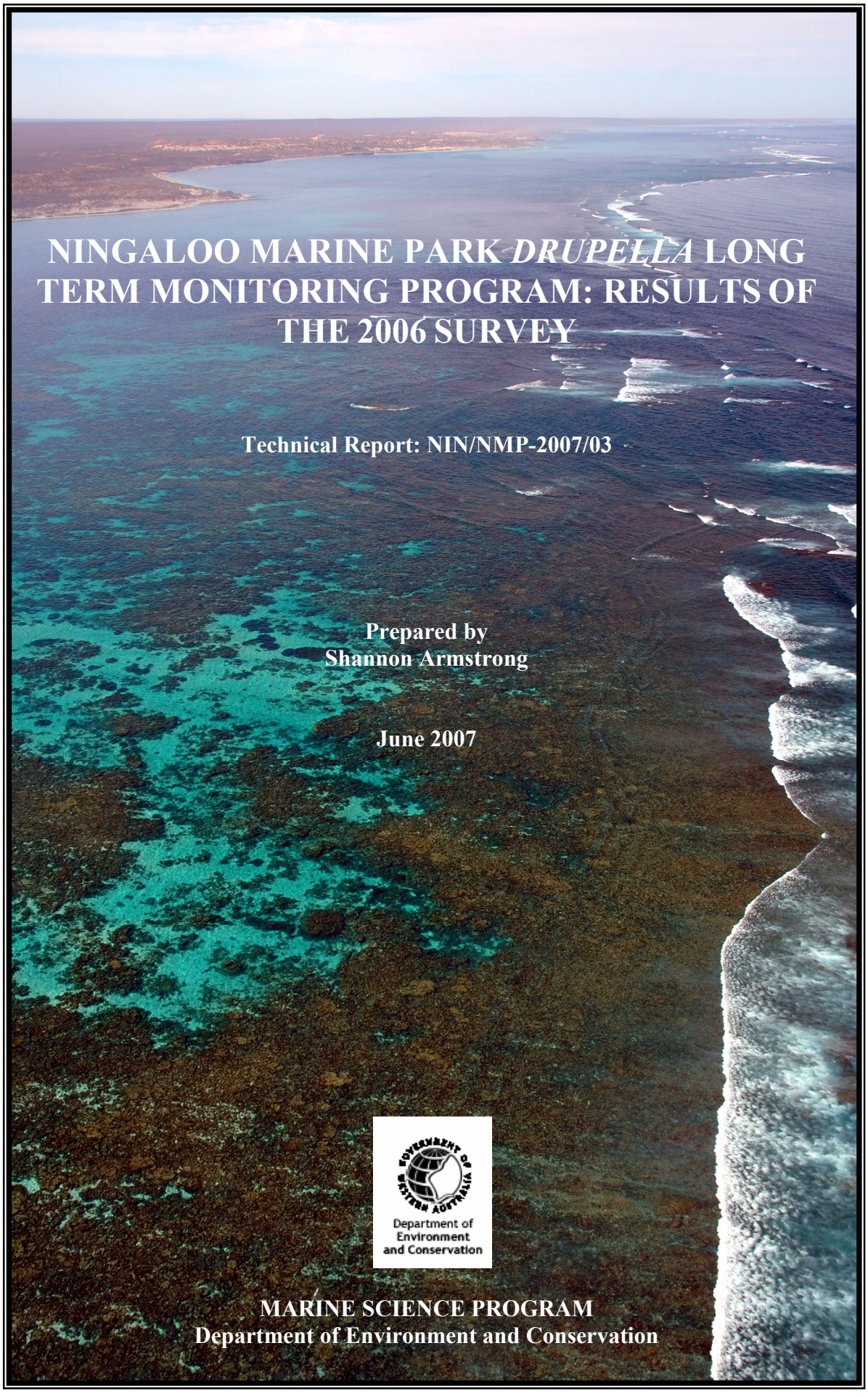

NINGALOO MARINE PARK *DRUPELLA* LONG TERM MONITORING PROGRAM: RESULTS OF THE 2006 SURVEY

Technical Report: NIN/NMP-2007/03

Prepared by
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Department of Environment and Conservation

MARINE SCIENCE PROGRAM
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Cover Page: Photograph of Ningaloo Reef facing south from the Coral Bay area, taken in early 2007.

SUMMARY

Between the mid 1980s and early 1990s, the feeding activity of unusually high densities of the corallivorous gastropod *Drupella cornus* resulted in massive coral damage along at least 100 km of Ningaloo Marine Park (NMP), with coral mortality approaching 100% at some areas. To date, the density of *D. cornus,* the area and severity of associated coral damage and longevity of the outbreak itself that occurred ay NMP during this event was on a greater scale than recorded on other reefs elsewhere in the world.

As coral communities are a key performance indicator of management of NMP and the Muiron Islands Marine Management Area (MIMMA) it is essential to keep a watching brief on spatial and temporal changes to *Drupella* densities and cover of associated corals in these conservation reserves. Adhering to this management need, the aim of the Ningaloo Marine Park *Drupella* Long-term Monitoring Program (NMPDMP), lead by the Department of Environment and Conservation, is to monitor long-term changes to the density of *Drupella* sp. and cover of associated coral communities at the NMP and the MIMMA. Monitoring of *Drupella* at NMP has resulted in a data set describing the status of *Drupella* populations and coral communities dating back to 1987.

Between 1987 and 2006, the direction and amplitude of change in *Drupella* density and percent cover of live hard coral has varied considerably between locations. Overall however, relative to the outbreak densities recorded during the late 1980s and early 1990s, *D. cornus* densities have been low to moderate and have not greatly affected coral cover at the NMP and MIMMA. Survey data indicate that the current *Drupella* population represents no immediate threat to the coral communities at NMP or MIMMA.

This data report presents the most current information available on the status of *Drupella* populations and coral reef communities at NMP and the MIMMA. It also presents a summary of the changes to *Drupella* density and live hard coral at NMP over time.

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1.1 INTRODUCTION

1.2 BACKGROUND

To date, there have been reports of outbreak *Drupella* spp. populations causing extensive coral damage in four areas of the tropical Indo-West Pacific region: Western Australia, Japan (Moyer *et al.* 1982; Fujioka & Yamazato, 1983), the Philippines (Moyer *et al.* 1982), and the Marshall Islands (Bucher, 1986). Relative to the events elsewhere, the outbreak of *D. cornus* observed at Ningaloo Reef, Western Australia, was on a greater scale in terms of the density of snails, area and severity of coral damage and longevity of the outbreak itself during the mid 1980s to the early 1990s. The feeding activities of high numbers of *D. cornus* caused massive coral damage along at least 100 km of northern Ningaloo Reef, and by 1989, live hard coral cover had been reduced by a mean of >75% at several backreef locations (Ayling & Ayling, 1987; Forde, 1994).

Large numbers of *Drupella cornus* were first observed at Ningaloo Reef in 1982 and later confirmed in 1985 (Simpson, pers. comm., 2005; Forde, pers. comm., 2005). In early 1987, the Department of Conservation and Land Management[1] initiated a broad scale survey of the then proposed Ningaloo Marine Park to obtain some preliminary information on the biological habitats and density of recreationally important fish species at four selected locations: Sandy Bay, Osprey Bay Pass, South Osprey Bay and Ned's Camp. This survey was conducted by Ayling & Ayling (1987), who noted that large numbers of *D. cornus* were consuming hard corals at all four locations. As a result, the survey was extended to cover density estimates of *Drupella* at these four locations and at four additional locations along the reef (Tantabiddi Creek, North Mandu Mandu, Winderbandi Point and Coral Bay). In 1989, the first six long-term *Drupella* monitoring locations were established and surveyed by Sue Osborne and Jim Stoddart (Osborne pers. comm.): Tantabiddi, Turquoise Bay, Osprey Bay, Winderbandi, Coral Bay Lagoon and Pelican Point. The Osprey Bay location was in close proximity to the South Osprey Bay location surveyed in 1987 by Ayling and Ayling (1987). In 1991, these six locations were re-surveyed and seven new long-term *Drupella* monitoring locations were established by Osborne and Williams (1995): Bundegi, Ned's Camp, Bunderra, Lefroy Bay, Cloates, Bruboodijoo and Coral Bay Backreef. This resulted in a total of thirteen long-term *Drupella* monitoring locations. In 1994, these thirteen locations were re-surveyed by Osborne and Williams (1995). The same thirteen locations were re-surveyed again in 2005 by Armstrong (2005). In 2006, four of these locations were re-surveyed (Turquoise Bay, Osprey Bay, Coral Bay Backreef and Pelican Point) and six new *Drupella* long-term monitoring locations were established in the southern extension of the NMP and the MIMMA. This resulted in a total comprehensive set of nineteen *Drupella* long-term monitoring locations, positioned approximately every 20 km along the NMP (Fig 1).

This data report presents the most current information available on the status of *Drupella* populations and coral reef communities at NMP and the MIMMA. It also presents a summary of the changes to *Drupella* density and live hard coral at NMP over time.

[1] On the 1st of July 2006, the Department of Conservation and Land Management and the Department of Environment amalgamated and renamed the Department of Environment and Conservation (DEC).

1.3 OBJECTIVE, ASSOCIATED MANAGEMENT STRATEGIES, OUTPUTS AND OUTCOMES

1.3.1 Objective

Overall, the objective of the NMPDMP is to record changes in *Drupella* sp. density and covers of associated benthic communities at NMP and MIMMA, by monitoring these variables on a long-term basis. The primary objective of the 2006 NMPDMP was to:

- Gain an appropriate spatial coverage of the status of *Drupella* populations and associated coral communities at the NMP and MIMMA by establishing sites at the MIMMA and within the 2005 southern extension of the NMP

1.3.2 Associated management strategies

The NMPDMP has addressed or will continue to address the following management strategies highlighted in the NMP and MIMMA Management Plan 2005-2015:

- Undertake research to develop a cost effective protocol to monitor *Drupella* population trends in the reserves (DEC, high management priority): Strategy 10, pg. 29.
- Monitor the distribution and abundance of *Drupella cornus* in the reserves at least every three years (DEC, high management priority): Strategy 11, pg. 29.

1.3.3 Outputs

The following outputs will be generated as a result of the 2005 and 2006 NMPDMP surveys:

Science

- Field Program Report - NIN/NMP-2006/02
- Data Report (this report) - NIN/NMP-2007/03
- Scientific paper (submitted)

Communication

- LANDSCOPE magazine article – December edition 2007
- DEC Conservation News article – May edition 2007
- Park Note – Exmouth district
- Radio interview: ABC North West (13/06/07)

1.3.4 Outcomes

The results of the NMPDMP have and will continue to provide planning and operational management with an improved understanding of: 1) long-term changes and current status of a key performance indicator (KPI) of management of NMP and MIMMA i.e. coral communities, 2) long-term changes to, and current status of the impact on this KPI from a known significant threat i.e. *D. cornus*.

2 METHODS

2.1 STUDY LOCATION

The Ningaloo Reef is located approximately 1000 km north of Perth in Western Australia, and runs parallel to the coastline as a discontinuous barrier for over 280 km.

It is the largest fringing coral reef system in Australia and the only coral reef in the world fringing the west coast of a continent (Taylor & Pearce, 1999). Temperate and tropical currents converge in the Ningaloo region, resulting in a diversity of marine life including more than 500 species of fish, 250 known species of corals and approximately 600 species of molluscs (CALM, 2005). The area has very high ecological and social conservation significance and was gazetted as a marine park in 1987. In 2005, the Park boundary was amended to include the southern section of the Ningaloo Reef. The Muiron Islands Marine Management Area was also gazetted in 2005.

2.2 SURVEY LOCATIONS

Prior to the initial surveys in 1991, aerial photographs combined with ground truthing were used to select thirteen locations of predominantly hard coral reef substratum. At each location, three replicate sites were selected, distributed within similar areas of reef for that location. Sites were located within typical *Drupella* habitat, i.e. backreef and lagoonal communities with high coral cover.

The thirteen locations are positioned approximately every 10-20 km along the reef from Bundegi Reef in the north (21° 49'S, 114° 10'E) to Pelican Point in the south (23° 20'S, 113° 46'E) (Fig 1). Locations are in extensive shallow reef flats (<2 m depth) at Ned's Camp, Turquoise Bay, Osprey Bay, Bunderra, Winderabandi, Cloates, Bruboodijoo, Coral Bay Backreef and Pelican Point. Locations at Tantabiddi and Coral Bay Lagoon are in a lagoon (<5 m depth), bordered from the reef flat and inshore environment by sand. The Lefroy Bay location is an area of large bommie clusters (<5.5 m depth). At Bundegi, the location is a shallow fringing reef flat in the sheltered waters of the Exmouth Gulf (<4 m depth); this is the only location on the eastern side of North West Cape (Fig 1).

A similar method was used to select six new survey locations in 2006. Again, locations were selected to represent typical *Drupella* habitat and sites were intended to be representative of the location and were therefore selected to be similar within a location or to represent the full range of *Drupella* habitat within a location. A total of four representative locations were selected, approximately every 10-20 km along the reef in the southern extension of NMP. Two locations were selected at the MIMMA, one at each of North and South Muiron Islands. Location selection was further influenced if information about the coral communities in the area was available from previous surveys. At Gnaraloo Bay and Cape Farquhar, previous surveys of coral communities had been undertaken during the Ningaloo Marine Park Long-Term Monitoring Program (NMPMP) (Cary *et al.* 1999). Historical data assist in determining temporal changes, and therefore the new *Drupella* monitoring locations were selected to be in close proximity to NMPMP locations. Figure 1 shows the complete set of NMPDMP locations on a satellite image of NMP including management zones boundaries. Table 2 in Appendix 1 lists the GPS coordinates of every NMPDMP site, and summarises each in terms of depth, management zone and reef habitat. A habitat database stored on the Marine Science Program (MSP) server has additional habitat and spatial information about each site. Figures 4 to 13 are aerial photographs of the locations surveyed in 2006.

