* resemble the species shown under the name *Montipora confusa* in Veron (2000). However, the type specimen of *M. confusa* Nemenzo which the author has examined, is formed of thin branches with thin ridges, matching the photographs in Veron (2000) of *M. vietnamensis*. The type specimen of *M. vietnamensis* (shown in Veron, 2002) is thick and has relatively large ridges, and better fits with the photos in Veron (2000) appearing under the name *M. confusa*. The colonies observed and photographed in this study are perhaps not a perfect match to the species shown in Veron (2000) under the name of *M. confusa*, or the type specimen of *M. vietnamensis*, but may be within the range of variation. Veron and Turak (2006) report both these species in the Solomon Islands, East Papua New Guinea, and West Papua, Indonesia.

Another species of interest is *Millepora tuberosa*, which is one of the five species listed as endangered. This is an infrequently reported species. Randall and Cheng (1984) report it from Mauritius, the Marianas (where it is common), Taiwan, and Yap and Truk in the Micronesia. It was recognized from one photo taken by Fenner during the Fenner and Muir (2009) CI RAP study, presented in Figure 1.9. It is present but uncommon in American Samoa, where the author has confirmed the identification with samples. Living colonies are always a purplish red color (Randall and Cheng, 1984), and it is encrusting, so it could easily be mistaken for coralline algae. It has lumps on it, as does *Millepora exaesa*, but it forms flat encrustations on substrate, while *M. exaesa* commonly encrusts rubble. Razak and Hoeksema (2003) synonymize *M. tuberosa* with *M. exaesa*. Their study was of museum specimens, and they almost certainly have never seen *M. tuberosa* alive, as it is very different from *M. exaesa* . *M. exaesa* is yellow (as shown in Razak

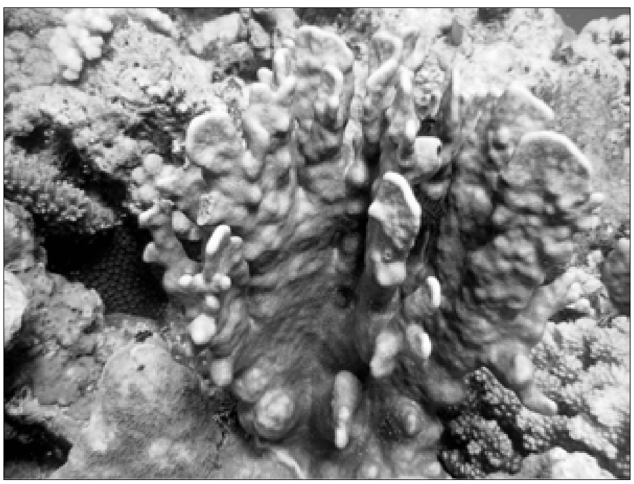

Figure 1.5. The one colony of *Heliopora coerulea* (blue coral) found in this study. Note the broken branch on the left which shows the blue color of the skeleton.

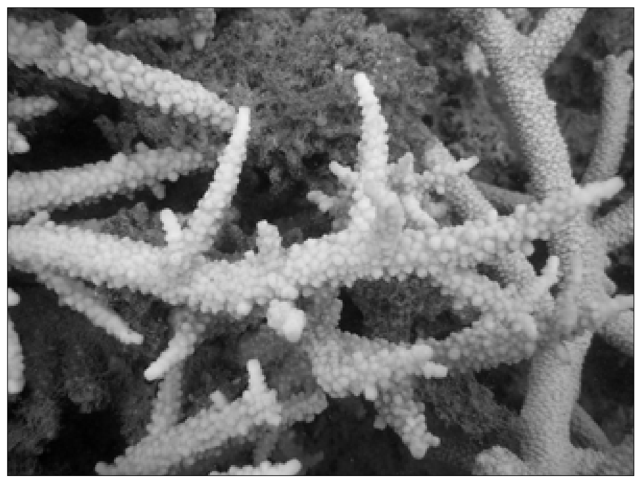

Figure 1.7. Living *Acropora rudis* colonies found in this study.

