Broad and fine scale habitat associations of juvenile *Trochus niloticus* in Western Australia: implications for stock enhancement and assessment.

by

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a dissertation for the

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Masters of Tropical Environmental Management (SBI540)
Completed: 18/12/2000
Statement of Authorship

"I declare that this dissertation is my own work and has not been submitted in any other form for any other degree or diploma at any university or other institution of tertiary education. Information derived from the published and unpublished work of others has been acknowledged in the text and list of references".

Signed

Jamie Colquhoun
18/12/2000

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Abstract

Information for restocking is needed on habitats of trochus in Western Australia (W.A). An investigation into the habitat preferences of trochus on reefs in King Sound W.A. was conducted, in two parts, on a macro-habitat and micro-habitat scale. Broad-scale surveys were done on four reefs in King Sound, W.A. Surveys along transects were used to examine the density and size distribution of juvenile (<50 mm) and adult (>50 mm) trochus among 4 intertidal reef habitats: reef platform, patch reef, sand/seagrass, and rocky/boulder. No single habitat was preferred exclusively by juvenile or adult trochus. A two-factor ANOVA showed that the distribution of juvenile trochus on these reefs was highly patchy at scales within habitats (predominantly), among habitats and among reefs. Trochus rarely occurred in habitats dominated by sand. Analyses suggest that greater sampling effort (15 to 30 transects) is required to increase precision of abundance estimates to a level of 0.2 or 0.1. High densities of larger size classes in the rock habitat indicate its suitability for translocation of large juveniles. Higher abundances of smaller juveniles in the reef platform and patch reef habitats, occupying most reef area, indicate that both habitats are suitable for seeding of small juveniles. Fine scale surveys were conducted on 3 reefs. Sampling rings (paired) were used to examine differences of percentage abiotic and biotic area cover around juvenile trochus and in random areas, among 2 intertidal habitats: reef and rock. Frequency distributions of juveniles (mouthparts) in contact with substrates and biota were calculated. Randomised block univariate and multivariate ANOVAs showed juveniles preferred different substratum and algae in different habitats but this was similar among reefs. Juvenile trochus were selecting micro-habitats within macro-habitats with substrates that offered refuges and abundant crustose algae. Juvenile and adult trochus broad-scale and fine-scale habitat preferences relate to preferred stock enhancement habitats and improved stock assessment methods.
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Chapter 1: Introduction

1.1: Preamble

One of the objectives of ecology is to identify factors affecting the coexistence of species like Trochus niloticus Linnaeus (trochus) within a community and to understand how these factors influence patterns of distribution and abundance (Watanabe, 1984). Organisms have an ecological niche (Odum, 1971), an abstract term, but important in determining associations of organisms with abiotic and biotic factors in the environment. The ecological niche includes all of the organism's requirements, i.e. all of the environmental conditions that are necessary to maintain itself in a population and the amounts of each of the resources that it requires to do so (Begon et al., 1990). Variability in benthic invertebrate abundances inevitably occurs at a hierarchy of spatial and temporal scales (Underwood et al., 2000). Variability can affect trochus abundances directly by only providing appropriate habitat in some places, or indirectly by modifying biological interactions among different species (Underwood et al., 2000).

The emphasis on variability among populations, temporally and spatially, has often concentrated on large spatial scales with respect to patterns governed by strong environmental gradients (Menge, 1978; Underwood, 1996). However, recent studies have emphasised the large variability in abundances of individual species at very small scales, i.e. among patches of habitat only centimetres or metres apart within a site, rather than among sites (Underwood et al., 2000). Recent studies on gastropods have indicated that small-scale variations in habitat may greatly affect distributions of juveniles (Castell, 1997; Stoner, 1994). In some cases, the physical features of habitat are satisfactory to explain the patterns (Thompson et al., 1996; Archambault & Bourget, 1996). In some areas, variability in abundances of single species are best explained by the processes acting at different spatial scales, although in others, small scales alone explain most of the variability (Underwood et al., 2000).

Populations of organisms typically occupy patches of habitat within different habitats (Chapman, 2000), which provide the required conditions and resources to sustain population numbers. The availability and quality of habitat vary spatially
Variability occurs because of individual differences in behaviour, rates of growth, etc., coupled with differences in population dynamics among largely separated populations living in discrete patches of habitat (Underwood et al., 2000). The structure, sizes and spacing of patches of habitat are each very important in determining abundances of local populations and their rates of change (Underwood et al., 2000).

Interactions of local populations are determined by factors that maintain individuals within, or cause dispersal among patches of habitat (Chapman, 2000). The life history of an organism depends on the habitat of the organism concerned; therefore, 'habitat' plays a crucial role in moulding life histories (Begon et al., 1990). One of the most obvious features of benthic marine communities is the recurrence of particular species or species assemblages with particular substrates and the resources provided by those substrates (Johnson, 1971; Bacescu; 1985; Sheperd & Daume, 1996; Gunkel, 1997; Marth et al., 1999).

The development of gastropod populations is strongly reliant on factors such as substrate size, availability of larvae, larval choices at the time of settlement, early mortality, physical and biological parameters, and seasonal variations in all of the above (Gunkel, 1997). The abiotic and biotic characteristics of intertidal substratum in one of the most important environmental factors affecting distributions and associations of benthic animals (Bacescu, 1985), but cannot be viewed completely independently of the responses to other factors. Substratum irregularity is an important factor in controlling community structure in marine benthos, but in most cases this has been attributed to a larger number and variety of possible refuges (Gunkel, 1997). Ray-Culp et al., (1999) suggested that the Queen Conch, *Strombus gigas*, may reach a size refuge because experiments indicated that conch size afforded more protection than habitat complexity. Substrate biota, living (bacteria, phytobenthos) or dead (organic remains), can constitute a rich food source and provide essential building material (Bacescu, 1985), for a host of marine animals.

Seaweeds and algae are the primary producers of coral reefs and are the basic elements of a very complex food web that involves many organisms (Allan and Steene, 1999). They provide nutrition for a multitude of primary consumers like microorganisms, molluscs, crustaceans, and fishes. Algae as well as other components of coral reefs like corals, sponges, ascidians and anemones are important components of reef habitats for organisms. However, many can have physical and
chemical defenses that inhibit foraging, and affect the distribution of many taxa (Steneck, 1992; Stoner, 1994; Chanas & Pawlik, 1996). Therefore, some components (biotic and abiotic) can negatively affect abundance of a particular animal, while other components are associated in a positive way.

