

***FACTORS AFFECTING NUDIBRANCH DIVERSITY IN
THE WAKATOBI MARINE NATIONAL PARK***

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***Chapter 1:
Introduction***

1.1 - What is a nudibranch?

Nudibranchs, or “sea slugs”, belong to a subclass of the Gastropod Molluscs, called Opisthobranchia (Gremli, 1993). They are shell-less molluscs; the word nudibranch meaning “naked gills”. The order Nudibranchia can be divided into four suborders based on their general appearance. These are the Doridaceans, Aeolidaceans, Dendrotaceans, and Arminaceans. The most commonly found nudibranchs are the Doridaceans.

Plate 1.1 shows the dorid nudibranch, *Chromodoris annae*. This plate clearly demonstrates some of the main features of this suborder, which can also be found on most species of the other three suborders. The most prominent features are the rhinophores on top of the head and the gill plume to the rear of the dorsal side of the

nudibranch. The rhinophores are paired tentacle-like sensory organs. The gill plume is the nudibranch's respiratory structure. Many species have the ability to retract their gills or rhinophores when disturbed (Jeffords, 2001). Nudibranchs of the suborders Aeolidioidea, Dendronotoidea, and Arminoidea all possess finger-like outgrowths known as cerata (Plate 1.2). These cerata contain the extended digestive system of the nudibranch and are used for respiration, especially in those species that do not possess a gill plume (Dive oz, 2000).

Plate 1.1: *Chromodoris annae* with its main anatomical features labelled (Dive gallery, 2001).

Plate 1.2: *Flabellina sp.* with cerata labelled (Photograph courtesy of Adam Powell, 2001).

Nudibranchs are hermaphroditic but self-fertilization does not occur. They reproduce when two fertile individuals pair off, connecting on their right sides, to exchange special sperm sacs. Once the eggs are fertilized they are deposited in ribbon-like strands.

Nudibranchs tend to be brightly coloured and relatively slow moving. They range in size, from just one centimetre or less, to more than a quarter of a metre long. Unlike other molluscs they do not have the protection of a shell. They use a combination of protective colouration, camouflage and chemicals to defend themselves against potential predators. The flesh of a nudibranch can be toxic or distasteful due to various chemical secretions often obtained from their food source. For example, the species *Facelina coronata* feeds mostly on the organ pipe hydroid *Tubularia sp.* The

hydroid nematocysts (stinging cells) are not digested but are stored in the cerata on the back of the slug. If the nudibranch is attacked, the cerata are raised and pointed towards the attacker and the hydroid nematocysts are used for its own defense (Stone and Deeble, 1984). Bright colours indicate to predators that the nudibranch has undesirable and inedible qualities (Allen and Steene, 1999). Some nudibranchs have developed precise resemblance to their prey organisms, and so go undetected by predators.

Nudibranchs can be found in most marine habitats, from intertidal pools down to the greatest depths reached by SCUBA (Self Contained Underwater Breathing Apparatus) divers. Their greatest distribution is throughout the seas of the Indo-Pacific. They can be found exposed on top of corals and sponges, or hidden underneath rocks or in crevices, but are rarely seen swimming in open water. The easiest way to find a nudibranch is to search for its source of food, which include algae, sponges, hard and soft corals, bryozoans and hydroids (Allen and Steene, 1999). Major ecosystems occupied by nudibranchs are coral reefs, known for their high productivity and species diversity.

1.2 - Corals and coral reefs

Corals are members of the Phylum Cnidaria. They are simple multi-celled organisms that tend to grow in colonies, with the exception of a few solitary corals of the genus *Astrangia*, along the seaward slopes of warm waters rarely exceeding 60 metres (Singarajah, 1997).

There are two basic types of coral, commonly known as 'hard' and 'soft'. The hard corals belong to the subphylum Anthozoa. They are found in various growth forms that include massive, tabulate, encrusting and branching (Gremli, 1993). The majority of hard corals live as colonies containing thousands of small individual polyps that secrete a slimy calcareous substance which later becomes hardened. This calcareous exoskeleton is known as a corallite (Singarajah, 1997). Many corallites join together to contribute to the formation of a reef network. These reef-building hard corals have a symbiotic relationship with zooxanthellae, a group of single-celled algae. The zooxanthellae invade the tissue of the developing coral polyps where they are able to reproduce and photosynthesize. Most of the carbohydrates produced during photosynthesis are then passed onto the coral host, supplementing its food intake, thus increasing its reef-building capacity (Gremli, 1993).

The soft corals (Alcyonarians) are not reef-building but still make up a part of the reef community. They lack the rigid skeleton of the hard corals so their bodies appear as a fleshy branched or lobed mass. Soft corals belong to the group of Octocorals because they have polyps bearing eight tentacles embedded in the fleshy body.

Coral reefs only form under certain environmental conditions. They require waters with temperatures between 25 and 29°C, a relatively shallow platform less than 100 metres below sea level to grow on, and can tolerate only a minimum of sediment deposition and pollution (Goudie and Viles, 1997). They derive their primary energy from solar radiation and so thrive in areas of maximum sunlight (Allen and Steene,

1999). Their distribution is therefore restricted to the clear, shallow, coastal waters of tropical seas between the latitudes 30 degrees north and south.

In order to investigate the relationship between the variables stated above, three sample sites within the study area will be looked at, recording coral cover along transects at different depth ranges, as recommended by Loya (1978), as well as the occurrence of nudibranchs.

1.3 - Research rationale

The occurrence of nudibranchs has been studied in many parts of the world such as Australia, Southern Africa, Antarctica, and the British Isles, yet little is known about the nudibranchs of the Tukang Besi archipelago of Sulawesi, Indonesia. Many nudibranch species have been found in the area by Operation Wallacea volunteers and scientists (see section 3.1.1) but little research has been done into their ecology and, specifically, into the following factors:

- abundance - the number of organisms in a population (Begon *et al*, 1996);
- species richness - the number of species per unit area (Huston, 1994) of a community (Begon *et al*, 1996);
- species diversity - an index of community diversity that takes into account both species richness and the relative abundance of species (Begon *et al*, 1996); and
- equitability - the evenness with which individuals are distributed among species in a community (Begon, Harper and Townsend, 1996).

There are many variables that could affect the distribution of nudibranchs throughout different habitats, such as coral cover and the availability and types of food. The

relationship between nudibranch species dynamics and coral cover would be an interesting topic of investigation for two principle reasons. The first is that coral cover is an indicator of general reef health. A “healthy” reef will have over 30% coral cover (hard and soft combined) and low coverage of rubble, rock and sand, among other factors. A study conducted by Bell and Galzin (1984) showed a direct relationship between live coral cover and species diversity of benthic organisms. It is therefore hypothesised that more individual nudibranchs and greater species richness and diversity will be recorded where the coral cover is greater. The second reason is that many nudibranchs feed on and live in close association with certain coral species, making coral cover an obvious variable to investigate. For example the Dendronotid nudibranch, *Marioniopsis fulvicola*, is a specialist predator of the alcyonacean octocoral, *Parerythropodium fulvum fulvum* (*P. f. fulvum*). A study by Avila *et al* (1999) showed that out of the total number of observed *P. f. fulvum* colonies, 24.5% of them were occupied by *Marioniopsis fulvicola*. The nudibranch was found to match the colour of its prey, and its gill clusters resembled the shape and appearance of the coral polyps. The nudibranchs were very cryptic and were sometimes only discovered once the coral surface was disturbed, causing polyps to retract, thus exposing the nudibranch.

1.4 - Aims

Given the information in section 1.3, the aims below will be examined. These are to investigate the relationships between:

- nudibranch abundance;
- nudibranch species richness;

- nudibranch species diversity; and
- nudibranch species equitability at each of three different dive sites, five different coral cover percentage ranges, and at two varying depth ranges within the Wakatobi Marine National Park.

1.5 - Objectives

In order to fulfil the aims of the investigation the following steps need to be taken:

- Identify three different sites that can be surveyed within the marine national park;
- Identify two depth ranges suitable for each survey site;
- Randomly choose locations within the three reef sites at the two depth ranges to place a 15m survey transect. Fifteen transects will be placed at each depth range at each site;
- Record the substrate cover along each transect, using the following categories: hard coral, soft coral, sponges, sand/rubble, and other (bare, algae, unidentifiable substrate);
- Record and identify to species level any nudibranchs found within 1m of either side of the transect line. The resulting area surveyed in each transect will be 30 square metres. It is feasible that an area of this size can be thoroughly searched in the amount of time that divers can spend in the water (maximum 50 minutes);
- Analyse the data using various statistical techniques to determine any correlations within the results.

Chapter 2:

Study Area

2.1 - Indo-Pacific coral reefs

In the past, the Indo-Pacific ocean has been considered as the “largest ecological system on earth” (Sheppard *et al.*, 1992 taken from Tamascik, 1997). It is a region of great coral reef diversity, containing approximately 85% of global reefs (Smith, 1978). As the world’s largest archipelago, Indonesia is positioned in a prime location with respect to global circulation patterns. The Pacific to Indian Ocean current brings with it clean oceanic water to the archipelago to dilute sediments from land masses (Wilkinson & Buddemeier, 1994).

2.2 - The Tukang Besi Archipelago and the Wakatobi Marine National Park

The Tukang Besi archipelago is situated within the Wallacea region of Indonesia (Figure 2.1). This region is a distinct, roughly heart-shaped biogeographic zone, whose boundaries stretch from the east coast of Sulawesi, south to the Timor Sea, and then up the west coast of Irian Jaya and into the western Pacific past the island of Halmahera (Stanzel & Newman, 1997). The Tukang Besi itself falls between

5°15'S, 123°23'E and 6°8'S, 124°37'E. It is made up of four main islands, many smaller islands and fringing and atoll reefs. The high level of biodiversity in the Tukang Besi is comparable to that of the Great Barrier Reef in Australia.

The four main islands of the Tukang Besi archipelago make up the Wakatobi Marine National Park (**W**angi Wangi, **K**aledupa, **T**omia, and **B**inongko: Figure 2.2). The area, situated in the Banda Sea, South East Sulawesi, was declared a national park in July 1996 and covers an area of 1.39 million hectares. The park's reefs generally have broad reef flats with a patchwork of seagrass beds and corals. Steep reef slopes or walls are common (Stanzel & Newman, 1997).

Figure 2.1: Map of the Tukang Besi Islands within the Wallacea Region, Indonesia
(Operation Wallacea, 2001).

Figure 2.2: The four main islands of the Tukang Besi Archipelago (Derived from Operation Wallacea, 2001).

Table 2.1 gives a brief description of the reef sites to be surveyed in this Independent Research Exercise (IRE). The criteria for site selection are outlined in section 3.1.2.

Table 2.1: Description of survey sites.

Site name	Location	Maximum depth (m)	Visibility (m)	Other features
Kaledupa (Plate 2.1)	North of Kaledupa island	30	20	Pristine reef site.
Home Reef (Plate 2.2)	West of Hoga island, just off the beach	25-30	20	Vertical reef wall with overhangs, caves and crevices. Strong current rare.
Sampela (Plate 2.3)	West of Hoga island, adjacent to Bajo sea gypsy village of Sampela	12	approx. 7	High sedimentation input. Coral covered with layer of sediment.