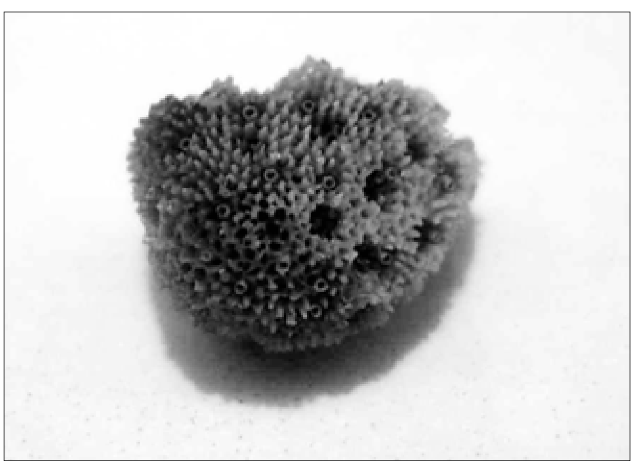

Figure 1.6. The small sample, about 7 mm across, of *Heliopora coerulea* collected in this study.

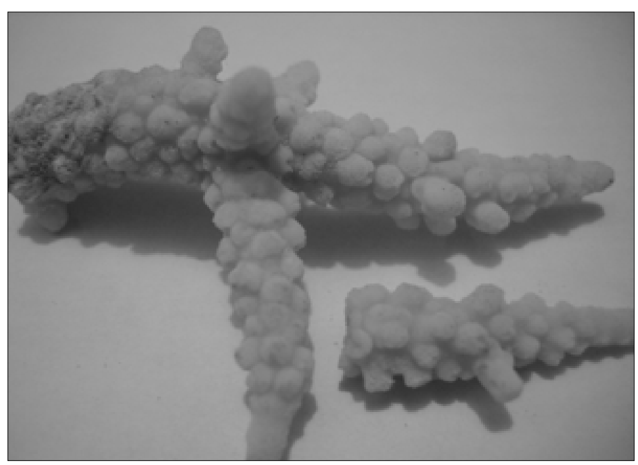

Figure 1.8. Samples of *Acropora rudis* collected in this study. Note the large radial corallites with very thick walls and small calices.

and Hoeksema 2003), though it can have pink areas or be all pink. The pink is lighter and more red than the purplish red color of *M. tuberosa*, and it is much less common than the yellow color and usually is only part of the colony. Not only is the color different, but the lumps are much smaller on *M. tuberosa* . It was first found in American Samoa by R. Randall, who showed it to C. Birkeland, who strongly agrees it is easily distinguished from *M. exaesa*, and a valid species (C. Birkeland, personal comm.). *M. tuberosa* has apparently not yet been found in Indonesia where Razak and Hoeksema (2003) did their study. The author has also found it in Madagascar where it was uncommon to rare. It is probably rarely reported because of its similarity to coralline algae on the one hand and *M. exaesa* on the other, plus it may be uncommon to rare most places, and few people know how to identify it. Randall and Myers (1983) show a color photo of *M. tuberosa*, which has a yellowish color on a large part of the colony, which is not typical.

Alveopora minuta was described by Veron in 2000 from Bali, Indonesia, and now is listed as an endangered species. Since then it has only been reported from Raja Ampats (Papua, Indonesia), and the Solomon Islands (Veron and Turak 2006), so the present record is only the fourth known location, and a range extension. It has the smallest corallites of any *Alveopora*, and the most reduced skeleton of any Scleractinia, with only tiny points for septa, or no septa at all. Two small samples fit the description perfectly. A second, slightly larger sample was found in the samples from Fenner and Muir (2009) which also fits.

Acropora pectinatus was described by Veron in 2000 from Flores, Indonesia, and this appears to be the first report elsewhere since then.

Eight distinctive species were seen, photographed and samples collected, which appear to be new species. The new species consist of two *Acropora*, two *Goniopora*, one *Alveopora*, one *Porites*, one *Goniastrea*, one *Mycedium*, and one *Psammocora*.