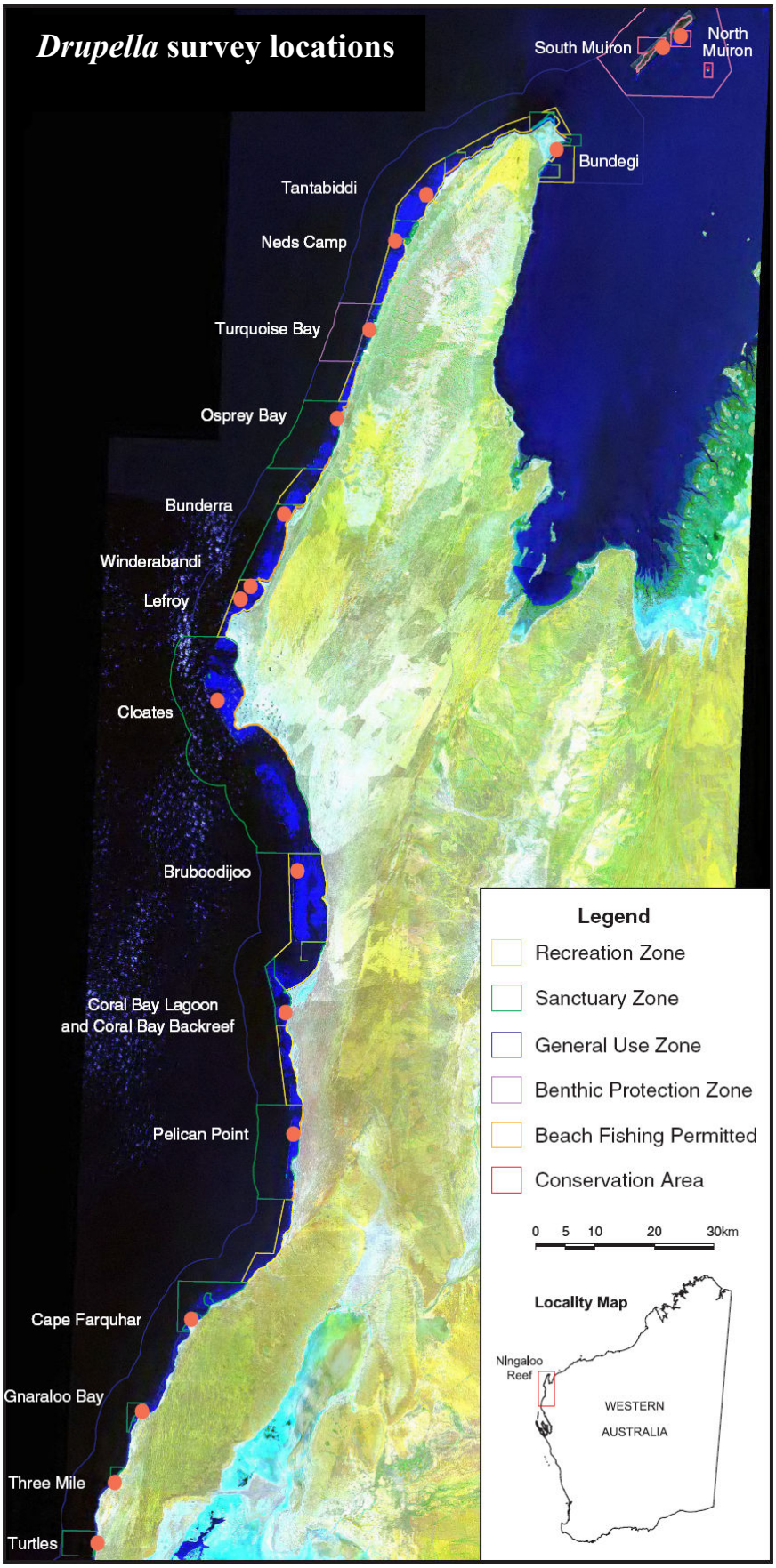


Figure 1. Overview of the nineteen *Drupella* long-term monitoring locations within NMP. The thirteen locations surveyed in 1991, 1994 and 2005 were Bundegi to Pelican Point. The six locations established in 2006 were the southern four and the two located at the MIMMA. Four of the existing locations were also re-surveyed in 2006: Turquoise Bay, Osprey Bay, Coral Bay Backreef and Pelican Point.

2.3 SURVEY DESIGN

The NMPDMP uses a nested survey design of three replicate 0.5 x 20 m belt transects per site and three replicate sites per location (Fig 2).

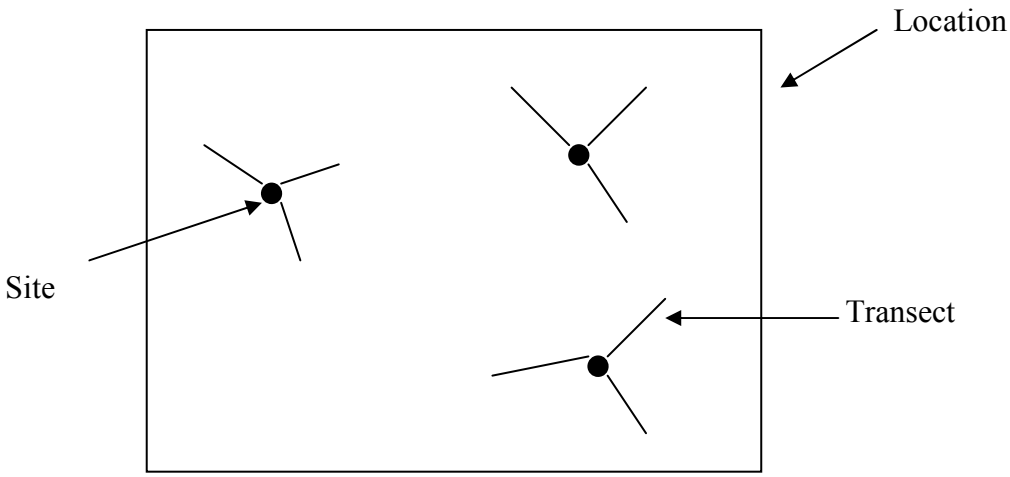


Figure 2: Diagram of the NMPDMP hierarchical or nested survey design.

2.4 DETAILED SURVEY METHODS

In 2006, the survey team consisted of three personnel: one videographer, one *Drupella* counter and one vessel skipper. It is important that the *Drupella* counter is very familiar with the cryptic nature of *Drupella*, the appearance of their feeding scars and the identification of *Drupella*'s preferred coral prey species. To maintain consistency in the results, it is recommended that same person be the *Drupella* counter for the duration of the field trip. Effort must also be made to ensure that the ability of the *Drupella* counter to find and identify *Drupella* and their prey is consistent between surveys. This can be achieved by training new staff to identify *Drupella* in the field and comparing the number of *Drupella* counted by new and experienced staff along the same transects prior to sampling.

The position of each survey site was found using a GPS and marked with a weighted buoy. In 2006, when new site positions were established, coordinates were recorded in the field using a handheld Garmin GPS MAP76 (Datum WGS84) in decimal minutes. If the vessel could not closely approach the position of the site then a snorkeller brought the GPS (waterproof to 1 m) to the site, recorded the position on the GPS if it was a newly established site, and marked the position with a weighted buoy.

Using a random compass bearing, the first of the three 0.5x20 m belt transects for that site was established. One measuring tape would be laid out for 20 m in the direction of the randomly chosen compass bearing from the centre GPS coordinate for that site marked by the weighted buoy. Since sites were intended to represent *Drupella* habitat, directions were avoided that had large areas of no *Drupella* habitat i.e. sand. Once the first 20 m tape was laid, the benthic community along each transect was recorded using a Sony HDR-HC1/E digital video camera in an Amphibico underwater housing. The diver moved slowly along the transect, holding the camera approximately 50 cm above the substratum on wide angle zoom whilst recording the entire 0.5x20 m transect on the right hand side of the measuring tape (Fig 3). The measuring tape remained in the field of view on the left hand side of the screen whilst recording.

Figure 3. Photograph showing two DEC divers: the diver in the foreground is videoing the benthic communities along the transect, whilst the other is visually counting and recording the number of *Drupella* within 50cm on the right-hand side of the transect.

Once the videographer commenced filming, the *Drupella* counter began estimating density by visual search within 50 cm on the right-hand-side of each transect, and recorded the information on an underwater *Drupella* data sheet (Section 1, Appendix 2). It is very important for only the snails within 50 cm on the right-hand-side of the tape to be included in the count, as the total *Drupella* count for each transect will be divided by 10 to give a density of *Drupella* in m^{-2} values. The clipboard that the underwater transect data sheet was secured to had a ruler marked along its side and was used by the diver as a guide to determine if snails were inside the 50 cm boundary.

The size class of each snail was also determined using this ruler and recorded (see Armstrong (2005) for a description of the size classes ascribed to each snail). The presence or absence of *Acanthaster planci* (Crown of Thorns Starfish) within 2.5 m either side of each transect was also noted. The information recorded on the underwater *Drupella* data sheet was transferred (as soon as possible) to the transect data sheet (Section 1, Appendix 2). Once the first transect had been videoed and surveyed for *Drupella,* the process was repeated for the remaining two transects for that site.

An underwater habitat data sheet was completed at each site to record observations of the dominant fish species present and dominant substratum types. A 360° underwater video shot was also taken at each site to provide a panorama view of the habitat type and rugosity of the substrate for future reference. Habitat and spatial information about each survey location, including the bioregion, biological assemblage, video tape

number and GPS coordinate were entered into the habitat database stored on the MSP server.

In addition, each NMPDMP location has a long-term monitoring data sheet associated with it (Appendix 6). This data sheet contains information that will aid re-location of the sites and helpful logistical information including: photograph of the vessel launch area used to access the survey location, distance of location from the vessel launch site, position of location in relation to obvious land and sea markers, availability of CDMA/digital mobile reception, the frequency and channel of available radio communications, mud map of the location and details of the vehicle and vessel route used to access the location.

2.5 VIDEO DATA ANALYSIS

A point sampling method was used to analyse the video footage. A point was randomly placed on the video screen and the underlying benthic habitat type was recorded approximately every 15 cm along the transect (the position of the point was changed randomly for each transect). This equated to approximately 130 survey points for each transect. A total of 31 different categories were used to quantify the benthic community composition along each transect (Table 3, Appendix 2 lists these categories). The number of points recorded for each benthic category was used to calculate the mean percentage cover of each benthic habitat type at each study location.

2.6 STATISTICAL ANALYSIS

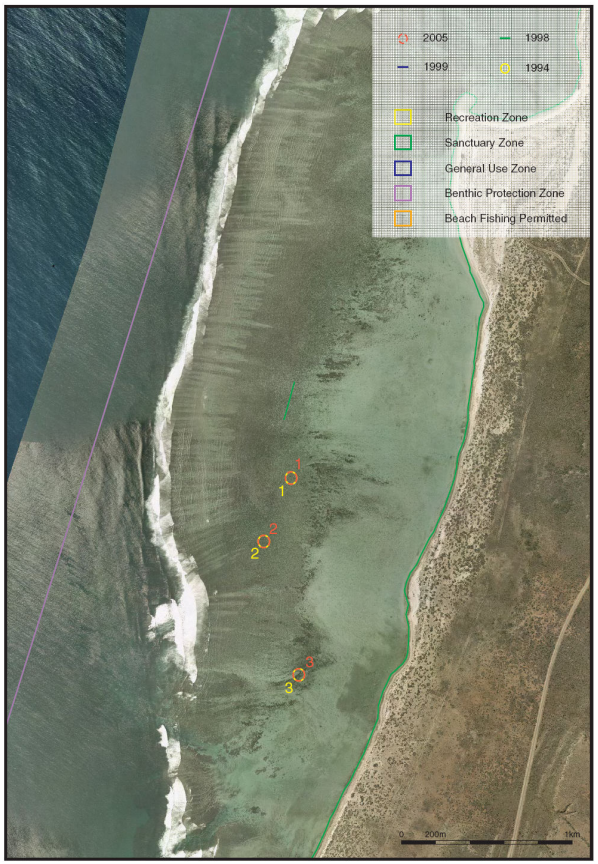
Prior to all analyses, due to significant skewness, the *D. cornus* density data were square root transformed in order to achieve homoscedasticity. One-way ANOVA tests (SPSS 9.05 for Windows) were used to identify significant differences in mean *D. cornus* density and mean live hard coral cover between locations, sites and survey years. The data from the 1987, 1988 and 1989 surveys were excluded from this analysis due to inconsistencies in methods used between locations and survey years. When significant differences were detected, pairwise differences were tested using the Tukey honestly significant difference (HSD) method. One-way ANCOVA tests were used to test for interactions between *D. cornus* density and percent cover of live hard coral over time at each location. Data from all survey years were graphed for general comparisons of trends in mean *D. cornus* density and mean live hard coral cover over time.

Note: Due to adverse weather conditions only one site at the Turtles location was surveyed in 2006. The video data taken at Turtles was analysed using only two benthic categories: live hard coral and other substrate. The mean density of *D. cornus* and mean cover of live hard coral recorded at site one at Turtles is presented in the results.

Figure 4. North Muiron survey location.

Figure 5. South Muiron survey location.