Kaledupa, Home Reef, and Sampela were all fringing reefs and have all previously been shown to have similar conditions such as temperature, salinity and light intensity (at the surface).

Plate 2.1: Underwater view of the Kaledupa survey site (Photograph courtesy of Adam Powell, 2001).

Plate 2.2: Underwater view of the Home Reef survey site (Photograph courtesy of Adam Powell, 2001).

Plate 2.3: Underwater view of the Sampela survey site (Photograph courtesy of Adam Powell, 2001).

Chapter 3:

Methodology

3.1 - Primary data collection

3.1.1 - Operation Wallacea

Operation Wallacea is a non-profit charity organization that runs a series of scientific wildlife survey and conservation projects in South East Sulawesi. The Wakatobi

Marine National Park is one of their three principal study areas. The data for this IRE was collected whilst staying at the Operation Wallacea marine base on the island of Hoga, within the marine park. The use of the organization's facilities such as boats and SCUBA equipment, enabled the nudibranch and coral cover data to be collected.

3.1.2 - Selecting the survey sites

Survey site selection was limited to areas that Operation Wallacea used within their daily dive schedule. Criteria used by Operation Wallacea to determine their dive sites included the following:

- each site had to be within a certain distance from the marine base (maximum of 30 minutes away by speed boat) so that divers could be transported there and back with enough time to carry out their dive (maximum of 50 minutes), all within a two hour time limit;
- there had to be a deep enough channel of water through which the boat could travel to get to the dive site without damaging or causing too much disturbance to the reef or sea bed below;
- there had to be a mooring buoy or a suitable place to drop the boat's anchor.

As a result of the above criteria, Kaledupa, Home Reef and Sampela were selected as nudibranch and reef study sites (see section 2.2).

Other dive sites were considered but were found to be unsuitable for the diving surveys. These included Coral Gardens and the Inner Pinnacle, to the north-west and

west of Hoga, respectively, which both experienced frequent surface currents making it difficult to carry out survey work (Operation Wallacea, 2001).

3.1.3 - Selecting the depth ranges

Depth selection was largely limited to the depths to which each reef site extended. Transects could only be laid above 12m at Sampela as this was its maximum depth. From this depth limitation it was decided that transects would be categorised as being less than or greater than 12m deep.

3.1.4 - Reaching and preparing the dive sites

- Carrying out the survey work required making dives using SCUBA equipment and the “buddy-pair” system (two divers working together). At least two buddy pairs were required to carry out a complete survey at each site.
- Once moored at the dive site, the buddy pairs swam from the boat to the reef edge before descending to the required depth.
- A transect tape was laid along the reef wall, using protruding features such as massive corals, to hook the tape securely to the reef surface. The same length of

tape was used to measure out three 15m transects (Figure 3.1).

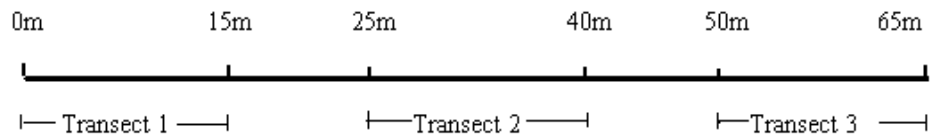


Figure 3.1: Example layout of the transect tape to include three separate 15m transects.

3.1.5 - Data collection

- One buddy pair in the survey group swam along the transect recording the substrate type directly underneath the transect tape. Each 15m transect was split into 1m sections. Each 1m section was described by giving each substrate type (hard/soft coral, sponge, etc.) a value from 0 to 10 to show how much of the surface was covered by which substrate. For example, the 1m section of transect shown in Figure 3.2 would be described as having the following substrate profile:

Hard coral: 3/10; Soft coral: 0/10; Sponge: 1/10; Sand/rubble: 4/10; Other: 2/10.

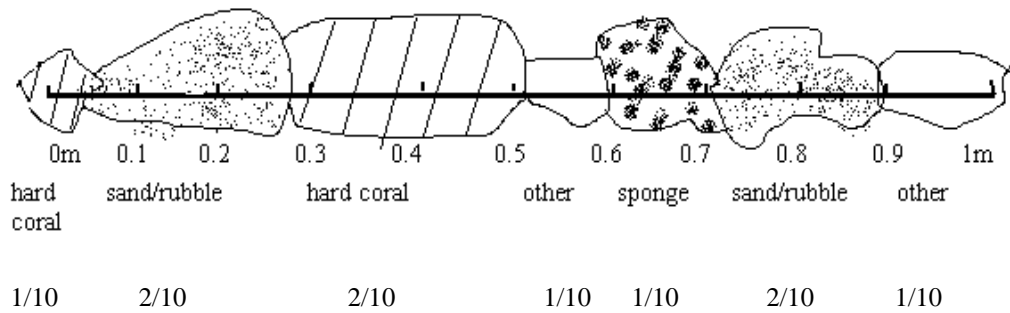


Figure 3.2: Example of a 1m section of a transect with the substrate cover shown.

- One diver in another buddy pair swam along the transect searching for nudibranchs within 1m above the transect tape. The other buddy swam along searching for nudibranchs within 1m below the tape, recording any that were found. Each transect covered an area of 30 square metres and each 1x15m section took about 20 minutes to survey. If a nudibranch was found, the following information was recorded about it on a white slate using a pencil:
 - its distance along the transect (m);
 - the substrate on which it was found;
 - a description of the nudibranch (e.g. species name if known; its colour and features such as rhinophores and gill structure);
 - its size (cm); and
 - behaviour (e.g. resting, feeding, moving, mating, etc.).
- All survey data was entered into a database on return to shore. Nudibranch literature was used to identify the nudibranchs found on the reef.

3.2 - Secondary data

Several sources of secondary information were utilized to aid the identification of the nudibranchs found during the survey period, as well as to supplement the overall data set to be analysed. Secondary information sources included the following:

- species lists and field sketches (Appendix B) compiled by Operation Wallacea volunteers and scientists over previous survey seasons;
- survey data collected by other volunteers throughout the most recent survey season (June to September 2001); and
- nudibranch literature written by experts such as Gosliner (1998), Coleman (1989), and Jeffords (2001).

3.3 - Methods of data analysis

3.3.1 - Coral cover analysis

As one aim of this IRE was to determine whether percentage coral cover influenced the abundance, species richness, diversity, and equitability of nudibranchs, it was necessary to firstly determine whether coral cover actually varied between sites and depth ranges surveyed.

Considering coral cover alone (both hard and soft), Analysis of Variance (ANOVA) was used to determine whether the percentage of cover was significantly different between the three dive sites, Home Reef, Kaledupa and Sampela. The Kruskal-Wallis test, as used by Stafford-Smith (1993) in coral reef analyses, could also have been used to compare the coral covers, this time comparing median percentage values rather than the mean. The use of ANOVA required the formulation of

hypotheses. In this case the null hypothesis was that there was no significant difference in coral cover percentage between sites, and the alternative hypothesis was that there was a significant difference between the sites.

ANOVA had the ability to determine whether there was a significant difference between all three sites, but did not show which pairs of sites, if any, were significantly different from one another. To visually display which of the three sites were significantly different from each other, the 95% confidence intervals (Figure 3.3) were plotted around the mean coral cover percentages for each site. If the confidence intervals for any pair of sites overlapped (B and C), they were found not to be significantly different from one another, and the coral cover data could have easily fallen within the data set for either site. If the confidence intervals for a pair of sites did not overlap (A and B, A and C), they were shown to be significantly different from one another.

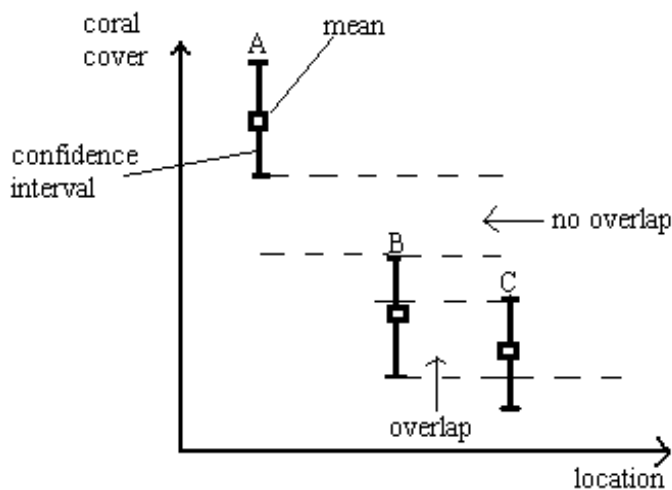


Figure 3.3: Diagram to explain the use of 95% confidence intervals.

ANOVA was also used to compare coral cover at different depths. The Mann-Whitney U-test could have been used but ANOVA was chosen for consistency with the previous analyses of coral cover at different dive sites. The null hypothesis here was that there was no significant difference in coral cover between the two depth ranges. The alternative hypothesis was that there was a significant difference in coral cover between the two depth ranges.

3.3.2 - Nudibranch abundance and species richness

After comparing coral cover between the three sites and at the two depth ranges, the nudibranch data was analysed. Relationships between nudibranch abundance and species richness, and coral cover and dive site were all investigated using the Kruskal-Wallis test. This non-parametric test involved comparing the median data values of each variable within the samples by assigning a rank to each observation. The Kruskal-Wallis test was suitable for the data sets in question as it did not require the samples to be of equal size and three or more samples could be analysed at once. The test statistic, K, was calculated using the following equation:

$$K = \left[\frac{\sum(R^2/n) \times 12}{N(N+1)} \right] - 3(N+1)$$

Where:

R = sum of the ranks of the observations in each sample (i.e. coral cover range);

n = number of observations in each sample;

N = total number of observations (Fowler *et al*, 1998).

K was then compared with the tabulated distribution of χ^2 . The degrees of freedom were the number of samples less one. As with ANOVA, hypotheses had to be formulated. The null hypothesis was that there were no significant differences between nudibranch abundance/species richness and coral cover/dive site. The alternative hypothesis was that there was a significant difference.

The Mann-Whitney U-test was used to compare the median number of nudibranchs and nudibranch species per depth range (i.e. above and below 12m). This non-parametric test did not require data to be normally distributed and samples did not have to be of equal size, though two samples were required. This test was similar to the Kruskal-Wallis test in the way that it ranked each observation and the sum of the ranks was used to calculate the test statistic rather than the actual observation values.

The calculation of the test statistic involved the following equations:

$$U_1 = n_1 n_2 + \frac{n_2(n_2 + 1)}{2} - R_2$$

$$U_2 = n_1 n_2 + \frac{n_1(n_1 + 1)}{2} - R_1$$

Where:

n_1 = the number of observations in sample 1;

n_2 = the number of observations in sample 2;

R_1 = the sum of the ranks in sample 1; and

R_2 = the sum of the ranks in sample 2 (Fowler *et al*, 1998).

The smaller of the two U values was then compared to the table of critical values for a two-tailed Mann-Whitney U-test at the 0.05 significance level. If the calculated U

value was less than the critical value in the tables, the null hypothesis that there was no significant difference between median numbers of nudibranchs or species above and below 12m would be rejected. The alternative hypothesis that there was a significant difference would be accepted.

