The fish communities and main fish populations of the Jurien Bay Marine Park

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1.0 Executive Summary

The Strategic Research Fund for the Marine Environment funded a range of floral and faunal research projects to determine the characteristics of the marine communities in the Jurien Bay Marine Park (JBMP), which was gazetted in 2003. This project has determined the diversity, density and species compositions of the fishes that occupy reefs, seagrass, unvegetated sand and nearshore surf zone habitats in three different types of management zones in the JBMP. The zones were (1) General use zones, where all types of fishing are allowed. (2) Scientific reference zones, where recreational and commercial rock lobster fishing and selected shore-based fishing activities are allowed. (3) Sanctuary zones, where no boat-based fishing is permitted. Future management of the marine park requires a sound understanding of the relationships among the fish faunas, both within and among the main habitat types in each of the different management zones, and of the variability that occurs at different spatial scales.

The vision provided by the management plan for the JBMP was: "In the year 2025, the marine flora and fauna, habitats and water quality of the Jurien Bay Marine Park will be in the same or better condition than in the year 2005. The area will support viable and ecologically sustainable fishing, aquaculture, recreation and nature-based tourism and the marine park will be considered an important asset by the local community" (Anon., 2005). Key performance indicators, described in the management plan, were designed to ensure that this vision is met. This requires data on how estimates of abundance of fishes varied according to the type of sampling method used during this study. The baseline values for different sampling methods can then be used, in the future, to assess whether the vision for the marine park has been achieved.

This study used the following complementary sampling methods to survey fishes in the different habitats in the JBMP, *i.e.* underwater visual census (UVC) and baited remote underwater video stations (BRUVS) over reefs, BRUVS and trawling in seagrass and over unvegetated sand and seine netting in surf zones. The combined results from the different methods demonstrated that the fish fauna of the JBMP is diverse and comprises temperate, sub-tropical and tropical species. Variability in the fish faunas was detected both within and among the main habitat types and was

related to the range of physical and biological characteristics present. The compositions of species sampled by each method differed. In particular, whereas the samples obtained using UVC, trawling and seine netting contained a range of trophic groups, those collected employing BRUVS were dominated by carnivorous species. These differences in ichthyofaunal composition within and among habitat types and between sampling methods must thus be taken into account when selecting the methods used both for long-term monitoring of fish communities and for providing the types of data necessary for assessing whether the marine park is achieving its objectives.

Biological studies were conducted on three abundant and ecologically important labrid species, *i.e.* the Western King Wrasse *Coris auricularis*, Brown-spotted Wrasse *Notolabrus parilus* and Southern Maori Wrasse *Ophthalmolepis lineolatus*. Each species was found to be a protogynous hermaphrodite and to attain similar maximum lengths of 32 to 40 cm and similar maximum ages of *ca* 11 years. However, the peak spawning periods of *C. auricularis* (autumn/early winter), *N. parilus* (winter/early spring) and *O. lineolatus* (spring/summer) are offset and the dietary compositions of these species differed. These results demonstrate that the spatial and temporal food resources are partitioned among these abundant co-occurring labrids.

Acoustic telemetry was used to study the movements of the adults of *Pseudocaranx georgianus* and the juveniles of *Pagrus auratus* to investigate whether spatial management plans can benefit the stocks of these types of species, which are targeted by fishers. The results demonstrate that the adults of the first species and the juveniles of the second species live in relatively small areas that include different habitats and may thus be protected by the establishment of areas that are restricted to fishing. However, spatial closures would need to contain the different types of habitats that they use and bear in mind that closed areas may have a limited carrying capacity and thus not benefit stocks on a larger scale.

2.0 Acknowledgements

3.0 General Introduction

3.1 Marine protected areas

The International Union for Conservation of Nature defined marine protected areas (MPAs) as "any area of intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment" (Kelleher, 1990). The IUCN (1980) stated that MPAs can help to achieve three main objectives of living resource conservation, *i.e.* maintain essential ecological processes and life support systems, preserve genetic diversity and ensure sustainable utilization of species and ecosystems.

3.1.1 Fisheries management goals

The fisheries management goals of MPAs are primarily concerned with sustaining yields of exploited species and restoring or rebuilding their stocks both insider and outside those areas and insuring against failures of traditional management approaches, such as the use of minimum legal size limits or catch limits (Bohnsack, 1999; Roberts *et al.*, 2003). These benefits may be realised by increased abundance, body size, reproductive output, recruitment and/or fishery yields of key species. Indeed, the abundance of exploited species has been reported in several cases to be greater within than outside protected areas, including, for example, *Pagrus auratus* and *Glaucosoma hebraicum* in the Abrolhos Islands in Western Australia (Russ & Alcala, 1996; Edgar & Barrett, 1999; Babcock *et al.*, 1999; Russ *et al.*, 2005; Watson *et al.*, 2007). The value of MPAs as a fisheries management tool depends, however, on the characteristics of the targeted species, such as their life histories and movements (*e.g.* Cole *et al.*, 2000). The establishment of protected areas may be of little benefit to highly mobile species that move considerable distances and do not occupy a home

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range or revisit specific sites repeatedly, *e.g.* spawning aggregation sites (Kenchington, 1990).

Studies of reserves suggest that benefits to protected populations may appear within one to three years since their establishment and continue to grow for many years (Russ & Alcala, 1996; Halpern & Warner, 2002; Halpern, 2003; Gell & Roberts, 2003). However, responses are species-specific, can be slow, complex and vary with MPA boundary configuration and benefits may not be detected for decades (Williamson *et al.*, 2004; Russ *et al.*, 2005; Barrett *et al.*, 2007; McLean *et al.*, 2010).

3.1.2 Indirect effects of MPAs

While MPAs may be established with the intention of providing protection for exploited species, they can also provide the opportunity for multi-species management and the protection of whole marine ecosystems (Allison *et al.*, 1998; Pinnegar *et al.*, 2000). It is therefore important to understand the likely indirect responses of those ecosystems to protection and potentially an increase in the abundance of exploited species. This requires knowledge of ecological interactions among species and the possibility of ecological 'flow on' effects, such as trophic cascades. Fish species influence the dynamics of other organisms through feeding, *i.e.* whether they are herbivorous, carnivorous or otherwise, excretion and their role as prey (Curley *et al.*, 2002). For example, the removal of piscivorous fish can lead to an increase in the abundance of prey species (Hixon & Beets, 1993). Studies in a New Zealand marine reserve demonstrated that predation can play a key role in ecosystem regulation (Babcock *et al.*, 1999). Increased abundance of *P. auratus* within protected areas has resulted in a shift in community structure and indicates that fishing has had ecological impacts beyond the target species. Similarly, Watson *et al.* (2007) recorded higher abundances of several abundant non-targeted species inside MPAs at the Abrolhos Islands,

Western Australia, and suggested that the indirect effects of fishing will depend on the specific role played by non-targeted species within the ecosystem.

3.2 The Jurien Bay Marine Park

The Jurien Bay Marine Park (JBMP), which is located *ca* 200 km north of Perth on the central west coast of Western Australia, covers an area of *ca* 824 km^2 (Fig. 3.1). This marine park is approximately 90 km long, extending from Green Head (30° 4.18' S) southwards to Wedge Island (30° 49.88' S) and encompasses waters from the low water mark westwards to 3 nm from the territorial baseline, *i.e.* the seaward limit of Western Australian coastal waters (Anon., 2005; Seas and Submerged Lands (Territorial Sea Baseline) Proclamation, 2006).

Establishment of the JBMP was motivated by the recognition of the importance of conserving the State's marine biodiversity and, in particular, unique areas of Western Australia's marine waters, such as those of the central west coast (MPRSWG, 1994; Anon., 2005). Conservation of marine biodiversity and management of human uses are the major management objectives of the JBMP, *i.e.* conservation and maintenance of key ecosystem structure and function, facilitation and management of recreational and commercial activities within an equitable and ecologically-sustainable framework and promotion of education, nature appreciation and scientific research (Anon., 2005).

3.2.1 Major habitats and associated biota

The limestone reef system in the JBMP is representative of that found along the central west coast and which represents a major marine ecosystem within the bioregion (Searle and Semenuik, 1985; IMCRA, 1997). The southwards-flowing Leeuwin Current influences its biogeography and is responsible for the presence of tropical faunal and floral

species in an essentially warm temperate region (Pearce & Walker, 1991; Hutchins, 1994; 2001).

Marine habitats of the JBMP are dominated by intertidal and subtidal reef platforms, seagrass meadows and sparsely or unvegetated subtidal and/or intertidal sand (Fig. 3.1; Anon., 2005). To the east of the 20 m depth contour, at a distance of five to seven kilometres from shore, lies a series of elongate limestone reefs, running parallel to the shore, with numerous associated emergent rocks and islands (Fig. 3.1). This reef system is the longest continuous limestone reef system in Australia, extending approximately 400 km from Dongara to Trigg (Anon., 2005). Ocean swells break on many of these reefs, thus protecting the waters to the east from the prevailing swells and seas and accounting for the presence of sheltered, shallow, lagoonal environments with depths of less than 10 m (Fig. 3.1; Anon., 2005). At least 125 algal species have been recorded in the JBMP, with red algae dominating the diversity. *Ecklonia radiata* is the dominant canopy-forming macro-algal species on subtidal, high energy, limestone reefs, while offshore reef platforms in waters deeper than 20 m are dominated by red algae, which are interspersed with patches of sand (Anon., 2005). Small coral communities are relatively common on the subtidal reefs, although there are no coral reefs within the region (Anon., 2005).

Seagrass meadows within the Jurien Bay Marine Park, which contain up to nine species of seagrass, cover an area of approximately 215 km^2 or 25 % of the total area of the JBMP (Anon., 2005). Dense seagrass meadows, which are located within 4 km of the shore, are dominated by *Posidonia sinuosa* and *Amphibolis* spp. (Fig. 3.1). Deeper basins support less dense seagrass meadows, while higher energy mobile sand areas support meadows of *Halophila ovalis*, which are often removed by winter storms (Anon., 2005).
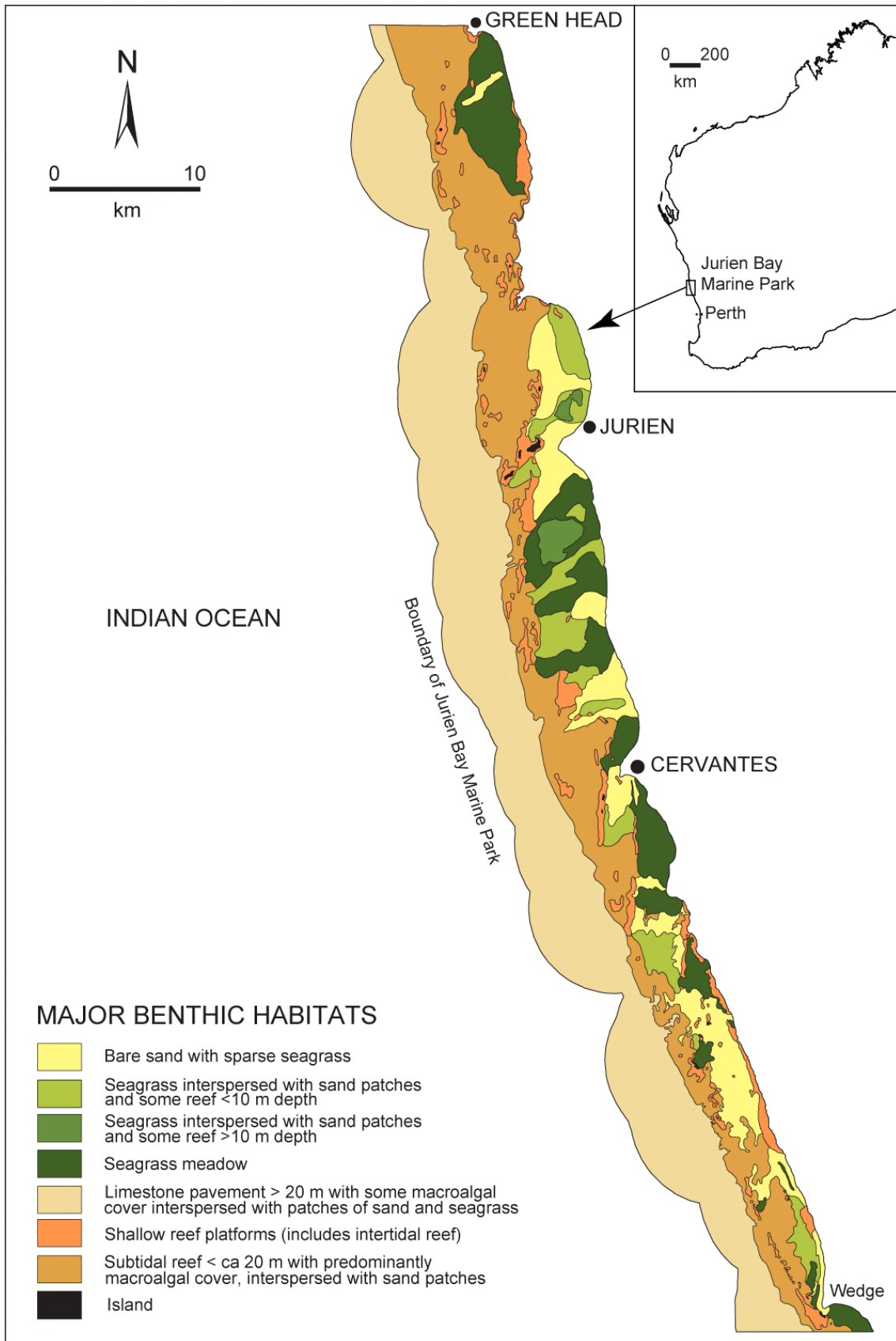
Figure 3.1. The main benthic habitats represented within the Jurien Bay Marine Park. Derived from the Jurien Bay Marine Park Management Plan 2005 – 2015 (Anon., 2005).

3.2.2 Management scheme

The Jurien Bay area supports commercial fishing for Western Rock Lobster demersal and nearshore teleosts, abalone, sharks, aquarium fishes and also aquaculture operations. Recreational fishing is popular and expected to increase. Although the JBMP was not established with the sole intention of providing support to exploited fish stocks, conservation of such targeted species is an intended goal through the management of commercial and recreational practices within the JBMP.

To achieve its objectives, the marine park is divided into different zones (Fig. 3.2). General use areas occupy the majority of the JBMP (77 %) and are open to all methods of recreational and commercial fishing. Scientific reference zones encompass 17 % of the park and allow commercial and recreational rock lobster fishing and selected shore-based fishing activities, *e.g.* line fishing. However, boat-based line fishing is not allowed in those zones. Sanctuary zones occupy 3.7 % of the park and fishing and other extractive activities are only allowed in some of those zones, which permit various types of shore-based fishing (Anon., 2005). There are also small zones for aquaculture and Rock Lobster puerulus monitoring (Fig. 3.2). The JBMP was formally gazetted in August 2003.

JURIEN BAY MARINE PARK
ZONING AND PERMITTED USES

LEGEND

- Jurien Bay Marine Park Boundary
- Sealed Road
- Unsealed Road
- DCLM Managed Lands

MARINE PARK ZONING SCHEME

- General Use Zone
- Special Purpose (Aquaculture) Zone
- Special Purpose (Shore-based activities) Zone
- Special Purpose (Puerulus monitoring) Zone
- Special Purpose (Scientific reference) Zone
- Sanctuary Zone

USES PERMITTED IN JURIEN BAY MARINE PARK ZONES

Y. Yes
N. No
A. Proposal will be assessed by relevant agencies in accordance with standard procedures.
a. Subject to the Marine Act 1983.
b. Subject to the FRM Act 1994.
c. Subject to licence and the provisions of the CALM Act 1984 and Wildlife Conservation Act 1950.
d. Licence required from DCLM and/or DoF.
e. Activities permitted unless activity is shown to be incompatible with the specified primary purpose of the zone.

ACTIVITY	General Use	Special Purpose (Aquaculture)	Special Purpose (Shore-based activities)	Special Purpose (Puerulus monitoring)	Special Purpose (Scientific reference)	Sanctuary
COMMERCIAL						
Commercial rock lobster fishing [b]	Y	Y[e]	Y	N	Y	N
Commercial abalone fishing [b]						
Non shore-based	Y	Y[e]	N	N	N	N
Shore-based	Y	Y	Y	N	Y	N
Commercial gill netting [b]						
Non shore-based	Y	Y[e]	N	N	N	N
Shore-based	Y	Y[e]	Y	N	Y	N
Commercial long line [b]	Y	Y[e]	N	N	N	N
Commercial beach seine [b]	Y	Y[e]	Y	N	Y	N
Commercial wetlining [b]	Y	Y	N	N	N	N
Commercial aquarium collecting	Y	Y	N	N	N	N
Commercial specimen collecting [b]	Y	Y[e]	N	N	N	N
Aquaculture [b]	A	A	A	N	A	N
Mineral & petroleum exploration (seismic)	A	A	A	A	A	A
Petroleum drilling and mineral development	A	A	A	A	A	A
Charter vessels-fishing [d]	Y	Y[e]	N	N	N	N
Charter vessels-other [c]	Y	Y[e]	Y	Y[e]	Y[e]	Y
RECREATION						
Boating (motor & non-motorised) [a]	Y	Y[e]	Y	Y	Y[e]	Y
Surface water sports [a]	Y	Y[e]	Y	Y[e]	Y[e]	Y
Recreational abalone fishing						
Non shore-based	Y	Y	N	N	N	N
Shore-based	Y	Y	Y	N	Y	N
Recreational rock lobster fishing [b]	Y	Y[e]	Y	N	Y	N
Recreational line fishing [b]						
Non shore-based	Y	Y[e]	N	Y[e]	N	N
Shore-based	Y	Y[e]	Y	Y[e]	Y	N
Recreational netting [b]						
Non shore-based	Y	Y[e]	N	N	N	N
Shore-based	Y	Y[e]	Y	N	N	N
Spearfishing [b]	Y	Y[e]	N	N	N	N
Recreational crabbing [b]	Y	N	N	N	N	N
Recreational specimen collecting [b]	Y	Y[e]	N	N	N	N
Diving	Y	Y[e]	Y	Y	Y	Y
Wildlife interaction [c]	Y	Y[e]	Y	Y[e]	Y[e]	Y
OTHER ACTIVITIES						
Proposals for marine infrastructure (eg moorings) [d]	A	A	A	A	A[e]	A
Research [d]	Y	Y[e]	Y	Y[e]	Y	Y

Figure 3.2. Map of the Jurien Bay Marine Park, showing management zone scheme. Provided by the Department of Environment and Conservation.