Studying early post-settlement processes or associations in gastropod communities can be problematic because settlers are difficult to detect, extract, or observe non-destructively (Nash, 1993; Castell, 1997; Ray-Culp et al., 1999). Therefore the magnitude of recruitment or habitat preferences is estimated using older individuals large enough to be observed, with studies usually reporting findings for juveniles that have already been settled on the benthos for weeks or months (Ray-Culp et al., 1999).

Literature on trochus and other benthic invertebrates of tropical coral reefs lacks a quantitative approach. Associations' trochus have with different habitats; substrates and biota within intertidal and subtidal reef habitats, among habitats and among reefs are mainly qualitative. There is a wealth of quantitative research relating to temperate intertidal rocky shores and related flora and fauna but very little from the tropical regions. Many of the ecological paradigms relating to benthic communities have been developed through research related to temperate regions. However whether many of these paradigms are similar and appropriate for coral reef communities is yet to be determined. A regional approach to the ecology of benthic invertebrates is recommended so ecological paradigms can encapsulate many of the environmental gradients experienced worldwide.

1.2: Background

Trochus is a large herbivorous gastropod, which is important to artisanal fishers in the tropical and subtropical waters of the eastern Indian and western Pacific Oceans. They provide an important traditional food source in many communities, and are typically cooked, dried or occasionally canned (Hahn, 1989; Clarke and Ianelli, 1995). Primarily they provide a valuable source of income through the sale of the shell used in the manufacture of mother-of-pearl buttons, decorative inlay work, jewellery and paints (Hahn, 1989; Clarke and Ianelli, 1995). The shell is exported to Europe, the USA and Asia and the annual demand for shell is estimated at 3,000 to
5,000 tonne world wide (Clarke and Ianelli, 1995). However, global demand is considered to outweigh supply (Crowe et al., 1997).

The importance of the shell trade to coastal communities or nations cannot be measured only in terms of cash earnings or Gross National Product (Hahn, 1989). Shells in these nations, villages or communities are variously recognised in terms of their 'beauty', 'colour', and 'sheer radiance' (Pannell, 1993). That is, their aesthetic attraction; in terms of their economic appeal as objects of wealth within the context of exchange; in terms of their political allure as tokens of power and prestige; and in terms of their seductive role as symbols with cosmological and ontological significance (Pannell, 1993). The industry is ideally suited to subsistent coastal communities.

The harvest of shell does not require investment in expensive equipment or vessels (Glucksman & Lindholm, 1982). The reefs on which trochus inhabit are often contiguous with small population centers and the saleable product requires no preservation and is easily processed to provide a source of locally produced and preserved high quality protein (Glucksman & Lindholm, 1982).

Since commercial fishers began harvesting trochus the price has steadily increased luring more fishers to the industry and increasing harvests. Trochus has been overfished and stocks are depleted in Palau, Yap, Truk, Australia, Indonesia, New Caledonia, Vanuatu, and the Philippines so as a result, some stringent conservation measures have been established (Heslinga and Hillman, 1981). The International Union for the Conservation of Nature has placed trochus on its list of "commercially threatened invertebrates" (Hahn, 1989). In Indonesia trochus has been listed as a protected species in a declaration by the minister of forestry (No. 12/DPTS-II/1987) and a total ban on fishing has been put in place (Latama, 1999). A moratorium has also been declared periodically since 1922 for the Micronesian fishery (Clarke and Ianelli, 1995).

Rapid declines in abundance shortly after commencement of commercial fisheries suggest that trochus is highly susceptible to overfishing (Heslinga et al., 1984; Nash, 1993; Castell, 1997). In many regions, reefs have been overfished and stocks are depleted. For reasons unknown, replenishment of populations is often poor despite the fact that trochus larvae are planktotrophic and neighbouring reefs can have healthy breeding populations (Nash, 1995).
Reseeding techniques have been used in mollusc fisheries for stock enhancement with varying degrees of success (Heslinga et al., 1983; Scheil, 1992; Stoner & Davis, 1994; Amos, 1995; Stoner & Ray, 1996; Crowe et al., 1997). The development of culture methods for trochus has allowed easy production of mass numbers of juvenile trochus (Heslinga et al., 1983; Lee, 1997), and release of these 'seeds' is now a viable option for stock enhancement. However, problems implementing these techniques are generally associated with a lack of preliminary ecological knowledge of the animal. The principal problems confronted in reseeding programs seem to be predation of seeds, fitness of seeds, and suitability of seeding habitats (Shiel & Weldon, 1987; Yamaguchi, 1990; Ray & Stoner, 1994; Ray et al., 1994; Castell, 1997). Juveniles <30 mm shell basal width (SW) are rarely found in surveys and little is known of their ecology (Rao, 1937; Heslinga et al., 1984; Smith, 1987; Arifin & Purwate, 1993; Magro & Black, 1995; Castell, 1997; Colquhoun, pers. obs.).

The lack of ecological knowledge about juvenile trochus is a major constraint to the feasibility of reseeding techniques. Seeding feasibility will be determined by the economic balance between the costs of producing hatchery-reared juveniles of various sizes and the proportion that reach maturity after release (Castell, 1996). In order to estimate the success of reseeding techniques in the field habitat preferences of wild juvenile trochus need to be identified.

1.3: The Trochus Fishery in Western Australia.

A small commercial trochus fishery exists at the mouth of King Sound, off the northwestern coast of Australia. The fishery has a long history of exploitation. Trochus has provided the main source of work and economic return for the region's Aboriginal communities since 1979, when Fisheries Western Australia (W.A.) issued a license to the Bardi Aborigines Association of One Arm Point and the fishery recommenced after a break of 40 years. Annual catches of trochus have declined from 135 tonne of shell harvested in 1980, from a 'virgin' commercial fishery with no size or effort restrictions (Ostle, 1997), to less than 10 tonnes per annum currently. Sustainable harvests are estimated to be between 30 and 50 tonnes annually (Magro & Black, 1995; Ostle, 1997) but there is limited data on which to support these assumptions.
The trochus-fishing license requires a monthly record of catch for each individual permit holder. However, problems and limitations with the data make it difficult to monitor the fishery effectively (Magro, 1997). Current community imposed restrictions include a recently increased minimum harvest size of 75 mm SW, up from 65 mm SW and seasonal closures during peak spawning season. These new measures were put in place to allow more animals to achieve sexual maturity and accomplish at least one or more spawning before capture. This assumes increased recruitment to the fishery due to higher reproductive output at peak spawning periods but has yet to be tested. In an effort to avoid the effects of overfishing management techniques like the use of size-limits, limited entry, limited season, total allowable catch, sanctuaries and logbooks can be employed (Crowe et al., 1997). This has prompted research into alternative management strategies.

