REPORT

CORAL REEF BIODIVERSITY COMMUNITY-BASED ASSESSMENT AND CONSERVATION PLANNING IN THE MARSHALL ISLANDS: BASELINE SURVEYS, CAPACITY BUILDING AND NATURAL PROTECTION AND MANAGEMENT OF CORAL REEFS OF THE ATOLL OF RONGELAP.

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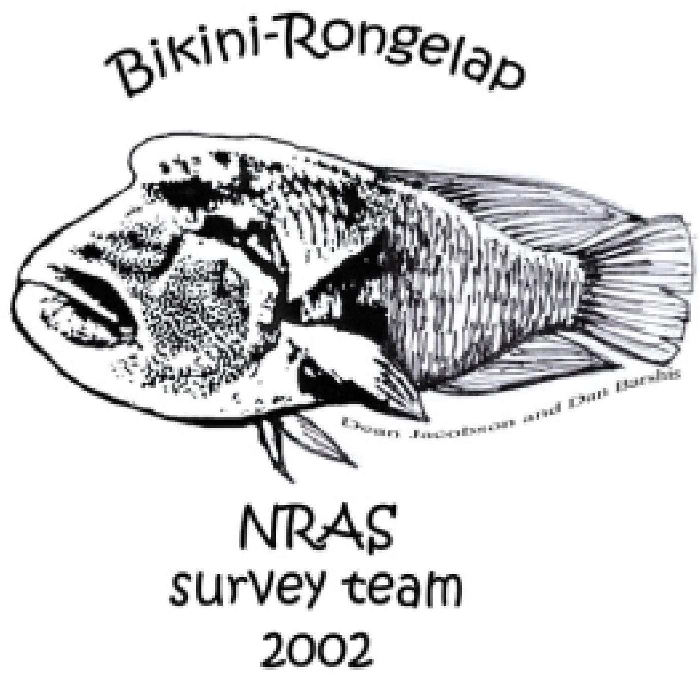


3. Results

3.1 Summary of achievements

In total, fourteen science divers were involved in the study of the health and biodiversity of coral reefs in Rongelap. The collected information will be issued to local governments and international organisations that study the status of coral reefs around the world. The survey team compiled a range of different data at 14 sites at Rongelap Atoll (Table 1). 12 of these sites were based on Rongelap-Rongelap island (Figure 1). In total 434 dives were conducted to accomplish this survey.

Table 1. Surveys accomplished at 14 survey sites at the southern Rongelap Atoll

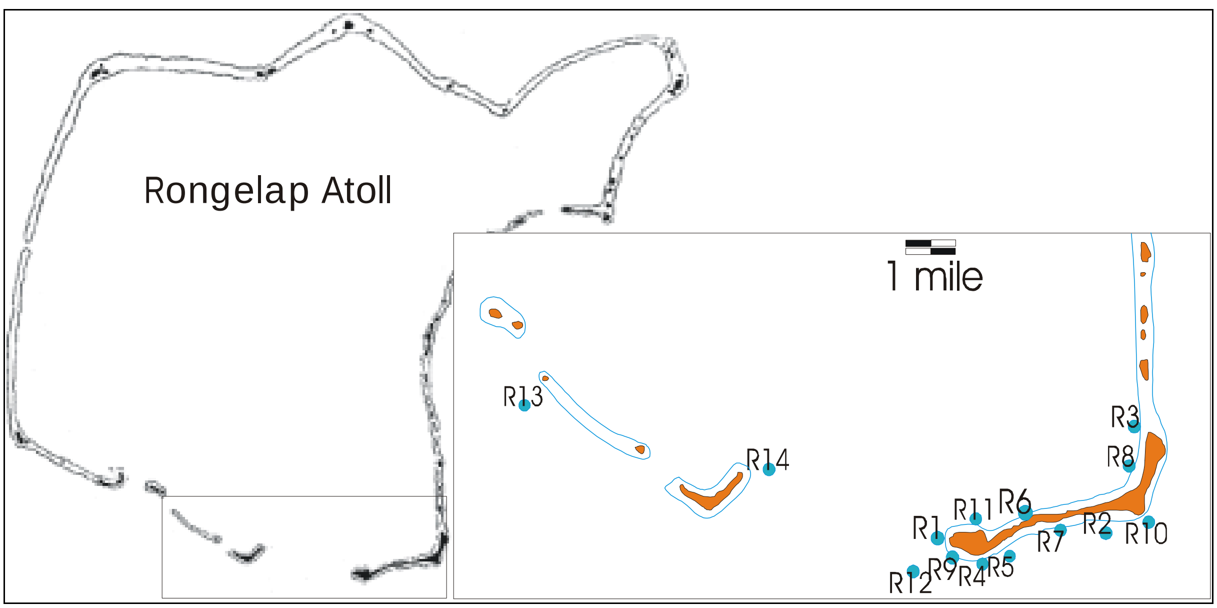
Survey	Effort
50m fish census: biomass and abundance of beta-diversity	3 depths
50m benthic census: substratum, corals and soft corals	3 depths
50m algae survey: biodiversity and %cover in quadrats	3 depths
Fish biodiversity	1 person
Coral biodiversity and collection	2 persons
Photography	1 person
Digital Photography	1 person
GPS (Global Positioning System) co-ordinates	1 person

The team selected two sites which were outstanding in their biological diversity, and that represent typical habitats found in the area. These sites were surveyed as above, but additionally there were repeated biodiversity surveys, a deep survey to include deep dwelling organisms, and the establishment of a permanent transect. The permanent transects are based at 11 meters of depth at PT 2 (R10) and at 7 meters at PT1 (R1). They consist of 11 pins cemented into the reef matrix along a 50 m transect; the pins are used to enable relocation of the transect, since, in order to avoid adverse impacts on the reef condition and development on the permanent transect, the tape itself was not placed permanently and needs to be re-laid at the next visit. Pins are located at either end and in 5 m steps along the transect. The permanent transects enable temporal monitoring of the reef. At Jaboan point (Site R1), the team conducted a Reef Check© survey. Reef Check is an internationally acclaimed and established method of assessing and comparing reef health on a global scale (ReefCheck, 2002). The location was recorded by Global Positioning System (GPS), using the “Degree Minute.decimal-minute “ setting and WGS 84 projection (Table 2).

Table 2. GPS co-ordinates of survey sites on Rongelap atoll.

Site name	Latitude	Longitude
R1	N 11 09.20707	E 166 50.18976
R2	N 11 09.39472	E 166 53.14641
R3	N 11 10.74334	E 166 53.74411
R4	N 11 09.10086	E 166 50.32076
R5	N 11 08.93800	E 166 50.58275
R6	N 11 09.46714	E 166 52.00121
R7	N 11 09.43624	E 166 52.92400
R8	N 11 10.43048	E 166 53.75506
R9	N 11 09.12210	E 166 50.25059
R10	N 11 09.30557	E 166 53.40841
R11	N 11 09.23958	E 166 50.62749
R12	N 11 09.16394	E 166 50.21003
R13	N 11 11.49714	E 166 43.42705
R14	N 11 10.09542	E 166 46.79730
PT1	N 11 09.23154	E 166 50.12474
PT2	N 11 09.30557	E 166 53.40841
Reef Check	N 11 09.20707	E 166 50.18976

Figure 1. Map of Rongelap atoll (after Spennemann, 1998) and detail of survey sites in southern Rongelap.



3.2 Ecological data

We present here an ecological analysis of the set of data, separated by categories of target objects and organisms (substrate, target corals, seaweeds, fish). We used simple statistical descriptors (mean and standard deviation) for this analysis and we concentrated on the differences among zones and regions with different location and topographical characteristics: depth layers, lagoon versus ocean, geographical location around the island and the Southern side of the atoll (Table 3).

Table 3. Matrix of ecological analysis to facilitate quick referencing.

	Section No.		
Categories analysed	Depth	Lagoon vs Ocean	Bio-geographic zones
Substratum	3.2.1.1	3.2.1.2	3.2.1.3
Coral targets	3.2.2.1	3.2.2.2	3.2.2.3
Fish targets	3.2.3.1	3.2.3.2	3.2.3.3
Algae	3.2.4.1	3.2.4.2	3.2.4.3

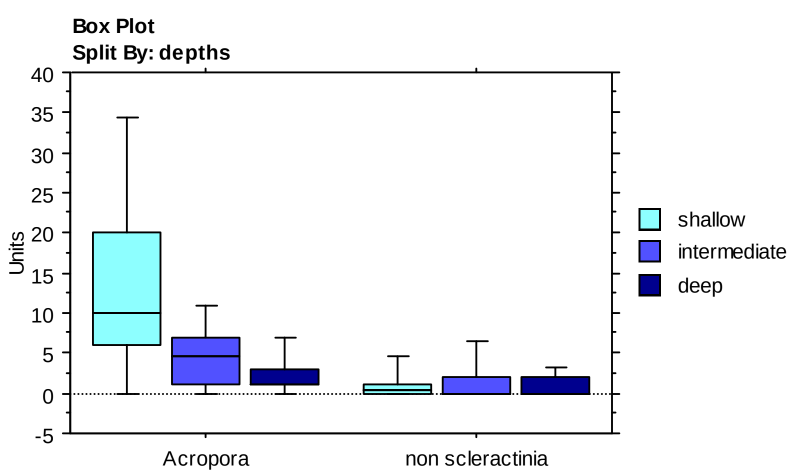
3.2.1 Substrate

We analyzed differences in distribution of the categories of substrate recorded. The comparisons of average values analyzed were studied for 3 depth layers, ocean versus lagoon sites, and 5 geographical locations. For depth and locations we used the Kruskal-Wallis test for multiple comparisons for non-parametric data (Zar, 1999) and for ocean *vs* lagoon we used a *t*-test. Differences to be considered meaningful were only those that gave a statistically significant level of probability equal or $p < 0.05$.

3.2.1.1 Depth

We analyzed the depth preference of different categories of corals recorded, such as the zooxanthelleate hard corals (scleractinia) and other reef-building corals such as blue and fire corals. Both *Acropora* ($p_{Anova} = 0.008$) and non scleractinia corals ($p_{Anova} = 0.05$) showed sharp differences of coverage with the depth. *Acropora* corals are more abundant at shallower depths (>10m) while non scleractinia (blue and fire corals) are more important at deeper layers (Figure 2).

Figure 2. Differences among the three depth layers for *Acropora* and non scleractinia corals.



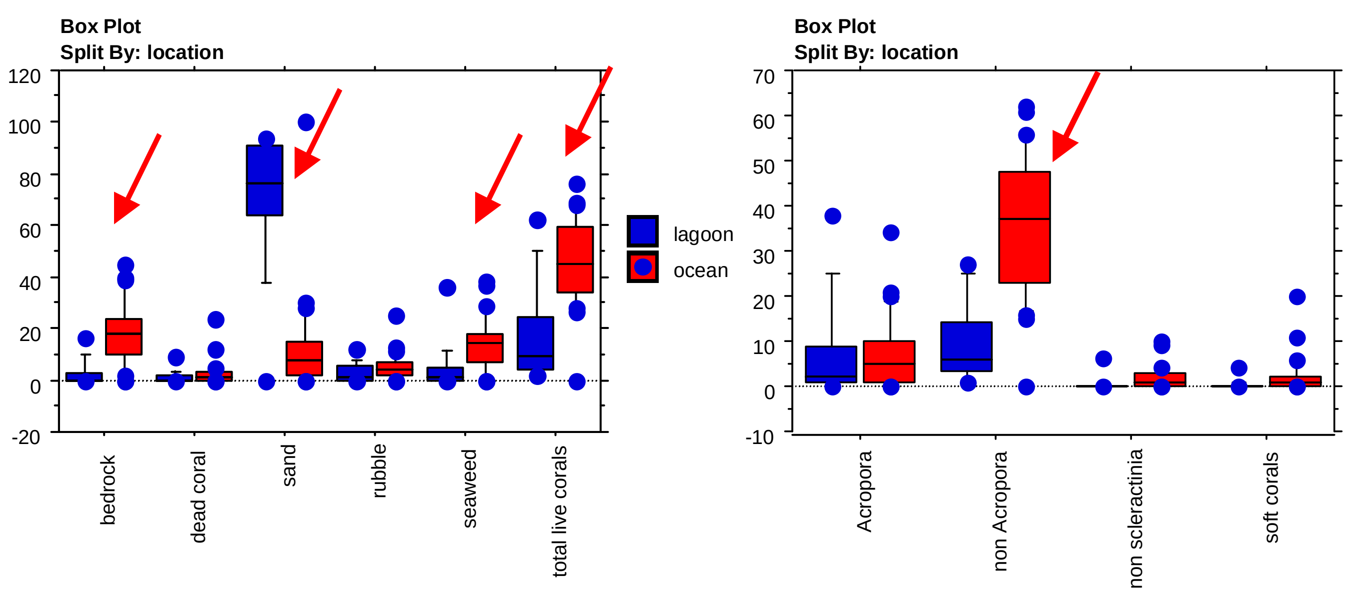
3.2.1.2 Lagoon vs Ocean

The substrate of lagoon and ocean sites was very different. Most of the components of what covers the ocean floor (substrate categories) show very different proportions of coverage at the two different locations: bedrock, live coral - among these, non-*Acropora* coral and non *scelaractinia* corals (fire, lace and blue coral) - as well as seaweeds are more abundant at the ocean location. Sand –as expected – shows higher coverage at the lagoon sites. Results are summarized in Table 4 and Figure 3. Dead coral, rubble, *Acropora* and soft corals were not significantly different at the two locations.

Table 4. Difference of substrate coverage between ocean (O) and lagoon (L) sites. P is the probability value associated with the statistical test (*t*-test). Categories with significant results are marked in bold.

Category	Significant/ Non significant	Higher in L or O	P value
Bedrock	**S**	**O**	**<.0001**
Dead coral	NS	-	.38
Sand	**S**	**L**	**<.0001**
Rubble	NS	-	.18
Live coral	**S**	**O**	**<.0001**
Acropora	NS	-	.95
Non *Acropora*	**S**	**O**	**<.0001**
Non scleractinia	**S**	**O**	**.04**
Seaweeds	**S**	**O**	**.005**
Soft	NS	-	.37

Figure 3. Differences in substrate coverage between ocean and lagoon sites. Arrows indicate significant results ($p < 0.05$).



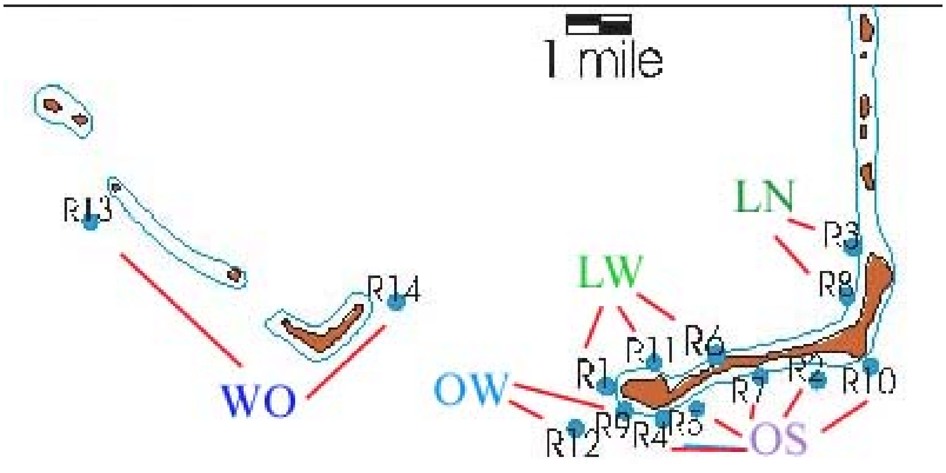
3.2.1.3 Geographical locations

We analyzed the differences in percentage coverage of the same substrate categories among preselected geographical zones around southern Rongelap atoll. Locations were classified as lagoon and ocean sites, and sites containing both ocean and lagoon habitats, as observed in Jaboan. The different regions were chosen by their differences in exposure, location in relation to passes and topography (see Figure 4).

Table 5. Sites grouped by bio-geographical zone. L = lagoon, O = ocean, J= Jaboan.

Site name	Lagoon/ocean	Geographical zone
R1	L (J)	Lagoon W
R2	O	Ocean S
R3	L	Lagoon N
R4	O	Ocean S
R5	O	Ocean S
R6	L	Lagoon W
R7	O	Ocean S
R8	L	Lagoon N
R9	O (J)	Ocean W
R10	O	Ocean S
R11	L	Lagoon W
R12	O (J)	Ocean W
R13	O	W Ocean (pass)
R14	O	W Ocean (pass)

Figure 4. Map of the pre-selected bio-regions, chosen as function of the sites exposure and topography.



Bedrock, rubble, sand, total live corals, non *Acropora*, non scleractinia and seaweeds show sharp differences in their relative coverage. The differences were evaluated using the Kruskal-Wallis test (Table 6) for multiple comparisons of average values.

