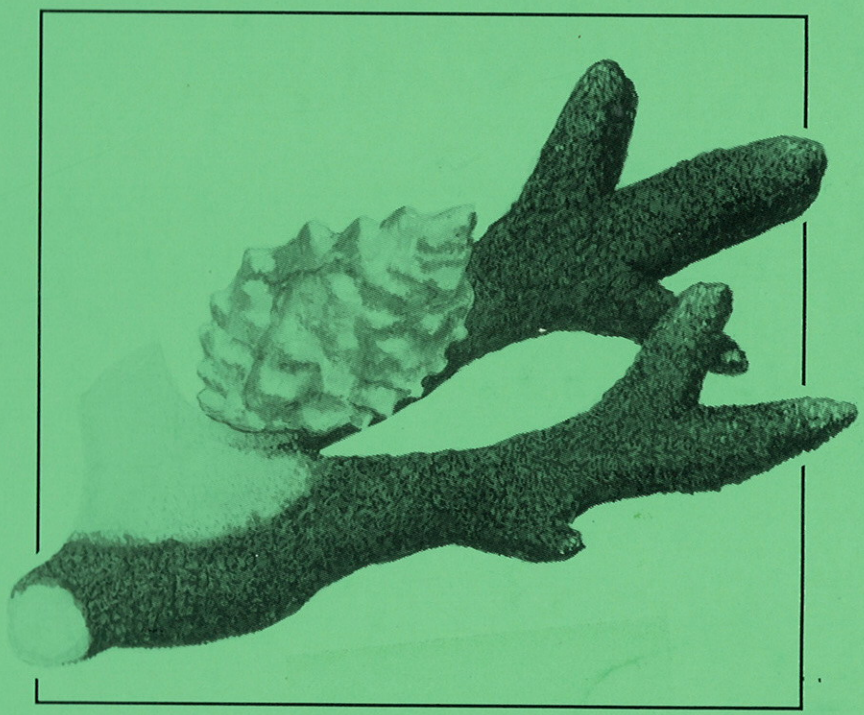
# *Drupella Cornus*: a Synopsis

**Proceedings of a Workshop held at the Department of Conservation and Land Management, Como, WESTERN AUSTRALIA 21 - 22 November 1991**

*CALM Occasional Paper No. 3/92 FEBRUARY 1992*



**Edited by Stephanie Turner**

**Published by the**

**Department of Conservation and Land Management**
**Como, Western Australia**

# DRUPELLA CORNUS
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EDITORIAL.

This compilation of short communications constitutes the Proceedings of the Drupella Workshop held at the C.A.L.M. Training Centre in Perth on the 21st and 22nd of November 1991. None of the papers included in this Proceedings have been peer-reviewed. The purpose of this publication is to provide a summary of the work that was presented at the Workshop, for both the participants and those interested people or groups who were unable to attend the Workshop. The order of the manuscripts is as they were presented at the Workshop.

ACKNOWLEDGEMENTS.

The organizing Committee would like to extend their gratitude to the Australian National Parks and Wildlife Service for providing financial assistance with the funding of the Workshop.

Special thanks to the Exmouth C.A.L.M. office and to all the people at Exmouth and Coral Bay who were involved with the Workshop field-trip.

Jan Rayner (W.A. Wildlife Research Centre) organized the travel arrangements for several of the participants for which we are grateful.

Finally, the Committee would like to thank all those people who participated in making the Workshop so informative, in particular those who gave presentations and/or chaired sessions. Special thanks to those participants who travelled considerable distances to attend.

ORGANIZING COMMITTEE:

Dr Steve Hopper
Dr Sue Osborne
Dr Tony Start
Dr Stephanie Turner

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# INTRODUCTORY REMARKS

**Barry Wilson**
**Director of Nature Conservation**

I don't believe it is necessary for me to review the history of the *Drupella* story. All of you are because you have an interest in the matter and I am sure you are familiar with the background. What I would like to do is make a few introductory remarks on the significance of it all in terms of environmental management.

There are many parallels with the crown of thorns (cot) saga:

1. A natural coral predator about which little was known was discovered to be aggregating in large numbers and feeding heavily to the extent that extensive areas of coral were being killed.
2. The phenonemon was noticed and reported independantly at several different localities at about the same time.
3. It was immediately assumed that there had been some kind of ecological disturbance causing an upset of the "normal" predator-prey balance.
4. It was also assumed that the disturbance was human-induced - "woe are we - what have we done - it must be our fault".
5. A range of explanatory hypotheses was proposed, principally :

* predator pressure release - probably a fish predator on the snail, the disturbance being attributed to over-fishing.
* physical damage to the settlement areas by storm damage, dredging or blasting.
* physical disturbance by siltation or flooding with fresh water after storms or change in upstream catchment management.

6. A realization that there was virtually no knowledge base for assessing these hypotheses subjectively, let alone test them scientifically.
7. A research phase to gather basic information.

It would be ungracious of me to point out that after 25 years of crown of thorns research we are still not much better informed than we were at the beginning. But this in itself brings sharp focus onto one very important lesson - for me anyway. You may not share this view.

It seems to me that the cot saga has shown us that ecological processes in the marine environment are infinitely more complex than we had imagined. Simple explanations with

one to one causal relationships between the organisms involved and the observed phenonema are very unlikely to be true.

We seem attracted to the concept that the natural world should be basically simple and stable and that the odd things that happen are abnormal. But recent chaos theory suggests that events like these may be from sheer coincidence of several chance events. It could even be that the complex factors producing such events are unknowable and unpredictable.

This could lead us to the view that research is a waste of time in terms of producing useful prescriptions for management. Well - I believe that conclusion would be a terrible mistake, although it would be an error for us to imagine that research can quickly lead us to solutions. It is absolutely imperative that we attempt to at least acquire enough information on marine ecosytem functions to lay down some ground rules.

In my view one of the greatest priorities for management-oriented marine research is to establish what the normal state of things is, that is in respect of marine community structure and dynamics. By this I do not mean to imply that I see stability as normal. On the contrary, what we have to establish is the range, frequency and amplitude of natural change in marine ecosystems.

Without that we will remain forever ignorant and unable to even begin to interpret seemingly odd situations like the cot and *Drupella* so-called plagues. We cannot assess whether sudden increase in predator numbers with devastating local or regional affects is natural/normal or unnatural/abnormal. Until we can do that we have no logical right to assume that human actions are responsible.

I am not saying that we should not speculate along those or any other lines. I am saying that we should not allow ourselves to give those speculations any degree of substance. We have to focus on the facts - to begin with the easily observable fact that *Drupella* eat the hell out of areas of coral reef and do vast damage.

As a marine park manager my **first** question is what will happen next? Will the coral regrow? If so, how quickly and will the regrowth community be of the same species composition as before?

My **second** question is will it happen again? And if so, how often? Will more snail recruits keep coming to consume the regrowing coral colonies? Or are the snail population explosions cyclic or episodic and do they correlate with any observable environmental change? These are long-term questions needing years of painstaking monitoring data.

My **third** question is , if the answer to the second is affirmative, can we prevent it? With a loud corollary - *should we attempt to prevent it*?

It is the second and third questions that require an understanding of the cause or causes. These are vital questions. If we couldn't answer such questions then we would have to retreat to the side benches and admit that marine park management is only about managing people. Perhaps that's the way it really is.

The truth is that marine ecosystem management is a very new concept and we have very little idea what the basic tenets are. What this says to me is not that it's all too hard and we should go home and watch Attenborough on TV. It says that there is a hell of a lot of basic work to be done and we should get on with it.

But on a different plane I would like to say that this predator-prey business in marine ecosystems, and phenonema like cot and *Drupella*, are absolutely fascinating. If you like a good detective story get into this one. The fact that the solution is still beyond us only adds spice to the mystery. You get the sensation that if we could just get to the bottom of these mysteries we would have vastly better insights into the wonders of the marine world.

It seems to me that the really interesting mysteries are solved by piecing together the bits of the story one by one until a picture emerges that is recognizable. What I expect to hear and see during this seminar are some of the bits.

We will study them and argue about their relevance and significance and whether any picture is yet emerging. It's early days yet though and I don't think any of us expect too much. We are at the stage where we are still gathering basic information on the scale and scope of the problem - if it is one. The main function of such a workshop is to put up what information we have gathered and see what we can learn from each other. It's one of the nice things about science - finding a common problem to tug at.

I would like to congratulate Stephanie and the others who initiated the workshop and did all the work in getting it together. And to wish you all good luck and good fun, both here and when you go back to your own research programs.

# TAXONOMY OF DRUPELLA (Gastropoda, Muricidae)

Barry Wilson
Director of Nature Conservation, CALM

My contribution to the *Drupella* jigsaw puzzle is to try to put names on the primary pieces. That this is necessary is evident from the terrible confusion already in the literature due to incorrect identification of the muricid gastropods reported as being obligate coral-eaters. I know that for most of you taxonomy is deadly dull but this is an example of how necessary it is to get the names right so that we can talk sense to each other.

In some of the recent discussions of the *Drupella* problem 5 species have been implicated and several synonomous names have been used to identify some of them. By my account there may be only two species in *Drupella.* Both are obligate coral-eaters and they alone produce the reef damage we are here to talk about. Other species which have been assigned to the genus do not belong there. I must qualify this, however, by noting that the two species which I acknowledge are polytypic and further study may show that they comprise more than one entity, and that there is a third, unidentified coral-eater on our reefs which may turn out to be another species of *Drupella.*

The following formal account gives details of the taxa as I see them.

## Genus **DRUPELLA** Thiele, 1925

*Purpura elata* Blainville (= *cornus* Röding)

The shell form of this genus is little different to that of the Indo-West Pacific genus *Cronia* but the radula of *Drupella* is very different. In fact it is unique among the muricids in having very long, reed-like lateral teeth which are sharply and minutely denticulate at the base and terminally bifid or denticulate. Along the length of the radula the laterals outnumber the centrals. It can be assumed that this unique radular type is an adaptation to coral-eating.

There has been much confusion about the generic nomenclature of the genus as well the species.

To begin with the type species of the genus was designated by Thiele as *Drupa ( Drupella) ochrostoma* Blainville. I will suggest later that *ochrostoma* is actually a very different species in a different genus. It has been shown that the material which Thiele had was

actually what we now call *cornus*. The matter was resolved by the International Commission in a ruling in 1980 when it designated *elata* Blainville as the type of the genus. I will show that *elata* is synonym of *cornus*.

If all that leaves you breathless you could simply take my word for it that the type of *Drupella* is *cornus*.

**Drupella cornus** (Röding, 1798)

*Shell*: massive and very thick, adults usually covered with a thick calcareous growth; body whorl with 4 spiral rows of prominent, pointed or compressed and angular nodules, and fine spiral cords in the interspaces; outer lip sharp-edged though thick and inwardly inclining in adults, with 5-7 small inner nodules; columella smooth or with 1-4 tiny anterior denticles. White or cream; columella and outer lip white although the edge may be green, interior white to yellow or orange.

*Body*: colour like *D. rugosa* but much paler and with much less and paler mottling (more blotched than mottled); eye band green - made up of denser and darker olive-green mottles; operculum dark brown.

3.8 cm. Indo-West Pacific; Abrolhos, WA to Capricorn Group, Qld.
*Synonyms: elata* Blainville, 1832; *eburnea* Kuster, 1862; *dealbata* Reeve, 1846.

The confusion between *cornus* and *elata* arose because it was claimed that the aperture of the Pacific form is typically white while the Indian Ocean form has a yellow aperture. In fact samples from both oceans normally include individuals of both types. Further study may show that there is a greater propensity for yellow apertures in Indian Ocean populations but that would hardly warrant species distinction. It is for this reason that *cornus* and *rugosa* are regarded here as synonyms.

**Drupella rugosa** (Born,1778)

*Shell :* ovate to biconical; body whorl with 5 spiral rows of axially aligned nodules forming axial ribs, 11-12 per whorl, nodules may be low to obsolete or prominent and pointed, the row at the shoulder is the first and the largest, the anterior row is smallest and about the same height and thickness as the fasciole, prickly spiral threads present in the interspaces, fasciole scabrous; outer lip thick in adults, with 6-7 inner denticles; columella with 2-4 weak transverse anterior nodules. Cream,white or pale orange, nodules sometimes brown or orange; aperture and columella white, mauve or yellow.

*Body* : pale green, mottled with darker olive-green and flecked with white; white flecks larger and more numerous on the siphons and eye tentacles; sole of foot pale yellow; base of eye tentacles and siphon very pale green to colourless, with white flecks, just below the eye itself there is a band of pale green which lacks the darker green mottles but has a concentration of "internal" white flecks; there are two obscure, small brownish patches on

top of the foot just behind the front edge; penis coloured as the eye tentacles; operculum yellow-brown.

3.3 cm. Indo-West Pacific; North West Cape, WA to Capricorn Group, Qld. *Synonyms: concatenata* Lamarck, 1822; *fragum* Blainville, 1832.

The colouring of this species is polytypic. The typical form is white with a faintly tinted columella but samples from Queensland, taken from single feeding groups, include specimens with moderately to prominently brown nodules and stongly tinted columella (the *concatenata* form). Western Australian populations comprise only the strongly coloured form. This leaves the taxonomic position ambivalent. It is possible that further study may show that the Western population deserves subspecies status in which case the name *concatenata* would apply. Genetic studies are needed to clarify this situation.

**Literature reports.**

If my synonomies are correct, the early accounts of *Drupella* aggregations with coral damage must be reassessed with respect to which of the two species was responsible.

Moyer et al ,1982 observed 2 species damaging coral reefs in Japan and 2 in the Philippines. I have not been able to examine any voucher material of theirs and so cannot be certain which species these authors observed. However, on the basis of my synonomies, they probably observed both *cornus* and *rugosa* in Japan but only *rugosa* at the Philippine locality. A simple transposition of synonyms would be as follows:

| | Moyer et al | senior synonym |
|---|---|---|
| Miyake-jima, Japan : | *fragum* | *rugosa* |
| | *elata* | *cornus.* |
| Philippines : | *fragum* | *rugosa* |
| | *rugosa* | *rugosa* |

Fujioka & Yamazato, 1983 reported damage in the Ryukyu Is as done by *Drupella fragum* for which you should read *Drupella rugosa.*

**Dwarfism.** Another problem has arisen because of literature reports that *D. cornus* is sexually dimorphic with the males being dwarf. This report seems to have originated with Walter Cernohorsky but I believe that it was based on a mis-identification of his material.

The specimens which I have seen identified as dwarf male *cornus* are actually small *rugosa* and they are not all male. There is no evidence from exhaustive measurements of *cornus* samples by me and others that this species is sexually dimorphic.

### Other species

Three other muricids are sometimes placed in *Drupella* but do not belong there. As far as I can determine, none of them are obligate coral-eaters, viz.:

*Pascula ochrostoma* (Blainville, 1832)

*Muricodrupa fenestrata* (Blainville, 1832)
= *cariosus* Wood, 1828
= cancellata Quoy & Gaimard, 1833
(This is the type of the genus *Muricodrupa* named by Iredale

*Morula (Oppomorus) nodulifera* (Menke, 1829)
= *chaidea* Duclos, 1832
(This is the type of the subgenus named by Iredale.)

During the course of several of the studies to be reported at this seminar by Western Australian and Queensland researchers specimens have been collected which, on shell characters alone, seem somewhat different to either *D. cornus* or *D. rugosa,* being more stout and thick-shelled. They were observed to be feeding on corals. The status of these specimens remains uncertain. I hope that some of you will have opportunities to study the live animals of them. They may be another variant of *rugosa* or *cornus,* but there is a possibility that they will turn out to be be a third species of *Drupella.* In that event, a name for it would be problematical.

# A PRELIMINARY SUMMARY OF *DRUPELLA CORNUS* DISTRIBUTION AND ABUNDANCE PATTERNS FOLLOWING A SURVEY OF NINGALOO REEF IN SPRING 1991

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## INTRODUCTION

Surveys of Ningaloo Reef indicate that although common, *Drupella cornus* did not cause massive coral damage before 1980 (Meagher, 1980; Marsh, pers. comm., Western Australian Museum). In addition, visual estimates by scientists from the Western Australian Museum suggest that although variable, live coral cover in back reef areas during 1976 to 1980 was commonly greater than 50 percent.

It is likely that the *Drupella cornus* outbreak at Ningaloo Reef started during the early 1980s. Unusually large numbers of *Drupella* were first observed in the southern section of Ningaloo Reef in 1982 (Forde, pers, comm., University of Western Australia). A subsequent visit in 1985 to sites in the central and northern sections of Ningaloo Reef indicate that the infestation was already widespread during the mid 1980s (Wilson, pers, comm., Department of Conservation and Land Management).

In 1987, a survey of fish numbers and reef habitats facilitated the collection of more data on *Drupella* distribution and abundance patterns. The majority of sample sites during this survey were in the northern section of Ningaloo Reef where the percentages of live coral were low and surviving colonies were heavily infested with snails (Ayling and Ayling, 1987).

An extensive survey of Ningaloo Reef was carried out during 1989. By this time, the activity observed two years earlier in the northern section of the reef had caused extensive coral damage with some areas reduced to rubble. Although the impact of *Drupella* was most evident in the northern section of the reef, measurements of snail densities indicated that they were most abundant towards the southern end of the reef (Stoddart, 1989) and it was suggested that a wave of infestation has slowly moved south (Holborn, 1990).

This preliminary report summarizes the results of a survey that was carried out during September and October of 1991 to determine the status of *Drupella cornus* on Ningaloo Reef.

## METHODS

Thirteen sites of predominantly hard substrate were selected from aerial photographs of Ningaloo Reef. The sites were distributed so that there were three back reef sites (located on the sheltered side of the reef crest) and one mid lagoonal site in each of the northern, central and southern thirds of the reef. The thirteenth site was located on Bundegi Reef which is in Exmouth Gulf.

At each of the thirteen sites, there were three replicates. The replicates were distributed within an area of reef that looked similar on the aerial photo for that site. At each replicate, both snail densities and the status of hard corals were determined. Snail densities were estimated by three divers each of whom established a 5metre x 5metre quadrat using pre-marked ropes. The quadrats were placed on predominantly hard substrate in close proximity to the boats, but their boundaries rarely abutted. When the quadrats were marked, the divers searched first their own quadrat for 15 minutes, then they rotated to their neighbours quadrat for 15 minutes and finally they moved to the third quadrat for another 15 minute search. During each 15 minute search, the divers placed all live and dead *Drupella* that they could find in a cloth sample bag which was labelled and then sealed. In this way, each 5metre x 5metre quadrat was searched by three divers for a total of 45 minutes and nine sample bags were used to collect snails from each replicate. Back on dry land, the contents of all sample bags were sorted and the numbers of live and dead *Drupella* were recorded. In addition, up to 130 live snails from each site were measured using vernier callipers. The greatest shell length was used as a record of snail size.

Coral was monitored by three divers at each replicate. The three divers laid 20metre tapes over the substrate and used a line intersect method to estimate the amount of live hard coral. Corals were identified to the level of familly except for members of Acroporidae which were split further to the level of genus. Substrate that was not hard coral was categorized as either hard substrate or soft substrate according to whether it was suitable or not for the settlement of hard corals. Having completed the substrate cover measurements, the divers returned to the beginnings of their tapes to measure coral sizes. The divers measured the greatest radius of each of the the first 35 hard coral colonies which occurred beneath their tapes. Colonies were defined by the boundaries of live tissue and in cases where tissue damage had resulted in many separate colonies on connected skeletal material, a maximum of five such related colonies were measured. In this way, a total transect length of 60metres was sampled and over 100 corals were measured at each replicate.

The same eight divers conducted the entire survey. None of the divers were novices and all but one member of the team had extensive experience on coral reefs. Of the eight divers, three were dedicated to coral monitoring, while the other five worked on *Drupella* densities. Four of the five *Drupella* divers were familiar with Ningaloo Reef and already knew how to look for snails. However, the first field day was dedicated to training in order to refresh their memories and to familiarize the fifth diver.

## RESULTS

The total numbers of live and dead snails that were found in each replicate plus average live and dead *Drupella* densities are presented in table one. The average densities of *Drupella* at each site are also represented in figure one. There is some variation among replicates within certain sites. However, the overall live *Drupella* densities at the three southern back reef sites were higher than those recorded at back reef sites in the central and northern sections of the reef. The lowest density of live

| | | SNAIL DENSITIES | | | | SNAIL SIZES | | | LIVE CORAL | | SOFT SUBSTRATE | | HARD SUBSTRATE | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | LIVE | | DEAD | | | | | | | | | | |
| SITE | replicate | total found | no. per sq. m. | total found | no. per sq. m. | sample size | mean (cm) | standard deviation | transect length (m) | % cover | transect length (m) | % cover | transect length (m) | % cover |
| Bundegi | 1 | 209 | 1.45 | 2 | 0.04 | 105 | 4.56 | 0.28 | 37.19 | 51.78 | 3.23 | 1.87 | 19.58 | 46.35 |
| | 2 | 50 | | 4 | | | | | 28.05 | | 0.00 | | 31.95 | |
| | 3 | 68 | | 2 | | | | | 27.97 | | 0.13 | | 31.90 | |
| Tantabiddi | 1 | 162 | 2.80 | 20 | 0.26 | 105 | 3.67 | 0.27 | 28.88 | 52.92 | 3.60 | 2.56 | 27.52 | 44.52 |
| | 2 | 59 | | 10 | | | | | 36.09 | | 0.76 | | 23.15 | |
| | 3 | 409 | | 29 | | | | | 30.29 | | 0.25 | | 29.46 | |
| Ned's Camp | 1 | 23 | 0.21 | 67 | 0.38 | 47 | 2.94 | 0.60 | 0.83 | 3.83 | 9.36 | 20.73 | 49.81 | 75.44 |
| | 2 | 1 | | 10 | | | | | 2.73 | | 12.18 | | 45.09 | |
| | 3 | 24 | | 9 | | | | | 3.33 | | 15.78 | | 40.89 | |
| Turquoise | 1 | 70 | 0.38 | 6 | 0.10 | 87 | 3.46 | 0.46 | 6.83 | 11.06 | 20.45 | 25.67 | 32.72 | 63.27 |
| | 2 | 1 | | 15 | | | | | 5.77 | | 10.86 | | 43.37 | |
| | 3 | 14 | | 1 | | | | | 7.31 | | 14.89 | | 37.80 | |
| Osprey | 1 | 2 | 0.05 | 2 | 0.04 | 11 | 3.31 | 0.37 | 8.88 | 16.21 | 12.20 | 20.28 | 38.92 | 63.51 |
| | 2 | 9 | | 3 | | | | | 10.87 | | 16.52 | | 32.61 | |
| | 3 | 0 | | 4 | | | | | 9.43 | | 7.78 | | 42.79 | |
| Bunderra | 1 | 8 | 1.78 | 8 | 0.18 | 97 | 3.55 | 0.23 | 2.91 | 14.79 | 12.90 | 13.14 | 44.19 | 72.07 |
| | 2 | 4 | | 10 | | | | | 3.29 | | 6.66 | | 50.05 | |
| | 3 | 389 | | 22 | | | | | 20.42 | | 4.09 | | 35.49 | |
| Winderabandi | 1 | 55 | 0.56 | 10 | 0.14 | 105 | 3.18 | 0.34 | 10.56 | 14.85 | 12.74 | 21.57 | 36.70 | 63.58 |
| | 2 | 48 | | 16 | | | | | 6.87 | | 16.07 | | 37.06 | |
| | 3 | 23 | | 5 | | | | | 9.29 | | 10.02 | | 40.69 | |
| Lefroy Bay | 1 | 55 | 2.96 | 15 | 0.32 | 105 | 3.80 | 0.35 | 25.26 | 45.02 | 3.81 | 3.74 | 30.93 | 51.24 |
| | 2 | 290 | | 24 | | | | | 36.43 | | 2.13 | | 21.44 | |
| | 3 | 163 | | 33 | | | | | 19.35 | | 0.79 | | 39.86 | |
| Cloates | 1 | 2 | 0.02 | 4 | 0.06 | 3 | 3.43 | 0.54 | 4.32 | 18.53 | 14.77 | 22.21 | 40.91 | 59.26 |
| | 2 | 1 | | 7 | | | | | 16.62 | | 9.30 | | 34.08 | |
| | 3 | 2 | | 2 | | | | | 12.42 | | 15.90 | | 31.68 | |
| Bruboodjoo | 1 | 230 | 1.82 | 6 | 0.09 | 104 | 3.47 | 0.54 | 22.22 | 19.73 | 16.79 | 17.32 | 20.99 | 62.95 |
| | 2 | 166 | | 10 | | | | | 11.48 | | 13.99 | | 34.53 | |
| | 3 | 14 | | 5 | | | | | 1.81 | | 0.39 | | 57.80 | |
| Coral Bay Lagoon | 1 | 18 | 0.09 | 4 | 0.02 | 21 | 4.45 | 0.49 | 29.42 | 43.71 | 0.89 | 3.39 | 29.69 | 52.90 |
| | 2 | 0 | | 0 | | | | | 6.09 | | 4.87 | | 49.04 | |
| | 3 | 3 | | 0 | | | | | 43.17 | | 0.34 | | 16.49 | |
| Coral Bay back reef | 1 | 109 | 3.36 | 13 | 0.27 | 130 | 3.25 | 0.37 | 7.41 | 10.63 | 7.20 | 9.37 | 45.39 | 80.00 |
| | 2 | 504 | | 23 | | | | | 8.14 | | 5.03 | | 46.83 | |
| | 3 | 142 | | 24 | | | | | 3.59 | | 4.63 | | 51.78 | |
| Pelican | 1 | 1184 | 15.95 | 26 | 0.36 | 105 | 3.46 | 0.35 | 41.81 | 79.82 | 3.88 | 5.09 | 14.31 | 15.09 |
| | 2 | 1303 | | 28 | | | | | 51.95 | | 2.11 | | 5.94 | |
| | 3 | 1101 | | 26 | | | | | 49.92 | | 3.17 | | 6.91 | |

TABLE 1. Substrate cover plus *Drupella* sizes and densities at thirteen sites along Ningaloo Reef in Spring 1991. Snail densities are recorded as both the numbers of snails found within three 5metre x 5metre quadrats, which was the area sampled at each replicate, and an average number of snails per square metre from all samples within a site. Substrate cover is presented both as the lengths of substrate type on the 60metres of transect at each replicate and the percentages of each cover type from all samples within a site.