3.3 Project objectives

This project forms part of a multi-institutional collaboration to investigate ecological interactions in the Jurien Bay Marine Park (JBMP). The recent establishment of the JBMP provides the opportunity to obtain baseline data on the fish faunas of its major habitat types and management zones, which will allow management bodies and researchers in the future to determine the following for those habitats.

(1)   Whether there have been positive or negative impacts on the abundance of exploited and non-targeted fish species in zones that prohibit fishing.

(2)   The influence of different levels of fishing restrictions, *i.e.* "no fishing" sanctuary zones *vs* "limited fishing" scientific reference zones, on the abundance of exploited and non-targeted species.

(3)   Whether there are changes in community composition in zones with different levels of protection from fishing.

(4)   Whether there is evidence of the spillover of individuals of exploited or non-targeted species from sanctuary zones into adjacent waters as indicated by increases in their abundance in those adjacent areas.

The broad objectives of this project were thus as follows.

(1)   To determine the diversity and densities of fish species and their compositions in reef, inshore seagrass and unvegetated sand, and nearshore unvegetated surf zone habitats in the three major management zones of the JBMP, *i.e.* general use, scientific reference and sanctuary zones.

(2)   To elucidate biological parameters of three abundant and ecologically important labrid species, *i.e.* the Western King Wrasse *Coris auricularis* (Valenciennes), the Brown-spotted Wrasse *Notolabrus parilus* (Richardson) and the Southern Maori

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Wrasse *Ophthalmolepis lineolatus* (Valenciennes), which focused on the reproductive biology, age compositions, growth patterns and diets of those three species.

(3)   To determine the movements of individuals of the commercially and recreationally important Silver Trevally *Pseudocaranx georgianus* (Cuvier) and Pink Snapper *Pagrus auratus* (Forster) to develop an understanding of the usefulness of protected areas for the management of the stocks of such species and whether these species use the various habitats available to them in the JBMP.

Specific hypotheses that were tested within those broad objectives are included in each chapter.

4.0 General materials and methods

4.1 Sampling timing, locations and methodologies employed

4.1.1 Fish community studies

The fish communities of the Jurien Bay Marine Park (JBMP) were sampled at sites in three main habitats, *i.e.* reefs, seagrass and unvegetated sand, and the three main management zones, *i.e.* general use, scientific reference and sanctuary zones. Sampling was undertaken seasonally for two consecutive years and employed the following regimes.

(1)   Underwater visual census (UVC) of reef fishes in each season between autumn 2005 and autumn 2007 in each of the three management zones in two locations, *i.e.* (1) between Green Head and Sandy Point (referred to as Green Head; Fig. 4.1) and (2) between North Head and Black Rock (referred to as Jurien; Fig. 4.2). In each zone, censuses were undertaken at protected and shallow inner and mid-reef sites and at deeper and exposed outer reef sites.

(2)   Trawling of seagrass beds was conducted in each season between Autumn 2005 and Summer 2006/07 in inshore waters in each of the three zones at Green Head and Jurien. Inshore unvegetated sand was trawled in each season between Autumn 2005 and Summer 2005/06 in each zone and location, except for the Green Head scientific reference zone, where there was insufficient sand habitat (Figs 4.1, 4.2).

(3)   Baited remote underwater video was used to sample fishes in all of the above habitats, *i.e.* reefs and inshore seagrass and sand between summer 2005/06 and autumn 2007 in each of the three zones at Green Head and Jurien. Baited remote underwater video stations were deployed at each of the reef sites surveyed using UVC and at the same locations as each replicate trawl in the inshore seagrass beds and unvegetated sand (see earlier; Figs 4.1, 4.2).

(4)   Seine netting of nearshore unvegetated surf zones was conducted between Winter 2005 and Autumn 2007 in each of the three zones in the Green Head and Jurien locations and also in a third location between Cervantes and Wedge (referred to as Cervantes) (Fig. 4.3).

4.1.2 Biological studies

(1)   Samples of the three labrid species selected for biological studies, *i.e. Coris auricularis*, *Notolabrus parilus* and *Ophthalmolepis lineolatus*, were obtained between January 2005 and October 2007 with the aim of collecting samples for each calendar month. Samples were collected using different methods in waters < 25 m deep in the Green Head and Jurien locations at as many of the different reefs in the JBMP as possible (see Fig. 3.1 for reef habitat locations) to minimise the impact of fish removal from any one reef. Additional samples of *N. parilus* were obtained from the above-described trawling of seagrass beds.

(2)   The movements of *Pseudocaranx georgianus* and juvenile *Pagrus auratus* were studied for up to one year, between the springs of 2006 and 2007, in and immediately to the south of the Boullanger Island sanctuary zone, immediately to the south of Jurien Bay (Fig. 4.2).

Specific details of each of the community and biological sampling regimes and methodologies employed in the field and laboratory are described in further detail in each chapter. Surface water temperature, wind direction and strength, sea state, swell height and tidal height and state were recorded during each season of sampling. The Department of Planning and Infrastructure provided their data on the height of swell and seas recorded at Jurien for the period during which sampling took place. Family and species names used in this study were derived from the California Academy of Sciences Catalog of Fishes (http://research.calacademy.org/ichthyology/), CSIRO CAAB database (http://www.cmar.csiro.au/caab/caabsearch-frames.htm), Gomon *et al.* (2008) and relevant current taxonomic literature. Species identification was, in some cases, confirmed by Drs Sue Morrison and Glenn Moore of the Western Australian Museum.
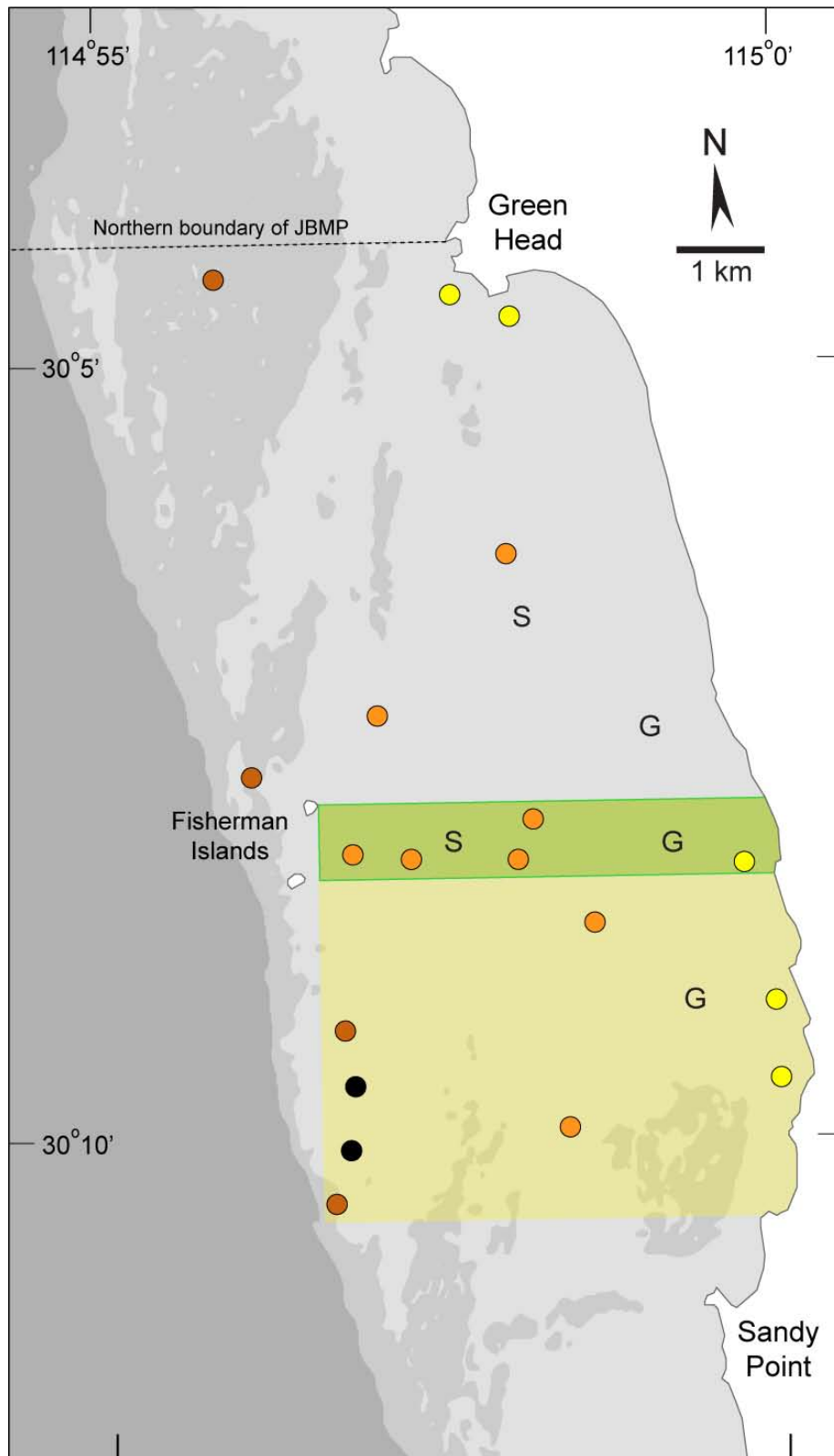
Figure 4.1. Map of sites in the scientific reference (☐), sanctuary (☐) and general use (remainder of waters) zones between Green Head and Sandy Point in the Jurien Bay Marine Park (JBMP).
Inner (◯), mid (●), and outer (●) reef sites surveyed using underwater visual census and baited remote underwater video (BRUV); additional outer reef BRUV sites (●); Trawl and BRUV sites in seagrass (G) and sand (S). Bathymetry: 0 – 10 m ☐ , 11-20 m ☐ , 21-50 m ☐
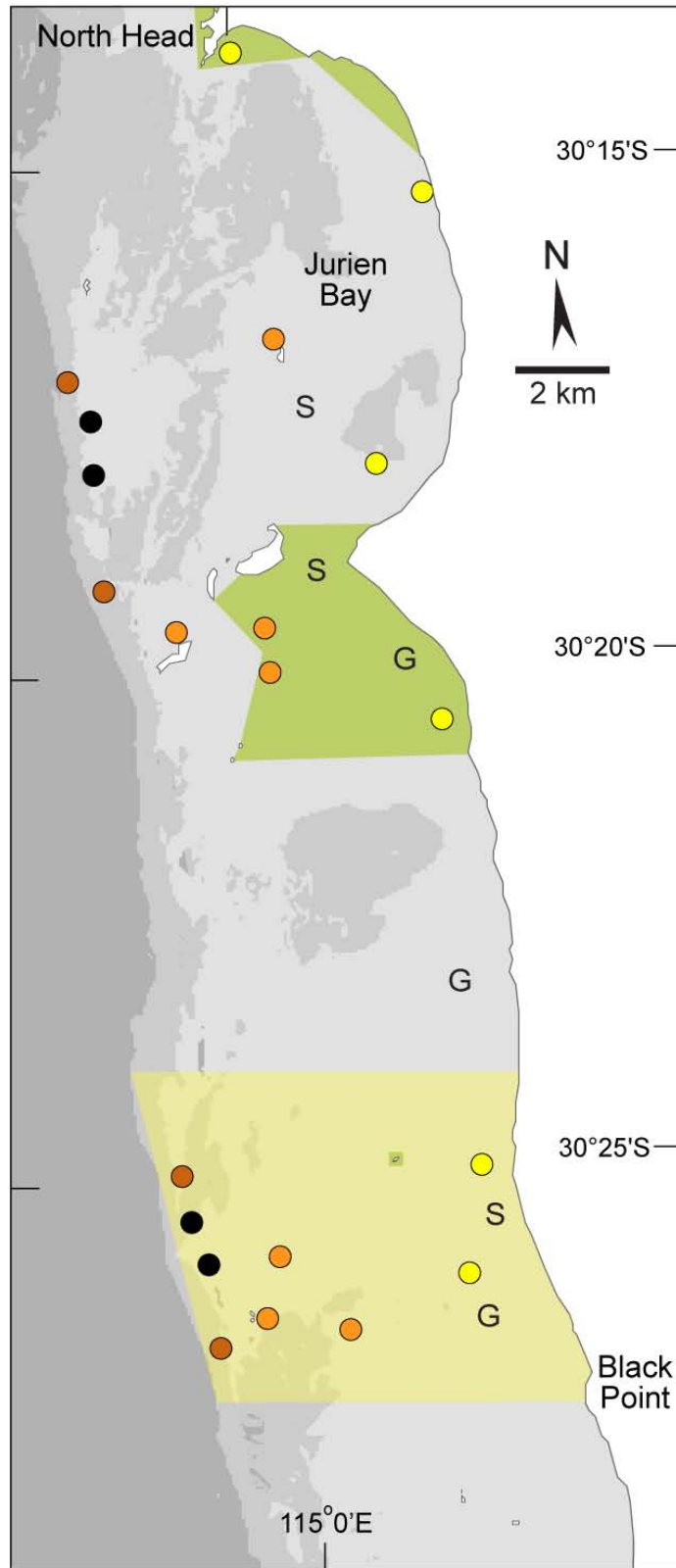
Figure 4.2. Map of sites in the scientific reference (▢), sanctuary (▢) and general use (remainder of waters) zones between North Head and Black Point in the Jurien Bay Marine Park (JBMP).
Inner (◯), mid (◯), and outer (◯) reef sites surveyed using underwater visual census and baited remote underwater video (BRUV); additional outer reef BRUV sites (●); Trawl and BRUV sites in seagrass (G) and sand (S). Bathymetry: 0 – 10 m ▢ , 11-20 m ▢ , 21-50 m ▢
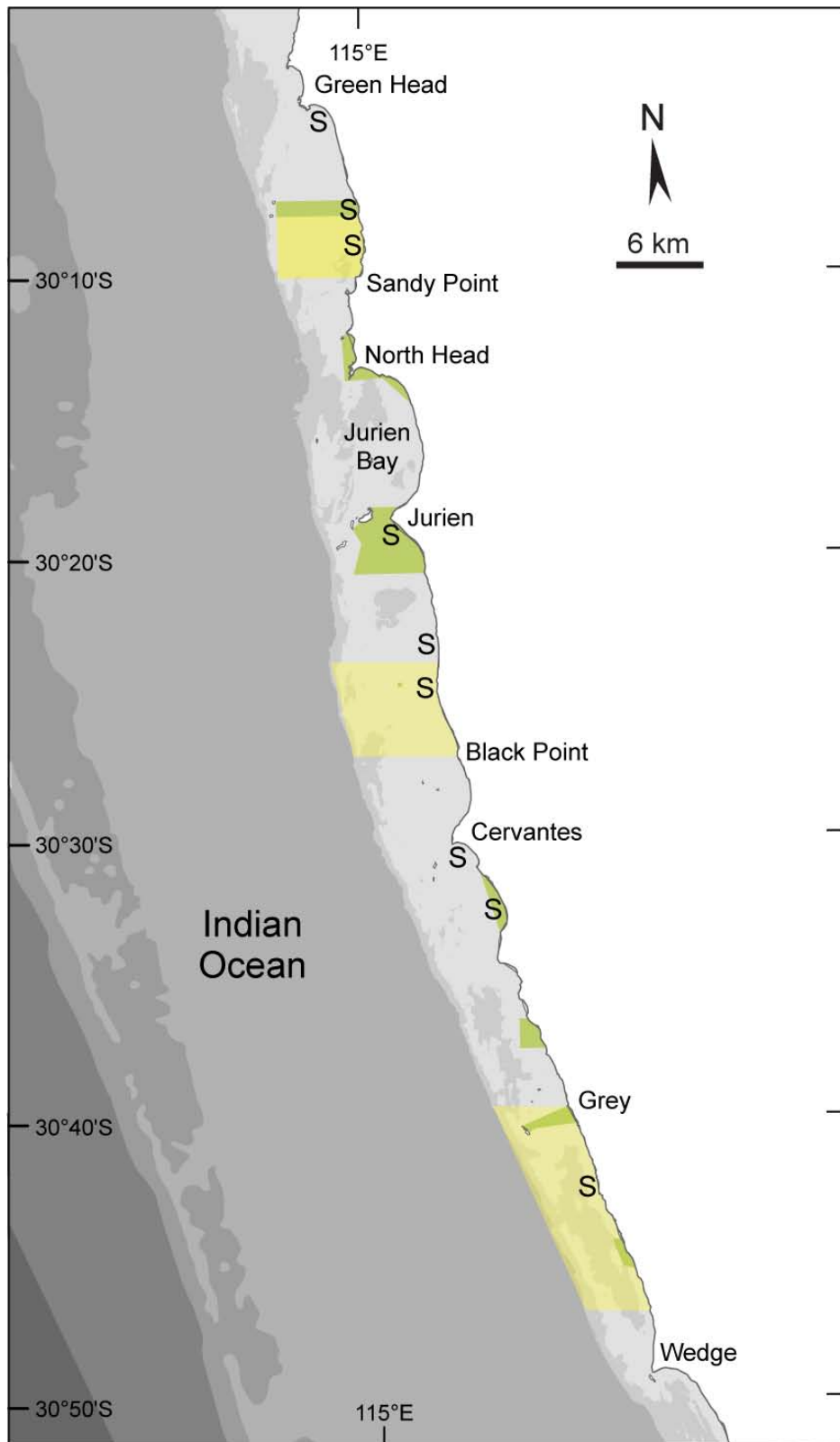
Figure 4.3. Map of seine netting sites (S) in the scientific reference ( ), sanctuary ( ) and general use (remainder of waters) zones between Green Head and Wedge in the Jurien Bay Marine Park (JBMP). Bathymetry: 0 – 10 m , 11-20 m , 21-50 m , 50-100 m .