The Australian Centre for International Agricultural Research (ACIAR), Fisheries W.A. and Aboriginal communities of the Dampier Peninsula, W.A. have been evaluating the potential of different stock enhancement techniques for the fishery since 1995 with varied success. Juveniles are readily cultured locally due to improved spawning techniques developed by Lee (1997). Three techniques are currently being evaluated:

- Reseeding with very small juveniles (1-4 mm SW)
- Broodstock translocation and corralling (>75 mm SW)
- Intermediate culture of juveniles in cages (12-20 mm SW)

Information on juvenile and adult trochus distribution, abundance and habitat preferences are lacking for this region. Therefore suitable reseeding, translocation, and intermediate culture habitats, which maximise survivorship are difficult to assess. Information on the habitat preferences, size distribution and abundance within reefs and between reefs will increase the potential of these techniques and aid the development of effective methods for accurate stock assessment and monitoring. The aims of the following two chapters are:

- to determine which broad-scale reef habitats are preferred by wild juveniles on coral reefs in King Sound and whether these are different to the habitats preferred by adults.
to determine which fine scale abiotic and biotic characteristics of reefs in King Sound are preferred by juvenile trochus and whether these are differ among habitats and reefs.

Chapter 2. Habitat preferences of juvenile trochus in Western Australia: implications for stock enhancement and assessment.

2.1: Introduction

Restocking of trochus (*Trochus niloticus*) populations commenced with the translocation of adults in the South Pacific region in the 1920's (review: Crowe *et al.*, 1997). The development of culture methods has allowed easy production of mass numbers of juvenile trochus (Heslinga *et al.*, 1983; Lee, 1997), and release of these 'seeds' is now a viable option for stock enhancement. However, strategies for release of cultured juveniles are still in their infancy and information is needed, such as the appropriateness of reef habitats for seeding.

The principal problems in reseeding programs seem to be predation, fitness of juveniles and suitability of seeding habitats (Yamaguchi, 1990; Nash, 1993; Castell, 1997). On Orpheus Island, Great Barrier Reef, Castell (1997) showed that juvenile trochus were abundant chiefly on the reef flat habitat while adults were more common on the reef crest and slope. However, regional differences in the ecology of trochus are inherent (Amos, 1991; Nash, 1993) and reefs in other regions can have different gross structure and habitats. The lack of knowledge on habitats preferred by juvenile trochus, in regions of interest, compromises the success of restocking programs.

A small commercial trochus fishery exists at the mouth of King Sound off the northern coast of Western Australia (W.A.). The Aboriginal communities of the region intend to restock depleted reefs with hatchery-produced juveniles. While some information on juvenile distribution, abundance and habitat preferences is available from other regions, little is known of the ecology of juveniles on reefs in W.A. Suitable seeding habitats, which have naturally high abundances of juvenile trochus, need to be identified. Information on habitat preferences, size distribution and abundance within and among reefs will increase the potential of reseeding. In
addition, such information would aid the development of effective methods for accurate stock assessment and monitoring. The aims of this study were to determine which reef habitats are preferred by wild juveniles on coral reefs in King Sound and whether these are different to the habitats preferred by adults.

2.2: Study area

Surveys were carried out from May to June, 2000 on the intertidal sections of 4 fringing reefs at the mouth of King Sound in W.A. (16°25'S, 123°07'E) (Fig. 1). The reefs appear to be constructed dominantly by encrusting coralline algae and are algae-dominated reefs (Brooke, 1995). Two reef types are common; one characterised by seaward intertidal terraces and the other by a gently sloping reef front. Intertidal terraces have a stepped seaward margin causing a damming effect landward.

The reefs chosen for this study are among a number of reefs in the region currently being used for research into stock enhancement. The 4 study reefs vary in size, are representative of reefs in the region and have natural stocks of juvenile and adult trochus. The intertidal areas of the reefs were partitioned into 4 habitats: coral rubble platform (platform), patch reef (patch), sand/seagrass (sand), and rocky/boulder (rock). A subtidal live coral habitat at the seaward edge of the reefs was not examined due to water depth.
2.3: Characteristics of reef habitats.

The reef platform habitat generally occurs on the seaward margin of the reefs and forms part of the reef slope and reef flat. A diverse algal community dominates the surface cover on the reef platform while interspersed low massive hard corals, soft corals, sponges, ascidians and zoanthids are less abundant.

The patch reef habitat occupies most of the area on these reefs and occurs behind or at the sides of the coral rubble platform habitat and extends to the back sand and seagrass habitat. It is a network of pools, sand, coral rock and rubble overlying a hard siltstone or quartz base. Standing water at low tide is generally <metre in depth with a dominant over story of Sargassum sp. and Turbinaria sp.

The sand and seagrass habitat is situated mainly on, but not isolated to, the back of reefs. It is dominated by sand, with isolated patches of coral rock or rubble. Seagrasses (e.g. *Thalassia hemprichii, Enhalus acoroides* and *Halophila ovalis*) are the most common biota.
The rock and boulder habitat is composed of siliceous quartz-gneiss and granite boulders. It forms the sides of fringing reefs extending from the subtidal live coral habitat back into the intertidal sand and seagrass habitats.

2.4: Materials and methods

The density of trochus within each habitat was determined by surveying randomly positioned 50 m x 2 m strip transects, approximately 50 m apart, in each habitat and perpendicular to the shoreline. For the larger reefs, representative areas of each habitat were identified for sampling. Six transects were surveyed in each habitat on each reef except in the sand habitat on Jackson Island Reef where only 2 transects were surveyed due to lack of habitat area. Surveys were conducted by walking slowly along the center of the 50m tape while holding a 2m wide 'T' bar delineating 1m either side of the tape. All trochus sighted within each transect were counted, shell basal width measured and recorded into 10 mm size classes. Surveys were restricted to approximately 2 hours before and after low tide, depending on reef height and tide.

Data of size class distribution were graphed and density scaled to individuals per hectare. Mean precision (S.E./mean) of abundance was calculated for each habitat in the study. For the benefit of future sampling, the mean required sampling effort (n) for each habitat was calculated for three levels of precision, 0.1, 0.2, 0.3. For analyses of juveniles, data on individuals < 50 mm were used. Adults were considered > 50 mm as the minimum size at commencement of sexual maturity is ~50 mm (Gimin & Lee, 1997). Cochran's test was used to determine homogeneity of variances amongst reefs and habitats. A 2-factor ANOVA was used to analyse the density of juvenile trochus among reefs and habitats. The total areas of each reef and habitats within reefs were estimated from aerial photos and distances estimated during field surveys.