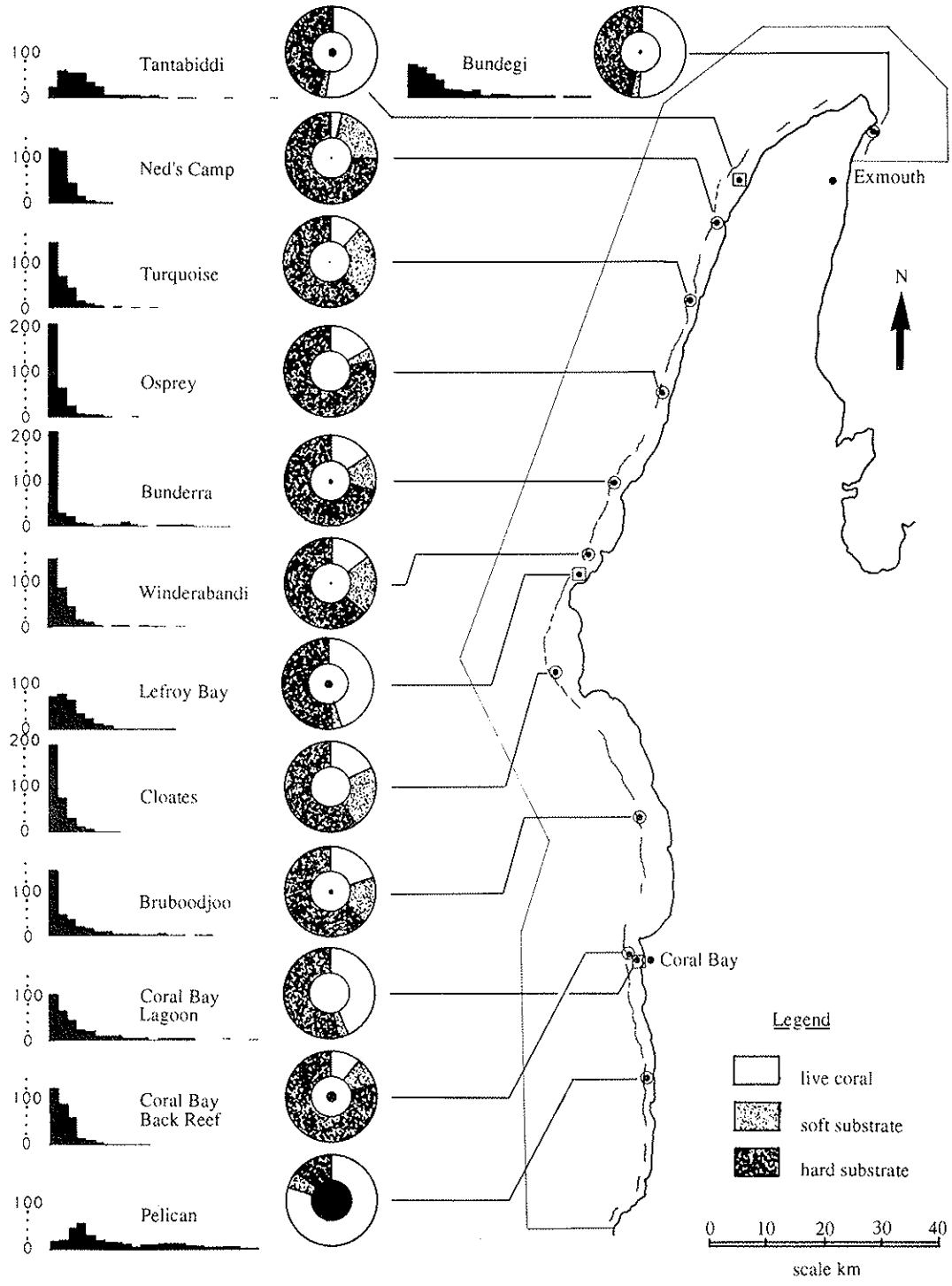


FIGURE 1. Substrate type and *Drupella* densities at thirteen sites along Ningaloo Reef in Spring 1991. The histograms represent the size frequency distributions of hard coral colonies. Each column represents a size class of 5cm in colony radius. The pie diagrams represent the proportions of live hard coral, soft substrate and hard substrate at each site. *Drupella* densities are represented by the radius of the black dot or disc in the centre of each pie diagram. The locations of the thirteen sites are shown on the map of Ningaloo Marine Park. Back reef sites are represented by circles and mid lagoonal sites are represented by squares.

snails was recorded at Cloates while the highest density of live snails was recorded on the back reef at Pelican where a density of 15.95 snails per square metre was recorded. Live snail densities at mid lagoonal sites did not correspond with those at adjacent back reef sites. In the northern and central sections of the reef, mid lagoonal sites harboured higher densities of live snails than back reef sites whereas the mid lagoonal site at Coral Bay in the southern section of the reef had a much lower density of snails than the southern back reef sites.

At all but two sites, the densities of dead *Drupella* were lower that the densities of live *Drupella*. The exceptions to this trend were at Cloates and at Ned's Camp. Ned's Camp harboured the highest density of dead snail with 0.38 snails per square metre.

The means and standard deviations of shell sizes for each site are presented in table one. Shells collected from Bundegi and the lagoonal site at Coral Bay were larger than those collected at other sites. The snails sampled at Ned's Camp were smaller than those from other sites.

The total lengths of live coral, hard substrate and soft substrate are presented for each replicate in table one. The overall percentages of live coral plus hard and soft substrate for each site are also presented in table one and they are represented by pie diagrams in figure one. There is some variation among benthic cover measurements from replicates within certain sites. The summarized percentage cover values for each site indicate that the lowest percent live coral cover was recorded off Ned's Camp which was the most northerly back reef site and the highest percent live coral cover was recorded at Pelican which was the most southerly back reef site. However, data from the other back reef sites did not support a trend of gradual increase in percent live coral from the northern to the southern sections of the reef. With the exception of Pelican, Bundegi Reef and the three mid lagoonal sites were characterized by higher percentages of live coral than the back reef sites.

Colony sizes of all live corals at each site are represented by size frequency histograms in figure one. Sites with high percentages of live coral were characterised by proportionally more large colonies than sites with low percentages of live coral. With the exception of Pelican, very small coral colonies predominated at back reef sites. Although the majority of these small colonies were the remains of large colonies, new coral recruits were evident.

## DISCUSSION

Previous work has indicated that divers vary considerably in their abilities to find *Drupella* in the natural environment (Osborne and Williams, these proceedings). To minimize discrepancies resulting from differences in diver abilities the same team of five divers carried out the whole survey. In addition, snail searches in the 5metre x 5metre quadrats were repeated by different divers so that their range of abilities was spread amongst the experimental samples. Future modelling of snail counts from repeat searches will determine an index of ability value for each diver. This will then be used to adjust the data so that the snail counts more closely approximate the number of snails within each sample area.

Although replicates at each site were located in close proximity and within areas that looked identical on aerial photos, variation among *Drupella* densities and live coral cover measurements were recorded at some sites. Considerable variation in the amounts of live coral cover were recorded among replicates within three sites. The

high density of live snails in replicate three at Bunderra corresponded with a relatively high value of live coral cover. Just eight and four live snails were found in replicates one and two respectively while the corresponding live coral cover values were 4.85 percent and 5.48 percent. However, replicate three was characterised by 34.03 percent live coral with a corresponding live snail collection of 389. A similar correlation between live coral cover and live snail densities was recorded among the replicates at Bruboodjoo. Here the high variation among live snail counts of 230, 166 and 14, corresponded with percent live coral cover values of 37.03, 19.13 and 3.02 respectively. The other site where live coral cover varied among replicates was in Coral Bay lagoon. Here the comparatively low value of live coral cover at replicate two was the result of a coral kill in 1989. A northerly wind during the coral spawning event of that year empounded the spawn in Coral Bay resulting in the de-oxygenation of water and a mass kill of all marine life.

At Tantabiddi, live snail counts varied considerably among replicates. Here, although similar percentages of live coral were recorded in all replicates, the distribution of preferred coral prey, namely *Acroporas* and *Montiporas* (Ayling and Ayling, 1987), was less even. Percentage cover values for *Acroporas* plus *Montiporas* were 25.83 percent in replicate one, just 17.72 percent in replicate two and 47.75 percent in replicate three. This variation in coral cover type corresponded with the variation in live snail counts of 162, 59 and 409 respectively. Similar variations among live snail densities from replicates at Bundegi and the back reef at Coral Bay could not be related to variations in live coral cover and perhaps represent a level of patchiness in the natural distribution of *Drupella*.

The patchy distributions of *Drupella* and live coral cover were further emphasized by casual observations in reef areas adjacent of those selected for survey. In some cases, quite minor differences on aerial photos represented major changes in reef habitat. For this reason, comparisons with data from previous surveys are restricted to observations from within the same site boundaries.

Six of the thirteen sites that were surveyed during the present survey were also sampled at the beginning of 1989. *Drupella* densities and percentage live coral cover values from the 1989 survey are presented in table two. Comparisons indicate that the majority of *Drupella* densities and percent live coral cover values from 1989 lie within the variation among the 1991 scores from individual 5metre x 5metre quadrats and 20metre transects for the same sites. Exceptions occur at both

| | Tantabiddi | Turquoise | Osprey | Winderabandi | Coral Bay Lagoon | Pelican |
|---|---|---|---|---|---|---|
| *Drupella* densities (snails per sq. m.) | 7.3 | 0.7 | 0 | 1.9 | 0 | 18.1 |
| Percent live coral | 42.0% | 9.5% | 14.0% | 5.5% | 66.4% | 68.8% |

TABLE 2. *Drupella* densities and percent live coral cover values from 1989. Density values for Tantabiddi, Turquoise and Osprey were calculated from samples of 20 square metres while live coral cover was calculated from 40 metre line intersect transects. The sample sizes at Winderabandi, Coral Bay Lagoon and Pelican were 10 square metres and 20 metres of line intersect transect.

Tantabiddi, where there appears to have been a reduction in the density of *Drupella*, and at Winderabandi, where a reduction in *Drupella* densities has been accompanied by an increase in live coral cover since 1989.

During a previous survey in 1987, both *Drupella* density and live coral cover were measured at Osprey. Two mean densities of 9.6 and 16.3 snails per square matre were recorded at this site which indicate that the snails were plaguing in 1987 and their densities have since decreased significantly. The change in *Drupella* densities at this site has been accompanied by an increase in live coral cover from 4.2 percent in 1987 to 16.21 percent in 1991.

Studies on the Great Barrier Reef revealed average *Drupella* densities of 0.61 snails per square metre. At this density minor coral damage was evident, but it was considered unlikely that the *Drupella* population was inflated (Oxley, 1988). Of the 13 sites sampled during the 1991 survey of Ningaloo Reef, as many as six supported *Drupella* populations with densities less than 0.61 snails per square metre. However, only one of these sites, Coral Bay Lagoon, appeared never to have been infested by *Drupella*. At Neds, Turquoise, Osprey, Winderabandi and Cloates, the presence of dead snails, low percentages of live coral, high proportions of very small coral colonies and the obvious skeletal remains of previous corals all provide evidence of prior infestations. The results of this survey therefore indicate that in 1991 most of Ningaloo Reef has either already been infested by *Drupella* or is presently supporting *Drupella* populations which are likely to cause significant reductions to live coral cover in the future.

The reduction in *Drupella* densities and the increase in live coral cover which have been recorded at Winderabandi and Osprey since 1989 and 1987 are encouraging. In addition, the significant numbers of newly recruited coral colonies at several of the back reef sites suggest that recovery might be possible. However, as yet it cannot be assumed that the reef will return to the conditions that were reported during the 1970s.

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# INCIDENCE OF *DRUPELLA* ON CORAL MONITORING TRANSECTS BETWEEN SERRURIER ISLAND AND MERMAID SOUND

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## INTRODUCTION

This paper describes the incidence of *Drupella* gastropods on coral monitoring transects off the Pilbara coastline of Western Australia. The transects were established for various projects and developments which required implementation of a Marine Biological Monitoring Programme (MBMP) following environmental impact assessment by the Western Australian Environmental Protection Authority (EPA).

## BACKGROUND

Between October 1985 and May 1988, over 45 fixed transects were established by LeProvost Environmental Consultants (LEC; formerly LeProvost, Semeniuk & Chalmer) on coral reefs between Serrurier Island and Gidley Island (Mermaid Sound) on the inner North West Shelf (Table 1; Fig. 1). These transects have been monitored on a semi-annual or annual basis on behalf of the following companies managing petroleum exploration and production activities off the Pilbara coast:

- Hadson Energy Limited (Hadson; the Harriet oil and gas field, formerly operated by Bond Petroleum Pty Ltd [1985-present]);
- West Australian Petroleum Pty Ltd (WAPET; the Saladin oil field [1988-present]);
- Western Mining Corportation Pty Ltd (WMC; the South Pepper/North Herald/Chervil oil fields [1987-1990]); and
- Woodside Offshore Petroleum Pty Ltd (Woodside; delegated operator for the North West Shelf Gas Project on behalf of the Joint Venture Participants [1986-present]).

**TABLE 1**

**Coral Transect and Monitoring Details**

| REGION | DATES OF SURVEYS | NUMBER OF TRANSECTS | TRANSECT TYPE |
|---|---|---|---|
| MERMAID SOUND (including Dampier Archipelago; Fig. 2) | January/October 1986; | 14 | 20-30 m x 0.3 m |
| | January/August 1987; February 1988 | 14 | 20-30 m x 0.3 m |
| | March/July/October 1989; | 14 | 20-30 m x 0.3 m |
| | July 1990; | 10 of 14 | 20-30 m x 0.3 m |
| | June 1991/November 1991. | 9 of 14 | 20-30 m x 0.3 m (belt transects, perpendicular to shoreline) |
| VARANUS ISLAND (Lowendal Islands to Ah Chong Island; Fig. 3) | October 1985;June/December 1986 | 10 | 5 m x 1 m |
| | January/July 1987; July 1988 | 11 | 5 m x 1 m |
| | April 1989; June 1990; April 1991 | 11 | 5 m x 1 m |
| AIRLIE ISLAND (Rosily Island to Barrow Shoals; Fig. 4) | December 1987 (baseline survey); | 10 | 5 m x 1 m |
| | January/December 1988; | 11 | 5 m x 1 m |
| | July/December 1989; July 1990. | 11 | 5 m x 1 m |
| THEVENARD ISLAND (Serrurier Island to Direction Island; Fig. 5) | May 1988 (baseline survey); | 12 | 5 m x 1 m |
| | November 1988; May/November 1989; | 13 | 5 m x 1 m |
| | May/November 1990; October 1991. | 13 | 5 m x 1 m |
| EAGLEHAWK ISLAND | August 1989; November 1989; November 1990. | 2 | 25 m x 0.3 m and 5 m x 1 m (shallow reef) |
| DUGONG REEF (on Barrow Shoals) | December 1989 (inspection); | 0 | |
| | July 1990 (baseline survey); | 7 | 50 m x 0.1 m |
| | March 1991; October 1991. | 6 | 50 m x 0.1 m (line intercept transects of shallow reef) |
| PASSAGE ISLAND (including Meda Reef) | October 1991 (baseline survey) | 6 | 50 m x 1 m (video transects of shallow reef) |

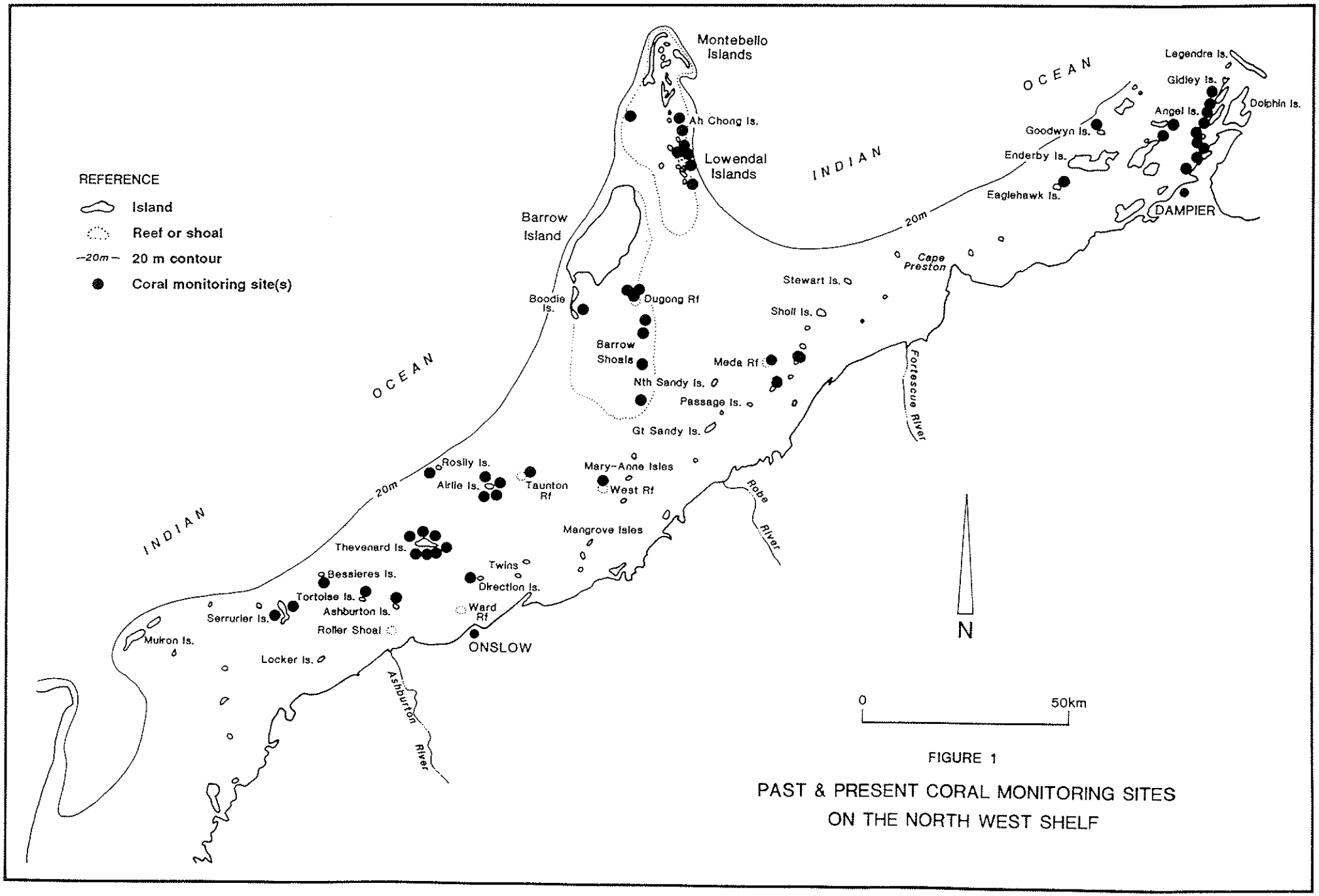



FIGURE 1

PAST & PRESENT CORAL MONITORING SITES ON THE NORTH WEST SHELF

These companies are responsible for operating MBMPs in accordance with conditions set by the EPA following project assessment or, in the case of Woodside, on its own initiative.

The number of transects was increased between 1989 and 1990, when two were established at Eaglehawk Island on behalf of United Salvage Pty Ltd following the wrecking of the McDermott Derrick barge DB20, and when seven were installed over tabular and staghorn *Acropora* 'gardens' at Dugong Reef (Barrow Shoals) on behalf of WAPET, so that corals within 1 km of an exploratory well drilled in 1991 could be monitored. More recently, six transects have been installed at the Passage Island chain on behalf of Hadson as part of its monitoring programme for the installation of a gas transmission line between Varanus Island and the mainland.

No transect has been established specifically to obtain information on corallivores such as *Drupella*, and all have been installed for one or more of the following reasons:

- to enable predictions in the impact assessment documentation to be tested (e.g. oil spill effects or other specified potential impacts on nearby corals);
- to provide and/or maintain an up-to-date a baseline data set (in the event of a petroleum spill or serious accident); and/or
- for general surveillance purposes (including information on the extent and frequency of changes to monitored corals arising from natural causes such as cyclones, regional bleaching events, etc).

## CORAL MONITORING METHODS

### Approach

Owing to logistical constraints and the cost of monitoring corals in remote areas off the Pilbara coastline, fixed but non-replicated transects were established for each project following inspection of colour aerial photographs and ground-truthing during initial 'baseline' field surveys. The use of fixed transects enabled coral colonies representative of each site to be inspected, photographed and re-mapped onto water-proof sheets at approximately six or twelve month intervals (this approach helped offset the lack of replicate transects and inability to determine variation within and between sites).

## Type and Location of Transects

The type of transect, its establishment date, and the frequency of monitoring has varied according to the start-up date and nature of each development and the contract period. Inspection dates for all transects are shown in Table 1.

Belt transects (0.3 m wide) were established as part of Woodside's monitoring programme for the development of the shipping channel and LNG terminal facilities on the Burrup Peninsula between 1986 and 1990 (Table 1; Fig. 2). These were installed to monitor fringing reef corals in Mermaid Sound and the Dampier Archipelago. These transects are perpendicular to the shoreline (from the low intertidal zone to the point where hard substrate gives way to soft sediments below 6 m) and typically 20-30 m in length.

For those developments involving the production and load-out of crude oil at Varanus Island (Hadson), Airlie Island (WMC) and Thevenard Island (WAPET), a series of 5 m x 1 m transects were established in the region of each oil field (Table 1; Figs 3-5). Most of these were located imediately beneath the low intertidal zone and mainly on patch reefs (including 'bommies') which, according to the results of oil spill trajectory modelling, had a high likelihood of intercepting an oil spill. In the case of the transects established near Varanus Island, the majority of these cover a significant proportion (~10% to ~55%) of the shallow subtidal area of the bommies which had been selected for monitoring.

Details of the other transects installed at Eaglehawk Island (west of Dampier), Dugong Reef (north-east Barrow Shoals) and the Passage Island chain are given in Table 1. In addition, inshore coral reefs near Onslow (at Roller Shoals and Ward Reef) were inspected and photographed in October 1991, in preparation for a baseline survey and establishment of new transects for WAPET's Roller development.

All transects were positioned so that the type and cover of monitored corals were representative of the surrounding area and, in the case of the small 5 m x 1 m transects, where colony abundance was high. Thus emplacement of these transects over large colonies (>2 m diameter) was avoided, since this would have considerably reduced the number and diversity of individual colonies within the transect.

## Collection of Data

During each survey, the locations and outlines of coral colonies within, or intercepting, transects have been mapped two-dimensionally onto plastic sheets. Freehand mapping of colonies in the 5 m x 1 m transects is facilitated by using a 25 x 25 cm grid supported by a 1 x 1 m aluminium frame, with a similar grid represented on the mapping sheet (Fig. 6). Each 1 m by 1 m quadrat is also photographed with the grid

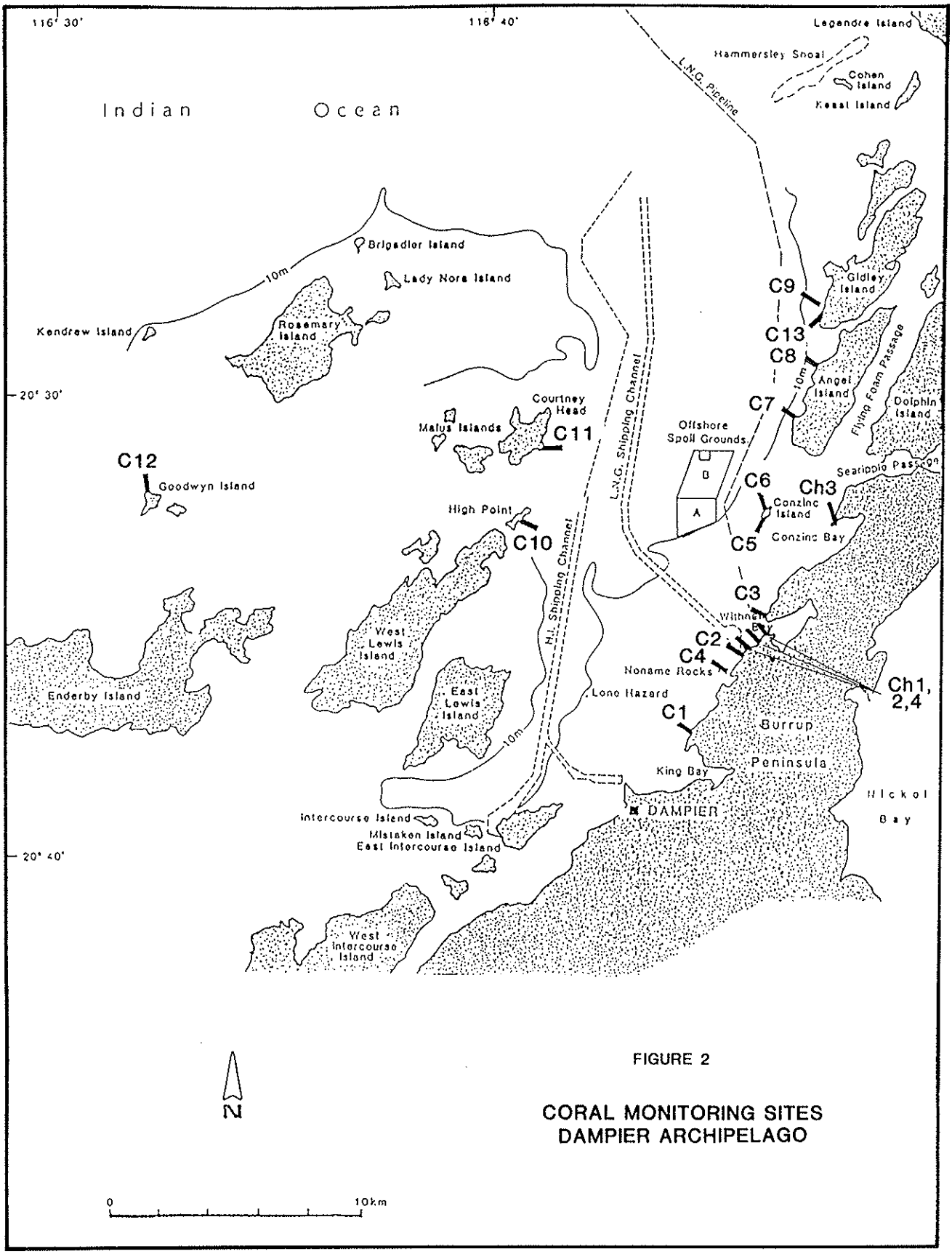



FIGURE 2

**CORAL MONITORING SITES**
**DAMPIER ARCHIPELAGO**

in place to maintain a visual archive. The maps were subsequently used to monitor changes to colony numbers in each transect, as well as the percentage of the substrate (in the vertical projection) covered by living hard coral at the time of each survey.

Mapping also involved recording the location of any bleached, partially dead or recently-dead colonies, and the incidence of Crown of Thorns starfish and (since November 1989) *Drupella* (Fig. 6). Brief inspections are also made of the condition of nearby corals up to 6 m from the transect boundaries. The time spent inspecting, mapping and photographing each transect typically ranges from 45 to 100 minutes, depending on the degree of coral cover and topographical complexity.

### Assessing *Drupella* numbers

After *Drupella* aggregations were first encountered in November 1989, the number of these muricid snails which could be seen within transects without disturbing the corals were counted. Whether or not *Drupella* were found in a particular transect, an estimate of the density of visible snails was made by visual assessment during the inspection of corals beyond the transect. Because only visual assessments could be made, the density of visible snails was estimated using three broad levels based on the counts obtained in the 5 m x 1 m transects. These levels of density were 'low' (1-5 per 5 $m^2$), 'moderate' (6-30 per 5 $m^2$) and 'high' (>30 per 5 $m^2$). A null score was recorded if no snails were found either on or near the transect.

*Drupella* observed within or near transects were either counted *in situ*, or temporarily displaced by the diver to enable more accurate counting and to check for empty shells. Snails were not sized owing to constraints imposed by air supply and survey schedules. Separation of individuals at the species level (e.g. *Drupella cornus* versus *Drupella rugosa*) was not attempted. However, the vast majority that have been counted were large (~25-45 mm) and had the robust appearance characteristic of *Drupella cornus*. Feeding aggregations of *D. rugosa* have not been observed at Ningaloo Reef or Exmouth Gulf (Dr S. Turner, pers comm.).

Three LEC divers (all with substantial experience before 1985) have undertaken the transect inspections for the various programmes (mostly PNC to July 1990, then RWH until present). Moreover, almost all inspections have been undertaken with two of these divers in the water, and all three had commenced counting *Drupella* before the end of 1989. Thus the density class information since 1989 provides a temporal data set on *Drupella* aggregations that is based on comparable search efforts over a range of fixed sites.