5.0 Fish communities of reef habitats of the Jurien Bay Marine Park

Fairclough, D. V. and Potter, I. C.

5.1 Introduction

The compositions of reef fish communities and the abundance and size distribution of individual fish species are related to a range of factors, including environmental factors, competitive forces and anthropogenic effects. Environmental factors, such as substrate type, rugosity, the composition of any algal or seagrass communities and the types of nearby alternative habitats, play a major role in structuring fish assemblages in any location (*e.g.* Andrew & Mapstone, 1987; Choat & Ayling, 1987; Holbrook *et al*., 1990; Harman *et al*., 2003; Hyndes *et al.*, 2003; Anderson & Millar, 2004; Valesini *et al.*, 2004). These factors influence habitat complexity and thus, through the provision of refugia and prey, the extent of predation on fish. For example, as high-relief limestone reefs are more structurally complex than low-relief reefs, they offer greater refuge from predation and thus support a greater abundance and diversity of fish (Harman *et al*., 2003). Anderson & Millar (2004) found that diversity and total abundance of fish were both positively related to variation in kelp density, indicating that the algal structure and heterogeneity of the habitat may play a role in providing refugia from predation, particularly for juvenile fish. Structural complexity, in the form of relief and algal composition can also influence the compositions of invertebrate species and thus prey availability (Wellenreuther & Connell, 2002; Anderson & Millar, 2004; Vanderklift & Kendrick, 2004; Tuya *et al*., 2008).

The composition of fish communities and its diversity and species richness in different habitat types, *e.g.* reefs and sand, often change with distance from the shore and depth and exposure to wave action (Holbrook *et al*., 1990; Newman *et al.*, 1997; Connell & Lincoln-Smith, 1999; Hyndes *et al.*, 1999; Travers & Potter, 2002; Fulton & Bellwood, 2004; Denny, 2005; Travers *et al.*, 2006; Williams *et al.*, 2008). For example, some of the variation

between fish assemblages of nearshore and offshore marine waters of south-western Australia were attributed by Hyndes *et al.* (1999) to certain species moving out of their nearshore nursery areas as they increase in size and into deeper offshore waters where they spawn. Furthermore, closely-related and thus morphologically similar species, *e.g.* labrids, typically partition spatial and/or food resources, resulting in different species compositions among available habitats (Ross, 1986; Fulton and Bellwood, 2004; Denny, 2005; Fairclough *et al.*, 2008).

As human pressure on marine resources grows, more areas are being closed to fishing with the aim of protecting biodiversity and/or benefiting fish populations. There are documented examples of increases in abundance and biomass of targeted species in such areas (see review by Halpern, 2003; Lester *et al.*, 2009). However, the contribution of such increases to fished stocks at a broader scale is a complex issue and any spillover effects may be negated by displaced fishing effort (see Field *et al.*, 2006; Penn and Fletcher, 2010). Furthermore, Willis *et al.* (2003) found that many studies yielded ambiguous results, commonly as a function of inappropriate sampling design, and that relatively few studies had established that increases in abundance could not be accounted for by solely by natural variation. There are varying examples of the length of time required, following protection of an area from fishing, to realise purported benefits, which is not surprising given the array of biological characteristics of targeted fish species (*e.g.* Russ and Alcala, 2004; McClanahan and Graham, 2005; Russ *et al.*, 2005). Indeed, for any targeted species, benefits may only be realised if the areas closed to fishing provide the types of resources, *e.g.* space, habitat and food, that those species require at different stages in their life cycle and thus lead to increases in the biomass of such species (see *e.g.* McLean *et al.*, 2010).

The reef fish communities on the mid-west coast of Australia, from Kalbarri (27°43' S) to Lancelin (31° S), consist of a combination of warm-temperate, subtropical and

tropical species and are dominated by the Labridae, Pomacentridae, Monacanthidae and Serranidae (Hutchins, 1994; 2001; Fromont *et al.*, 2006). The most abundant species in fish communities of this region recorded during timed underwater visual census (UVC) by Hutchins (1994; 2001) and by UVC along strip-transects by Fromont *et al.* (2006) and Tuya *et al.* (2009) was the labrid *Coris auricularis*, which accounted for 35 % of all individuals recorded by Fromont *et al.* (2006). Other abundant species included the labrids *Halichoeres brownfieldi* and *Notolabrus parilus* and the pomacentrid *Parma mccullochi* (Hutchins, 2001; Fromont *et al.*, 2006). The other few published studies on the fish fauna of the mid-west coast (not including the Houtman-Abrolhos Islands) have compared that of those in shallow reefs and seagrass (Howard, 1989), surveyed specific families occupying only reef habitats (Tuya *et al.*, 2009) and investigated interactions between predators and prey (Howard, 1988; Vanderklift *et al.*, 2007).

The objective of the present study was to determine the numbers of fish species, the relative density of each species and the compositions of the fish communities over inner, mid- and outer reef habitats in the general use, scientific reference and sanctuary zones of the Jurien Bay Marine Park (JBMP). This will provide quantitative baseline data at different spatial scales for future comparative studies. The study also investigated those environmental factors that are likely to be correlated with those variables, *e.g.* distance from shore, depth, structural complexity and algal composition, to enable future monitoring programs to be designed to account for the factors responsible for variations in the fish fauna. The following specific hypotheses were explored.

(1) The fish fauna of outer exposed reefs is less diverse and houses fewer individuals than more protected inner and mid- reefs and has a different species composition.

(2) The numbers of species, density of fishes and composition of the fish fauna at inner, mid- and outer reef locations do not differ among marine park zones.

(3) The composition of fish species at inner, mid- and outer reefs is correlated with environmental variables such as distance from shore, depth, rugosity/relief and algal composition.

5.2 Materials and methods

5.2.1 Sampling regime

Fishes

Underwater visual census (UVC) of the fish communities of reef habitats in the JBMP was conducted whenever possible in each season between Autumn 2005 and Autumn 2007. Two sites were surveyed, where available, at inner, mid- and outer reef locations, which were < 2 km, *ca* 2.5-6 km and *ca* 5-7 km from shore, respectively, in a general use, scientific reference and sanctuary zone in two "regions", (1) Green Head to Sandy Cape, referred to as Green Head, and (2) North Head to Black Rock, referred to as Jurien (Figs 4.1, 4.2; Table 5.1). The inner and mid- reef sites were in shallower, *i.e.* maximum depth 4-9 m and 5-11 m, respectively, and more protected waters than outer reefs, which were deeper (max. 12-18 m) and directly exposed to swell and seas (Table 5.1).

Surveys were conducted at a third mid-reef site in the Jurien scientific reference zone to increase replication. Only one inner reef site, that was large enough to be surveyed, was available in the only sanctuary zone at Green Head and the two inner sanctuary zone sites at Jurien were located in two different sanctuaries for the same reason (Figs 4.1, 4.2). None of the sanctuary zones extended to outer reefs. While the Green Head sanctuary zone did extend to > 6 km from shore, potential "outer reef" sites in this zone lay in waters that were protected from wave action by islands and were thus more similar to mid- reefs. Sampling was conducted at those two sites in addition to two strictly "mid-reef" sites, providing increased replication.

Table 5.1. Reef sites surveyed by underwater visual census in the Jurien Bay Marine Park and their "region", marine park zone (General use, GU; Scientific reference, SR; Sanctuary, SZ), reef location (inner, mid-, outer), distance from shore and maximum depth.

Region	Marine park zone	Reef Location	Site number	Distance from shore (km)	Max. depth (m)
Green Head (GH)	GU	Inner	1	0.5	6
	GU	Inner	32	0.6	9
	SR	Inner	9	0.7	6.4
	SR	Inner	34	0.7	5
	SZ	Inner	29	0.9	5.5
	GU	Mid	2	2.5	7
	GU	Mid	3	4.0	6
	SR	Mid	8	3.4	9
	SR	Mid	33	2.9	8
	SZ	Mid	5	3.5	5
	SZ	Mid	6	5	6.5
	SZ	Mid	27	4.7	6
	SZ	Mid	28	3.2	6
	GU	Outer	4	5.9	13
	GU	Outer	31	5.7	15
	SR	Outer	7	5.4	12
	SR	Outer	35	5.7	14
Jurien (JB)	GU	Inner	10	1.0	8.5
	GU	Inner	36	0.1	4
	SR	Inner	19	1.8	7
	SR	Inner	23	1.1	5.5
	SZ	Inner	16	0.6	5
	SZ	Inner	20	0.3	5
	GU	Mid	11	3.9	9
	GU	Mid	13	4.5	10
	SR	Mid	17	4.6	9
	SR	Mid	18	5.8	9
	SR	Mid	26	3.8	11
	SZ	Mid	14	3.2	5.5
	SZ	Mid	15	3.5	7.1
	GU	Outer	12	4.8	15
	GU	Outer	21	7.2	18
	SR	Outer	22	6.6	14
	SR	Outer	24	6.5	16

During each season, when visibility in the water was at least 5 m, seven 25 x 5 m strip-transects were surveyed at each site at Green Head and Jurien (Fig. 5.1). The senior author conducted all surveys to minimise and standardise any bias in the counts and length estimations of fish and estimates of transect width. The dimensions of transects were chosen
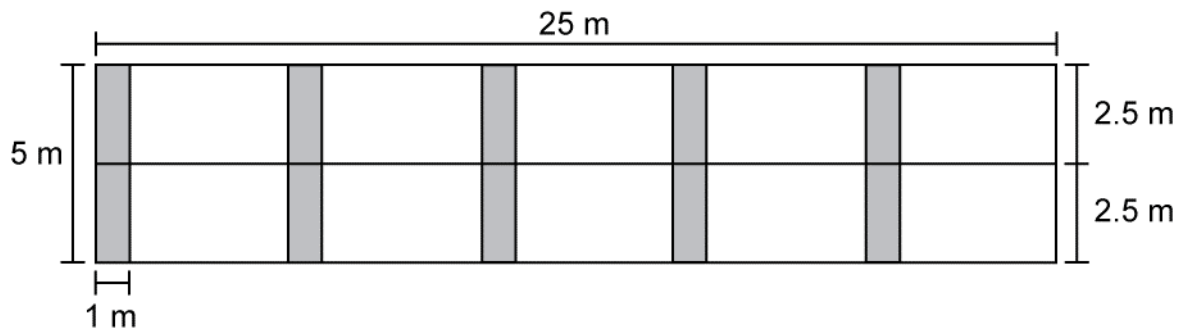
Figure 5.1. Schematic drawing of a transect, showing length (25 m), total width (5 m), centre line along which the diver swam, distance surveyed either side of the centre line (2.5 m) and location (grey shading) on each transect and dimensions (5×1 m) of five belts surveyed for benthic characteristics.

due to the small size of some of the reefs available to survey and as visibility was rarely

$\geq$ 10 m. This also ensured that surveys were conducted only within reef habitat and allowed

for sufficient replication at each site (see Kingsford, 1998). The length of each transect was

measured using a 25 m long rope. To minimise the likelihood of disturbing fish prior to

counting, one end of the rope was attached to a dive weight, which was placed on the

substrate at the beginning of each transect, after which the rope was unravelled while

swimming along the transect (see *e.g.* Williamson *et al.*, 2004). The 5 m width of each

transect was estimated by eye as being 2.5 m either side of the diver. Prior to each sampling

season, the senior author trained to estimate distance underwater (see Harvey *et al.*, 2004).

Transects were located haphazardly during each survey. At those reef sites that were

long and narrow, the transects were aligned longitudinally, with each successive transect

commencing *ca* 25 m from the end of the previous transect, while at all other sites, transects

formed a grid pattern, with each replicate being parallel, but at least 50 m apart. At each site,

surveys were conducted within a similar area of reef on each sampling occasion. Fishes were

identified to species where possible and the number of individuals of each species recorded.

When the end of each transect was reached, the senior author returned to the beginning of

that transect, surveying cryptic fishes underneath ledges and in reef holes within the

boundaries of the transect. Individuals of selected commercial, recreational and abundant

species were assigned to 50 mm total length (TL) categories, rather than estimating exact lengths, due to issues of accuracy and precision associated with estimating lengths by eye (Harvey *et al.*, 2001). Fish > 500 mm TL were all assigned to the length category "≥ 500 mm", as there can be substantial error in estimating by eye the lengths of large fishes (*e.g.* Edgar *et al.* 2004). Prior to each sampling season, the senior author trained in estimating fish lengths using plastic fish templates of a range of lengths (see Williamson *et al.*, 2004). The sex of each fish was recorded when possible, using sexually dimorphic characteristics, such as colour phase in labrids (juvenile, female, male) and the presence of a dorsal fin filament in male *Glaucosoma hebraicum*. Note that while colour phase can be broadly used to identify the sex of labrids in many cases, there is always some overlap of colour patterns during sexual transition (*e.g.* Coulson *et al.*, 2009).

Environmental variables

Rugosity was measured on one occasion in the area surveyed for fishes at each reef site using the methods of Luckhurst and Luckhurst (1978). At each site, a 25 m rope, with marks at 5 m intervals, was laid out in a straight line along four consecutive transects (see Fig. 5.1). A 10 m long chain was laid consecutively at each 5 m mark in a straight line perpendicular to the transect rope along the reef surface, ensuring that it followed all reef contours and the centre of the chain intersected the transect rope. The straight-line distance between the two ends of the chain was measured to the nearest 0.1 m using a tape measure. A rugosity index (R) for each replicate was calculated using the following formula: $R = 1$- (straight line distance/total chain length). Possible rugosity values thus ranged from 0 to 1 and increase with increasing rugosity.

A small straight-line distance measurement for an individual replicate could be obtained when the measurement was taken over substrate that consisted of many small

undulations or holes or which had very high relief, giving high rugosity indices for structurally very different habitat. Thus, a subjective classification of the average height of vertical relief above the reef substrate at the location of each replicate measurement of rugosity was also recorded as either low (< 1 m), moderate (1-2 m) or high (> 2m).

Depth soundings (to the nearest 0.1 m) were acquired from the areas typically surveyed by UVC at four reef sites, to produce three-dimensional maps of reef bathymetry. Soundings were obtained by driving a vessel at *ca* 1 knot along transects on an approximately east-west and north-south grid pattern and logging location (latitude and longitude) and depth every two seconds using a Garmin GPSMap 176c (WGS84 datum) and Windows Hyperterminal™ on a laptop computer. Transects were approximately 10 m apart. The locations and depths of each of the four reef sites, were then mapped using Surfer 8$^{©}$ to provide a three dimensional image of the reef surface.

During UVC of fishes, the second diver recorded the percentage cover of the substrate by dominant macrophytes, sponges, corals and sand in a 1 m wide belt across the transect, *i.e.* 5 m across and 1 m along the transect (area = 5 m^2; Fig. 5.1), at five locations along each transect. The dimensions of the "belt" were estimated by eye, with its mid-point being the transect rope (described earlier). As different second divers were used, only readily identifiable species, genera or major morphological groups were recorded (Table 5.2). Unidentifiable algae were assigned to a plant Division, *i.e. Heterokontophyta: Phaeophyceae* (brown algae), *Rhodophyta* (red algae), *Chlorophyta* (green algae), and a morphological group depending on their physical structure, *i.e.* foliose, filamentous, cartilaginous or calcareous (Table 5.2).

Table 5.2. Identifiable species and major morphological groups used for recording percentage cover of macrophytes (and for analyses) in each replicate at each reef site.

Species/major groups	Species examples from groups
Brown algae (Phaeophyceae)	
Ecklonia radiata	
Sargassum spp.	
Scytothalia doryocarpa	
Scaberia agardhii	
Calcified browns	*Padina* sp. (only)
Filamentous browns	*Hincksia* sp.
Other branching browns	*Platythalia* sp., *Dictyopteris* sp., *Cystophora* sp.
Other small browns	*Colpomenia* sp.
Green algae (Chlorophyta)	
Caulerpa spp.	*Caulerpa obscura, Caulerpa racemosa*
Codium sp.	*Codium spongiosum*
Filamentous greens	*Cladophora* sp.
Foliose greens	*Ulva* sp.
Red algae (Rhodophyta)	
Branching foliose reds	*Asparagopsis* sp., *Callophycus* sp., *Curdiea* sp., *Osmundaria prolifera, Plocamium* sp., *Pterocladia* sp.
Calcareous epiphytic reds	*Jania micrarthrodia*
Calcareous reds	*Metamastophora flabellata, Metagniolithon* sp., *Amphiroa gracilis, Amphiroa anceps*
Crustose calcareous reds	*Hydrolithon* sp., *Lithophyllum* sp.
Filamentous reds	*Ceramium* sp.
Seagrasses	
Cymodoceans	*Amphibolis antarctica, Amphibolis griffithii, Syringodium isoetifolium*
Hydrocharitaceans	*Halophila* sp.
Posidonians	*Posidonia australis, Posidonia sinuosa*
Zosteraceans	*Heterozostera tasmanica*
Turf	Includes brown, green and red turfs

5.2.2 Statistical analyses

The number of sites surveyed was restricted in autumn and winter 2005 and winter 2006 by frequent large swells that occur in the JBMP region as a result of cold weather fronts that prevent access to sites and reduce visibility. Thus, to maintain balance in terms of the numbers of sites (34) surveyed per season, analyses were restricted to data from the springs, summers and autumns of the two years of sampling.

Univariate analyses

The numbers of individuals of each fish species recorded on each transect were treated as a density, *i.e.* fish 125 m^{-2}. The following univariate tests were each conducted using permutational multivariate analysis of variance (PERMANOVA; using the PRIMER v6 statistical package, in conjunction with the Windows PERMANOVA+ module; Anderson, 2001; Clarke and Gorley, 2006; Anderson *et al.*, 2008). PERMANOVA was chosen for univariate analyses as it produces outputs from a test statistic that is derived by permutation and thus avoids the need to meet the assumptions of ANOVA, *i.e.* normality and homogeneity of variances. As there were imbalances in replication, as a result of different numbers of sites in some zone/reef location combinations, each analysis was performed using type III sums of squares, which is recommended for unbalanced, multifactorial designs (Quinn & Keough, 2002).