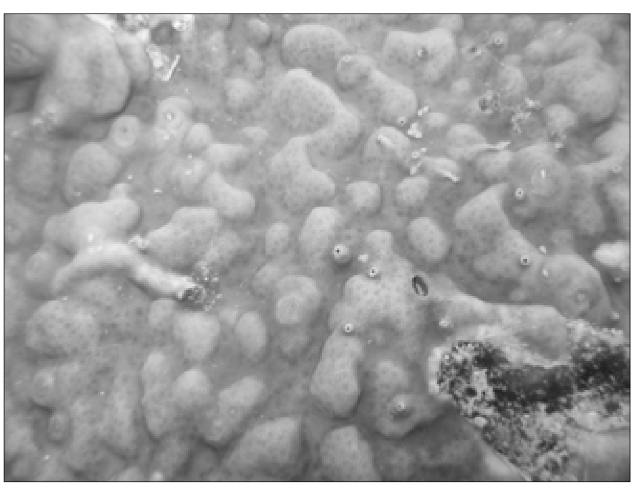

Figure 1.9. A closeup photo of *Millepora tuberosa* taken during the Fenner and Muir (2009) study. The lumps are only about 5–10 mm long. The color is characteristic.

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 species that had not been reported previously for that site. This can happen whether the newly discovered species are within the known range of their species or not, because species are known only from specific locations within their range and have not been reported from other locations within their range. The species may actually be spread evenly throughout its range, or it may only occupy some suitable habitat within that range. 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 about 550 species are now known from Indonesia, the number of species known in New Caledonia is very high, and the rate at which additional species is being found is very high. In just the four years since the list by Pichon (2006) was published, 146 additional species have been reported from New Caledonia (Table 1.10), over 80 by the author. It is highly probable that additional searching will reveal more species.

Table 1.9 shows all of the species identified from samples, whether the sample was the first skeletal confirmation for that species in New Caledonia, and the sites that samples for that species came from. Some of the species were species that had been reported before from sightings but for which a sample had not yet been collected. A total of 122 species were confirmed by samples and 44 species were confirmed by samples for the first time.

Species without site numbers represent species for which tags on specimens did not record site. The site numbered “0” was a practice site on which data was not taken.

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. Fenner and Muir (2009) found on the northeast of Grande Terre that coral diversity was greater farther from shore, and was negatively correlated with turbidity, such that coral diversity was lower in higher turbidity (lower visibility) water. They also found that coral diversity was positively correlated with the depth range at sites, so diversity was higher when the site had a greater depth range. Depth ranges were less near shore.

The sites in this study are located in different areas of lagoon between Touho and Ponerihouen. Some were located at fringing reefs near the shores of Grande-Terre. Others were located on patch reefs and around small islands 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 fringing reefs along the shore of Grande-Terre was 50.5 compared to 76.8 on the outer slopes of the barrier reef, (Figure 1.10). Actually, the highest diversity was at sites in the lagoon (86.8 species), with the outer barrier next, followed by passes

Table 1.10. Coral Species Verified from Samples.