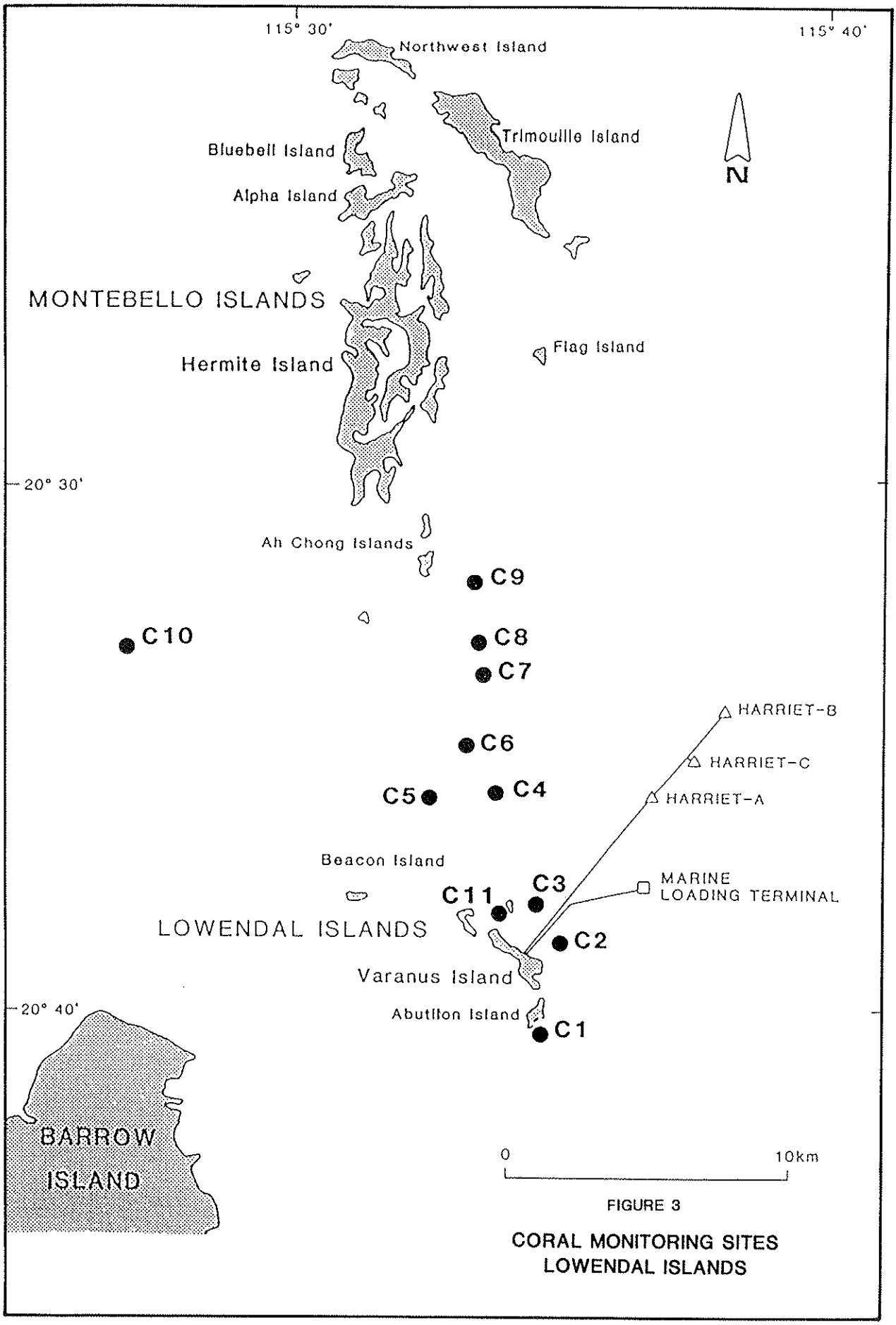
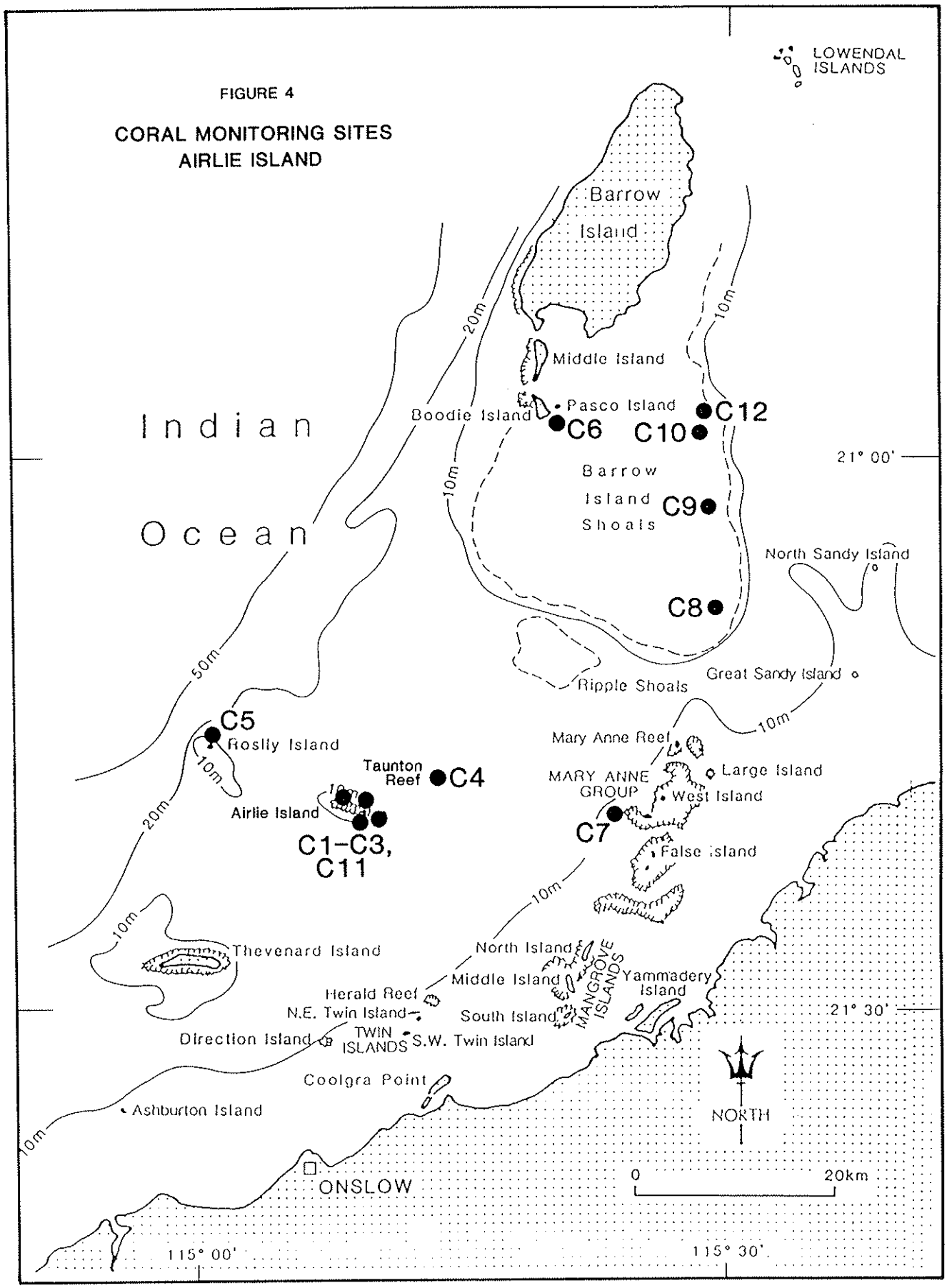



FIGURE 3

**CORAL MONITORING SITES**
**LOWENDAL ISLANDS**

FIGURE 4

**CORAL MONITORING SITES**
**AIRLIE ISLAND**



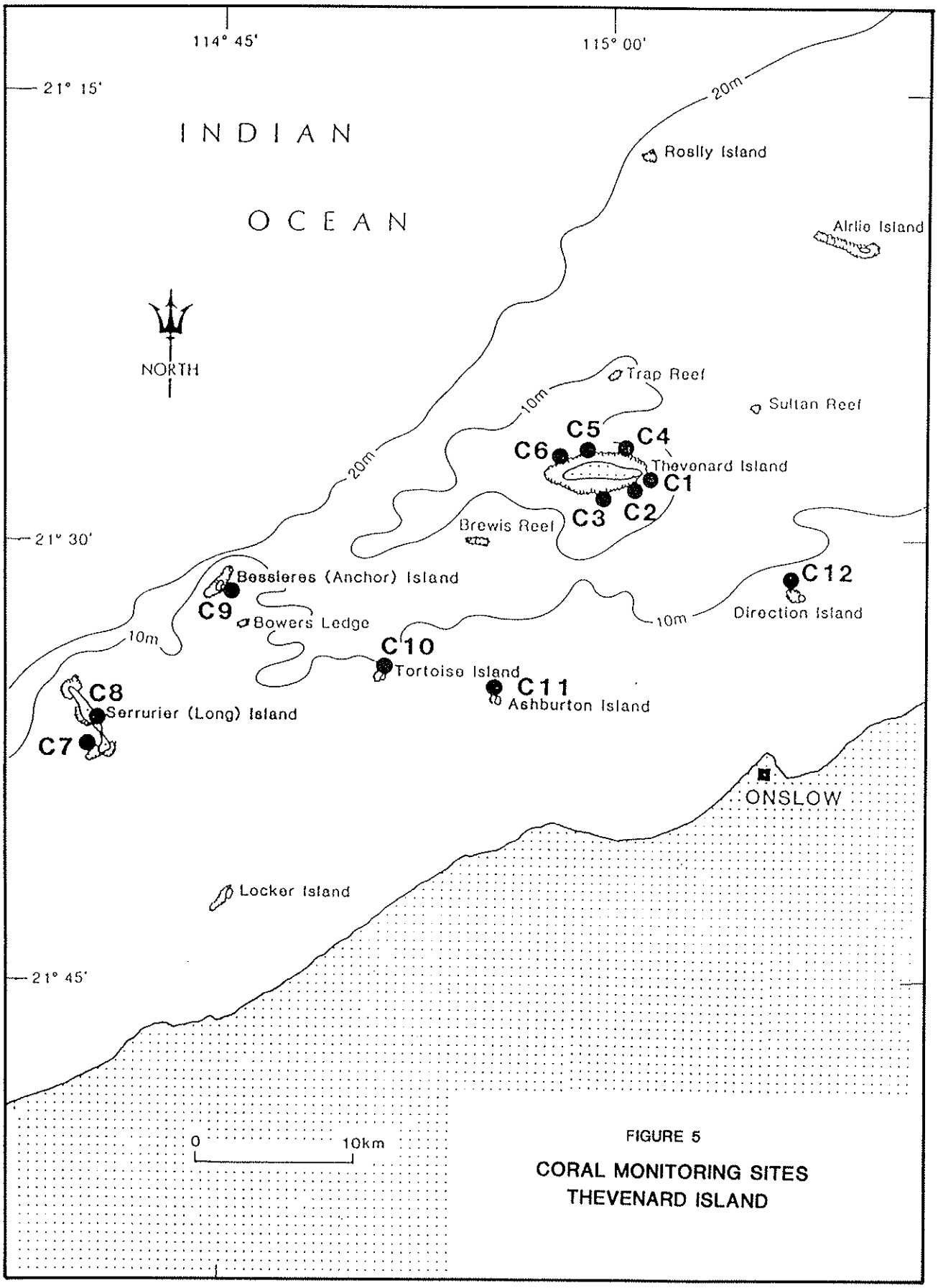


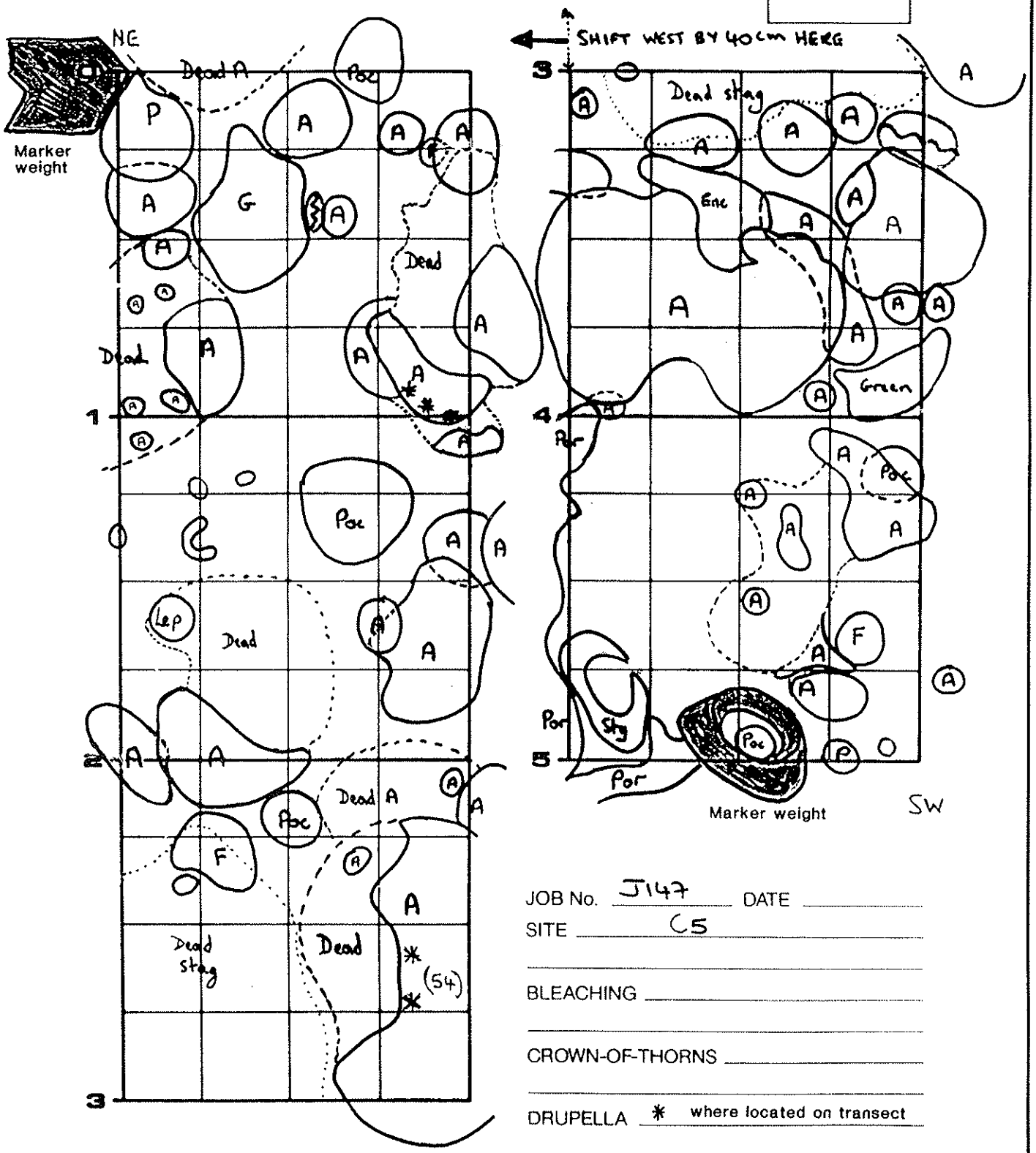

FIGURE 5

CORAL MONITORING SITES
THEVENARD ISLAND

*LeProvost Environmental Consultants*

SITE LOCATION: LOWENDAL ISLANDS
C5: 20° 36.280'S 115° 32.790'E

NORTH
NE




JOB No. J147 DATE

SITE C5

BLEACHING

CROWN-OF-THORNS

DRUPELLA * where located on transect

NOTES

FIGURE 6

## INCIDENCE OF *DRUPELLA*

The incidence of *Drupella* is presented on an annual basis in Figures 7 (for end of 1989), 8 (for 1990) and 9 (for 1991). These figures provide values for monitoring sites which had been visited at least once by the end of 1989, 1990 and 1991 respectively, and each value represents the highest density found on or near the transect during a particular year. Note that a high density signifies the presence of one or more aggregations (and is equivalent to >6 $m^{-2}$), while a moderate density (equivalent to 1-5 $m^{-2}$) indicates that only clusters or small aggregations were found on or near a transect. A low density (1-5 snails visible in the transect, and equivalent to <1 $m^{-2}$) signifies that only a few individuals or a single small cluster had been recorded either on or off the transect. Null values (no snails seen) are not shown in Figs 7-9, but can be determined by comparing these figures with Figure 1.

Clusters and small aggregations of *Drupella* adults producing moderate densities were first observed in November 1989 close to transects established at Thevenard, Tortoise and Ashburton Islands (Fig. 7). These transects had been established in May 1988 (Table 1), and no clusters or aggregations had been encountered at this time or during the subsequent semi-annual surveys in November 1988 and May 1989. At these sites, the density of visible snails in November 1989 ranged from moderate to low (Fig. 7).

Aggregations of *Drupella* producing a high density of visible snails within transects (i.e. >30 animals) were first encountered in the December 1989 survey of sites near Airlie Island and the Mary-Anne Passage (Fig. 7). During this survey, 60 individuals were counted on four colonies within the transect at West Reef, while a moderate density was recorded for a site on Barrow Shoals (C9; Figs 4,7), where 23 of 29 snails counted within the transect 27 were found on one table *Acropora* colony. The Airlie Island MBMP had been established on behalf of WMC in December 1987 and these sites were also being monitored semi-annually (Table 1).

The clusters and aggregations have been found principally on *Acropora* spp., although 18 of the individuals counted on the West Reef transect in December 1989 were on *Porites* colonies. *Drupella* have subsequently been observed on other genera including *Montipora*, *Pocillopora*, *Stylophora*, as well as occasionally on favid species. However, the largest aggregations and the largest feeding scars have been found on corymbose and tabular *Acropora* spp., and banded feeding scars characteristic of *Drupella* aggregations cannot be seen in transect photographs taken before late 1989.

Since 1989, the number of sites between Serrurier Island and Varanus Island where high and moderate densities of visible *Drupella* were found has increased (c.f. Figs 7-9). Thus by the end of 1990, the number of sites where high and moderate densities were encountered increased from one to eight and from four to nine respectively (Fig. 8). One of these sites (at transect C5 some 4 km north-west of Varanus Island; Figs 3, 8), represents the first record of a *Drupella* aggregation detected in the

Lowendal Island group since the start of coral monitoring in October 1985 (Table 1). By the end of 1990, densities exceeding 5 $m^{-2}$ had also been encountered at Serrurier Island, Bessieres Island, Thevenard Island and Direction Island (Fig. 8).

The highest number of *Drupella* obtained from a single colony (a table *Acropora* spp.) has been 123 (in May 1990 at Bessieres Island; site C9 in Fig. 5). At this time, the total number counted within the C9 transect was 193, and the area of this 5 m x 1 m transect covered by living coral was mapped at 2.7 $m^2$ (i.e. 54% cover). By November 1990, mapping showed that coral cover had declined to 2.35 $m^2$, which represented a 13% fall over 6 months. The decline at C9 (almost all to *Acropora* spp. where the *Drupella* were located) continued into 1991, and by October 1991 only 1.1 $m^2$ of the transect (22%) remained covered (mainly by massive species including *Porites* and *Platygyra* spp., with remnant *Acropora* and *Montipora* colonies). This fall represented a loss of over half of the coral cover which had been mapped in November 1990.

The largest reduction in coral cover among the *Drupella*-affected sites near Varanus Island has been at transect C5 (Figs 3,6), where living coral cover in this 5 m x 1 m transect has fallen by 31% between 1990 and 1991 (i.e. from 2.6 $m^2$ in June 1990 to 1.8 $m^2$ in April 1991). The incidence of elevated numbers of *Drupella* at monitoring sites in the Lowendal Islands further increased between the 1990 and 1991 annual surveys. Thus the number of sites where the density of visible adults exceeded 1 $m^{-2}$ and 5 $m^{-2}$ rose from nil to four and from one to two respectively (c.f. Figs 8, 9). The highest counts so far recorded near Varanus Island were in April 1991, and where the three largest aggregations on single *Acropora* heads comprised 74, 56 and 54 adult snails. The last of these was inside transect C5 (Figs 3,6). Here, the total number was 93 (counted inside the transect) and 79 (on corals outside the transect).

In contrast to the detected increase in *Drupella* numbers at sites between Serrurier Island and the Lowendal Islands, clusters or aggregations of this predator have not yet been found on or near the transects in Mermaid Sound or the Dampier Archipelago (including Eaglehawk Island), and which have been monitored on the dates listed in Table 1. However, it is recognised that the belt transects in the Dampier Archipelago and Mermaid Sound differ by extending from the low intertidal zone into the deep subtidal zone (6-12 m).

On the other hand, no study has suggested that *Drupella* aggregations are restricted only to the shallowest part of the subtidal zone (1-2 m), and there has been an equal opportunity for clusters or aggregations of snails to be encountered on corals located on and beside these transects. Moreover, to date there have been no reports of serious or unusual damage to coral cover and/or large aggregations in this area (Dr S. Turner, CALM; pers comm.). Given the publicity surrounding the effects of *Drupella* and the Ningaloo Reef and the fact that many reefs in the Dampier region are visited by recreational divers, it is therefore considered unlikely that a widespread and marked elevation in *Drupella* numbers could have occured since 1989 without detection.