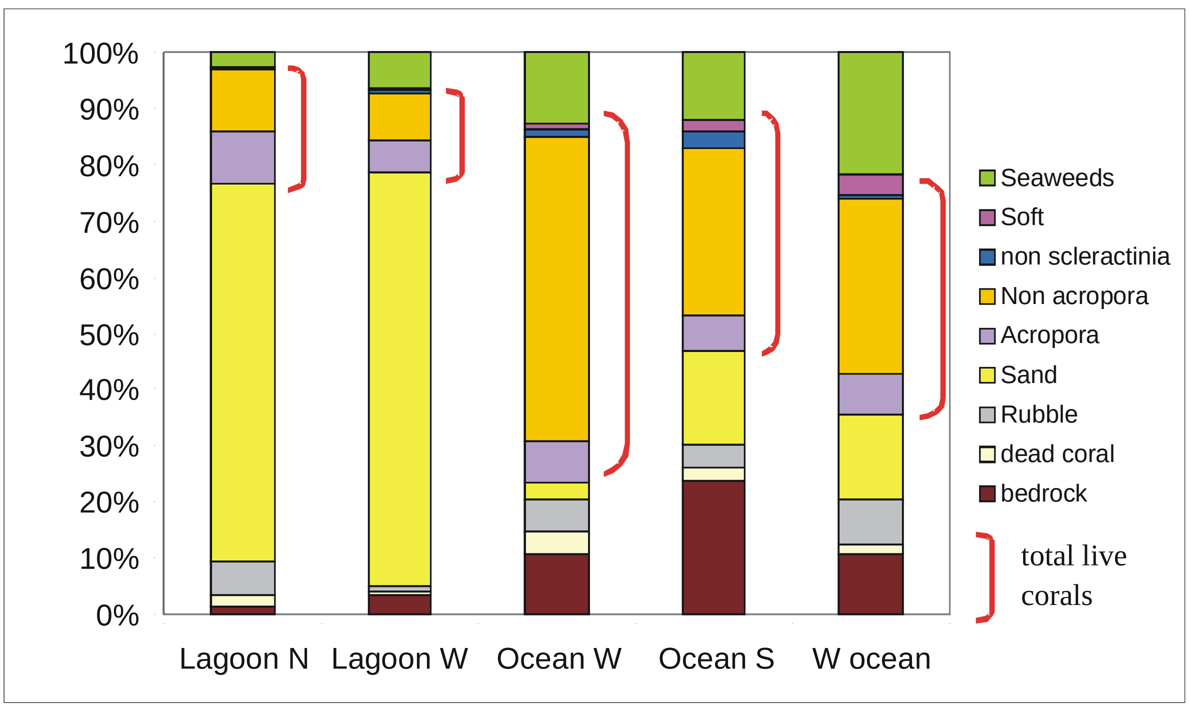
Table 6. Summary of differences of substrate coverage among substrata in five biogeographical locations. Values of p for each independent test are given. (L = lagoon; O = Ocean). Bold characters indicate statistically significant results ($p<0.05$).

	Dead coral	Bed-rock	Rubble	Sand	Sea-weeds	Total live corals	*Acropora*	Non *Acropora*	non scleractinia	Soft
K-W p	0.3	**0.0002**	**0.04**	**0.0003**	**0.005**	**0.0004**	0.31	< **0.0001**	**0.006**	0.30

The proportions of substrata varied for different bio-geographical zones (Figure 5). Sites at Jaboan point were an exception as they contained both lagoon and ocean features in one location. They were included with the Ocean West and Lagoon West zones.

Sand is the typical substrate of lagoon areas, while bedrock and live corals are the typical substrate of ocean sites. Non *Acropora* is characteristic of ocean areas, while *Acropora* does not present preferences, different species being adapted to either ocean or lagoon location. Ocean West zone supports the highest proportional coverage of non *Acropora* corals. In the zone Ocean South, off the Southern side of Rongelap-Rongelap island, and West Ocean – West off the South pass – we recorded more bedrock and sand compared to the Ocean West zone. This is probably related to higher exposure compared to the West Ocean (at the tip of the island and on East side of the pass). Seaweeds were of very low abundance at the northern lagoon locations.

Figure 5. Relative percentage of substrate coverage among 5 bio-geographical zones.



3.2.2 Coral target species

In the previous section we analyzed substrata coverage, which included coral target species in the total live coral cover. We here look more closely at patterns within the target coral assemblages. We selected 17 most abundant (highest record at a site > 10 %) or most recurrent (present at least at 5 sites) species or genera of coral (**Error! Reference source not found.**) and analyzed their distribution at the three depth layers, at the two locations lagoon and ocean, and among the six different geographical areas.

3.2.2.1 Depth

There was no significant preference of corals for certain depths from our data. All genera and species were distributed relatively homogenously across depths. Only *Acropora palifera/cuneata* has sharp depth preference and it is most abundant at the shallower layer (>10m; p k-w = 0.02, Figure 6).

Figure 6. Depth preference in *Acropora palifera/cuneata* (Cricketbat coral).

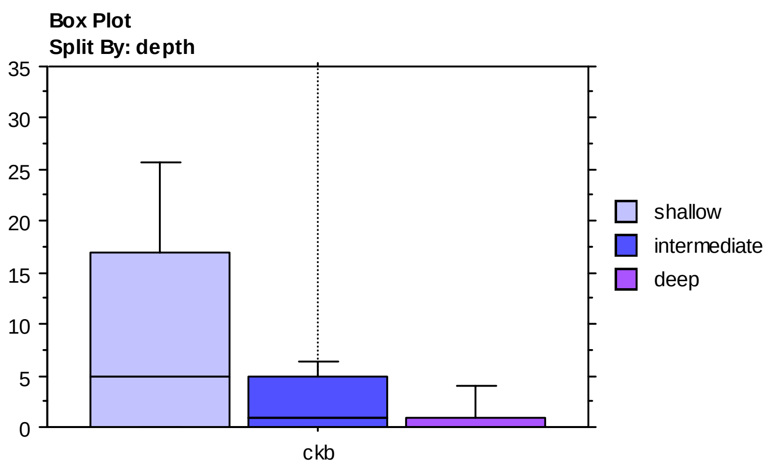


Table 7. Selected target coral species and genera for comparisons of coverage, based on abundance (highest record at one site > 10 %) and recurrence (present at least at 5 sites). Bold corals had presence > 15 and total abundance > 5%, used in the regional differences analysis.

Species or genus	Common name	Abbreviation	No. of sites present	Max coverage (%)
Acropora palifera/ cuneata	**Cricketbat coral**	**Ckb**	**22**	**32**
Porites lobata/austrlaliensis…	**Lobe coral**	**Lob**	**34**	**32**
Seriatopora hystrix	**Thorn coral**	**Th**	**22**	**22**
Porites cylindrica	**Gingerroot coral**	**Gr**	**19**	**18**
Montipora spp.	**Sand paper coral**	**Sdp**	**22**	**16**
Pocillopora verrucosa	**Medium Broccoli coral**	**Mbc**	**15**	**10**
Pocillopora damicornis	Broccoli coral	Bc	12	9
Stylophora pistillata	Finger coral	Fn	11	8
A. subglabra/echinata/speciosa	Bottlebrush *Acropora*	BB	6	8
Favites spp.	**Crater coral sharing**	**Cs**	**20**	**7**
Favia spp.	**Crater coral with valleys**	*Cv*	**15**	**5**
Astreopora	**Volcano coral**	**Vo**	**26**	**6**
Heliopora coerulea	Blue coral	Bl	14	6
Pocillopora eyduoxi/…	Large Broccoli coral	Lbc	10	5
Leptastrea spp.	**Angular crater coral**	**Ac**	**14**	**5**
Oulophyllia spp.	Large brain coral	Lbr	11	3
Ctenactis echinata, Herpolita limax	Long mushroom	Lmu	11	2

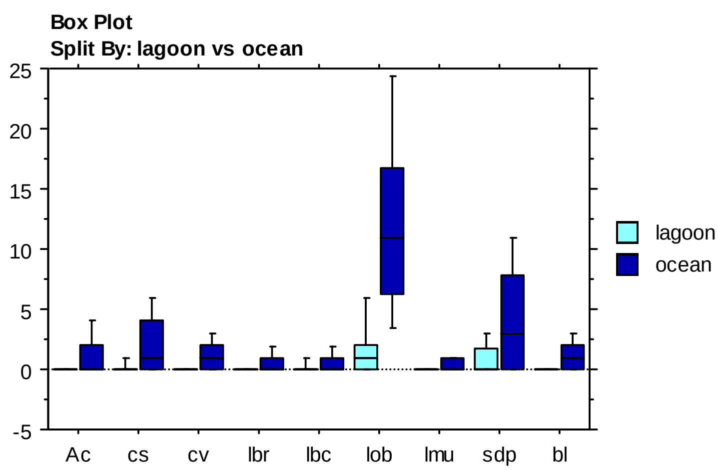
3.2.2.2 Ocean vs lagoon

Depending on habitat and physical conditions, differences in the coral communities in lagoon and ocean sites should be expected. The lagoon waters are shallower, and more turbid, and support mainly small patch-reefs on sandy substratum. Ocean waters are very clear, allowing light to penetrate deeper. Significant differences between these two locations were shown for *Leptastrea*, *Favites*, *Favia*, *Oulophyllia*, *Pocillopora eyduoxi*, *Porites* massive, C. *echinata*/*H. limax*, *Monitopora* and *Helipora coerulea* (in bold in Table 11). All of these corals are significantly more abundant at the ocean sites. The differences between these corals were often due to a lack of species or genera at sites inside the lagoon (Figure 7). This could be a function of the relative scarcity of patch-reefs which makes encountering them on a 50 m transect difficult. More likely, however, these species/ genera were less common or lacked on the small patch-reefs.

Table 8. Difference of abundance between lagoon and the ocean sites, analyzed by t-tests for the 17 most recurrent species and genera.

Species or genus	P t-test	Lagoon Mean	Lagoon Standard deviation	Ocean Mean	Ocean Standard deviation
A. palifera/cuneata(ckb)	0.2	2.2	8.2	5.2	6.4
***Porites lobata/austrlaliensis* (lob)**	**<0.0001**	**1.6**	**2.4**	**12.3**	**7.8**
Seriatopora hystrix (th)	0.6	2.2	5.6	1.6	2.7
Porites cylindrica (gr)	0.15	1.2	2.8	3.3	5.1
***Montipora spp.*(sdp)**	**0.02**	**1.0**	**1.7**	**4.1**	**4.7**
Pocillopora damicornis (bc)	0.09	0.07	0.3	0.9	1.8
Pocillopora verrucosa (mbc)	0.09	0.5	1.8	1.8	2.5
Stylophora pistillata(fn)	0.12	0.13	0.4	0.9	1.8
(bb) (bottlebrush Acropora)	0.4	0.2	0.6	0.6	1.7
***Favites spp.* (cs)**	**0.003**	**0.2**	**0.4**	**2.1**	**2.3**
***Favia spp.*(cv)**	**0.002**	**0.07**	**0.3**	**1.3**	**0.3**
Astreopora (vo)	0.3	0.9	1.6	1.5	1.4
***Heliopora caerulea* (bl)**	**0.005**	**0**	**0**	**1.2**	**1.5**
***Pocillopora eyduoxi/…*(lbc)**	**0.2**	**0.13**	**0.4**	**0.6**	**1.2**
***Leptastrea spp.*(Ac)**	**0.01**	**0.07**	**0.3**	**1.3**	**1.7**
***Oulophyllia spp.*(lbr)**	**0.01**	**0**	**0**	**0.6**	**0.8**
***Ctenactis echinata, H. limax* (lmu)**	**0.04**	**0.07**	**0.3**	**0.4**	**0.57**

Figure 7. Differences of coverage between ocean and lagoon sites for selected species.



3.2.2.3 Geographical zones

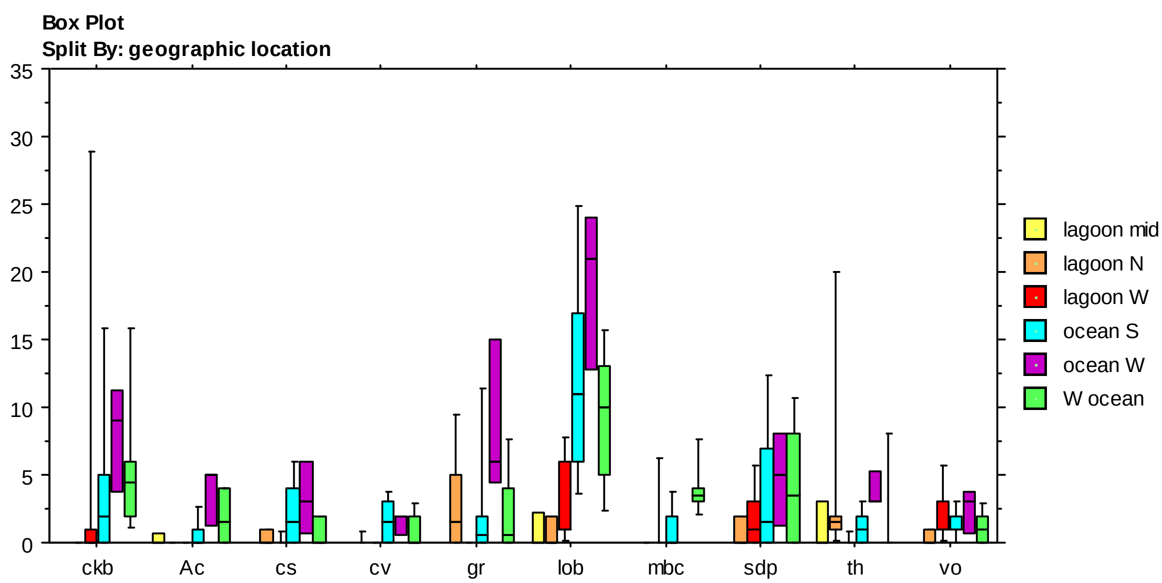
Among the 17 selected target species we specifically analyzed the ones that have presence > 15 and total abundance > 5% for differences among bio-geographical zones (compare Table 10), corals in bold). The selected corals showed some variation among the zones. We applied the Kruskal-Wallis test for multiple comparisons to illustrate the differentiations (Table 9).

Almost all the selected categories had preferential geographical locations, where they were more abundant than anywhere else. Only *Leptastrea*, *Montipora* and *Astreopora* were not significantly different among the regions. *Acropora palifera/cuneata*, (ckb), *Favites* (cs), *P. cylindrica* (gr), *Porites massive* (lob) and *Seriatopora hystrix* (th) showed higher abundance at the ocean west locations (OW) – off the Western tip of Rongelap-Rongelap. The genus *Favia* (cv) was more abundant at the Southern ocean (SO) locations and *Pocillopora verrucosa*(mbc) at the outer pass location (West ocean, WO, Figure 8).

Table 9. Difference of selected coral target species/genera among the zones. (P_{K-W} = probability value, P< 0.05 = significant).

Species or genus	Common name	Abbr.	P_{K-W}
A. palifera/cuneata	**Cricket-bat coral**	**Ckb**	**0.006**
Leptastrea spp.	Angular crater coral	Ac	*0.06- ns*
Favites spp.	**Crater coral sharing**	**Cs**	**0.004**
Favia spp.	**Crater coral with valleys**	*Cv*	**0.01**
Porites cylindrica	**Gingerroot coral**	**Gr**	**0.0002**
Porites lobata/australiensis…	**Lobe coral**	**Lob**	**0.0001**
Pocillopora verrucosa	**Medium Broccoli coral**	**Mbc**	**0.002**
Montipora spp.	Sand paper coral	Sdp	*0.24 – ns*
Seriatopora hystrix	**Thorn coral**	**Th**	**0.03**
Astreopora spp.	Volcano coral	Vo	*0.27- ns*

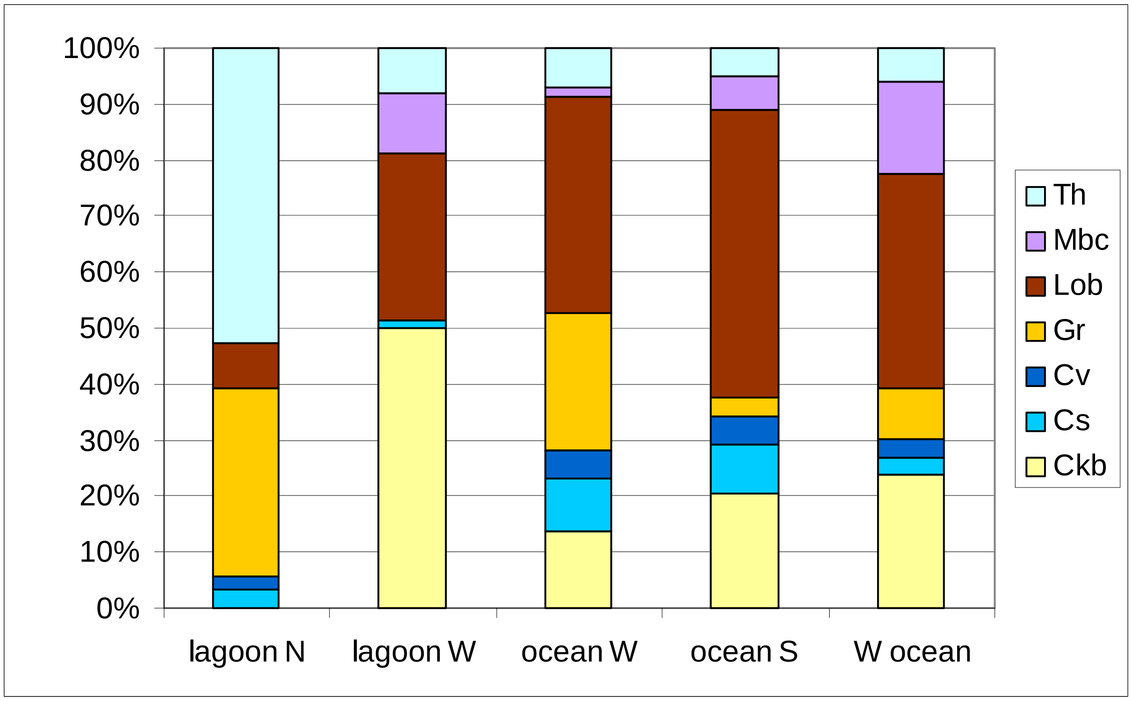
Figure 8. Difference of distribution of 10 selected coral species/genera among five bio-geographical zones.