	Species	Sites
1.	*Acanthastrea echinata*	3
2.	*Acanthastrea rotundoflora*	
3.	*Acropora aculeus*	7
4.	*Acropora akajimensis**	22
5.	*Acropora batunai**	41
6.	*Acropora carduus*	5
7.	*Acropora cerealis*	1, 31, 44
8.	*Acropora copiosa**	35
9.	*Acropora dendrum*	16
10.	*Acropora grandis*	15
11.	*Acropora halmaherae*	13
12.	*Acropora* cf. *inermis**	34
13.	*Acropora jacquelineae**	2
14.	*Acropora kirstyae*	13, 16, 36
15.	*Acropora loisettae**	16, 22
16.	*Acropora microphthalma*	2
17.	*Acropora muricata*	3, 31
18.	*Acropora nana*	0
19.	*Acropora pectinatus**	3
20.	*Acropora pharaonis*	16
21.	*Acropora plana**	19
22.	*Acropora rosaria*	2, 3, 4
23.	*Acropora rudis**	12
24.	*Acropora secale*	2, 10
25.	*Acropora selago*	2, 7, 23, 36
26.	*Acropora spicifera*	11
27.	*Acropora subulata*	7
28.	*Acropora tenella*	41
29.	*Acropora teres**	13
30.	*Acropora valida*	1
31.	*Acropora vaughani*	36
32.	*Alveopora fenestrata*	4
33.	*Alveopora minuta**	18
34.	*Anacropora forebsi*	16
35.	*Anacropora puertogalerae*	15, 16
36.	*Anacropora reticulata**	17
37.	*Anacropora spinosa**	15
38.	*Astreopora suggesta**	31
39.	*Cladopsammia* sp.*	10
40.	*Coeloseris mayeri*	3
41.	*Coscinaraea columna*	20
42.	*Coscinaraea exesa*	3, 20, 44
43.	*Coscinaraea monile*	38
44.	*Coscinaraea* sp. per *Psammocora vaughani* in Veron (2000)*	1
45.	*Cyphastrea seralia*	47
46.	*Ctenactis albitentaculata*	16
47.	*Dendrophyllia* cf. *coccinea**	0, 19
48.	*Dendrophyllia* cf. *gracilis**	1
49.	*Eguchipsammia* sp.*	
50.	*Echinophyllia aspera*	9
51.	*Echinopora lamellosa*	22
52.	*Echinopora mammiformis*	4
53.	*Favia rotundata*	3
54.	*Favites complanata*	2
55.	*Favites halicora*	34
56.	*Favites pentagona*	
57.	*Fungia granulosa*	13
58.	*Fungia horrida*	20
59.	*Fungia scabra*	3
60.	*Galaxea astreata*	4, 16
61.	*Goniastrea edwardsi*	
62.	*Goniastrea minuta*	2
63.	*Goniastrea pectinata*	4
64.	*Platygyra yaeyamaensis**	2, 3, 29
65.	*Goniopora* cf. *eclipsensis**	5
66.	*Goniopora stutchbury*	
67.	*Heliopora coerulea**	19
68.	*Hydnophora grandis*	3
69.	*Leptastrea bewickensis**	1, 2, 7
70.	*Leptastrea pruinosa*	1, 3
71.	*Leptoseris gardineri*	44
72.	*Leptoseris incrustans**	31, 35
73.	*Leptoseris striata**	35
74.	*Madracis kirbyi*	35
75.	*Montastrea salebrosa*	7, 19
76.	*Montipora altasepta**	15
77.	*Montipora caliculata*	7
78.	*Montipora digitata*	
79.	*Montipora* cf. *effusa*	22
80.	*Montipora floweri*	
81.	*Montipora gaimardi**	13
82.	*Montipora incrassata*	1
83.	*Montipora malampaya**	12, 15
84.	*Montipora meandrina**	47
85.	*Montipora monastereata**	5
86.	*Montipora "orientalis"* per Veron, 2000*	48
87.	*Montipora stellata*	12
88.	*Montipora stilosa**	35
89.	*Montipora verruculosus*	16
90.	*Oulophyllia bennettae**	44
91.	*Oxypora crassispinosa**	34
92.	*Oxypora lacera*	

Table 1.10. cont.

	Species	Sites
93.	*Palauastrea ramosa*	13
94.	*Pavona bipartita*	36
95.	*Pavona cactus*	46
96.	*Pavona chiriquensis*	19
97	*Pavona clavus*	
98.	*Pavona decussata*	27
99.	*Pavona explanulata*	
100.	*Pavona gigantea**	29
101.	*Pecitinia maxima**	4
102.	*Platygyra contorta**	39
103.	*Platygyra lamellina*	2
104.	*Platygyra pini*	
105.	*Podabacia motuporensis*	2
106.	*Porites* cf. *heronensis**	42
107.	*Porites horizontallata**	9
108.	*Porites lichen*	3, 20, 22
109.	*Porites monticulosa**	41
110.	*Porites vaughani*	4
111.	*Psammocora digitata*	4
112.	*Pseudosiderastrea tayami*	6, 48
113.	*Rhizopsammia verrilli**	29
114.	*Seriatopora guttatus**	20
115.	*Stylaster* sp.	29
116.	*Stylocoeniella guentheri*	44
117.	*Stylophora subseriata**	3
118.	*Symphyhllia hassi*	29
119	*Tubipora musica*	20
120.	*Turbinaria frondens**	38
121.	*Turbinaria irregularis*	4
122.	rhizangiid azooxanthellaté *	10, 48