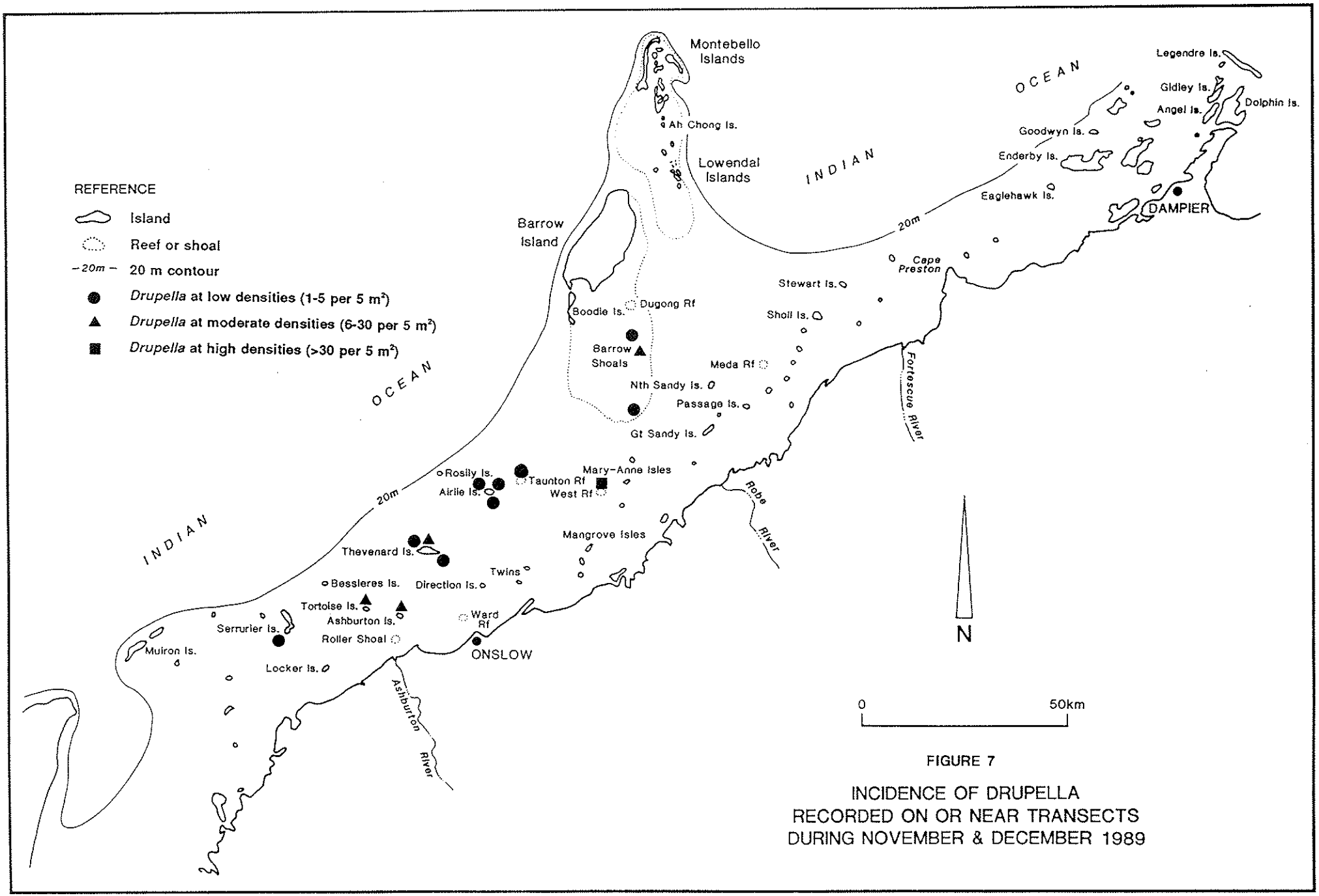



FIGURE 7

INCIDENCE OF DRUPELLA
RECORDED ON OR NEAR TRANSECTS
DURING NOVEMBER & DECEMBER 1989

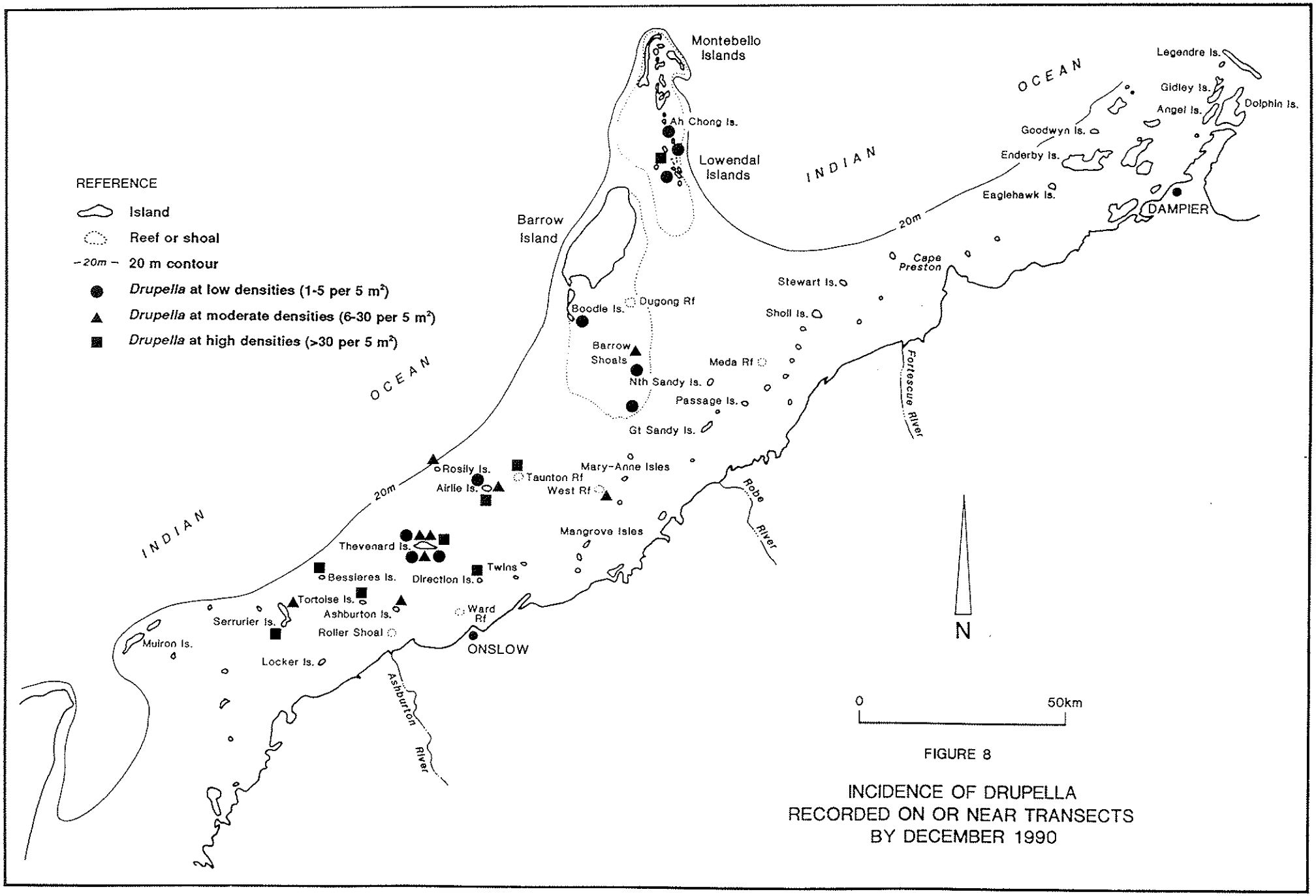



FIGURE 8

INCIDENCE OF DRUPELLA
RECORDED ON OR NEAR TRANSECTS
BY DECEMBER 1990

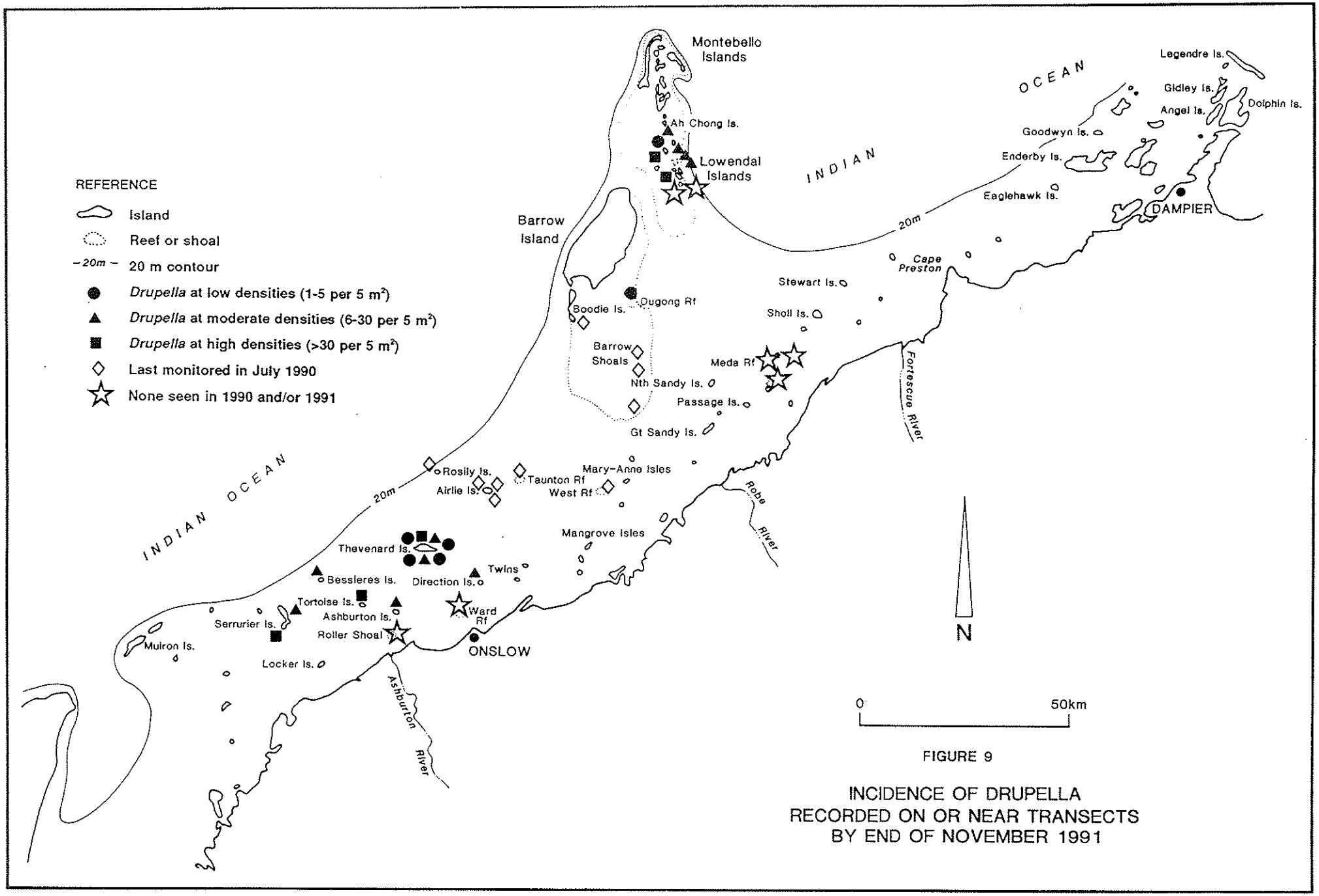



FIGURE 9

INCIDENCE OF DRUPELLA
RECORDED ON OR NEAR TRANSECTS
BY END OF NOVEMBER 1991

Finally, while elevated *Drupella* numbers have caused reductions to coral cover on reefs from the Lowendal Islands westwards, including reefs at the Muiron Islands which lie to the west of Serrurier Island (Mr M. Forde; pers comm.), aggregations and/or feeding scars have not been found at a number of reefs in the area between Onslow and the Lowendal Islands (e.g. monitoring sites on the south-east and north-west sides of Thevenard Island and near Varanus Island, as well as Ward Reef, Roller Shoals, Meda Reef and Passage Island; Table 1, Figs 7-9).

## SYNTHESIS

At many of the monitoring sites, an apparent increase in the incidence of feeding aggregations and feeding scars has coincided with marked falls in the amount of hard coral which, in cases such as those near Varanus Island, have not displayed such fluctuations to coral cover since their establishment in 1985. The following preliminary conclusions are therefore drawn from the records of the various monitoring programmes:

(i) there appears to be have been an increase in the number of feeding aggregations of *Drupella* over the past two years at sites on the inner north West Shelf where they were formerly not present;

(ii) feeding aggregations of *Drupella* (signifying elevated densities of adults) presently appear to be more prominent in the western half of the inner North West Shelf; and

(iii) in localities where *Drupella* aggregations have been encountered, their occurrence can be very patchy.

The information collected to date and summarised in Figures 7-9, including the sites where *Drupella* aggregations and feeding damage have not been found, provides background data against which future changes to *Drupella* populations on the inner North West Shelf can be assessed.

Monitoring future changes on reefs along the inner North West Shelf would show whether the apparent increase represents part of a normal cycle in this region (in which fluctuations to *Drupella* numbers are short-term and produce only temporary [and essentially inconsequential] falls in coral cover), or whether the increase represents the start of a major phenomenon similar to that which has occurred on Ningaloo Reef. In addition, future monitoring would also indicate whether or not *Drupella* aggregations will become common in the more eastern sectors of the inner North West Shelf.

Further monitoring of selected sites would also help clarify current questions on *Drupella* population dynamics. Of particular interest is the question as to whether the apparent recent increases in the incidence of adult aggregations at sites between Serrurier Island and the Lowendal Island chain represent localised phenomena (presumably brought about by the same or similar factors which have operated on the Ningaloo Reef), or whether they represent a more direct effect following the marked rise of *Drupella* numbers on Ningaloo Reef in the 1980s (e.g. the result of increased larval dispersal from areas to the south-west of North West Cape and/or the Muiron Islands).

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# PRELIMINARY INFORMATION ON THE EFFECTS OF *DRUPELLA* SPP. GRAZING ON THE GREAT BARRIER REEF.

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## INTRODUCTION

In April 1987, while carrying out biological survey work for the West Australian (WA) Department of Conservation and Land Management (CALM) on the Ningaloo fringing reef tract, we first became aware of the coral grazing activities of the gastropod *Drupella* (Ayling and Ayling 1987). During that survey it became clear that damage caused by *Drupella* on the Ningaloo reefs was of the same level as that due to crown-of-thorns grazing on coral reefs.

Prior to 1987 we had not observed *Drupella* on the Great Barrier Reef (GBR) in spite of extensive observations and surveys of coral communities over an eight year period. However, following our return from WA, and our observations of *Drupella* grazing activities there, we looked at the GBR with new eyes. Since that time we have made surveys on almost 100 different reefs, from the turbid fringing reefs of Cape Tribulation, Magnetic Island and the Whitsunday Islands to outer shelf reefs such as the Ribbon Reefs and a range of mid-shelf reefs from Princess Charlotte Bay (14°S) to the Whitsunday Group (20°S), and we have found several species of *Drupella* to be present on all of them. Observations by other aware observers have reported *Drupella* from the Swain Group of reefs and the Capricorn-Bunker Group at the southern end of the GBR (22-23°S) and from Torres Strait (10°S).

In this report we will present a summary of early surveys made on the GBR between 1987 and 1990 and the results of a more detailed survey of *Drupella* damage carried out on 50 reefs in the Cairns Section of the GBR (14°30'S-18°S) in early 1991.

## PRELIMINARY SURVEYS

Our initial surveys showed that the most abundant species on the GBR was *Drupella rugosa*, a species with many small nodules that ranges in size as an adult from 20-25 mm and occasionally to 30 mm. A larger species, identified by Ian Loch of the Australian Museum as *D. cornus* and ranging in length from 32-40 mm is occasionally found. Although identified as *D. cornus* this species is slightly different from the species found at Ningaloo. There is also a smaller unknown species of *Drupella* ranging from 12-15 mm in length that we have only encountered a few times.

*D. rugosa* collected from any single location generally had a bimodal length frequency, with thin-lipped juveniles in one peak and adults in the other. This suggests that these gastropods reach an asymptotic size at which growth slows markedly or stops.

Preliminary counts using 20 x 1 m visually searched transects on Norman Reef (16°25'S) recorded mean densities of 1.1 per sq m. However, *D. rugosa*, being

smaller and more secretive than the species found at Ningaloo, is not easy to count visually and some preliminary destructive searches of sq m quadrats on Low Isles off Port Douglas revealed mean densities of almost 20 per sq m.

*D. rugosa* eats approximately the same range of coral species as did the *Drupella* at Ningaloo (Ayling and Ayling 1987). We recorded the coral species being grazed by *Drupella* on four reefs off Cooktown (table 1) and found that they preferred pocilloporids and most *Acropora* species but were occasionally found eating a few other species including *Porites* colonies.

**Table 1. *Drupella* Grazed Corals Observed on Four Reefs off Cooktown.**

| Species | No. Colonies Grazed | Species | No. Colonies Grazed |
|---|---|---|---|
| *Seriatopora hystrix* | 48 | *A. polystoma* | 3 |
| *Stylophora pistillata* | 3 | *A. digitifera* | 2 |
| *Pocillopora damicornis* | 13 | *A. lutkeni* | 2 |
| *Montipora incrassata* | 4 | *A. microphthalma* | 2 |
| *Acropora elseyi* | 22 | *A. nobilis* | 2 |
| *A. nasuta* | 21 | *A. sarmantosa* | 2 |
| *A. tenuis* | 12 | *A. selago* | 2 |
| *A. aculeus* | 8 | *A. azurea* | 1 |
| *A. formosa* | 8 | *A. humilis* | 1 |
| *A. longicyathus* | 7 | *A. nana* | 1 |
| *A. microclados* | 4 | *A. palifera* | 1 |
| *A. millepora* | 4 | *A. secale* | 1 |
| *A. brueggemanni* | 3 | *A. yongei* | 1 |
| *A. divaricata* | 3 | *Porites nigrescens* | 1 |
| *A. gemmifera* | 3 | *Porites* sp. | 1 |

During a trip in July 1990 to look the extent of the damage caused by TC Ivor we made spot checks on a number of reefs between Lizard Island and Princess Charlotte Bay (14°S-14°30'S) . On about 6 of these reefs *Drupella* damage was marked, especially on Davie Reef a small outer reef that had a high level of damage at all three sites visited. Although no quantification of *Drupella* damage was made at these reefs it was decided that some method of damage estimation should be developed for use during future surveys.

## THE EFFECTS OF *DRUPELLA* GRAZING IN THE CAIRNS SECTION OF THE GBR.

During January-March 1991 we made surveys of a wide variety of reef organisms on 50 reefs in the Cairns Section of the GBR Marine Park in a project funded by the GBRMPA and coordinated by Bruce Mapstone and Howard Choat of JCU. As part of this study the effect of *Drupella* grazing on coral communities was quantified.

On each reef 3 sites were surveyed on the front (windward) face and another 3 sites on the back (leeward) face. Four replicate 30 x 1 m transects were searched for coral colonies that had been damaged by *Drupella* grazing and the number

recorded, along with simultaneous counts of the number of undamaged colonies. For large coral masses, such as *Acropora* staghorn and bottlebrush thickets and extensive *Montipora* or *Turbinaria* plates and whorls, each 0.5 m square of the coral mass was defined as a 'colony'.

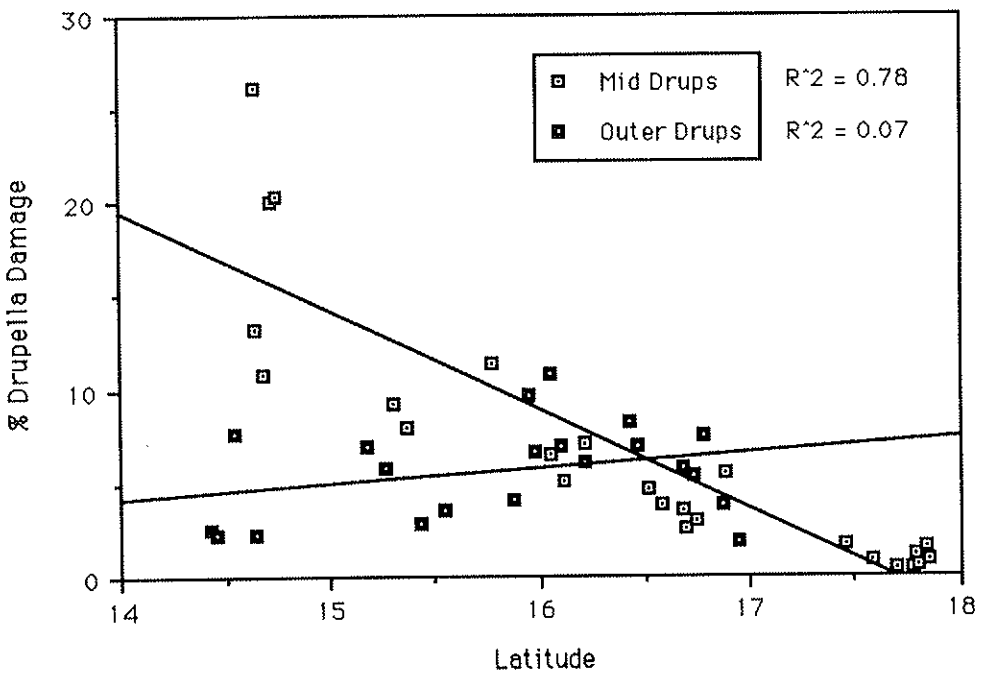
The results were converted to a percentage of the total corals that were damaged at each site and a mean percentage damage calculated for the entire reef (6 sites). Overall reef-wide damage figures ranged from an insignificant 0.4% to over 26% of coral colonies. The grand mean damage level for all 50 reefs was 6.6%. There was a significant S - N increase in the extent of *Drupella* damage on mid-shelf reefs of the Cairns Section, but this was not reflected on outer shelf reefs (table 2, figure 1).

**Table 2. Summary of Damage Patterns in the Cairns Section.**

Bold figures record mean percentage of total corals damaged; figures in brackets are mean total no. of corals per 30 sqm, followed by no. reefs surveyed in each area.

| Area | Inner Shelf | Mid-Shelf | Outer Shelf |
|---|---|---|---|
| Innisfail/Tully | | **0.9** (80.4) n=8 | |
| Cairns | | **3.9** (52.5) n=6 | **4.9** (48.1) n=5 |
| Port Douglas | **23.7** (35.7) n=1 | **6.2** (92.7) n=3 | **7.4** (81.9) n=8 |
| Cooktown | | **9.5** (88.8) n=3 | **4.8** (134.4) n=4 |
| Lizard Island | | **18.1** (74.7) n=5 | **3.7** (122.4) n=4 |

**Figure 1. Patterns of *Drupella* Damage in the Cairns Secion.**



The maximum recorded damage at any site was on the front reef of Nymph Island (14°40'S), north of Lizard Island where 48.3% of corals were damaged.

It appeared that a greater percentage of corals were damaged on reefs where coral cover had been reduced by TC Ivor 12 months before (Done et al. 1990).

Our survey in WA showed that *Drupella* grazing can be as destructive to hard corals over large areas as *Acanthaster* grazing. This survey suggested that these gastropods are present on at least some parts of the GBR in sufficient numbers to cause significant coral death.

## DISCUSSION

There seems to be a perception, both on the GBR and in WA, and in the wider context, that *Drupella* grazing is a new problem and anthropogenic effects must somehow be responsible. The emotive word 'outbreak' is being used to describe the high density populations that have been located.

Our contention is that this is not a new phenomenon. We started seeing *Drupella* on all reefs visited after our return from WA. This new awareness has now spread to other people and new examples of damage on the GBR are reported regularly. It is possible that prior to this awareness reefs devastated by *Drupella* were attributed to crown-of-thorns grazing. If a devastated reef is found after the event, how do we decide which grazer was responsible? During GBR-wide crown-of-thorns surveys in 1985 Moran et al. (1988) declared Tydeman Reef, which is adjacent to Davie, to have been devastated by crown-of-thorns in the past. In view of our observations of extensive *Drupella* damage on Davie Reef and on other reefs in the area in 1990 it may be that *Drupella* grazing was responsible for the coral damage observed on Tydeman that was attributed to crown-of-thorns.

Jack Moyer, who reported damage over relatively small areas of reef in Japan and the Philippines, blamed siltation from coastal development for the supposed increase in *Drupella* numbers (Moyer et al. 1982). The WA populations could hardly be attributed to this cause as the entire coast is a desert with 200 mm annual rainfall and very low human use apart from fishing. The highest density populations found to date on the GBR are remote from centres of population and from possible man-induced water quality changes.

**Table 3. Lethrinid Density on NW Cape and the GBR**

Figures shown are grand means per ha from a variable no. of sites.

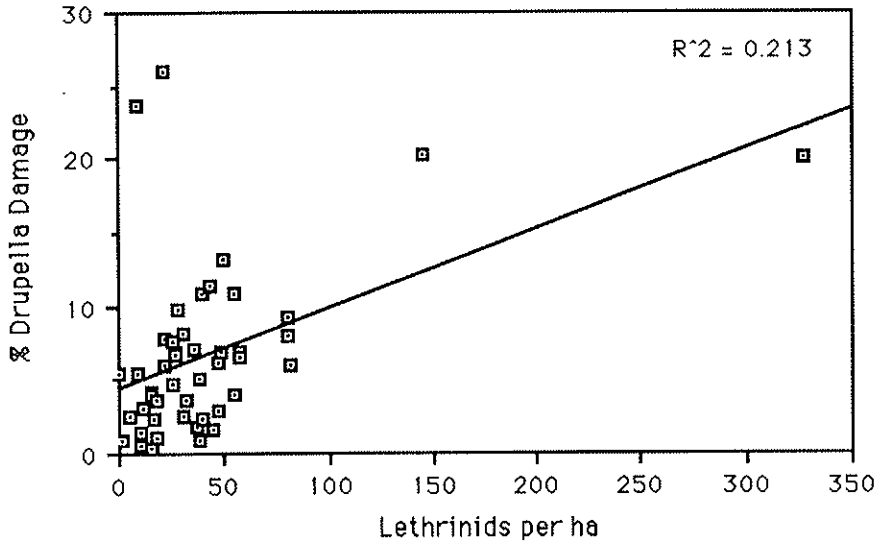
| | NW Cape | GBR | |
|---|---|---|---|
| | | Cairns | Central |
| Family | 13 sites | 47 reefs | 3 reefs |
| Lethrinidae | 200 | 40 | 26 |

In Ningaloo where there is a recreational fishery for the common local lethrinids it has been suggested that fishing pressure has encouraged the high density *Drupella*

populations. Lethrinids are potential predators, at least of small *Drupella* - it is hypothesised that removal of the fish by fishing pressure has resulted in increased densities of *Drupella*. Our data suggest that high numbers of *Drupella* are not correlated with low numbers of their potential major predators: the fish families lethrinidae and large labrids. Densities of these families on NW Cape were many times greater than in any GBR sites (table 3) and yet destructive populations of *Drupella* are not widespread on the GBR.

Densities of lethrinids on the northern Cairns Section reefs were greater than those on the southern reefs - the opposite of what might be expected if these fish were affecting *Drupella* numbers. A plot of lethrinid density against the percentage of *Drupella* damaged corals on the 50 reefs surveyed in 1991 showed a positive correlation (figure 2), indicating that removal of lethrinids by fishing pressure is unlikely to have been responsible for the high densities of *Drupella* observed on the Lizard Island area reefs.

**Figure 2. Relationship of *Drupella* Damage to Lethrinid Density.**




Our conclusion is that the problem is not as simplistic as some previous studies have suggested. We need a lot more information on the biology and ecology of *Drupella* before the reasons for the apparent population fluctuations can be understood.

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# INTERACTION BETWEEN CORAL ASSEMBLAGES AND CORALLIVOROUS GASTROPODS ON THE GREAT BARRIER REEF

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As a result of reports of recent outbreaks of drupellid gastropods there is a strong perception of the species as a serious destructive force on coral reefs. On the Great Barrier Reef recent survey work presents a different picture. On mid shelf reefs of the Northern Cairns Section corals damaged by corallivorous gastropods accounted for an average of 18.1% of damaged coral colonies (Ayling, 1991). A pilot survey conducted in this area at Lizard Island in June 1991 detected substantial numbers of *Drupella*, with *Drupella cornus* and *Drupella rugosa* co-occurring. These are members of a coral-associated assemblage of gastropods which includes herbivorous and possibly other corallivorous species.

The picture obtained from the Great Barrier Reef is one of chronic (persistent low-level) effects on the coral communities. The gastropod populations typically feed on corals of certain taxonomic groups (*Acropora* and Pocilloporidae) and growth forms (especially corymbose and bottlebrush), probably because these have closely packed branches which provide good shelter. This leads to the potential for gastropod predation to promote a significant shift in coral community dynamics by selectively removing certain species or growth forms.

The primary aim of this study is to obtain a quantitative overview of the role of these gastropod assemblages in reef community dynamics on the Great Barrier Reef. Initial emphasis is on the effect of *Drupella* populations on coral communities around the Lizard Island area. Initial pilot studies were aimed at understanding the nature of these assemblages, their taxonomy and dynamics and included the following objectives:

a) Collection of material for a taxonomic survey of the gastropod fauna associated with corals.

b) Examination of the distribution and abundance of gastropods on a local scale in relation to structural composition of the coral community.

c) Establishment of longer-term monitoring programs, using permanently marked sites.

Study sites are located at the north-eastern side of Lizard Island, sheltered from the south-east trade winds. All coral colonies found infested by corallivorous gastropods belonged to two groups of fast-growing species, the genus *Acropora* and the family Pocilloporidae. The coral communities consist of a high percentage of Acroporidae, but the Pocilloporidae are relatively rare. Amongst the *Acropora*, there is a high proportion of corymbose and bottlebrush growth forms and these are the growth forms that most commonly harbour corallivorous snails. Corymbose forms are defined as colonies that are composed of horizontal anastomosing branches and short vertical branchlets. Bottlebrush forms are defined as colonies that have short side branchlets projecting out from the main branch.

Line transects were used to characterize the coral communities. 5mx5m plots were used to measure the abundance and distribution of corallivorous gastropods. 10mx3m permanent sites have been photographed, mapped and marked.

In this report results are presented from initial pilot surveys of the gastropod and coral assemblage structures from selected study sites at Lizard Island. There are complex interactions involving a coral assemblage and a gastropod assemblage which require three

levels of description:

a) the characteristics of the coral community
b) the pattern of infestation of corals and
c) the characteristics of the gastropod assemblages.

Average infestation rates were 3-4% of the total coral colonies. This translates to 8-10% of the *Acropora* and Pocilloporidae.

# POPULATIONS, BEHAVIOUR AND EFFECTS OF *DRUPELLA CORNUS* ON THE NINGALOO REEF, WESTERN AUSTRALIA.

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## INTRODUCTION

Whelks of the genus *Drupella* are relatively common inhabitants of coral reefs throughout the Indo-Pacific. In Western Australia, *Drupella cornus* have been collected from coral reefs ranging from the Abrolhos Islands north to Broome (Museum of Western Australian collections), and are expected to occur on the less surveyed northern reefs. The earliest reported findings of *Drupella cornus* from the Ningaloo Reef region are those of Museum collections from Pt Quobba, just south of the reef, in 1960.

My initial observations of *Drupella* aggregations were made at Coral Bay in October 1985. Digitate corals were observed with up to 90 adult *Drupella* feeding on, or clustered around the colonies. Further observations in March 1986 found that those colonies initially under predation had been totally killed. Subsequent observations made by A. M. and A. L. Ayling in April 1987 of *Drupella* populations between Coral Bay and Osprey Bay, a distance of some 140 km, indicated the scope of the phenomena.

## POPULATIONS

Initial intensive investigations of *Drupella* biology commenced at Osprey Bay, a site proposed as a sanctuary zone within the Marine Park, and where previous research into fish populations and hydrology had already been undertaken. A series of eight 50m transects were laid on the back reef, perpendicular to the reef, and coral community structure recorded by line intersection. The area 25cm either side of the line was searched for *Drupella* . Since the hydrographic studies of the previous 12 months, the reef's coral communities had obviously degenerated, and live coral was generally less than 5% of the substrate, while live *Drupella* were scarce. On the one transect where dead shells were collected, 50 were found while only 1 live *Drupella* was recorded. Further studies therefore concentrated on regional assessments, and on specific studies centred at Coral Bay, where both *Drupella* and coral were still plentiful.

## REGIONAL ASSESSMENTS

A major regional survey of *Drupella* populations and reef community structure was undertaken in conjunction with CALM studies in February 1989. Transects 20m long and 0.5m wide were used, a search area of $10m^2$. A total of 34 transects were undertaken between Coral Bay and Neds Camp on the Ningaloo Reef, and a further 6 were done on Bundegi Reef, in Exmouth Gulf.