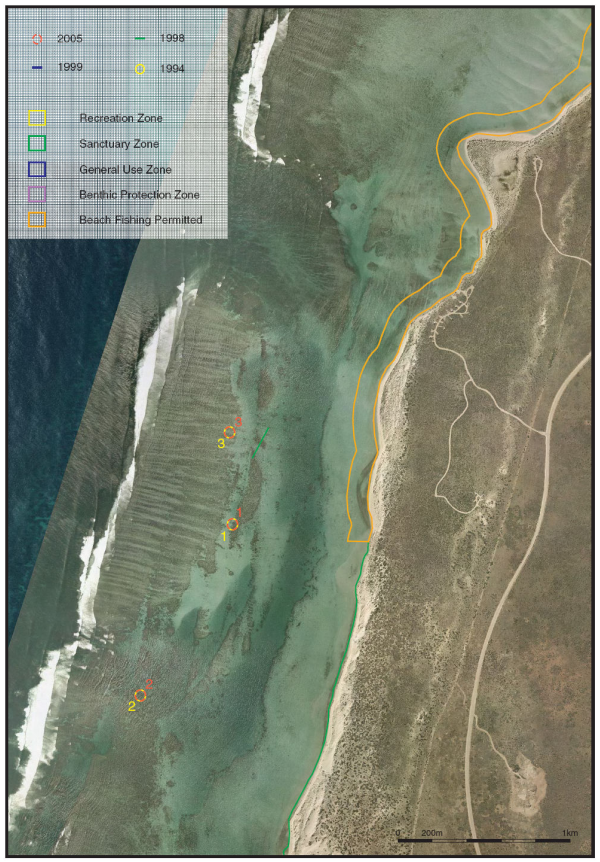
Turquoise



2005			1998			1994		
1	22 06 717	113 52 734	22 06 493	113 52 740		1	22 06 717	113 52 734
2	22 06 867	113 52 668				2	22 06 867	113 52 668
3	22 07 178	113 52 763				3	22 07 178	113 52 763

Figure 6. Turquoise Bay survey location.

Osprey



2005			1998			1994		
1	22 14 884	113 49 731	22 14 631	113 49 824		1	22 14 884	113 49 731
2	22 15 336	113 49 481				2	22 15 336	113 49 481
3	22 14 644	113 49 718				3	22 14 644	113 49 718

Figure 7. Osprey Bay survey location.

Figure 8. Coral Bay Backreef and Coral Bay Lagoon survey locations.

Figure 9. Pelican Point survey location.

Figure 10. Cape Farquhar survey location.

Figure 11. Gnaraloo Bay survey location.

Figure 12. Three Mile survey location.

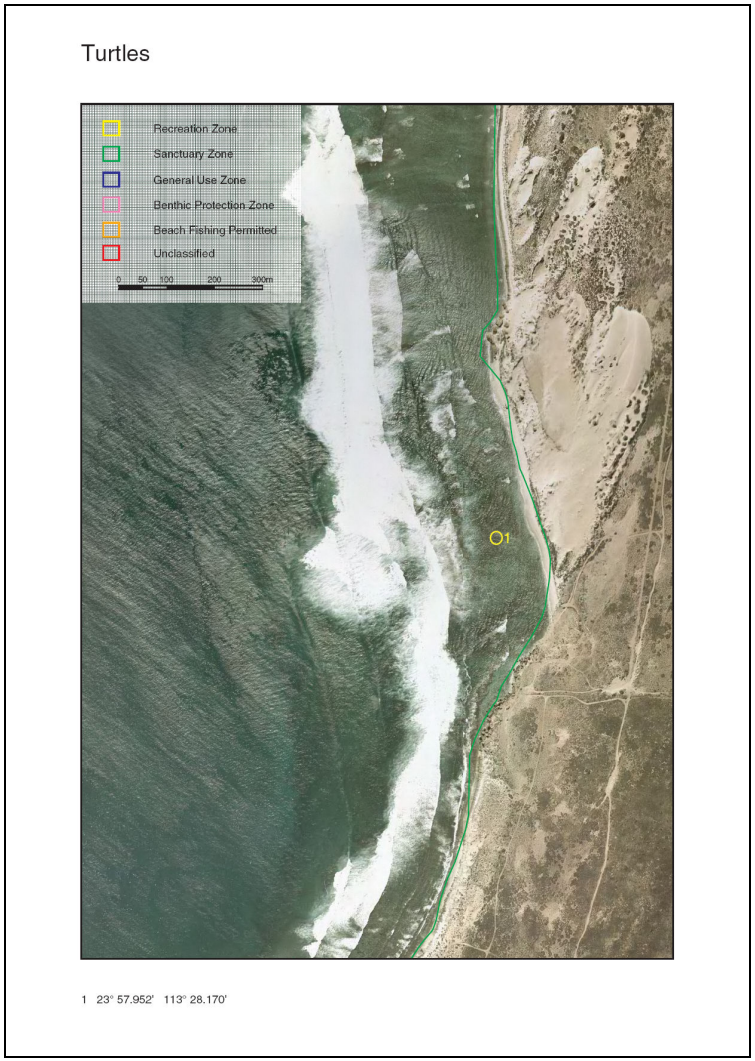


Figure 13. Turtles survey location.

3 RESULTS

3.1 THE CURRENT STATUS (AUGUST 2006) OF *DRUPELLA* AND *ACANTHASTER PLANCI* POPULATIONS AND ASSOCIATED BENTHIC REEF COMMUNITIES AT NMP AND MIMMA

3.1.1 Current *D. cornus* and Crown of Thorns density

In August 2006, *D. cornus* density was moderate to low at the majority of locations compared to the outbreak densities recorded during the late 1980s and early 1990s. These survey data indicate that current the *Drupella* population represents no immediate threat to the coral communities at NMP. Densities of *Acanthaster planci* are very low at NMP and MIMMA compared to the GBR, where high densities have caused widespread loss of coral cover in the past (Sweatman *et al.* 2005). The current density of *Acanthaster planci* at NMP and MIMMA represent no threat to coral communities.

In 2006, the highest mean density (m^{-2}) of *D. cornus* was recorded at Pelican Point (7.4 ± 2.32). Significantly higher ($p = <0.05$) densities of *D. cornus* were recorded at Pelican Point relative to 6 of the other 8 locations surveyed in 2006 (excluding Turtles). For results of the ANOVA tests for significant differences in *D. cornus* density between locations in 2006 see Table 11 in Appendix 3. Plate *Acropora* has been widely documented as a preferred coral prey of *D. cornus* (Robertson 1970; Fujioka and Yamazato 1983; Ayling and Ayling 1987; Oxley 1988; Stoddart 1989; Forde 1994). A high cover of plate *Acropora* was recorded at Pelican Point in 2006, relative to other survey locations, and may explain the high densities of *D. cornus* recorded there. In 2006, high densities of *D. cornus* were also recorded at Turtles (4.3 (no standard error is available as only one site was surveyed)), and Gnaraloo Bay (3.89 ± 1.41). In 2006, the lowest densities of *D. cornus* were recorded at North Muiron (0.2 ± 0.02), which was a significantly lower density ($p = <0.05$) than recorded at Pelican Point and Gnaraloo Bay during the same year.

Although *D. cornus* densities have been higher at NMP in the past, the highest densities of *D. cornus* recorded in 2006 at NMP are considerably higher than *Drupella* spp. densities recorded during studies at other reefs elsewhere in the world (Taylor 1980; Fujioka & Yamazato, 1983; Oxley, 1988; Hilliard & Chalmer, 1992; McClanahan, 2002; Sweatman *et. al.* 2005) (Table 1). However, the reasons for this remain unclear.

Table 1. Summary of *Drupella* spp. density at reefs worldwide.

Location	*Drupella* spp. mean density m^{-2}	Reference
Ningaloo Reef, Western Australia	0 – 18.76	This study
Ningaloo Reef, Western Australia	1.3-18.5	Ayling and Ayling, (1987)
Ningaloo Reef, Western Australia	0 – 18.1	Stoddart and Osborne (1989)
Sudanese Red Sea	~10	Taylor and Reid (1984)
Pilbara coastline, Western Australia	0.2->6.0	Hilliard and Chalmer (1992)
Central Great Barrier Reef	0 – 0.61	Oxley (1988)
Tung Tau Chau, Tolo Channel, Hong Kong	0.6	Taylor (1980)
Fringing reef at Sesoko Island, Okinawa, Ryukyu Islands, Japan	0.2 - 0.6	Fujioka and Yamazato (1983)
Fringing reefs of central Great Barrier Reef	0 – 0.11	Sweatman *et. al.* (2005)
Kenyan reefs	<0.03	McClanahan (2002)

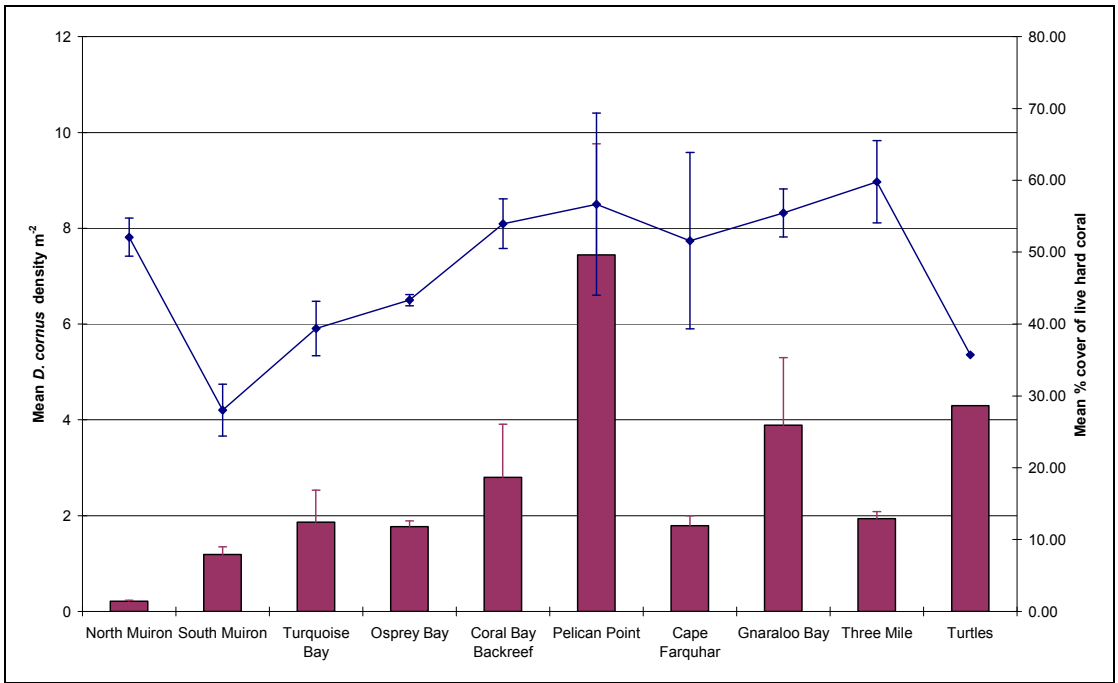


Figure 14. Mean density (m^{-2}) of *D. cornus* and mean % cover of live hard coral recorded in 2006. Lines represent live hard coral cover and columns represent *D. cornus* density. Locations are presented from north to south (left to right). Error bars are standard error. No standard error is displayed for Turtles as only one site was surveyed in 2006.

At North Muiron, three *Acanthaster planci* (Crown of Thorns Starfish) ranging from 15 to 25 cm in diameter were recorded in or adjacent to the transects surveyed in 2006. *A. planci* was not recorded at any other location surveyed in 2005 or 2006. In December 1989, a qualitative survey for the presence of *Drupella* and *A. planci* was undertaken at 9 sites along the eastern side of the North and South Muiron Islands (Sue Osborne, unpublished data). During this survey *Drupella* were observed but

were in lower numbers than recorded at other locations on the Ningaloo Reef during the same year. In 1989, *A. planci* were recorded at sites in close proximity to the South and North Muiron locations surveyed during the 2006 *Drupella* survey, and the highest number of *A. planci* (7 animals recorded by one diver in a 15 minute search) was recorded at the site closest to the North Muiron 2006 survey location. These findings are consistent with the findings of the 2006 *Drupella* survey. These results indicate that: North Muiron generally supports a lower density of *D. cornus* relative to other survey locations at Ningaloo Reef and; *A. planci* populations are stable and represent no immediate threat to coral communities at North Muiron Island.

Mean live hard coral % cover ranged from 59.8 ± 5.71 to 28 ± 3.61 in 2006 (Fig 14). This range falls within the range of live hard coral cover recorded at inner reefs in the northern and central Great Barrier Reef (Harriott *et al.,* 1994). In 2006, the highest mean percent cover of live hard coral was recorded at Three Mile (59.8 ± 3.71). A high mean percent cover of live hard coral was also recorded at: Pelican Point (56.7 ± 12.70); Gnaraloo Bay (55.5 ± 3.3); Coral Bay Backreef (53.9 ± 3.4); North Muiron (52 ± 2.6); and Cape Farquhar (51.6 ± 12.2). In 2006, the lowest mean percent cover of live hard coral was recorded at South Muiron (28 ± 3.61). A low cover of live hard coral was also recorded at Turtles (35.7) relative to the majority of other locations in 2006.

3.1.2 Differences in *D. cornus* density between 2005 and 2006

There was no significant difference in the mean density of *D. cornus* between the 2005 and 2006 surveys at all four locations re-surveyed in 2006: Turquoise Bay (p value = 0.14), Osprey Bay (p value = 0.65), Coral Bay Backreef (p value = 0.76) and at Pelican Point (p value = 0.48), (Tables 7 to 10 in Appendix 3 presents the results of these ANOVA tests).