* First confirmation from skeletal examination.

in the barrier reef, backreef on the barrier reef, and fringing reef. The one mangrove site had only one species, which was on the calcareous sand a number of meters away (just one colony). No corals were found near the mangrove roots.

The depth range of reefs was measured by the maximum depth of dives, since the author generally did not go below the depth of the last coral. In almost all cases the dive ended close to the surface. Because some corals are restricted to particular depths, the greater the depth range, the more species can be found. Some species are restricted to only shallow water, others to only deep water, and some inhabit a fairly wide range of depths. The depth preferences of Indo-Pacific corals are not well studied quantitatively. Figure 1.11 shows depth ranges for different reef types. The exterior barrier reef sites had the greatest depth range, followed by the lagoon sites, then the passes in the barrier, fringing reefs, backreefs on the barrier, and last the mangroves.

The pattern in mean depths appears somewhat similar to that for diversity, suggesting the two might be correlated. They are indeed correlated, with $r = 0.8953$, $p < 0.02$.

The number of species at individual sites and the depth range for those same sites are also correlated, $r = 0.6724$, and significant $p < 0.0001$. Thus it appears that depth range explains a good deal of the variation in number of coral species, as it did in Fenner and Muir (2009).

Sediment is a well-known stressor for corals, and corals can survive a limited amount of sediment precipitation. These reefs are close to a large land mass (Grande-Terre) with steep slopes and surface strip mining. In the previous report on reefs in the northwest (Fenner and Muir, 2009), a correlation was found between visibility and coral diversity at sites. Water clarity or visibility can serve as a proxy for the rate of sedimentation since the lower the visibility the greater the rate of sediment deposition. The correlation between visibility and the number of coral species at a site was $r = 0.323$, $p < 0.05$. Although the correlation is not high, it is significant because of the fairly large N (48 sites minus one on which coral data was not taken). These results are very similar to those for the northwestern reefs (Fenner and Muir, 2009).

The coral communities were also examined using cluster analysis and Multi Dimensional Scaling (MDS). Cluster

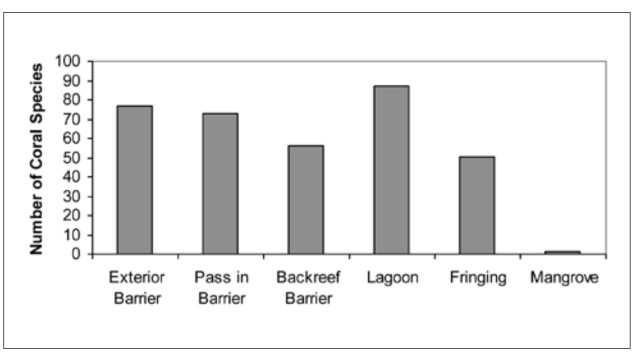

Figure 1.10. The mean number of coral species in different habitats in this study.