3.3.3 - Nudibranch species diversity and equitability

Species richness is a very simple index of diversity. There are other indices that can be used to show how evenly the total number of individuals within a sample are distributed among each species present (Fowler *et al*, 1998). Such indices include Simpson's diversity index and the Shannon-Weaver diversity index; the latter being the most widely used. The Shannon-Weaver index (H) is defined as:

$$H = - \sum_{i=1}^s p_i \ln p_i$$

Where:

p_i = the proportion of a particular species in a sample; and

\ln = the natural logarithm (Fowler *et al*, 1998).

The greater the value of H, the greater the resulting species diversity within the particular community.

Equitability (J), as defined in section 1.3, can be quantified by expressing the Shannon-Weaver index as a proportion of the maximum diversity possible if individuals were equally distributed between species. Equitability assumes a value between 0 and 1, with 1 representing most equally distribution of species throughout the particular community. The equation for J is as follows:

$$J = \frac{H}{H_{\max}} = \frac{-\sum_{i=1}^S p_i \ln p_i}{\ln S}$$

Where:

S = the total number of species in the community (i.e. species richness)

(Begon *et al*, 1996).

Chapter 4:

Results

4.1 - Summary of data collected

Table 4.1 gives a summary of the data that was collected over the duration of the survey period. Features of the three survey sites were outlined, which included the number of transects laid, different depths surveyed, individual nudibranchs and nudibranch species found, and the mean coral cover at each site. Both Kaledupa and Home Reef had two depth ranges surveyed and a total of 30 transects laid (15 transects above 12m and 15 transects below 12m). Just 15 transects were laid at Sampela, all at depths above 12m. A total of 88 nudibranchs were recorded altogether, with 31 from Kaledupa transects, 44 from Home Reef transects and 13 from Sampela transects. Within these 88 individuals, there were 28 different species of nudibranch recorded. Again, the greatest number of species were recorded in Home Reef transects (16), followed by Kaledupa (12) then Sampela (8). The mean average coral cover per transect (hard and soft corals) was calculated for each site. Kaledupa transects had the highest average (57.4%), followed by Home Reef (47.6%), and then Sampela (22.6%).

Table 4.1: Table to show summary of data items collected.

	Site	No. transects	No. depth ranges	No. nudibranchs	No. species	Mean coral cover (%)
	Kaledupa	30	2	31	12	57.4
	Home Reef	30	2	44	16	47.6
	Sampela	15	1	13	8	22.6
Total	3	75	2	88	28	

4.2 - Description of coral cover at the three dive sites

Home Reef had normally distributed coral cover over the five percentage groupings. At this site, the greatest frequency of transects fell in the range 40-60% cover, with very low frequencies in the outermost percentage ranges (0-20% and 80-100%). Kaledupa transects produced a slightly negatively skewed coral cover percentage distribution. Here, the highest frequency of transects (0.47) fell in the range 60-80% cover. A frequency of 0.43 transects were in the range 40-60%. No transects with 0-20% coral cover were recorded at Kaledupa. Sampela transects produced a positively skewed coral cover distribution. The highest frequency of transects fell in the range 20-40% cover (0.53), followed by 0.4 transects in the range 0-20%. Less than 0.1 of the transects fell into the mid-range percentage, 40-60%. No transects with 60-80% or 80-100% coral cover were recorded at Sampela. Home Reef and Kaledupa had a greater spread of coral cover values, demonstrated by their higher standard deviations (15.6 and 15.0, respectively) compared to that of the Sampela data (10.7) (Figure 4.1).

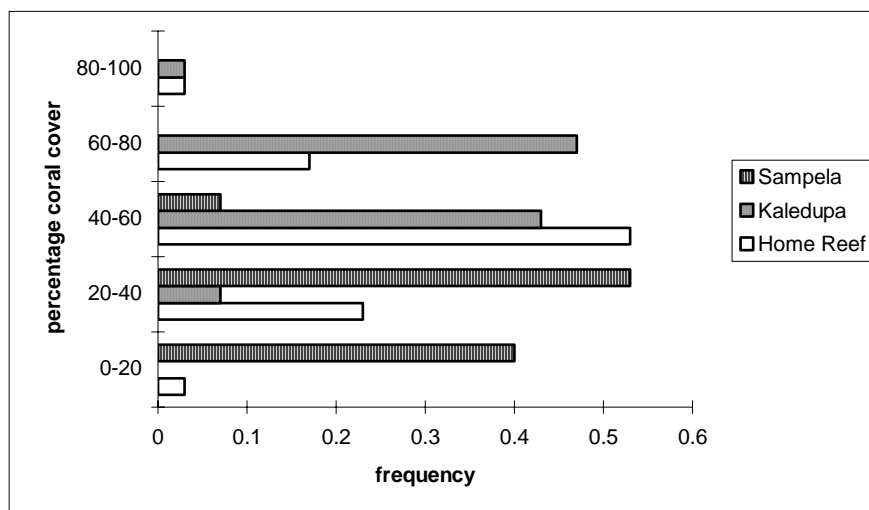


Figure 4.1: Frequency distribution of varying coral cover percentage ranges over the coral reef sites at Sampela, Kaledupa and Home Reef.

Kaledupa transects were mostly made up of hard corals (37%) and soft corals made up a further 21%. As expected for a pristine reef site, Kaledupa transects had comparatively low cover of sand/rubble (11%). Home Reef transects had a greater cover of hard corals than Kaledupa (40%) but a lower percentage of soft corals (7%). The cover of sand/rubble at Home Reef was also comparatively low (14%). The most obvious feature of the Sampela transects was the high percentage of sand/rubble compared to any other substrate type (57%). Hard and soft coral cover were relatively low at this reef site (15% and 7%, respectively). The substrate category 'other' made up a relatively large proportion of the total cover at Kaledupa, Home Reef and Sampela (27%, 34% and 18%, respectively). This category refers to anything other than hard coral, soft coral, sponge, or sand/rubble, which could include algae, bare ground or an unidentifiable substrate (Figure 4.2).

The ANOVA for the relationship between coral cover and dive site gave a test statistic value of 28.8, which had a significance of 0.00 (0.05 significance level). The null hypothesis was rejected and the alternative hypothesis that there was a significant difference in mean coral cover between the three sites was accepted. However, the confidence intervals (Figure 4.3) around the mean percentage of coral cover for both Kaledupa and Home Reef transects overlapped, showing that they were not significantly different from each other with regards to coral cover. The confidence intervals around the mean coral cover percentage for Sampela transects did not overlap with those of either Home Reef or Kaledupa, showing Sampela's coral cover to be significantly different from that of the other two sites.

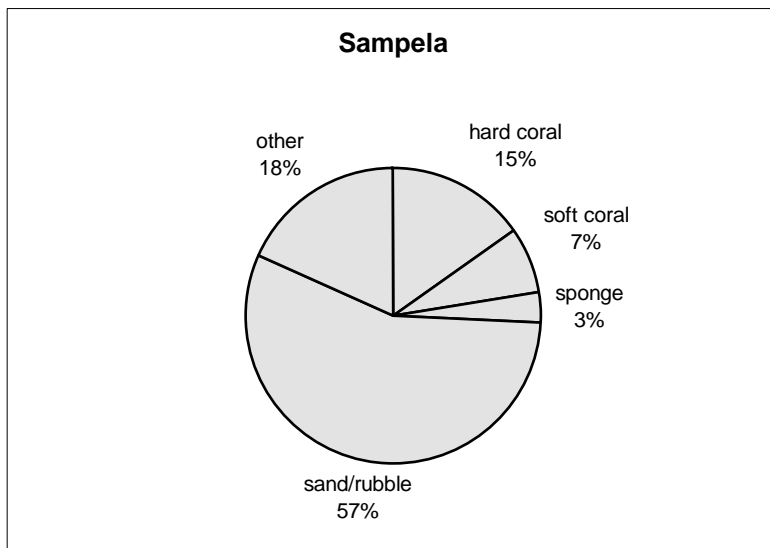
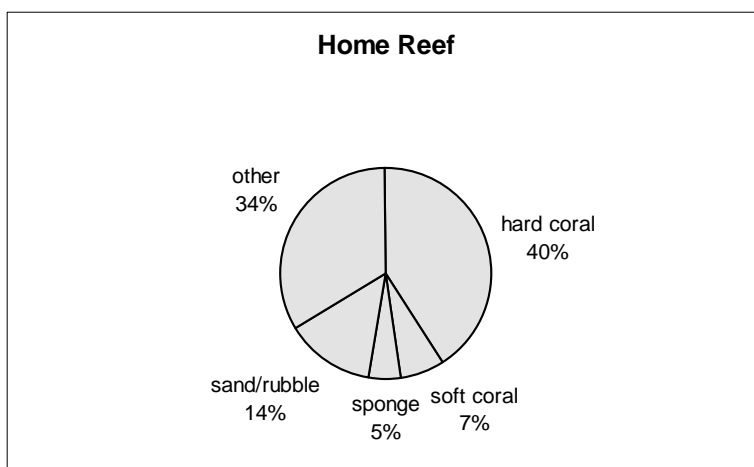
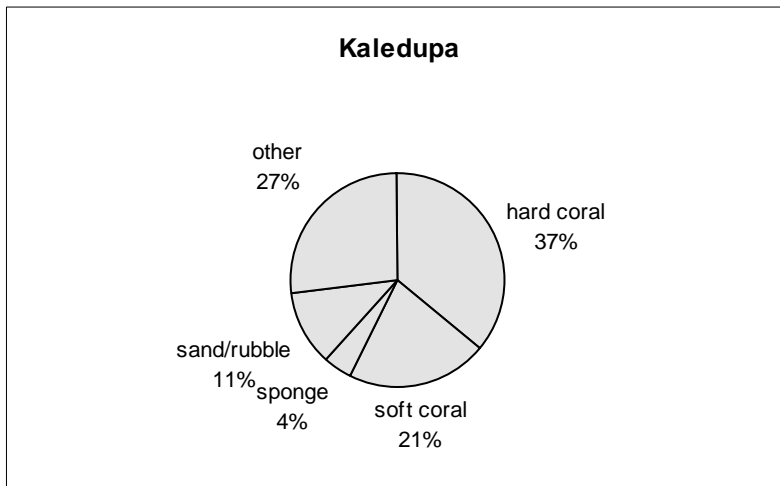


Figure 4.2: Pie charts to show percentages of varying substrates at Kaledupa, Home Reef and Sampela.