3.1.3 Current cover of benthic reef communities

The mean percent cover of benthic habitat categories recorded at the NMPDMP locations in 2006 is summarised in Appendix 2 - Table 5.

3.1.3.1 Benthic composition in 2006

Substrate composition in terms of mean percent of benthic cover at each location in 2006 is summarized in Figure 15. Live hard coral dominated benthic cover at the majority of survey locations in 2006.

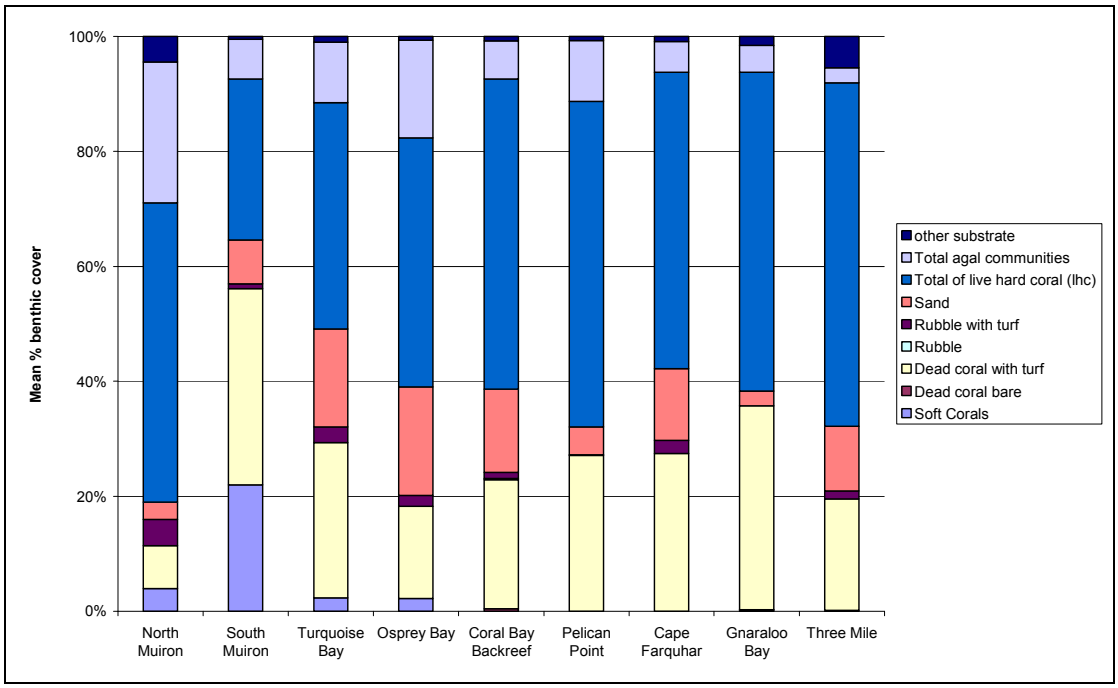


Figure 15. Substrate composition in terms of mean percent of benthic cover at each location in 2006. Locations are presented from north to south (left to right).

3.1.3.2 Live coral cover composition in 2006

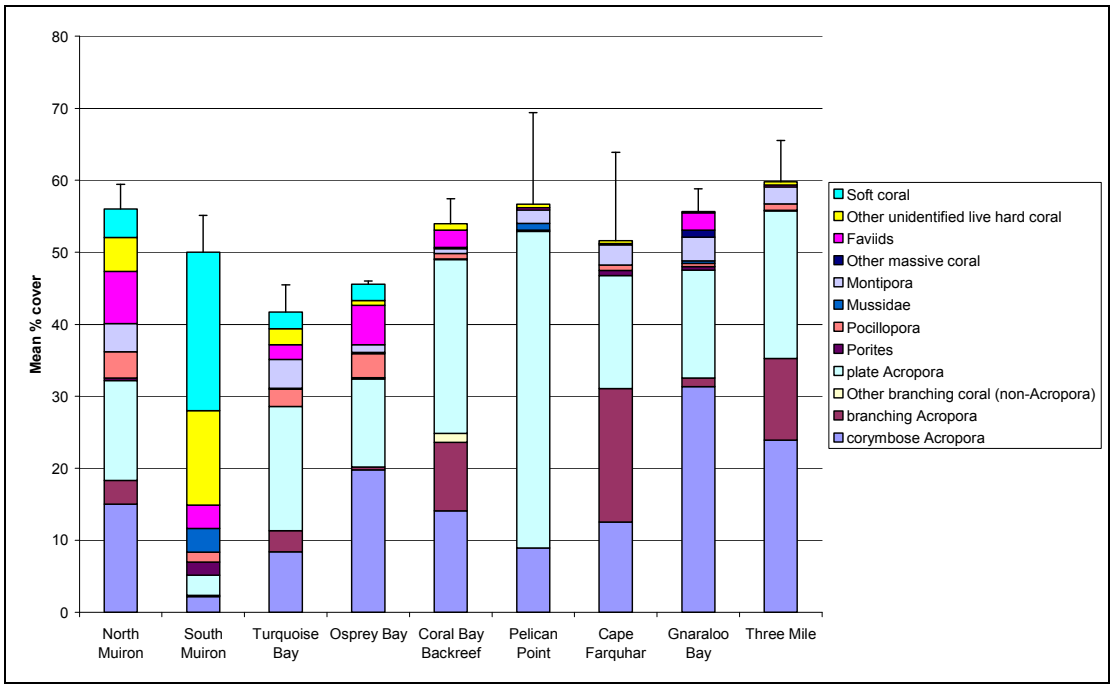


Figure 16. Live coral cover composition in 2006. Error bars are standard error. Totals equal the mean total cover of live coral (hard and soft corals) at each location.

Acropora corals dominated coral cover at the majority of locations in 2006 (Fig 16). Plate and corymbose *Acropora* corals dominated coral cover at the typical back reef locations (Turquoise Bay, Coral Bay Backreef, Pelican Point and Gnaraloo Bay). Soft coral communities dominated coral cover at South Muiron and soft coral cover was considerably higher at South Muiron compared to all other locations (Fig 16). The location at South Muiron is not suitable for long-term monitoring of *Drupella* due to the low cover of *Drupella* habitat (live hard coral) present there. Therefore, a more

appropriate *Drupella* monitoring location will be established at South Muiron Island during the 2008 *Drupella* survey.

3.1.3.3 Differences in live hard coral cover between 2005 and 2006

There was no significant difference in the percent cover of live hard coral between 2005 and 2006 at Turquoise Bay, Coral Bay Backreef and Pelican Point. At Osprey Bay live hard coral cover significantly increased ($p = 0.012$) by 17.5% ± 0.80 over the 17 month period between the 2005 and 2006 surveys (see Tables 7 to 10 in Appendix 3 for the results of these ANOVA tests). Similar increases in live hard coral cover over a similar time period (20% increase over one year) were recorded by Sweatman *et. al*., (2005) at fringing reefs of the Great Barrier Reef.

3.1.3.4 Extent of coral bleaching at these locations during the 2006 winter bleaching event

In July 2006, large areas of shallow backreef and patch-reef corals at Ningaloo Reef were bleached. The proportion of bleached coral was recorded at the *Drupella* locations surveyed during August 2006. Follow-up surveys indicated close to 100% recovery of bleached corals and no apparent changes to *D. cornus* densities as a result of the bleaching. See Armstrong *et al.* (2007) for a detailed report of the 2006 winter bleaching event.

3.2 DESCRIPTION OF METHODS USED AND LOCATIONS SURVEYED DURING PAST DRUPELLA SURVEYS AT NMP

3.2.1 Methods of past *Drupella* surveys

Qualitative and quantitative surveys of *Drupella* and coral communities at NMP have been conducted at different times at various locations by different researchers using a range of methods. To date, this information has not been collated. Therefore, Table 13 in Appendix 4 summarizes the methods used and locations surveyed during past *Drupella* surveys undertaken at NMP in: 1987 (Ayling & Ayling, 1987), 1989 (Stoddart & Osborne, 1989), 1988, 1989 and 1990 (Forde, 1994) 1991 and 1994 (Osborne & Williams, 1995), 2005 (Armstrong, 2005) and 2006 (this report).

3.2.2 Validation of statistical comparisons between the results generated by past methods

3.2.2.1 Comparison between different NMP *Drupella* survey methods

To check whether valid statistical comparisons could be made between the results generated by the different survey methods of Osborne and Williams (1995), and Armstrong (2005), the two different methods were carried out during a pilot study prior to the 2005 survey at Coral Bay Backreef on the same day. The results in terms of mean *Drupella* density and mean live hard coral percent cover were compared using one-way ANOVA tests. No significant difference was found between the mean number of *Drupella* m^{-2} ($p= 0.27$) or the mean percent cover of live hard coral ($p= 0.66$) generated from the two different survey methods. This indicates that comparisons between the results generated by the two different survey methods are statistically valid (see Tables 14 and 15 in Appendix 4 for the results of these ANOVA tests).

A study undertaken in Coral Bay indicated that total percent cover of live branching *Acropora* coral is likely to be significantly underestimated by point sampling relative to line intercept methods. This may result in an artifactual decline in live coral cover

if methods are switched from line intercept to point sampling between surveys (Long & Simpson, in prep). However, no significant decrease in the cover of branching *Acropora* coral was recorded between the 1994 (line intercept method) and 2005 (point sampling method) NMPDMP surveys. It is possible that the cover of branching *Acropora* coral was sufficiently low during both survey years at all locations to cause no significant difference in estimation of live hard coral cover between the line-intercept (1991, 1994) and point sampling methods (2005).

3.2.2.2 Comparison between different cover estimation methods

To check whether statistical comparisons between the results generated by the Ningaloo Marine Park Monitoring Program (NMPMP) (Cary & Grubba, 1998) and the NMPDMP (Armstrong, 2005) survey methods were valid, differences between the methods in terms of estimations of live hard coral percent cover were investigated.

For details of the methods used during the NMPMP surveys see Cary and Grubba, (1998). All the NMPMP transect locations are located in coral reef environments, with the majority fitting into the typical 'backreef' or 'lagoonal' classification. To make use of historical information on the benthic reef communities of NMP, NMPMP site selections in 1998 and 1999 were based on *Drupella* monitoring locations established in 1991 by Osborne and Williams (1995), where possible. Hence, 16 of the 34 NMPMP transect locations are in very close proximity to *Drupella* monitoring locations.

To test for differences, the NMPMP methods were performed at Pelican Point and Gnaraloo Bay during the 2006 NMPDMP survey. An ANOVA found there was no significant difference in estimates of live hard coral percent cover between the methods at Pelican Point ($p = 0.98$) or Gnaraloo Bay ($p = 0.66$) (see Tables 15 and 16 in Appendix 4 for the results of these ANOVA tests). Both locations are typical backreef environments with a high coral cover that is non-patchy in coverage. The end of the NMPMP transects (essentially one 170 m transect at each location) finished a considerable distance from the end of the NMPDMP transects. In a more heterogeneous reef environment the benthic composition could be very different toward the end of the NMPMP transect compared to the reef environment around the NMPDMP transects and a greater difference in live hard coral cover estimated by the two methods may be found.

These preliminary investigations suggest that comparisons between the results generated by the NMPMP and NMPDMP methods are statistically valid. Therefore it is likely that the NMPDMP benthic community data could be used as a proxy in the absence of the NMPMP data and vice versa.

3.2.2.3 Comparisons between the Ayling & Ayling (1987), Stoddart & Osborne (1989) and the Armstrong (2005) methods of estimating *Drupella* density

There are inconsistencies in the number of replicate samples surveyed between locations during both the Ayling & Ayling (1987) and Stoddart & Osborne (1989) surveys (Appendix 4 - Table 13). Therefore comparisons between the results generated by these methods and the Armstrong (2005) method are difficult and have not yet been investigated. The methods used during the 1987 and 1989 surveys appeared to provide reliable *D. cornus* and live hard coral values representative of the locations surveyed during those years. The data from the 1987 and 1989 surveys are

presented in Figure 17 but were not included in the one way ANOVA tests for significant changes in *D. cornus* density and live hard coral cover between survey years.

3.3 CHANGES TO *D. CORNUS* DENSITY AND LIVE HARD CORAL COVER AT NMP OVER TIME

D. cornus density and live hard coral cover data recorded during surveys in 1987, 1989, 1991, 1994, 2005 and 2006 at NMPDMP locations are summarised in Figure 17 and presented in Tables 18 and 19 in Appendix 4. Note that not all NMPDMP locations were surveyed during all survey years.

A high density of *D. cornus* was recorded at Pelican Point relative to other locations during all survey years. Even the lowest mean density of *D. cornus* recorded at Pelican Point was greater than the highest density recorded at any other location during all survey years. A high cover of live hard coral was also recorded at Pelican Point relative to other locations during all survey years. The highest cover of plate *Acropora* coral was also recorded at Pelican Point in 2005 and 2006 relative to other locations. Approximately 17% of changes in *D. cornus* density and 28% of changes in total counts of adult *D. cornus* recorded between locations in 2005 could be explained by changes in live hard coral cover (Armstrong, 2005). In particular, approximately 33% of changes in *D. cornus* density and 40% of changes in total counts of adult *D. cornus* were explained by changes in plate *Acropora* cover. Plate *Acropora* is widely recognized as a preferred prey type of *Drupella* spp. (Robertson 1970; Fujioka and Yamazato 1983; Ayling and Ayling 1987; Oxley 1988; Stoddart 1989; Forde 1994). It is likely that the consistently high densities of *D. cornus* recorded at Pelican Point can be explained by the high cover of *Acropora* plate coral present there.