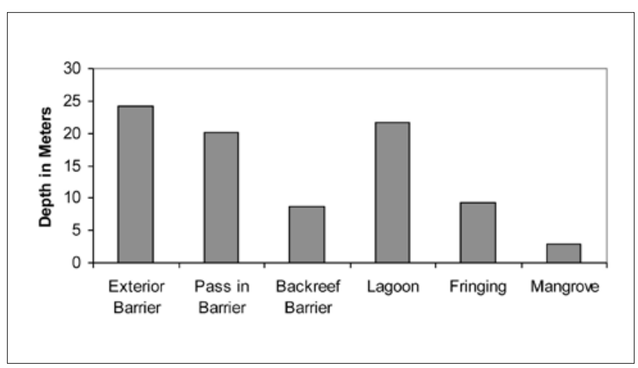

Figure 1.11. The mean depth of different types of reefs in this study.

analysis showed that the fringing reef sites along the shores of Grande- Terre were the most distinctive coral communities that were the least similar to other sites (Figure 1.12). Lagoon sites formed two separate clusters, as did barrier reef sites. Other than that, sites did not sort out clearly by reef type. In an ANOSIM analysis, the coral communities in the exterior barrier and lagoon were not significantly different ($p = 0.06$). In addition, the coral communities in the exterior barrier and pass were also not significantly different ($p = 0.13$). MDS analysis produced similar results. Both types of analysis were also carried out on all sites which the author has collected coral abundance data in New Caledonia, including sites in the northwest and southwest (Fenner and Muir, 2009). In this larger analysis, sites did not cluster clearly by which of the three regional areas they are in, nor by the type of reef. Thus, although New Caledonia has very distinctive zones in its reef system, coral communities are not clearly distinctive in the different zones.

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 Solomon Islands (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 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 1.13 presents the total number of species currently known at locations in the southwest Pacific adjoining New Caledonia, plus Hawaii and the Eastern Pacific for comparison. Indonesia has the highest number of coral species known, while Hawaii and the Eastern Pacific have the least among the sites shown, illustrating the strong longitudinal diversity gradient over the entire Pacific. New Caledonia can be seen to stand out as having a higher total number of coral species known that other sites in the South Pacific, with slightly more than eastern Papua New Guinea, though less than the Solomon Islands (both of which are considered by some to be in the Coral Triangle).

From the Great Barrier Reef to American Samoa, however, there is no clear longitudinal diversity gradient evident (Figure 1.13). In a recent publication, Veron et al. (2009) have presented the diversity of "bioregions" as determined from their large database of coral species records, "Coral Geographic." The data from that article also fail to show a strong gradient from Australia to the Samoan Archipelago. The cause for the lack of gradient within this area is not immediately apparent. Within the southwest Pacific, New Caledonia stands out (Figure 1.13) as having the highest total number of coral species now known, 140 species more than the mean for the southwest Pacific. One possible cause for this is the amount and time of study. The numbers for the Great Barrier Reef (GBR), southern Papua New Guinea (PNG), 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 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

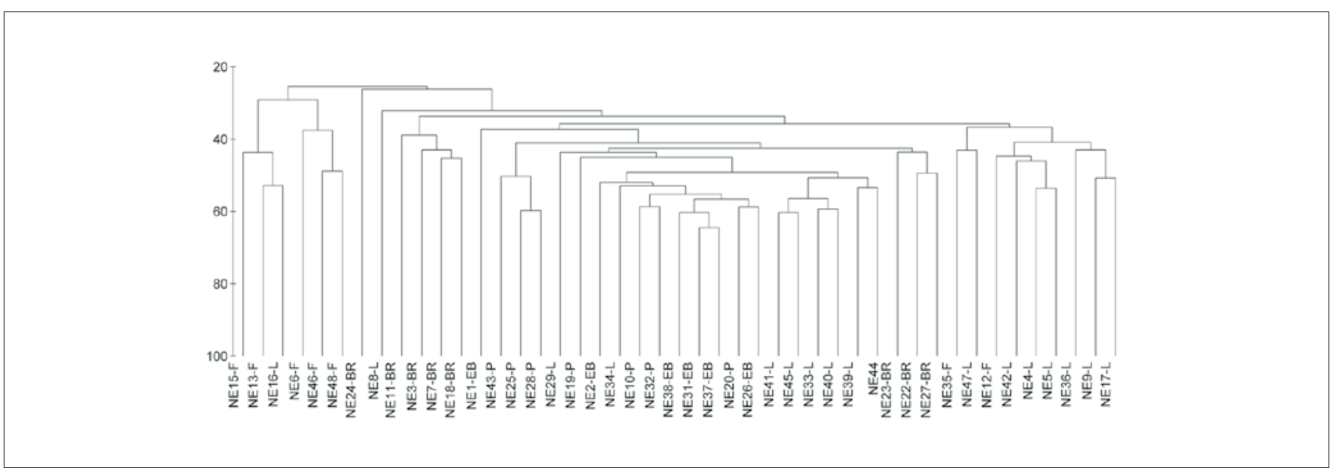

Figure 1.12. Cluster analysis of reef sites in this study, produced by Domingo Ochovillo.