We used these differences to describe the composition of each geographical zone by composition of most abundant and recurrent species and taxa (Figure 9).

The region at the North side of the island, on the lagoon side, is mostly composed by *P. cylindrica* (gr) and *S. hystrix* (th). The Western side of the island, on the lagoon side, is instead mostly composed by *A. palifera/cuneata*, especially around Jaboan Point, and *P. lobata*/*austr*...
All ocean regions had high coverage of both *P. lobata* and *A. palifera/cuneata*, but the Ocean West area (ocean side of Jaboan point) supported a higher coverage of *P. cylindrica* and less *Pocillopora verrucosa* compared to the other two regions on the ocean side. The region off the Southern pass (W ocean) showed higher coverage of *P. verrucosa* and less *Favia* and *Favites.*

Figure 9. Composition of each geographic zone by the selected coral species.



3.2.3 Fishes

The fishes counted to the level of species or genera along the transects were grouped by families. The most abundant and recurrent ones were analysed for comparison of their total abundance at the different sites (Table 10). The totally most abundant family were the Pomacentridae (Damselfishes). The second most abundant fish family is the Apogonidae (Cardinalfish) (Figure 10).

Table 10. Fish families that are most abundant (> 100). In bold the ones with strong ecological significance or commercial value.

English common name	Latin name	Total abundance	Total abundance / m^3
Damselfishes	Pomacentridae	6,478	0.126
Cardinalfishes	Apogonidae	1,787	0.035
Groupers	**Serranidae**	**847**	**0.017**
Surgeonfishes	**Acanthuridae**	**831**	**0.016**
Wrasses	**Labridae**	**619**	**0.012**
Mackerels	**Scombridae**	**536**	**0.010**
Parrotfishes	**Scaridae**	**410**	**0.008**
Fusiliers	**Caesionidae**	**320**	**0.006**
Butterflyfishes	**Chaetodontidae**	**255**	**0.005**
Jacks	**Carangidae**	**204**	**0.004**
Snappers	**Lutjanidae**	**199**	**0.004**

Figure 10 shows the relative abundance of the all fish including cardinalfish and damselfish, clumping together the rest of the families. The high predominance of these two families in terms of numbers is clear in this graph. Figure 11 shows the percentage of total abundance of the major fish families (excluding Damselfish and Cardinalfish, that are the most abundant ones but have almost no commercial significance). Surgeonfish (Acanthuridae), Groupers (Serranidae), Makerels (Scombridae) (including some reef visiting tunas) and Parrotfish (Scaridae) were the most important in terms of abundance. However, the high abundance of Makerels was due to one observation at R13, off the Southern pass.

Figure 10. Relative abundance of the all fish including cardinalfish and damselfish, clumping together the rest of the families. This graph shows the high predominance of these two families in terms of numbers.

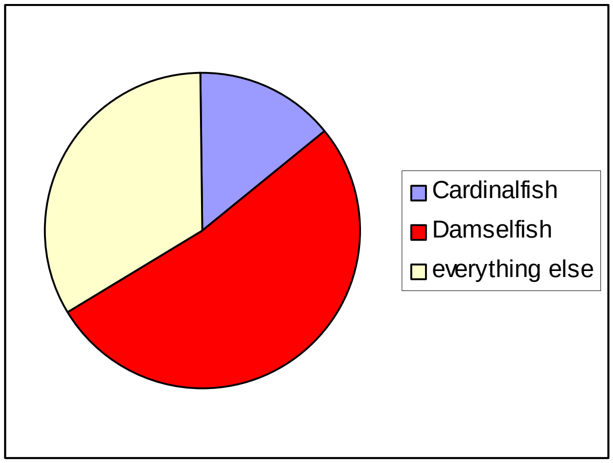
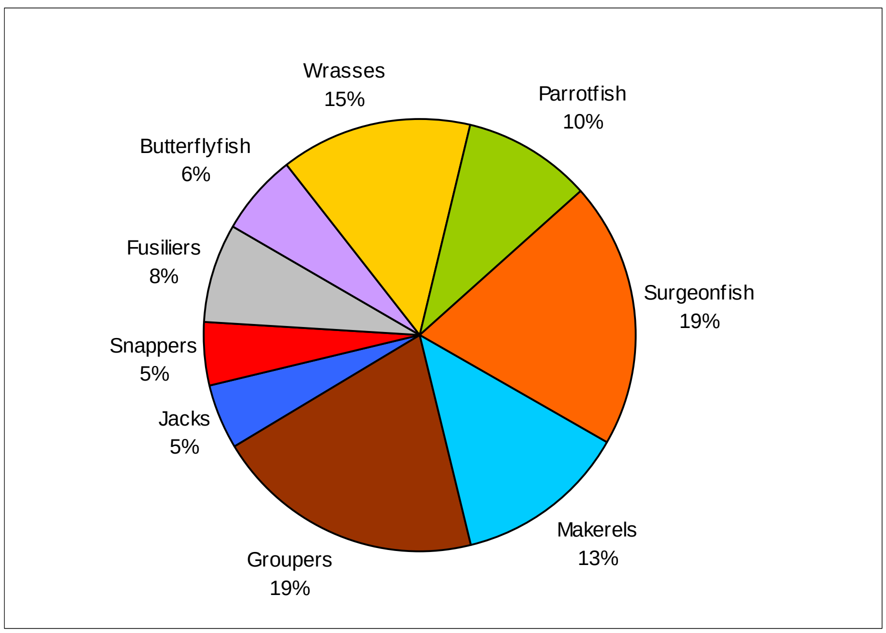


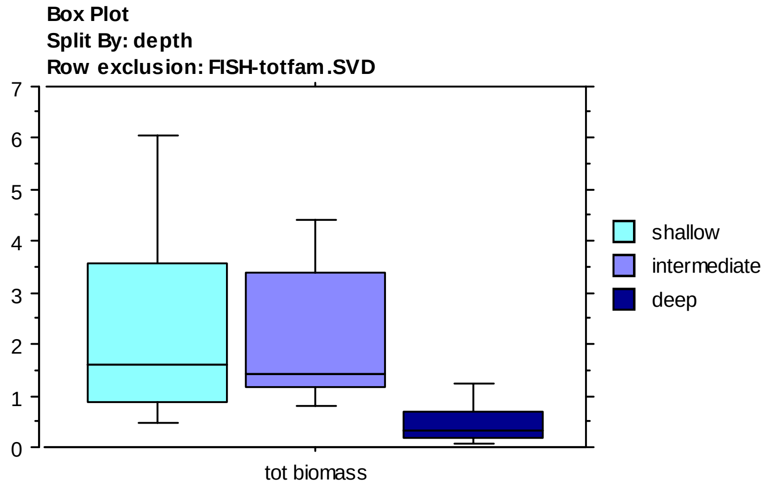
Figure 11. Relative abundance of the most important fish families in percent.



3.2.2.4 Depth

None of the fish families showed preference of depth in the depth range adopted in the surveys. However, biomass was significantly higher ($P_{K\text{-}W} = 0.0009$) at the first two layers (between 5 and 15 m, approximately), meaning that larger sizes of fish were found at this depth (Figure 12).

Figure 12. Distribution of total fish biomass at the three layers ($p_{K\text{-}W} = .0009$).



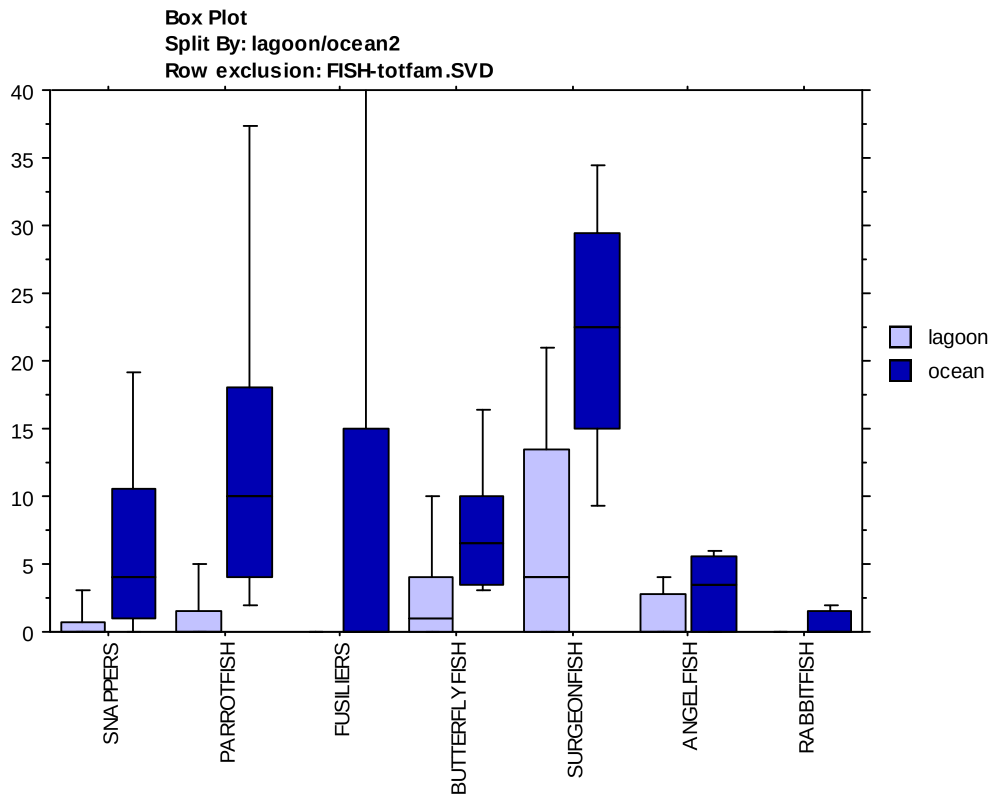
3.2.2.5 Ocean vs lagoon

Snappers, Parrotfishes, Fusiliers, Butterflyfishes, Surgeonfishes, Angelfishes (total abundance <100, in italics in Table 11), Rabbitfish (total abundance < 25, in italics in Table 11), showed significant differences in between the two zones. All of these fish families were more abundant in the ocean side (Figure 13). Angelfishes and Rabbitfishes were included in this analysis, although their abundance is less than 100 total counts, because they displayed a significant difference between the two habitats.

Table 11. Abundance of fish families showing difference of distribution between lagoon and ocean sites.

Family	p t-test	Lagoon		Ocean	
		Mean	St Dev	Mean	St Dev
Surgeonfishes	0.01	8.9	13.6	27.4	24.6
Parrotfishes	0.05	2.3	6.4	19.1	32.4
Fusiliers	0.05	0	0	12.6	23.6
Butterflyfishes	0.05	3.8	7.0	7.7	5.2
Snappers	0.02	0.78	1.5	7.0	9.5
Angelfishes	0.02	3.8	7.0	7.7	5.2
Rabbitfishes	0.04	0	27.4	0.8	1.4

Figure 13. Distribution of total abundance in lagoon and ocean sites for the most abundant families. Numbers are average values.



3.2.2.6 Geographical zones

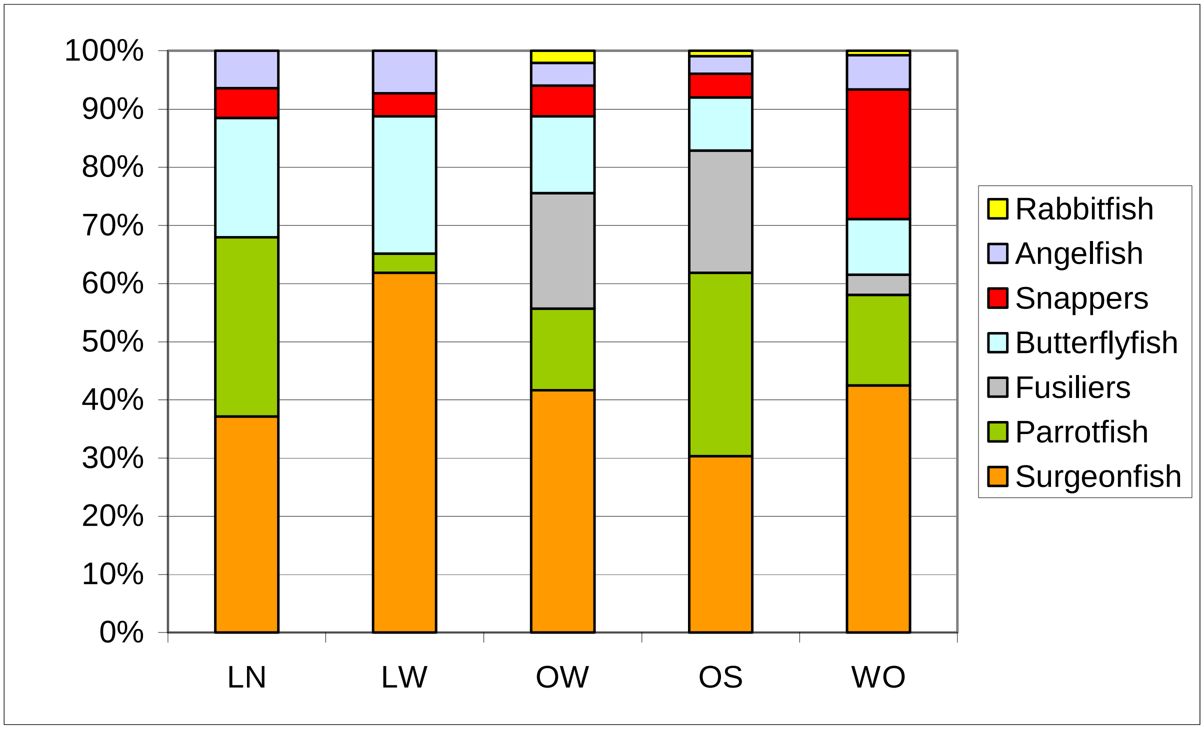
Varied fish assemblages were expected in the five distinct regions, as there were both differences in habitat and coral communities. The Kruskal-Wallis multi-comparison test to analyze difference in distribution among the five geographic zones resulted positive for 6 families (Table 12). This means that fish communities differed between the locations.

Table 12. Distribution of fishes among five zones, PKW<0.05 = significant.

Latin name	English common name	P_{KW}
Acanthuridae	Surgeonfish	0.004
Scaridae	Parrotfish	0.001
Chaetodontidae	Butterflyfishes	0.03
Lutjanidae	Snappers	0.0003
Pomacanthidae	Angelfish	0.01
Serranidae	Emperors	0.001

Each bio-geographical zone showed a distinct species composition (Figure 14). Surgeonfishes had a very irregular distribution, and they were found in large abundance in both lagoon and ocean sites. Lagoon regions had proportionally more butterflyfishes than the ocean regions. Rabbitfishes lacked in the lagoon areas, however they were seen on fish diversity surveys, which covered a larger area. The Northern lagoon zone contained a relatively abundant parrotfishes assemblage. Amongst the ocean areas, West Ocean (off the Southern pass) had the least relative abundance of Fusiliers and more Snappers. The Ocean South area held a comparatively higher number of Parrotfish than the other ocean areas.

Figure 14. Average abundance distribution of fish families among the five zones.