Although PERMANOVA makes no formal assumptions of homogeneity of variance, it is sensitive to spread, thus, transforming the data, if necessary, will reduce the likelihood of differences between groups as a result of spread (Anderson, 2001). For each of the variables subjected to PERMANOVA, *i.e.* rugosity, numbers of fish species and relative density of fishes, examinations of the relationships between the ln(x+1) transformed means and ln(x+1) transformed standard deviations of each variable, derived from each site in each reef location, zone and season, together with normal Q-Q plots, were conducted to gain an understanding of their distributions (see Clarke and Warwick, 2001; Quinn and Keough, 2002). A ln(x+1) transformation was required for the variable density of fishes, while none was necessary for numbers of species or rugosity. For each variable, a similarity matrix was derived from the transformed or untransformed data using Euclidean distance, which was then subjected to PERMANOVA using the designs described below. When a significant effect of a factor or interaction was detected, *i.e.* the null hypothesis of no difference was rejected based on

$p \leq 0.05$, pairwise PERMANOVA tests were conducted to determine which levels of each factor differed significantly.

The untransformed/transformed data for each variable were subjected to PERMANOVA using the following designs.

(1)   *Rugosity*. Two separate tests were conducted, each using a one-way design, to test the effects of relief (fixed, 3 levels, low, moderate and high) and reef location (fixed, 3 levels, inner, mid- and outer) on the variable rugosity.

(2)   *Numbers of fish species and density of fishes*. The total number of species and density of fishes were each analysed using two-way crossed designs. The factors were zone (fixed, 6 levels, Green Head general use, GHGU; Green Head scientific reference, GHSR; Green Head sanctuary, GHSZ; Jurien general use, JBGU; Jurien scientific reference, JBSR; and Jurien sanctuary, JBSZ) and reef location (fixed, 3 levels, inner, mid- and outer reef). Between one and four sites were located in any one zone/reef location combination. Site was not used as a factor, as it was not strictly of interest. Thus, each combination of zone/reef location comprised either seven, 14, 21 or 28 replicate transects in each season, which were treated as random.

To overcome a missing level in the sampling design, *i.e.* outer reef in sanctuary zones, two PERMANOVA tests were performed on the number of fish species and density of fishes. Firstly, all outer reef samples were excluded to allow for a test among all three zones using only inner and mid- reefs. Secondly, all sanctuary zone samples were excluded, leaving general use and scientific reference zones, to allow for a test across all sampled reef habitat types, *i.e.* inner, mid- and outer reefs. Season was not included as a factor in these analyses, as similar tests on the data collected using baited remote underwater video demonstrated that season had only a weak influence on the variables number of species and number of fishes

(see Chapter 8). As transects were laid haphazardly in the same general area of reef at each site, visual census would have included slightly different habitats at each site in each season.

Multivariate analyses

The densities of each fish species in each replicate at each site in all sampling seasons were ln(x+1) transformed using the PRIMER v6 statistical package. As in the above univariate analyses, the following analyses were conducted on two sub-sets of the data, to account for the absence of outer reefs in sanctuaries, *i.e.* (1) inner, mid- and outer reef locations in general use and scientific reference zones and (2) inner and mid- reefs in general use, scientific reference and sanctuary zones. Prior to constructing separate Bray-Curtis similarity matrices from the two ln(x+1) transformed data sets, a dummy variable of 0.1 was added to account for zero values in the data. The matrices were subjected to a two-way crossed (reef location × marine park zone) PERMANOVA to investigate whether there were any interactions between those two factors. Using the same data sets, a two-way Analysis of Similarities (ANOSIM; Clarke, 1993) was then conducted to determine the strength of any significant differences among the two main factors or interactions, followed by pairwise tests among the levels of each significant factor. Where significant differences were detected among groups of a factor, Similarity Percentages (SIMPER; Clarke and Gorley, 2006) was then used to determine which species typified and distinguished each of those groups. Non-metric multidimensional scaling (nMDS) ordination plots were used to visualise differences and similarities between groups of factors and the basis of interactions between factors, as indicated by PERMANOVA.

Relationship between environmental variables and the composition of fishes

To investigate the relationship between the fish composition data and the 30 measured environmental predictor variables at each site, *i.e.* distance from shore, depth, rugosity, % frequency of low, moderate and high relief and the % cover of algal groups, sponges, corals and sand, a distance-based linear model was constructed using the DISTLM routine (multivariate multiple regression) in PRIMER (McArdle and Anderson, 2001). DISTLM tests the null hypothesis of no relationship between the fish composition data and (1) each environmental variable separately and (2) each variable conditional on the other variables already fitted in the model. Each environmental variable was fitted in a step-wise fashion to produce the most parsimonious model, which included the variables most important in describing the variation (adjusted R^2) in the fish composition data.

As some environmental variables were measured only once, *e.g.* rugosity, they were each averaged to the site level, providing an environmental "signature" for each site. While distance from shore, depth, rugosity and % frequencies of low, moderate and high relief did not require transformation, the % cover variables were square root transformed. Variables were normalised to remove any effects of different measurement scales. Draftsman plots were constructed to investigate pairwise correlations between environmental variables. As no two variables were highly correlated, *i.e. r* either < -0.95 or > 0.95, all were included in the analysis. The ln(x+1) transformed data for the composition of fishes at each site in each season were also averaged for each site and a Bray-Curtis similarity matrix constructed, prior to DISTLM analysis. A constrained ordination plot was constructed from the above analysis, which produces axes that are directly and linearly related to the predictor variables. Vectors were overlaid on the plot for each variable identified by the DISTLM model as having a significant relationship with the fish data. The length and direction of each vector indicates the strength of the correlation and whether it was negative or positive.

5.3 Results

5.3.1 Structural complexity of reefs

The percentage of low, moderate and high vertical relief recorded was highly variable within and among the different sites and reef locations, *i.e.* inner, mid- and outer reefs (Table 5.3). The overall percentages of low and moderate relief increased and decreased, respectively, with increasing distance from shore, *i.e.* from inner to outer reefs, while the percentage of high relief recorded at each reef location was similar (20-23 %; Table 5.3).

Mean rugosity indices (*RI*) ranged from 0.14 to 0.41 and sites which comprised solely or almost exclusively low vertical relief, *i.e.* 5, 7, 14, and 28, had some of the lowest mean rugosity indices, *i.e.* 0.15-0.20, while some of those that were dominated by high vertical relief (sites 6, 12, 19 and 23; 55-80 %) had some of the highest mean *RI*s, *i.e.* 0.29-0.39 (Table 5.3; Fig. 5.3). Separate mean *RI* calculated from all replicates at all sites that had low, moderate or high relief increased with increasing relief and thus provided a good metric for the subjective categories of vertical relief (Fig. 5.4a). The mean *RI* was significantly different among those categories and between each pair of categories. The mean *RI* differed significantly among reef locations and was significantly greater at inner than both mid- and outer reefs and at mid- than outer reefs (Table 5.4; Fig. 5.4b).

Three-dimensional maps demonstrate the variability of reef topography that can occur within a particular site. Two of the sites (9 and 26) had similarly moderate mean rugosity indices, *i.e.* 0.32 and 0.31, respectively, and comprised mostly low to moderate vertical relief (Table 5.3). Three-dimensional images of those two sites demonstrated that they were both relatively flat with many small undulations, but that site 26 comprised some large and relatively deep holes, which presumably contributed to the greater variability of rugosity measurements at that site than at site 9 (Figs 5.3, 5.5a, b). Sites 1 and 19 were each characterised by similarly high mean rugosity indices (0.38, 0.39) and comprised a large

Table 5.3. Percentage composition of low (< 1 m), moderate (1-2 m) and high (> 2 m) vertical relief and mean rugosity index (*RI*) ± 1 S.E. at each site surveyed by underwater visual census in the JBMP.

Region	Zone	Reef location	Site number	Low	Mod	High	*RI*	S.E.
Green Head	GU	Inner	1	20	55	25	0.38	0.023
	GU	Inner	32	20	50	30	0.32	0.024
	SR	Inner	9	50	40	10	0.32	0.026
	SR	Inner	34	20	70	10	0.38	0.019
	SZ	Inner	29	60	40	0	0.28	0.026
	GU	Mid	2	15	30	55	0.37	0.026
	GU	Mid	3	35	40	25	0.26	0.025
	SR	Mid	8	68	28	4	0.27	0.019
	SR	Mid	33	20	40	40	0.37	0.020
	SZ	Mid	5	100	0	0	0.14	0.016
	SZ	Mid	6	20	20	60	0.29	0.018
	SZ	Mid	27	65	35	0	0.25	0.017
	SZ	Mid	28	85	15	0	0.16	0.013
	GU	Outer	4	53	27	20	0.17	0.033
	GU	Outer	31	33	47	20	0.30	0.019
	SR	Outer	7	100	0	0	0.20	0.013
	SR	Outer	35	75	15	10	0.17	0.025
Jurien	GU	Inner	10	30	60	10	0.34	0.023
	GU	Inner	36	60	40	0	0.32	0.020
	SR	Inner	19	10	25	65	0.39	0.023
	SR	Inner	23	5	15	80	0.39	0.028
	SZ	Inner	16	75	25	0	0.26	0.018
	SZ	Inner	20	30	65	5	0.29	0.017
	GU	Mid	11	30	20	50	0.37	0.026
	GU	Mid	13	15	40	45	0.41	0.029
	SR	Mid	17	40	45	15	0.25	0.024
	SR	Mid	18	10	60	30	0.35	0.027
	SR	Mid	26	40	40	20	0.31	0.030
	SZ	Mid	14	100	0	0	0.15	0.017
	SZ	Mid	15	40	60	0	0.35	0.029
	GU	Outer	12	20	25	55	0.35	0.024
	GU	Outer	21	53	29	18	0.21	0.031
	SR	Outer	22	53	40	7	0.28	0.017
	SR	Outer	24	55	25	20	0.25	0.027
Overall		**Inner**		**35**	**44**	**21**	**0.33**	**0.007**
		Mid		**46**	**31**	**23**	**0.29**	**0.008**
		Outer		**54**	**26**	**20**	**0.24**	**0.010**

Table 5.4. Results of two one-way PERMANOVA tests on the effect of relief category, *i.e.* low, moderate and high, and reef location, *i.e.* inner, mid- and outer, on the variable rugosity index, derived from replicate measurements taken at each site in the JBMP. *df* = degrees of freedom, *MS* = mean squares, $p \leq 0.001$***. *ECV* = estimates of components of variation.

Source	Relief category	Residual
df	2	659
MS	2.88	0.007
Pseudo-F	402.5***	
ECV	0.007	

Source	Reef location	Residual
df	2	659
MS	0.36	0.01
Pseudo-F	24.7***	
ECV	0.002	
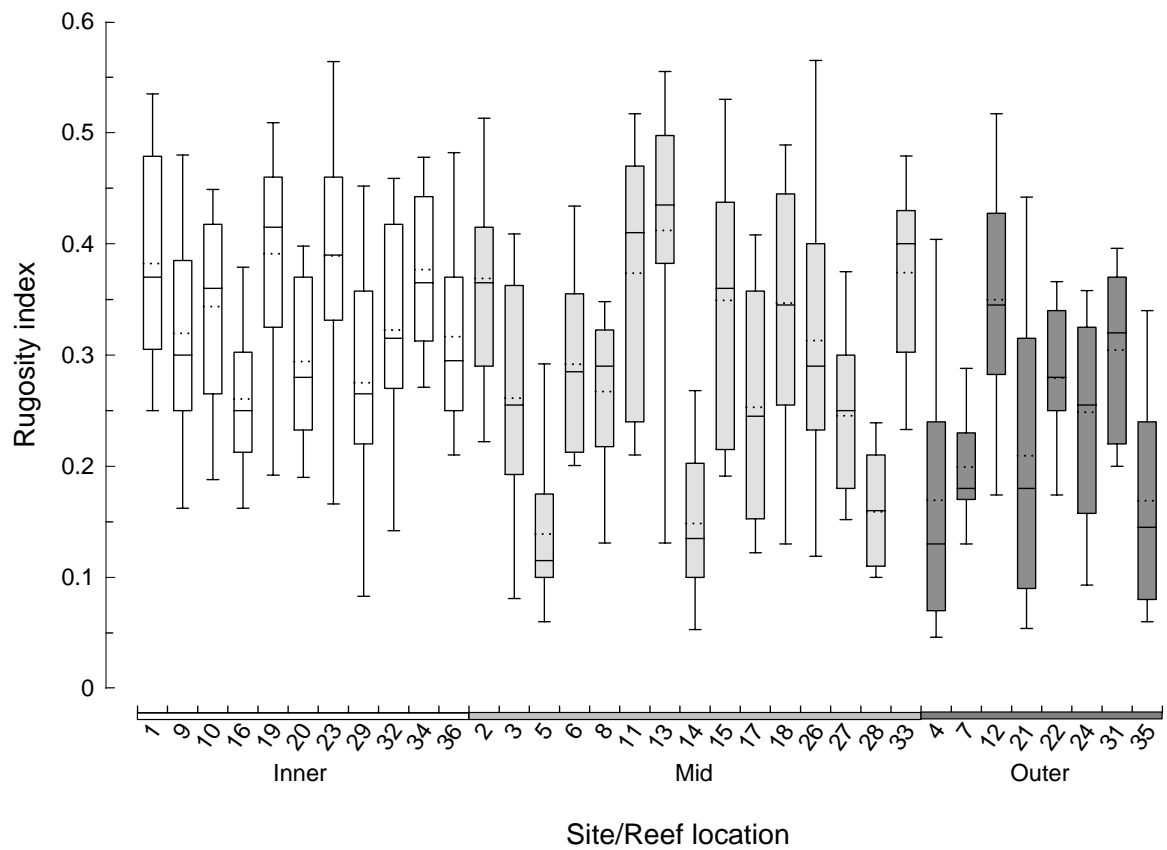
Figure 5.3. Box (25th, 50th [median] and 75th percentiles, including mean shown as dotted line) and whisker (10th and 90th percentiles) plot of rugosity indices at each site at each reef location, *i.e.* inner, mid- and outer reefs, of the Jurien Bay Marine Park.
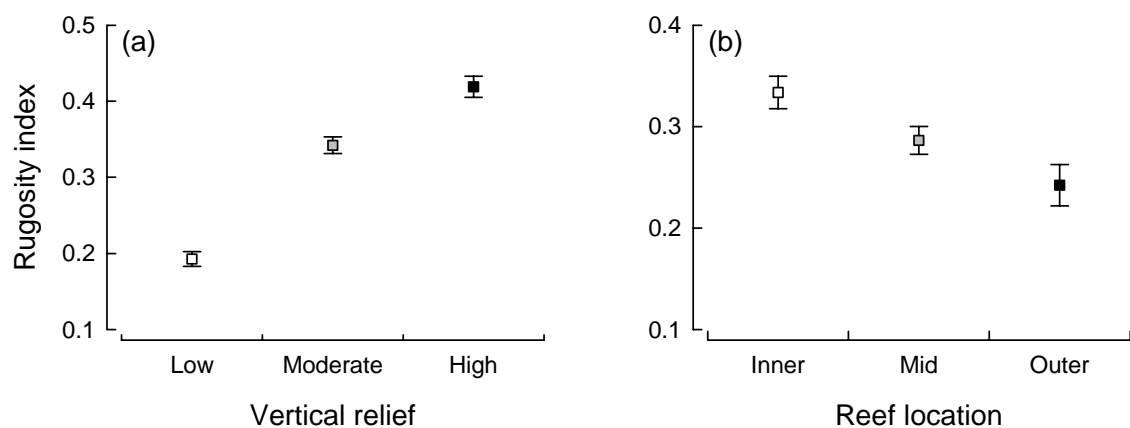
Figure 5.4. Mean ± 95 % confidence intervals of rugosity indices derived from measurements taken (a) in replicates categorised as having low, moderate and high vertical relief and (b) at all sites at each reef location, *i.e.* inner, mid- and outer reefs, of the Jurien Bay Marine Park.
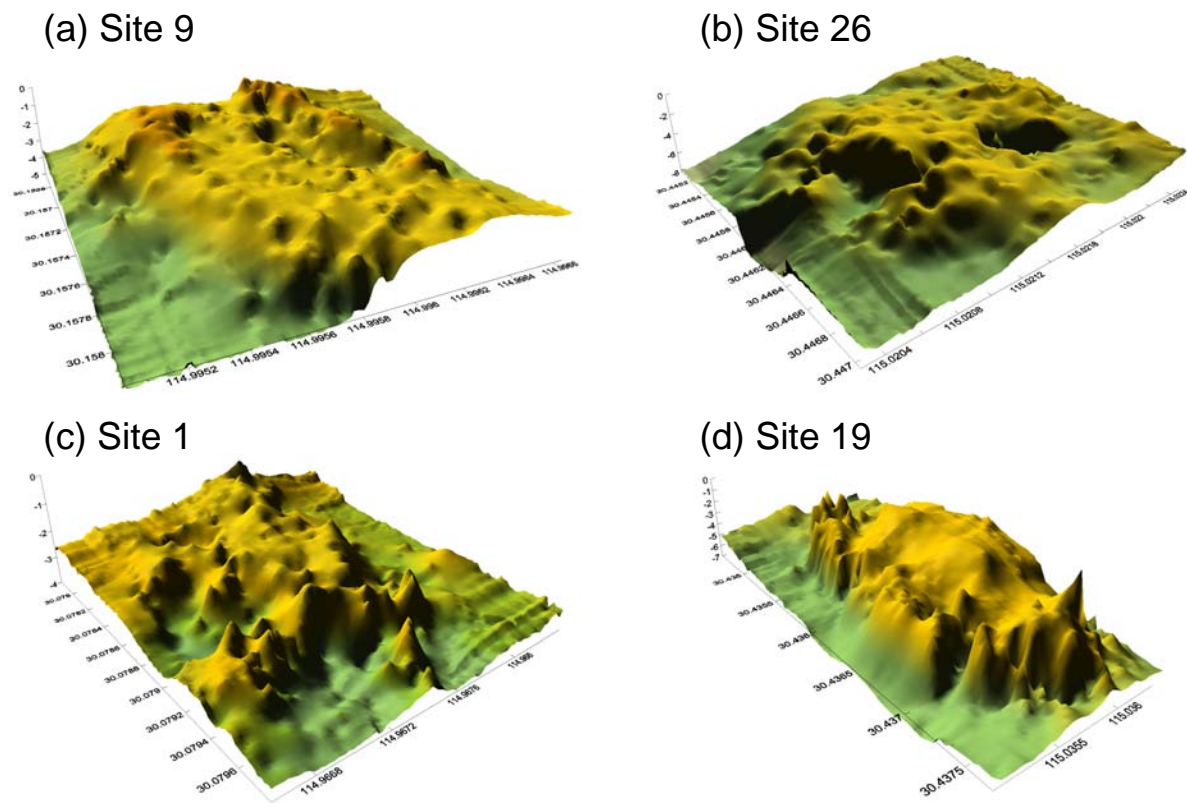
Figure 5.5. Three-dimensional bathymetry map of the reef surface of site (a) 9, (b) 26, (c) 1 and (d) 19, plotted on x (longitude, decimal degrees), y (latitude, decimal degrees) and z (depth, metres) axes.

percentage of moderate and high relief, respectively (Table 5.3). However, the three dimensional maps of their surface demonstrated the very different structural complexity at those sites (Fig. 5.5c, d). Site 1 comprised many steep-sided rocks, ledges or walls, some of which reached from the substrate almost to the surface, *i.e.* a depth of 3-4 m, while site 19 consisted of a large vertical wall along the western side of the reef, which regularly reached from the substrate to the surface, *i.e.* a depth of up to 7 m. The latter site was also characterised by numerous holes along the top of its western side and an essentially flat top to the east and immediately below the surface. Its eastern side could not be effectively mapped by boat, as it comprised a vertical wall up to 5 m in height, which extended from the substrate to the surface along most of its length. Overhangs and narrow caves were common at the base of the reef walls, which were not effectively measured with either rugosity index methods, subjective relief assessments or vessel-based bathymetry soundings.