No *D. cornus* were recorded in 1989 or 1991 at Osprey Bay. The lowest mean densities of *D. cornus* were recorded in 1991 at Cloates (0.022 m^{-2} ± 0.009) and Coral Bay Lagoon (0.16 m^{-2} ± 0.07). The lowest mean percent covers of live hard coral were recorded at Osprey Bay in 1989 (4.2%) and Ned's Camp in 1991 (4.27% ± 0.89) and 1994 (5.88% ± 1.73).

A general increase in *D. cornus* density over time was recorded at four locations: Ned's Camp, Turquoise Bay, Cloates, and Coral Bay Lagoon. Regression analyses of *D. cornus* density with time (1991 to 2005) were highly significant at both Cloates ($p< 0.001$) and Turquoise Bay ($p< 0.001$) reflecting consistent increases in *D. cornus* density over time. At Turquoise Bay the increase in *D. cornus* density was associated with a consistent significant increase in live hard coral over time for which the regression analysis with time was also highly significant ($p< 0.001$). The increases in *D. cornus* density at Coral Bay Lagoon and Ned's Camp were associated with increases in live hard coral cover. At Osprey Bay *D. cornus* density decreased considerably between 1987 and 1989 after which it increased steadily over time. The increase in *D. cornus* density between 1991 and 2006 at Osprey Bay was associated with an increase in live hard coral cover over the same time period.

A general decrease in the density of *D. cornus* over time occurred at three study locations: Pelican Point, Bundegi and Tantabiddi. The regression analyses of *D. cornus* density with time (1991 to 2005) were significant for both Pelican Point ($p< 0.001$) and Bundegi ($p= 0.002$). At all three locations, the decreases in *D. cornus*

density were associated with a consistent decrease in live hard coral cover over the same time period.

The greatest variation in mean *D. cornus* density and mean live hard coral cover between locations was recorded in 1991, when *D. cornus* density ranged from approximately 0 to 18 m^{-2} and live hard coral cover ranged from approximately 4 to 80%. Relative to data from previous surveys, in 2005, variations in both variables recorded between locations was least, with *D. cornus* density ranging from 0.2 to 5.3 m^{-2} and live hard coral cover ranging from 19.0 to 52.5%.

These trends suggest that *D. cornus* densities were substantially higher at the majority of NMPDMP survey locations prior to 1991. These were outbreak densities relative to the values recorded at these locations during subsequent surveys. Although the direction of change in *D. cornus* density over time was not consistent between all locations, overall, there appeared to be a decrease in *D. cornus* density between 1991 and 1994, and an increase between 1994 and 2006, with densities generally highest in 1991. The densities recorded from 1994 onwards appeared to reflect 'normal' *D. cornus* densities, and are therefore likely to represent no significant current threat to coral communities at NMP.

The 2005 regression analyses indicated that the density of *D. cornus* at any given location at Ningaloo Reef is not purely a function of food availability: locations that have a similar cover of live hard coral will not necessarily support similar densities of *D. cornus*. Even nearby areas with a similar coral cover will not necessarily support a similar density of *Drupella* spp. as evidenced by the high variation in mean *D. cornus* density recorded between adjacent locations. This variation suggests that *D. cornus* population dynamics can vary considerably over small spatial scales. However, consistently high *D. cornus* densities were recorded at some locations over time, whilst at others, consistently low densities were recorded.

The results suggest that factors controlling *D. cornus* population density are highly location-specific at Ningaloo Reef. As a consequence it is not feasible to generate quantitative definitions of non-outbreak or outbreak populations, except on a location-specific basis. Conversely, the steady decline in *D. cornus* densities observed across Ningaloo Reef following the outbreak in the late 1980s indicates that the factors controlling population outbreaks of *D. cornus* may affect many locations more or less simultaneously. Therefore, a significant increase in *D. cornus* density across most or all monitoring locations may serve as an effective management definition of an outbreak. Whilst *D. cornus* densities increased at eight of thirteen locations between 1994 and 2005, this increase was only significant at five locations. There is no indication that *D. cornus* populations at Ningaloo Reef in 2005 were approaching outbreak densities, or greatly affecting coral cover.

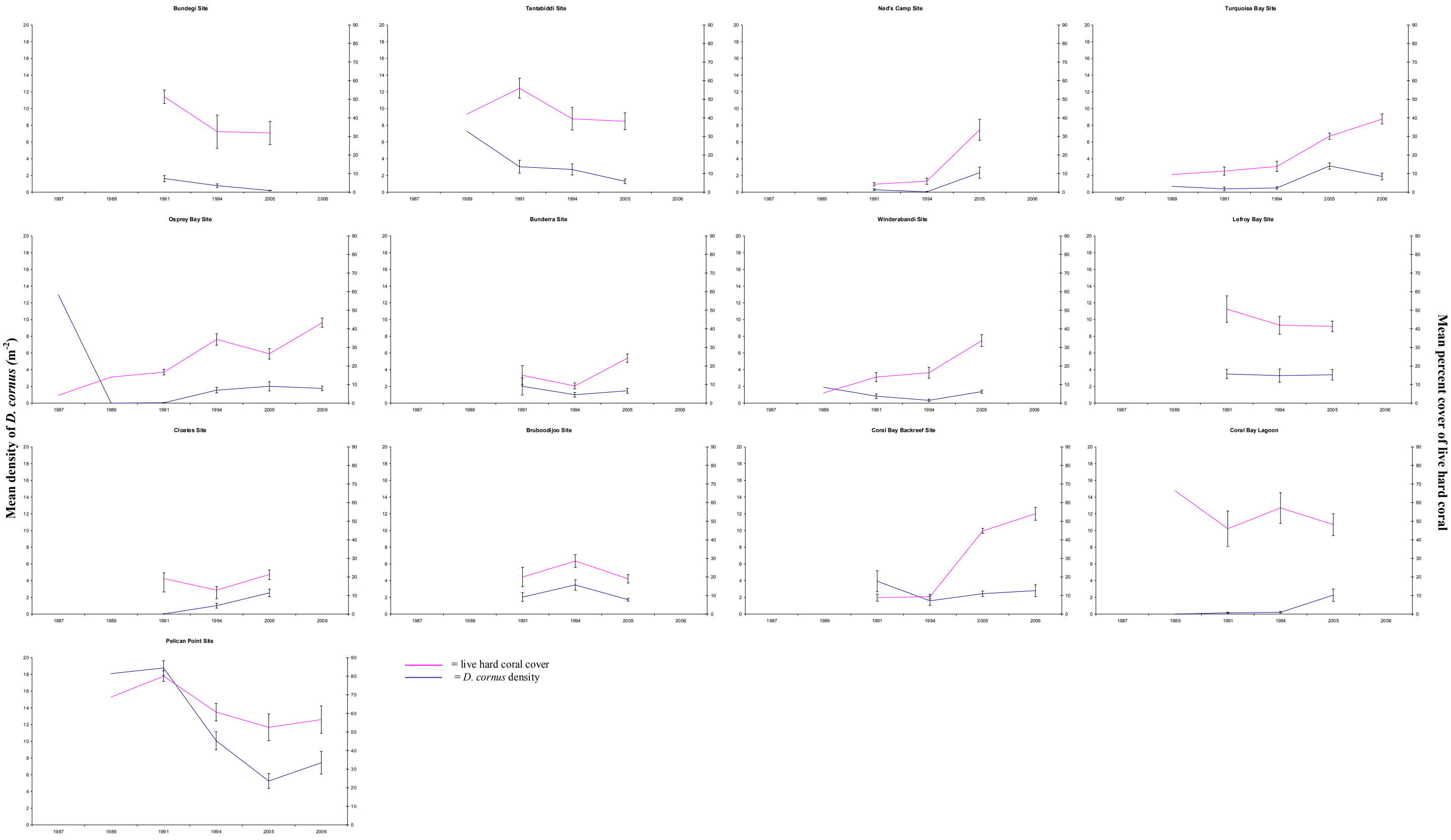


Figure 17. Changes to mean *D. cornus* density (m^{-2}) and mean live hard coral cover at NMP over time. Osprey Bay was the only location surveyed in 1987 (Ayling & Ayling, 1987). Tantabiddi, Turquoise Bay, Osprey Bay, Winderabandi, Coral Bay Lagoon and Pelican Point locations were surveyed in 1989 (Stoddart & Osborne, 1989). Error bars are standard error. No standard error values were available for the 1989 or 1987 data. The scale for mean *D. cornus* density is on the left y axis of each graph and the scale for live hard coral percent cover is on the right y axis of each graph.

4 IMPLICATIONS FOR MANAGEMENT

Present *Drupella* densities are low to moderate compared to the outbreak densities observed during the late 1980s and early 1990s, and represent no immediate threat to coral communities at NMP. Coral communities appear to have recovered from the *Drupella* outbreak event in the 1980s, with live hard coral cover increasing consistently over time at most locations. DEC will continue to keep a watching brief on *Drupella* and coral communities at NMP, by undertaking surveys at least every three years as outlined in the NMP and MIMMA Management Plan. In the meantime any anecdotal information regarding changes in localized densities of *Drupella* should be reported to DEC's MSP.

Issue 1: Mechanical damage to corals may attract *Drupella*

Although the reasons for 'outbreaks' in *Drupella* densities remain unclear, it is important to try, if possible, to mitigate any potential anthropogenic causes of increased numbers of *Drupella*. Research has shown that mucus produced by damaged coral (e.g. anchor damage, inexperienced diver damage) is a feeding stimulus for *Drupella* (Morton *et. al*. 2002). Qualitative observations from a heavily visited dive and snorkel site named Asho's Gap at Coral Bay suggest that *Drupella* feeding aggregations are being attracted to broken coral, most likely caused by divers or inexperienced boaters. Continuing coral damage during such activities could attract increased numbers of *Drupella* to this site causing local declines in live coral cover and fish resulting in a reduction in the attractiveness of the site for diving and snorkelling.

Management Recommendation 1: A simple education pamphlet should be developed and distributed by Exmouth District as soon as possible to encourage more sustainable diving and boating practices to address this issue.

5 DATA MANAGEMENT

5.1.1 Report

Hard copies of this report will be held at the following locations:

1. Marine Science Program, Science Division, Department of Environment and Conservation, 17 Dick Perry Avenue, Western Australia, 6152. Ph: (08) 9334 0333.

2. Woodvale Library, Science Division, Department of Environment and Conservation, Ocean Reef Road, Woodvale, Western Australia, 6026. Ph: (08) 9405 5100 Fax: (08) 9306 1641.

3. Archives, Woodvale Library, Science Division, Department of Environment and Conservation, Ocean Reef Road, Woodvale, Western Australia, 6026. Ph: (08) 9405 5100 Fax: (08) 9306 1641 (CD also attached).

4. Department of Environment and Conservation: Exmouth, 20 Nimitz St, Exmouth, WA, 6007. Ph: (08) 99478000 Fax: (08) 99478050.

5. Serials Section, State Library of Western Australia. Alexander Library Building, Perth Cultural Centre, Perth, Western Australia, 6000.

6. North West Research Association Field Station, Coral Bay, WA. Ph: (08) 99485136

Digital copies of this report will be held at the following:

1. The Science Division Server:
T:\529-CALMscience\Shared Data\Marine Science Program\MSP_reports\MSP_2007-03

2. CD-ROM [MSP_2007-03]

5.1.2 Raw data sheets

Copies of the raw data sheets completed during the 2006 survey are held in the MSP and Exmouth District libraries.

5.1.3 Benthic habitat data

Collected marine benthic habitat data has been entered into the Habitats Database, which is located on the Science Division Server:

T:\529-CALMscience\Shared Data\Marine Science Program\MSP databases\MSP Habitats 200611.mdb

5.1.4 Digital video records

All mini digital video (MDV) footage collected during the survey is held at two locations:

1. MDV masters have been archived in the Ningaloo Marine Park Video Archive file 2006/005668-1 held at the Information Management Branch, Department of Environment and Conservation, 17 Dick Perry Avenue, Kensington, Western Australia. Ph: (08) 9334 0392.

2. Digital copies on DVDs have been stored at the Marine Science Program, Science Division, Department of Environment and Conservation, 17 Dick Perry Avenue, Kensington, Western Australia. Ph: (08) 9334 0299 Fax: (08) 9334 0327.

5.1.5 Digital still photographs

All digital still photographs taken during the survey are archived on the Science Division Server:

T:\529-CALMscience\Shared Data\Marine Science Program\ MSP (Communication) \image library\images

5.2 REPORT DISTRIBUTION

- Dr Neil Burrows, Director, Science Division, DEC

- Dr Chris Simpson, Leader, Marine Science Program, DEC
- Jennie Cary, District Manager, Exmouth, DEC
- Dr Alan Kendrick, Senior Regional Marine Ecologist, Pilbara Region, DEC

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APPENDIX 1: SUMMARY OF THE *DRUPELLA* LONG-TERM MONITORING LOCATIONS

Table 2. Summary of the nineteen *Drupella* long-term monitoring locations.