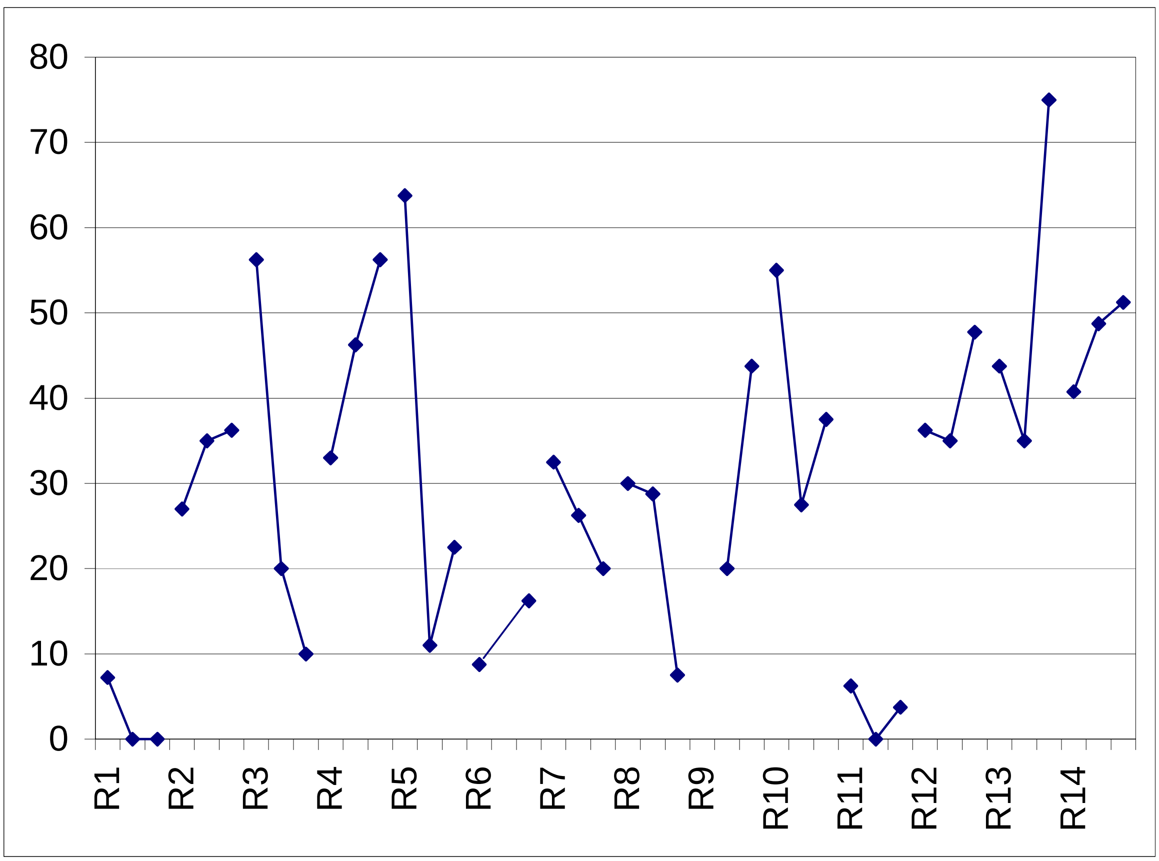


3.2.4 Seaweeds

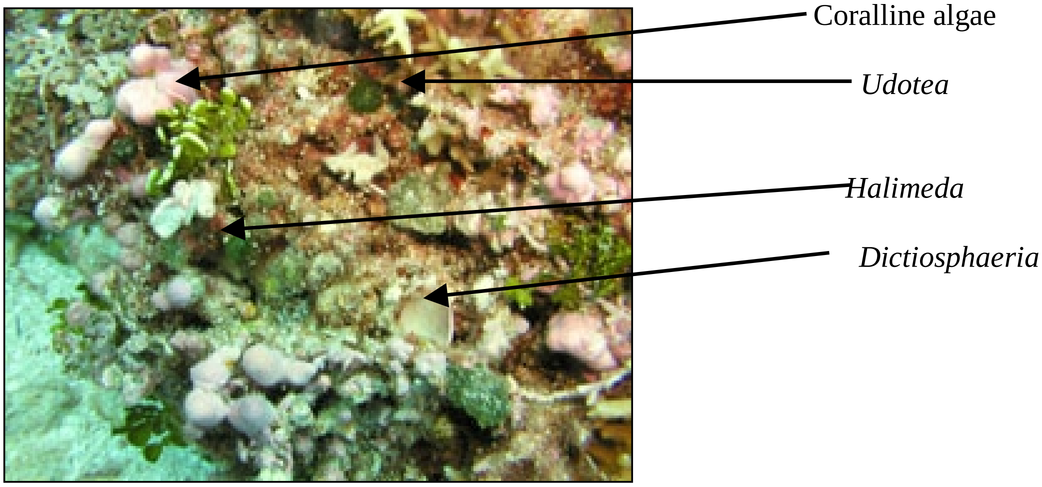
The total coverage of seaweeds varied between 0% and 75%. Ocean sites appeared in certain areas to be fairly covered by algae, but not to the point of overgrowing the corals (Figure 15). The most common seaweeds (in terms of presence and abundance) were *Micriodyction*, *Halimeda*, *Udotea/Avrainvillea* group, red coralline algae, and blue-green algae.

Macroalgae communities on rock substratum were very diverse (Photograph 1). Most overhangs and caves were dominated over by several species of *Halimeda*. *Microdyction* competes with *Halimeda*, but these two main seaweeds cover different depth layers, with *Microdyction* usually deeper than *Halimeda*. *Halimeda* is a genus that is able to invade any habitat, from sand flats, to caves, bedrock, dead coral, overhangs, and at any depth (Photograph 2).

Figure 15. Seaweed cover (in %) at all sites, missing values for sites R6 and R9. Lines connect three transects in each site. R6 and R9 miss data from one transect.



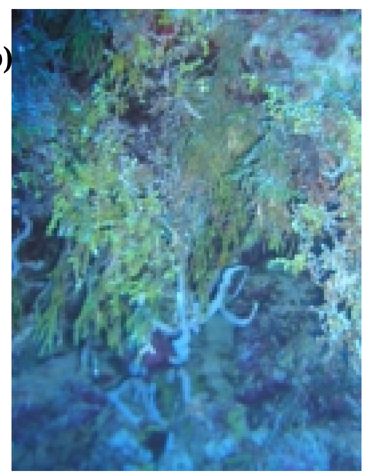
Photograph 1. Algae assemblage with a high diversity of coralline algae and fleshy algae.



Photograph 2. *Halimeda* (a) on sand, and (b) in overhang on reef wall.

(a)

(b)



Algae data were collected by target species/genera list. We selected algae present at more than 10 sites for the subsequent analysis (**Error! Reference source not found.**6).

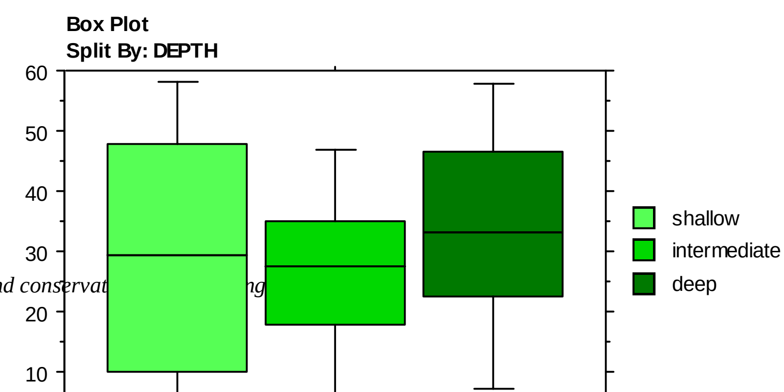
Table 13. Frequency of seaweeds in quadrats at all sites. In bold are algae present at more than 10 sites.

Latin name	Common name	Number of counts
Microdyction	**gauze seaweed**	**51**
Halimeda	**sand seaweed**	**111**
Udotea/Avrainvillea	**fan seaweed**	**41**
Lithophyllum	**coralline pink**	**20**
***Phormidium* sp**	**purple hairy**	**41**
Dictyosphaeria cavernosa	large bubble	1
Dictyosphaeria verslusii	small bubble	1
Venticaria ventricosa	sinking dark marble	1
Caulerpa serrulata	saw-blade	7
Caulerpa racemosa	sea grape	5
Caulerpa sertularioides	feather	1
Caulerpa	little daisy	1
Codium spp.	green velvet	2
Neomeris annulata	green finger	1
Enteromorpha cf	green filamentous	2
Jania spp.	purple spikes	1
Asparagopsis spp.	red fringy	1
Oscillatoria sp.	Red mat	2

3.2.4.1 Depth

The coverage of seaweeds does not change substantially among the three depth layers (Figure 16). This indicates a homogeneous distribution of macroalgae across the depths. However, it is likely that algae communities would change if deeper depths were included. The very clear waters around Rongelap- Rongelap island probably meant that the expected community shift could not yet be detected at 18 m depths.

Figure 16. Variation of seaweeds coverage among the three depths, in % coverage.



3.2.4.2 Ocean vs Lagoon

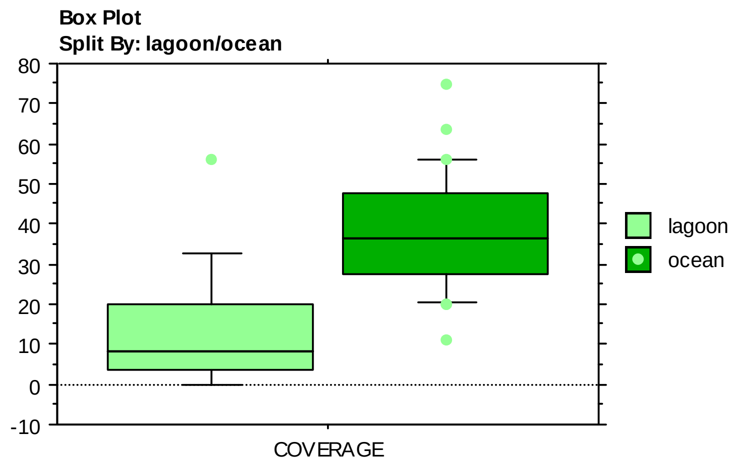
Both coverage and number of identified species were significantly more abundant at the ocean sites, as shown in Figure 17. In the lagoon, they were found on sandy substrate as well as boulders and bommies.

Figure 17. Statistical characteristics of algae coverage in lagoon and ocean sites, (a) mean algae coverage and probability value associated to *t*-test (P), (b) difference in algae coverage.

a)

P < .0003	lagoon	ocean
Mean	13.9	38.7
Std. Deviation	15.6	14.5

b)



3.2.4.3 Geographical zones

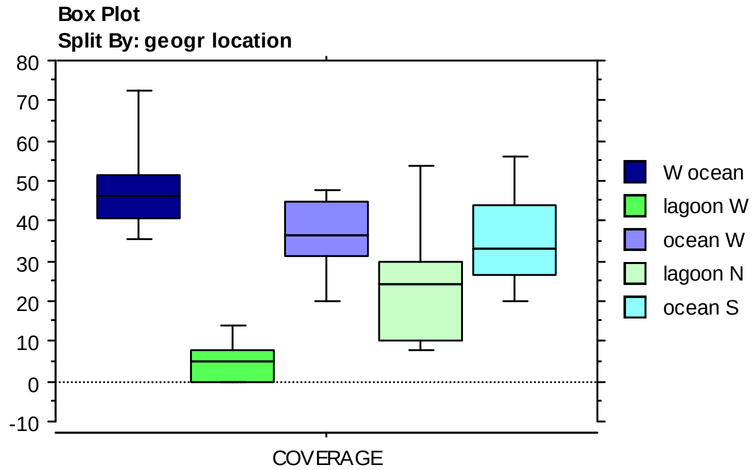
When studying the coverage of total seaweeds among the five geographical zones, we discovered sharp differences in the algal communities and coverage (Figure 18 and

Table **14**). Value of *p* for the Kruskal-Wallis test of multiple comparison = 0.0002. Total coverage was highest at the West Ocean sites (west off of Southern pass), and lowest at the lagoon west sites.

Table 14. Values of mean and standard deviation for total coverage of seaweeds in percent (StDev= standard deviation, P_{KW} = probability value associated with the Kruskal-Wallis test of differences among groups average values). P = 0.0002.

Geographical area		Coverage (%)
Lagoon N	Mean	25.4
	StDev	17.7
Lagoon W	Mean	5.3
	StDev	5.6
Ocean W	Mean	36.6
	StDev	10.7
Ocean S	Mean	35.3
	StDev	14.6
W Ocean	Mean	49.1
	StDev	13.9

Figure 18. Difference of algae coverage among the five bio-geographic zones.

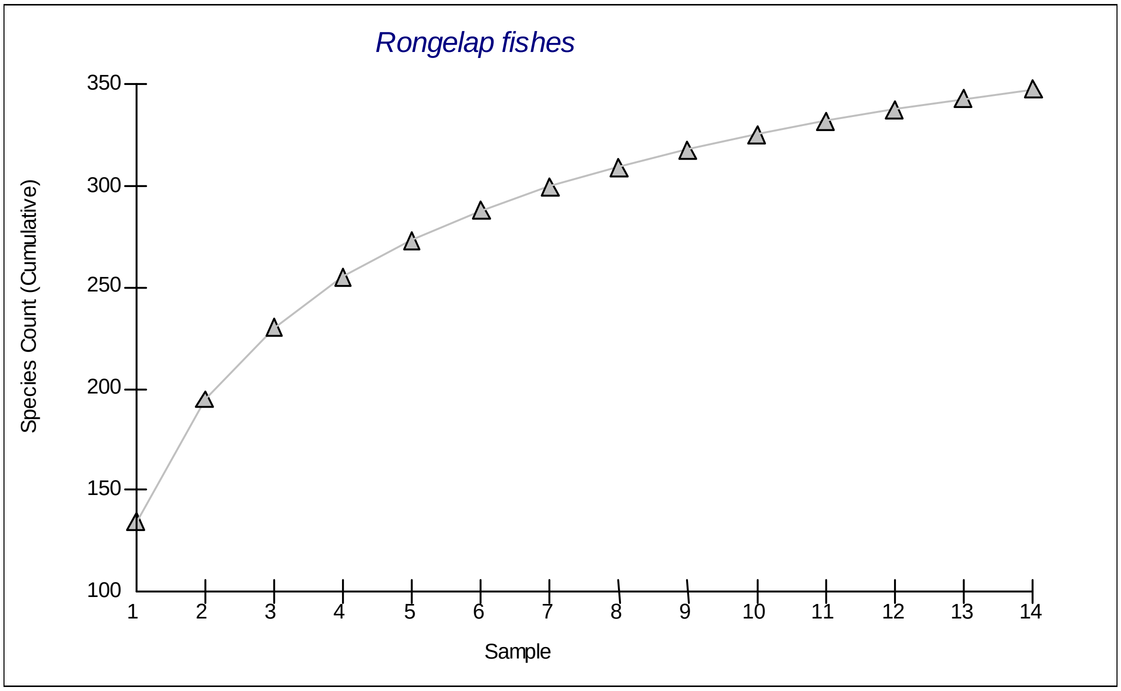


3.3 Diversity data

3.3.1 Fish diversity

A total of 361 fish species were recorded from Rongelap atoll. They were observed on dives at 14 sites, additional dives and snorkels undertaken in the area. Fishes observed on the 14 sites exclusively amount to 339 species. With higher sampling effort a much higher total species number can be expected. Randall and Randall (1987) report 817 reef, shore and epipelagic fishes from the Marshall Islands, Allen (2002) refer to a total of 795 reef fishes for the Marshall Islands overall. The species accumulation curve from this survey suggests that a high number of additional species can be expected if the area is increased and more dives are carried out (**Figure 19**). Assuming that each dive adds a few new species to the accumulated total number, after around 50 to 60 dives a plateau is reached for a small regional setting such as an embayment, atoll or group of islands. At the plateau, only 1 to 2 species are added per dive (Fenner, pers.comm., Beger, unpublished data). At Rongelap we were still adding 10 to 15 species per dive. In order to compile a comprehensive fish species list for the entire Rongelap atoll, a wider range of sites must be sampled. Considering the small size of Rongelap Rongelap, however, it is indicative of the health and pristine condition of these reefs that we recorded more than half of the fishes known from the Marshall Islands.

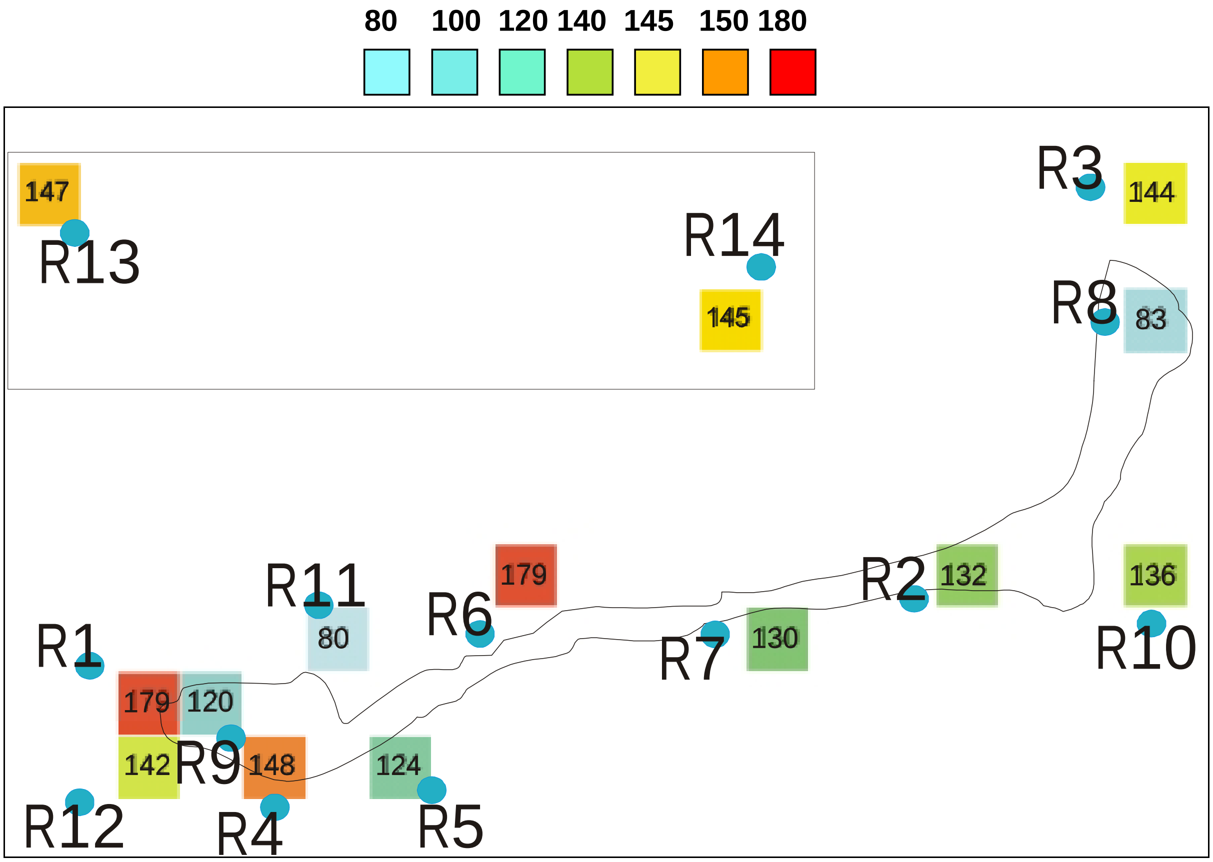
Figure 19. Species-area accumulation curve for fishes of Rongelap atoll for 14 sites, data from single dives only.