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5.3.3 Fishes: numbers of species and total density of fishes

A total of 205,811 fishes, representing 137 species from 49 teleost and 5 elasmobranch families, were recorded during underwater visual census (UVC) of the reefs of the JBMP. Of the identified species, the majority (86) have temperate distributions, 13 are subtropical, 28 are tropical and 8 occur in temperate to tropical waters (Table 5.5). Twenty-eight species observed are endemic to Western Australia, including some of the most abundant, *e.g. Coris auricularis*, *Parma mccullochi* and *Kyphosus cornelii*. The most speciose teleost families recorded were the Labridae (25 species), Monacanthidae (10 species) and the Pomacentridae and Serranidae, each with 9 species. Two urolophid and one species of each of the dasyatid, rhinobatid, myliobatid and heterodontid elasmobranch families were recorded (Table 5.5). Note that siganids could not be identified to species *in situ*, due to the similarity of their morphological characteristics, and as two species occur in the Jurien region, *i.e. Siganus fuscescens* and *S. canaliculatus*. Similarly, identification to species was not possible for the carangid species complex (*Pseudocaranx* spp.), or of the plotosids *Cnidoglanis macrocephalus* and *Plotosus albilabrus*, monacanthids *Acanthaluteres vittiger* and *A. spilomelanurus* and atherinids (except *Atherinomorus waigiensis*). Counts of individuals of each of those congeneric or confamilial species are combined for the purpose of analyses.

Ten species contributed 75 % to the total numbers of individuals recorded over reefs. The Western King Wrasse *Coris auricularis* was the most abundant species, with 56,521 fish recorded, representing 27 % of all individuals. All other recorded species each contributed less than 9 % to the total numbers of individuals, while only 17 species, all teleosts, contributed more than 1 % each to that total. Other relatively abundant species included Rough Bullseye *Pempheris klunzingeri*, Blue Sprat *Spratelloides robustus*, McCulloch's Scalyfin *Parma mccullochi*, Brownspotted Wrasse *Notolabrus parilus*, Western Buffalo

Bream *Kyphosus cornelii* and Miller's damselfish *Pomacentrus milleri*, for which, greater than 10,000 individuals were recorded, each representing between 5 and 8 % of the total numbers of fish recorded (Table 5.5). The labrids *C. auricularis* and *N. parilus* were each encountered on almost all transects surveyed, *i.e.* 1,769 and 1,773 of 1,821, respectively. However, the former species was more abundant, *i.e.* 31 *vs* 6 fish 125 m^{-2}. Other frequently observed species, *i.e. P. mccullochi* and *A. maculatus*, were also similarly less abundant, *i.e.* 7 and 3 fish 125 m^{-2}, respectively, than *C. auricularis*. The second and third most abundant species, *P. klunzingeri* and *S. robustus*, were recorded on far fewer (542) and substantially fewer (21) transects, respectively.

Seventy-nine species recorded occupy only reef habitats, while 21 species occur in reef and seagrass, 11 in reef and sand and 12 in all three habitats. In addition three species inhabit reefs and the sand associated with reefs, while two occur only in sand associated with reefs (Table 5.5). Four species typically occur in seagrass and sand, while two are found solely in seagrass and two in sand. Other than *C. auricularis* and *S. robustus*, species that are of interest to fishers in Western Australia and are typically associated with reef habitats, were not abundant. *Arripis georgianus* was the third most abundant of such species, but represented only 0.7 % of fishes recorded. *Choerodon rubescens*, *Pseudocaranx* sp. and *Epinephelides armatus* represented *ca* 0.5, 0.4 and 0.3 % of all fishes recorded, respectively, while *Glaucosoma hebraicum* and *Pagrus auratus* comprised only 0.04 and 0.01 % (Table 5.5).

Table 5.5. Fishes recorded during underwater visual census of reef habitats of the JBMP between Autumn 2005 and Autumn 2007, interest to commercial and/or recreational fishers (^{F}), biogeographical distributions in Australian waters (Distn; T, temperate; S, subtropical; Tr, tropical; *endemic to W.A.), typical marine habitats occupied (S, sand; G, seagrass; R, reef; (S), sand associated with reef), total numbers of individuals recorded of each species (n), % contribution to total numbers of individuals recorded (%), number of replicate transects in which species was recorded (Freq, total number of replicates = 1821), and overall mean density (fish 125m^{-2}) of each species from all sites.

Family	Species	Distn	Habitats	n	%	Freq	Mean density
Labridae	*Coris auricularis*^{F}	S*	R(S)	56521	27.46	1769	31.04
Pempherididae	*Pempheris klunzingeri*	T	R	17206	8.36	542	9.45
Clupeidae	*Spratelloides robustus*^{F}	T	RS	15340	7.45	21	8.42
Pomacentridae	*Parma mccullochi*	T*	R	12809	6.22	1587	7.03
Labridae	*Notolabrus parilus*^{F}	T	RG	10898	5.30	1773	5.98
Kyphosidae	*Kyphosus cornelii*	S*	R	10843	5.27	788	5.95
Pomacentridae	*Pomacentrus milleri*	Tr	R	10248	4.98	934	5.63
Serranidae	*Caesioscorpis theagenes*	T	R	7491	3.64	73	4.11
Apogonidae	*Apogon victoriae*	S*	RG	7157	3.48	654	3.93
Labridae	*Halichoeres brownfieldi*	S*	RG	6754	3.28	928	3.71
Labridae	*Austrolabrus maculatus*	T	R	5541	2.69	1310	3.04
Pomacentridae	*Chromis westaustralis*	S*	R	3293	1.60	103	1.81
Monodactylidae	*Schuettea woodwardi*	T	R	3256	1.58	80	1.79
Pempherididae	*Parapriacanthus elongatus*	T	RS	2816	1.37	33	1.55
Kyphosidae	*Kyphosus sydneyanus*	T	R	2771	1.35	335	1.52
Labridae	*Pseudolabrus biserialis*	T*	R	2738	1.33	892	1.50
Plesiopidae	*Trachinops noarlungae*	T	R	2283	1.11	114	1.25
Pseudochromidae	*Labracinus lineatus*	Tr*	R	1658	0.81	786	0.91
Chaetodontidae	*Chelmonops curiosus*	T	R	1533	0.74	818	0.84
Pomacentridae	*Parma occidentalis*	S*	R	1430	0.69	571	0.79
Arripidae	*Arripis georgianus*^{F}	T	RGS	1397	0.68	64	0.77
Sphyraenidae	*Sphyraena obtusata*^{F}	T-Tr	RGS	1299	0.63	30	0.71
Microcanthidae	*Neatypus obliquus*	T	R	1250	0.61	146	0.69
Odacidae	*Olisthops cyanomelas*	T	R	991	0.48	498	0.54
Enoplosidae	*Enoplosus armatus*	T	RG	947	0.46	230	0.52
Pomacentridae	*Chromis klunzingeri*	T*	R	941	0.46	117	0.52

Table 5.5 cont.

Labridae	*Choerodon rubescens*[F]	S*	RG	921	0.45	537	0.51
Pempherididae	*Pempheris multiradiata*	T	R	909	0.44	249	0.50
Carangidae	*Pseudocaranx sp.*[F]	T	RS	903	0.44	84	0.50
Labridae	*Ophthalmolepis lineolatus*	T	R	857	0.42	460	0.47
Labridae	*Dotalabrus alleni*	T*	RG	824	0.40	426	0.45
Labridae	*Thalassoma lutescens*	Tr	R	710	0.34	316	0.39
Labridae	*Pictilabrus laticlavius*	T	R	695	0.34	462	0.38
Siganidae	*Siganus sp.*	Tr	RG	671	0.33	22	0.37
Odacidae	*Siphonognathus beddomei*	T	R	653	0.32	134	0.36
Labridae	*Pictilabrus viridis*	T*	R	599	0.29	337	0.33
Labridae	*Bodianus frenchii*[F]	T	R	552	0.27	322	0.30
Serranidae	*Epinephelides armatus*[F]	S*	R	505	0.25	372	0.28
Haemulidae	*Plectorhinchus flavomaculatus*[F]	Tr	R	472	0.23	370	0.26
Scorpididae	*Scorpis georgianus*	T	R	452	0.22	258	0.25
Apogonidae	*Siphamia cephalotes*	T	RG	452	0.22	40	0.25
Microcanthidae	*Microcanthus strigatus*	T	R	446	0.22	37	0.24
Mullidae	*Parupeneus spilurus*[F]	Tr	RS	433	0.21	213	0.24
Plotosidae	*Plotosus lineatus*	Tr	R	432	0.21	7	0.24
Pomacentridae	*Stegastes obreptus*	Tr	R	426	0.21	118	0.23
Labridae	*Anampses geographicus*	Tr	R	346	0.17	163	0.19
Labridae	*Thalassoma lunare*	Tr	R	289	0.14	172	0.16
Pinguipedidae	*Parapercis haackei*	T	(S)	278	0.14	173	0.15
Odacidae	*Heteroscarus acroptilus*	T	RG	274	0.13	236	0.15
Plesiopidae	*Paraplesiops meleagris*	T	R	267	0.13	211	0.15
Latidae	*Psammoperca waigensis*[F]	Tr	RG	238	0.12	133	0.13
Atherinidae	*Atherinid sp.*	-	-	200	0.10	1	0.11
Terapontidae	*Pelates octolineatus*	T	GS	200	0.10	2	0.11
Apogonidae	*Apogon rueppellii*	T-Tr	RGS	167	0.08	23	0.09
Cheilodactylidae	*Cheilodactylus rubrolabiatus*	T	R	143	0.07	138	0.08
Labridae	*Suezichthys cyanolaemus*	S*	(S)	137	0.07	33	0.08
Nemipteridae	*Pentapodus vitta*	T-Tr*	GS	129	0.06	98	0.07

Table 5.5 cont.

Blenniidae	*Cirripectes hutchinsi*	T-Tr*	R	127	0.06	97	0.07
Chaetodontidae	*Chaetodon assarius*	S*	R	123	0.06	90	0.07
Trypterigidae	*Helcogramma decurrens*	T	R	122	0.06	103	0.07
Labridae	*Scarus ghobban[F]*	Tr	R	109	0.05	61	0.06
Labridae	*Thalassoma septemfasciata*	S*	R	109	0.05	88	0.06
Monacanthidae	*Meuschenia hippocrepis[F]*	T	R	97	0.05	76	0.05
Urolophidae	*Trygonoptera ovalis*	T*	RGS	88	0.04	83	0.05
Glaucosomatidae	*Glaucosoma hebraicum[F]*	S*	R	79	0.04	61	0.04
Monacanthidae	*Meuschenia galii*	T	R	79	0.04	75	0.04
Ostraciidae	*Anoplocapros amygdaloides*	T	RG	75	0.04	68	0.04
Tetraodontidae	*Torquigener pleurogramma*	T	RGS	70	0.03	33	0.04
Monacanthidae	*Meuschenia flavolineata*	T	R	64	0.03	54	0.04
Sparidae	*Rhabdosargus sarba[F]*	T	RGS	62	0.03	12	0.03
Cheilodactylidae	*Cheilodactylus gibbosus*	T*	R(S)	45	0.02	42	0.02
Mullidae	*Parupeneus chrysopleuron*	Tr	RS	42	0.02	13	0.02
Cheilodactylidae	*Dactylophora nigricans*	T	RG	37	0.02	34	0.02
Odacidae	*Siphonognathus caninus*	T	R	36	0.02	34	0.02
Ostraciidae	*Anoplocapros lenticularis*	T	R	33	0.02	32	0.02
Carangidae	*Seriola hippos[F]*	T	RS	32	0.02	24	0.02
Mullidae	*Upeneichthys vlamingii[F]*	T	RS	28	0.01	27	0.02
Serranidae	*Hypoplectrodes nigroruber*	T	R	28	0.01	26	0.02
Serranidae	*Epinephelus rivulatus[F]*	Tr*	R	27	0.01	25	0.01
Monacanthidae	*Scobinichthys granulatus*	T	RG	25	0.01	20	0.01
Serranidae	*Othos dentex[F]*	T	R	23	0.01	22	0.01
Pomacentridae	*Parma victoriae*	T	R	21	0.01	15	0.01
Girrelidae	*Girella tephraeops*	T*	R	17	0.01	11	0.01
Sparidae	*Pagrus auratus[F]*	T	RS	17	0.01	14	0.01
Carangidae	*Trachurus novaezelandiae*	T	RGS	17	0.01	1	0.01
Girellidae	*Girella zebra*	T	RS	16	0.01	11	0.01
Lethrinidae	*Lethrinus nebulosus[F]*	Tr	R	14	0.01	7	0.01
Monacanthidae	*Acanthaluteres sp.*	T	RG	12	0.01	12	0.01

Table 5.5 cont.

Labridae	*Stethojulis bandanensis*	T	R	11	0.01	9	0.01
Ostraciidae	*Aracana aurita*	T	RG	9	0.00	9	< 0.01
Labridae	*Achoerodus gouldii*[F]	T	R	9	0.00	9	< 0.01
Diodontidae	*Diodon nicthemerus*	T	RG	9	0.00	9	< 0.01
Labridae	*Leptoscarus vaigiensis*	Tr	G	8	0.00	4	< 0.01
Pempherididae	*Pempheris schwenkii*	Tr	R	8	0.00	3	< 0.01
Monacanthidae	*Monacanthus chinensis*	Tr-T	RG	7	0.00	5	< 0.01
Apogonidae	*Apogon aureus*	Tr	R	6	0.00	6	< 0.01
Labridae	*Eupetrichthys angustipes*	T	RS	6	0.00	5	< 0.01
Blenniidae	*Plagiotremus rhinorhynchos*	T	R(S)	5	0.00	5	< 0.01
Labridae	*Thalassoma amblycephalum*	T	R	5	0.00	5	< 0.01
Dasyatidae	*Dasyatis brevicaudata*	T	RGS	4	0.00	4	< 0.01
Serranidae	*Acanthistius pardalotus*	S	R	3	0.00	3	< 0.01
Monacanthidae	*Chaetodermis penicilligera*	Tr	RS	3	0.00	3	< 0.01;
Muraenidae	*Gymnothorax woodwardi*	T*	R	3	0.00	3	< 0.01
Labridae	*Thalassoma purpureum*	T	R	3	0.00	3	< 0.01
Pomacentridae	*Abudefduf bengalensis*	Tr	R	2	0.00	2	< 0.01
Serranidae	*Acanthistius serratus*	T	R	2	0.00	2	< 0.01
Pomacentridae	*Abudefduf vaigiensis*	Tr	R	2	0.00	1	< 0.01
Aplodactylidae	*Aplodactylus westralis*	T*	R	2	0.00	1	< 0.01
Plotosidae	*Plotosid* sp.[F]	T-Tr	SGR	2	0.00	2	< 0.01
Serranidae	*Callanthias australis*	T	R	2	0.00	2	< 0.01
Pomatomidae	*Pomatomus saltatrix*[F]	T-S	RS	2	0.00	1	< 0.01
Syngnathidae	*Phyllopteryx taeniolatus*	T	RG	2	0.00	2	< 0.01
Labridae	*Pseudojuloides elongatus*	Tr	G	2	0.01	3	< 0.01
Scorpididae	*Scorpis aequipinnis*	T	R	2	0.00	2	< 0.01
Carangidae	*Seriola lalandi*[F]	T	R	2	0.00	2	< 0.01
Plesiopidae	*Trachinops brauni*	T*	R	2	0.00	2	< 0.01
Rhinobatidae	*Trygonorrhina fasciata*	T	SR	2	0.00	2	< 0.01
Monacanthidae	*Unid monacanthid*	-	-	2	0.00	2	< 0.01
Acanthuridae	*Acanthurus dussumieri*	Tr	R	1	0.00	1	< 0.01

Table 5.5 cont.