2.5: Results

The surveys showed that no single habitat could be identified as the habitat exclusively preferred by either juvenile or adult trochus. Juvenile and adult trochus were found commonly in 3 of the 4 intertidal habitats on these reefs (Fig. 2); reef
platform, patch reef and rock. Juveniles in the rock habitat were large (40-50 mm) (Fig.2). The surveys confirmed that juvenile trochus do not prefer habitats dominated by sand. Only 2 juvenile trochus were recorded in the sand habitat on one reef. Juvenile trochus <30 mm SW and adults >100 mm SW were not encountered in the surveys. The distribution of trochus among habitats on different reefs was broadly similar and no size class was dominant (Fig. 2).

While juvenile and adult trochus occur commonly within platform, patch reef and rock habitats on these reefs, their distribution within habitats was highly patchy. This is shown by mean precision (S.E./mean) of abundance values within habitats, which ranged from 0.39 to 0.42. Considerably more sampling effort is required to increase precision to a more acceptable level (Table 1). Each recorder can position and census approximately 6 transects (50 m x 2 m) per hour.

More than half of the surveyed transects on reef platform, patch reef and rock habitats did not contain juvenile trochus. Juveniles were not found in the rock habitat on Bowlan Reef and the patch habitat on Salural Reef (Fig. 3). Although juvenile trochus occurred in high numbers in the rock habitat, this habitat occupied a small proportion of area on all 4 reefs (Table 2). The reef platform was the only habitat in which juvenile trochus were found for all 4 reefs. The patch habitat generally covered the largest area on the reefs (Table 2).

Table 2.1: Mean number of (50 m x 2 m) transects (n) (± S.E) required for precision = 0.1, 0.2 and 0.3 for each habitat

<table>
<thead>
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<th>Precision</th>
<th>Platform</th>
<th>Rock</th>
<th>Patch</th>
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<tr>
<td>0.1</td>
<td>30 (± 7)</td>
<td>29 (± 3)</td>
<td>31 (± 15)</td>
</tr>
<tr>
<td>0.2</td>
<td>15 (± 4)</td>
<td>15 (± 2)</td>
<td>15 (± 7)</td>
</tr>
<tr>
<td>0.3</td>
<td>10 (± 2)</td>
<td>10 (± 1)</td>
<td>10 (± 5)</td>
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Table 2.2: Estimates of total intertidal reef area and percentage area coverage of each habitat out of the total reef area for each reef

<table>
<thead>
<tr>
<th>Reef Name</th>
<th>Total Intertidal Reef Area (ha)</th>
<th>%Reef</th>
<th>%Patch</th>
<th>%Sand</th>
<th>%Rock</th>
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<tbody>
<tr>
<td>Bowlan</td>
<td>238</td>
<td>31</td>
<td>48</td>
<td>18</td>
<td>3</td>
</tr>
<tr>
<td>Salural</td>
<td>66</td>
<td>21</td>
<td>62</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>Jackson</td>
<td>9</td>
<td>16</td>
<td>67</td>
<td>12</td>
<td>5</td>
</tr>
<tr>
<td>Poolning</td>
<td>13</td>
<td>49</td>
<td>39</td>
<td>9</td>
<td>3</td>
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<table>
<thead>
<tr>
<th>Reef Name</th>
<th>Total Intertidal Reef Area (ha)</th>
<th>%Reef</th>
<th>%Patch</th>
<th>%Sand</th>
<th>%Rock</th>
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<tr>
<td>Mean area</td>
<td>29.3</td>
<td>54.0</td>
<td>12.0</td>
<td>4.8</td>
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Notable during the surveys was that trochus were present in the rock habitat only where it was bordered by platform or patch habitat but not where adjacent to sand habitat. Trochus generally inhabit only a small part of the intertidal rock habitat that offers abundant cracks, crevices and shade and considerably more protection from desiccation than the platform or patch.

![Graph showing mean abundance of juvenile trochus (30-50 mm SW) within platform, patch reef and rock habitats on the 4 study reefs.](image-url)

**Figure 2.2**

Mean abundance of juvenile trochus (30-50 mm SW) within platform, patch reef and rock habitats on the 4 study reefs
Figure 2.3

Size class distribution of *T. niloticus* within habitats on the 4 study reefs. Y-axis is on a log scale and abundance data scaled from 100 m$^{-2}$ to hectare$^{-1}$.
Cochran's test indicated that variances of mean abundance of juvenile trochus were significantly heterogeneous, even after $\sqrt{x}$ transformations (Cochran's $C$: $P = .019$). Moreover, Figure 3 shows clearly that the abundances of juveniles varied significantly among habitats and reefs. Therefore, a 2 factor ANOVA was used in an exploratory sense only to determine the percentage of variance for all the terms in the model. Variability in abundance of juvenile trochus among transects accounted for the majority of the overall variation (63%). The reef x habitat interaction accounted for 25% of the variability in abundance. Variability among levels within the main effects, reef and habitat, explained a relatively small percentage of the overall variability in the data (9% and 3% respectively). These results show that the distribution of juvenile trochus on these reefs (Fig. 3) was highly patchy at scales within habitats (predominantly), among habitats and among reefs.

2.6: Discussion

The findings reiterate that regional differences in trochus ecology are inherent. The scope of this study limits the ability to detect spatial patterns in juvenile abundance to a broad resolution. Nevertheless, large juvenile trochus (30-50 mm SW) were found to inhabit 3 macro-habitats on reefs surveyed in King Sound. Variation in density and distribution of juvenile and adult trochus was particularly high within habitats on a reef, which demonstrates that their distribution was clumped or patchy. Densities of trochus populations are thought to be influenced by reef orientation, degree of exposure to surf or current, substrate type, food availability and water depth (Heslinga et al., 1983).

The high densities of trochus that were found in the rock habitat demonstrate this is one of their preferred habitats. Sims (1985) found that trochus on reefs in the Cook Islands had extremely clumped distributions in high-energy zones with animals clustered upon the bare rock walls of the deeper surge channels. Surveys at Dead Henoat, Indonesia found an abundance of juvenile trochus inhabiting the underneath of rocks and boulder throughout the entire shore (Dangeubun & Latuhamalo, 1998). This preferred habitat has previously been overlooked in trochus studies in W.A.

Juvenile trochus have been found to inhabit rock habitat in many regions because of substrate stability, abundance of food and less accumulation of silt (Sims, 1985; Hahn, 1989; McGowan, 1990; Nash, 1993). The intertidal part of the rock
habitat adjacent to platform or patch reef seems to offer suitable habitat for large juvenile and adult trochus and different physical and biological features from the platform and patch habitats. The rocks are usually smooth and covered with short filamentous and turfing algae.