The Ningaloo sites generally showed significant signs of *Drupella* damage, as indicated by the amount of standing dead *Acropora*, their preferred host, on the

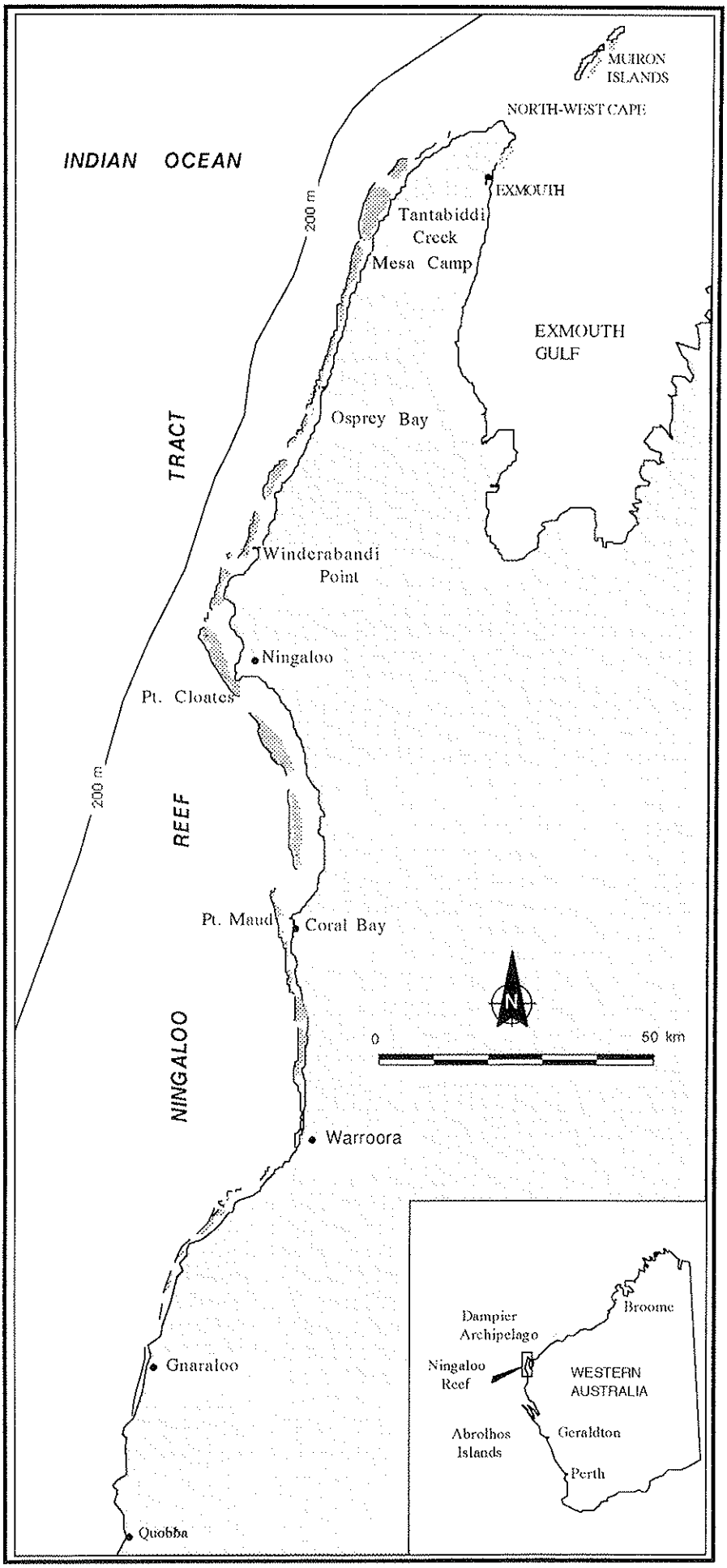


Figure 1. The Ningaloo Reef Tract of Western Australia

backreef. Dead standing *Acropora* accounted for up to 91% of the reef cover at some sites.

Earlier observations made by myself and A. M. and A. L. Ayling (1987) had indicated that the northern section of Ningaloo Reef had been most affected by *Drupella* with evidence of a southerly spread of abundant *Drupella* populations. For the broad scale of assessment of the backreef, the 17 sites surveyed south of Winderabandi Point to Coral Bay and the 17 transects north to Neds Camp were grouped and compared with the Bundegi Reef data.

The mean *Drupella* densities from the northern and Bundegi Reef areas were low, being 2.6 and 2.9 *Drupella* $m^{-2}$ respectively, while in the south the mean was 6.7 *Drupella* $m^{-2}$. Live coral cover was, however, very high at Bundegi averaging 76%, and considerably higher in the south, at about 35%, than to the north where the mean was less than 15%. When *Drupella* numbers were compared to live coral cover, both Ningaloo backreef densities were about 18 *Drupella* $m^{-2}$ live coral, while the Bundegi Reef densities were about 3.3 *Drupella* $m^{-2}$ live coral.

Population densities throughout the study area ranged from 0 to 24 *Drupella* $m^{-2}$, a figure comparable to the maximum densities of 20 *Drupella* $m^{-2}$ encountered by Fujioka and Yamazato (1983) at Okinawa, Japan.

Due to adverse weather conditions, only limited access could be gained to the forereef during the regional survey. However, during the course of research, observations of that habitat have been made. *Drupella* have been found in various abundances at all forereef sites examined, which supported coral, to a depth of 20m.

One aspect of the regional study was that recruits or juveniles were not located from Bundegi Reef and only low numbers were found on the Ningaloo Reef. Other research, in part aimed at locating juveniles, has also failed to find juveniles at Bundegi, while large numbers have been located from Ningaloo Reef areas.

## HABITATS

One aspect of *Drupella* biology crucial to studies on the Ningaloo Reef and not addressed within the literature, was the habitat selection of the recruit and juvenile stages of the whelk. The adults, although often cryptic, are usually located by the feeding scars they leave. On the Ningaloo Reef they are found individually, in small groups or in aggregations of up to 300 individuals. Feeding scars are most often found on corals of the genera *Acropora* and *Montipora* with less common occurrences on *Porites* and *Galaxea* and very rarely on members of the family Faviidae. These are the same coral genera preferred by *Drupella* on the coral reefs of Okinawa (Fujioka and Yamazato, 1983). Recruits also feed upon corals and were also located by feeding scars. These were distinctive, in that only a small number of branches were freshly scarred, while dead branches from earlier predation showed distinct weathering zonation over a small area, indicating a very slow rate of predation. Recruits ranged in total length from 2.2mm to about 22mm, and were almost exclusively found on digitate *Acropora* species. Whelks of this class size and of 28 to 40mm were generally found, but intermediate sized whelks were rare. One aim of the research done in 1990 was locating the missing size class between the sedentary juveniles and the large adults. These were again located by

distinctive feeding scars. Corals were found with scarring similar to that made by recruits, but with low or non-existent recruit populations. Searching of adjacent reef recesses and under rubble located aggregations of clean-shelled *Drupella*, ranging from about 20 to 30mm. *Drupella cornus* life strategy appears therefore, to involve a planktonic veliger stage (S. Turner, pers. comm.), followed by selective settlement in digitate corals where they live until outgrowth of the inter-branch space. They then form external aggregations still feeding upon the host coral before becoming free ranging adults.

## BEHAVIOUR

Experiments were conducted to appraise the social and feeding behaviours of adult *Drupella*. All the members of a feeding aggregation were collected and sexed to determine whether sexual bias was responsible for observed aggregations. Of the 197 individuals collected, 99 were female and 98 male. Other aggregations were collected, marked with enamel paint and placed on digitate corals, both undamaged and under predation, while pre-existing *Drupella* were removed. The marked *Drupella* failed to attack the pristine corals, but did feed on the damaged corals. Over 5 days the number of tagged *Drupella* on each of 6 heads under predation varied, and un-tagged whelks were also found.

The accidental breaking of another adjacent digitate coral resulted in massed *Drupella* on the broken piece the following morning, indicating an attraction to freshly damaged *Acropora*. Subsequently a damage experiment was undertaken on observed preferred and non-preferred coral species. Groups of 5 differently marked *Drupella* were placed 10, 20, 50 and 100cm from 6 pieces of broken *Acropora*. Two further groups of similarly marked snails were placed at the same distance from undamaged colonies as controls. Over 92% of the snails placed 10cm from the broken corals were found the following morning clustered upon them, while the numbers tailed off to about 12% of the animals placed 100cm from the broken corals. One such coral was found with 37 untagged *Drupella* clustered over it the next morning, which must have come from more than 1m away. The controls were untouched.

A complimentary experiment on non-preferred coral species was undertaken synchronously. Twenty-five marked snails were placed adjacent to 10 undamaged Faviid corals and to 10 corals of the same species damaged by a hammer and chisel. The following morning there were neither *Drupella* affixed to the corals nor were feeding scars apparent. The majority of the snails had not moved from their release site.

Further movement studies were undertaken on feeding aggregations. Whole aggregations of between 150 and 200 individuals were collected, painted and placed under a dead tabular *Acropora*, a live tabular *Acropora* under predation, and a live undamaged *Acropora*. Any pre-existing *Drupella* were removed. Overnight the majority of the tagged snails were within 30cm of the release point. Only at the undamaged coral was there any considerable movement, with 5 marked snails located on a broken piece of coral, with 32 unmarked *Drupella*, 2.1m from the release point. Over 7 days there was slow dispersion from all 3 groups. The coral under predation had a dynamic population of *Drupella* with increasingly unmarked numbers appearing, and tagged members found on other predated corals. Inspection of the 3 release points, 3 months later found the partially eaten coral completely killed and the undamaged coral still undamaged. Twenty-seven marked

*Drupella* were found still alive under the dead coral, apparently not having moved over the period.

Aggregations of *Drupella cornus* are, therefore dynamic assemblies apparently attracted to mucous or other secretions from damaged *Acropora*. These secretions from the polyps adjacent to the freshly eaten coral probably provide the stimulus to continue feeding along a front when *Drupella* usually shelter during the day.

A further behavioural mode which has been observed on the backreefs of Ningaloo Reef are of *Drupella* feeding on corals other than the preferred species and in exposed feeding positions during the day. These coral have included *Fungia* sp., *Goniastrea* sp., *Platygyra* sp., *Echinopora* sp., and *Stylophora* sp.. On these occasions *Drupella* are very obvious feeding both day and night contrary to reports from other locations. This behaviour has resulted in the extremely low live coral cover found between Neds Camp and Osprey Bay.

## EFFECTS

*Drupella* have had obvious and widespread effects upon the backreef communities on Ningaloo Reef. The northern third of the reef has had most of the *Acropora* species killed. The change in feeding mode from the preferred host species to almost all scleractinian corals is contrary to the hypothesis of Moyer et al. (1982) that the "weeding out" of fast-growing species provides space and enhances coral diversity. Some of the *Acropora hyacinthus* colonies eaten have exceeded 3m diameter and *Porites* of up to 1m diameter have been found dead, presumably from *Drupella* predation. Extrapolating from Simpson's (1988) studies of coral growth rates at the Dampier Archipelago, these corals would be in the order of 20 and 35 years old respectively.

The complete predation of all such tabular corals in some areas of the reef indicates that this phenomenon has not occurred in these areas over at least the last 20 years. The commencement of the out-break of *Drupella* on the Ningaloo Reef was not observed, and indications of recovery of the northern areas are now becoming apparent (K. Nardi, pers comm., 1989; K. Holborn, pers comm., 1991). However, evidence of secondary outbreaks have been found on other areas of the northern backreef. Digitate *Acropora* species appear to be among early reef colonisers, and also provide habitats for recruiting *Drupella*.

Large sections of the forereef of the Ningaloo Reef are presently without live or dead standing coral cover, while other similar areas have luxuriant coral cover. An earlier *Drupella* phenomenon could have caused these bare areas, as *Acanthaster planci* have been postulated as causing the bare substrates of Sailfish Reef in the Dampier Archipelago (Simpson and Grey, 1989).

Finally, whereas Bundegi Reef supports a population of very large adults with no juvenile aggregations, the Muiron Islands appear to support large numbers of juveniles and low numbers of adults. Cursory observations in April 1991 of the protected reefs of the Muiron Islands revealed large numbers of coral heads "infected" with *Drupella* recruits. One such coral head collected contained 120 recruits. This may be the beginning of an outbreak similar to that which has occurred on the Ningaloo Reef.

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# GROWTH RATES OF *DRUPELLA CORNUS*

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## BACKGROUND

The outbreak of *Drupella cornus* at Ningaloo Reef highlighted our ignorance of basic aspects of the population structure and dynamics of this species. As pointed out by Moran (1986) about the studies of the outbreaks of the crown-of-thorns starfish, field data on growth, mortality and longevity are critically important aspects which reveal the temporal scale of events in these populations; so far, these kinds of data exist neither for the crown-of-thorns starfish nor for *Drupella cornus*. In combination, rates of growth and of mortality give an indication of turnover in the population and therefore an understanding of how rapidly numbers might change.

As far as we can tell, there is no way of directly estimating the age of individual *Drupella cornus*. Like other gastropods, some *Drupella cornus* have growth check marks in the shells but they do not form a regular pattern which could be interpreted, nor is the interval of time between successive marks known. Therefore, we examined the rate of growth of individually marked *Drupella cornus* during a six-month interval during spring and summer at two sites on the backreef, one at Coral Bay where the snails were in an early stage of causing damage and the other at Yardie Creek where the snails had been damaging the corals for some time. Our aims were to determine how variable growth rates were within and between sites and to estimate the relationship between size and age.

## MARKING AND MEASURING

Our methods were simple and consisted of capturing, marking, and releasing individual *Drupella cornus* in August 1990, and recapturing them in February 1991 after 6 months. We were unable to randomly sample the population of snails because of the cryptic behaviour of the recruits and juveniles and their use of different microhabitats than the adults. Therefore, our samples of marked snails consisted of recruits and small juveniles removed from individual coral heads and adults collected from aggregations feeding on corals. We marked about 1500 snails (Table 1) using a 4-cornered file to make a deep groove in the heavy shells from the point where the outer lip inserted on the body whorl to the tip of the spire. As the snail grew, the lip advanced along the body whorl past the filed groove. We recaptured about one quarter of the snails at Coral Bay but only about one fifth at Yardie Creek (Table 1). On the recaptured snails, we measured the total length from tip of the spire to the notch of the anterior siphonal canal. The initial length of the snail when it was marked was measured from the tip of the spire to the initial location of the notch of the siphonal canal as judged from the position of the filed groove. This position was often very conspicuous because of a growth check mark associated with the filed groove. Table 2 shows that the presence of check marks was not confined to our marked snails and that the proportions of marked and unmarked snails that failed to grow were similar; we interpret this to indicate that our handling, marking and deployment of snails in the field did not drastically affect their growth.

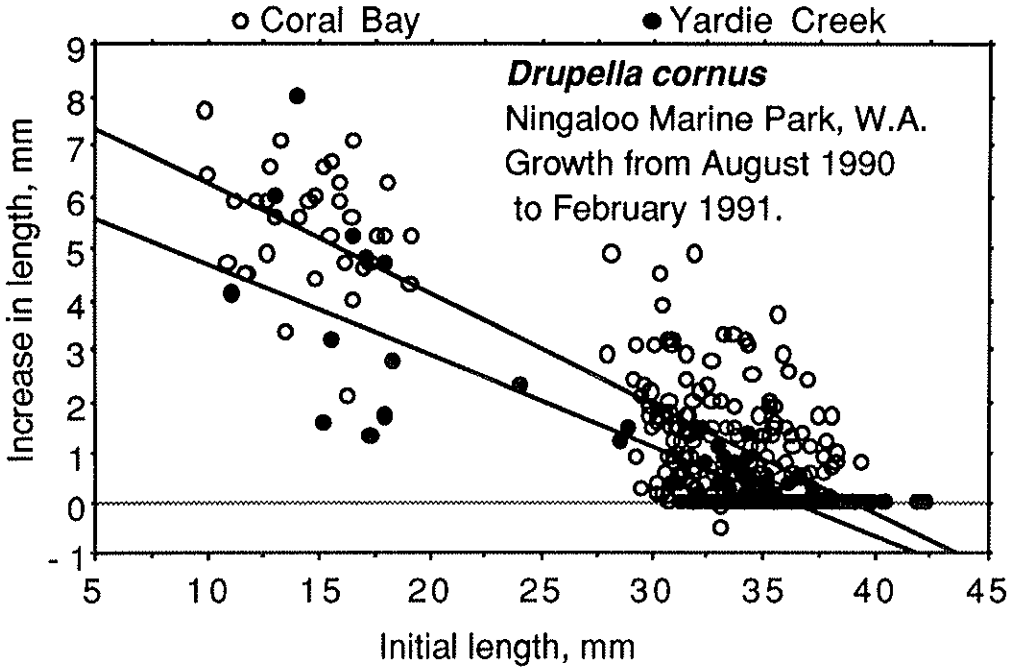


**FIGURE 1.** Relationship between increase in length (Y in in mm) (final length - initial length) and initial length (in mm) for *Drupella cornus* from Coral Bay ($Y = 8.4 - 0.22X$; $n = 205$; $r^2 = 0.70$) and from Yardie Creek ($Y = 6.5 - 0.18X$; $n = 114$; $r^2 = 0.73$).

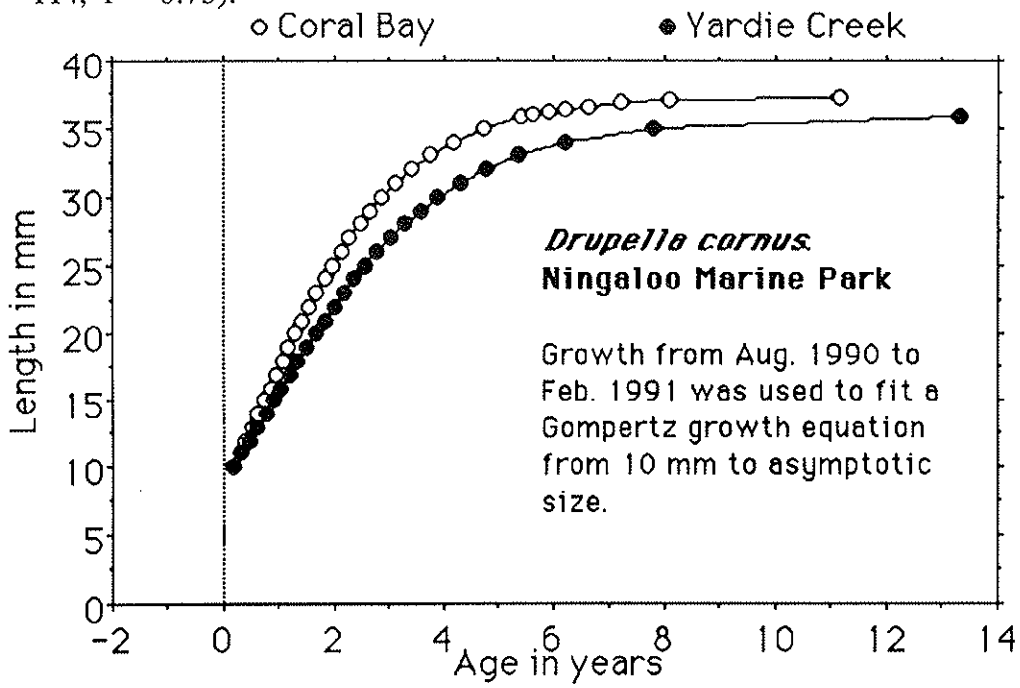


**FIGURE 2.** Gompertz growth equation ($S = S_\infty \exp[-\exp -b(t+t_0)]$) for *Drupella cornus*. Asymptotic sizes were 37.2 and 35.8 mm and b were -0.337 and -0.267 for Coral Bay and Yardie Creek respectively. Years are actually one half the number of 6-month time increments.

## GROWTH RATES

Figure 1 is a simple summary of the growth of 205 recaptured snails from Coral Bay and 114 from Yardie Creek; smaller snails increased in length more than larger ones, with size explaining about 70% of the variability in growth; snails larger than 40 mm failed to grow at all; and snails at Coral Bay grew faster than ones at Yardie Creek.

## GROWTH CURVE

We used the methods outlined in Kaufmann (1981) to determine which of several growth curves best described our data on *Drupella cornus*; by a small margin our data fitted a Gompertz equation ($S = S_{\infty} \exp[-\exp -b(t+t_0)]$) best. The estimates of the asymptotic lengths ($S_{\infty}$) were 37.2 mm at Coral Bay and 35.8 mm at Yardie Creek and the estimates of b were -0.337 and -0.267 respectively. We used these parameters to derive the size-at-age curves shown in Figure 2 for a snail starting at 10 mm long, the smallest initial size of snail that we recaptured. However, in order to present the ages in years we assumed that the growth rates from August to February were the same as from February to August and the ages in years are actually one half the number of 6 month intervals. If growth over summer to winter is slower than from autumn to summer, these ages will be underestimates. Figure 2 shows that snails would take almost 6 years to grow from 10 mm to their asymptotic size.

Our information about the early life of *Drupella cornus* is fragmentary and comes from the work of others. Dr. Stephanie Turner (pers. comm.) suggested that from egg to 15 mm snail might take about 1 year. Michael Forde (pers. comm.) observed 5 snails grow from 10 to 15 mm in 2 months in summer. Once the time taken to grow to 10 mm is known, the curves of Figure 2 can be shifted right along the x-axis by the appropriate amount.

## SURVIVORSHIP

We released marked snails on semi-isolated coral bommies and searched these and the immediate surroundings intensively to recapture marked snails. However, *Drupella cornus* can and do move about (Michael Forde pers. comm.), so it is unclear to what extent our rates of recapture (Table 1) reflect mortality or mortality plus emigration. If our 25% recovery of marked snails after 6 months were indicative of actual rates of survival, 1000 snails would be reduced to 1 in 2.5 years. This is a minimal estimate and seems excessively low in the light of our observations of apparently low abundance of recruits and juveniles, continued abundance of adult snails, and relatively low rate of growth We were unable to use information from changes in size frequency distributions to estimate rates of mortality because of our inability to obtain random samples of the population.

## CONCLUSIONS

In 6 months, 10 mm long *Drupella cornus* can increase in size by 5 to 6 mm but 30 mm long snails increase by only 1 to 2 mm; variability of rates of growth are associated with differences among individuals, initial length and sites. Based on a fit to a growth curve, *Drupella cornus* at Ningaloo Marine Park would take about 5 to 6 years to reach the mean size of adult snail. Our information about rates of mortality are insufficient for an accurate estimate turnover time in these populations. Nevertheless, based on modal sizes of adults, which cause conspicuous damage to the reef, the individuals causing the most damage are about 5 or 6 years old, with an expedted further life of an additional 2 years.

## ACKNOWLEDGEMENTS

We thank Mike Forde, Kelley Holborn, Alan Kendrick, and Stephen Chase for assistance in the field. Accommodation at the Milyering Visitors Centre, Cape Range National Park, was provided by Sue Osborne. Financial support was provided by the Australian Research Council, the Western Australian Department of Conservation and Land Management and the Department of Zoology.

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**TABLE 1.** Individually marked and recaptured *Drupella cornus* at two sites in Ningaloo Marine Park.

| | Coral Bay early infestation | | Yardie Creek established infestation | |
|---|---|---|---|---|
| | Marked in August | Recovered in February | Marked in August | Recovered in February |
| Adults | | | | |
| numbers | ~614 | 175 | 479 | 102 |
| percentage | | ~29 | | 21 |
| Juveniles: | | | | |
| numbers | 326 | 69 | 113 | 13 |
| percentage | | 21 | | 12 |
| Total: | | | | |
| numbers | ~940 | 244 | 592 | 115 |
| percentage | | ~26 | | 19 |

**TABLE 2.** Indication of lack of handling and marking effect on *Drupella cornus* at Coral Bay as judged by incidence of check marks associated with marking snails.

| | Numbers of: | | | |
|---|---|---|---|---|
| | Marked snails | | Unmarked snails | |
| | Check mark | No check mark | Check mark | No check mark |
| Recent growth | 85 | 29 | 21 | 5 |
| No recent growth | 0 | 22 | 0 | 37 |

Comparison of the two 2 x 2 contingency tables (Pielou 1974):

$\chi^2 = 3.3$, 1 df, $p = 0.07$

# THE GAMETOGENIC CYCLE OF *Drupella cornus* (RÖDING, 1798) AT NINGALOO AND ABROLHOS REEFS.

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## ABSTRACT

The gametogenesis of *Drupella cornus* populations from the Ningaloo Reef Tract and Houtman Abrolhos Islands, Western Australia was assessed from qualitative descriptions of the gross gonad condition, change in morphology of the penis and the histological examination of gonads of both sexes. Gametogenesis is continuous, with evidence of spermatogenesis in the males and the initial stages of oogenesis in the females, in all gonads sectioned. Mature gametes were present in both sexes throughout the study except for periods after spawning when the early and late recovery stages of gametogenesis predominated. Two synchronized spawning peaks were recorded at Coral Bay (Ningaloo Reef Tract), in late spring and early summer of 1989 and 1990. These spawning episodes correlated with a steep rise in seawater temperature. A population from the Houtman Abrolhos Islands to the south spawned at similar times but only 20% of specimens shed their gametes entirely. Reduced spawning episodes were also recorded sporadically throughout the study from both geographic locations, suggesting *Drupella cornus* populations will spawn more than once throughout an extended breeding season.

## INTRODUCTION

Since the early 1980's there has been a steady stream of literature documenting the feeding of the Muricid genus *Drupella* on scleractinian (stony) corals. *Drupella cornus* is carnivorous, feeding extensively but probably not exclusively on coral (Robertson, 1970). The feeding structure or radula in *Drupella cornus* is unlike that of other muricids as it is long, slender and equipped with denticulate lateral teeth armed with bifid tips (Arakawa, 1958). It is therefore well adapted to the removal of coral polyps from their surrounding protective calcareous theca. Removal of coral polyps leaves a bare, white patch of calcified skeleton (the feeding scar) which is soon invaded by filamentous algae.
The first population explosion of *Drupella spp* with associated widespread coral destruction was reported by Moyer, Emerson and Ross (1982), at Miyake-jima, Japan by *Drupella fragum* and at Mactan Island, Cebu in the Philippines by *Drupella rugosa*. Reports of damage to coral along the Ningaloo Reef Tract first began to appear in the early 1980's (Stoddart, 1989).

For *Drupella spp* outbreaks to occur, a favourable combination of environmental, exogenous and endogenous factors must have occurred at a stage during their life cycle causing them to reproduce successfully in large numbers. Therefore, knowledge of the reproductive cycles of *Drupella spp* will assist in understanding some of the reasons for these outbreaking populations.

## MATERIAL AND METHODS

Samples of the *Drupella cornus* were collected from two coral reef systems along the Western Australian coastline between June 1989 and November 1990.
Site 1 - Coral Bay situated towards the southern end of the Ningaloo Reef Tract, approximately 1100kms north of Perth. (23° 06S, 113° 30'E)
Site 2 - Big Rat Island situated in the Easter Group of the Houtman Abrolhos Islands, approximately 60kms west of Geraldton on Western Australia's mid-west coastline (28° 43's, 113° 47'E).

Monthly sampling was conducted during the day at both sites. Infested coral colonies were located and *Drupella cornus* were collected hapazardly from one or more coral colonies until a sample size of approximately 100 snails was obtained, for later processing.

The specimens were narcotised using 0.35M magnesium chloride until they no longer responded to touch, then measured to the nearest 0.1mm using Vernier callipers. Twelve females and five males were randomly selected, re-measured and cracked along the spire of the shell above the aperture, using a claw hammer.

The shell was eased open exposing the visceral mass of the animal and a portion of the distal end of the gonad and digestive gland tissue was excised, and preserved in formalin-seawater (10:90) for later histology. All specimens were examined in order to determine sex ratios in the populations. Any variation from a 1:1 sex ratio was tested using a chi-squared analysis, ($p>0.05$).

The criterion for determining the sex of *Drupella cornus* was the presence or absence of a penis. In males, morphological changes to the distal end of the penis were recorded from December 1989 to November 1990 for both sites.

Qualitative observations made on the gross gonad condition of usually 5 males and 12 females per month from each study site were described using the following criteria:

a) The visual percentage estimates of the volume occupied by the gonad in the coil of digestive gland/gonad tissue was assessed against the volume a ripe gonad would encompass; close to 50%

b) Gonad colouration in each sex.

c) The external appearance of the gonad was described as taut, granulated, streaked, containing hollow areas or hydrated and flaccid, depending on the stage of development of the gametogenic cycle.

d) A tentative staging for gametogenesis was assigned to each specimen to be compared with later histological staging.

The preserved gonad tissue was dehydrated in an alcohol series, embedded in paraffin wax and sectioned at 6 µm. The sections were routinely stained in Erlich's Haemotoxylin and Eosin.

Five stages were used to assess the gametogenic cycle for *Drupella cornus*. An early and late developmental stage, a ripe stage, partially spent and spent stages. These were adapted from Wells and Keesing (1989), used for the abalone *Haliotis roei*, modified from a method used by Wilson and Hodgkin (1967) for mytilid bivalves.

Surface seawater temperatures were taken opportunistically using a hand held thermometer. All seawater temperature data were collected from depths less than three metres.

## RESULTS

### Sex Ratios in Populations of *Drupella cornus*

*Drupella cornus* is gonochoristic in populations from the Ningaloo Reef Tract and Houtman Abrolhos Islands. During this study, no hermophrodites were identified and sex differentiation was evident in all animals examined. Departures from a 1:1 sex ratio were tested and showed no significant differences between months or sites (using chi-squared test, $p>0.05$).