currently known from an area is not a very accurate measure of the total diversity that is present and will eventually be found there, nor does it compare well with other sites which have received different types of studies.

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 1.14 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.

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 1.13) of the total number of species that there is little or no longitudinal diversity gradient across the southwest Pacific. The 2007 New Caledonia data (Fenner and Muir 2009) has the lowest number of species for one dive, but not for 10 dives. The 2009 data (this study) is close to the mean number of species for one dive, but the highest number of species 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 this study and the previous study, the number of coral species found at a site correlates with the depth range of the site (Figures 1.7 and 1.8). Figure 1.14 also includes bars for 2007 and 2009 New Caledonia studies which show the average number of coral species found on outer slope dives by the author in these studies. The result is a number more comparable to that in American Samoa, for instance, where all dives were on the outer reef slope. Interestingly, the outer reef slope dives had only slightly more corals than the average in 2009, while they had quite a bit more in 2007.

Although in a small standard size area there may be little or no longitudinal gradient in the South Pacific from the Great Barrier Reef to American Samoa, the total number of species known in an area is also likely to depend on the size of the area. This is known as the "species-area" effect. In general, the larger the area the more species there are, other things being equal. The relationship between number of species and area is generally a power relationship. New Caledonia is much larger than American Samoa, and even if the number of species in a small area is equal for both, the total number of species is likely to be higher in New Caledonia.