Location Site	Depth	NMP Management Zone	Reef Structural Zone	GPS coordinate, decimal minutes, WGS84 datum	
North Muiron					
1	4.7m	Conservation Area	Bommie field	21°39.343'	114°22.478'
2	5.4m	Conservation Area	Bommie field	21°39.377'	114°22.460'
3	5.3m	Conservation Area	Bommie field	21°39.418'	114°22.459'
South Muiron					
1	0.5-0.7m	Unclassified	Backreef	21°40.397'	114°20.780'
2	0.7-1m	Unclassified	Backreef	21°40.346'	114°20.807'
3	0.7-1m	Unclassified	Backreef	21°40.486'	114°20.712'
Bundegi					
1	2-3m	Recreation	Gulf- Lagoon	21°49.920'	114°10.623'
2	3.5m	Recreation	Gulf- Lagoon	21°49.726'	114°10.836'
3	3-4m	Recreation	Gulf- Lagoon	21°50.549'	114°10.621'
Tantabiddi					
1	4-5m	Recreation	Lagoon	21°54.286'	113°58.030'
2	3-4m	Sanctuary	Lagoon	21°54.470'	113°57.993'
3	3-4m	Sanctuary	Lagoon	21°54.507'	113°57.964'
Ned's Camp					
1	1.5-2m	Recreation	Backreef	21°58.557'	113°55.088'
2	1-1.5m	Sanctuary	Backreef	21°58.167'	113°55.161'
3	1-1.5m	Recreation	Backreef	21°58.337'	113°55.062'
Turquoise Bay					
1	0.5-1m	Sanctuary	Backreef	22°06.717'	113°52.734'
2	0.5-1.5m	Sanctuary	Backreef	22°06.867'	113°52.668'
3	0.5-1.5m	Sanctuary	Backreef	22°07.178'	113°52.763'
Osprey Bay					
1	0.5-1m	Sanctuary	Backreef	22°14.884'	113°49.731'
2	0.5-1m	Sanctuary	Backreef	22°15.336'	113°49.481'
3	0.7m	Sanctuary	Backreef	22°14.644'	113°49.718'
Bunderra					
1	0.5-1m	Sanctuary	Backreef	22°23.685'	113°44.716'
2	1-2m	Sanctuary	Backreef	22°23.273'	113°44.946'
3	0-2m	Sanctuary	Backreef	22°22.966'	113°44.958'
Winderabandi					
1	1-1.5m	Recreation	Backreef	22°30 342'	113°41.560'
2	1m	Recreation	Backreef	22°30 333'	113°41.784'
3	1m	Recreation	Backreef	22°29 925'	113°42.028'
Lefroy Bay					
1	1-3.5m	Recreation	Bommie field	22°31.534'	113°40.607'
2	1-3.5m	Recreation	Bommie field	22°31.525'	113°40.530'
3	1-3m	Recreation	Bommie field	22°31.434'	113°40.603'
Cloates					
1	0.5-2m	Sanctuary	Backreef	22°40.817'	113°38.525'
2	0.5-1m	Sanctuary	Backreef	22°41.480'	113°45.935'
3	1m	Sanctuary	Backreef	22°41.397'	113°45.751'
Bruboodijoo					
1	1.5m	Recreation	Backreef	22°56.242'	113°46.683'
2	2m	Recreation	Backreef	22°56.416'	113°46.708'
3	1-1.5m	Recreation	Backreef	22°56.708'	113°46.664'
Coral Bay Backreef					
1	1-1.5m	Sanctuary	Backreef	23°09.241'	113°45.030'
2	1-1.5m	Sanctuary	Backreef	23°09.005'	113°45.020'
3	0.5m	Sanctuary	Backreef	23°09.227'	113°45.103'
Coral Bay Lagoon					
1	3.5m	Sanctuary	Lagoon	23°09.207'	113°45.766'
2	<5m	Sanctuary	Lagoon	23°08.560'	113°45.935'
3	2.9m	Sanctuary	Lagoon	23°08.964'	113°45.751'
Pelican Point					
1	1-1.5m	Sanctuary	Backreef	23°20.153'	113°46.760'
2	1-1.5m	Sanctuary	Backreef	23°19.825'	113°46.790'
3	1-1.5m	Sanctuary	Backreef	23°19.641'	113°46.721'
Cape Farquhar					
1	1m	Sanctuary	Backreef	23°37.374'	113°37.055'
2	0.5-2m	Sanctuary	Backreef	23°37.517'	113°37.063'
3	1m	Sanctuary	Backreef	23°37.529'	113°36.888'
Gnaraloo Bay					
1	1-1.5m	Sanctuary	Backreef	23°45.886'	113°32.356'
2	1m	Sanctuary	Backreef	23°45.804'	113°32.334'
3	0.5m	Sanctuary	Backreef	23°45.882'	113°32.264'
Three Mile					
1	0.5-2m	Sanctuary	Lagoon	23°52.396'	113°29.780'
2	0.5-2m	Sanctuary	Lagoon	23°52.366'	113°29.786'
3	0.5-3m	Sanctuary	Lagoon	23°52.327'	113°29.794'
Turtles					
1	0.5-1m	Sanctuary-	High wave energy Backreef	23°57.952'	113°28.170'

APPENDIX 2: DATA

Table 3. Benthic habitat categories and codes for analyzing *Drupella* benthic video transect footage.

Living reef corals	
Acropora (plate)	AP
Acropora (branching)	AB
Acropora (corymbose)	AC
Montipora	MONT
Pocillopora	POC
Branching coral (non *Acropora*)	B
Faviids	FAV
Porites	POR
Other massive corals	MAS
Fungia	FUNG
Soft coral	SOFT
Mussidae	MUSS
Other live hard coral – unidentifiable	O
Algae	
Brown macro algae	MAC
Algal turf community	TURF
Encrusting coralline algae	ET
Other green algae	GA
Other red Algae	RA
Sea grass	SG
Benthic Substratum	
Dead coral bare	DCB
Dead coral covered with turf	DCT
Bare coral rubble	BCR
Coral rubble covered with turf	CRT
Sand	S
Pavement	PAV
Other	
Drupella scar on plate *Acropora*	DS AP
Drupella scar on corymbose *Acropora*	DS AC
Drupella scar on branching *Acropora*	DS AB
Winter bleaching	
Plate *Acropora* winter bleached	AP WB
Corymbose *Acropora* winter bleached	AC WB
Branching *Acropora* winter bleached	AB WB
Invertebrates	
Clam	CLAM
Dead clam	DCLAM
Holothurian	HOLO
Drupella	DRUPE
Echinoderms	Urch

Table 4. *D. cornus* density data recorded at the survey locations in 2006.

***D. cornus* density (m-2) in 2006**							
Site name	**Transect**	**Rep**	**Site**	**Site name**	**Transect**	**Rep**	**Site**
North Muiron	0.1			Pelican Point	10.3		
	0.2	0.1666667			15	11.466667	
	0.2				9.1		
	0.1				2.6		
	0.3	0.2333333	0.2111111		6.5	3.4333333	7.4444444
	0.3				1.2		
	0.2				7.6		
	0.2	0.2333333			7.6	7.4333333	
	0.3				7.1		
South Muiron	1.1			Cape Farquhar	1.6		
	2.1	1.4666667			1.7	1.5666667	
	1.2				1.4		
	1.5				1.6		
	0.6	0.9333333	1.1888889		1.7	1.6	1.7888889
	0.7				1.5		
	1.6				2.8		
	1.4	1.1666667			0.7	2.2	
	0.5				3.1		
Turquoise Bay	1.9			Gnaraloo Bay	7.3		
	1.2	1.9			6.7	6.7	
	2.6				6.1		
	4.2				2.1		
	2.3	3	1.8666667		2.6	2.5666667	3.8888889
	2.5				3		
	0.5				2.1		
	0.7	0.7			2.4	2.4	
	0.9				2.7		
Osprey Bay	0.9			Three Mile	2.4		
	1.9	1.9333333			1	2.0666667	
	3				2.8		
	2.7				2.2		
	1.1	1.5333333	1.7666667		2.2	2.1	1.9333333
	0.8				1.9		
	1.6				1.6		
	2.4	1.8333333			0.4	1.6333333	
	1.5				2.9		
Coral Bay Backreef	2.8			Turtles	4.8		
	3	2.5333333			6.8	4.3	
	1.8				1.3		
	4.6				n/a		
	7.4	4.8333333	2.8		n/a	n/a	n/a
	2.5				n/a		
	1.1				n/a		
	0.7	1.0333333			n/a	n/a	
	1.3				n/a		

Table 5. Summary of benthic video data (in terms of mean % cover) recorded at locations in 2006. Codes for location names: NM- North Muiron, SM- South Muiron, TUR-Turquoise Bay, OSP-Osprey Bay, CBB-Coral Bay Backreef, PPT-Pelican Point, FARQ- Cape Farquhar, GNA- Gnaraloo Bay, TMI- Three Mile, TUT- Turtles. Note that the video footage taken at the Turtles location was analysed using only two categories: live hard coral cover and other substrate.

Category	NM 06	SM 06	TUR 06	OSP 06	CBB 06	PPT 06	FARQ 0(	GNA 06	TMI 06	TUT
plate *Acropora*	13.89	2.80	17.22	12.22	24.12	43.96	15.69	15.01	20.49	n/a
corymbose *Acropora*	15.01	2.21	8.39	19.76	14.11	8.96	12.54	31.36	23.93	n/a
branching *Acropora*	3.31	0.14	2.95	0.45	9.52	0.00	18.55	1.17	11.32	n/a
Montipora	3.93	0.00	4.04	1.04	0.70	1.90	2.83	3.33	2.34	n/a
Pocillopora	3.66	1.39	2.43	3.34	0.76	0.16	0.72	0.46	0.88	n/a
Branching coral (non-*Acropora*)	0.00	0.00	0	0.00	1.22	0.00	0.00	0.00	0.00	n/a
Massive coral	0.00	0.00	0	0.00	0.17	0.00	0.00	0.94	0.00	n/a
Brain corals	7.22	3.28	2.05	5.47	2.40	0.30	0.16	2.40	0.29	n/a
Porites	0.32	1.83	0	0.18	0.08	0.00	0.71	0.46	0.12	n/a
Other unidentified live coral	4.74	13.10	2.18	0.69	0.87	0.49	0.40	0.00	0.44	n/a
Soft Corals	3.95	21.98	2.31	2.24	0.00	0.00	0.00	0.18	0.00	n/a
Urchins	0.08	0.00	0	0.17	0.32	0.00	0.00	0.00	0.00	n/a
Holothurian	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.17	0.00	n/a
Clams	0.15	0.07		0.00	0.18	0.40	0.51	0.34	0.18	n/a
Brown macroalgae	0.00	0.30	0	0.00	0.04	0.00	0.00	0.00	0.00	n/a
Turf algal community	24.55	6.60	9.81	15.09	5.91	9.75	4.73	1.59	1.77	n/a
Green algae	0.00	0.00	0	0.96	0.13	0.00	0.00	0.00	0.00	n/a
Red algae	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.00	n/a
Coralline encrusting red algae	0.00	0.00	0.74	0.97	0.55	0.82	0.65	3.13	0.80	n/a
Dead coral bare	0.00	0.00	0	0.00	0.43	0.00	0.00	0.09	0.17	n/a
Dead coral with turf	7.47	34.16	27.03	15.99	22.43	27.13	27.40	35.50	19.34	n/a
Rubble	0.00	0.00	0	0.00	0.25	0.00	0.00	0.00	0.00	n/a
Rubble with turf	4.57	0.78	2.75	1.91	1.04	0.08	2.34	0.00	1.42	n/a
Sand	2.96	7.69	17.01	18.90	14.52	4.84	12.44	2.53	11.25	n/a
Total of live hard coral (lhc)	52.08	28.02	39.38	43.33	53.97	56.68	51.60	55.47	59.81	35.70
Total winter bleaching % cover	0.00	0.00	11.44	11.19	3.79	47.32	15.03	33.67	0.00	n/a
Total % of lhc winter bleached	0.00	0.00	26.63	25.79	6.80	81.41	24.04	58.18	0.00	n/a
Total all live coral (hard and soft)	56.03	50.00	41.69	45.56	53.97	56.68	51.60	55.65	59.81	n/a
Total dead hard coral	7.47	34.16	27.03	15.99	22.86	27.13	27.40	35.59	19.51	n/a
Total inverts	0.23	0.07	0.08	0.17	0.50	0.40	0.51	0.51	0.18	n/a
Total agal communities	24.55	6.905	10.55	17.013	6.6264	10.571	5.3764	4.72667	2.56381	n/a

Table 6. Raw live hard coral cover data recorded at the survey locations in 2006.

Live hard coral cover in 2006							
Site name	**Transect**	**Rep**	**Site**	**Site name**	**Transect**	**Rep**	**Site**
North Muiron	47.1014			Pelican Point	90.3226		
	45.1389	46.78686667			81.6456	78.3894	
	48.1203				63.2		
	56.1151				40.1575		
	55.4745	55.21456667	52.0834		32.3529	34.39236667	56.68393333
	54.0541				30.6667		
	55.4913				44.6809		
	56.9444	54.24876667			77.4648	57.27003333	
	50.3106				49.6644		
South Muiron	36.1963			Cape Farquhar	67.4074		
	18.8976	26.6313			57.7236	66.23413333	
	24.8				73.5714		
	38.7097				66.242		
	33.1288	34.85526667	28.021		59.6859	61.37896667	51.60275556
	32.7273				58.209		
	24.8175				29.1045		
	20.0772	22.57643333			37.6923	27.19516667	
	22.8346				14.7887		
Turquoise Bay	34.9206			Gnaraloo Bay	45.4545		
	49.2063	40.42326667			47.1074	49.55316667	
	37.1429				56.0976		
	46.8254				71.2		
	48.4127	45.33576667	39.38391111		44.7761	61.13933333	55.46803333
	40.7692				67.4419		
	25.1656				58.3333		
	39.2	32.3927			52.0599	55.7116	
	32.8125				56.7416		
Osprey Bay	30.5344			Three Mile	76.555		
	53.6	41.9337			62.4277	71.05873333	
	41.6667				74.1935		
	52.4194				68.1661		
	41.6	43.31896667	43.32782222		52.3077	55.9237	59.80761111
	35.9375				47.2973		
	47.5806				66.1538		
	46.1538	44.7308			43.5484	52.4404	
	40.458				47.619		
Coral Bay Backreef	47.2			Turtles	44.64		
	45.6954	53.5602			32.35	35.79666667	
	67.7852				30.4		
	63.7795				n/a		
	57.037	60.16463333	53.96594444		n/a	n/a	n/a
	59.6774				n/a		
	61.1111				n/a		
	37.0079	48.173			n/a	n/a	
	46.4				n/a		

APPENDIX 3: RESULTS OF STATISTICAL ANALYSES

Table 7. Results of the ANOVA test showing the significance of the differences between the *NMPDMP* data at Turquoise Bay between 2005 and 2006.