Pleuronectidae	*Ammotretis elongatus*[F]	T	S	1	0.00	1	< 0.01
Scyliorhinidae	*Aulohalaelurus labiosus*	T*	R	1	0.00	1	< 0.01
Monacanthidae	*Brachaluteres jacksonianus*	T	RG	1	0.00	1	< 0.01
Clinidae	*Cristiceps australis*	T	RG	1	0.00	1	< 0.01
Monacanthidae	*Eubalichthys cyanoura*	T	R	1	0.00	1	< 0.01
Heterodontidae	*Heterodontus portusjacksoni*	T	RGS	1	0.00	1	< 0.01
Serranidae	*Hypoplectrodes wilsoni*	T	R	1	0.00	1	< 0.01
Labridae	*Labroides dimidiatus*	Tr	R	1	0.00	1	< 0.01
Platycephalidae	*Leviprora inops*[F]	T	GS	1	0.00	1	< 0.01
Tetraodontidae	*Lagocephalus sceleratus*	T-Tr	RGS	1	0.00	1	< 0.01
Myliobatidae	*Myliobatus australis*	T	RGS	1	0.00	1	< 0.01
Terapontidae	*Pelsartia humeralis*	T	GS	1	0.00	1	< 0.01
Pempherididae	*Pempheris ornata*	T	R	1	0.00	1	< 0.01
Blenniidae	*Plagiotremus tapeinosoma*	Tr	R	1	0.00	1	< 0.01
Ephippidae	*Platax teira*	Tr	R	1	0.00	1	< 0.01
Pteroidae	*Pterois volitans*	Tr	R	1	0.00	1	< 0.01
Microcanthidae	*Tilodon sexfasciatum*	T	R	1	0.00	1	< 0.01
Urolophidae	*Urolophus circularis*	T*	R	1	0.00	1	< 0.01

5.3.4 Univariate analyses on number of fish species at Green Head and Jurien

Using the data for the number of species in general use and scientific reference zones at inner, mid- and outer reef locations, PERMANOVA detected a significant difference among both reef location and marine park zone and a significant interaction between those two factors (Table 5.6). Pairwise PERMANOVA demonstrated that the number of species was significantly lower over outer reefs than both inner and mid- reefs ($p = 0.001$; Fig. 5.6a). The number of species was also significantly lower in the GHGU than JBGU zone ($p = 0.032$) and in the GHSR than the JBGU and JBSR zones ($p \leq 0.034$; Fig. 5.6b). The number of species was significantly lower at the outer reef location than the inner and mid- reefs in the GHGU and GHSR zones and at the inner than mid- reefs in the GHGU zone ($p \leq 0.004$). However, there were no differences between reef location in the JBGU and only the inner and outer reefs differed significantly in the JBSR zone ($p = 0.002$). There were no significant differences in the number of species at inner reefs among zone and, at the mid- reef location, only the GHGU differed significantly from the JBGU and JBSR ($p = 0.01, 0.001$, respectively). Over outer reefs, the number of species differed significantly between both the GHGU and GHSR and both the JBGU and JBSR zones ($p \leq 0.002$) (Fig. 5.6a).

When the data for the number of species in general use, scientific reference and sanctuary zones at inner and mid- reef locations were used, a significant difference was detected among marine park zone and there was a significant interaction between reef location and zone (Table 5.6; Fig. 5.6b). Significant pairwise differences among zone occurred between the JBSZ and each of the GHGU ($p = 0.001$), GHSR ($p = 0.004$), GHSZ ($p = 0.016$), JBGU ($p = 0.008$) and JBSR ($p = 0.002$) zones. The interaction between reef location and zone was influenced by a significant difference in the number of species between inner and mid- reefs in only the GHGU zone ($p = 0.003$) and JBSZ ($p = 0.015$). The number of species at the inner reef location differed only between the JBSR zone and the

Table 5.6. Results of a two-way crossed PERMANOVA employing data for the number of species at (1) inner, mid- and outer reef locations (L) in the general use and scientific reference zones (Z) and (2) inner and mid- reef locations in general use, scientific reference and sanctuary zones at Green Head and Jurien in the JBMP. df = degrees of freedom, MS = mean squares, $p \leq 0.05^*$, $p \leq 0.01^{**}$, 0.001^{***}. ECV = estimates of components of variation.

		Main effects		
Source	*Reef location*	*Zone*	*L × Z*	*Residual*
		Inner, mid and outer reefs		
df	2	3	6	1037
MS	415.02	44.738	93.585	13.294
Pseudo-F	31.218***	3.365*	7.040***	
ECV	1.078	0.348	0.962	
		Inner and mid reefs		
df	1	5	5	1079
MS	7.162	59.024	56.711	15.256
Pseudo-F	0.470	3.869**	3.717**	
ECV	-0.128	0.511	0.704	

GHSZ and JBSZ ($p = 0.024$, 0.046, respectively). At the mid- reef location, the number of species differed significantly between the GHGU and the JBGU, JBSR and JBSZ ($p \leq 0.015$) and between the JBSZ and the GHSR, GHSZ, JBGU and JBSR zones ($p \leq 0.002$) (Fig. 5.6b).

5.3.5 Univariate analyses on density of fishes at Green Head and Jurien

Using the data for each of the three reef locations in the general use and scientific reference zones, the density of fishes differed significantly among both reef location and marine park zone (Table 5.7; Fig. 5.6c). There was also a significant interaction between reef location and zone. Pairwise PERMANOVA tests demonstrated that the density of fishes was significantly lower at outer reefs than both inner and mid- reefs ($p = 0.001$; Fig. 5.6c). The density of fishes differed significantly between the GHGU and JBSR zones ($p = 0.007$) and between the GHSR and both the JBGU ($p = 0.036$) and JBSR ($p = 0.001$) zones.

For the significant reef location × zone interaction, the density of fishes in both the GHGU and GHSR zones was significantly lower over outer reefs than both inner and mid- reefs ($p = 0.001$; Fig. 5.6c). A much weaker difference occurred between inner and mid- reefs in the GHGU zone ($p = 0.039$), but no difference was detected in the GHSR zone ($p = 0.306$). No differences in the density of fishes were detected among reef location in the JBGU zone,

while the inner reefs of the JBSR contained significantly larger densities of fishes than both the mid- ($p = 0.003$) and outer reef ($p = 0.001$) in that zone. When the interaction between zones at each reef location was investigated, the densities of fishes in the inner reefs in the GHGU zone were significantly lower than those in the JBSR zone ($p = 0.016$; Fig. 5.6c). While the densities over inner reefs in the GHSR and JBGU were lower than those in the JBSR zone, they were not significantly different ($p = 0.052$ and 0.051; Fig. 5.6c). Over mid-reefs, the density of fishes was significantly greater in the GHGU zone than each of the GHSR ($p = 0.014$), JBGU ($p = 0.001$) and JBSR zones ($p = 0.012$), while over outer reefs, densities in both the GHGU and GHSR zones were significantly lower than in both the JBGU and JBSR zones ($p \leq 0.002$).

When the data for the density of fishes from the inner and mid- reefs in the general use, scientific reference and sanctuary zones were subjected to PERMANOVA, marginally significant effects of reef location and zone were detected. However, the strength of the significant interaction was greater (Table 5.7). Pairwise tests found no difference among reef location for the density of fishes indicating that the difference in the main test was weak. A significantly greater density of fishes was found in the GHGU and JBGU zone ($p = 0.03$) and the JBSZ ($p = 0.003$) and in the JBSR *vs* those latter two zones ($p = 0.015, 0.001$, respectively; Fig. 5.6d). For the reef location × zone interaction, the density of fishes differed significantly between the inner and mid- reef locations in only the JBSR ($p < 0.002$) and JBSZ ($p = 0.002$) zones. Fish densities were significantly greater in the JBSR than the other five zones at the inner reef location ($p < 0.05$). At the mid- reef location, densities were significantly greater in the GHGU than the GHSR and the three Jurien zones ($p < 0.01$), in the GHSR *vs* the JBSZ ($p < 0.05$), the GHSZ *vs* the JBGU and JBSZ zones ($p < 0.05$) and the JBSR *vs* the JBSZ zone ($p = 0.013$; Fig. 5.6d).

Table 5.7. Results of a two-way crossed PERMANOVA employing data for the ln transformed density of fishes (fish 125 m^{-2}) at (1) inner, mid- and outer reef locations (L) in the general use and scientific reference zones (Z) and (2) inner and mid- reef locations in the general use, scientific reference and sanctuary zones at Green Head and Jurien in the JBMP. df = degrees of freedom, MS = mean squares, $p \leq 0.05$*, 0.01**, 0.001***. ECV = square root of estimates of components of variation.

	Main effects			
Source	*Reef location*	*Zone*	*L × Z*	*Residual*
	Inner, mid and outer reefs			
df	2	3	6	1037
MS	14.452	2.508	5.012	0.509
Pseudo-F	28.407***	4.931**	9.851***	
ECV	0.201	0.088	0.228	
	Inner and mid reefs			
df	1	5	5	1079
MS	1.817	1.473	1.521	0.462
Pseudo-F	3.938*	3.193*	3.295**	
ECV	0.052	0.078	0.112	
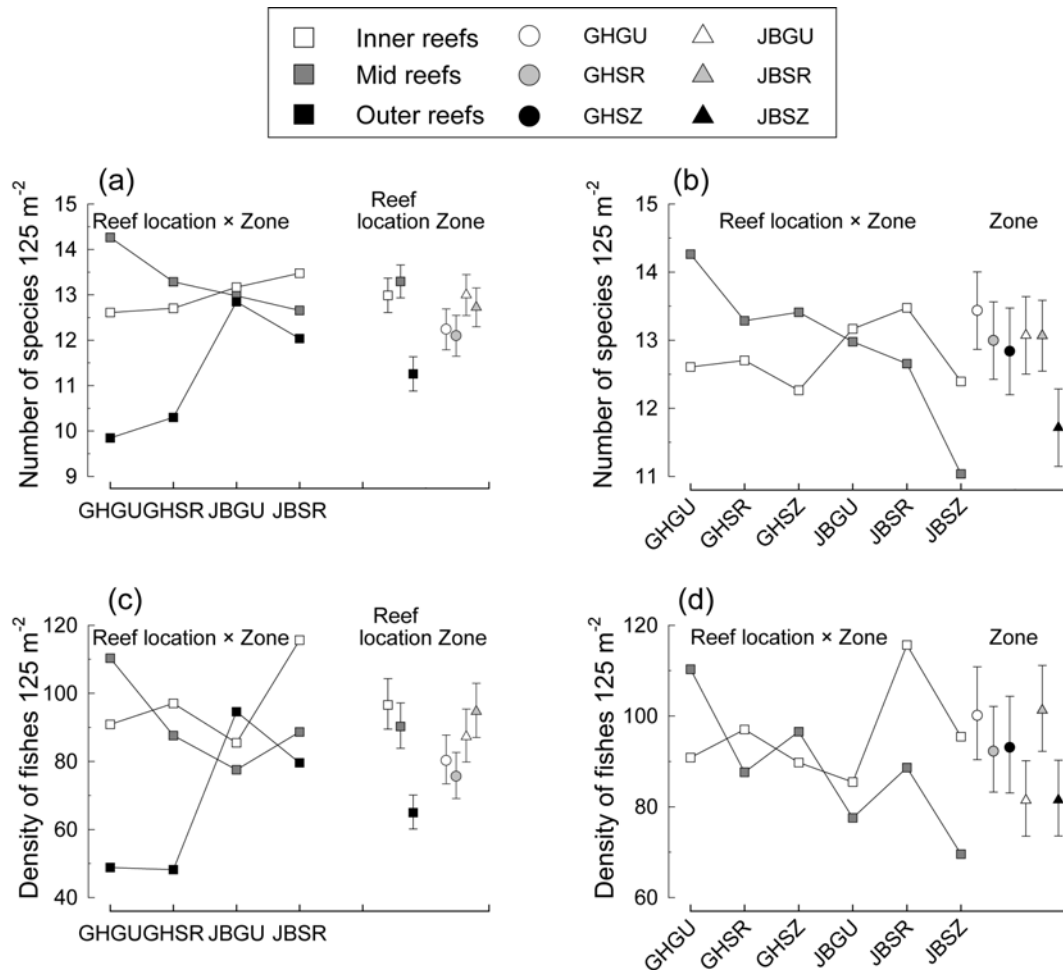
Figure 5.6. Mean number of species (a) and density of fishes (c) at inner, mid- and outer reef locations in the Green Head general use (GHGU), Green Head scientific reference (GHSR), Jurien general use (JBGU) and Jurien scientific reference (JBSR) zones and the overall mean ± 95 % CIs at each reef location and/or marine park zone and mean number of species (b) and density of fishes (d) at inner and mid- reef locations in the GHGU, GHSR, Green Head sanctuary zone (GHSZ), JBGU, JBSR and Jurien sanctuary zone (JBSZ) and the overall mean ± 95 % CIs in each zone.

5.3.6 Composition of fishes at Green Head and Jurien

The results of two PERMANOVA tests, using the densities of fish species recorded over (1) inner, mid- and outer reefs in the general use and scientific reference zones and (2) inner and mid- reefs in the general use, scientific reference and sanctuary zones, at Green Head and Jurien, each demonstrated that the composition of fish species differed significantly among reef location and marine park zone (Table 5.8). A significant interaction was also detected between those two factors in each test.

Separate complementary two-way ANOSIM tests on the first and second data sets confirmed that species composition was significantly related to both reef location and zone in each case ($p = 0.1$ %). However, the corresponding global R statistics revealed that composition was influenced more by reef location than zone (R = 0.511 *vs* 0.260, 0.322 *vs* 0.278). Pairwise ANOSIM tests among reef location, using the first data set, *i.e.* comprising inner, mid- and outer reef locations in the general use and scientific reference zones, demonstrated that the greatest difference lay between inner and outer reefs (R = 0.723), followed by mid- and outer (0.468) and then inner and mid- reefs (0.366). The test among reef location, using the second data set, *i.e.* comprising inner and mid- reefs in general use, scientific reference and sanctuary zones, produced the same result as the main test (R = 0.322). Using the first data set, pairwise ANOSIM tests found weak to moderate differences between the compositions in each pair of zones (R = 0.206-0.332), with the difference being greatest between the GHGU and JBGU zones and weakest between the GHGU and GHSR zones (Table 5.9). When the data for inner and mid- reefs from all three zones was used, the greatest differences lay between the GHGU and each of the Jurien zones and GHSR *vs* JBGU, JBGU *vs* JBSR and JBSR *vs* JBSZ (Table 5.9).

Non-metric multi-dimensional scaling plots (nMDS) derived from the first data set and coded for reef location showed that the fish composition in outer reefs was distinct from

Table 5.8. Results of a two-way crossed PERMANOVA on the similarity matrix derived from the ln density of each fish species 125 m^{-2} at (1) inner, mid- and outer reef locations (L) in the general use and scientific reference zones (Z) and (2) inner and mid- reef locations, in general use, scientific reference and sanctuary zones at Green Head and Jurien in each season. df = degrees of freedom, MS = mean squares, $p \leq 0.001***$. ECV = square root of estimates of components of variation.

	Main effects			
Source	Reef location	Zone	L × Z	Residual
Inner, mid and outer reefs				
df	2	3	6	1037
MS	150750	27150	25612	1218.1
Pseudo-F	123.8***	22.3***	21.026***	
ECV	20.8	10.0	16.8	
Inner and mid reefs				
df	1	5	5	1079
MS	83696	32949	26140	1225.8
Pseudo-F	68.3***	26.9***	21.3***	
ECV	12.9	13.8	17.3	

Table 5.9. Results (R statistics) of pairwise ANOSIM tests among marine park zone of the fish composition data for (1) inner, mid- and outer reef locations in the general use and scientific reference zones and (2) inner and mid- reef locations in the general use, scientific reference and sanctuary zones. Green Head, GH; Jurien, JB; General Use, GU; Scientific Reference, SR; Sanctuary, SZ.

Inner, mid and outer reefs in general use and scientific reference zones						
	GHGU	GHSR	JBGU	JBSR		
GHGU						
GHSR	0.206					
JBGU	**0.332**	0.286				
JBSR	0.268	0.239	0.254			
Inner and mid reefs in general use, scientific reference and sanctuary zones						
	GHGU	GHSR	GHSZ	JBGU	JBSR	JBSZ
GHGU						
GHSR	0.267					
GHSZ	0.077	0.243				
JBGU	**0.437**	**0.340**	0.262			
JBSR	0.317	0.264	0.264	**0.334**		
JBSZ	**0.330**	0.272	0.275	0.261	**0.370**	

those of both inner and mid-reefs (Fig. 5.7a). Thus, while the samples for both inner and mid-reefs partially overlapped, neither overlapped those of outer reefs. Using the second data set, the samples for inner and mid- reefs again overlapped (Fig. 5.7b). The samples for the different marine park zones overlapped each other to some degree, which is reflected in the relatively low R-statistics for pairwise tests between zones (Fig. 5.7a, b, *cf.* Table 5.9).