The high densities of juvenile and adult trochus found in the rock habitat suggest that this habitat may also be suitable for the translocation of large juveniles and adults. The edges of boulders may offer increased protection from desiccation, currents and predation and have accessible food resources, therefore increasing survivorship of trochus. Although, the rock habitat lacks the reef matrix and small-scale refuges present in the platform habitat so may not be suitable for transplanting small hatchery reared juveniles. Habitats with large numbers of naturally occurring juveniles should be the most suitable habitats for hatchery produced 'seed'.

Areas of the platform or patch habitat that are topographically complex, at the scale of 10s of centimetres, with holes and crevices for refuge are likely to be the preferred habitat for reseeding small juveniles. It is assumed that juveniles <30 mm SW inhabit such cavities (Nash, 1993). Juveniles of shell basal width <30 mm are found rarely in surveys and little is known of their ecology (Heslinga et al., 1984; Arifin & Purwate, 1993; Nash, 1993; Castell, 1997; Purcell & Colquhoun, pers. obs.). Castell (1997) suggested that small-scale variations in habitat may greatly affect the survival of juveniles and consequently should be considered in reseeding experiments.

Adult trochus >100 mm are also very rarely found on reefs in King Sound (Magro, 1997). This may be due to longevity of the species in this region or to fishing pressure. Until further studies can be done on a broader spatial scale, perhaps on reefs that incur little or no fishing pressure, the maximum size of trochus will be unknown.

A different approach to previous studies needs to be taken when estimating population size or potential reseeding and translocation sites in this region. Due to the variation in size and location of the different habitats on reefs, it is important that all the potential habitats for trochus are identified and surveyed and the total area each habitat covers is estimated for each reef. Previous studies have concentrated on dividing reefs into zones (Magro & Black, 1995; Castell, 1997; Magro, 1997); each zone representing a section of the reef defined by a certain distance from the reef
edge or shore. Few studies have divided a reef into habitats defined by physical and biological characteristics, regardless of distance from the reef edge or shore.

Without adequate levels of temporal and spatial sampling effort, patterns of distribution and abundance are difficult to distinguish with clumped distributions. More extensive monitoring of the 3 preferred habitats on more reefs would estimates of population size. Sufficient survey effort will sample more of the population and provide acceptable confidence limits to reliably detect declines in abundance from overfishing and success from reseeding or translocation experiments (Nash, 1993). An average of 15 transects per habitat would increase precision notably to a desirable level of 0.2. This combined information will contribute to the protocol required for future surveys of trochus in W.A.
3.1: Introduction

Juvenile trochus typically inhabit structurally complex, shallow, intertidal reef flats on exposed reefs that consist of consolidated coral platform, rubble and rock and provide abundant crevices for shelter from desiccation and algae for food (Hahn, 1989; Nash, 1993; Long et al., 1993; Castell, 1997). Previous studies in the region indicate that small juvenile trochus can be found under coral pieces during the day or scattered across the reef grazing during the night on coral reefs that are relatively flat with a wide distribution of dead coral (Magro, 1997). The size of these juveniles and the habitats they preferentially select are not clear. Shokita et al. (1991) suggests that on coral reefs in Japan, nursery areas of juvenile trochus have a characteristic substrate and flora either being found in *Modiolus auriculatus* colonies covered with the algae *Jania* sp. and *Gelidiella* sp. or in areas of coral rubble. Castell (1997) found on Orpheus Island, Queensland, that there were differences in the microhabitats of juveniles of different size classes and small juveniles were generally found on small fragments of coralline rubble with little or no fleshy algae. Individuals <15 mm SW were found frequently attached to very small fragments of coralline rubble, whereas juveniles 15 to 30 mm SW were usually found on larger rocks and coral bench (Castell, 1997).

However, regional differences in juvenile trochus ecology and reef structure and geomorphology indicate juveniles may utilise different abiotic and biotic resources on different coral reefs in their distribution and a regional approach is recommended (Amos, 1991; Nash, 1993). Magro (1997) found that reefs in King Sound were mostly flat, the most dominant reef substrate was composed of rock/coral pavement and the most abundant biological feature on all reefs was small macroalgae algae, large macro algae and turf algae. Significantly greater densities of legal size trochus (>75 mm SW) were reported in the reef edge zone relative to the reef flat zone of reefs (Magro, 1997). However, densities of juvenile trochus were not compared to reef characteristics. Nash (1993) suggests that high-density trochus populations seem to occur only where both juvenile and adult habitat is present. The
characteristics of these habitats and whether juveniles and adults show different preferences to certain abiotic and biotic features in these juvenile and adult habitats is unclear. The abiotic and biotic characteristics of reefs have rarely been related to resource requirements and preferences of juvenile trochus. Information on juvenile ecology like the relationships between abiotic and biotic reef characteristics and juveniles may lead to more successful methods for the culture of juveniles, fisheries management and stock enhancement and assessment techniques (Yamaguchi, 1993; Stoner, 1994; Foale, 1998).

Due to the vulnerability of trochus populations to overfishing (Nash, 1993; Burhanuddin, 1997), management of trochus fisheries needs to be based on ecological knowledge. An ecological approach to stock enhancement that includes field testing of hatchery-reared stocks and potential outplant sites toward the goal of releasing fit hatchery stock in optimal sites is recommended (Stoner, 1994; Crowe et al., 1997). Few quantitative assessments of specific associations between juvenile trochus and abiotic and biotic characteristics of coral reefs have been reported.

Juvenile trochus <30 mm SW are difficult to find on reefs (Nash, 1993; Castell, 1997; Colquhoun, in press) although evidence suggests that in some regions this is not the case. Due to the inability to detect an abundance of juvenile trochus <30 mm SW in many regions, size class distribution and associations of small juveniles cannot be ascertained. Abiotic and biotic associations can only be determined from surveys of the smallest animals that can be found. The aim of this study was to explain microhabitat preferences of juvenile trochus in similar areas within habitats on reefs in King Sound and determine if these preferences were consistent among habitats and reefs.

3.2: Study area

Surveys were carried out from May to June 2000 on the intertidal sections of 3 fringing reefs at the mouth of King Sound in W.A. (16°25'S, 123°7'E) (Fig.3.1).
The reefs appear to be constructed dominantly by encrusting coralline algae and are algae-dominated reefs (Brooke, 1995). Two reef types are common; one characterised by seaward intertidal terraces and the other by a gently sloping reef front. Intertidal terraces have a stepped seaward margin causing a damming effect landward.