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Drupella number per sq m	Between Groups	2.407	1	2.407	3.228	.147
	Within Groups	2.982	4	.746		
	Total	5.389	5			
Live Hard Coral av % cover	Between Groups	128.807	1	128.807	5.510	.079
	Within Groups	93.508	4	23.377		
	Total	222.315	5			
Sqrt of Drupella per m sq	Between Groups	.290	1	.290	2.783	.171
	Within Groups	.417	4	.104		
	Total	.708	5			
Algal Turf Communities	Between Groups	35.122	1	35.122	.943	.386
	Within Groups	148.960	4	37.240		
	Total	184.082	5			
Dead coral covered with turf	Between Groups	67.447	1	67.447	1.353	.309
	Within Groups	199.421	4	49.855		
	Total	266.868	5			
Acropora plate coral	Between Groups	19.986	1	19.986	.254	.641
	Within Groups	314.955	4	78.739		
	Total	334.941	5			
Acropora plate and branching, Pocillopora, Montipora	Between Groups	13.452	1	13.452	.755	.434
	Within Groups	71.238	4	17.809		
	Total	84.690	5			
Pocillopora coral	Between Groups	6.664	1	6.664	6.053	.070
	Within Groups	4.404	4	1.101		
	Total	11.068	5			
Montipora coral	Between Groups	4.455	1	4.455	.463	.533
	Within Groups	38.457	4	9.614		
	Total	42.912	5			

Table 8. Results of the ANOVA test showing the significance of the differences between the *NMPDMP* data at Osprey Bay between 2005 and 2006.

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Drupella number per sq m	Between Groups	8.963E-02	1	8.963E-02	.227	.659
	Within Groups	1.581	4	.395		
	Total	1.670	5			
Live Hard Coral av % cover	Between Groups	422.800	1	422.800	18.918	.012
	Within Groups	89.396	4	22.349		
	Total	512.196	5			
Sqrt of Drupella per m sq	Between Groups	9.796E-04	1	9.796E-04	.022	.889
	Within Groups	.179	4	4.471E-02		
	Total	.180	5			
Algal Turf Communities	Between Groups	26.223	1	26.223	.818	.417
	Within Groups	128.220	4	32.055		
	Total	154.443	5			
Dead coral covered with turf	Between Groups	1234.196	1	1234.196	73.245	.001
	Within Groups	67.401	4	16.850		
	Total	1301.597	5			
Acropora plate coral	Between Groups	114.119	1	114.119	23.640	.008
	Within Groups	19.310	4	4.827		
	Total	133.429	5			
Acropora plate and branching, Pocillopora, Montipora	Between Groups	144.377	1	144.377	10.834	.030
	Within Groups	53.305	4	13.326		
	Total	197.682	5			
Pocillopora coral	Between Groups	13.301	1	13.301	2.285	.205
	Within Groups	23.279	4	5.820		
	Total	36.580	5			
Montipora coral	Between Groups	8.174	1	8.174	1.393	.303
	Within Groups	23.478	4	5.870		
	Total	31.653	5			

Table 9. Results of the ANOVA test showing the significance of the differences between the *NMPDMP* data at Coral Bay Backreef between 2005 and 2006.

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Drupella number per sq m	Between Groups	.190	1	.190	.100	.768
	Within Groups	7.581	4	1.895		
	Total	7.770	5			
Live Hard Coral av % cover	Between Groups	126.347	1	126.347	6.015	.070
	Within Groups	84.019	4	21.005		
	Total	210.366	5			
Sqrt of Drupella per m sq	Between Groups	3.113E-03	1	3.113E-03	.019	.898
	Within Groups	.669	4	.167		
	Total	.673	5			
Algal Turf Communities	Between Groups	3.630E-02	1	3.630E-02	.004	.951
	Within Groups	33.333	4	8.333		
	Total	33.370	5			
Dead coral covered with turf	Between Groups	110.997	1	110.997	1.416	.300
	Within Groups	313.644	4	78.411		
	Total	424.642	5			
Acropora plate coral	Between Groups	291.963	1	291.963	12.043	.026
	Within Groups	96.970	4	24.242		
	Total	388.933	5			
Acropora plate and branching, Pocillopora, Montipora corals	Between Groups	589.854	1	589.854	10.642	.031
	Within Groups	221.697	4	55.424		
	Total	811.551	5			
Pocillopora coral	Between Groups	.861	1	.861	12.754	.023
	Within Groups	.270	4	6.754E-02		
	Total	1.131	5			
Montipora coral	Between Groups	13.751	1	13.751	.997	.374
	Within Groups	55.144	4	13.786		
	Total	68.895	5			

Table 10. Results of the ANOVA test showing the significance of the differences between the *NMPDMP* data at Pelican Point between 2005 and 2006.

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Drupella number per sq m	Between Groups	7.187	1	7.187	.606	.480
	Within Groups	47.468	4	11.867		
	Total	54.655	5			
Live Hard Coral av % cover	Between Groups	25.903	1	25.903	.056	.825
	Within Groups	1853.063	4	463.266		
	Total	1878.966	5			
Sqrt of Drupella per m sq	Between Groups	.240	1	.240	.437	.545
	Within Groups	2.199	4	.550		
	Total	2.439	5			
Algal Turf Communities	Between Groups	3.766	1	3.766	.069	.806
	Within Groups	219.613	4	54.903		
	Total	223.379	5			
Dead coral covered with turf	Between Groups	126.042	1	126.042	.411	.556
	Within Groups	1226.456	4	306.614		
	Total	1352.497	5			
Acropora plate coral	Between Groups	34.447	1	34.447	.051	.832
	Within Groups	2697.882	4	674.471		
	Total	2732.329	5			
Acropora plate and branching, Pocillopora, Montipora corals	Between Groups	24.054	1	24.054	.034	.862
	Within Groups	2813.652	4	703.413		
	Total	2837.706	5			
Pocillopora coral	Between Groups	4.002E-02	1	4.002E-02	3.908	.119
	Within Groups	4.096E-02	4	1.024E-02		
	Total	8.097E-02	5			
Montipora coral	Between Groups	7.119E-03	1	7.119E-03	.002	.966
	Within Groups	13.873	4	3.468		
	Total	13.880	5			

Table 11. Results of the ANOVA and Tukey HSD tests for significant differences in *D. cornus* density between locations surveyed in 2006.

(I) Location	(J) Location	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Coral Bay Backreef	Gnaraloo Bay	-0.33	0.34	0.98	-1.53	0.87
	Pelican Point	-1.04	0.34	0.12	-2.23	0.16
	Cape Farquhar	0.27	0.34	1.00	-0.93	1.47
	Three Mile	0.23	0.34	1.00	-0.97	1.43
	North Muiron	1.13	0.34	0.07	-0.07	2.33
	Osprey Bay	0.28	0.34	0.99	-0.92	1.48
	Turquoise Bay	0.28	0.34	1.00	-0.92	1.48
	South Muiron	0.51	0.34	0.84	-0.68	1.71
Gnaraloo Bay	Coral Bay Backreef	0.33	0.34	0.98	-0.87	1.53
	Pelican Point	-0.70	0.34	0.53	-1.90	0.49
	Cape Farquhar	0.60	0.34	0.71	-0.60	1.80
	Three Mile	0.56	0.34	0.78	-0.64	1.76
	North Muiron	1.46	0.34	0.01	0.26	2.66
	Osprey Bay	0.61	0.34	0.69	-0.59	1.81
	Turquoise Bay	0.61	0.34	0.70	-0.59	1.81
	South Muiron	0.85	0.34	0.31	-0.35	2.04
Pelican Point	Coral Bay Backreef	1.04	0.34	0.12	-0.16	2.23
	Gnaraloo Bay	0.70	0.34	0.53	-0.49	1.90
	Cape Farquhar	1.30	0.34	0.03	0.10	2.50
	Three Mile	1.26	0.34	0.03	0.06	2.46
	North Muiron	2.16	0.34	0.00	0.96	3.36
	Osprey Bay	1.32	0.34	0.03	0.12	2.52
	Turquoise Bay	1.31	0.34	0.03	0.11	2.51
	South Muiron	1.55	0.34	0.01	0.35	2.75
Cape Farquhar	Coral Bay Backreef	-0.27	0.34	1.00	-1.47	0.93
	Gnaraloo Bay	-0.60	0.34	0.71	-1.80	0.60
	Pelican Point	-1.30	0.34	0.03	-2.50	-0.10
	Three Mile	-0.04	0.34	1.00	-1.24	1.16
	North Muiron	0.86	0.34	0.29	-0.34	2.06
	Osprey Bay	0.01	0.34	1.00	-1.18	1.21
	Turquoise Bay	0.01	0.34	1.00	-1.19	1.21
	South Muiron	0.25	0.34	1.00	-0.95	1.45
Three Mile	Coral Bay Backreef	-0.23	0.34	1.00	-1.43	0.97
	Gnaraloo Bay	-0.56	0.34	0.78	-1.76	0.64
	Pelican Point	-1.26	0.34	0.03	-2.46	-0.06
	Cape Farquhar	0.04	0.34	1.00	-1.16	1.24
	North Muiron	0.90	0.34	0.24	-0.30	2.10
	Osprey Bay	0.05	0.34	1.00	-1.14	1.25
	Turquoise Bay	0.05	0.34	1.00	-1.15	1.25
	South Muiron	0.29	0.34	0.99	-0.91	1.49
North Muiron	Coral Bay Backreef	-1.13	0.34	0.07	-2.33	0.07
	Gnaraloo Bay	-1.46	0.34	0.01	-2.66	-0.26
	Pelican Point	-2.16	0.34	0.00	-3.36	-0.96
	Cape Farquhar	-0.86	0.34	0.29	-2.06	0.34
	Three Mile	-0.90	0.34	0.24	-2.10	0.30
	Osprey Bay	-0.85	0.34	0.31	-2.05	0.35
	Turquoise Bay	-0.85	0.34	0.30	-2.05	0.35
	South Muiron	-0.61	0.34	0.69	-1.81	0.59
Osprey Bay	Coral Bay Backreef	-0.28	0.34	0.99	-1.48	0.92
	Gnaraloo Bay	-0.61	0.34	0.69	-1.81	0.59
	Pelican Point	-1.32	0.34	0.03	-2.52	-0.12
	Cape Farquhar	-0.01	0.34	1.00	-1.21	1.18
	Three Mile	-0.05	0.34	1.00	-1.25	1.14
	North Muiron	0.85	0.34	0.31	-0.35	2.05
	Turquoise Bay	0.00	0.34	1.00	-1.20	1.19
	South Muiron	0.23	0.34	1.00	-0.97	1.43
Turquoise Bay	Coral Bay Backreef	-0.28	0.34	1.00	-1.48	0.92
	Gnaraloo Bay	-0.61	0.34	0.70	-1.81	0.59
	Pelican Point	-1.31	0.34	0.03	-2.51	-0.11
	Cape Farquhar	-0.01	0.34	1.00	-1.21	1.19
	Three Mile	-0.05	0.34	1.00	-1.25	1.15
	North Muiron	0.85	0.34	0.30	-0.35	2.05
	Osprey Bay	0.00	0.34	1.00	-1.19	1.20
	South Muiron	0.24	0.34	1.00	-0.96	1.44
South Muiron	Coral Bay Backreef	-0.51	0.34	0.84	-1.71	0.68
	Gnaraloo Bay	-0.85	0.34	0.31	-2.04	0.35
	Pelican Point	-1.55	0.34	0.01	-2.75	-0.35
	Cape Farquhar	-0.25	0.34	1.00	-1.45	0.95
	Three Mile	-0.29	0.34	0.99	-1.49	0.91
	North Muiron	0.61	0.34	0.69	-0.59	1.81
	Osprey Bay	-0.23	0.34	1.00	-1.43	0.97
	Turquoise Bay	-0.24	0.34	1.00	-1.44	0.96

Table 12. Results of the ANOVA and Tukey HSD tests for significant differences in live hard coral cover between locations surveyed in 2006.