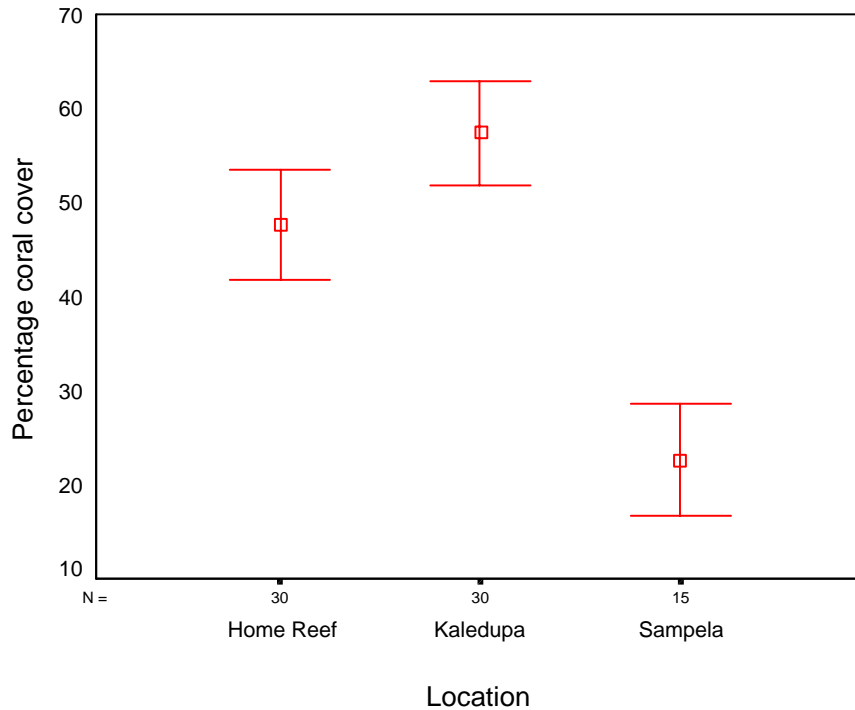


Figure 4.3: The mean coral cover percentages at Home Reef, Kaledupa and Sampela, with 95% confidence intervals displayed.

4.3 - Description of coral cover above and below 12m

The samples of transects surveyed above and below 12m had very similar mean coral covers (45.8% and 47.5%, respectively). Both depth ranges displayed normally distributed coral cover (Figure 4.4), with a greater frequency of transects falling in the range of 40-60% cover (0.36 and 0.47 for above and below 12m, respectively). Samples below 12m in particular, had very few transects in the two outermost coral cover percentage ranges (0-20% and 80-100%). Samples taken from above 12m had a greater spread of data than those from below, as shown by its standard deviation value (20.9 compared to 16.7).

At both depth ranges the transects were mostly covered by hard corals (above 12m: 30%; below 12m: 39%). Soft coral cover at both depth ranges were comparatively low (above 12m: 15%; below 12m: 9%). Transects above 12m had a relatively high percentage of sand/rubble (25%) compared to those below (15%). In both samples, ‘other’ substrates had relatively high percentages of the overall cover (above 12m: 26%; below 12m: 32%) (Figure 4.5).

The ANOVA for the relationship between coral cover and depth gave a test statistic value of 0.138, which had a significance of 0.71 (0.05 significance level). The null hypothesis that there was no significant difference in coral cover between the two depth ranges was accepted.

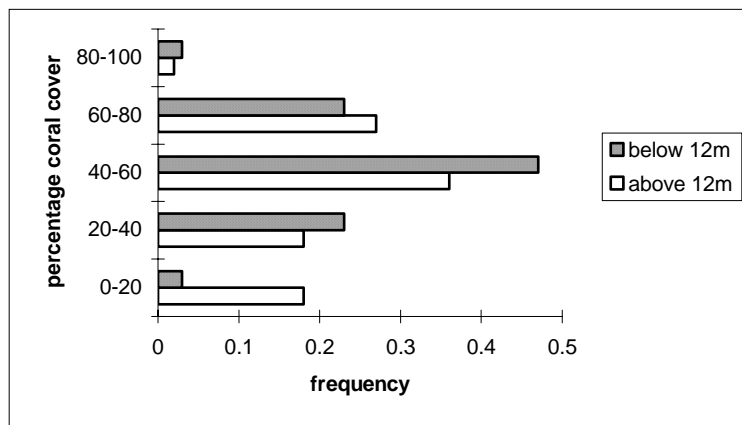


Figure 4.4: Frequency distribution of varying coral cover percentage ranges in transects above and below 12m.

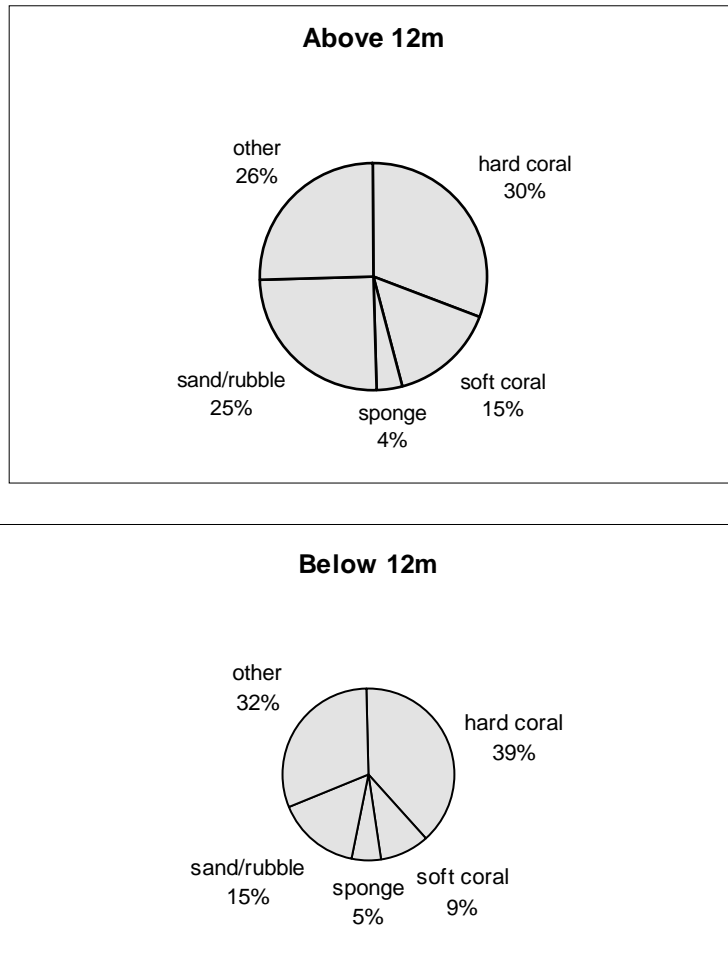


Figure 4.5: Pie charts to show mean percentage cover of varying substrates in transects above and below 12m.

4.4 - Coral cover and nudibranch populations

The 9 transects sampled with 0-20% coral cover yielded 7 individual nudibranchs and 5 nudibranch species. Species diversity (1.48) was relatively low within these transects but a high proportion of the maximum diversity possible were expressed amongst the nudibranchs found, as shown by the equitability value (0.76). The 15 transects with 20-40% coral cover yielded a total of 21 nudibranchs of 13 different species, making it the most species diverse group of transects (species diversity: 2.31; equitability 0.76). The 30 transects with 40-60% coral cover yielded 41

nudibranchs of 12 different species. Again, species diversity was relatively high (2.06) but equitability was low in comparison (0.55), suggesting that maximum diversity potential was not fulfilled. The 19 transects with 60-80% coral cover contained 15 individual nudibranchs of 9 different species. The equitability value for this sample was comparatively high (0.7). The remaining 2 transects surveyed had 80-100% coral cover. They yielded 4 nudibranchs of 4 different species. Species diversity (1.39) was proven to be the maximum possible for this small sample (equitability: 1.00) (Table 4.2).

Table 4.2: Table to describe the number of transects sampled at each coral cover percentage range, as well as nudibranch abundance, species richness, diversity, and equitability.

Percentage coral cover	0-20%	20-40%	40-60%	60-80%	80-100%
Number transects	9	15	30	19	2
Nudibranch abundance	7	21	41	15	4
Species richness	5	13	12	9	4
Species diversity index	1.48	2.31	2.06	1.90	1.39
Equitability	0.76	0.76	0.55	0.70	1.00

The mean number of nudibranchs per transect varied with each coral cover grouping (Figure 4.6). The lowest mean number of nudibranchs per transect occurred within the groupings 0-20% and 60-80% cover (0.7 nudibranchs in both). Transects with 20-40% and 40-60% cover both had twice as many nudibranchs as the latter two groupings (1.4), and those with the greatest coral cover, 80-100%, had the highest mean number of nudibranchs per transect (2). The mean numbers of nudibranch

species per transect were very similar to those of individual nudibranchs per transect (Figure 4.6). The two highest coral cover groupings, 60-80% and 80-100% cover, had an equal number of species as they did individual nudibranchs (0.7 and 2, respectively). The remaining coral groupings, 0-20%, 20-40% and 40-60%, had a slightly lower mean number of species than individual nudibranchs (0.6, 1.2 and 1.1 respectively).

The Kruskal-Wallis tests, at both 0.05 and 0.02 levels of significance, proved that neither nudibranch abundance nor species richness were significantly different from one coral cover percentage grouping to the next.

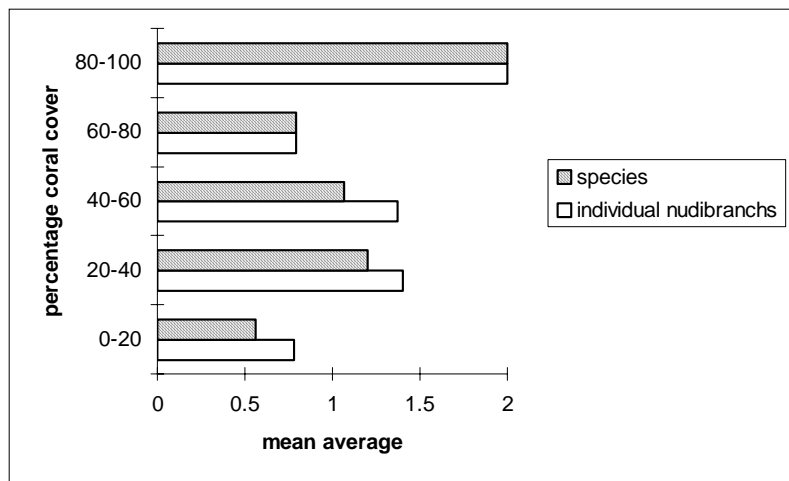


Figure 4.6: Mean number of individual nudibranchs and nudibranch species per transect within each coral cover percentage range.

Despite there being no apparent significance between species richness and coral cover, some interesting observations were made from the raw data (Appendix A). Two nudibranch species, *Halgerda* sp. (Plate 4.1) and *Risbecia tyroni*, appeared only in the 0-20% coral cover grouping (Figure 4.7a). The species *Chromodoris lochi*

was most abundant in this particular range, with three sightings. Eight species from the 20-40% coral cover grouping were from the Chromodorididae family, which included *C. lochi* (3) and *C. coi* (2) (Figure 4.7b). As well as these Chromodorids, 6 *Phyllidia pustulosa* were recorded, making it the most frequently recorded species within this group of transects. *P. pustulosa* was also the most abundant species in transects with 40-60% and 60-80% coral cover (15 and 6, respectively). As in the 20-40% grouping, there was a relatively high occurrence of Chromodorids in transects with 40-60% cover (Figure 4.7c). Other species in this percentage group included *Nembrotha kubaryana* (1), *Nembrotha lineolata* (1), and *Phyllaplysia* sp. (6). Transects with 60-80% cover contained 3 species of nudibranch that were not found anywhere else (Figure 4.7d). These were *C. kuniei*, *Jorunna funebris*, and *Thurdilla flavomaculate*. One of each of 4 species were recorded in the remaining group of transects. These were *Atys naucum*, *C. willani*, *N. lineolata*, and *P. pustulosa* (Figure 4.7e).