Amongst the sampled sites on Rongelap island and the southern atoll, species numbers per site varied greatly (

Figure 20). The number of fish species at each site varied from 80 to 179, with an average of 135 species (28.5 Standard Deviation). The highest fish species counts with 179 species per site were reported at R1 in the pass at Jaboan and R6, a lagoon site. Lagoon sites vary greatly in their fish biodiversity, depending on the numbers, size and variety of coral mounds scattered on the sandy substratum. The outer wall sites on the oceanward side of the island supported a relatively uniform fish biodiversity. The tip of the island (R1 in Jaboan) supported a particularly high variety of fishes, because its variety of habitats includes both exposed wall and lagoonal features.

Figure 20. Fish species richness at sites on Rongelap Rongelap and southern islands (inset, for exact location compare Figure 1), numbers in colored squared represent total fish species richness on a color scale (red – richest, blue – poorest sites).



3.3.1.1 *Community structure of fishes*

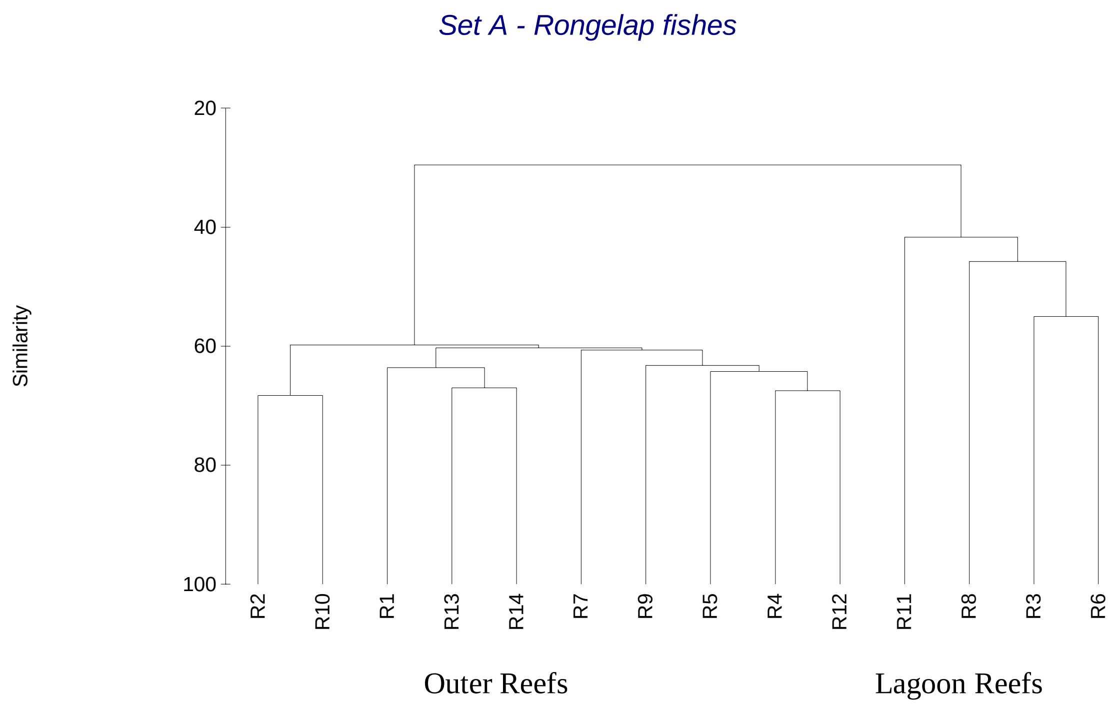
The fish fauna of Rongelap atoll was mainly composed of species associated with coral reefs. The moray eel family (Muraenidae) was expected to be one of the most speciose groups (compare Randall and Randall, 1987). However on this project not many species were detected owing to their cryptic habits. They are best sampled using strong liquid ichthyocides such as rotenone, which were avoided on this trip to minimize impacts. Although the goby family (Gobidae) ranked highly amongst the families, it was not adequately sampled owing to their crypticism and small size. One of the shortcomings of the visual census methodology used on this survey is that it often fails to detect cryptic and nocturnal species. These species live in crevasses and caves, are extremely small, have a camouflaged color pattern or hide during the day.

As mentioned above, we aimed to distribute sampling sites evenly between the sheltered lagoonal reef and the exposed outer walls. Fish communities are distinctly different at these parts of the atoll. The steep outer drop-offs harbor several epi-pelagic species such as Bluefin Jacks (*Caranx melampygus*) and Rainbow Runners (*Elagatis bipinnulata*). Several fishes only occur at the deeper section of the wall below 30 m of depth, such as Helfrich's Dartfish (*Nemateleotris helfrichi*) and Starck's Tilefish (*Hoplolatilus starki*). Other specialists are associated with the outer reef surge and are only found in the exposed shallows. Such species included, but were not limited to, the Achilles Tang (*Acanthurus achilles*), the Whitespotted Surgeonfish (*A. guttatus*), mixed roaming schools of parrotfish (*Chlorusus frontalis, Scarus altipinnis, Cetoscarus bicolor*), and the Midget Chromis (*Chromis acares*).

The sheltered lagoon habitats supported different fish species, which were surprisingly diverse and abundant. Most fishes were found associated with patch reefs on the sandy substratum. Large schools of herbivorous fish were observed roaming between these coral bommies, usually these schools included surgeonfish and parrotfish. An abundant variety of groupers was found near and on the patch reefs. They were significantly more diverse in the lagoon sites than the outer sites. The most abundant species were the Highfin Grouper (*Epinephelus maculates*) and the Speckled Grouper (*Epinephelus cyanopodus*). A number of specialist species was reported from the sheltered shallow zone that only experiences mild surge. The most prominent species observed were sergeant damselfishes (*Abudefduf sordidus*) and the Grey Demoisielle (*Chrysiptera glauca*).

A cluster analysis based on Bray-Curtis similarity was used to determine community patterns in the fishes. The resulting dendrogram illustrates the distinctive separation of lagoon and outer reef habitats, which clustered with 42 percent and 60 percent similarity respectively (Figure 21).

Figure 21. Dendrogram of Bray-Curtis similarity illustrating distinct fish communities for lagoon and outer reefs.



3.3.1.2 Endemism and Rarity

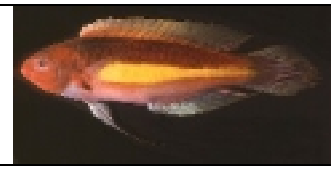
Considering the ability of marine fish larvae to disperse in the water column and travel with ocean currents, there are few endemic species on coral reefs compared to terrestrial environments. However, the Marshall Islands are relatively isolated in the Central Pacific, with the northern atolls being particularly remote. Huge distances to possible sources of larvae with few in between as stepping stones for species dispersal, a prevailing north-easterly wind and current and large distances between atolls have facilitated the development of several unique species of fish endemic to the Marshall Islands or the northern central Pacific. Endemic species are fished that only occur in a restricted geographical range.

The following endemic species were observed:

Cirrhilabrus rhomboidalis (Randall) – This small wrasse is only known from the Marshall Islands, with specimen collected from Kwajalein. It only occurs below 40m (120ft) on outer reef slopes, and aggregates in groups above the substratum (picture from Fishbase, (2002).

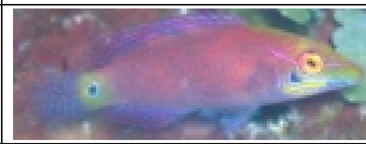
Cirrhilabrus balteatus (Randall) – This small wrasse occurs in medium sized aggregations at a depth range from 10 to 25m on the outer exposed reef slopes, but also around larger patchreefs inside the lagoon. It is endemic to the Marshall Islands (picture from Fishbase, 2002).

Cirrhilabrus luteovittatus (Randall) – This small wrasse occurs in medium sized aggregations at a depth range from 10 to 25m on the outer exposed reef slopes. It is only found in the Marshall Islands, Phonpei and the Caroline Islands (picture from Fishbase, 2002).

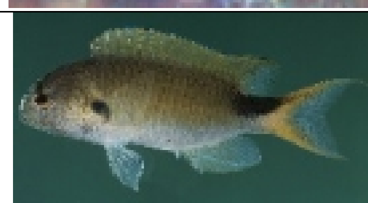


Cirrhilabrus sp. (possibly *katherinae*) – This small wrasse occurred on the outer drop-off on Rongelap Rongelap, and the southern islands (site R13). After consultation with John E. Randall from a picture we believe that the wrasse observed is either a new species, or a species not previously recorded from the Marshall Islands (*C. katherinae*).

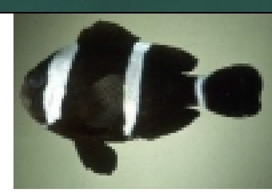
Pseudocheilinus ocellaris (Randall) – This bright coloured wrasse is only found below 25m of depth under ledges and overhangs. It is wary and often difficult to see. It was only recently described from the Northern Marshall Islands (Randall 1999).



Pomachromis exilis (Allen and Emery) – The slender reef damsel is a shallow reef restricted range damselfish, which is only recorded from the Marshall Islands and the Caroline Islands (picture from Fishbase, 2002).

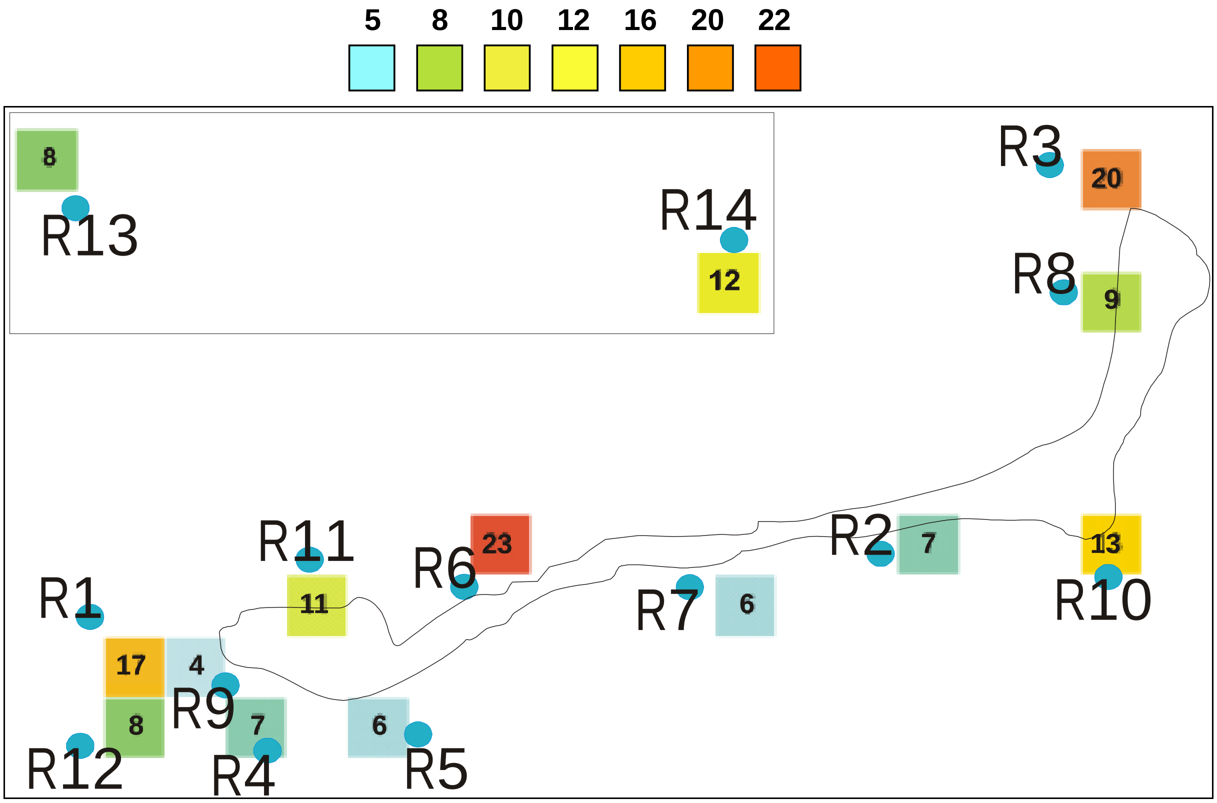


Amphiprion tricinctus (Schultz and Welander) – The three-banded clownfish is endemic to the Marshall Islands. It is relatively common around Rongelap and occurs associated with the anemone *Stichodactyla mertensi* (black fish) and *Heteractis aurora* (orange fish) (Fishbase 2002).



Rare species are fishes that only occur in relatively few spots on a reef, or are so cryptic that it is difficult to assess the probability of their presence at a given site. For coral reef ecosystems, there is little information on rarity and how to manage rare species. Recommendations on the conservation of rare fish species highlight the need to establish marine protected area networks incorporating the appropriate habitats (Jones et al., 2002). To demonstrate the potential locations of rare species on Rongelap atoll, we plotted the abundance of fishes that only occur once or twice throughout the whole dataset (14 sites, Figure 22). The hotspots for rare species richness do only partially overlap with total species richness.

Figure 22. Richness of rare fish species with the threshold of T=2 at 14 sites on Rongelap Atoll. The map shows how many rare fishes were reported from each site, numbers in colored squared represent rare fish species richness on a color scale (red – richest, blue – poorest sites)



3.3.1.3 *Coral Fish Diversity Index (CFDI)*

A leading expert in Indo-Pacific reef fish diversity recently devised a convenient method for assessing expected species richness in a site, a restricted geographic area or a region (Werner and Allen, 1998). Six relatively conspicuous and easy to identify fish families are chosen to calculate the Coral Fish Diversity Index: butterflyfishes (Chaetodontidae), angelfishes (Pomacanthidae), damselfishes (Pomacentridae), wrasses (Labridae), parrotfishes (Scaridae), and surgeonfishes (Acanthuridae). The number of species in these groups is added and inserted in a regression formula for restricted localities less than 2,000 km^2,

$$\text{Total expected fish species richness} = 3.39(\text{CFDI}) - 20.595 \quad (1)$$

that calculates the total expected species richness (Allen, 2002). The fish fauna in Rongelap atoll has a Coral Fish Diversity Index of CFDI= 172 (Table 15). The formula predicts a total expected species number of 562 fish species at Rongelap-Rongelap and the southern part of the atoll. This method enabled us to estimate fish species richness despite the low number of sites and the likelihood that rare or cryptic species were overlooked. It is likely that this number would increase with increasing reef area visited.

Table 15. Number of species from six target fish families at Rongelap atoll

Fish families	Number of Species
Butterflyfishes (Chaetodontidae)	24

Angelfishes (Pomacanthidae)	10
Damselfishes (Pomacentridae)	39
Wrasses (Labridae)	57
Parrotfishes (Scaridae)	16
Surgeonfishes (Acanthuridae)	26
Total CFDI	**172**

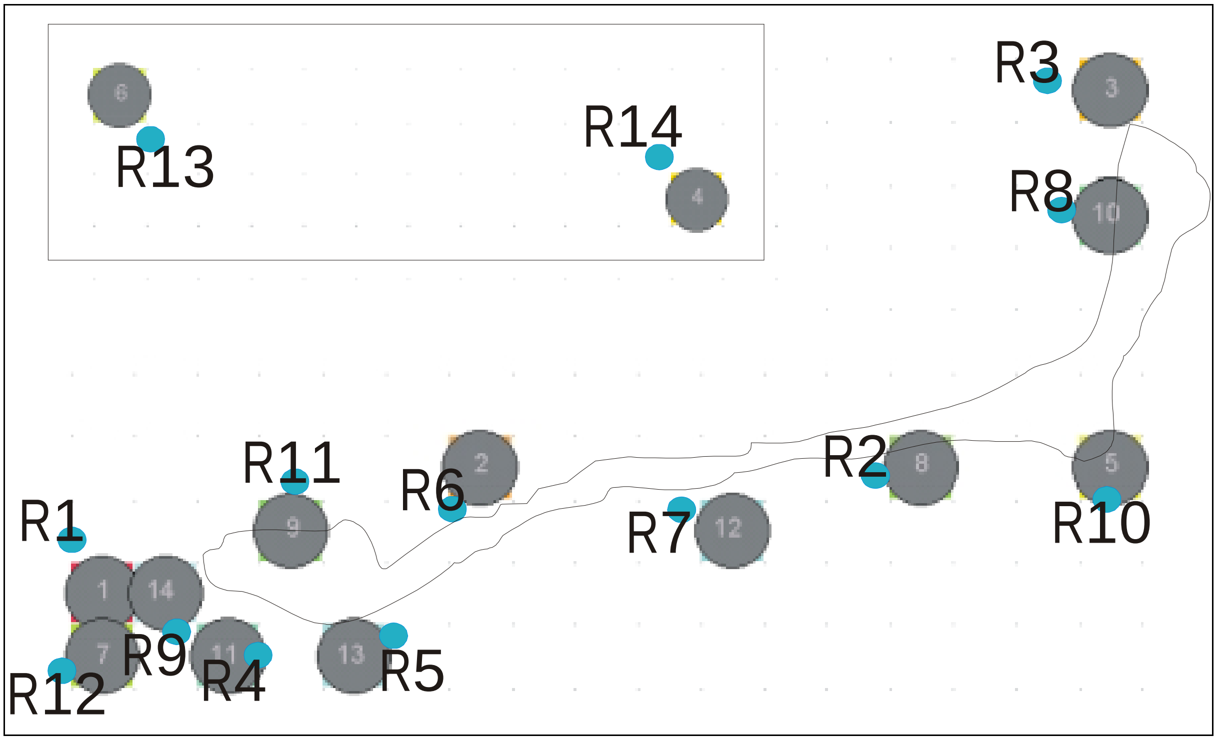
Allen (2002) refers to a CFDI of 221 in the RMI, derived from Randall and Randall (1987). This estimates a total of 822 reef fishes for the whole of the Marshall Islands (using a formula for large regions). Considering the small size of the island, our data captured a large proportion of these fishes, indicating the exceptional status of Rongelap reefs.