The reefs chosen for this study are among a number of reefs in the region currently being used for research into stock enhancement. The 3 study reefs vary in size, are representative of reefs in the region and have natural stocks of juvenile and adult trochus. Two habitats were examined: reef and rock habitat.

3.3: Characteristics of reef habitats.

The reef habitat incorporates coral rubble, consolidated reef platform and patch reef habitat which generally makes up the greater reef area on reefs in the region. The biota include a diverse algal community with interspersed low massive
hard corals, soft corals, sponges, ascidians and zoanthids. Pools with standing water at low tide < 1 metre in depth are evident on most reefs.

The rock habitat is composed of siliceous quartz-gneiss and granite boulders. It forms the sides of fringing reefs extending from the subtidal live coral habitat back into the intertidal sand and seagrass habitats. This habitat includes a littoral zone relatively devoid of algae but with an abundance of barnacles and oysters. Below the littoral zone is an area of rock with smooth surfaces covered with turf, and crustose algae.

3.4: Materials and Methods

Fine-scale abiotic and biotic associations of juvenile trochus were determined by surveying paired 30 cm sampling rings around juvenile trochus and in random areas. Searches were carried out within each habitat on each reef to locate juveniles. Juveniles were considered <50 mm SW as the minimum size at commencement of sexual maturity is ~ 50 mm (Gimin & Lee, 1997). Searches were conducted by walking slowly along in a straight line holding a 2 m wide 'T' bar, systematically searching each habitat for juveniles. For larger reefs, representative areas of each habitat were identified and searched for juveniles.

Sampling design

**Figure 3.2.** The Randomised Block sampling design used for this study. Habitat levels denoted as R, reef; and B, boulder. Quadrat levels denoted as J, juvenile; R, random.
For every juvenile encountered, 4 preliminary recordings were taken: substrate type and biota its mouthparts were in contact with, whether it was located in a hole, crevice or crack and shell basal width. Holes were considered to be areas with depressions and crevices no > 300 mm wide by 300 mm deep. Variables encountered under the mouthparts of juveniles are provided in Table 3.1.

Table 3.1. Abiotic and biotic variables under the mouthparts of juveniles recorded in surveys in all habitats on all 3 study reefs.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Abiotic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biotic</td>
<td>Abiotic</td>
</tr>
<tr>
<td>Turf &amp; filamentous algae</td>
<td>Coral rubble</td>
</tr>
<tr>
<td>Crustose fleshy algae</td>
<td>Consolidated reef</td>
</tr>
<tr>
<td>Crustose coralline algae</td>
<td>Rock</td>
</tr>
<tr>
<td>Geniculate coralline algae</td>
<td>Coral rock</td>
</tr>
<tr>
<td>Macro fleshy algae</td>
<td>Holes</td>
</tr>
<tr>
<td>Sargassum sp.</td>
<td></td>
</tr>
<tr>
<td>Clam</td>
<td></td>
</tr>
</tbody>
</table>

The percentage surface area cover of the substrate and biota (estimated to the nearest 1%) was then estimated in each quarter of a 30 cm diameter ring using paired samples. One was a fixed sample placed immediately around the juvenile and one was a random sample (with no juvenile) collected from areas 5 m away from each juvenile at a random coordinate. Percentage surface area cover was recorded separately for substrate (abiotic) and biota, each totaling 100%. The complete list of abiotic and biotic variables is provided in Table 3.2. Random rings were sampled to compare areas in terms of abiotic and biotic characteristics on each reef. Mean sediment depth was recorded from each quarter of the ring by pushing a calibrated steel rod into the middle of a quarter as far down as possible. Topographic complexity (TC) was measured twice across the diameter of each ring sampled using a 30 cm ball chain.
Table 3.2. Variables recorded for percentage cover in the random and fixed (juvenile) sample rings from all habitats on the 3 study reefs.

<table>
<thead>
<tr>
<th>Invertebrates</th>
<th>Plants</th>
<th>Substrate type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biotic</td>
<td></td>
<td>Abiotic</td>
</tr>
<tr>
<td>Hard coral</td>
<td>Turf &amp; filamentous algae</td>
<td>Coral rubble</td>
</tr>
<tr>
<td>Soft coral</td>
<td>Macro fleshy algae</td>
<td>Consolidated reef platform</td>
</tr>
<tr>
<td>Ascidian</td>
<td>Crustose coralline algae</td>
<td>Rock</td>
</tr>
<tr>
<td>Xooanthid</td>
<td>Crustose fleshy algae</td>
<td>Coral rock</td>
</tr>
<tr>
<td>Anemone</td>
<td>Geniculate coralline algae</td>
<td>Holes</td>
</tr>
<tr>
<td>Sponge</td>
<td>Turbinaria sp.</td>
<td></td>
</tr>
<tr>
<td>Barnacle</td>
<td>Sargassum sp.</td>
<td></td>
</tr>
<tr>
<td>Oyster</td>
<td>Seagrass</td>
<td></td>
</tr>
<tr>
<td>Clam</td>
<td>Bare substrate</td>
<td></td>
</tr>
</tbody>
</table>

Frequency distributions of juvenile trochus that had mouthparts in contact with particular substrate and biota were calculated and graphed. The mean difference in percent cover of each variable for each pair of samples (juvenile & random) was calculated (J-R = Difference) and graphed. Box plots were used to examine homogeneity of variances within groups and whether distributions approached normality. Separate randomised block univariate (RBU) ANOVAs were used to test if there were differences in mean sediment depth and topographic complexity between the random and juvenile areas (Q-type) and whether these were consistent among reefs and between habitats. The model used in the analysis used the block terms as error terms for the main effects and interactions. A log(x) transformation was required for the mean sediment depth data due to heterogeneous variances within groups. Distributions of groups were positively skewed so a log(x) transformation (see Underwood, 1981) was used before randomised block multivariate (RBM) ANOVAs was used to test for differences in Q-Type of substrate (biotic) variables among reefs. Due to large differences in substrate type between habitats, multivariate test were conducted for each habitat seperately. Differences in random and juvenile samples of biota between habitats and among reefs were tested using a RBM ANOVA. The ascidian, anemone, seagrass and soft coral variables were eliminated from the analyses because they occurred rarely in replicates to permit analysis. Biota data was arcsine transformed (see Underwood, 1981) due to heterogeneous variances within groups. Paired samples (blocks) needed to be balanced in the model, therefore 10 blocks, selected randomly from the data from each habitat*reef combination, were used in each analyses.
3.5: Results

The surveys showed that juvenile trochus had preferences for substrates that offered a combination of structural complexity in the form of holes, cracks and crevices and particular types of encrusting algae and these preferences were different between habitats on reefs but similar among reefs. A total of 106 juvenile trochus were recorded in the surveys. The mean shell basal width was 44 mm and the range was 29 to 50 mm SW.