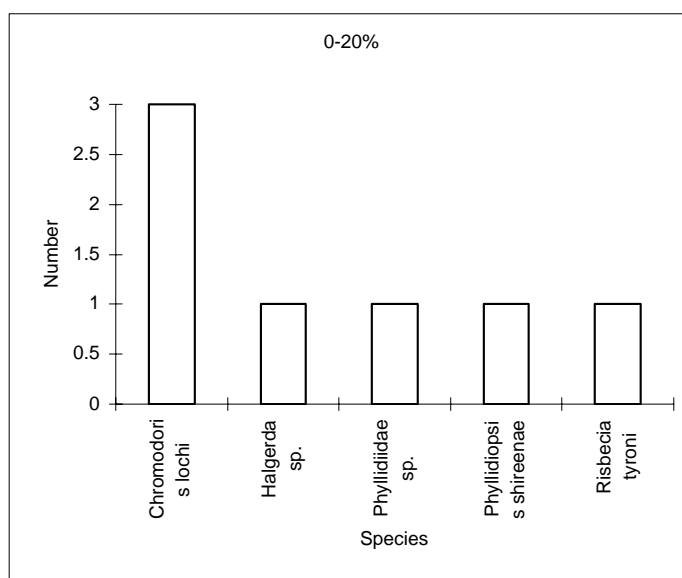


Figure 4.7a: Bar chart to show the occurrence of particular nudibranch species in transects with 0-20% coral cover.

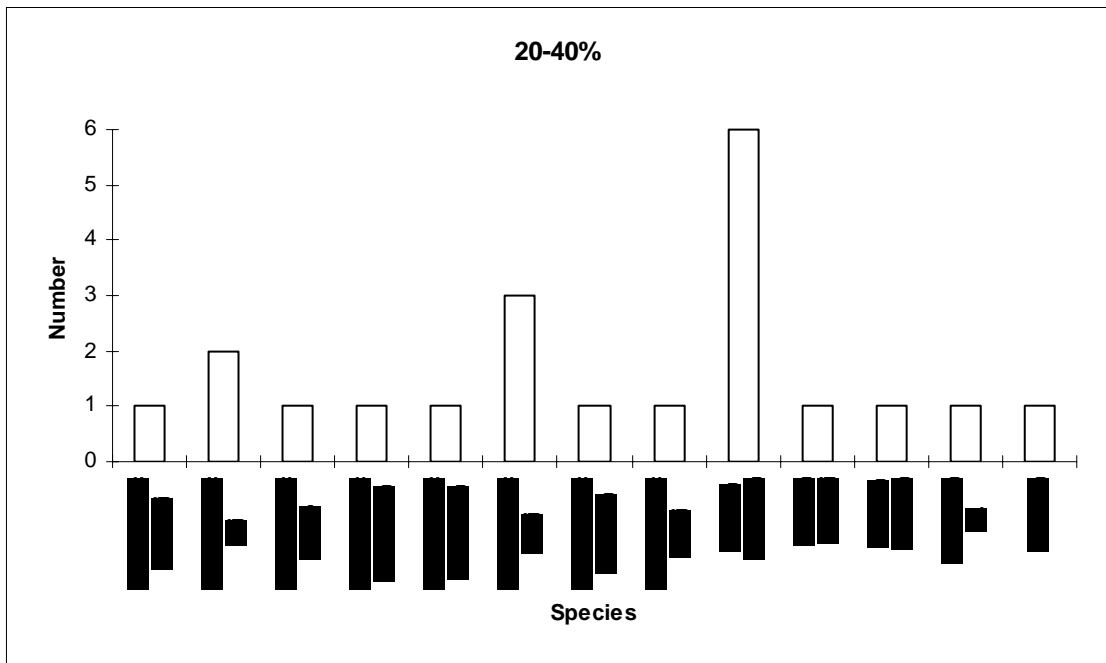


Figure 4.7b: Bar chart to show the occurrence of particular nudibranch species found in transects with 20-40% coral cover.

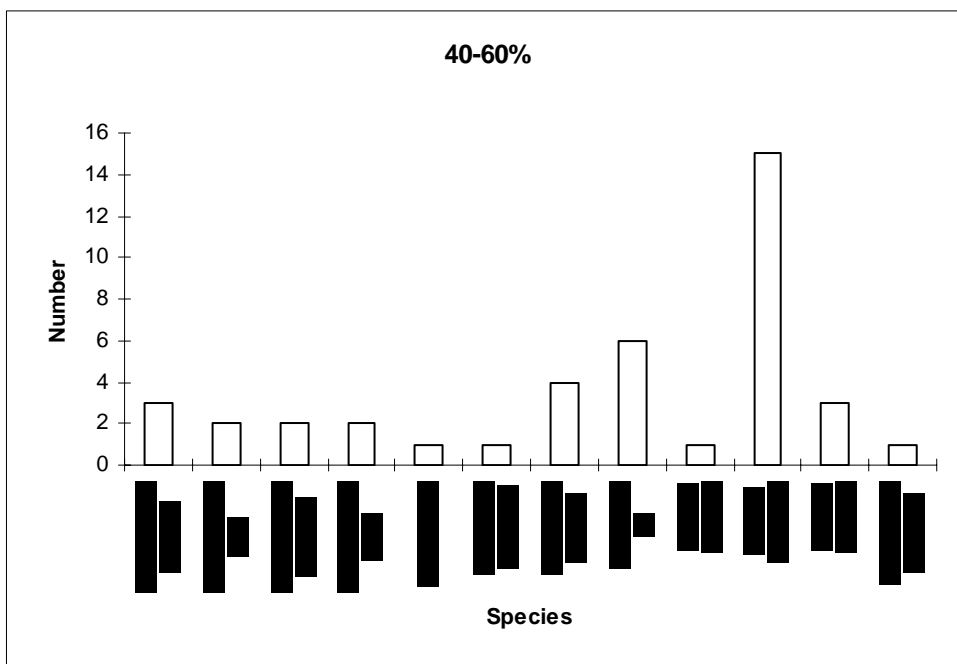


Figure 4.7c: Bar chart to show the occurrence of particular nudibranch species in transects with 40-60% coral cover.

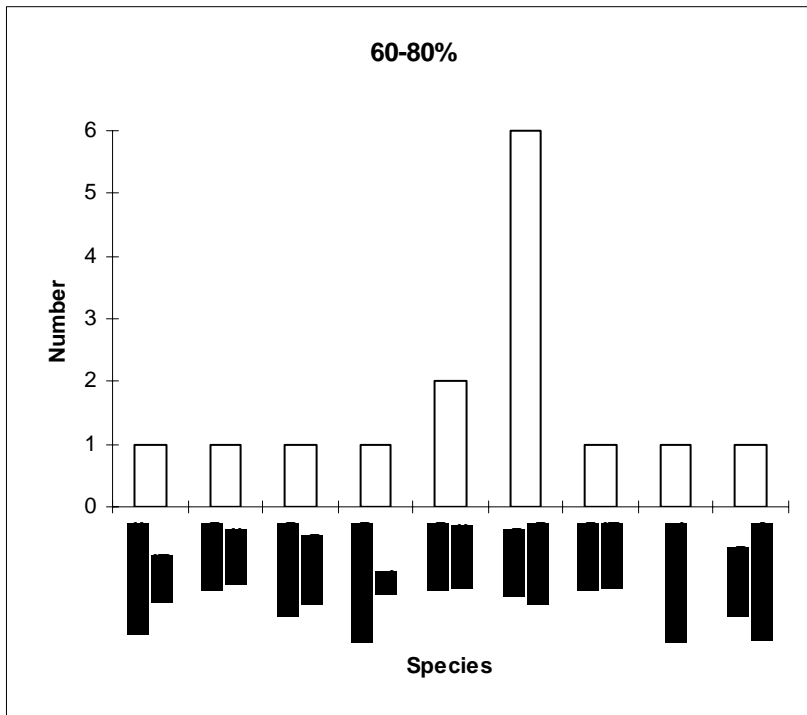


Figure 4.7d: Bar chart to show the occurrence of particular nudibranch species in transects with 60-80% coral cover.

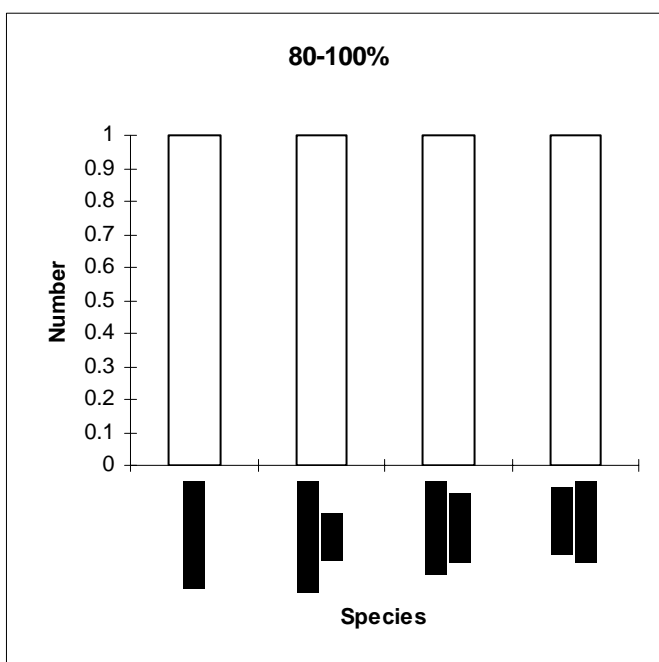


Figure 4.7e: Bar chart to show occurrence of particular nudibranch species in transects with 80-100% coral cover.

Plate 4.1: *Halgerda* sp. (Photograph courtesy of Adam Powell, 2001).

4.5 - Comparison of nudibranch populations at the three dive sites

Home Reef transects contained the greatest range of species (16), greatest nudibranch abundance (44) and the highest species diversity index value (2.44) out of all the sites. At Home Reef there were also the greatest mean number of nudibranchs per transect (1.5) (Figure 4.8). As expected due to reduced transects in the sample, Sampela had the smallest total number of nudibranchs (13), number of species (8) and species diversity (1.74). However, out of all the samples, Sampela had the greatest proportion of the maximum diversity possible, as indicated by its equitability (0.68). Kaledupa displayed an average of one nudibranch per transect, lower species diversity than Home Reef (1.99), and the lowest equitability of all the

sites (0.58). All of the surveyed samples displayed similar mean species richness per transect (Figure 4.8). (Table 4.3).

The Kruskal-Wallis tests, both at 0.05 and 0.02 levels of significance, indicated that neither nudibranch abundance nor species richness were significantly different from one study site to the next

Table 4.3: Species lists for Kaledupa, Home Reef and Sampela, and nudibranch abundance, species richness, diversity, and equitability at each site.