3.3.1.4 Marine reserves: Facilitating reef biodiversity conservation

Marine protected areas are a widely recognized means for both fisheries management and the conservation of biodiversity (Roberts et al., 2001, Roberts et al., 2002). It is still a young and little practiced approach to prioritize potential reserve sites by considering the conservation of marine biodiversity. However, procedures based on *complementarity*, where sites are selected to complement each other with respect to the species included in a reserve network, were shown to be most efficient (Beger et al., in press, Leslie et al., in press). We used the complementarity reserve prioritization method to highlight priority sites for coral reef fish conservation on Rongelap island (Figure 23). This illustrates that while the ocean sites support on average a higher number of fishes and more abundant species, the lagoon habitat forms an important ecosystem supporting many rare, habitat specific and cryptic species. In the reserve prioritization for fishes, the first site selected (R1) – a lagoon site- was one of the two sites with the highest species numbers. The second ranked site (R6) was a lagoon site with a highly diverse but distinct fish assemblage. The third site (R3) was also a lagoon site, which contained many rare species (threshold rarity, T=2). This indicates that the importance of lagoonal sites should not be underestimated.

While selection procedures based on diversity are effective for including a large proportion of fishes in a reserve network, there are significant limitations to these approaches. They do not take into account the likely persistence of species in protected areas. A species is considered represented when there is only one or a few individuals in a reserve, which is not likely to represent a viable population. They also do not consider socio-economic factors, fisheries and ownership of adjacent land.

Figure 23. Priority sites for the conservation of fish species richness



3.3.2 Coral diversity

The principle aim of the coral survey was to provide an inventory of coral species and compare the relative coral abundance and diversity at different sites with the view of selecting marine protected areas. The primary group of corals surveyed were the zooxanthellate scleractinian corals (those containing single-cell algae which contribute to building the reef). Also included were 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), and a small number of azooxanthellate corals (*Balanophyllia* and *Stylaster*) which also produce calcium carbonate skeletons and contribute to reef building.

The results of this survey allow a comparison of the faunal richness of Rongelap atoll with other parts of the Pacific and S.E. Asia. However the list of corals presented is probably an underestimation, due to the limited number of sites sampled.

A total of 170 coral species were recorded from surveys of Rongelap atoll. Only 34 corals were previously recorded from Rongelap atoll (Wells, 1954). These results compare well to previous coral surveys in the Marshall Islands. Maragos (1994) found 269 species on a survey of several atolls in the northern Marshall Islands. A recent survey of the neighbouring atoll of Alinginae yielded 192 species (Maragos, pers.comm.). Rongelap atoll is the third largest atoll in the world. Reef survey sites were generally of two distinct types: exposed walls and lagoonal sites. Wall habitats comprised of a narrow fringing reef (up to 50 m wide) and reef crest interspersed with deep channels leading to a steep wall drop-off. Lagoon sites were composed of small patch reefs and bommie developments amongst sand. Further site information is provided elsewhere in this report.

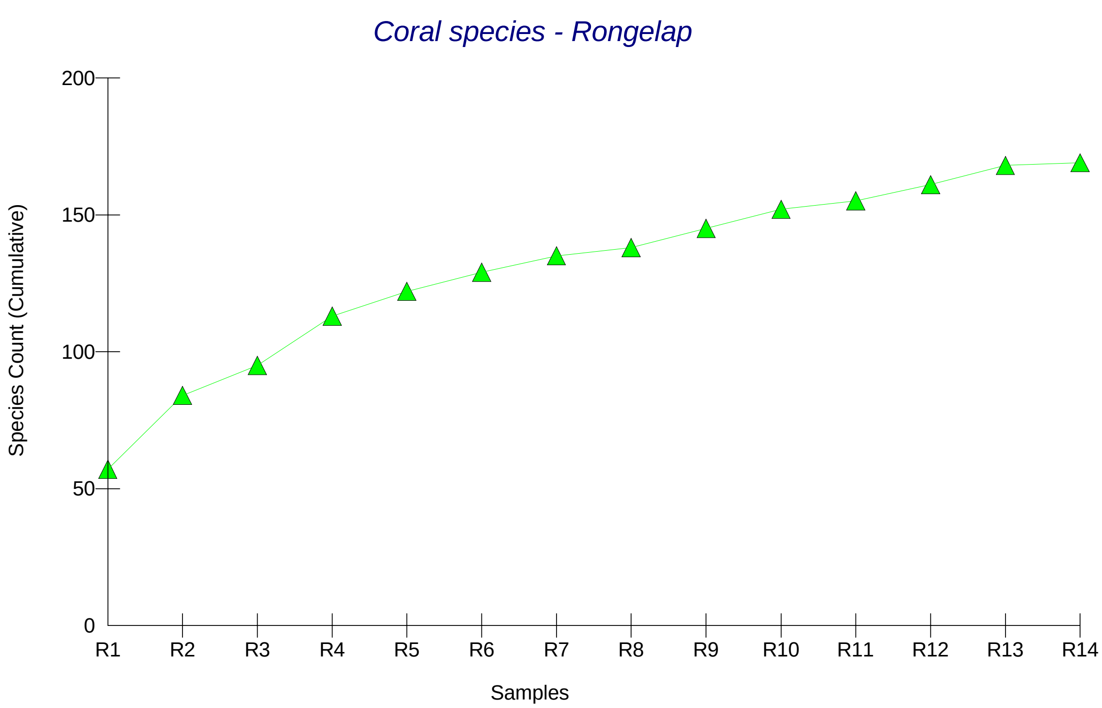
3.3.2.1 Coral Diversity

The coral fauna consisted mainly of Scleractinia. *Acropora* is the most speciose genus (Table 16) followed by *Montipora*. The total coral species richness for Rongelap atoll surpasses previous records (Wells, 1956), yet is still considered to be an underestimation of the actual total coral diversity of the entire atoll. The species accumulation curve (Figure 24) suggests that higher diversity would be expected if the sampling intensity were increased. Thus the entire atoll must be sampled in order to gain a comprehensive species list for Rongelap. Given the limited part of Rongelap atoll that was sampled in this study, the coral diversity is high with respect to the Marshall Islands as a whole which are estimated to have approximately 250 species of coral (Veron and Fenner, 2000), and Bikini atoll, which was surveyed as part of this project and where 198 species of coral were recorded (Richards, personal communication). It is suggested that reefs of Rongelap atoll are very healthy and some of the most pristine atoll reefs in the world.

Table 16. Genera with the greatest number of species.

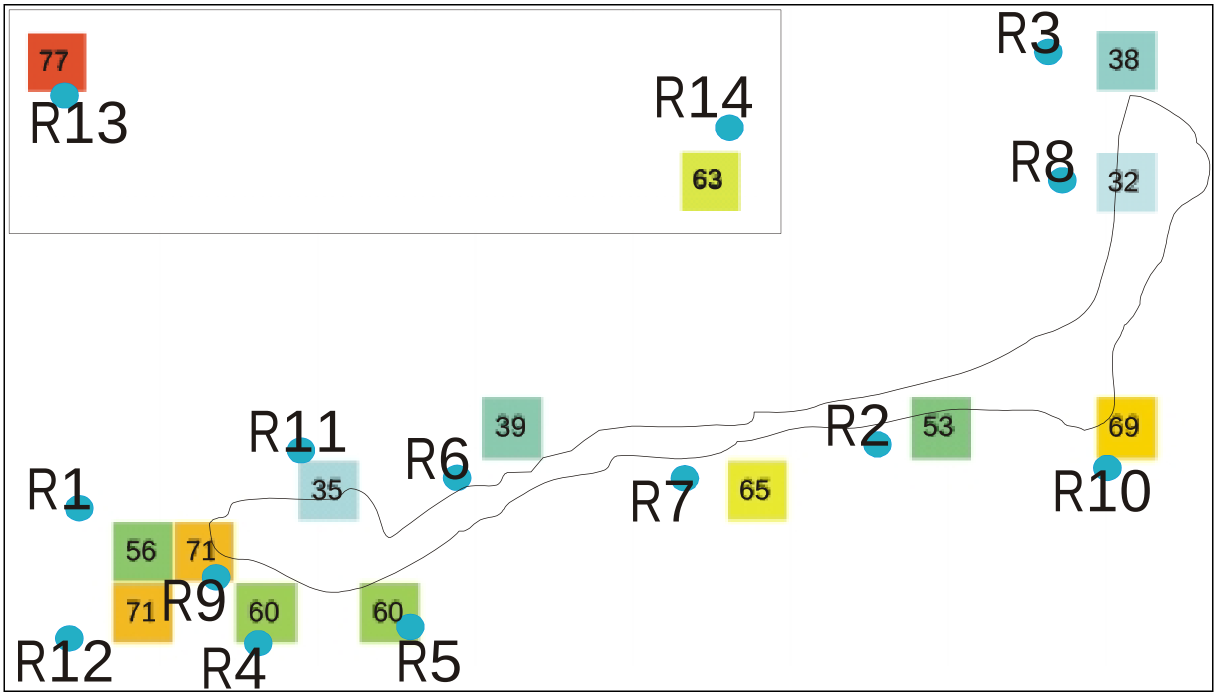
RANK	*GENUS*	*NO. SPP.*
1	Acropora	44
2	Montipora	21
3	Favities	7
3	Favia	7
3	Fungia	7
3	Porites	7
4	Psammocora	6
5	Pocillopora	5
6	Pavona	4
6	Hydnophora	4

Figure 24. Species-area accumulation curve for corals of Rongelap atoll for 14 sites.



Species numbers per site varied greatly with wall sites having consistently higher diversity than lagoonal sites (Figure 25). The southern island of Eniroruuri had the highest coral diversity with 77 species per site. The exposed wall at Jaboan pass has the highest diversity on Rongelap island (70 species). There is a distinct increase in coral species numbers around biogeographical features such as exposed points, where it is considered some accumulation of larvae may occur in the lee of currents.

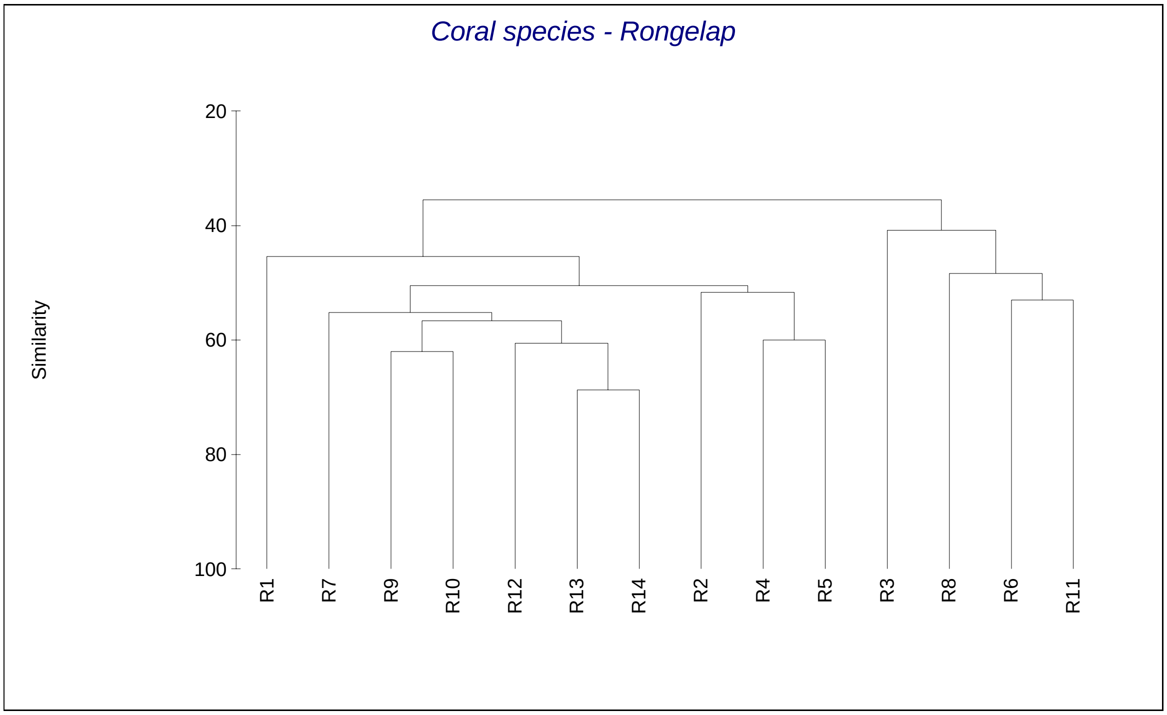
Figure 25. Coral species richness at sites on Rongelap Rongelap island and southern islands.



3.3.2.2 Coral community structure

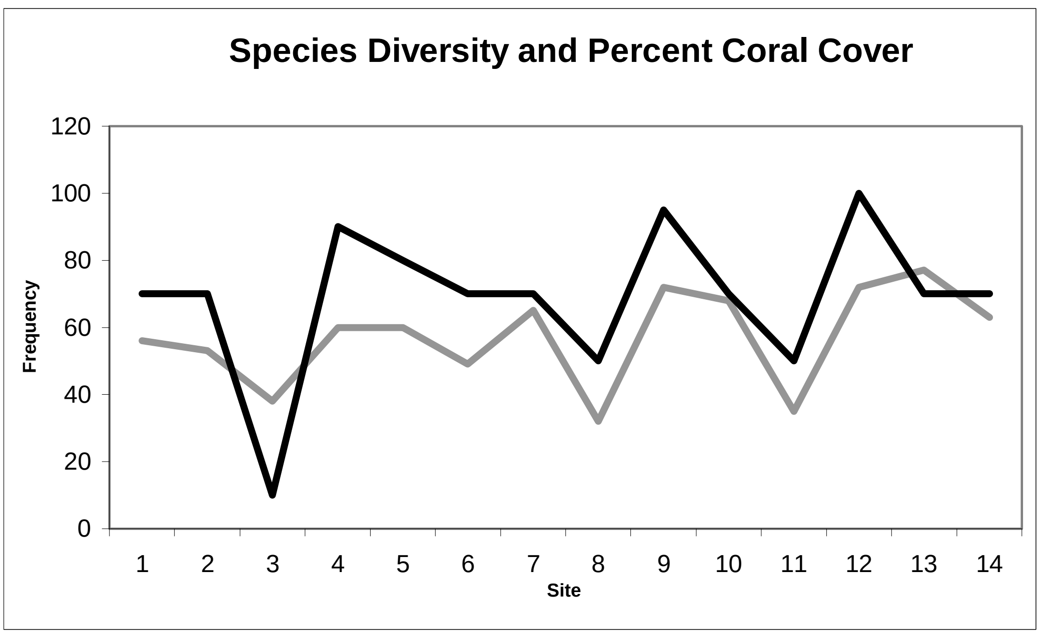
A cluster analysis based on Bray-Curtis similarity was used to determine community patterns in the corals. The resulting dendogram illustrates the distinctive separation of lagoon and outer reef habitats (Figure 26). Lagoonal sites (sites R3, R8, R6, R11) clustered together in a distinct separation from wall sites. The corals of Jaboan Pass (site R1) are placed apart from other wall sites, and the coral composition may indicate Jaboan Pass represents transitional habitat between wall and lagoonal locations. There is high similarity between the three high diversity of exposed wall sites (R12, R13, R14), which are adjacent to deep water passes and exposed to high water movement.

Figure 26. Dendogram of Bray-Curtis similarity showing distinct coral communities for lagoon (R3, R8, R6, R11) and oceanic wall reefs (R7, R9, R10, R12, R13, R14; R1 = Jaboan Pass).



11 out of 13 sites at Rongelap atoll had over 70% live coral cover (Figure 27). A higher coral cover correlated to a high coral diversity at most sites. Coral cover was only 10% on bommies at the northern tip of Rongelap island, but the species diversity was quite high compared with other lagoon sites. This result may be a reflection of the very shallow nature and high energy regime of this site, meaning that only very small isolated coral bommies persist.

Figure 27. Species diversity (gray) overlaid with percent cover (black), showing a correlation between diversity and percent coral cover at most sites in Rongelap Island.