### Gross Morphology of the Penis

The morphology of the penis in male *Drupella cornus* specimens changes during the reproductive cycle. The shaft of the penis has a distal swelling, known as the penial papilla (Dr W. Ponder, 1989 pers comm), which appeared to increase and decrease in size in relation to the development of the testis. Males were recorded as:

(i) Developed Penial Papillae (DPP)
(ii) Reduced Penial Papillae (RPP)
(iii) Absent Penial Papillae (APP)

### Gross Morphology of the Gonad Tissue

In general, the male gonads are an ochre/orange colour in the early/late developmental stages, a golden colour when ripe, orange/brown and tinged with green when partially spent and brown with visible white streaks when fully spent. The female gonads are a cream/pale yellow colour in the early/late developmental stages, cream when ripe, pale yellow and tinged with green when partially spent and brown with visible white streaks when fully spent.

Besides colour, the external appearance changes noticeably from being taut and exhibiting a distinct scalloped edge along the margin with the digestive gland in the ripe condition, while early/late stages have some hollow areas present and appear slightly granulated and streaked. The partially spent stage exhibits obvious hollow areas and is heavily granulated with visible streaking. The spent gonad is flaccid, watery and contains numerous white streaks which may run towards the digestive gland.
Visual estimates of the volume occupied by the gonad in the visceral coil were recorded. Ripe gonads occupied 35% to 50% of the coil volume, early/late and partially spent gonads varied between 20% and 35%, whilst the spent gonads were less than 20% of the total volume.

## TABLE 1

**Criteria Used to Assess Stages of the Gametogenic Cycle in Adult *Drupella cornus***

| STAGE | MALE | FEMALE |
|---|---|---|
| EARLY DEVELOPMENT | Large numbers of spermatogonia and spermatocytes present around tubules. Thin layer of spermatids and spermatozoa present. | All cell stages present with large portion of oogonia and primary oocytes. Some stalked oocytes present. |
| LATE DEVELOPMENT | Gonad lumen moderately packed with spermatozoa. Layers of spermatocytes and spermatids occupy up to half of the gonad lumen. | Moderate numbers of oogonia and primary oocytes still present. Large proportion of cells are stalked oocytes. Yolk granules and lipid droplets beginning to appear. |
| RIPE | Gonad lumen densely packed with spermatozoa. Few spermatocytes and spermatids present around tubules. | Gonad lumen densely packed with mature oocytes free from trabeculae. Very few stalked oocytes present. Obvious vitelline membrane enclosing densely packed yolk granules and lipid droplets in the cytoplasm. |
| PARTIALLY SPENT | Gonad lumen partially collapsed in places. Obvious spaces around tubules vacated by sperm. Other areas appear ripe, packed densely with spermatozoa. Spermatocytes and spermatids still present. | Gonad lumen partially collapsed with trabeculae folded. Obvious hollow areas between moderate numbers of mature oocytes present. Some areas remain densely packed. Yolk granules and lipid droplets still enclosed by the vitelline membrane. Very few oocytes present. |
| SPENT | Gonad lumen collapsed. Few or no spermatogonia or spermatocytes present. Some spermatozoa still present. | Gonad lumen collapsed with trabeculae folded. A few unspawned mature oocytes may be present. Oogonia and early oocytes beginning to appear. |

### Staging Sequences for the Gametogenic Cycle

The five stages used to assess the gametogenic cycle for both male and female *Drupella cornus*, are summarised in Table 1.

### The Gametogenic Cycle of *Drupella cornus*

Histological examination of the gonad sections of each sex of *Drupella cornus*, from both study sites, revealed a similar pattern of reproduction. Gametogenesis is continuous with spermatogenesis in the males and the initial stages of oogenesis in the females present in all gonad sections. Populations from Coral Bay displayed mature gametes nearly all year round except for late summer and early autumn. During this period, early and late developmental stages predominated. This suggested a late spring mating and subsequent spawning period. During late autumn and early winter 1990, individual specimens were recorded at different stages of the gametogenic cycle.

The Big Rat Island population recorded mature gametes in the gonad sections for both sexes throughout the study. The pattern of reproductive activity for the *Drupella cornus* population from Big Rat Island is not as clearly defined as for the Coral Bay population. The partially spent stage was evident in samples throughout the study with other stages being recorded for individuals, inconsistently.

### Seawater Temperature

Although seawater temperatures varied at both sites from year to year, both exhibited maximal temperatures between January and March (24°C-26°C) and minimal temperatures (18.9°C-21°C) in July through August .

## DISCUSSION

The techniques used to determine the gametogenic cycle for *Drupella cornus* were the histological assessment and gross gonad condition of males and females, and observations on the change in morphology of the penis.

Although no sexual dimorphism could be detected in *Drupella cornus* on the basis of shell shape and size, sexes could be distinguished easily because males bear a conspicuous penis. Sex ratio data for populations of *Drupella cornus* from the Ningaloo Reef Tract and the Houtman Abrolhos Islands showed that ratios of males:females was very close to 1:1. The distal end of the penis of *Drupella cornus* is known as the penial papilla. The penial papillae of males undergoes seasonal resorption after the breeding season and then re-develops. The penis itself is not shed.

The gametogenic cycle for *Drupella cornus* is continuous (Nardi 1991, in prep) and therefore unlike some molluscs where a resting stage occurs Tranter (1958), Wilson and Hodgkin (1967). After a spawning episode, eg. late spring and early summer in Coral Bay 1989, the gonads were in the early and late recovery stages of gametogenesis by late summer, with ripe and partially spent stages evident by mid autumn.

TABLE 2

**Male and Female Gonad Stages of *Drupella cornus* from Coral Bay - Ningaloo Reef Tract - August 1989 to November 1990**

| DATE | SAMPLE SIZE | EARLY DEV. | LATE DEV. | RIPE | PARTIALLY SPENT | SPENT |
|---|---|---|---|---|---|---|
| 04.08.89 | 4(11) | | | | 4(10) | |
| 12.09.89 | 6(11) | | | | 6(10) | ( 1) |
| 07.10.89 | 4(11) | | | | 1(10) | 3( 1) |
| 13.11.89 | 5(12) | | | | | 5(12) |
| 15.12.89 | 6(13) | | | | 1( 1) | 5(12) |
| 25.01.90 | - | - | - | - | | |
| 25.02.90 | 5(12) | 3(11) | 2( 1) | | | |
| 22.03.90 | 7(10) | 2( 7) | 4( 3) | | 1 | |
| 05.04.90 | 4(12) | | ( 4) | 4( 2) | ( 6) | |
| 10.05.90 | 5(12) | ( 3) | | | 5( 9) | |
| 21.06.90 | 5(12) | | | ( 7) | 5( 5) | |
| 26.07.90 | - | - | - | - | - | - |
| 14.08.90 | 5(12) | | | | 5(12) | |
| 13.09.90 | 5(12) | ( 1) | | ( 1) | 4(10) | 1 |
| 17.10.90 | 6(12) | ( 1) | | | 6(11) | |
| 15.11.90 | 5(12) | | | | 1( 6) | 4( 6) |

**Male and Female Gonad Stages of *Drupella cornus* from Big Rat Island - Houtman Abrolhos Islands - June 1989 to November 1990**

| DATE | SAMPLE SIZE | EARLY DEV. | LATE DEV. | RIPE | PARTIALLY SPENT | SPENT |
|---|---|---|---|---|---|---|
| 26.06.89 | 6(11) | ( 1) | ( 2) | 1 | 5( 8) | |
| 15.09.89 | 5(12) | | | | 5(11) | ( 1) |
| 17.10.89 | 5(13) | | | | 5(13) | |
| 26.11.89 | 5(12) | | ( 2) | | 5(10) | |
| 19.12.89 | 6(12) | | ( 4) | 4 | 2( 7) | ( 1) |
| 24.01.90 | 7(12) | | ( 2) | | 6(10) | 1 |
| 09.02.90 | 5(11) | | | 1 | 3(11) | 1 |
| 11.03.90 | 6(11) | ( 1) | | 2 | 4(10) | |
| 23.04.90 | 5(12) | | ( 9) | | 5( 3) | |
| 18.05.90 | 6(10) | | | 4( 6) | 2( 4) | |
| 20.06.90 | 5(11) | | | | 5(11) | |
| 05.08.90 | - | - | - | - | - | - |
| 08.09.90 | 5(12) | 3 | ( 1) | | 2( 8) | |
| 07.10.90 | 5(12) | | ( 2) | | 5(10) | |
| 02.11.90 | 5(12) | | | | 4(11) | 1( 1) |

Key: - no data collected
females in parentheses

The histological data and gross gonadal condition of both sexes, confirmed the presence of mature gametes from mid autumn to early summer for Coral Bay samples and throughout the year for the Big Rat Island population. The high proportion of individuals per sample from both study sites in the partially spent stage indicated a prolonged breeding season. Tavera and Faustina (1933) cited by Giese (1959), suggest that in warm seas the tendency is towards continuous breeding but with more intensive activity during some seasons.

Egg laying was not observed in the field. The histological evidence, gross gonadal condition and penial papillae data for Coral Bay populations in November and December, 1989 and November 1990 are consistent with the view that major spawning episodes for *Drupella cornus* occurred between 13 November and 15 December 1989 and commenced approximately 15 November 1990. Nearly all the specimens examined from both sexes were spent at this time in 1989 and either spent or in the latter phases of the partially spent stage in November 1990. These were the only two occasions from either study site that major spawning episodes were detected. Sporadic spawning episodes involving low numbers of snails in the population from Coral Bay occurred during the study. This pattern of sporadic spawning was also prevalent for the Big Rat Island population.

Seasonal fluctuations in seawater temperature have been correlated with the onset of gametogenesis and subsequent spawning episodes for marine invertebrates, eg. Wilson and Hodgkin (1967), Underwood (1974), Joll (1980) and Byrne (1990). A distinction has been drawn between the season of gametogenic activity and the much narrower season of actual spawning, Wilson and Hodgkin (1967). Seawater temperatures recorded from shallow reef areas may be subject to localised weather conditions. Simpson and Masini (1986) found that seawater temperatures in the lagoonal areas of the Ningaloo Reef Tract to be highly variable, spatially and temporally. This is also the case for the Houtman Abrolhos Islands, (A. Pearce 1990 pers. comm). A similar seawater temperature pattern was recorded for both geographical sites which are affected by the warm Leeuwin Current which flows south from the tropics, usually between the months of March and August each year. A sudden steep rise in seawater temperature appears to be a contributing factor towards the syncronized spawning peaks recorded at Coral Bay. The steady rise of seawater temperature recorded at Big Rat Island resulted in a reduced spawning episode during a similar period.

This raises the question of other environmental and exogenous factors being implicated in triggering spawning episodes for *Drupella cornus*. Some of these factors may include; resource partitioning, the occurrence of rough weather, phytoplankton availability, tidal range, and photoperiod. The possibility that pheremones or gametes in the water and endogenous factors may also play a role, Fox (1924), Himmelmann (1975), Minchen (1987), McEuen (1988), Pearse et al (1988), cited by Byrne (1990) should not be discounted.

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# THE EARLY LIFE HISTORY OF DRUPELLA CORNUS

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## INTRODUCTION.

Many marine invertebrates exhibit population outbreaks at irregular intervals (Coe, 1956). Although population fluctuations may arise because of varying mortality or survival at any of the stages in the life cycle of the organism concerned, Thorson (1950) suggested that these fluctuations may be primarily attributable to processes affecting the early life cycle stages. It is likely, therefore, that an understanding of the early life history of Drupella cornus will contribute towards an explanation for the recent increase in the numbers of this snail along Ningaloo Reef.

## MATERIALS AND METHODS.

### Larval Rearing.

Reproductively mature D. cornus are maintained in covered 2.5L plastic aquaria. Each aquarium is supplied with aeration and running, non-recirculated seawater at 20°-26°C, which approximates the temperatures recorded in the natural habitat at the time the snails are collected.

Larvae are reared either in the laboratory or using in situ larval culturing equipment anchored on the reef at Coral Bay (see Olson, 1985, 1987; Olson et al., 1987, 1988). In the laboratory, larvae are reared in 4ml or 3000ml containers at an average density of 1-2 larvae/ml, and are fed a 1:1:1 mixture of Isochrysis galbana (Tahitian strain), Chaetoceros gracilis and Pavlova lutheri at a final concentration of 10,000 cells/ml, in 105um filtered natural seawater.

Larvae are tested for metamorphic competence by exposing them to small pieces of live coral species, coralline algae encrusted dead coral, or a solution of 20mM KCl which has been shown to induce metamorphosis in a number of marine invertebrates (Yool et al., 1986).

### The spatial and temporal distribution of juvenile D. cornus along Ningaloo Reef.

Live coral colonies were collected from reef flat and back reef edge sites at Bundegi Reef, Neds Camp, Bloodwood, and Coral Bay in June/July 1990, October/November 1990 and January/February 1991, and examined for the presence of juvenile (<1cm shell length) D. cornus.

RESULTS.

Copulation and spawning have been observed in both the laboratory and the field. In the laboratory, egg capsules are attached to the sides, floors or lids of the aquaria, or inside the outlet pipes. In the field, D. cornus have been observed spawning capsules within small crevices in the rock substratum and dead bases of corals, and in shells. It is not known whether the females are gregarious. Gregarious spawning behaviour has, however, been documented for a number of muricids. There is no evidence of capsule protection by D. cornus, as the females move away from the spawn mass once a period of spawning has been completed.

Under laboratory conditions, spawning, which predominantly occurs at night-time, often continues for several days - one female was observed to produce a total of 115 capsules over 16 days. The capsules from each spawning event are generally deposited in discrete, close-packed clusters. The capsules are kidney-shaped in cross-section with distinct concave and convex sides, and average 2.8x3.2x1.8mm in size (n=25). The egg capsules are orientated so that the convex side of one capsule is aligned with, and in close proximity to, the concave side of the adjacent capsule. Capsules are generally attached directly to the substratum by a flattened base, and joined to adjacent capsules by a confluent basal membrane. There is no evidence of a basal attachment stalk. Each capsule has a sealed, oval exit pore (0.7x0.5mm in size), situated approximately one-third of the way down the concave side of the capsule, through which the veligers leave the capsule at hatching.

Each capsule contains between 300-1400 embryos (n=50). The eggs are spherical, pale creamy white in colour, 170µm in diameter (n=200), and embedded in a gel-like substance within the capsules. The general patterns of cleavage, gastrulation and early development of the veligers is essentially the same as described for other indirectly developing prosobranch gastropods (e.g. D'Asaro, 1966; Kumé & Dan, 1968). D. cornus does not appear to produce food or nurse eggs, and there is no evidence that cannibalism occurs within the capsules spawned in the laboratory. The development time appears to be temperature dependent - veligers hatch in 27-37 days at 21.5°C and in 20-29 days at 25.5°C. Newly hatched veligers have dextrally coiled shells, with $1^1/_3$-$1^1/_2$ whorls, and an average size of 265x215µm (n=75). They are characterised by the presence of a well developed bilobed, ciliated velum, a foot and an operculum, prominent eye-spots, and a darkly pigmented anal gland. Characteristic features of the shell include the larval beak, which is a prolongation of the outer edge of the shell aperture extending over the shell opening, between the velar lobes. There is a concentration of red/brown pigmentation at the growing edge of the shell, in the region of the larval beak and the developing shell columella. Feeding and shell growth appear to begin very soon after hatching (see Figure 1). A distinct demarcation is evident between the shell growth that occurs

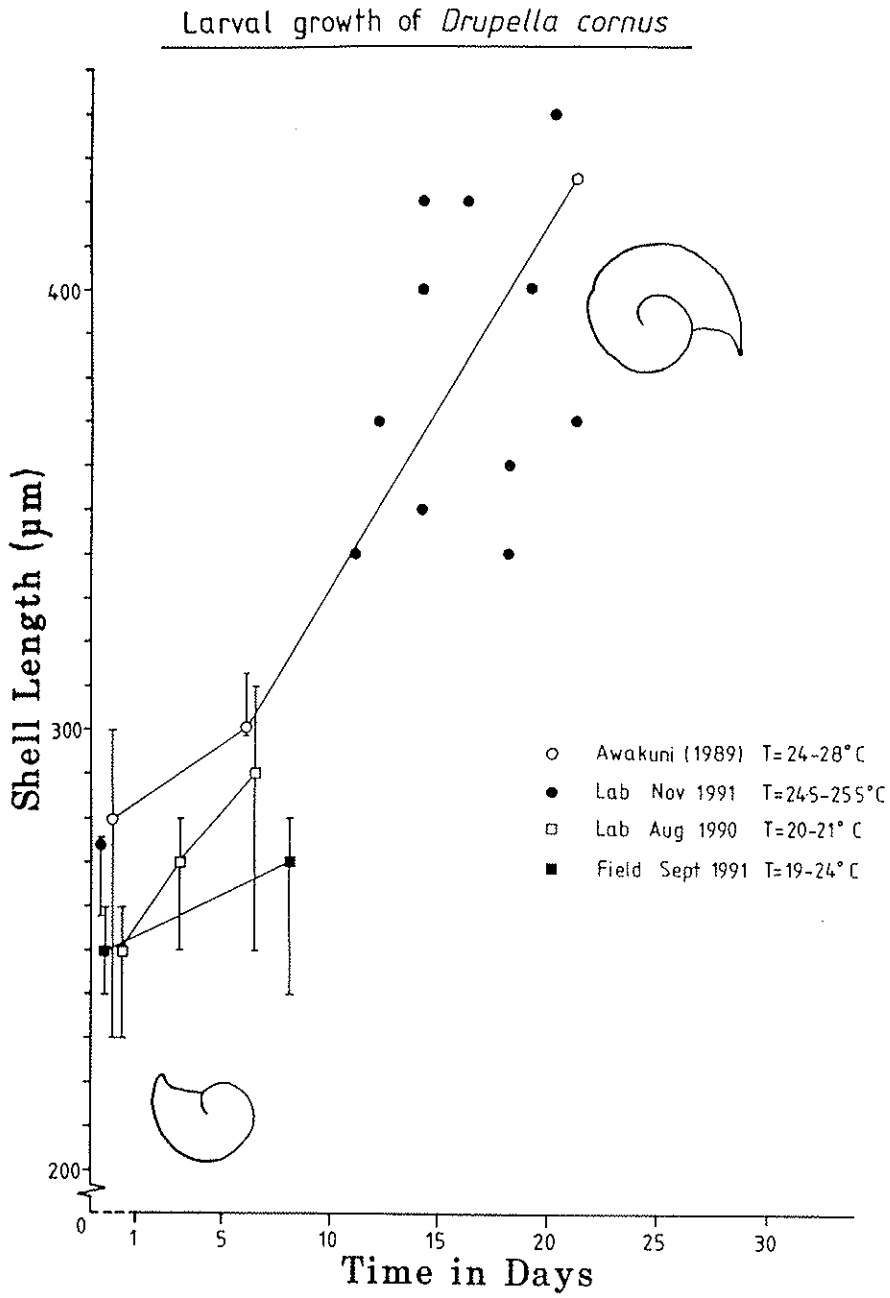


FIGURE 1 : Larval growth of Drupella cornus veligers in the laboratory (August 1990 and November 1991), the field (September 1991) and in a study by Awakuni (1989). Mean shell length and range in length are shown.

August 1990 : larvae reared in 3 litre-volume chambers. (n=11 at hatching; n=9 at 4 days after hatching; n=16 at 7 days after hatching).
November 1991 : larvae reared in 4 ml-volume chambers. (n=10 at hatching; each point thereafter represents the size of individual larvae).
September 1991 : larvae reared in 3 litre-volume chambers. (n=7 at hatching and at 9 days after hatching).
Awakuni (1989) : larvae reared in 2 litre-volume beakers (n=23 at hatching; n=17 at 7 days after hatching; n=1 at 22 days after hatching).

within the egg capsule before hatching (the protoconch I), and the shell that is grown during the planktonic larval period after hatching (the protoconch II).

The individual fecundity of female D. cornus may be high. Considerable numbers of capsules may be deposited, each containing several hundred small eggs, all of which appear to develop into veliger larvae. The life-time fecundity of D. cornus will be determined by their adult life-span, the age at which sexual maturity is attained, and the frequency of spawning.

Larvae from laboratory or field-spawned capsules reared in situ at Coral Bay all died within a few days of hatching. There was no evidence of larval feeding and growth was either absent or reduced (see Figure 1). The low survivorship of larvae in the field experiments may have arisen because the larvae were food-limited. Chlorophyll a values for water samples collected adjacent to the larval rearing equipment were very low - 0.09µg Chl a/l (range = 0-0.3µg Chl a/l) (Lucas (1982) cited average values of 0.2-0.5µg Chl a/l for West Pacific coral reefs). It is known from the laboratory studies that phytoplankton are a suitable food source for D. cornus larvae, but this does not necessarily imply that this is the only food source utilised. Bacteria, dissolved organic compounds, detritus etc. are all potential food sources. However, none of these are quantified by chlorophyll a measurements. There is considerable controversy over the extent to which planktonic larvae may be food limited in the wild (e.g. Lucas, 1982; Paulay et al., 1985; Bell, 1987; Olson, 1987; Olson et al., 1987; Uchida & Nomura, 1987).

No larvae have so far been successfully reared through to settlement. However, a relatively extended planktonic life (probably of several weeks) can be inferred since hatching occurs at an early veliger stage, when the shell has approximately $1^1/_2$ whorls, and the protoconchs of juvenile D. cornus collected in the field are between 3-4 whorls in size, and between 0.7-0.95mm (n=47) in length. The well defined apertural beak is also characteristic of most long-term planktotrophic prosobranch veligers (D'Asaro, 1966).

Juvenile D. cornus were recorded at all the sites examined, with the exception of Bundegi Reef, and in greatest numbers at the back reef edge site at Coral Bay (mean density = $6/m^2$, range = $0-33/m^2$). There was a peak in the abundance of very small D. cornus (0.1-0.7mm shell length) in February 1991, with lower numbers being recorded in November 1990. In June 1990 slightly larger juveniles (0.4-1.3mm) were more prevalent. Nardi (1991), in a study of the gametogenic cycle of D. cornus, recorded a peak in the spawning activity of the Coral Bay population in late spring/early summer of 1989 and 1990. The temporal variation in the size distributions of the juveniles recorded in the present study may reflect this seasonal reproductive activity. 84% of all the juveniles recorded in the present study were found on the corymbose/caespitose growth forms of Acropora, in particular on A. verweyi, A. nasuta and

A. cerealis (coral identification confirmed by Dr J.E.N. Veron). Lower numbers were found on other growth forms of Acropora, and other coral species (e.g. Pocillopora damicornis, Seriatopora caliendrum, Cyphastrea serailia, Montipora species). Juveniles were also generally, but not exclusively, found in coral colonies with larger D. cornus individuals present. Whether this is the result of an aggregative settlement behaviour in response to the presence of adult conspecifics per se, or whether the larvae are settling in response to damaged coral resulting from the feeding activities of the adults, is as yet undetermined.

DISCUSSION.

The presence of a relatively long-term (>1 week) free-swimming planktonic veliger stage in the life cycle of D. cornus is in contrast to many other species of muricid gastropods which undergo direct development (see Spight, 1975, 1976). Thorson (1950) has suggested that species with long planktonic larval lives (2 weeks - 3 months) are the most likely to undergo large fluctuations in numbers from year to year, because of the vagaries of a planktonic existence. Species with relatively constant populations have either very short planktonic stages (hours or days) in their life cycles, or undergo direct development. Results from the laboratory observations indicate that female D. cornus are potentially very fecund, thus, small changes in the rate of mortality of the early stages may be reflected in relatively large changes in the absolute numbers of recruits into the post-settlement adult populations. Because of the low survivorship of the planktonic stages of many marine invertebrates, subtle shifts in the balance of factors affecting larval development and survival can have a significant effect on the numbers recruiting into the population, and thus on the dynamics of the population as a whole. Mortalities occurring during the planktonic larval stages in the life cycle of many species may represent a major source of mortality for the population as a whole (Thorson, 1950). Many factors (including the abundance and quality of the available food resources, water temperature, the availability of suitable settlement surfaces, transport by currents away from recruitment sites, and predation) may directly affect larval development, growth and survival, and may also have a significant indirect effect by prolonging larval residence time in the plankton with concomitant effects on their survival. Occasionally optimal conditions for survival may occur, resulting in increased recruitment into the adult population. However, any explanation of the D. cornus outbreaks at Ningaloo must also be able to account for the fact that there are no reports of outbreaks of other reef invertebrates with planktonic stages in their life cycles.

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# POPULATION GENETICS OF *DRUPELLA CORNUS*

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## BACKGROUND

The nature of recruitment and the connections among populations are fundamental to the spatial scale of local populations. The scope for recruitment over large distances is especially great for marine species with planktotrophic larvae, which means that local populations are not necessarily independent. On the other hand, the potential for dispersal is not always realized, resulting in substantial local autonomy of populations.

The outbreak of *Drupella cornus* at Ningaloo Reef highlighted our ignorance of basic aspects of the population structure of this species. The history of the outbreak seems to have been one of spreading outwards from the initial area of infestation. This pattern suggests local recruitment, rather than extensive mixing of planktonic larvae. In addition, the outbreak has been largely confined to the backreef areas, whereas adjacent forereef and lagoonal habitats appear to have been much less affected, again raising questions about the extent of mixing of populations even over short distances.

Genetical analyses provide useful approaches to the study of connectedness and the structure of populations, and are especially important in situations in which more direct approaches are difficult. Planktonic dispersal presents such a situation, as marking of larvae is generally impossible. In addition, the different stages of the outbreak of *D. cornus* at Ningaloo Reef, along with the differences between habitats, could favour genetic divergence among local populations.

With this background, we have examined aspects of the population genetics of *D. cornus* in Western Australia. Based on an electrophoretic study of enzyme variation at 10 polymorphic loci, we have attempted to answer three major questions. First, are recruits produced locally or are they from distant sources? Mixing over large distances will cause relative genetic homogeneity among areas, whereas isolation will allow genetic differences to accumulate among local populations. Second, are there detectable genetic differences between expanding and declining populations, or between populations from different habitats? Third, is it possible that some of the variation in the effects of *Drupella* is due to the presence of more than one species?

## ADULT POPULATIONS

Within Ningaloo Reef, samples were collected from 9 sites between Bundegi in the north and Coral Bay in the south, a distance of approximately 180 km. Each sample included 70 to 82 adults. Three of these sites were taken from the forereef, backreef, and lagoon habitats within 2.5 km of each other near Yardie Creek. Of the other 6 sites, 5 were lagoonal (Bundegi, Tantabiddi, Mesa, Osprey Bay, Coral Bay) and 1 was backreef (Fraser Island). These samples represented stages of

infestation ranging from none (Bundegi), through early (Tantabiddi, Osprey Bay, Yardie forereef, Coral Bay), and established (Yardie lagoon and backreef, Fraser Island), to old (Mesa). To place the genetic variation at Ningaloo Reef into its broader geographic context, samples were also obtained from Dampier in the north and the Abrolhos Islands (Beacon Island and Rat Island) in the south, spanning an overall distance of 1170 km.

None of the genetic comparisons suggested that there might be more than one species of *Drupella* in our samples. The overall picture of allelic frequencies at the 10 polymorphic loci is one of small differences among sites (Figure 1). The degree of subdivision can be quantified as the standardized variance in allelic frequencies, $F_{ST}$ (Weir and Cockerham 1984), which is the proportion of allelic variation due to differences among populations. The summary in Table 1 makes three important points. First, there are statistically significant differences in the genetic composition of the samples. Second, this variation is not a function of distance between samples except at a scale of a few km. Inclusion of the samples from outside Ningaloo Reef does not increase the range of genetic divergence, and sets of allelic frequencies do not characterize particular geographic sets of populations (Figure 1). Within Ningaloo Reef, the variation was not associated with habitat or stage of infestation. Third, regardless of their statistical significance, the variations in allelic frequencies are small.