Site	Kaledupa	Home Reef	Sampela
No. transects	30	30	15
Species (number)	<i>Atys naucum</i> (1) <i>Chromodoris kuniei</i> (1) <i>Nembrotha lineolata</i> (2) <i>Phyllidia elegans</i> (2) <i>Phyllidia pustulosa</i> (12) <i>Phyllidia rudmani</i> (1) <i>Phyllidia varicosa</i> (2) <i>Phyllidiidae</i> sp. (1) <i>Phyllaplysia</i> sp. (6) <i>Phylodesmium</i> sp. (1) <i>Reticulidia</i> sp. (1) <i>Thurdilla flavomaculate</i> (1)	<i>Chromodoris boucheti</i> (4) <i>Chromodoris coi</i> (2) <i>Chromodoris elizabethina</i> (1) <i>Chromodoris geometrica</i> (1) <i>Chromodoris lochi</i> (7) <i>Chromodoris magnifica</i> (3) <i>Chromodoris willani</i> (4) <i>Flabellina</i> sp. (1) <i>Jorunna funebris</i> (1) <i>Nembrotha kubaryana</i> (1) <i>Nembrotha lineolata</i> (4) <i>Phyllidia exquisita</i> (1) <i>Phyllidia pustulosa</i> (10) <i>Phyllidia rudmani</i> (1) <i>Phyllidia varicosa</i> (1) <i>Phyllidiopsis shireenae</i> (2)	<i>Chromodoris diana</i> (1) <i>Chromodoris lochi</i> (1) <i>Halgerda</i> sp. (1) <i>Phyllidia pustulosa</i> (6) <i>Phyllidia varicosa</i> (1) <i>Phyllidiidae</i> sp. (1) <i>Risbecia tyroni</i> (1) unknown (1)

Abundance	31	44	13
Species richness	12	16	8
Species diversity index	1.99	2.44	1.74
Equitability	0.58	0.64	0.68

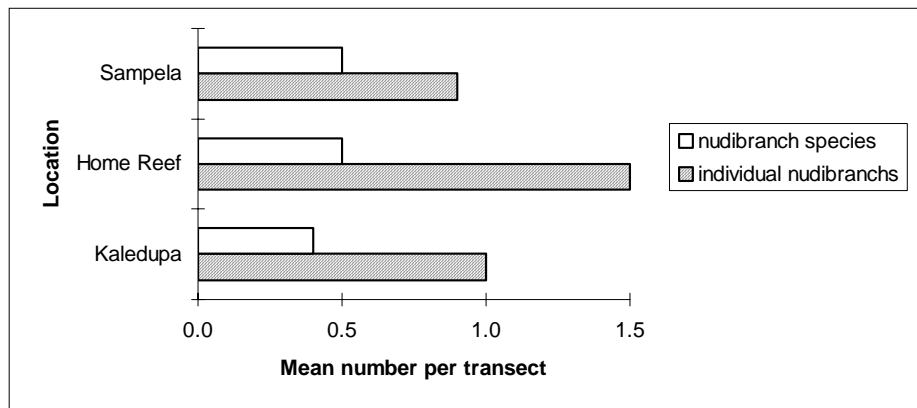


Figure 4.8: Mean number of individual nudibranchs and nudibranch species per transect at each dive site.

P. pustulosa made up the highest of the total number of nudibranchs recorded at all three sites (Kaledupa: 12; Home Reef: 10; Sampela: 6) (Table 4.3 and Figures 4.9a, b and c). A further 5 nudibranchs at Kaledupa were Phyllidiid species (*P. elegans*: 2; *P. rudmani*: 1; and *P. varicosa*: 2). Only one nudibranch from the Chromodorididae family, *C. kuniei*, appeared in Kaledupa transects, compared to 22 from 7 species at Home Reef (Figure 4.9b). Four more Phyllidiid species were recorded at Home Reef, as well as 2 species from the Polyceridae family, *N. kubaryana* (1) and *N. lineolata* (4). In addition to the *P. pustulosa*, Sampela transects yielded one individual from each of 7 other species of nudibranch (Figure 4.9c).

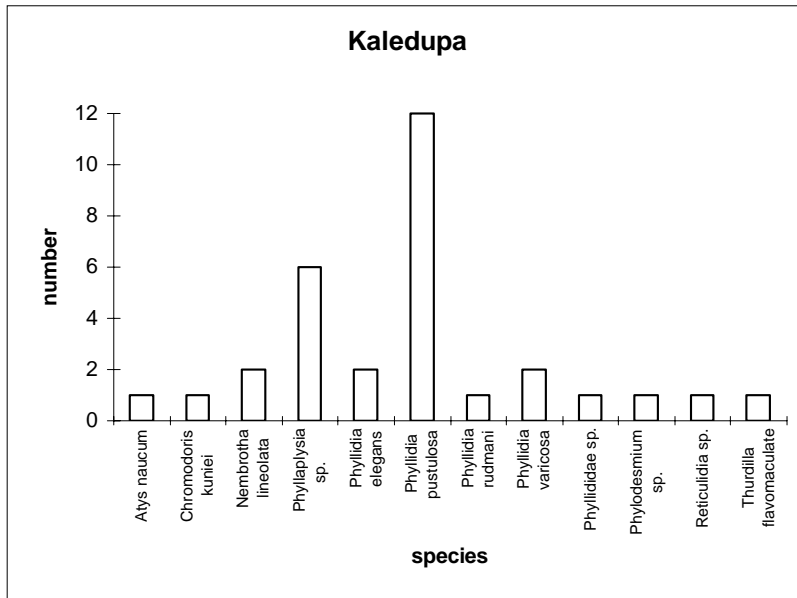


Figure 4.9a: Bar chart to show the range of nudibranch species recorded in Kaledupa transects and the number of individuals of each of these species.

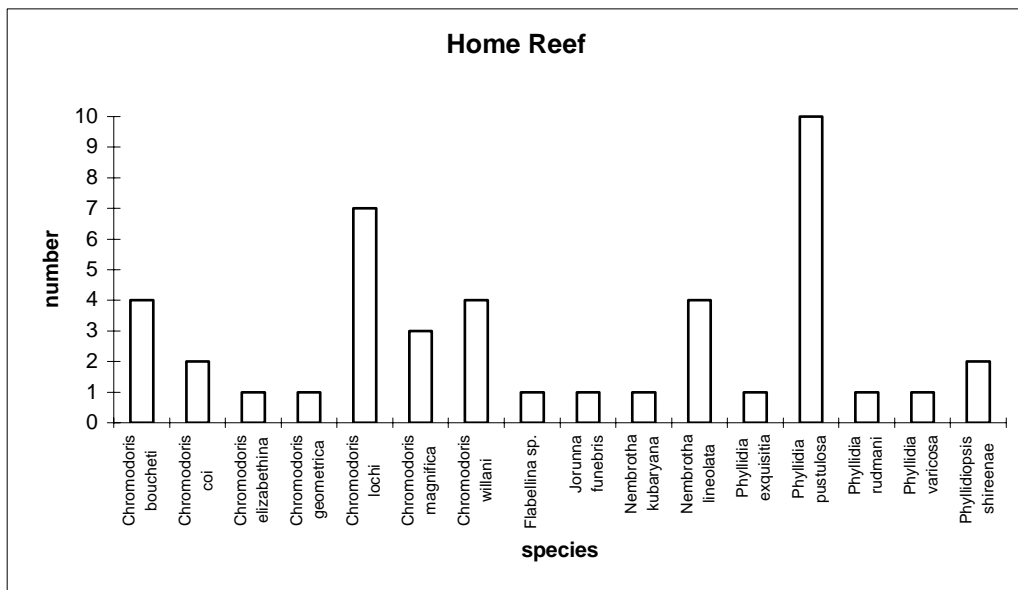


Figure 4.9b: Bar chart to show the range of nudibranch species recorded in Home Reef transects and the number of individuals of each of these species.

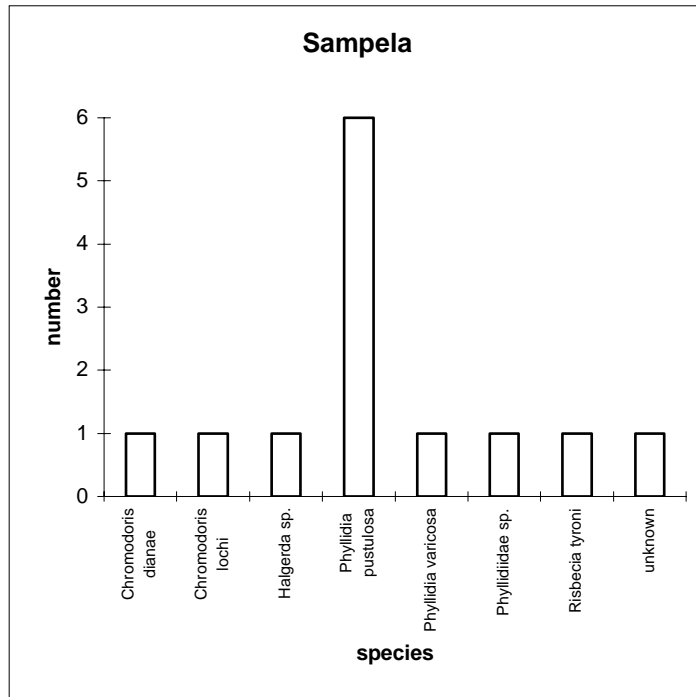


Figure 4.9c: Bar chart to show the range of nudibranch species recorded in Sampela transects and the number of individuals of each of these species.

4.6 - Comparison of nudibranch populations above and below 12m

Samples taken from below 12m had a higher mean number of nudibranchs and nudibranch species per transect (1.4 and 1.1, respectively), as well as higher species richness (20), diversity (2.66) and equitability (0.71) than transects above 12m (1.0, 0.9, 16, 2.15 and 0.56, respectively) (Table 4.4 and Figure 4.10). The null hypotheses for Mann-Whitney *U*-tests for abundance and species richness were accepted. There were no significant differences between these two variables above or below 12m.

Table 4.4: Table to show nudibranch abundance, species richness, diversity, and equitability of samples taken above and below 12m.

Depth	Above 12m	Below 12m

No. transects	45	30
Nudibranch abundance	45	43
Species richness	16	20
Species diversity index	2.15	2.66
Equitability	0.56	0.71

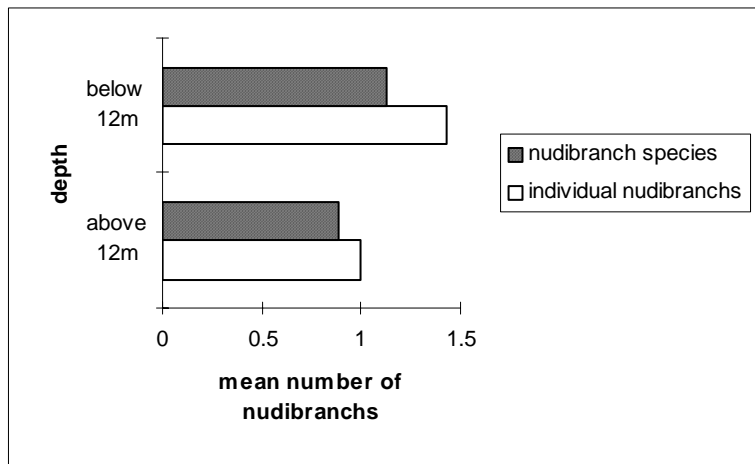


Figure 4.10: Mean number of individual nudibranchs and nudibranch species per transect above and below 12m.