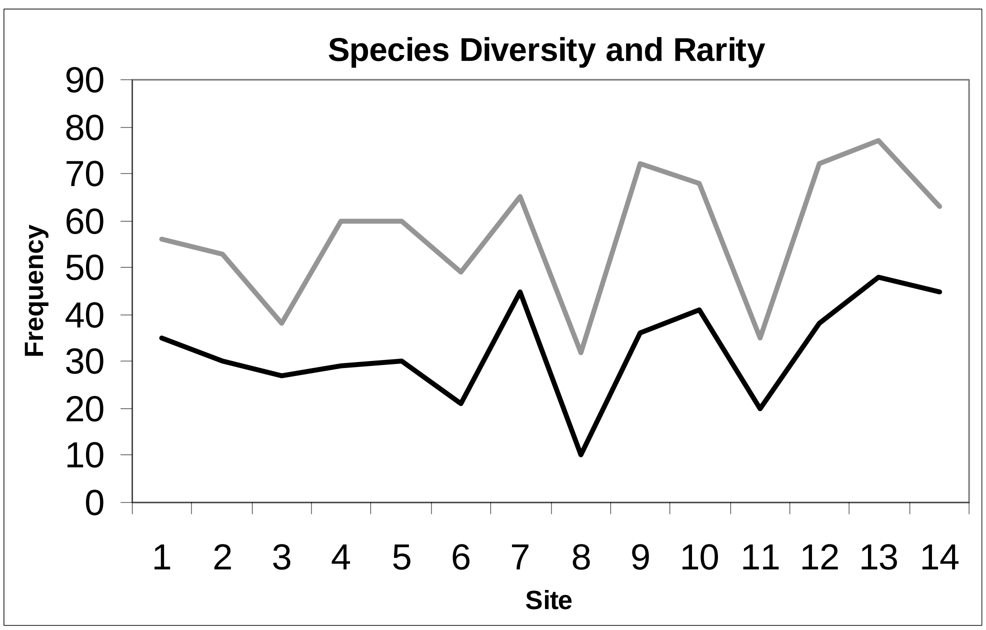


3.3.2.3 Endemism and Rarity

No coral species recorded were endemic to the Marshall Islands. Seven major range extensions were recorded in this study and many of these species were recorded from the Central Pacific Ocean for the first time. Further 9 minor range extensions were recorded for species that have not been recorded in the Marshall Islands before. Most of the species labelled “sp” are likely to be undescribed; these species require further study.

The sampling undertaken was insufficient to draw conclusions about the abundance and range of species recorded. However, the following analysis of rarity may provide insight into rarity patterns at Rongelap island. There are two key elements of rarity: geographic range and abundance. 20% of coral species at Rongelap atoll were locally rare in both the geographic and abundance senses. 56 % of coral species within coral communities at Rongelap atoll had a low relative abundance and occurred only once. A greater number of geographically rare species is not usually explained by the presence of greater diversity (Fenner, 2002, Jones et al., 2002). Results of this study do indicate however that the number of species with a rare relative abundance was closely related to the presence of greater diversity (Figure 28). This indicates that the community assemblage must be diverse to accommodate species with low abundances. 25 % of corals species at Rongelap atoll are site-restricted or geographically rare as they were recorded from one site only. It is expected that with further sampling this percentage will be reduced as a more comprehensive estimate of the abundance and range of these species will be revealed.

Figure 28. Plot of species richness (gray) versus rarity (black) at Rongelap atoll, showing the number of rare species (relative abundance) was related to overall diversity.



New Records for the Marshall Islands:

The following species were recorded from the Marshall Islands for the first time:

Acanthastrea brevis — This submassive coral was occassionally observed at lagoon and wall sites around Rongelap Rongelap but was not observed at the southern islands. Observed to growing as relatively small colonies, the very tall septal teeth of this species made it very conspicuous. This species is considered uncommon and was previously recorded from SE Asia, the West Indian Ocean and Red Sea. A voucher specimen of this species was collected and is housed at the Museum of Tropical Queensland.

Coscinarea monile — This encrusting coral has free margins and was observed at both lagoonal and wall sites at Rongelap Rongelap island. It was not observed at the southern islands. Colonies have a smooth surface due to the even and finely serrated septa. All colonies were a uniform brown color. This species is common in the western Indian Ocean but is considered uncommon in S.E. Asia. It has not previously been recorded from the Pacific Ocean. A voucher specimen of this species was collected and is housed at the Museum of Tropical Queensland.

Seriatopora dentritica **—** This compact bushy coral closely resembles *Seriatopora hystrix* but it has much thinner and more delicate branches. The fine branches have corallites that are aligned in rows down the branch. An adult colony of this species was observed only once at one wall location but was clearly distinguished from the *S. hystrix* which was growing nearby. This species is usually uncommon and has only been recorded from S.E. Asia, it has never been recorded from the Central Pacific.

Montastrea salebrosa **—** This coral normally grows as massive spherical colonies but at Rongelap island it was encrusting with free margins. Single colonies were observed from two exposed wall sites. This species has very circular corallites which are packed close together. The exert polyps (some more exert than others) which face different directions, and extensive extratentacular budding distinguish this species in the field. This species is considered rare and previously known only from SE Asia, the GBR and parts of the Western Pacific. A voucher specimen was collected and is housed at the Museum of Tropical Queensland.

Acropra loisetteae **—** This species has usually has an open branching growth form, but at the one lagoonal site on Rongelap island it had more of an arborescent table growth form. The thin curved branches with few radial corallites distinguish this species. It has not been recorded often in the literature so there is little known of its variability. It grows in lagoonal situations and often with other branching species. At Rongelap island it was brown in color with dark blue tips. This rare species has previously only been recorded from Malaysia and Western Australia. A voucher specimen of was collected and is housed at the Museum of Tropical Queensland.

Acropora nana **—** This corymbose species has very slender upright and non-tapering branches. It has evenly sized tubular radial corallites which are pressed against the branch, calice openings are round to oval with an upwardly extending lower wall. It was recorded from SE Asia, Australia, PNG, Fiji, Samoa and the Society Islands. Previous records from Northern Hemisphere Pacific Ocean localities were doubtful and this is the first verified identification from this region. The growth form of this species made it obvious in the field. It was located quite commonly in shallow reef edge locations along the exposed walls of Rongelap island and southern island sites. A voucher specimen was collected and is housed at the Museum of Tropical Queensland.

***Acropora speciosa* —** This species grows as a side attached thin plate with fusing horizontal branches which give off tapering vertical branches. There are few radial corallites apart from around the base of branchlets. This species was recorded in small numbers from both lagoonal and wall habitats at Rongelap island. Within the lagoon it occurred at the base of walls on patch reefs. The tapering branchlets with narrow axial corallites distinguished this species in the field. Previously this species had been recorded from SE Asia, PNG, GBR and Fiji. Records of this species from Pacific Ocean localities in the Northern Hemisphere were doubtful and this is the first verified identification from this region.

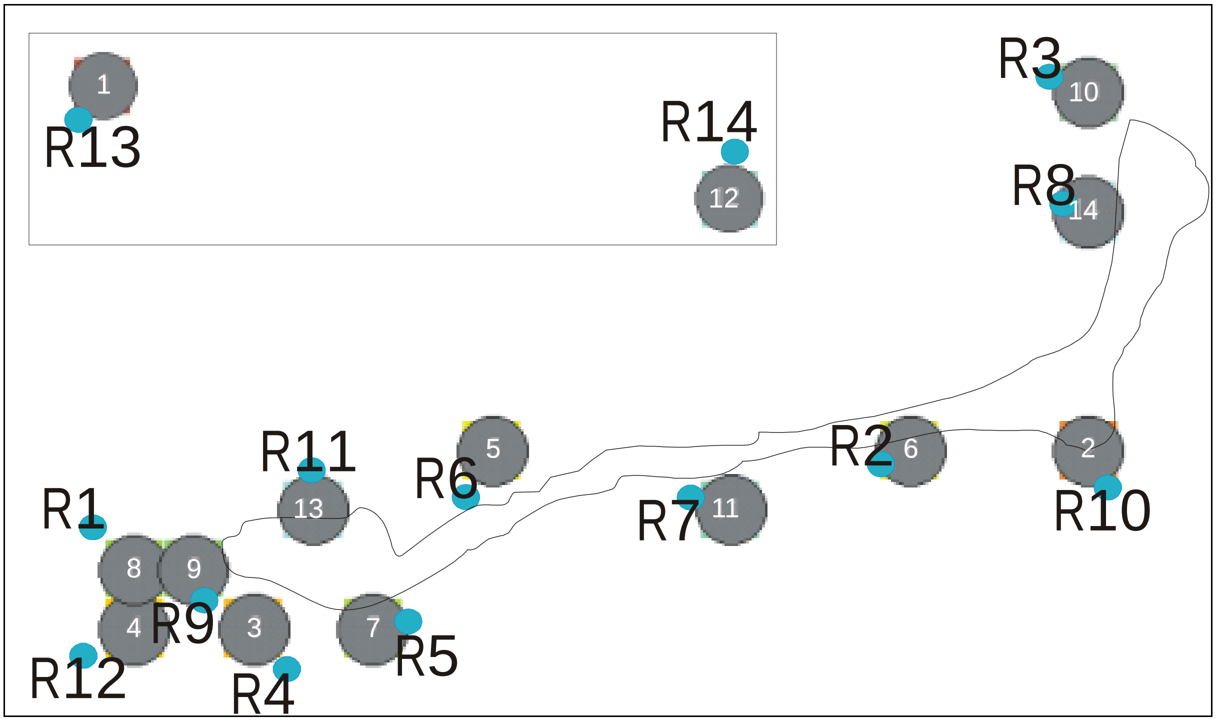
3.3.2.4 Coral Biodiversity Conservation

Increased human impacts have caused "massive and accelerating decreases in abundance of coral reef species and have caused global changes in reef ecosystems over the last two centuries" (Hughes et al., 2002). As a result, frequency and severity of coral bleaching and disease have also increased. Rongelap atoll is in the unique situation of being both a very remote atoll, and having very little recent fishing pressure or pollution. Stress responses such as coral bleaching or other disturbances were not observed in this study and have never been recorded at Rongelap atoll. Coral bleaching- even if very rare in the RMI- was however recorded in Majuro for the first time in the past ten years, in 2002 (ReefBase, 2002). Thus the oceanic reefs of Rongelap atoll have inadvertently been protected and are today some of the best representatives of oceanic reefs.

Although pristine today, the oceanic reefs of Rongelap atoll are highly vulnerable to future overexploitation if the resource base is not protected. Marine reserves have been shown as the most effective method of protecting reefs and their services in the long term.

We used the complementary reserve prioritization method to highlight priority sites for coral conservation at Rongelap atoll (Figure 29). This method focused on those sites with high coral diversity and species, which are site-restricted (occurring at one site only). It is proposed that the south wall site at Eniroruuri Island (R13) would be the priority site for coral species conservation amongst those sampled at Rongelap atoll. This site had the highest coral species diversity.
On Rongelap island, the oceanic wall site R10 was the priority site for coral conservation. This site had relatively high diversity and a large number of site-restricted species. Occurring adjacent to the airport terminal, this site was very accessible for shore-diving and had a relatively safe entry/exit point compared with other wall sites. A permanent transect was established here. Sites R4 and R12 are on the exposed wall side of Jaboan Pass are the next two priority sites. With high diversity and coral cover, these sites may be both a source and a sink for coral larvae. Many species of coral were recorded from these sites only.

Figure 29. Priority sites for the conservation of coral species richness.



3.4 Permanent transects

Two permanent transects were pinned down at two representative sites for future references and monitoring activities. One site is located on the windward site of the atoll, R10, and it has been chosen as good location for a permanent transect for its accessibility and for the high level of quality of reef and general fauna.
The other site, R1, is located at the Jaboan point, and it is been selected for a recommendation for a conservation management. The presence of the permanent transect will help monitor the location.

TOPOGRAPHICAL DESCRIPTION OF THE TWO SITES

Two detailed physical profiles were done at the two permanent transect sites (R1 and R10). Information on the topography of the ocean floor and on the substrate coverage was collected and analyzed. The following figures describe these data.

At R10 the profile was done along three transects perpendicular to the shoreline. One of the transects was inside a deep groove and two were on either side of it. The groove profile is much flatter and longer than the two other parallel to it, indicating a cut into the slope, a feature that is typical of windward ocean-side of atolls, as described by Emery *et al*. (1954).

As it can be noted from the Figure 30, the three profiles are quite different in their proportion of substrate kinds. Along the second profile inside the groove (Figure 31) live coral is more abundant at deeper strata; live coral is then substituted by dead coral, rubble and sand at shallower depths. The bottom of grooves is usually covered by sand and rubble, due to the high current and the eroding activity of waves. The other two transects present a high relative coverage of coral. Seaweeds are generally proportionally more important at depths > 5m.

At R1 four different profiles were accomplished, three perpendicular to the shore (Figure 32) and one parallel to it at 4 different depths.

Along the first transect the proportion of live coral is low at depths shallower than 10 m. This transect was close to a groove and the substrate most representative of this feature is a sand-rubble bottom, as it is obvious in Figure 33. Overall, the proportion of live coral is higher along these transects than at R10. This is a further indication of the particular health and richness of this site at Jaboan point.

Figure 30: Profiles of bottom topography at three neighboring locations at site R10**.**

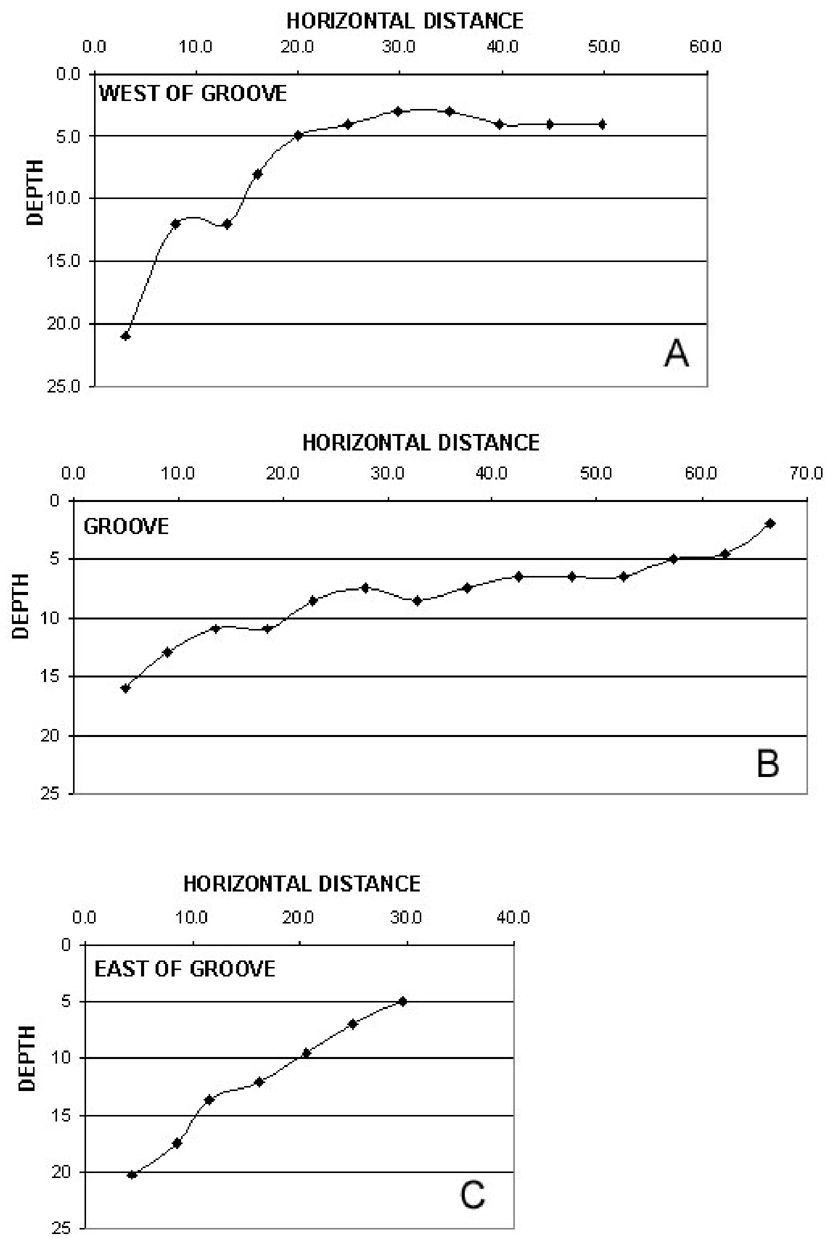


Figure 31: Percentage coverage of the three profiles at site R10.