Frequency distributions of juvenile trochus for different substrates indicated a preference for coral platform in the reef habitat and coral rock in the rock habitat (Fig. 3.1). Substrate differences between juvenile areas and random areas in the rock habitat were similar among reefs, but this was not the case for habitat (Table 3.4). Juveniles were negatively associated with rock substrates in the rock habitat (Fig. 3.2), even though rock was the dominant feature of this habitat. Topographic complexity differed between areas with juveniles and random areas among reefs and between habitats (Table 3.3). Juveniles selected areas in the rock habitat and reef habitat with holes and crevices, although preference was greater in the rock habitat on most reefs (Fig. 3.1 Fig. 3.2). Differences in mean sediment depth (MSD) was highly significant between the reef and rock habitat (Table 3.4). The reef habitat (MSD = 8.93 ± 19.45 S.D.) had significantly more sediment than the rock habitat (MSD = 2.78 ± 13.73 S.D.) and this was consistent (non-significant) among reefs.

Table 3.3. Randomised Block univariate ANOVA table comparing differences of MSD and TC variables between reefs, habitats and random and fixed samples (Q-type).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Source of variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>Sig.of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSD</td>
<td>Reef</td>
<td>.08</td>
<td>2</td>
<td>.04</td>
<td>.786</td>
</tr>
<tr>
<td>MSD</td>
<td>Habitat</td>
<td>1.92</td>
<td>1</td>
<td>1.92</td>
<td>.001</td>
</tr>
<tr>
<td>MSD</td>
<td>Reef*habitat</td>
<td>.29</td>
<td>2</td>
<td>.14</td>
<td>.439</td>
</tr>
<tr>
<td>MSD</td>
<td>Reef*Q-type</td>
<td>.60</td>
<td>2</td>
<td>.30</td>
<td>.183</td>
</tr>
<tr>
<td>MSD</td>
<td>Habitat*Q-type</td>
<td>.00</td>
<td>1</td>
<td>.00</td>
<td>9.185</td>
</tr>
<tr>
<td>(TC)</td>
<td>Reef</td>
<td>1.08</td>
<td>2</td>
<td>.54</td>
<td>.008</td>
</tr>
<tr>
<td>(TC)</td>
<td>Habitat</td>
<td>1.08</td>
<td>1</td>
<td>1.08</td>
<td>.002</td>
</tr>
<tr>
<td>(TC)</td>
<td>Reef*habitat</td>
<td>2.05</td>
<td>2</td>
<td>1.02</td>
<td>.000</td>
</tr>
<tr>
<td>(TC)</td>
<td>Reef*Q-type</td>
<td>1.64</td>
<td>1</td>
<td>1.64</td>
<td>.000</td>
</tr>
<tr>
<td>(TC)</td>
<td>Habitat*Q-type</td>
<td>2.46</td>
<td>1</td>
<td>2.46</td>
<td>.000</td>
</tr>
</tbody>
</table>
Juvenile trochus were associated with similar types of algae in both habitats but crustose fleshy was preferred in the rock habitat and crustose coralline in the reef habitat (Fig. 3.1). Preferences for biota were significantly different between random and juvenile areas among reefs and habitats (Table 3.4), indicating that juveniles utilise different resources depending on the habitat they are occupying. The highest frequencies of juveniles occurred in areas that had a high abundance of crustose fleshy algae in the rock habitat and crustose coralline algae in the reef habitat (Fig. 3.1). Very few associations of juvenile and invertebrates were recorded (Fig. 3.4). However, there were differences between areas with juveniles and random areas among habitats and reefs (Table 3.4). Juveniles had some preference for areas with barnacles and were occasionally found on clamshells (Fig. 3.4), but this was not consistent between habitats and among reefs.

Table 3.4: Randomised Block multivariate ANOVA comparing differences of biotic variables between reefs, habitats and random and fixed samples (Q-type). Statistics are for Pillais Trace.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Approximate F.</th>
<th>df. numerator</th>
<th>df. error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Habitat*Q-type</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Reef*Q-type</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Reef*habitat</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Habitat</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Reef</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Reef<em>habitat</em>Q-type</td>
<td>1.96352</td>
<td>28</td>
<td>84 .010</td>
</tr>
<tr>
<td>Habitat*Q-type</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 3.5: Randomised Block multivariate ANOVA comparing differences of abiotic variables between reefs, habitats and random and fixed samples (Q-type). Statistics are for Pillais Trace.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Source of variation</th>
<th>Approximate F.</th>
<th>df. numerator</th>
<th>df. error</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substrate (Reef)</td>
<td>Reef*Q-type</td>
<td>1.74304</td>
<td>4</td>
<td>24 .173</td>
<td></td>
</tr>
<tr>
<td>Substrate (Reef)</td>
<td>Reef</td>
<td>5.46196</td>
<td>8</td>
<td>50 .000</td>
<td></td>
</tr>
<tr>
<td>Substrate (Rock)</td>
<td>Reef*Q-type</td>
<td>3.26587</td>
<td>10</td>
<td>48 .003</td>
<td></td>
</tr>
</tbody>
</table>
Figure 3.3: Frequency (%) distributions of the mouthparts of juvenile trochus on different substrates and algal types among reefs and habitats within reefs.
Figure 3.4: Percentage cover difference (95% C.I.) of substrate type between juvenile sample and random sample among reefs and between habitats within reefs. Sample size (n) at base of graph.
Figure 3.5: Percentage cover difference (95% C.I.) of algal type between juvenile trochus sample and random sample among reefs and between habitats within reefs. Sample size (n) at base of graph.
Figure 3.6: Percentage cover difference (95% C.I.) of invertebrates between juvenile sample and random sample between habitats pooled across reefs. Sample size (n) at base of graph. Note scale difference for % cover difference.
3.6: Discussion

The findings affirm that juvenile trochus are selecting micro-habitats within different macro-habitats on the study reefs. The micro-habitats in each macro-habitat offer a form of refuge and specific abiotic and biotic resources. The findings suggest that reef areas that offer consolidated reef platform and coral rock, fine scale topographically complexity and have abundant crustose and turf algae should be the preferred habitat of juvenile trochus 30-50 mm SW on reefs in King Sound. Even though clear patterns have emerged, the scale of this study was limited to 3 reefs and the findings may not apply to juveniles across reefs in the region. Studies have indicated that there is a shift in microhabitat, with growth (Castell, 1997). The positive relationship between juveniles and holes in the rock habitat may indicate animals may be seeking refuge from predators or desiccation, or both.