The overall $F_{ST}$ of 0.008 is typical of species with extensive genetic mixing. On the Western Australian coast, for example, $F_{ST}$ is 0.003 for the limpet *Siphonaria jeanae* over distances up to 500km and 0.013 for the urchin *Echinometra mathaei* over distances of 1300 km (Johnson and Black 1984; Watts et al. 1990). For both of those species, significant variation occurs on a scale of a few km, with little additional variation over distances of hundreds of km. Furthermore, genetic differences among cohorts of recruits in *S. jeanae* and *E. mathaei* within sites are as great as the differences among populations hundreds of km apart. From these comparisons, it is clear that the small genetic differences observed among populations of *D. cornus* do not imply isolation of local populations. Nevertheless, the observed differences could reflect recent changes due to localized recruitment. Interpretation of these small differences requires analysis of the genetic composition of recruits in the local populations.

## RECRUITS

If the genetic differences observed in the adults reflect real subdivision of the populations, recruits at different sites should show the same differences as the adults (or possibly greater differences if divergence is recent). Our attempts to make such comparisons proved unsuccessful, however, because of the complexity of patterns of recruitment.

Recruits of *D. cornus* are generally found in aggregations on small digitate corals, and not on the tabular corals preferred by the adults. There are marked differences in size-frequency distributions of recruits on different coral heads, suggesting that settlement of aggregates of recruits occurs on different heads at different times.

We examined the genotypes of 484 recruits from a total of 22 groups on individual coral heads from 5 sites: Tantabiddi (2 groups); Yardie forereef (4); Yardie backreef (7); Yardie lagoon (5); and Fraser Island (4). Only groups with at least

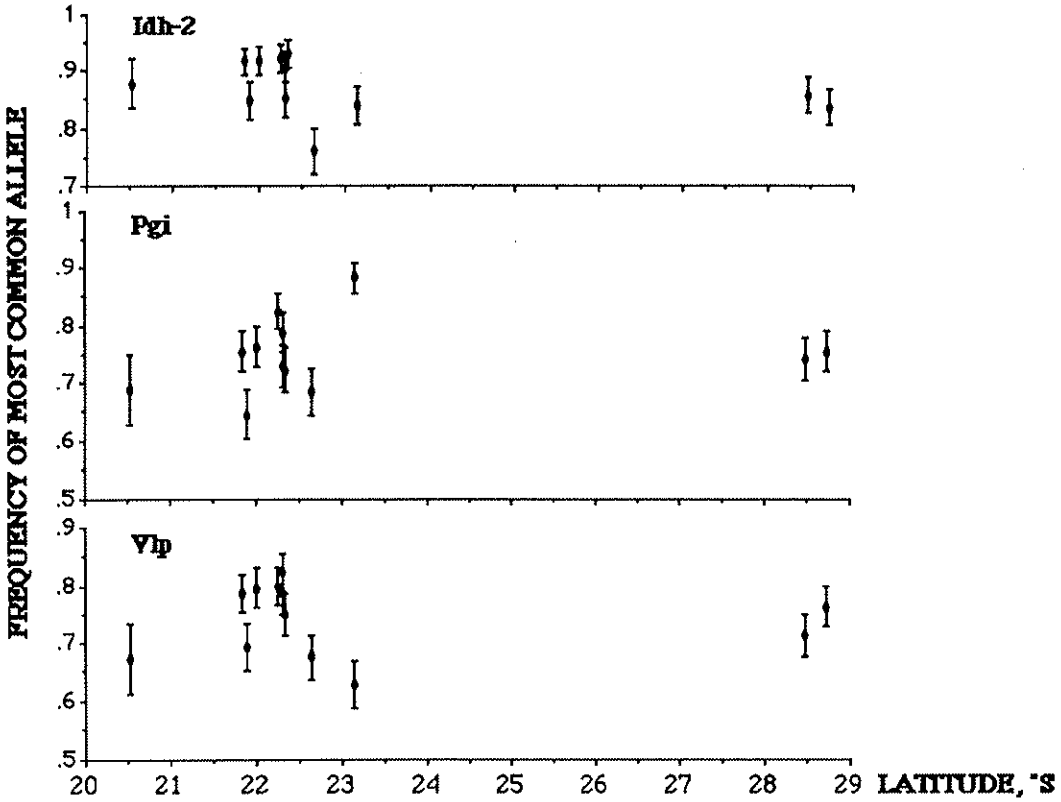


FIGURE 1. Frequencies of the most common allele at each of the 3 loci which show significant variation among 11 samples of adult Drupella cornus. Vertical lines = S.E.

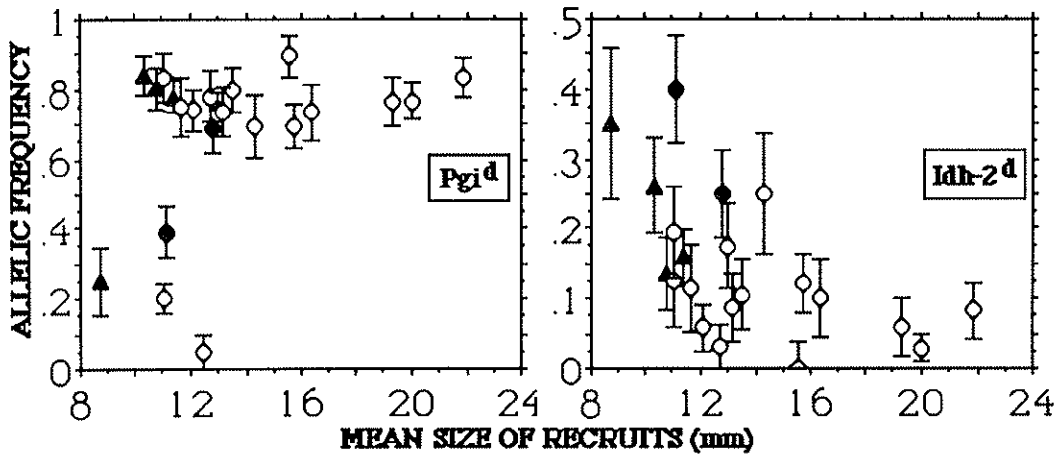


FIGURE 2. Allelic frequencies for Pgi and Idh-2 in recruits from individual coral heads. Circles = Yardie. Dots = Tantabiddi. Triangles = Fraser. Vertical lines = S.E.

10 individuals were included.

Genetic differences among these groups of recruits were much larger than those found among the adult populations. Among all 22 groups, the average $F_{ST}$ was 0.0499, nearly 7 times as large as that for the adults (Table 1). The differences in allelic frequencies among the recruits do not parallel the geographic patterns found for the adults. Instead, heterogeneity among the recruits occurs on a very local scale. The average $F_{ST}$ among groups of recruits from the same site was 0.0441. Thus, more than 90% of the genetic differences among groups of recruits is within sites. This heterogeneity makes it difficult to compare recruits with adults, because the group on an individual coral head, and not the individual recruit, is the appropriate unit of replication.

Of the 10 loci examined, *Idh-2* and *Pgi* contribute most to the heterogeneity among the recruits. In each case, the genetic differences are associated with the mean size of recruits (Figure 2). The $Pgi^d$ allele occurs at a frequency of at least 0.69 in all but 4 groups, in which the frequency is 0.05 to 0.39. All 4 of the peculiar groups had relatively small recruits. Similarly, at the *Idh-2* locus, the frequency of $Idh\text{-}2^d$ is negatively correlated with mean size of recruits. These patterns are local, rather than geographical, indicating that they result from patterns of recruitment at a local scale. This finding suggests that groups of larvae produced by few adults may retain a high degree of cohesion.

## CONCLUSIONS

The genetic similarities among populations of *D. cornus* are consistent with extensive gene flow. There is no evidence of different genetic groups related to habitat, stage of infestation, or geography over more than 1100 km. It appears that extensive dispersal is the norm for *D. cornus*, but this does not necessarily mean that there is no local recruitment associated with the outbreak. If, for example, infestations were associated with a switch to predominantly local recruitment, it would take several generations for genetic differences to accumulate.

Tests of such subtle genetic changes would require comparisons of different cohorts. The fine-scale genetic heterogeneity of the recruits, however, greatly complicates such comparisons. That heterogeneity is not evidence for subdivision of the populations. Instead, it indicates that the process of recruitment is patchy, and very likely involves settlement of aggregated groups of larvae.

## ACKNOWLEDGEMENTS

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**TABLE 1.** Levels of genetic subdivision, measured as $F_{ST}$, among populations of adult *Drupella cornus* and among groups of recruits at different spatial scales.

| | Spatial Scale of Comparisons of Adults | | | Recruits |
|---|---|---|---|---|
| Locus | 1170 km All Sites | 180 km Ningaloo Reef | 2.5 km Local Habitats | 90 km |
| *Idh-1* | 0.013 | 0.003 | 0.000 | 0.149[n] |
| *Idh-2* | 0.015*** | 0.019*** | 0.009 | 0.053* |
| *Mdh-1* | 0.002 | 0.001 | 0.004 | 0.024[n] |
| *Mdh-2* | 0.002 | 0.002 | 0.006 | 0.026 |
| *Mdh-3* | 0.005 | 0.005 | 0.006 | 0.007 |
| *Mpi* | 0.006 | 0.007 | 0.007 | 0.035 |
| *Pgi* | 0.012** | 0.016*** | 0.003 | 0.190*** |
| *Pgm-1* | 0.001 | 0.002 | 0.001 | 0.019 |
| *Pgm-2* | 0.007 | 0.007 | 0.011* | 0.025 |
| *Vlp* | 0.011* | 0.014*** | 0.002 | 0.014 |
| Mean | 0.0075 | 0.0074 | 0.0048 | 0.0499 |
| ±S.E. | 0.0016 | 0.0021 | 0.0011 | 0.0008 |

*P<0.05; **P<0.01; ***P<0.001; [n]Statistical test not possible.

# PROPOSAL FOR THE STUDY OF THE DEMOGRAPHY AND POPULATION GENETICS OF FIVE SPECIES OF CORAL ON NINGALOO REEF, WESTERN AUSTRALIA.

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## Background

The Ningaloo Reef was declared a marine park in 1987 because of its rich coral communities. In the late 1970's and early 1980's its beauty rivalled that of the Great Barrier Reef. However, since about 1988, much of Ningaloo has been devastated by *Drupella cornus*. Coral cover in the back-reef zone (i.e. the shallow reef flats adjacent to the sandy lagoon) has been reduced by more than 75% in two thirds of the reef (Stoddart, 1989). The areas most badly affected by the outbreaks in 1988/89 were Ned's Camp, Mesa Camp, Osprey Bay, Sandy Bay and Winderabandi Point. Since then less than 1% live coral cover has been observed in these places.

Populations or species which are devastated by catastrophic disturbances may be replaced in time through recolonisation. Recolonisation and regeneration of an area depend upon a sufficient supply of viable recruits. The rates of recruitment, survivorship and growth will determine the time taken for the population to restore its pre-disturbance structure. These will depend upon a number of factors:

i. Mode and timing of reproduction of prospective colonising species.
ii. Mode of fertilisation of parents.
iii. Dispersal capability of prospective recruits.
iv. Survival and growth to sexual maturity of recruits.
v. The degree of connectedness of populations supplying the recruits.

These factors will vary for different species of coral so that the rates of recolonisation should continuously differ among species. For example, corals utilise a diverse set of reproductive options, both sexual and asexual. Consequently, mode of reproduction is a major determinant of the spatial and temporal limits of a species' niche. This project will, therefore, focus on which types of corals are best at recolonising decimated areas and which life history characteristics are most important in producing them.

## Aims

In an attempt to understand the process of recovery following devastation by *Drupella cornus*, I plan to study the life history, patterns of recruitment, and genetic subdivision of corals at Ningaloo Reef. The specific aims of the project are:

i. To examine the patterns of recruitment in five species of corals over two years. Seasonality of recruitment, species composition and abundance over time, will be investigated.
ii. To quantify the growth and mortality rates of these young corals using demographic techniques. This will enable estimates to be made regarding the length of the recovery process.

iii. To establish an electrophoretic key, using gene markers, whereby recruits can be identified at a few days of age. The identification of recruits before six months of age has previously been impossible using current taxonomic criteria.
iv. To quantify levels and patterns of genotypic diversity for the same five species over the length of Ningaloo Reef. This information will be used to test independently the importance of mode of reproduction (sexual versus asexual) and mode of fertilisation (internal versus external). It will also provide estimates of gene flow and thus information on the actual dispersal of species.
v. To examine the relationships between life-history characteristics and levels of genetic variation.

Major aspects of the life histories (recruitment rates, growth, mortality and mode of reproduction) and population genetics will be quantified for *Acropora hyacinthus, A. digitifera, Montipora aequituberculata, Pocillopora damicornis and Seriatopora hystrix*. These species were chosen on their following characteristics:-

i. Ease of identification (L. Marsh 1991 pers. comm.)
ii. Different growth forms were chosen because adult *D. cornus* prefer tabular corals (e.g., *A. hyacinthus* and *M. aequituberculata*) whilst the juveniles prefer the digitate corals (e.g. *A. digitifera*) (Forde and Simpson, 1989).
iii. Different modes of reproduction - *Pocillopora damicornis* is able to produce asexual planulae (Stoddart, 1983) whilst the remaining species almost exclusively reproduce sexually.
iv. Different modes of fertilisation - *Acropora hyacinthus, A. digitifera* and *Montipora aequituberculata* broadcast their gametes whilst *P. damicornis* and *S. hystrix* brood their larvae (Ayre and Resing, 1986; Stoddart 1983; Wallace, 1985; Wallace and Bull, 1981).

## Investigation of coral life histories

Sixty-four terracotta settling tiles (150mm x 150mm), bolted onto steel racks, have been set up at six sites on the back reef of Ningaloo. These tiles were chosen because of the abundance of spat they attract and because they are cheap, readily available, have minimal preparation and provide a standard surface easily replicated within and between experiments (Harriott and Fisk, 1987; C. Simpson pers. comm.). The experimental design is a nested orthogonal design (Figure 1).

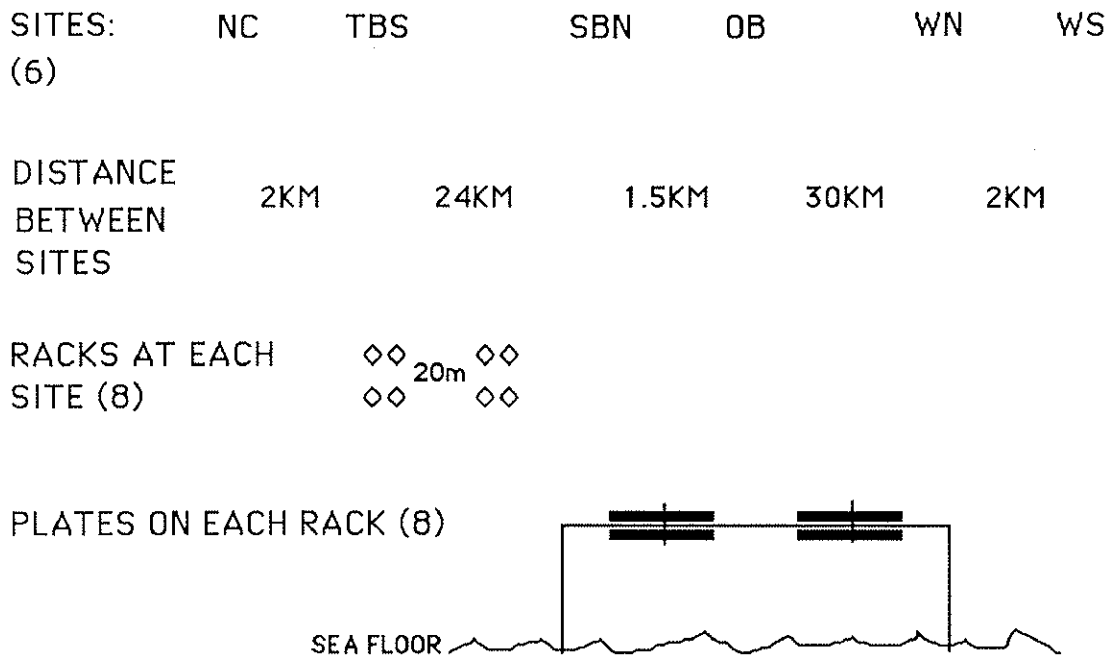


Figure I. Design and Placement of Settlement Racks and Tiles.
NC=Ned's Camp; TBS=T-Bone Sth; SBN=Sandy Bay Nth; OB=Osprey Bay; WN=Winderabandi Nth; WS=Winderabandi Sth.

At each site, four racks of 4 pairs of plates have been placed approximately 20 cm above the substrate. Plates are in pairs since it allows the coral recruits a choice of orientation for their attachment. Previous studies have shown that recruits prefer the underside of plates (Wallace and Bull, 1981; C. Simpson 1991 pers. comm.) or the gap between pairs of plates (Harriott and Fisk, 1987). This design was chosen to allow for the detection of different scales of recruitment. All six sites share the following characteristics:-

i. They share similar histories of devastation by *D. cornus*.
ii. Coral cover at each site is as close to zero as possible.
iii. Sites are geographically placed so as to provide information on spatial recruitment differences.

In addition to these six sites, settling plates have been placed at an extra three sites (viz: Tantabiddi, Coral Bay and Pelican Point) which have above 40% live coral cover. This is to asses the potential pool of recruits from areas which have not been devastated by *D. cornus*.

Growth and mortality of the recruits will be quantified using photogrametry whereby stereopairs of photographs will be taken with infra-red film. The stereopairs of photographs allow for the assessment of the change in volume of the young corals over time, whilst the infra-red film distinguishes between live and dead tissue.

The identification of a sub-sample of the recruits will be carried out using gene markers. Settling plates will be harvested at intervals of four months, the assumption being that the proportions of the different species settling are the same for each plate.

## Investigation of coral population genetics

ADULTS

It might be expected that corals with either a) highly competent larve (e.g., *Pocillopora damicornis* ; Richmond, 1987) and/or b) larvae which are able to raft (e.g., *Seriatopora hystrix* ; Veron, 1986) would disperse widely and thus have high levels of gene flow. However, laboratory observations have shown that many coral species have larvae which are competent to settle within hours of release (Ayre 1991 pers. comm.). In addition, pilot studies on the genetic structure of *Seriatopora hystrix* have shown that little gene flow occurs within central regions of the Great Barrier Reef (Ayre and Dufty, 1991). The degree of connectivity between populations will influence the rate of recovery from disturbances and species with more discrete or isolated populations will take longer to recover from perturbations. Accordingly, the genetic structure of corals will be compared both locally and over the length of Ningaloo Reef.

Corals will be collected from sites which range from a few kilometres apart to hundreds of kilometres apart. Samples will be obtained initially from six backreef sites and where possible, near to the sites where the settling plates have been set up. Samples from between 50 and 100 coral heads of each species from each site will be required for the genetic analyses on the adults (1800-3600 individuals in total). Gel electrophoresis, of between 6 and 9 polymorphic loci will be used to quantify the genetic structure and estimate the connectedness of populations. This technique was chosen because it is simple and quick to use and is cost efficient.

RECRUITS

For species which have planktonic larvae and a sedentary adult stage the genetic consequences are quite different. Planktonic dispersal of larvae promotes gene exchange among populations that may otherwise be isolated whereas a sedentary adult stage is subject to localised selection which may produce genetic differences among local populations. Thus, planktonic dispersal, although causing uniformity on a large scale, can give rise to fine-scale genetic patchiness. Such fine-scale genetic variation could result from either post-settlement selection or spatial heterogeneity in the genetic composition of the supply of recruits (Johnson and Black, 1982). Thus, the genetic composition of the recruits, and not the adults, will have the major influence on the genetic composition of local populations (Watts *et al.* 1990). This influence will be ephemeral in the case of short-lived species (e.g., *Siphonaria jeanae*, Johnson and Black, 1984) or persistent for long-lived species (e.g., *Echinometra mathaei*, Watts *et al.*, 1990) or species with long generation times. It is possible to separate the effects of post-settlement selection from variation in genotypes of recruits by studying recruits over more than one generation and comparing them to the adult population (Johnson and Black, 1984). In addition, by studying the population genetic structure of adults only, it is impossible to determine whether differences detected among populations have arisen because of a lack of gene flow between isolated populations or due to selection pressures despite high levels of gene flow. Evolutionarily, these scenarios have different consequences. Differences in populations arising despite high levels

of gene flow are a result of localized adaptation and are not accumulated over time. Changes in the genetic composition of adults reflect single-generation effects of selection and recruitment (Johnson and Black, 1984). In contrast, genetic heterogeneity without gene flow allows for the accumulation of genetic differences over time and is passed on from one generation to the next. Thus it is my intention to quantify the genetic variation of recruits over a number of generations and compare their population genetic structure with that of the adult populations for each of the six species of corals.

However, before this can be done, an electrophoretic key for the recruits has to be established so that different species can be identified using gene markers. It is not possible to identify recruits to species level before at least six months of age, using current taxonomic criteria. This electrophoretic key is also necessary for the quantification of the growth and mortality of the young recruits that settle on the tiles.

## Acknowledgements

This project is funded jointly by Mobil Exploration and Producing Australia and the University of Western Australia. Thanks go to my supervisor, Dr Michael S Johnson, for his support and for encouraging stimulating discussions regarding the development of the project. Conservation and Land Management has also provided support, in particular Dr Sue Osborne. This project would be impossible without field assistants. Thanks go to Dr Stephanie Turner, Alan Roberts, Craig Skepper and Carolyn Garavanta.

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# A PRELIMINARY SUMMARY OF THE EFFECTS OF HAND REMOVAL OF *DRUPELLA CORNUS* ON NINGALOO REEF

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## INTRODUCTION

*Drupella cornus* infestations, result in coral mortality on a massive scale. As a consequence, the causes and management of these population explosions have been the subjects of debate. With millions of tourist dollars in jeopardy, natural resource managers are placed under public pressure to control the infestations. However, the absence of scientific understanding precludes the implementation of well informed management decisions. From a managers viewpoint, there are two basic questions which must be answered; 1) is the plague a natural phenomenon? and, 2) how can the plague be controlled? As a consequence of any delay in the availability of a scientifically verified answer to question 1), natural resource managers must decide whether to manage all of the affected area as though it were a natural phenomenon, manage all of the affected area as though it were a human induced phenomenon, or divide the affected area and implement appropriate management regimes under both scenarios. Even if subsequent research indicates the plague to be part of a natural cycle, there may still be small sections of reef where some form of control of the plague species might be justified. In addition, awaiting a conclusive answer to question 1) could considerably delay the development of control measures. It is therefore appropriate to investigate control techniques before question 1) is fully answered.

Holborn (1990), recommended that management of *Drupella* is likely to be most effective at the larval and recruitment stages. However, efforts so far have concentrated on adult populations. Japanese workers have been removing aggregated snails by using air-lift pumps and trials are in progress to test the effectiveness of baited traps (Yamaguchi, pers. comm. University of the Ryukyus).

The control techniques which have so far been investigated are labour intensive and therefore expensive to implement. One method of minimizing cost is to enlist volunteer assistance. With increasingly restricted budgets, management agencies are under pressure to reduce expenditure and a trend towards increased volunteer involvement is emerging.

This report summarizes the results of an experiment to investigate the effectiveness of hand removal as a technique for controlling *Drupella cornus* in a small area of Ningaloo Reef. The effectiveness of volunteer involvement is also considered.

## METHODS

An experimental area was selected offshore from the township of Coral Bay on the back reef section of Ningaloo Reef where a *Drupella cornus* infestation was in full progress. The area was characterized by mostly hard substrate on which branching and plate *Acroporas* predominated but large numbers of snails were active causing obvious coral scaring and mortality.

The corners of two plots, each 25 metres by 25 metres were marked permanently with star irons. Both plots were orientated approximately parallel to the reef crest. One was treated as the experimental area while the other was used as a control. Care was taken to select experimental and control plots with minimal large scale substrate variation.

When each survey was carried out, marker buoys were attached to the corners and ropes were stretched between corner marks to define the plot boundaries underwater. The centre point of each boundary rope was marked to facilitate the placement of line transects, and a tape measure was then run between the rope marks across the centres of each plot. This was done twice, once in a north/south orientation and then in an east/west direction. The tape was used to estimate substrate type and live coral cover using a line intercept technique. In this way, a total transect length of 50 metres (2 x 25m) was sampled in both the experimental and control plots.

Within the experimental plot, ropes were used to delimit a grid of 25 squares each five metres square. Tension was maintained on the ropes which were also secured at each pre-marked cross over point to ensure the formation of geometrically regular grid squares. Numbered strands of surveyors tape were secured near the centre of each square to facilitate square identification.

Within the control area, between three and five grid squares were selected and defined using ropes. Grid squares through which the transects passed were avoided and of the remaining 16 squares, an effort was made to minimize the selection of squares which had been sampled during previous surveys. Marked strands of surveyors tape were secured within each selected grid square to facilitate square identification.

Divers using SCUBA apparatus spent 20 minutes removing all the *Drupella* that they could find within an allocated square. Snails were placed in labelled calico specimen bags until processing. Grid squares were searched repeatedly by at least two and usually by three or sometimes more divers during each survey. Collections were conducted over two or three day periods. Following the first survey, work on the experimental area was divided to ensure that all repeat searches within individual grid squares were completed during a single day.

A effort was made to minimize coral damage during searches. Divers were instructed to secure all gauges and other equipment appendages to prevent damage

to the substrate. They were also requested not to enter the control grid unless involved in control collections and to approach their allocated squares along the shortest route from the edge of the plots. In addition, divers were instructed to avoid supporting themselves on live coral and they were told not to break coral in order to collect snails which were beyond their reach.

Surveys were conducted on the following dates: 1) 30th June and 1st July 1990; 2) 21st and 22nd August 1990; 3) 16th and 17th February 1991; and 4) 9th March1991. The intervals between surveys were seven weeks, seven months and three weeks respectively. During the first three surveys, line transects were carried out and all experimental grid squares and selected squares in the control area were searched for *Drupella*. In March, survey work was limited to searches within the control grid plus an incomplete search of the experimental plot.

A total of 32 divers were involved during all four surveys. Most were volunteers with a wide range of abilities and experience. Each diver was assigned to one of four categories of experience namely: novice, recreation diver, scientific diver, or *Drupella* diver, according to their previous diving history. However, care was taken to ensure that approximately half of the divers involved in each survey had either worked with *Drupella* before or were experienced scientific divers.

Collected snails were processed as follows; the date, diver's name, grid number and search number were recorded together with the numbers of live and dead snails from each sample bag. Maximum shell length was measured using vernier callipers. Random samples of 100 shells were measured from each grid square during the first two surveys, but during the February 1991 and March 1991 surveys, most shells were measured with samples of each individuals collection being kept separate to enable comparisons of diver abilities.

Control samples were usually processed on board a boat and returned immediately to the grid square from which they were collected. In March 1991 however, logistic constraints necessitated their processing on shore. Animals were kept overnight immersed in the waters of Coral Bay and they did not appear to suffer any ill effects before being returned to the control area the following morning. Snails collected from the experimental area were not returned.

The numbers of recovered snails were used to determine both the abilities of divers and estimates of snail density using the model:

$$F_i = (T - \sum_{j=1}^{i=i} F_j) \times D_i \qquad - (1)$$

where

$F_i$ is the number of snails found on the ith dive;
T is the total number of snails in the search area; and
$D_i$ is the ability of the diver to find snails.

Equation (1) was log-transformed and solved using linear least-squares estimation. This procedure achieved two aims. First, bias introduced by varying abilities of

divers to find snails was determined, thus enabling and estimate to be made of the number of *Drupella* snails initially present.