Two-way crossed SIMPER (reef location × zone) on both the first and second data sets indicated that the labrids *Coris auricularis* and *Notolabrus parilus* and the pomacentrid *Parma mccullochi* were almost always responsible for typifying the composition of fish
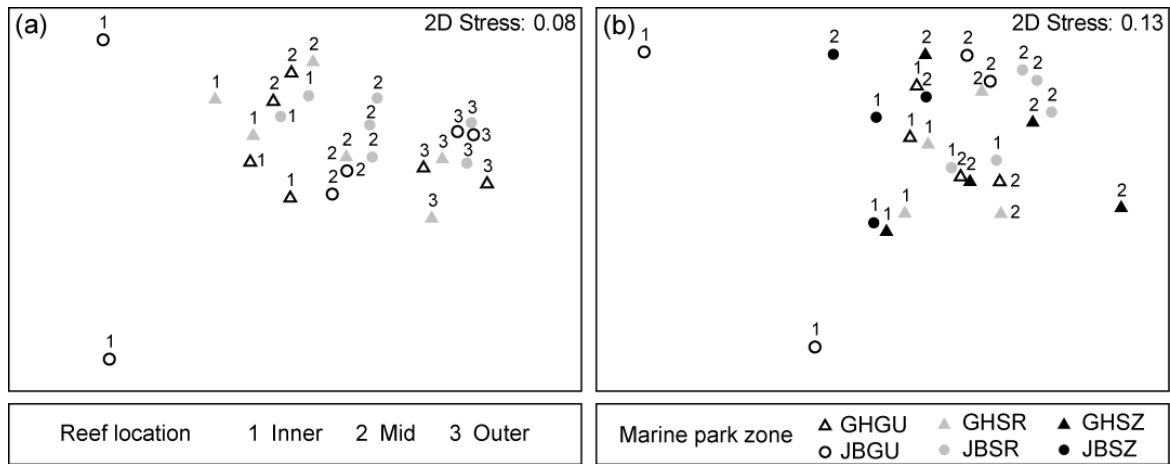
Figure 5.7. Non-metric multi-dimensional scaling plots derived from the similarity matrix constructed from the densities of each fish species at each site in the inner, mid- and, where present, outer reef locations in general use, scientific reference and sanctuary zones, coded for (a) reef location and (b) marine park zone. Green Head, GH; Jurien, JB; General Use, GU; Scientific Reference, SR; Sanctuary, SZ.

species of each reef location and marine park zone (Tables 5.10-5.12). Inner and mid- reefs were also typified by the pomacentrid *Pomacentrus milleri* and the labrid *Austrolabrus maculatus*, respectively, while *A. maculatus* and two other labrids, *i.e. Pseudolabrus biserialis* and *Ophthalmolepis lineolatus*, also typified the outer reefs. The composition of fish species was almost always distinguished among reef habitats by varying abundances of some of the above seven species (Table 5.10). This was also essentially true among zones when the first data set was examined using SIMPER (Table 5.11). However, the kyphosid *Kyphosus cornelii* was also important in distinguishing the GHGU from GHSR and JBSR zones, by being more abundant in the former zone. Using the second data set, and as indicated by relatively low R statistics in most pairwise comparisons among zones (see Table 5.9), only a few species were responsible for distinguishing among those zones, *i.e.* dissimilarity/SD $\geq$ 1.3. *Pomacentrus milleri*, which was typically more abundant in the Green Head zones, was often important in distinguishing their fauna from those in the Jurien zones (Table 5.12). In contrast, the labrid *Halichoeres brownfieldi*, typified the fauna in the JBSZ and almost always distinguished the fauna in that zone from the others (Table 5.12).

Table 5.10. Species detected by SIMPER as most important for typifying the fish faunas at inner, mid- and outer reef locations (grey cells) and for distinguishing among the faunas of those habitat types (white cells) using the data for (1) inner, mid- and outer reefs in the general use and scientific reference zones and (2) inner and mid- reefs in the general use, scientific reference and sanctuary zones of the JBMP. Species arranged in order of descending importance. Superscripts indicate the habitat in which column [1] or row [2] each species was most abundant.

	Inner	Mid	Outer
Inner	***Notolabrus parilus*** ***Coris auricularis*** ***Parma mccullochi*** ***Pomacentrus milleri***		
Mid	*Austrolabrus maculatus*[2] *Pomacentrus milleri*[1]	***Coris auricularis*** ***Parma mccullochi*** ***Notolabrus parilus*** ***Austrolabrus maculatus***	
Outer	*Pseudolabrus biserialis*[2] *Austrolabrus maculatus*[2] *Pomacentrus milleri*[1] *Ophthalmolepis lineolatus*[2] *Parma mccullochi*[2]	*Pseudolabrus biserialis*[2] *Ophthalmolepis lineolatus*[2] *Austrolabrus maculatus*[2] *Notolabrus parilus*[1]	***Coris auricularis*** ***Austrolabrus maculatus*** ***Notolabrus parilus*** ***Parma mccullochi*** ***Pseudolabrus biserialis*** ***Ophthalmolepis lineolatus***

Inner and mid reefs in general use, scientific reference and sanctuary zones

	Inner	Mid
Inner	***Notolabrus parilus*** ***Coris auricularis*** ***Parma mccullochi*** ***Pomacentrus milleri***	
Mid	*Pomacentrus milleri*[1] *Austrolabrus maculatus*[2] *Apogon victoriae*[1]	***Coris auricularis*** ***Notolabrus parilus*** ***Parma mccullochi***

Table 5.11. Species detected by SIMPER as most important for typifying the fish faunas of each marine park zone (grey cells) and for distinguishing among the faunas of those zones (white cells) using the data for inner, mid- and outer reefs in the general use and scientific reference zones of the JBMP. Species arranged in order of descending importance. Superscripts indicate the zone in which column [1] or row [2] each species was most abundant. Green Head, GH; Jurien, JB; General Use, GU; Scientific Reference, SR.

Zone	GHGU	GHSR	JBGU	JBSR
GHGU	***Coris auricularis*** ***Notolabrus parilus*** ***Parma mccullochi***			
GHSR	*Notolabrus parilus*[2] *Kyphosus cornelii*[1] *Parma mccullochi*[1] *Coris auricularis*[2] *Austrolabrus maculatus*[2]	***Coris auricularis*** ***Notolabrus parilus*** ***Parma mccullochi*** ***Austrolabrus maculatus***		
JBGU	*Parma mccullochi*[1] *Notolabrus parilus*[1]	*Notolabrus parilus*[1] *Parma mccullochi*[1] *Austrolabrus maculatus*[1]	***Coris auricularis*** ***Notolabrus parilus*** ***Parma mccullochi***	
JBSR	*Kyphosus cornelii*[1] *Notolabrus parilus*[1] *Austrolabrus maculatus*[2] *Parma mccullochi*[2] *Coris auricularis*[2]	*Notolabrus parilus*[1] *Parma mccullochi*[2]	*Parma mccullochi*[2] *Austrolabrus maculatus*[2] *Notolabrus parilus*[2]	***Coris auricularis*** ***Parma mccullochi*** ***Notolabrus parilus*** ***Austrolabrus maculatus***

Table 5.12. Species detected by SIMPER as most important for typifying the fish faunas of each marine park zone (grey cells) and for distinguishing among the faunas of those zones (white cells) using the data for inner and mid- reefs in the general use, scientific reference and sanctuary zones of the JBMP. Species arranged in order of descending importance. Superscripts indicate the zone in which column [(1)] or row [(2)] each species was most abundant. Green Head, GH; Jurien, JB; General Use, GU; Scientific Reference, SR; Sanctuary Zone, SZ.

	Inner and mid reefs in general use, scientific reference and sanctuary zones					
	GHGU	**GHSR**	**GHSZ**	**JBGU**	**JBSR**	**JBSZ**
GHGU	*Notolabrus parilus* *Coris auricularis* *Parma mccullochi* *Pomacentrus milleri*					
GHSR	*Pomacentrus milleri[2]* *Kyphosus cornelii[1]*	*Coris auricularis* *Notolabrus parilus* *Parma mccullochi* *Pomacentrus milleri*				
GHSZ	*Pomacentrus milleri[1]*	*Pomacentrus milleri[1]*	*Coris auricularis* *Notolabrus parilus* *Parma mccullochi*			
JBGU	*Pomacentrus milleri[1]* *Parma mccullochi[1]*	*Pomacentrus milleri[1]*	*Parma mccullochi[1]*	*Notolabrus parilus* *Coris auricularis*		
JBSR	*Pomacentrus milleri[1]* *Kyphosus cornelii[1]*	*Pomacentrus milleri[1]* *Labracinus lineatus[1]*	*Kyphosus cornelii[1]*	*Parma mccullochi[2]* *Austrolabrus maculatus[2]*	*Coris auricularis* *Parma mccullochi* *Notolabrus parilus* *Austrolabrus maculatus*	
JBSZ	*Pomacentrus milleri[1]* *Halichoeres brownfieldi[2]*	*Halichoeres brownfieldi[2]* *Pomacentrus milleri[1]*	*Halichoeres brownfieldi[2]* *Notolabrus parilus[2]*	*Parma mccullochi[2]* *Notolabrus parilus[2]*	*Halichoeres brownfieldi[2]* *Austrolabrus maculatus[2]*	*Notolabrus parilus* *Coris auricularis* *Parma mccullochi* *Halichoeres brownfieldi* *Pomacentrus milleri*

Interaction between the effects of reef location and marine park zone

Investigation of the interaction between reef location and zone, using the data for inner, mid- and outer reefs in the general use and scientific reference zones, demonstrated that the fish composition differed significantly among the reef locations within each zone, *i.e.* GHGU, GHSR, JBGU and JBSR (Global R = 0.416-0.594, p = 0.1 %). Each pair of comparisons between mid- *vs* outer and inner *vs* mid- reefs produced significant results, with the strength of those differences varying among zone (Table 5.13). The strongest pairwise difference among reef locations within zones occurred between inner and outer reefs in the GHSR, JBGU and JBSR zones (R = 0.733-0.785; Table 5.13). While a strong difference was also evident between the faunas in those two reef locations in the GHGU zone, it was slightly weaker than that of mid- *vs* outer reefs in that zone (R = 0.610 *vs* 0.647). When the second data set was used, the difference between inner and mid- reefs was greatest in the JBGU zone, followed by the GHSR zone, while the weakest difference occurred in the JBSZ (Table 5.14).

Table 5.13. Results (R statistics) of pairwise ANOSIM tests among reef location, using the data set for inner, mid- and outer reef locations in the Green Head and Jurien Bay general use and scientific reference zones. Green Head, GH; Jurien, JB; General Use, GU; Scientific Reference, SR.

Reef location	GHGU	GHSR	JBGU	JBSR
Inner *vs* outer	0.610	0.785	0.766	0.733
Mid *vs* outer	0.647	0.457	0.481	0.361
Inner *vs* mid	0.324	0.400	0.560	0.254

Table 5.14. Results (R statistics) of pairwise ANOSIM tests among reef location, using the data set for inner and mid- reef locations in the Green Head and Jurien Bay general use, scientific reference and sanctuary zones. Green Head, GH; Jurien, JB; General Use, GU; Scientific Reference, SR; Sanctuary, SZ.

Reef location	GHGU	GHSR	GHSZ	JBGU	JBSR	JBSZ
Inner *vs* mid	0.324	0.400	0.293	0.560	0.254	0.202

Non-metric multi-dimensional scaling plots derived separately from the data for the GHGU, GHSR, JBGU and JBSR zones and coded for reef location showed clear separation of the points representing each reef location, reflecting the above high R statistics in pairwise

tests (Fig. 5.8a-d). While the points for outer reefs were always well separated from those for inner reefs, the proximity of the points for inner reefs *vs* mid- reefs and mid- *vs* outer reefs varied. The dispersion of points for each reef location in each zone differed, reflecting the variability in fish composition at sites within reef location/zone combinations (Fig. 5.8a-d). The nMDS plot for the GHSZ indicated that, while the composition of fishes at inner reefs was distinct from mid-reefs, there was only one site available at inner reefs in that zone and there was high variability in the composition of fishes at the four mid- reef sites (Fig. 5.18e). In the JBSZ, the points for inner and mid- reefs overlapped to some extent, indicating that fish composition in those two reef locations were more similar (Fig. 5.8f).

When the composition of fishes at each reef location was compared among zones, using the first data set, the fish compositions in each pair of zones were significantly different ($p = 0.1$ %). However, in most cases, the strength of those differences decreased from inner to mid- and then to outer reef locations (Table 5.15). The strongest differences were detected between inner reefs in the JBGU zone and the GHGU, GHSR and JBSR zones (R-statistics $\geq$ 0.40), while differences among zones in outer reefs were weak (R-statistics $\leq$ 0.18; Table 5.15). Using the second data set, the same differences as for the first data set occurred in both inner and mid- reefs between pairs of general use and scientific reference zones. Over inner reefs, the difference between the JBGU and JBSR zones remained the strongest, with the GHGU *vs* JBGU and GHSR *vs* JBGU also remaining two of the greatest differences (Table 5.16). However, a strong difference between the fish composition in the GHSZ *vs* JBSR and moderate differences between those in the GHGU *vs* GHSZ and JBSR *vs* JBSZ were also detected. Over mid- reefs, the same differences occurred between the general use and scientific reference zones. Moderate to strong differences were also detected between the fish compositions of the JBSZ and each of the other five zones (Table 5.16).

Figure 5.8. Non-metric multi-dimensional scaling plots derived from the similarity matrices constructed from the densities of each fish species in each season at each site in inner, mid- and outer reef locations separately for the (a) Green Head general use zone (GHGU), (b) Jurien general use zone (JBGU), (c) Green Head scientific reference zone (GHSR) and (d) Jurien scientific reference zone (JBSR) and in the inner and mid- reef locations in the (e) Green Head sanctuary zone (GHSZ) and (f) Jurien sanctuary zone (JBSZ).

Table 5.15. Results (R statistics) of pairwise ANOSIM tests among marine park zone, using the data set for inner, mid- and outer reef locations in the Green Head and Jurien Bay general use and scientific reference zones. Green Head, GH; Jurien, JB; General Use, GU; Scientific Reference, SR.

Zone	GHGU	GHSR	JBGU	JBSR
Inner reefs				
GHGU				
GHSR	0.254			
JBGU	**0.442**	**0.402**		
JBSR	**0.377**	**0.354**	**0.579**	
Mid- reefs				
GHGU				
GHSR	0.280			
JBGU	**0.432**	0.278		
JBSR	0.281	0.211	0.188	
Outer reefs				
GHGU				
GHSR	0.083			
JBGU	0.121	0.178		
JBSR	0.136	0.172	0.039	

Table 5.16. Results (R statistics) of pairwise ANOSIM tests among marine park zone, using the data set for inner and mid- reef locations in the Green Head and Jurien Bay general use, scientific reference and sanctuary zones. Green Head, GH; Jurien, JB; General Use, GU; Scientific Reference, SR; Sanctuary Zone, SZ.

Zone	GHGU	GHSR	GHSZ	JBGU	JBSR	JBSZ
Inner reefs						
GHGU						
GHSR	0.254					
GHSZ	**0.345**	0.189				
JBGU	**0.442**	**0.402**	0.116			
JBSR	**0.377**	**0.354**	**0.532**	**0.579**		
JBSZ	0.196	0.106	0.013	0.244	**0.345**	
Mid reefs						
GHGU						
GHSR	0.280					
GHSZ	0.011	0.256				
JBGU	**0.432**	0.278	0.298			
JBSR	0.281	0.211	0.207	0.188		
JBSZ	**0.464**	**0.438**	**0.340**	0.278	**0.385**	

The nMDS plot derived from the fish composition data at each site in each season over inner reefs demonstrated that the samples for the JBGU were well separated from those of the other five zones (Fig. 5.9a). Furthermore, the samples representing each season of sampling at each of the two sites in the JBGU were clearly separated from each other. Stress was relatively high for the nMDS plots representing mid- reefs in each zone (Fig. 9b, c). However, the location of the samples for the pairs of zones which produced the highest R statistics in pairwise ANOSIM tests (Tables 5.15, 5.16) were clearly separated, *e.g.* GHGU *vs* JBSZ and JBGU, GHSR *vs* JBSZ. Furthermore, the samples for the GHGU, JBGU and JBSZ

were less dispersed than those for other zones, indicating that the composition of fishes was more similar among sites over mid- reefs within those zones. Over outer reefs, the samples for the GHGU and GHSR zones overlapped, but mostly lay to the left of those for the JBGU and JBSR zones, which also overlapped (Fig. 5.9c). The overlap and, in most cases, wide dispersal of the samples for each zone is reflected in the relatively small R-statistics in the above pairwise ANOSIM tests among zones and thus their similarity.

One-way SIMPER on reef location, using the data for each zone separately, indicated that *C. auricularis*, *N. parilus* and *P. mccullochi* typified the fauna in the inner, mid- and outer reef locations in each of the Green Head zones and most reef locations in the Jurien zones (Table 5.17). *Pomacentrus milleri*, *Apogon victoriae* and *H. brownfieldi* also typified some inner reefs (GHSR, GHSZ, JBSZ). Over mid-reefs, additional species also typified different zones, *e.g. P. milleri* (GHGU, GHSR), *A. maculatus* (GHSR, JBSR) and *H. brownfieldi* (JBSZ), while over outer reefs, *A. maculatus* always typified each zone and *Pseudolabrus biserialis* typified those of the Jurien zones (Table 5.17). Varying abundances of those species often distinguished between faunas in the different zones at each reef location.