Two species featured frequently in transects above 12m. These were *P. pustulosa* (19) and *N. lineolata* (5). Other species included Chromodorids, other Phyllidiids, *Risbecia tyroni*, *Flabellina* sp., and *Halgerda* sp. (Figure 4.11). Again, in the sample below 12m, *P. pustulosa* was the most frequently recorded species, with a total count of 9 individuals. Following *P. pustulosa*, *Phyllaplysia* sp. was the second most frequently recorded nudibranch below 12m. Six individuals of this species were found together in a single transect at the Kaledupa site. Other species recorded

included *N. lineolata*, *Jorunna funebris*, *P. exquisita*, and *Thurdilla flavomaculate* (Figure 4.12).

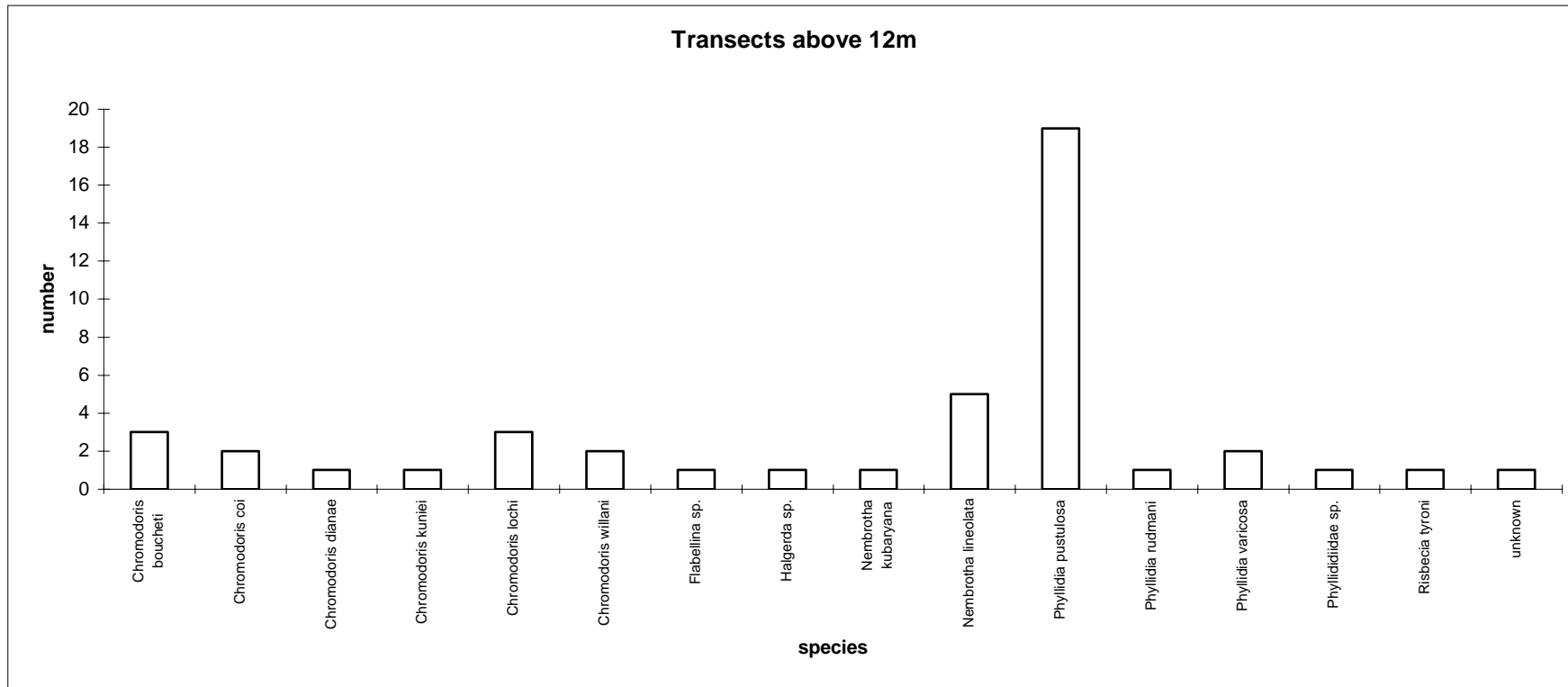


Figure 4.11: Bar chart to show the total number of each nudibranch species found in all transects above 12m.

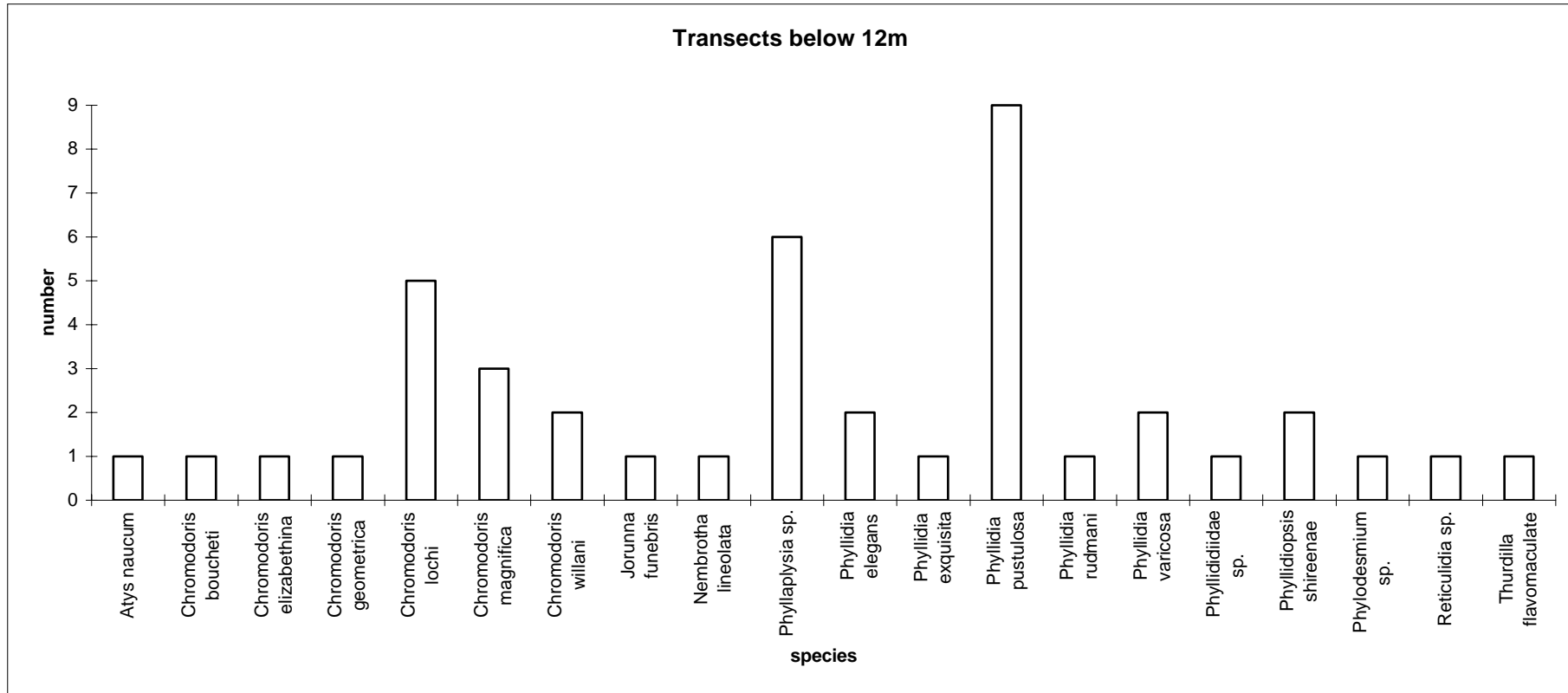


Figure 4.12: Bar chart to show the total number of each nudibranch species found in all transects below 12m.

Chapter 5:

Discussion

5.1 - Coral cover at the three dive sites

Coral cover was found to be significantly lower in Sampela reef transects compared to those of Kaledupa and Home Reef due to the reef being covered in a layer of sandy sediment (Plate 2.3). Corals covered with sediments restrict the ability of the photosynthetic zooxanthellae within them to trap light, hence limiting the coral growth rates. Riegl (1995) has shown that sedimentation has a detrimental effect on scleratinian and alcyonacean corals, eventually resulting in coral mortality.

Reduced visibility and the sand coating on the Sampela reef was due to higher sedimentation inputs. Mangrove and seagrass systems act as a sediment filter. Since these systems have been destroyed directly behind the Bajo sea gypsy village of Sampela (Plate 5.1), possibly due to the movements of its fishermen, sediments have been allowed to settle onto the coral. The village may also have been a source of organic sediment due to its lack of waste disposal facilities (Plate 5.2). Home Reef and Kaledupa reefs were not subjected to the same pressures as Sampela.

Plate 5.1: Photograph of the Bajo sea gypsy village.

Plate 5.2: Photograph of the interior of the Bajo sea gypsy village, giving some indication of the poor quality of the water due to a lack of waste disposal facilities.

5.2 - Coral cover above and below 12m

There was no significant difference in percentage coral cover with varying depths over the reef sites, but greater variation in coral cover between transects above 12m was evident. Studies by Loya and Slobodkin (1971) and Loya (1972) suggest that coral species diversity increases with depth. Therefore, transects below 12m could have had a greater range of coral species.

The average percentage coral cover for all transects above 12m (45.8%) was higher than the average for Sampela transects (22.6%). These data suggest that the mean percentage coral cover for transects above 12m from Kaledupa and Home Reef would be higher if Sampela transects were not included. Transects below 12m indicated a great cover of reef-building hard corals and a lower proportion of sand/rubble (39% and 15%, respectively), than those above 12m (30% and 25%, respectively: Figure 4.5). This suggests greater reef health below 12m, in line with the work of Loya and Slobodkin (1971) and Loya (1972). Higher benthic species richness and diversity would be expected in these “healthier” parts of the reef below 12m.

5.3 - Coral cover and its relationships with nudibranch populations

Although the coral cover percentage grouping 80-100% had the maximum possible species diversity (Table 4.2), data may have been misleading as there were only 2 replicate transects within this grouping. Others had as many as 30.

Apart from the group 80-100% coral cover, transects with 20-40% and 40-60% cover had higher mean numbers of individual nudibranchs and nudibranch species than any other grouping (Figure 4.8), as well as species diversity indices (2.31 and 2.06, respectively). Transects with 40-60% cover expressed a smaller proportion of

maximum diversity potential, compared to those with 20-40%, as shown by their equitability values (Table 4.2). Despite no correlation between nudibranch abundance nor species richness and coral cover, the data implies that nudibranchs were best suited to a reef environment with low to medium coral cover.

As neither the abundance nor species richness of nudibranchs were significantly different with varying coral cover, other environmental variables may have had an influencing effect. Many studies of reef data do not rely heavily on statistical tests due to the complexity of reef systems as a whole. It would be very easy to wrongly attribute a particular statistically proven correlation to a totally unrelated variable (Gamito and Raffaelli, 1992).