Gunkel (1997) on reefs in the Bahamas found that sessile benthic communities that develop on rough surfaces consist of a larger number of species reaching higher diversities than communities that recruit onto smooth surfaces. Therefore, substrate complexity can have a substantial influence on the structure and development of major organisms within these communities. Most reefs in King Sound have both smooth and rough surfaces: intertidal rock habitat generally has smooth surfaces and the reef habitat has rough surfaces. Increased diversity may indicate higher competition and more predator species that may limit recruitment success because post-settlement larvae and recruits are being preyed upon before they reach a size refuge (Marth et al., 1999)

Castell (1997) indicated that juvenile trochus on Orpheus Island, Queensland move from small rubble to larger rocks or coral bench and from very shallow to deeper intertidal pools as juveniles increased in size. Positive relationships have been found between the size of trochus and the presence of dead massive corals and coral platform (Castell, 1997). Juveniles on the study reefs in King Sound preferred coral rock in the rock habitat eventhough the greater area of this habitat was made up of boulders, without a carbonate composition. Juveniles were negatively correlated to boulders in the rock habitat on the study reefs in King Sound.

Microhabitat selection by juveniles may be a consequence of active substrate or food selection, a need to avoid predators or related to competition. This study indicates that large juveniles prefer two types of crustose algae that are abundant in
reef and rock habitats. However, juveniles are more commonly found on crustose fleshy algae in the rock habitat and crustose coralline in the reef habitat. Shepherd & Cannon (1988) found differences in the habitat occupied by small and large juveniles of *Haliotis laevigata* and *H. scalaris* on temperate reefs were related to their different diets.

Juveniles of other gastropods, like Queen Conch *Strombus gigas* and abalone *H. laevigata*, select for different substrates and biota at different stages of their life cycle (Shepherd & Daume, 1996; Stoner, 1994). Relationships between crustose coralline algae and the settlement and post-larval growth of abalone are well known and explanations of chemical, biological and physical relationships have been offered (Shepherd & Daume, 1996). Heslinga (1981) found that a red crustose coralline algae, *Porolithon* sp. with a thin film of microscopic algal cells are a preferred substratum for settlement of trochus larvae. To what extent this relationship determines distributions and abundance of juvenile trochus recruits needs further investigation but it is likely that this positive association is due to food preferences by trochus. Relationships between trochus and crustose coralline algae and crustose fleshy algae in this study would suggest that these algae might have a substantial affect on distributions and abundance of trochus on reefs in King Sound. Different forms of crustose algae were abundant on the 3 study reefs but identification to species level was beyond the scope of this study.

Species identification of different species of algae and associated biofilms preferred by juveniles in conjunction with gut analysis would further narrow down factors affecting juvenile distribution and abundance. The relationships between habitat and juveniles in this study may be used in conjunction with satellite images and Geographic Information Systems to estimate the total juvenile habitat area and these areas can be targeted for stock assessment and stock enhancement. Larger scale studies of size class distribution in juvenile trochus on a wider range of reefs may confirm whether broad-scale and fine-scale patterns of distribution, abundance and habitat preferences are regional and to what degree size influences these patterns.
Trochus have clumped distributions on a broad-scale on reefs in King Sound (Colquhoun, in press). Different habitat patches on reefs provide abiotic and biotic characteristics preferred by trochus which seem to mask trochus distributions. On a finer scale, within these patches of habitat, juvenile trochus further select for suitable substratum, refuges and algae that provide the resources required. Castell (1997) has found similar patterns of distribution on Orpheus Island, Queensland, however methods and variables investigated varied between studies and comparisons of abundance were not done regionally due to the small reef scale of the study.

The characteristics of habitat must be considered one of primary forces influencing the structure of trochus populations (Chapman, 2000). Even though this study only looked at patterns of juvenile and adult trochus distribution and abundance and habitat selectivity on a small number of reefs some clear patterns emerged which will help future research in the region. Some of the information may also be applied to fisheries management, stock enhancement and assessment. The limits of this research need to be recognised so the findings are not applied to inappropriate scales that the research did not investigate. The limitations of this study are that the findings should not be applied across reefs in this region. A much larger scale study on many more reefs would be required.

Trochus have a wide distribution and are part of a diverse benthic community inhabiting coral reefs whose communities and structure vary regionally so trochus are adapted to localised abiotic and biotic characteristics of particular reef systems. Understanding the structure and function of populations and how they relate to other components of the community in terms of abiotic and biotic characteristics helps develop improved techniques for fisheries management, stock enhancement and assessment and may ensure the sustainability of the fishery. Vulnerable commercial trochus fisheries need to be managed more rigorously than less vulnerable species. In the case of the indigenous trochus fishery in W.A. ecological knowledge about habitat associations and communication with the indigenous participants of the fishery seem to be the keys to improved management and regulation.

The appropriate spatial and temporal scale to investigate patterns in community structure is important because variations in habitat at different scales have different influences on trochus populations, as seen in this study. The ecology
of trochus in known to vary regionally so investigations at this scale may perhaps a
good starting point. Research into trochus ecology on a regional scale may give rise
to a more diverse body of information on which to acquire information for
management. Particular ecological questions should be approached at the appropriate
scale. This may not be possible initially because of a lack of basic ecological
knowledge of the species in your region so drawing on the body of knowledge
derived from other regions may help decipher some of the problems but it may also
lead you into investigations that are not suitable for your stock. Temporal scales were
not examined in this study due to constraints but may be no less important in
influencing the structure and dynamics of trochus populations than spatial scales.
Research was only conducted in the day during spring tides because of access and
the time required to conduct surveys. For many species diurnal and seasonal affects
on distribution and abundance may explain the patterns under investigation however
in others this may have little affect on patterns. Financial and logistical constraints
can hamper many studies and important ecological patterns may be missed.

Another important constraint in this study was the inability to locate new
recruits on the study reefs. This may be due to limitations related to temporal or
spatial scales or an inability to sample juveniles in region where new recruits are
assumed to inhabit cavities and spaces within the reef matrix that have an abundance
of detritus until they reached a size and shell thickness when they are not as
vulnerable to predators and can be detected. Until more about the ecology of these
recruits is known stock enhancement techniques using trochus ‘seed’ (<10 mm SW)
may be compromised. Reseeding reefs using juveniles 1-4 mm SW is estimated to be
the most economically viable method because large quantities can be produced at
relatively low cost and reefs can be seeded with a minimum amount of effort. This is
important because fishers of trochus are generally members of subsistent
communities, heavily reliant on the small income trochus may provide and with very
limited resources in which to develop and apply enhancement techniques.
References