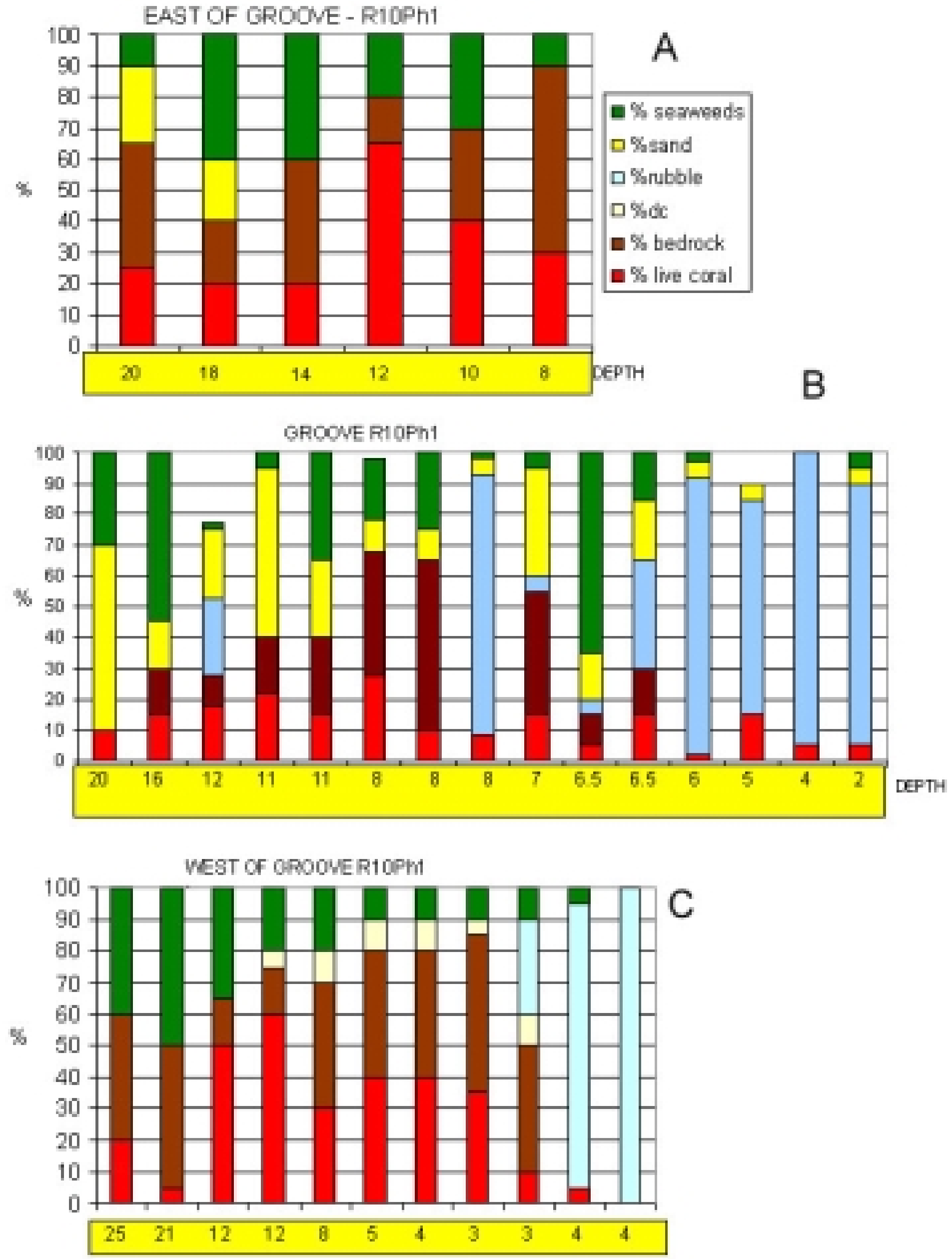

EAST OF GROOVE - R10Ph1
A
% seaweeds
%sand
%rubble
%dc
% bedrock
% live coral
%
DEPTH
20 18 14 12 10 8
B
GROOVE R10Ph1
%
20 16 12 11 11 8 8 8 7 6.5 6.5 6 5 4 2
DEPTH
WEST OF GROOVE R10Ph1
C
%
25 21 12 12 8 5 4 3 3 4 4

Figure 32: Profiles of bottom topography at three neighboring locations at site R1.

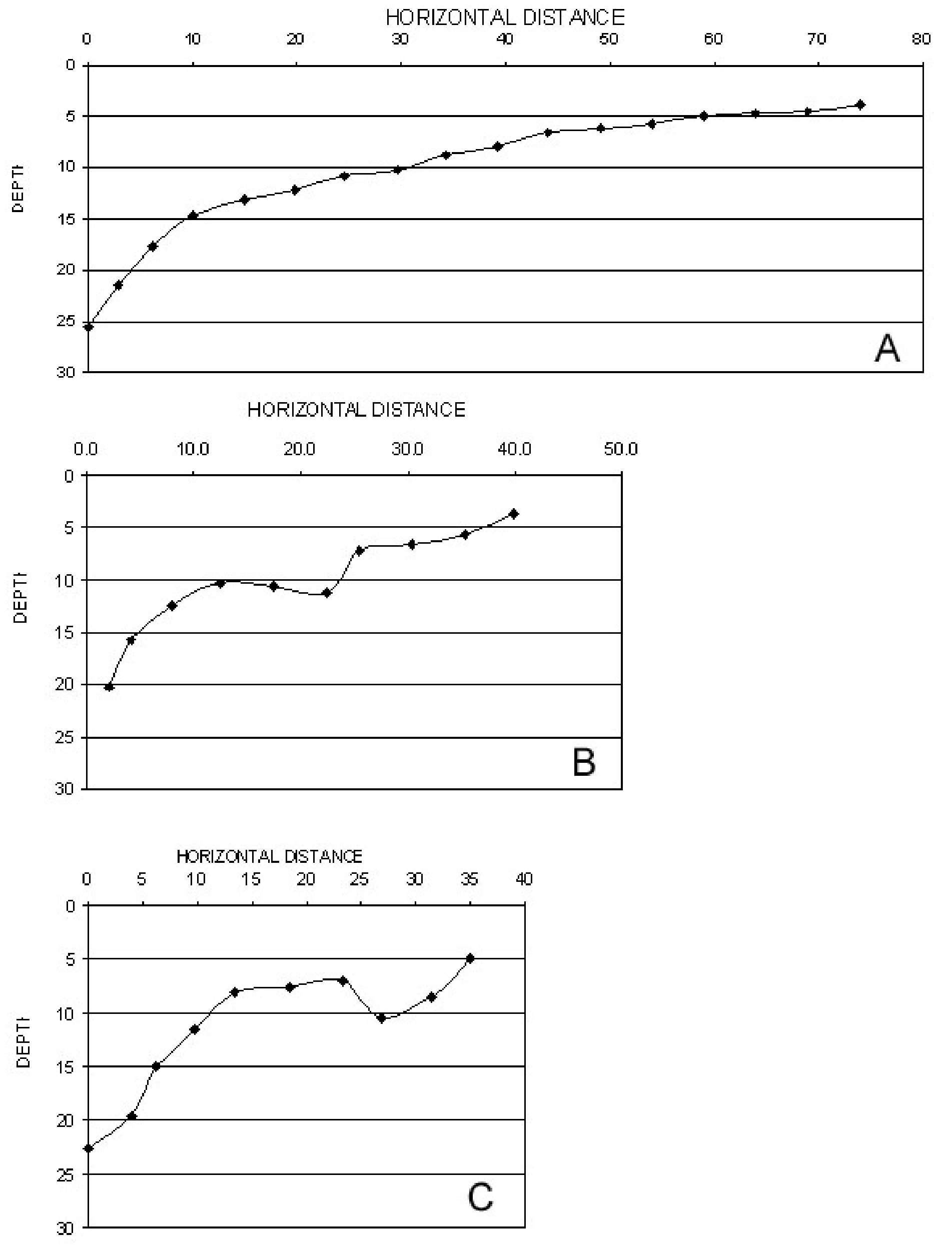
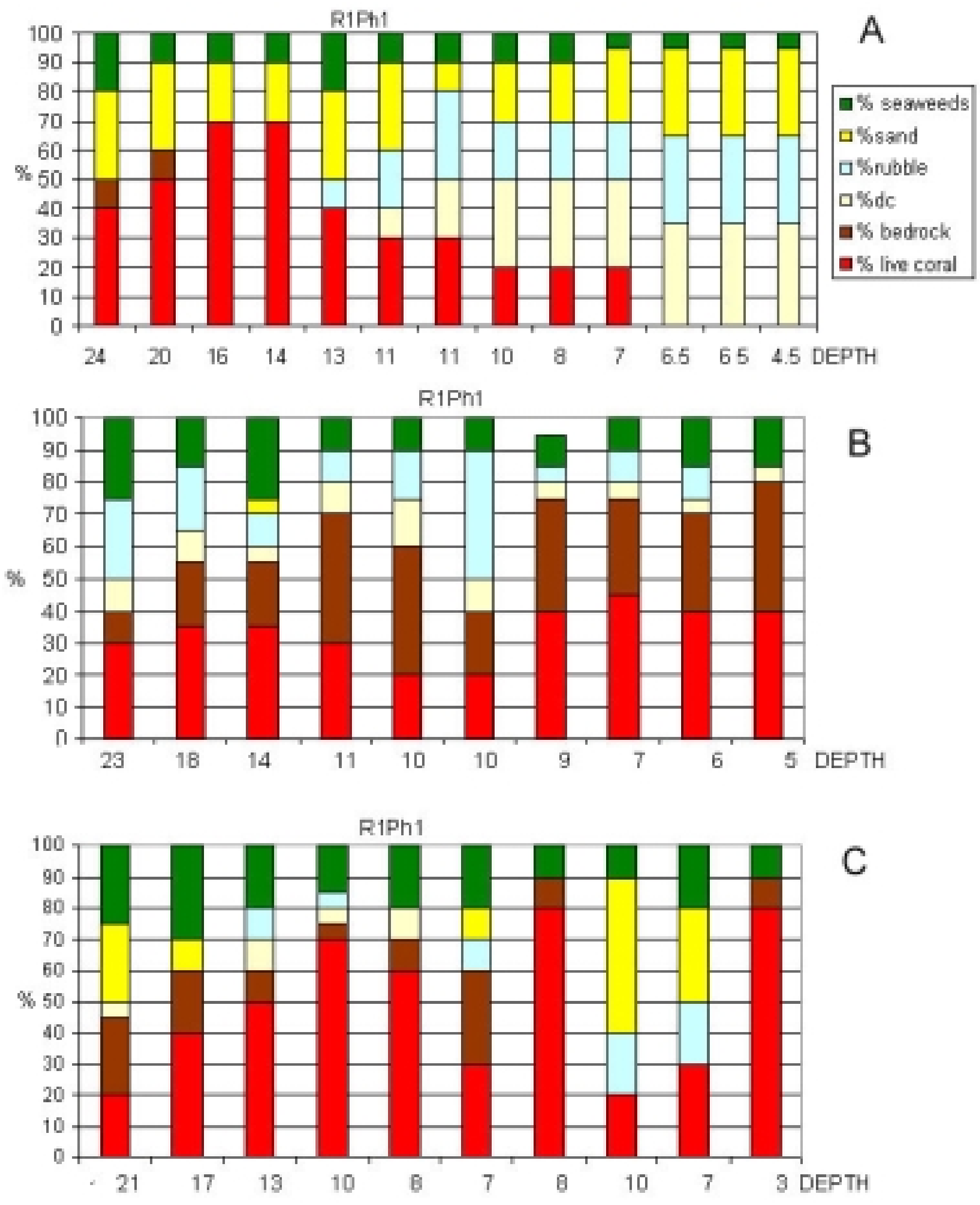


Figure 33: Percentage coverage of the three profiles at site R1.



4. Results and Discussion

In order to summarize the results section and to highlight the most important results, we provided a list of findings below (Table 1). For each previous chapter we summarize the main results.

Table 17. Major findings of the NRAS 2002 project on Rongelap Atoll.

	Result
Substrate	Hard coral cover was higher at shallower sites, averaging 39% of total substrate.
	Ocean had higher coral cover than the lagoon, particularly non-*Acropora*.
	Lagoon had higher sand cover than the ocean.
	Substrate proportions varied with bio-geographical zone.
	More rock was recorded on exposed sites.
Coral Targets	All species were evenly distributed by depth, only *Acropora palifera/ cuneta* preferred shallower depths.
	Higher coral cover was recorded on ocean sites.
	Many coral species were lacking or in low numbers in the lagoon.
	Most corals were relatively homogenously distributed between zones, but subject to the above point.
Fish Targets	The most abundant family was the damselfishes.
	Shallower reefs contained a higher fish biomass than deeper reefs.
	There was no depth differentiation by families.
	Fishes were more abundant on the ocean side.
	Fishes were heterogeneously distributed across bio-geographical zones.
Seaweeds	Algae cover did not change with depth.
	Ocean sites contained algae in higher abundances and more frequently.
	The southwestern sheltered zones had a higher algae cover than other zones.
	There were fewer algae in the western part of the lagoon.
Fish Diversity	361 fish species were recorded on Rongelap Island.
	Sites with high species richness did not contain many rare species.
	Lagoon sites ranked very high as fish conservation priorities, containing rare and

	distinctly different species compared to ocean sites.
	Both a lagoon and an ocean site should be considered for conservation
Coral Diversity	The survey raised the known coral species of Rongelap Atoll from 34 to 170.
	16 range extensions were recorded, with many of these species recorded in the Pacific Ocean for the first time.
	Most sites had high coral cover, diversity and new recruits.
	Oceanic wall reef sites were the most species rich.

The NRAS team found a distinct zonation between the outer fringing and lagoonal patch reefs of Rongelap Island. Coral reef zonation is a well-known characteristic of coral reefs (Alevizon et al., 1985, Acosta and Robertson, 2002). Different habitats and associations of species present in different areas of the island and depth zones resulted from the effect of wave action, exposure, topography and light conditions (Dunning et al., 1992).

This zonation was represented by a variety of habitats present at Rongelap Island, with the strongest differences apparent between lagoon and ocean side. On the lagoon the lesser water circulation, the higher protection from the wind compared to the ocean side and the different current patterns provid a calmer habitat. Here sand accumulates and corals usually do not construct barriers of reef, but patches or mounts of reef accretion. However, still inside the lagoon there are differences of coral associations and ecological communities due to the difference in wind impact and current circulation that control sedimentation, light and temperature. These are major physical parameters that control coral growth and community relations. The sharper differences were usually found between windward and leeward side.

Similarly, on the ocean side we expected and found visible differences in both a geological and biological structure of the reef between the windward and leeward side. Coral communities are often influenced by exposure, including impacts from waves, currents, winds and storms, but also sedimentation. These expectations were met at Rongelap Island. Windward reefs present usually more marked zonation, with boulders and a rubble zone on the reef flat, and spurs and grooves on the slope. There is usually more silting in the deeper part of the slope. Leeward reefs do not present boulders and rubble zone, nor spurs and grooves. The reef slope drop more gently in these protected areas, whereas exposed reefs usually had a very steep dropoff.

Ocean regions: Wall habitats that were studied comprised a narrow fringing reef (up to 50 m wide) and reef crest interspersed with deep channels leading to a steep wall drop-off. The western side of the South pass regions contains the highest total coral coverage. The Western tip of Rongelap-Rongelap is represented by high coverage of *Acropora palifera/cuneata*, *Favites*, *P. cylindrica*, *Porites austr.- and Seriatopora hystrix*. The outer wall sites on the oceanward side of the island supports a relatively uniform fish biodiversity. The tip of the island (R1 in Jaboan) supports a particularly high variety of fishes, because its variety of habitats include both exposed wall and lagoonal features. The highest fish species counts with 179 species per site were reported here.

Lagoon regions: Lagoon sites are composed of small patch reefs and bommie developments amongst sand. The sheltered lagoon habitats support different fish species, which were surprisingly diverse and abundant. Most fishes were found associated with patch reefs on the sandy substratum. Large schools of herbivorous fish were observed roaming between these coral bommies, usually these schools included surgeonfish and parrotfish. An abundant variety of groupers was found near and on the patch reefs. They were significantly more diverse in the lagoon sites than the outer sites. This indicates that the importance of lagoonal sites should not be underestimated for future conservation measures.

Corals: A total of 170 coral species were recorded from surveys of Rongelap atoll, 136 more than previously reported. Seven major range extensions were recorded in this study and several of these species were recorded from the Central Pacific Ocean for the first time. *Acropora* was the most speciose genus followed by *Montipora*. Both coral coverage and number of identified species were significantly more abundant at the ocean sites. In the lagoon, they were found on sandy substrate as well as boulders and bommies. We recorded a high coral cover and beta-diversity throughout the survey sites, combined with good fish biomass values. Our coral diversity records indicate a high diversity of corals, and also a high likelihood that new species may still be discovered there. Considering the small size of Rongelap Rongelap, this relatively high number was indicative of the health and pristine condition of these reefs. The total coral species richness for Rongelap atoll surpasses previous records yet is still considered to be an underestimation of the actual total coral diversity of the entire atoll. Based on the current availability of data, we would propose that the south wall site at Eniroruuri Island (R13) would be the priority site for coral species conservation amongst those sampled at Rongelap atoll. This site had the highest coral species diversity. On Rongelap Island, the oceanic wall site R10 was the priority site for coral conservation. This site had relatively high diversity and a large number of site-restricted species. Site R1, or the tip of Jaboan point, is suggested for conservation for both values of biodiversity, and for management reasons.

Fishes: Fish biomass was significantly higher between 5 and 15 m, approximately, where the larger fish were found. Snappers, Parrotfishes, Fusiliers, Butterflyfishes, Surgeonfishes, Angelfishes, Rabbitfish prefered the ocean sites. We recorded more than half of the fishes known from the RMI, including several endemic species only known from the Northern Marshall Islands.

In summary, the entire atoll must be sampled in order to gain a comprehensive species list for Rongelap for both corals and fish. Reefs of Rongelap Island were very healthy and were some of the most pristine atoll reefs in the world. Although pristine today, the oceanic reefs of the atoll are highly vulnerable to future overexploitation if the resource base is not protected. Marine reserves have been shown as the most effective method of protecting reefs and their services long term.