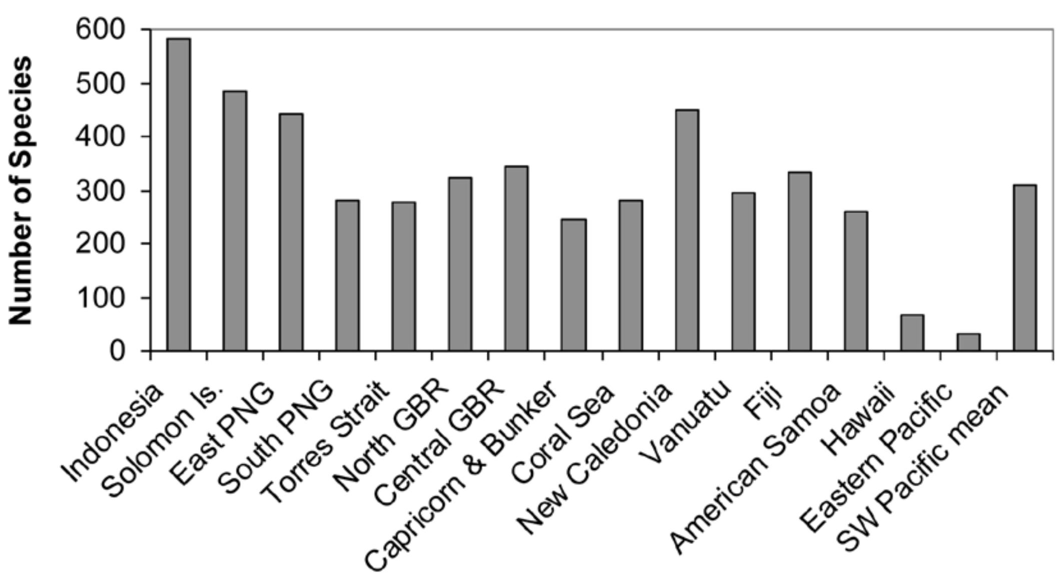

Figure 1.13. The total number of coral species known from different areas of the Southwest Pacific, with comparison figures for Hawaii and the East Pacific. Abbreviations for localities are: Is. = islands, PNG = Papua New Guinea, GBR= Great Barrier Reef, SW Pac = Southwest Pacific. Data sources are: 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: Fenner and Muir (2009); present study; Vanuatu: Veron (1990b); Fiji: Fenner (2007); American Samoa: Fenner (unpublished); Hawaii: Fenner (2005); Eastern Pacific: Glynn (1997). The SW Pacific mean excludes the Solomon Is., East PNG, Hawaii and Eastern Pacific. The graph was modified after Fenner and Muir (2009) where it was modified from Fenner and Ley (2008).

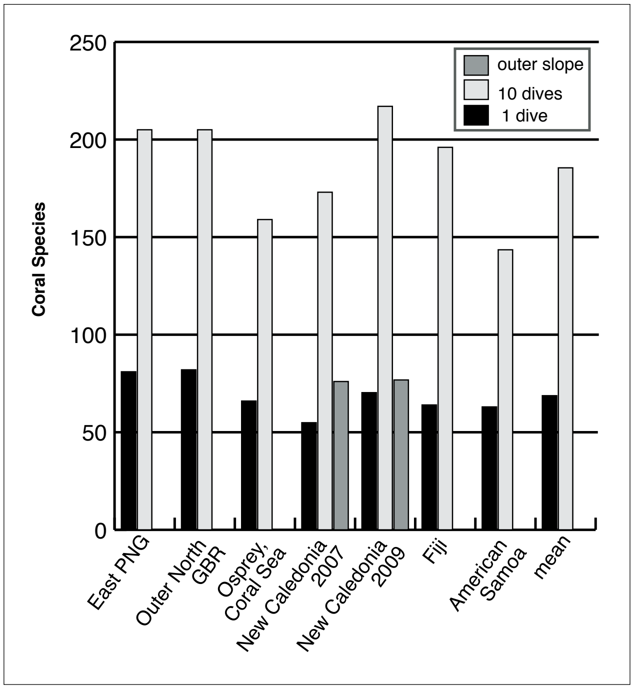

Figure 1.14. The number of coral species found in different areas of the Southwest Pacific by D. Fenner on one dive and 10 dives. Included for New Caledonia is the number of species found in one dive on the outer slope. Abbreviations for localities are: PNG = Papua New Guinea, and GBR = North Great Barrier Reef.

CONSERVATION RECOMMENDATIONS

The average number of coral species found per site in this survey was greater than in either the southwest or the northwest (Fenner and Muir 2009). This would be an attractive feature of this area for consideration for MPA's, though many other things should be considered as well, such as diversity in other groups, general reef health, community interest, etc.

Sediments did not appear to have as much damaging effect on these reefs as they did on the northwest. Some fringing reefs in the northwest had significant numbers of recently dead corals, heavy layers of mud, and very low visibility. Visibility was greater near shore in the northeast, and there were few if any dead coral colonies. At least two fringing sites even had abundant healthy-looking corals near shore (sites 13 and 35), though another (30) had no corals in the small area the author searched, only macroalgae (other team members found some coral farther down the reef).

The fives sites with the most species in descending order were sites 41, 40, 33, 45, and 32. The sites with the highest CI index were (in descending order) sites 41, 19 and 40 (tied), and 9 and 29 (tied). The sites with the highest rarity index were 36, 40, 35, 29 and 41. Sites 40 and 41 appear on all three lists, and so should be given top priority for protection. All the other sites are on one list each, and should be given second priority for protection. *Anacropora spinosa*, an endangered species, was common at site 13 and uncommon at site 15. These two sites have value for conservation as they have significant populations of an endangered coral species. Sites 4, 12, 18, 22, 23, and 48 could also be considered for conservation since they each have one endangered coral species, though that species is rare at each of those sites (and differs between sites).

New Caledonia is very rich in coral species, and appears to have many species that have not yet been identified. It is a prime location for further taxonomic research to identify the rich community of unidentified species that remains.

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