Several species distribution patterns were observed between different coral cover groupings. Species within the family *Chromodorididae* such as *C. boucheti*, *C. lochi* and *C. wiilani*, were most abundant in the coral cover ranges that were most species diverse overall (20-40% and 40-60% cover). This family prey on sponges, thus coral cover was likely to be of less importance to them than the cover of sponges. The *Phyllidiid* species, *P. pustulosa*, was most abundant in transects with 20-40, 40-60, and 60-80% coral cover, and was the most recorded species overall. *P. pustulosa* and other *Phyllidiids* are the most frequently seen nudibranchs in the Indo-Pacific seas (Diveoz, 2000). Unlike some other nudibranch species they are firm-bodied, very poisonous, with no known predators. Hence they can safely be active during the day. *P. pustulosa* in particular, has proven to be a successful member of coral reef communities, so much so that other dorid nudibranchs and some flatworm species mimic its colouration for their own defence against predators. The nudibranchs from

the *Polyceridae* family, *N. kubaryana* and *N. lineolata*, were not recorded in any transects with less than 40% coral cover. *N. lineolata* tends to be a large nudibranch species and was one of the largest recorded in this survey, measuring 7 cm. Larger nudibranchs possibly require a higher cover of coral substrate than smaller species.

5.4 - Nudibranch populations at the three dive sites

Home Reef had the greatest mean number of nudibranchs per transect (1.5), possibly owing to its higher percentage of hard coral than other sites. As expected, Sampela had the lowest mean number of nudibranchs per transect (0.8) and the highest average percentage of sand/rubble (57%), possibly limiting its suitability as a habitat for nudibranchs. For example, hard corals provide more opportunity than sand/rubble for other nudibranch food sources to grow upon. Even though differences in nudibranch numbers were observed from site to site, none were significant. This was consistent with the coral cover being unrelated to nudibranch abundance as coral cover varied between sites and the number of individual nudibranchs found did not.

Though there were no significant differences in either abundance or richness of nudibranchs between sites, the diversity and equitability data varied. The highest number of nudibranchs were recorded in Home Reef transects, where species diversity was highest (2.44). Kaledupa and Sampela had fairly similar species diversity (1.99 and 1.74, respectively). Of all three sites Kaledupa transects expressed lowest equitability and thus the smallest proportion of the maximum diversity possible.

Low species diversity and mean number of nudibranchs per transect at Sampela could have been caused by low coral cover, and the high percentage of sand/rubble may have limited the establishment and growth of food sources such as corals, sponges, hydroids and tunicates. The dull, sandy environment of Sampela may have made brightly coloured species such as Chromodorids, appear less cryptic, providing possible explanation why Sampela had fewer dorid nudibranchs than the other two sites. For example, the *Risbecia tyroni* (Plate 5.3) would be much less noticeable in Sampela's sandy environment than a *C. diana* (Plate 1.1).

Plate 5.3: *Risbecia tyroni* (Dive Gallery, 2001).

Species recorded that were known to especially prey on corals were *Phylodesmium* sp. and *Flabellina* sp. One individual of the former was recorded at Kaledupa, and one of the latter was found at Home Reef. Neither were sighted at the Sampela site, again providing evidence for its reduced coral cover compared to the other sites. As discussed in section 5.3, Phyllidiid species, *P. pustulosa* in particular, were very

abundant throughout all three survey locations since daytime is recognised as being their favoured period of activity.

5.5 - Nudibranch populations above and below 12m

Neither nudibranch abundance nor species richness were significant between depth ranges but the sample below 12m had higher mean nudibranchs and nudibranch species per transect. Species diversity indices and equitability values were also greater at increased depth, possibly in line with the higher mean proportion of hard coral cover in the sample. An alternative explanation for increased nudibranch numbers below 12m could relate to the effect that depth has on colours. Fewer colours can be distinguished at greater depths. *P. pustulosa* (Plate 5.4) and other Phyllidiids, whom are less influenced by predators in their distribution, are able to inhabit shallower waters as they have no need to hide their bright colours. However, species such as *C. kuniei* and *C. coi* (Plate 5.5), who do not have such defensive poisonous properties as the Phyllidiids, would have been more inconspicuous at depth where their colouration would have been less noticeable.

Plate 5.4: *Phyllidia pustulosa* (Slugsite, 2001).

Plate 5.5: Photograph of *Chromodoris kuniei* (top) and *Chromodoris coi* (bottom)

(Photograph courtesy of Adam Powell, 2001).

5.6 - Other influencing factors over nudibranch populations

5.6.1 - Food associations

As already discussed, many nudibranchs live in close association with their prey. Nudibranchs typically display stenophagous (specialist) prey associations, feeding on one or two prey species (Todd *et al*, 2001). For example, *Catriona gymnota* is rarely found eating any hydroid other than *Tubularia sp.*, and in choice experiments had a

specific preference for it (Braams and Geelan, 1953). McDonald and Nybakken (1997) compiled a list of the diets of 600 known nudibranch species from the World's oceans through the study of all relevant nudibranch data published before 1996. It was found that approximately 50% of species preyed on one species alone, and 75% preyed on between one and three species (Todd *et al*, 2001). It is therefore regarded that nudibranchs with a preference for a certain food source will be restricted to the range of that prey species. Some species even migrate according to a change in food preference as they mature (Edmunds, 1987).

5.6.2 - Life cycles and life styles

The majority of nudibranch literature state that nudibranchs live for approximately one to one and a half years. Their life-span can be influenced by a variety of factors, including availability of food and the general environmental conditions. As expected, when food is plentiful there can be population explosions. There can also be times of great reduction in numbers due to limited food or through natural causes. Thus, it is possible that the nudibranch surveys carried out for this study could have been conducted in either a time of population explosion or decline. The study would have to be carried out over a longer period of time, maybe over a number of years, to be more representative of the nudibranch population dynamics in the Wakatobi Marine National Park.

Due to the various stages in the life cycles of nudibranchs, some may not have been detectable over the duration of the survey. For example, juveniles may have been too small to see amongst the complex coral reef system. A nudibranch's lifestyle can

influence when and for how long it will be present in a particular marine environment.

Diveoz (2001) categorised nudibranchs as having one of the following two life styles:

1. Nudibranchs that feed upon hydroids etc. (ephemeral prey) tend to appear several times in a particular year;
2. Those feeding upon sponges live longer, possibly over a year.

Some of the nudibranchs that may inhabit the Wakatobi Marine National Park for some of the year may not have been present at the time of data collection and thus it is not certain that all potential nudibranch species were fairly represented.

5.6.3 - Nudibranch behaviour

Many nudibranch species found in the tropics hide during the day, only emerging at night to avoid predation. Phyllidiids (e.g. *Phyllidia pustulosa*, *Phyllidia varicosa*, etc.), with their distasteful mantle secretions, are often the only commonly seen species found during daylight hours in the tropical seas. From looking at the raw data (Appendix A) it was evident that out of a total of 88 individual nudibranchs found in all transects surveyed, 37 (42%) of them were Phyllidiids. This may have been an indication that specific species prefer different times of the day to be active.

5.7 - Limitations

As with the majority of practical research projects, limitations were encountered throughout the duration of this IRE, as discussed below:

5.7.1 - Limitations of primary data collection

- As approached in 3.1.2, there were limited sites that could have been included in the survey. Thus, the chosen sites may not have been truly representative of the Wakatobi Marine National Park. All three were nearer to Kaledupa than any of the other main islands that made up the National Park.
- Transects could not be laid down deeper than 12m at Sampela so that data from just 15 transects was collected instead of 30 as was from the other two dive sites. Despite this, it was decided that data would still be collected from this location because of its high sedimentation rate and thus its suspected low coral cover in comparison to the Kaledupa and Home Reef survey sites.
- There were limitations to the depths that could be surveyed safely. In theory, advanced open water divers can dive to a depth of 30m so transects could have been laid at this depth. However, due to the harmful effects of nitrogen narcosis and decompression sickness, for example, it would have been unsafe for a diver to stay at such a depth for the length of time needed to lay the transect tape and collect the data. As a precaution, transects tended to be laid no more than 15m deep.
- The depths at which transects were laid were only approximate due to the changes in depth caused by tidal action.
- During data collection, mistakes may have been made in either identifying the substrate type or estimating the proportion of the transect that a particular substrate covered, thus giving incorrect results. Nudibranchs may also have been identified incorrectly as it was inappropriate to take them out of the water to compare them with published literature back at the research centre.

- Dive conditions such as visibility and the presence of currents could also have had an affect on the efficiency of the survey team. The more confident and comfortable in the water that the divers felt, the more likely they were to carry out the survey accurately and thoroughly.

5.7.2 - Limitations of secondary data collection

A problem with using divers to help collect data for a research project that was not their own could have been that they were not too concerned with their accuracy. As there were many people involved in the collection of the complete data set there was no guarantee that the exact same techniques of data collection were used by all involved persons.

5.7.3 - Limitations of statistical methods

It is often difficult to decide upon the appropriate statistical method to use when analysing data such as that collected for this IRE. Prior experience of the use statistics can be considered essential so that data can be analysed correctly and efficiently.

5.8 - Future investigation opportunities

The following list suggests possible topics for further investigation as a result of this IRE:

- The relationship between increased coral/benthic species diversity and increased depth;
- The relationship between coral cover and nudibranch size;

- Nudibranch population dynamics and sponge communities within the Wakatobi Marine National Park; and
- A comparison between nudibranch population dynamics in daylight and night time hours.

Chapter 6:

Conclusions

6.1 - Realisation of aims and objectives

During the course of this study all of the original aims and objectives were met with one exception. Relationships between nudibranch abundance, species richness, diversity, and equitability were investigated at the three chosen dive sites, five coral cover groupings, and at two depth ranges. The exception was that there was no sample taken below 12m at the Sampela site and so half as many transects were surveyed here. The objectives set out to identify two depth ranges suitable for all three sites, not just Kaledupa and Home Reef. Despite this, statistical methods were utilised that were suited to analysing the 'incomplete' data set and some interesting results were concluded (Chapter 5).

6.2 - Improvements

As with many research projects there is always room for improvement, often relating to the initial design of the investigation. The identification of areas in need of improvement were discussed in section 5.7, some of which could not easily have been rectified. For example, overcoming the restricted access to a wide range of survey sites would be difficult due to the constraints of Operation Wallacea site selection criteria, and environmental conditions such as currents. Adjustments could be made to the data collection process by using alternative survey methods, such as timed nudibranch counts instead of laying out transects. This method involves divers scanning a reef site for a set length of time, recording any nudibranchs they find, then comparing with the counts for the other sites chosen. The quality and accuracy of the divers' nudibranch and coral identification skills could be improved by spending more time out of the water studying them before conducting the surveys, also improving the efficiency of their use of time once in the water.

6.3 - Final conclusion

As a preliminary study, this IRE has approached some interesting ideas for the future study of nudibranch population dynamics within a coral reef ecosystem, as suggested in section 5.8. Although the majority of the statistical tests performed proved no significance between the nudibranch populations and the various environmental variables investigated throughout the study, some patterns were hinted at in the data (see Chapter 5). In particular, depth seemed to be an influencing factor in the distribution of nudibranchs over the study area. There was not only increased coral cover below 12m but increased nudibranch abundance, species richness, diversity and

equitability. Given the opportunity, the effects of depth on nudibranch and coral community dynamics would definitely be worthwhile to investigate further.

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