## RESULTS AND DISCUSSION

### Substrate cover

The amount of sea bed covered by any substrate type was calculated as the sum of the distances between the boundaries of that substrate type along the line transect. Distances were converted to percentage cover by dividing by the total transect length (25 metres).

| | CONTROL | | EXPERIMENTAL | |
|---|---|---|---|---|
| DATE | N-S | E-W | N-S | E-W |
| June | 27.0 (25.1) | 13.3 (10.2) | 39.2 (35.5) | 36.3 (33.2) |
| August | 28.7 (20.8) | 31.5 (26.0) | 45.3 (41.6) | 45.9 (43.6) |
| February | 24.8 (20.5) | 13.5 (10.9) | 39.4 (37.7) | 41.8 (40.2) |

TABLE 1. Percentages of live coral cover along four 25 metre transects during June 1990, August 1990 and February 1991. Figures in brackets are the percentages of live *Acroporas* while figures outside brackets are the percentages of all live coral.

*Acropora* was the dominant genus within both experimental and control plots (Table 1). Throughout the sampling period, the experimental area contained a higher percentage of living coral than the control area.

There is no evidence of any trend toward changes of live coral cover as a result of the experiment. However, as corals grow slowly, the detection of any consistent trend after just seven and a half months would be unlikely.

Transect data from August indicated that there was more live coral at this time. This could not have represented a real change in coral cover since July because of slow coral growth. There was a strong surge while these data were being gathered and it is likely that the tape was bent onto nearby substrate. Such variation within the data will necessitate the continuation of this experiment for some time if real changes in coral cover are to be detected. To minimize variation with subsequent surveys, effort should be made to work only in ideal underwater conditions and to increase the replication of transects.

### Diver abilities

The index used to describe the ability of each diver is equivalent to the proportion of snails within a sample area which that diver would be likely to find. Diver ability index values ranged from 15.3354% to 89.6484% with an overall mean value of 47.2% (Table 2). More experienced divers were better at finding *Drupella* snails than novice and recreational divers. Novice and recreational divers generally found less than half of the snails within a plot.

| EXPERIENCE CATEGORY | NUMBER OF DIVERS | MEAN INDEX ABILITY VALUE | STANDARD DEVIATION | NO. DIVES REQUIRED TO REMOVE 75% SNAILS |
|---|---|---|---|---|
| Novice | 7 | 27.71 | 7.94 | 5 |
| Recreation | 11 | 42.39 | 16.12 | 3 |
| Scientific | 6 | 57.10 | 17.17 | 2 |
| *Drupella* | 8 | 63.32 | 16.24 | 2 |

TABLE 2. Diver experience categories and search abilities. The ability index values are equivalent to the percentages of snails which a diver would remove from an experimental area. The right hand column represents the amount of effort required by each diver category to undertake the same task.

Based on the mean abilities of each group, the minimum number of dives required for divers within each experience category to remove 75 percent of the snails within the experimental area was calculated. On average, it takes novice divers more than twice the effort of either scientific or *Drupella* divers to complete the same task. In addition, novice divers are relatively clumsy underwater and cause more coral damage than experienced divers. As a result, scientists need to be selective when recruiting divers to undertake even simple tasks such as the removal of snails, and the enlisting of inexperienced volunteer divers is a false economy.

The ability of each diver to find juvenile snails was investigated by correlating the proportion of small snails (less than 2.95cm) found by each diver with their search ability indices. A small correlation ($R^2 = 0.16$) was detected. This implies that divers who were good at finding snails were more likely to be good at finding juvenile snails than divers with low ability index values.

**Variations in snail numbers**

Model-corrected estimates of snail numbers were compared between dates, and between control and experimental grids using contrasts following analysis of variance. As this experiment is as yet incomplete, we do not present the ANOVA results here. The following summarizes our interim results: Variation among the numbers of snails within control and experimental plots on different survey dates are summarized in figure one. No significant differences were detected between control samples from the first and second surveys, nor between the combined control data from the first and second survey and the experimental data from the first survey. No significant difference was found between control samples from the third and fourth surveys. However, the number of snails within the experimental plot on the third survey was significantly different from the combined control samples from surveys three and four. The repeated hand removal of snails had therefore resulted in a reduction in snail numbers within the experimental plot.

Although the intervals between surveys ranged from three weeks to seven months, by careful examination of the data we found no evidence to suggest that there were more snails towards the edges of the experimental grid than in the centre. It can

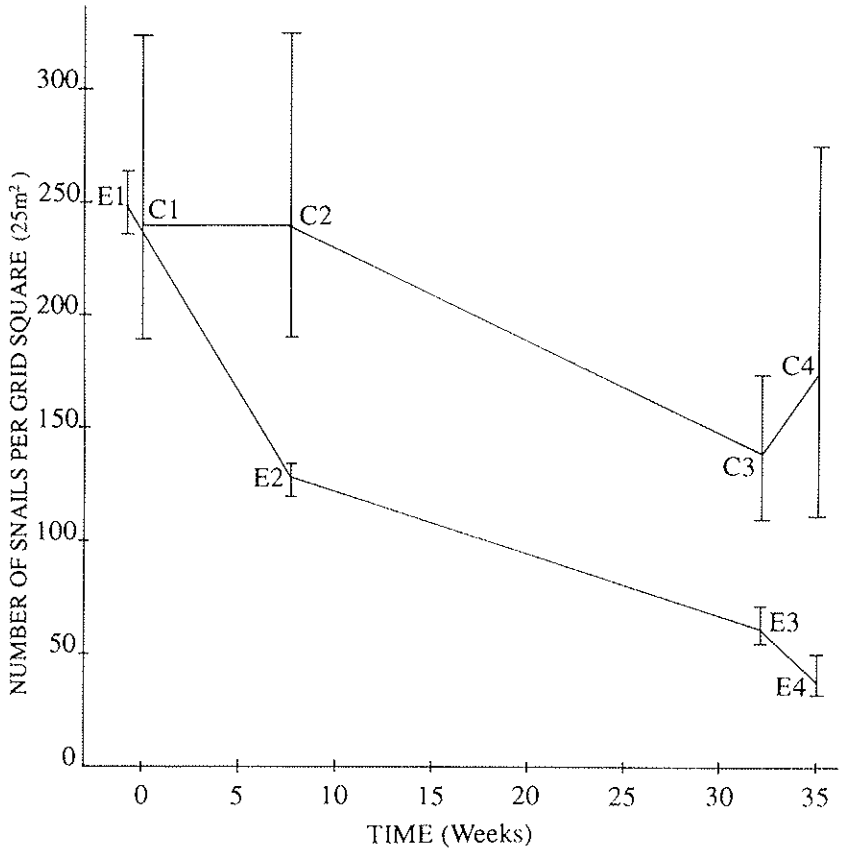


FIGURE 1. Mean number (± s.e.) of *Drupella* snails estimated to be present in experimental (E) and control (C) grids between date (week 0) and date (week 35).

therefore be concluded that there was no significant external recolonization as a result of migration by adjacent adult *Drupella*. This is in contrast to previous experiments which indicated that *Drupella* can move up to three metres in 24 hours, and may be attracted towards damaged coral (Forde pers. comm. University of Western Australia). The snails used in these movement studies had been removed from the water to facilitate marking and this disturbance may have influenced their behaviour.

There was a tendancy for the numbers of snails within an individual grid square to remain either high or low in subsequent surveys. All three paired comparisons between consecutive dates showed a significant trend. This probably signifies the patchy distribution of prefered *Drupella* habitat, and a concomitant clustered distribution for *Drupella* snails.

**Variations in snail sizes**

Variations in *Drupella* snail sizes were analyzed using contrasts following ANOVA. As this experiment is as yet incomplete, we do not present the ANOVA results here. Interim results are summarized in figure two where variations among snail sizes within control and experimental plots during different surveys are presented. No significant differences were detected between control samples during

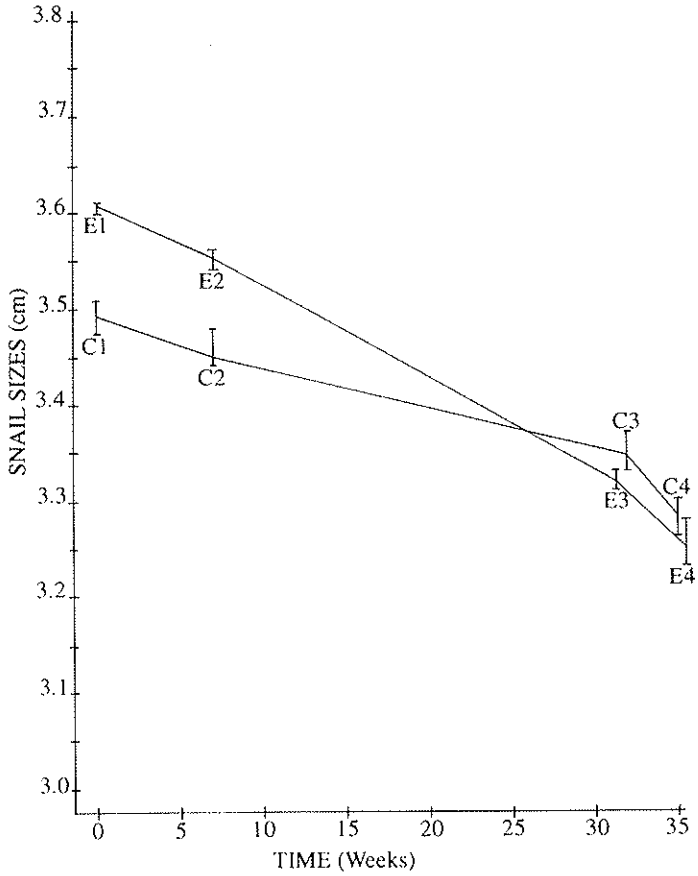


FIGURE 2. Mean maximum shell length (± s.e.) of *Drupella* snails collected on experimental (E) and control (C) grids between date (week 0) and date (week 35).

surveys one and two. However, snails in the experimental plot during the first survey were significantly larger than those within the control plot. A significant difference was detected between the sizes of snails in the control plot during surveys three and four, but this may be explained by the exceptional ability of one diver to find juvenile snails. Snail sizes within the experimental plot on the third survey were not significantly different from the snail sizes from the control plot at the same time.

During the course of the experiment, snail sizes fell in both the experimental and control plots. However, the decrease in sizes within the experimental plot was greater than within the control plot. This could indicate that recruitment into the experimental area was primarily from larval settlement and growth rather than from adults immigrating from surrounding substrate. However, this hypothesis is clouded by the reduction in size of animals outside the experimental plot.

## CONCLUSION

- Early results of experimental hand removal of *Drupella* snails indicate that a significant reduction in snail numbers can be achieved within a limited area. This decline appears to persist over a 35 week period.
- Hand removal appears to selectively reduce the numbers of large snails and

there is no evidence of significant recolonization by adult snails.
- Novice divers are of limited use in snail removal exercises.

## REFERENCE

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# SUMMARY OF *DRUPELLA* WORKSHOP

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## INTRODUCTION

Barry Wilson presented a challenge by asking, Is research necessary? His enthusiastic affirmative answer was an appeal to establish for *Drupella cornus* at Ningaloo Marine Park what were the range, frequency and amplitude of events associated with this coral-eating gastropod. Furthermore, he warned us about speculations and suggested that we approach three sets of questions. First, what is happening now to *Drupella cornus* and the corals at Ningaloo Marine Park, will the reef regrow, and will it have the same species of corals? Second, will the the dramatic increase in abundance of *Drupella cornus* happen again and if so how often? Finally, can we prevent future outbreaks of *Drupella cornus,* and if so, should we? The rest of the papers and discussions did not answer the questions but went some way to providing some of the information to show the way ahead. This account is our attempt to summarize what the workshop revealed about *Drupella cornus*; the names in parentheses refer to the authors of presentations at the workshop.

## TAXONOMY

The taxonomic status of *Drupella cornus* is not straightforward, but Wilson is convinced that there are only two species of coral-eating muricid in the genus *Drupella* involved in the outbreaks damaging corals in Australia: *Drupella cornus*, involved in the damage to Ningaloo Marine Park (Wilson, Forde, Osborne), and *Drupella rugosa,* which is most abundant on Queensland reefs (Ayling). Furthermore, the genetical analyses (Johnson, Holborn and Black) indicated that there was only one species involved in the outbreak population at Ningaloo Marine Park.

## THE OUTBREAKS

*Drupella cornus* have long been known to occur in Western Australia as far south as the Abrolhos Islands, but what is new is their great abundance in some local areas (Wilson). At Ningaloo Marine Park, the back reef is the habitat where these snails have been destroying the coral. The history of this outbreak of *Drupella cornus* at Ningaloo Marine Park seems to be as follows (Osborne). There was no record of massive aggregations of snails in the records of expediditons by the W.A. Museum in 1976 to 1980. First reports were from Coral Bay in 1982 and by 1985 "infestation" was a term used about the snails. Surveys in 1987 (Ayling and Ayling 1987), 1989 (CALM) and 1991 (Osborne) have revealed an abundance of *Drupella cornus* all along Ningaloo Marine Park, with densities in 1991 highest in the south at Pelican Point and Coral Bay, in the centre at Lefroy Bay and in the north at Tantabiddi. Furthermore, the occurrence of abundant *Drupella cornus* seems to be spreading.

Large numbers of recruits in digitate corals, but no adults, were observed at the Muiron Islands in April 1991 (Forde) and could be interpreted to be the beginning of a new outbreak. At even greater diatances from Ningaloo, increases in abundance of *Drupella* have been observed in permanent quadrats between Serrurier Island and Mermaid Sound (Hilliard). Although some of the quadrats

were established before *Drupella cornus* was recognized as a pest, others were set up more recently, and for all quadrats in recent years special attention has been made to recording the snail and the kind of damage it produces. At the Lowendahl Islands there has been a steady increase in the number of sites where *Drupella cornus* occurs, in their abundance at each site and in the amount of damaged coral at the site (30% decrease in coral in 6 months) (Hilliard).

In northern Queensland, damage by *Drupella* is now also recognized as being widespread (Ayling). A survey of almost 100 reefs, revealed a gradient in the proportion of the coral colonies being grazed from 26% at 14° to <1% at 20°S. Although both species of *Drupella* occurred at these sites, *D. rugosa* was the most abundant (Ayling), a pattern also found at Lizard Island (Cumming) where 8 to 10% of the acroporans and pocilloporans were infested with snails.

## LIFE HISTORY OF *DRUPELLA CORNUS* AT NINGALOO REEF

An amalgamation of several studies provides a reasonably clear picture of the life history of *Drupella cornus* at Ningaloo Marine Park. Histological examination of gonads of snails revealed that animals could be ripe and spent at various times of the year but there is no information appropriate to determine the length of the reproductive cycle (Nardi). However, so far female snails have laid eggs encased in capsules in the laboratory only in July to October (Turner) and egg capsules have been found in the field at this time as well (Turner). Captive females can produce up to 115 capsules containing between 300 to 1400 eggs. Free-living veliger larvae with 1.5 whorls in the protochonch hatch from the capsules after about 30 days and, in the laboratory, spend 2 days swimming actively at the surface before descending to the bottom of the containers where they feed and live without metamorphosing for at least one month (Turner). The smallest recruits found in the field have 4 whorls in the protochonch; based on laboratory growth rates they would take about 2 to 3 months after hatching to grow that large (Turner).

Although the length of larval life remains unknown, these observations indicate that there is the potential for substantial connections among populations provided by the dispersal of planktonic larvae. An electrophoretic study of enzyme variation at 10 polymorphic loci provided an indirect approach to understanding dispersal where direct study of larvae and recruitment were impossible (Johnson, Holborn and Black). The genetic similarities among adult populations of *Drupella cornus* are consistent with extensive gene flow. There is no evidence of different genetic groups related to habitat, stage of infestation, or geography over more than 1100 km. Extensive dispersal appears to be the norm for this snail. However, this does not necessarily mean that there is no local recruitment associated with the outbreak at Ninagloo Marine Park. Consistent with the possibility of such local recruitment is the finding of greater genetic subdivision among outbreak populations than among non-outbreak populations (Johnson, Holborn and Black). There is also fine-scale heterogeneity of recruits, but that is not evidence for subdivision of populations. Instead, it indicates that the process of recruitment is patchy, and very likely involves settlement of aggregated groups of larvae (Johnson, Holborn and Black).

Very small recruits appear in the field in Feburary (Turner). The smallest recruits occur in digitate acroporans where they remain and feed on the coral until they reach about 20mm long (Forde). Corals with these recruits are evident because of the feeding damage made by the snails. Snails larger than 20mm tend to move to the base of the coral and to the rubble beneath and they remain cryptic until they

reach 25mm in length, when presumably they join aggregations of adults snails larger than 25mm (Forde). As judged by the size distributions of snails in coral heads at different times of the year, the best estimate of the size at 1 year of age is about 10 to 15mm long (Turner).

Estimates of size-at-age derived from a fit to a Gompertz growth equation from marked snails recaptured after 6 months predicted that a 10 mm snail should grow to an asympototic size of about 37 mm at Coral Bay in about 5 to 6 years (6 to 7 years of age) (Black and Johnson). The modal size of adults at that site is 35mm. The smallest snails with histologically recognizable sexual organs were about 21mm long (Nardi) and therefore probably in their second year of life. Sexually mature snails, with ripe gonads, are at least 25mm long (Nardi), and therefore at least 3 years of age (Black & Johnson).

In the absence of estimates of annual mortality rates, the period of population turnover cannot be determined. Nevertheless, the major destruction of coral in a local outbreak occurs within the span of a single generation of *Drupella cornus*, and the large outbeak populations probably represent few cohorts. The history of the outbreak at Ningaloo Reef and the apparent expansion in the north (Forde, Hilliard) suggest a ripple effect of recruitment from high density populations. The most important question about the biology of these populations appears to be, what determines the success of particular cohorts of recruits?

# SUMMARY OF THE WORKSHOP DISCUSSION

Reporter : Stephanie J. Turner
(incorporating comments from Tony Start and Bob Black)

The Workshop Discussion began with a reminder from the Chairman (Dr Tony Start), that the high numbers of Drupella that are currently being observed at Ningaloo should not necessarily be regarded as an unnatural and/or undesirable phenomenon. Concern was expressed on several occasions during the Workshop, over the use of words such as 'infestations' and 'outbreaks', which imply that Drupella is a pest species and that its high numbers are having a deleterious effect on the reef. Furthermore, it was recognized that a lot of the research that has been undertaken to date, has been predicated by the possibility that the current high numbers of Drupella at Ningaloo Reef is unnatural, and may have arisen because of some (as yet unidentified) human influence. That this should be investigated was accepted, but it was stressed that researchers and managers should not be preoccupied with this notion simply because of a human perception that the large-scale destruction of live corals on a reef is a deleterious and unnatural occurrence. In several years time the community structure at Ningaloo Reef (and, incidentally, other Western Australian reefs) may be very different, but it was suggested that this is not necessarily cause for undue concern. It was, however, agreed that there is a basic need to understand the critical facets of the ecology of Drupella before it can be determined whether the current high numbers recorded at Ningaloo are a natural phenomenon or are human-induced. The task for researchers and managers is, therefore, to gather as much information as possible towards furthering an understanding of the cause(s) and effects of high numbers of Drupella at Ningaloo. It was recognized that management agencies need to understand the phenomena that cause major changes in the communities they are endeavouring to manage.

When asked whether further research on Drupella is warranted, in particular in view of the consideration that the current high numbers at Ningaloo may be part of a natural cycle, the group felt that, regardless of any emotive considerations or value judgments, further research will provide valuable information on coral reef ecology and general population ecology, which are of broad scientific interest. Any contribution towards furthering our understanding of the mechanisms that cause the numbers in a population to fluctuate, was recognized as being of fundamental ecological value.

(a) RESEARCH PRIORITIES:
Although extensive research into the general biology of Drupella has been carried out over the last 2-3 years, the participants agreed that there remain a number of key areas which need to be addressed. One of the aims of the final Workshop Discussion was

to identify important areas where future research efforts should be directed. The following subjects were covered:

REPRODUCTIVE BIOLOGY -
- the age at which sexual maturity is attained and, in conjunction with measurements of the longevity of Drupella, the number of years over which individuals are reproductively active.
- seasonality and/or synchrony in the breeding cycles within and between Drupella populations at different sites and over a number of years. As a result of the work that has already been undertaken, it was suggested that it should be possible to ascertain the gametogenic state of large numbers of individuals by examination of the overall physical appearance of the gonads, without the necessity for detailed histological examination.
- evidence for sperm storage in the females.

LARVAL BIOLOGY -
- larval behaviour in the field, in particular in relation to their dispersal.
- when and where the larvae settle.
- the relationship between the nutritional requirements of the larvae for survival through to settlement and metamorphosis, and the occurrence (temporally and spatially) of natural food resources at these levels.

JUVENILE BIOLOGY -
- measurement of juvenile growth rates.
- distribution and occurrence of juveniles, in particular the missing/cryptic cohort.

ADULT BIOLOGY -
- measurement of annual mortality rates to provide estimates of the longevity of Drupella, which will in turn enable population turnover times to be estimated and the future of the population to be predicted.

FEEDING BEHAVIOUR -
- feeding behaviour (intensive vs. small scale feeding modes) and feeding rates.
- effects of varying densities of Drupella on coral survival. There may be a threshold density of Drupella, over which the coral community is destroyed, but below which some form of equilibrium is maintained. Work on the Great Barrier Reef has suggested that fast-growing coral species can sustain damage to up to 30% of their area/annum and still maintain themselves.

PREDATION -
- predation was recognized as being of potentially critical importance on the larval and juvenile stages in the life-cycle. However, predation, on the planktonic stages in particular, is likely to prove difficult to investigate. Predation on the adults was not considered to be important in controlling the numbers of Drupella at Ningaloo.

GENETICS -

- although interesting results have been obtained from the genetics work already undertaken, and there is considerable scope for further related work, it was felt that genetics could not make any direct contribution towards understanding the processes controlling the success of local recruitment and was unlikely to lead to practical management options.

TEMPORAL PERSPECTIVES -

- paleoabundances of Drupella shells in the fossil record.
- evidence of previous Drupella outbreaks (or the activities of any other agent of coral mortality) may be obtained indirectly from a study of the size (and, consequently, the age) of the corals currently being eaten by Drupella.

CONCLUSIONS:

The early life history of Drupella was recognized as a high priority for further research. As there is no evidence to suggest that the phenomenon observed at Ningaloo is the result of the adult population moving along the reef, it is likely that the outbreaking populations at Ningaloo are recruit-driven. The processes controlling the success of local recruitment were considered to be the central issue if the fluctuations in Drupella numbers are to be understood. However, the factors controlling recruitment were recognized as being very difficult to determine. There is a need for basic information on the temporal and spatial variation in recruitment rates - where, when and how many. One suggested approach to documenting recruitment was to sample, over a long time period, large numbers of the corals where the recruits are characteristically found.

The results from this type of study would provide a measure of the variation in annual recruitment. Whether the current high numbers are within the normal variability of the population fluctuations could then be established. It was further suggested that there is a need to simultaneously study recruitment at other reefs as well as at Ningaloo (e.g. Abrolhos Islands and Dampier Archipelago). In view of the large breeding population that is currently present at Ningaloo, it was considered likely that there will be an increase in recruitment of Drupella onto reefs that are remote from Ningaloo.

The participants also agreed that it is important to establish (possibly through back-modelling), whether the present high numbers of Drupella are the result of a single, transient, chance event, or a series of events during the 1980s, and whether the conditions favouring these high numbers still exist.

The value of laboratory experimental studies was questioned, in particular with respect to the applicability of the results to field situations. Research into the early life history of Drupella was recognized as providing valuable information. However, because it is only possible in the laboratory, it was suggested that the results are unlikely to be a realistic indication of what is actually happening in the natural situation. It was noted that although

considerable work has been done on the early life history of crown-of-thorns there is still no information about the factors that actually enhance/reduce larval survival, where the larvae go in the water column, etc. Furthermore, it was suggested that it is unlikely that this information will ever be obtained given the techniques currently available. The group were urged to concentrate future research on examining questions that will provide useful answers, that can contribute directly towards our understanding of the high density populations which are being observed at Ningaloo. Rather than on issues which are impossible to answer in terms that are relevant to the natural situation.

(b) LONG-TERM MONITORING:
Another issue which was extensively discussed at the Workshop was the desirability of long-term monitoring. The value of long-term surveys that provide basic information on the distribution and abundance of Drupella over extended time periods was emphasized. It was suggested that a few years data may provide a valuable indication of what is happening within the Drupella populations under study. It was noted that long-term monitoring programs have only recently been established to document crown-of-thorns on the Great Barrier Reef.

A number of key points to be considered in any proposed long-term monitoring program for Drupella were identified:
- the results from different sites and different time periods must be statistically comparable (viz. transects of equal length/quadrats of equal size, equal numbers of replicates etc.).
- the methods adopted should be straight-forward and simple, requiring minimum sampling effort, so that they can readily be employed at a large number of sites. Line-transects (20m x 0.5m) were considered to be most suitable for long-term monitoring programs - transects have an advantage over quadrats in that they can rapidly be laid out and searched, thus maximizing the information that can be obtained.
- sampling should be undertaken regularly and consistently.
- to increase consistency in the data collection, wherever possible the same personnel should be employed throughout the monitoring program.

The participants agreed that the following four parameters should be recorded in any long-term monitoring of Drupella :
- % coral cover.
- coral colony size.
- densities of both juvenile and adult Drupella.
- size frequencies of the snails.

It was emphasized that the size frequencies of the snails have to be representative of the whole population (i.e. every Drupella in the transect/quadrat being monitored must be sampled). This issue was raised because the intermediate sized snails (2-2.5cm shell length) have not been adequately represented in previous surveys, because of their occurrence in a habitat distinct from that occupied by the recruits and adults. Furthermore, the sample sizes must be large enough to detect different cohorts in

the population. The value of a simple, complete size frequency distribution was emphasized. Information regarding the history and prognosis for the future of the population can be extracted from size frequency distributions. It was recognized, however, that to achieve this prerequisite of a complete population sample will necessitate destructive sampling. Furthermore, because of the marked clumping of the juveniles by size (and presumably, therefore, by age), recorded in the genetics study, there will be very real sampling problems in obtaining random samples. Thus, relatively large areas will have to be destructively sampled to achieve sample independence.

The real value of long-term monitoring studies, in terms of the solutions provided for effective management action, was questioned. The group were asked to consider what questions long-term monitoring would answer, in particular in the context of the research priorities examined at the beginning of the Discussion, and how the information could be applied to increase our understanding of the cause(s) of the fluctuating numbers of Drupella. Even though there are several examples of long-term monitoring studies, it was argued that none have led to the development of an effective management strategy. Long-term monitoring studies may reveal the patterns of population fluctuations, but they will provide no indication of the cause(s). It was considered that experimental studies addressing carefully posed questions, and designed to eliminate alternative explanations, are the only means by which causality can be effectively examined.

(c) FINANCIAL RESOURCES:
There was considerable concern over the lack of finances available for further research and long-term monitoring programs. The participants recognized Drupella on Ningaloo Reef as a problem of equal importance to the crown-of-thorns on the Great Barrier Reef. It was acknowledged, however, that there is a marked imbalance in the research being undertaken on these species. It was recommended that the Federal Government should be made aware of the implications of not treating Drupella as seriously as the crown-of-thorns, and of not balancing expenditure on marine research between the Indian and Pacific Ocean coasts. Special funds are urgently needed to enable the establishment of a long-term Drupella Research Program (cf. the crown-of-thorns, water quality and the effects of fishing special projects which are currently attracting substantial funds for research on the Great Barrier Reef). Aside from the tourism value (both realized and potential) of Ningaloo Reef to Western Australia (a figure of $15million/annum was given), the study of the dynamics of a major ecological community, such as Ningaloo Reef, was identified as a key factor in justifying any application for funds to support further research.

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