(I) Location	(J) Location	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Coral Bay Backreef	Gnaraloo Bay	-1.68	9.65	1.00	-35.51	32.15
	Pelican Point	-2.72	9.65	1.00	-36.55	31.11
	Cape Farquhar	2.36	9.65	1.00	-31.47	36.19
	Three Mile	-5.84	9.65	1.00	-39.67	27.99
	North Muiron	-2.06	9.65	1.00	-35.89	31.77
	Osprey Bay	8.40	9.65	0.99	-25.43	42.23
	Turquoise Bay	12.26	9.65	0.93	-21.56	46.09
	South Muiron	3.96	9.65	1.00	-29.86	37.79
Gnaraloo Bay	Coral Bay Backreef	1.68	9.65	1.00	-32.15	35.51
	Pelican Point	-1.04	9.65	1.00	-34.86	32.79
	Cape Farquhar	4.05	9.65	1.00	-29.78	37.87
	Three Mile	-4.16	9.65	1.00	-37.99	29.67
	North Muiron	-0.38	9.65	1.00	-34.21	33.45
	Osprey Bay	10.09	9.65	0.98	-23.74	43.91
	Turquoise Bay	13.95	9.65	0.87	-19.88	47.78
	South Muiron	5.65	9.65	1.00	-28.18	39.48
Pelican Point	Coral Bay Backreef	2.72	9.65	1.00	-31.11	36.55
	Gnaraloo Bay	1.04	9.65	1.00	-32.79	34.86
	Cape Farquhar	5.08	9.65	1.00	-28.75	38.91
	Three Mile	-3.12	9.65	1.00	-36.95	30.70
	North Muiron	0.65	9.65	1.00	-33.17	34.48
	Osprey Bay	11.12	9.65	0.96	-22.71	44.95
	Turquoise Bay	14.98	9.65	0.82	-18.85	48.81
	South Muiron	6.68	9.65	1.00	-27.15	40.51
Cape Farquhar	Coral Bay Backreef	-2.36	9.65	1.00	-36.19	31.47
	Gnaraloo Bay	-4.05	9.65	1.00	-37.87	29.78
	Pelican Point	-5.08	9.65	1.00	-38.91	28.75
	Three Mile	-8.20	9.65	0.99	-42.03	25.62
	North Muiron	-4.43	9.65	1.00	-38.26	29.40
	Osprey Bay	6.04	9.65	1.00	-27.79	39.87
	Turquoise Bay	9.90	9.65	0.98	-23.93	43.73
	South Muiron	1.60	9.65	1.00	-32.23	35.43
Three Mile	Coral Bay Backreef	5.84	9.65	1.00	-27.99	39.67
	Gnaraloo Bay	4.16	9.65	1.00	-29.67	37.99
	Pelican Point	3.12	9.65	1.00	-30.70	36.95
	Cape Farquhar	8.20	9.65	0.99	-25.62	42.03
	North Muiron	3.78	9.65	1.00	-30.05	37.61
	Osprey Bay	14.24	9.65	0.85	-19.58	48.07
	Turquoise Bay	18.11	9.65	0.64	-15.72	51.93
	South Muiron	9.81	9.65	0.98	-24.02	43.63
North Muiron	Coral Bay Backreef	2.06	9.65	1.00	-31.77	35.89
	Gnaraloo Bay	0.38	9.65	1.00	-33.45	34.21
	Pelican Point	-0.65	9.65	1.00	-34.48	33.17
	Cape Farquhar	4.43	9.65	1.00	-29.40	38.26
	Three Mile	-3.78	9.65	1.00	-37.61	30.05
	Osprey Bay	10.47	9.65	0.97	-23.36	44.30
	Turquoise Bay	14.33	9.65	0.85	-19.50	48.16
	South Muiron	6.03	9.65	1.00	-27.80	39.86
Osprey Bay	Coral Bay Backreef	-8.40	9.65	0.99	-42.23	25.43
	Gnaraloo Bay	-10.09	9.65	0.98	-43.91	23.74
	Pelican Point	-11.12	9.65	0.96	-44.95	22.71
	Cape Farquhar	-6.04	9.65	1.00	-39.87	27.79
	Three Mile	-14.24	9.65	0.85	-48.07	19.58
	North Muiron	-10.47	9.65	0.97	-44.30	23.36
	Turquoise Bay	3.86	9.65	1.00	-29.97	37.69
	South Muiron	-4.44	9.65	1.00	-38.27	29.39
Turquoise Bay	Coral Bay Backreef	-12.26	9.65	0.93	-46.09	21.56
	Gnaraloo Bay	-13.95	9.65	0.87	-47.78	19.88
	Pelican Point	-14.98	9.65	0.82	-48.81	18.85
	Cape Farquhar	-9.90	9.65	0.98	-43.73	23.93
	Three Mile	-18.11	9.65	0.64	-51.93	15.72
	North Muiron	-14.33	9.65	0.85	-48.16	19.50
	Osprey Bay	-3.86	9.65	1.00	-37.69	29.97
	South Muiron	-8.30	9.65	0.99	-42.13	25.53
South Muiron	Coral Bay Backreef	-3.96	9.65	1.00	-37.79	29.86
	Gnaraloo Bay	-5.65	9.65	1.00	-39.48	28.18
	Pelican Point	-6.68	9.65	1.00	-40.51	27.15
	Cape Farquhar	-1.60	9.65	1.00	-35.43	32.23
	Three Mile	-9.81	9.65	0.98	-43.63	24.02
	North Muiron	-6.03	9.65	1.00	-39.86	27.80
	Osprey Bay	4.44	9.65	1.00	-29.39	38.27
	Turquoise Bay	8.30	9.65	0.99	-25.53	42.13

APPENDIX 4: PAST *DRUPELLA* SURVEYS METHODS AND RESULTS

Table 13. Summary of methods used and locations surveyed during past *Drupella* surveys at NMP.

Year	1987	Aug-88	Dec-88	1989 Forde	1989 Stoddart	1991	1994	2005	2006
Drupella density	Visual search in 5x0.5 m transects	Visual search in 0.5 x 50 m	Visual search in 0.5 x 50 m	Visual search in 0.5 x 20 m transect/s	Visual search in 0.5 x 20 m transect/s	Visual search in 5x5 m quadrats	Same as 1991	Visual search in 0.5x20 m transects	Same as 2005
Coral cover	20 m transects Line intercept method	50 m transctes Line intercept method	50 m transctes Line intercept method	line intercept method	line intercept method	20 m transects Line intercept method	Same as 1991	20 m transects. Point sampling method	Same as 2005
Replication	5-30 Drupella transects and 5 coral transects per site	10 transects at Osprey Bay, 2 transects at Yardie Creek, 1 transect at Mesa Camp	6 transects at Coral Bay, 2 transects at Mesa Camp, 5 transects at Bundegi Reef, 2 transects at Yardie Creek	6 transects at Bundegi Reef and 34 transects along NMP between Mesa Camp and Coral Bay	1 or 2 transects per site	3 quadrats and 3 transects per replicate and three replicates per site (9 quadrats and transects per site)	Same as 1991	3 transects per replicate and three replicates per site	Same as 2005
Sites	Sandy Bay, Osprey Bay Pass, South Osprey Bay, Tantabiddi Creek, North Mandu Mandu, Winderabandi Point, Coral Bay	Osprey Bay, Yardie Creek, Mesa Camp	Yardie Creek, Mesa Camp, Coral Bay, Budegi Reef	Bundegi, Mesa Camp, Ned's Camp, Turquoise Bay, Osprey Bay, Yardie/Winda, Winderabandi, Winder/Cloates, Fraser Island, Ningaloo, Bruboodijoo, Point Maud, Coral Bay	Tanatbiddi, Turquoise Bay, Osprey Bay, Winderabandi, Coral Bay Lagoon, Pelican Point	Bundegi, Tantabiddi, Ned's Camp, Turquoise Bay, Osprey bay, Bunderra, Winderabandi, Lefroy, Cloates, Bruboodijoo, Coral Bay Lagoon, Coral Bay Backreef, Pelican Point	Same as 1991	Same as 1991 and 1994	Turquoise Bay, Osprey Bay, Coral Bay Backreef, Pelican Point, North Muiron Island, South Muiron
Reference	Ayling & Ayling (1987)	Forde (1994)	Forde (1994)		Stoddart & Osborne, (1989); Osborne & Williams (1995)	Osborne & Williams (1995)	Same as 1991	Armstrong (2005)	Armstrong (2005); this report
Notes	The South Osprey Bay site was in close proximity to the Osprey Bay site surveyed later in 1991				Same sites as surveyed in 1991, 1994, 2005. No GPS coordinates	No GPS coordinates	GPS coordinates for sites. Accuracy of replicate relocation was within ≤20 m of 1991 positions.	GPS coordinates for sites. Several GPS coordinates recorded in 1994 were wrong. In this case field notes made in 1994 were used to relocate replicates and their position was recorded by GPS in 2005.	GPS coordinates for sites

Table 14. Results of the ANOVA test showing no significant difference in mean D. cornus density between the results generated by the Osborne and Williams (1995) and the Armstrong (2005) methods.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2.276	1	2.276	1.327	.266
Within Groups	27.444	16	1.715		
Total	29.720	17			

Table 15. Results of the ANOVA test showing no significant difference in live hard coral cover between the results generated by the Osborne and Williams (1995) and the Armstrong (2005) methods.

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Armstrong	9	403.1	44.78889	16.28861
Osborne	9	392.71	43.63444	45.1746

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	5.997339	1	5.997339	0.195152	0.664575	4.493998
Within Groups	491.7057	16	30.73161			
Total	497.7031	17				

Table 16. Results of the ANOVA test showing no significant difference in live hard coral cover between the results generated by the NMPMP and the NMPDMP methods at Pelican Point.

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
nmpmp	3	168.896	56.29866	722.5533
nmpdmp	3	170.04	56.68	484.0411

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.218132	1	0.218132	0.000362	0.98574	7.708647
Within Groups	2413.189	4	603.2972			
Total	2413.407	5				

Table 17. Results of the ANOVA test showing no significant difference in live hard coral cover between the results generated by the NMPMP and the NMPDMP methods at Gnaraloo Bay.

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
nmpmp	3	151.8274	50.60913	288.5523
nmpdmp	3	166.39	55.46333	33.56973

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	35.34492	1	35.34492	0.21945	0.663847	7.708647
Within Groups	644.2441	4	161.061			
Total	679.5891	5				

Table 18. Summary of the *D. cornus* density data presented in Figure 17.

Drupella cornus												
	1987	**sterror**	**1989**	**sterror**	**1991**	**sterror**	**1994**	**sterror**	**2005**	**sterror**	**2006**	**sterror**
Nrth Muiron	~	~	~	~	~	~	~	~	~	~	0.21	0.02
South Muiron	~	~	~	~	~	~	~	~	~	~	1.188889	0.175154
Bundegi	~	~	~	~	1.62	0.37	0.77	0.22	0.2	0.04	~	~
Tantabiddi	~	~	7.3	n/a	3.04	0.78	2.72	0.67	1.3	0.27	~	~
Ned's Camp	~	~	~	~	0.30	0.11	0.05	0.03	2.33	0.67	~	~
Turquoise Bay	~	~	0.7		0.39	0.22	0.51	0.16	3.13	0.38	1.866667	0.394053
Osprey Bay	12.95	n/a	0	n/a	0.05	0.03	1.56	0.35	2.01	0.54	1.76	0.264575
Bunderra	~	~	~	~	2.01	1.03	1.00	0.28	1.47	0.29	~	~
Winderabandi	~	~	1.9	n/a	0.83	0.28	0.33	0.15	1.37	0.18	~	~
Lefroy	~	~	~	~	3.49	0.55	3.30	0.80	3.38	0.62	~	~
Cloates	~	~	~	~	0.02	0.01	1.01	0.30	2.53	0.46	~	~
Bruboodijoo	~	~	~	~	2.04	0.52	3.48	0.62	1.72	0.17	~	~
Coral Bay Backreef	~	~	~	~	3.93	1.26	1.60	0.55	2.44	0.32	2.8	0.698013
Coral Bay Lagoon	~	~	0	n/a	0.16	0.07	0.22	0.09	2.26	0.74	~	~
Pelican Point	~	~	18.1	n/a	18.77	0.87	10.06	1.08	5.25	0.89	7.44	1.351451
Cape Farquhar	~	~	~	~	~	~	~	~	~	~	1.788	0.242925
Gnaraloo Bay	~	~	~	~	~	~	~	~	~	~	3.88889	0.715977
3 Mile	~	~	~	~	~	~	~	~	~	~	1.93	0.273354
Turtles	~	~	~	~	~	~	~	~	~	~	4.3	n/a

Table 19. Summary of the live hard coral cover data presented in Figure 17.

Live hard coral cover												
	1987	sterror	1989	sterror	1991	sterror	1994	sterror	2005	sterror	2006	sterror
Nrth Muiron	~	~	~	~	~	~	~	~	~	~	52.08	1.49
South Muiron	~	~		~	~	~	~	~	~	~	28.02	2.42
Bundegi	~	~	~	~	51.33	3.61	32.55	8.94	31.86	6.22	~	~
Tantabiddi	~	~	42.00	n/a	55.94	5.35	39.50	6.03	38.16	4.51	~	~
Ned's Camp	~	~		~	4.28	0.89	5.89	1.73	33.52	5.68	~	~
Turquoise Bay	~	~	9.50		11.33	2.15	13.89	2.75	30.11	1.70	39.38	2.65
Osprey Bay	4.2	n/a	14.00	n/a	16.67	1.54	34.28	3.08	26.54	2.83	43.33	2.49
Bunderra	~	~	~	~	15.00	5.22	9.28	1.61	24.21	2.24	~	~
Winderabandi	~	~	5.50	n/a	14.06	2.44	16.33	2.92	33.64	3.17	~	~
Lefroy	~	~	~	~	50.61	7.16	41.94	4.78	41.32	2.79	~	~
Cloates	~	~	~	~	19.06	3.16	12.94	1.90	21.39	2.28	~	~
Bruboodijoo	~	~	~	~	19.94	5.19	28.56	3.39	19.01	2.25	~	~
Coral Bay Backreef	~	~	~	~	8.78	1.91	9.39	1.22	44.79	1.35	53.97	3.41
Coral Bay Lagoon	~	~	66.40	n/a	46.00	9.50	57.11	8.26	48.13	5.84	~	~
Pelican Point	~	~	68.80	n/a	80.06	2.83	60.72	4.71	52.54	7.22	56.68	7.42
Cape Farquhar	~	~	~	~	~	~	~	~	~	~	51.60	6.61
Gnaraloo Bay	~	~	~	~	~	~	~	~	~	~	55.47	3.11
3 Mile	~	~	~	~	~	~	~	~	~	~	59.81	4.13
Turtles	~	~	~	~	~	~	~	~	~	~	35.70	n/a