Separate one-way SIMPER analyses among zones for each reef location again showed that *C. auricularis*, *N. parilus* and *P. mccullochi* were almost always responsible for typifying each zone at each reef location and a range of species distinguished among zones over inner and mid- reefs (Table 5.18-5.20). The same species typified outer reefs in each zone in addition to *A. maculatus*. However, *P. biserialis* also typified the outer reefs of Jurien, but not those of Green Head. While SIMPER indicated that some species distinguished between the fish faunas in the different zones over outer reefs, the low R statistics in pairwise ANOSIM tests (Table 5.15) and low ratios of dissimilarity

indices/standard deviations for each of those species demonstrated that the extent of the
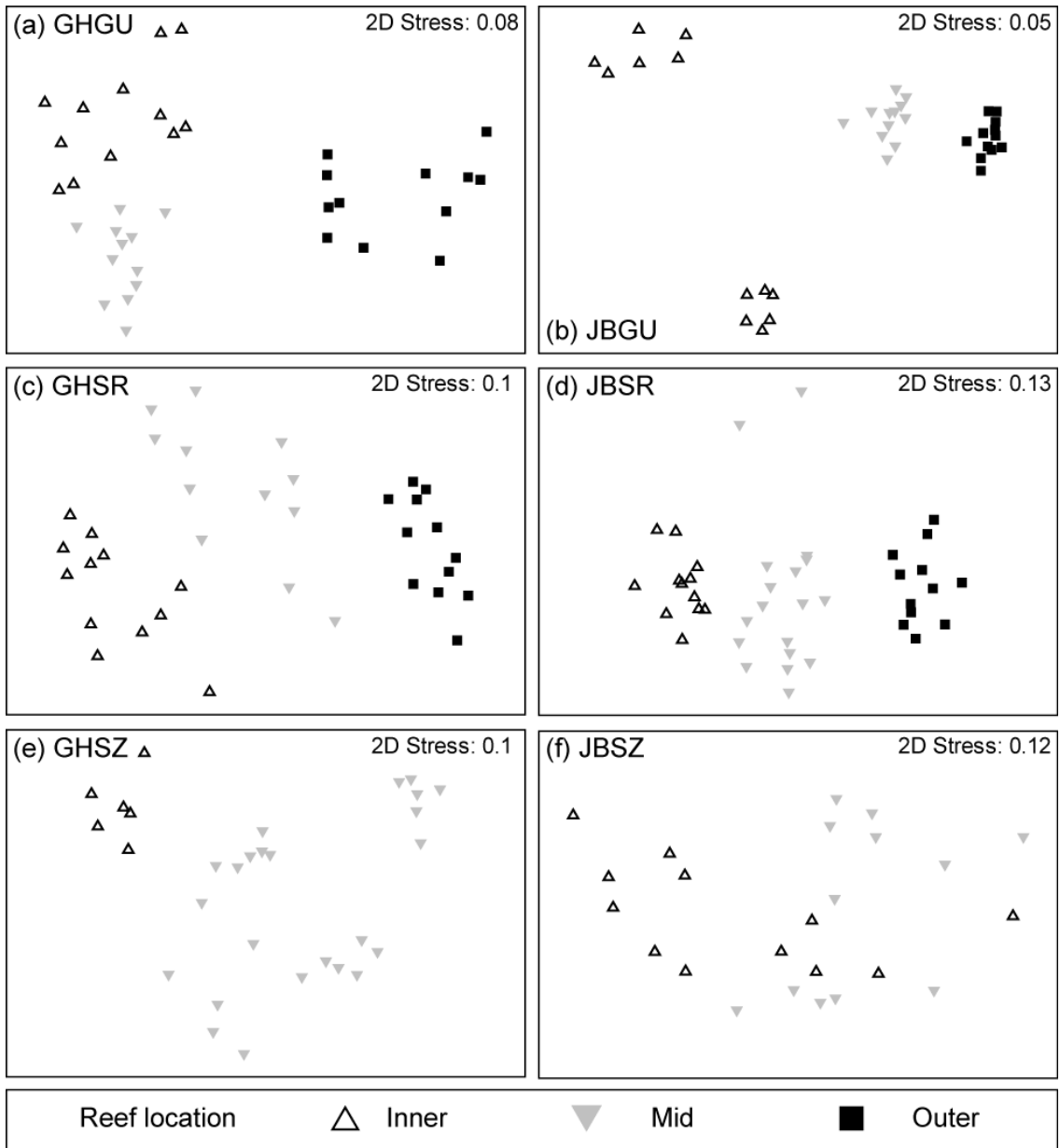
dissimilarity was low and variable (Table 5.20).
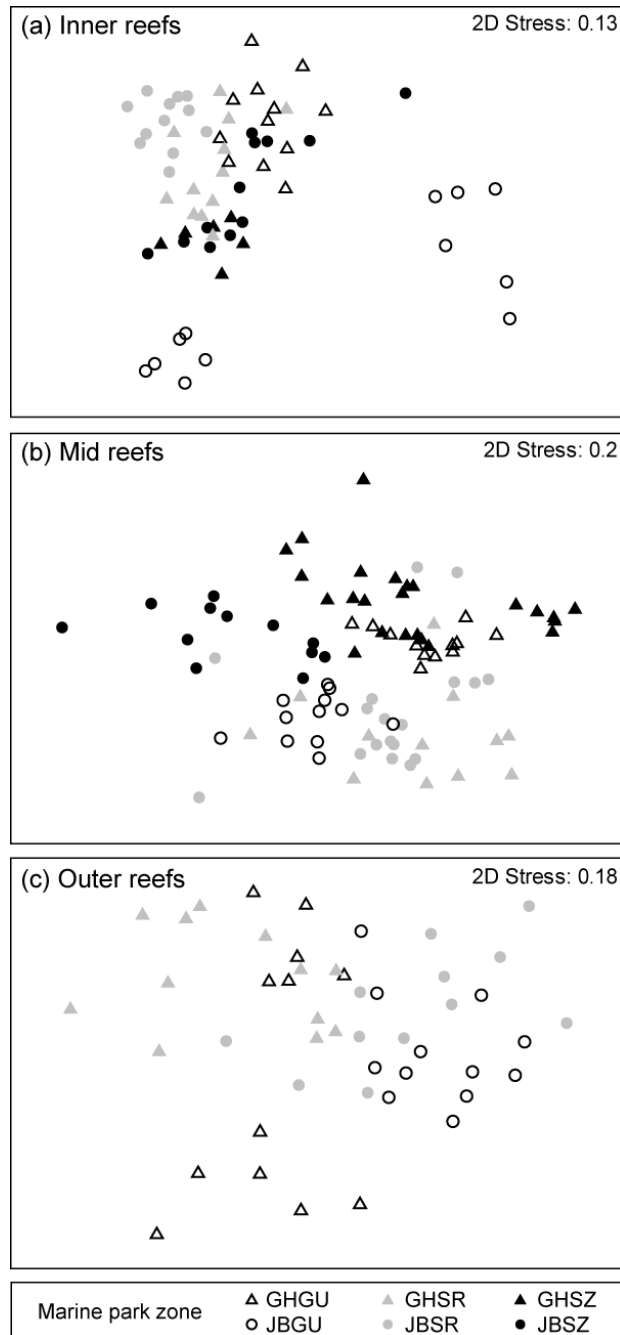
Figure 5.9. Non-metric multi-dimensional scaling plots derived from the similarity matrices constructed from the densities of each fish species at each site in each season in each marine park zone at (a) inner, (b) mid- and (c) outer reef locations. GHGU, Green Head general use zone; GHSR, Green Head scientific reference zone; GHSZ, Green Head sanctuary zone; JBGU, Jurien general use zone; JBSR, Jurien scientific reference zone; JBSZ, Jurien sanctuary zone.

Table 5.17. Species detected by SIMPER as most important for typifying the fish faunas at each reef location in each marine park zone (grey cells) and for distinguishing among the faunas at those locations (white cells) using the data for each zone separately. Species arranged in order of descending importance. Superscripts indicate the zone in which column [1] or row [2] each species was most abundant. Green Head, GH; Jurien, JB; General Use, GU; Scientific Reference, SR; Sanctuary Zone, SZ.

Reef location	GHGU			GHSR			GHSZ	
	Inner	*Mid*	*Outer*	*Inner*	*Mid*	*Outer*	*Inner*	*Mid*
Inner	**N. parilus** **C. auricularis** **P. mccullochi**			**C. auricularis** **N. parilus** **P. mccullochi** **P. milleri**			**C. auricularis** **A. victoriae** **N. parilus** **P. mccullochi** **P. milleri**	
Mid	K. cornelii^2 P. milleri^2 A. maculatus^2	**N. parilus** **C. auricularis** **P. mccullochi** **P. milleri**		A. maculatus^2 A. victoriae^1 P. milleri^1	**P. mccullochi** **C. auricularis** **N. parilus** **A. maculatus** **P. milleri**		A. victoriae^1 P. milleri^1 P. mccullochi^2	**C. auricularis** **N. parilus** **P. mccullochi**
Outer	P. milleri^1 P. biserialis^2 A. maculatus^2	P. milleri^1 L. lineatus^1 C. curiosus^1 P. biserialis^2 K. cornelii^1 N. parilus^1	**C. auricularis** **P. mccullochi** **N. parilus** **A. maculatus**	P. milleri^1 L. lineatus^1 A. maculatus^2 A. victoriae^1 P. biserialis^2 O. lineolatus^2	P. milleri^1 O. lineolatus^2 L. lineatus^1	**C. auricularis** **N. parilus** **A. maculatus** **P. mccullochi**		

Reef location	JBGU			JBSR			JBSZ	
	Inner	*Mid*	*Outer*	*Inner*	*Mid*	*Outer*	*Inner*	*Mid*
Inner	**A. victoriae** **N. parilus** **H. brownfieldi**			**C. auricularis** **P. mccullochi** **N. parilus**			**N. parilus** **C. auricularis** **P. milleri** **A. victoriae**	
Mid	P. mccullochi^2 A. victoriae^1 P. milleri^1	**C. auricularis** **N. parilus** **P. mccullochi**		B. frenchii^1 K. cornelii^1	**C. auricularis** **P. mccullochi** **N. parilus** **A. maculatus**		P. milleri^1 A. victoriae^1 H. brownfieldi^2	**C. auricularis** **N. parilus** **H. brownfieldi**
Outer	A. victoriae^1 P. mccullochi^2 P. biserialis^2 A. maculatus^2	A. maculatus^2 P. biserialis^2	**C. auricularis** **A. maculatus** **P. mccullochi** **P. biserialis** **N. parilus**	P. biserialis^2 P. mccullochi^2 A. maculatus^2 O. lineolatus^2 P. milleri^1	P. mccullochi^1 P. biserialis^2 O. lineolatus^2	**C. auricularis** **N. parilus** **P. mccullochi** **A. maculatus** **P. biserialis**		

Table 5.18. Species detected by SIMPER as most important for typifying the fish faunas of each marine park zone (grey cells) and for distinguishing among the faunas in those zones (white cells, left hand side) using the data for inner reef locations. Species arranged in order of descending importance. Superscripts indicate the zone in which column [1] or row [2] each species was most abundant. Green Head, GH; Jurien, JB; General Use, GU; Scientific Reference, SR; Sanctuary Zone, SZ.

	Inner reefs					
Zone	GHGU	GHSR	GHSZ	JBGU	JBSR	JBSZ
GHGU	*N. parilus* *C. auricularis* *P. mccullochi*					
GHSR	*P. milleri*^{2} *A. victoriae*^{2}	*C. auricularis* *N. parilus* *P. mccullochi* *P. milleri*				
GHSZ	*A. victoriae*^{2} *C. rubescens*^{2} *P. milleri*^{2}	*A. maculatus*^{2} *A. victoriae*^{2} *C. rubescens*^{2}	*C. auricularis* *A. victoriae* *N. parilus* *P. milleri*			
JBGU	*P. mccullochi*^{1} *P. milleri*^{2} *A. victoriae*^{2}	*P. mccullochi*^{1} *P. milleri*^{1} *N. parilus*^{1}	*P. mccullochi*^{1} *P. milleri*^{2}	*A. victoriae* *N. parilus* *H. brownfieldi*		
JBSR	*K. cornelii*^{2} *B. frenchii*^{2}	*P. milleri*^{1} *L. lineatus*^{1} *B. frenchii*^{2} *A. victoriae*^{1} *A. maculatus*^{2}	*A. victoriae*^{1} *K. cornelii*^{2} *P. milleri*^{1} *C. rubescens*^{1} *B. frenchii*^{2} *P. mccullochi*^{2}	*P. mccullochi*^{2} *P. milleri*^{1} *A. victoriae*^{1} *K. cornelii*^{2} *N. parilus*^{2}	*C. auricularis* *P. mccullochi* *N. parilus*	
JBSZ	*A. victoriae*^{2} *P. milleri*^{2}	*A. victoriae*^{2}	*C. rubescens*^{1} *C. curiosus*^{1} *A. maculatus*^{1}	*P. milleri*^{1} *P. mcullochi*^{2} *N. parilus*^{2}	*K. cornelii*^{1} *P. milleri*^{2} *A. victoriae*^{2} *B. frenchii*^{1} *A. maculatus*^{1}	*N. parilus* *C. auricularis* *P. milleri* *A. victoriae*

Table 5.19. Species detected by SIMPER as most important for typifying the fish faunas of each marine park zone (grey cells) and for distinguishing among the faunas in those zones (white cells, left hand side) using the data for mid-reef locations. Species arranged in order of descending importance. Superscripts indicate the zone in which column [1] or row [2] each species was most abundant. Green Head, GH; Jurien, JB; General Use, GU; Scientific Reference, SR; Sanctuary Zone, SZ.

	Mid reefs					
Zone	**GHGU**	**GHSR**	**GHSZ**	**JBGU**	**JBSR**	**JBSZ**
GHGU	*N. parilus* *C. auricularis* *P. mccullochi*					
GHSR	*K. cornelii*[1] *P. milleri*[1]	*C. auricularis* *P. mccullochi* *N. parilus* *P. milleri* *A. maculatus*				
GHSZ	*P. milleri*[1] *K. cornelii*[2]	*P. milleri*[1]	*C. auricularis* *N. parilus* *P. mccullochi* *K. cornelii*			
JBGU	*P. milleri*[1] *K. cornelii*[1] *O. cyanomelas*[2] *A. maculatus*[1]	*A. maculatus*[1] *P. milleri*[1] *O. cyanomelas*[2]	*O. cyanomelas*[2]	*C. auricularis* *P. mccullochi* *N. parilus*		
JBSR	*P. milleri*[1] *K. cornelii*[1]	*P. milleri*[1]	*K. cornelii*[1]	*A. maculatus*[2]	*C. auricularis* *P. mccullochi* *N. parilus* *A. maculatus*	
JBSZ	*H. brownfieldi*[2] *P. milleri*[1] *K. cornelii*[1]	*H. brownfieldi*[2] *A. maculatus*[1] *P. milleri*[1] *N. parilus*[2]	*H. brownfieldi*[2] *N. parilus*[2]	*H. brownfieldi*[2] *N. parilus*[2] *O. cyanomelas*[1]	*H. brownfieldi*[2] *A. maculatus*[2]	*C. auricularis* *N. parilus* *H. brownfieldi*

Table 5.20. Species detected by SIMPER as most important for typifying the fish faunas of each marine park zone (grey cells) and for distinguishing among the faunas of those zones (white cells, left hand side) using the data for outer reef locations. Species arranged in order of descending importance. Superscripts indicate the zone in which column [1] or row [2] each species was most abundant. Green Head, GH; Jurien, JB; General Use, GU; Scientific Reference, SR.

Outer reefs				
Zone	**GHGU**	**GHSR**	**JBGU**	**JBSR**
GHGU	*C. auricularis* *P. mccullochi* *A. maculatus* *N. parilus*			
GHSR	*P. biserialis*[1]	*C. auricularis* *A. maculatus* *N. parilus* *P. mccullochi*		
JBGU	*P. biserialis*[2] *P. mccullochi*[1]	*P. biserialis*[2]	*C. auricularis* *A. maculatus* *P. biserialis* *P. mccullochi* *N. parilus*	
JBSR	*P. mccullochi*[1] *C. auricularis*[1] *O. lineolatus*[2]	*P. biserialis*[2] *N. parilus*[1] *A. maculatus*[2]	-	*C. auricularis* *A. maculatus* *P. mccullochi* *P. biserialis* *N. parilus*

5.3.7 Relationship between fish communities and environmental variables

Draftsman plots indicated that several environmental variables (physical and substrate variables) were correlated to some extent, *i.e.* $r \geq 0.2$, but that the correlation coefficient was > 0.4 in only 36 of 406 pairwise comparisons among variables and never > 0.95. Thus, all of the variables were included in the DISTLM analysis.

The results of marginal tests using DISTLM demonstrated that 15 of the 30 environmental variables, when considered alone, had significant relationships with the fish composition data (Table 5.21). Depth and distance from shore each explained a substantial proportion of the variability in the fish composition data, *i.e.* 30 and 29 %. Although those two variables were highly correlated, *i.e.* $r = 0.71$, r was still < 0.95 and thus both were included in the DISTLM analysis. Other important variables were *Scytothalia doryocarpa* (20 %), cymodoceans (19 %), *Ecklonia radiata* (16 %), calcified phaeophytes (16 %) and filamentous phaeophytes (15 %; Table 5.21). The adjusted R^2 in the step-wise model was 0.27 ($p = 0.001$) after fitting the variable

"depth" and another six variables, *i.e.* turf, distance from shore, % low relief, calcified

phaeophytes, cymodoceans and calcareous rhodophytes, fitted in that order in the

step-wise model, each produced significant results in conditional tests ($p < 0.05$;

Table 5.22). The model indicated that depth was far more important than distance

from shore and the other fitted variables. Together, the above seven variables

explained 64 % of the variation in the fish composition data and the adjusted R^2 was

0.55. None of the remaining environmental variables when added to the step-wise

model produced a significant result in conditional tests and the additional proportion

of variation explained by each of those variables was low, *i.e.* ≤ 2.2 % (Table 5.22).

Table 5.21. Results of marginal tests of the DISTLM procedure demonstrating the relationship between each of the predictor variables and fish composition.

Predictor variables	SS (trace)	Pseudo-F	*P*	Prop. of variation (adj. R^2)
Depth	8809.6	13.466	0.001	0.296
Distance from shore	8556.7	12.923	0.001	0.288
Scytothalia doryocarpa	5896.1	7.9113	0.001	0.198
Cymodoceans	5673	7.5413	0.001	0.191
Ecklonia radiata	4882.1	6.2835	0.001	0.164
Calcified phaeophytes	4789.5	6.1415	0.001	0.161
Filamentous phaeophytes	4513.2	5.7238	0.001	0.152
Calcareous rhodophytes	4153.4	5.1934	0.001	0.140
Posidonians	4049.6	5.0433	0.001	0.136
Turf	3602.3	4.4094	0.001	0.121
Hydrocharitaceans	2794.3	3.3179	0.008	0.094
Corals	2752.1	3.2626	0.009	0.093
Foliose greens	2614.5	3.0837	0.009	0.088
Branching foliose rhodophytes	1945.9	2.2399	0.033	0.065
Rugosity	1855.7	2.1292	0.043	0.062
Caulerpa spp.	1782.1	2.0394	0.055	0.060
Sand	1603.1	1.8228	0.084	0.054
Sponges	1570.6	1.7838	0.096	0.053
Filamentous rhodophytes	1538.4	1.7453	0.098	0.052
Crustose calcareous rhodophytes	1528.8	1.7338	0.089	0.051
Zosteraceans	1526.5	1.731	0.117	0.051
% Moderate relief	1515.2	1.7176	0.091	0.051
% Low relief	1477.4	1.6725	0.107	0.050
% High relief	1388.9	1.5674	0.134	0.047
Filamentous chlorophytes	1244	1.3968	0.162	0.042
Scaberia agardhii	1179.4	1.3212	0.201	0.040
Other branching phaeophytes	733.87	0.80947	0.561	0.025
Sargassum spp.	729.35	0.80436	0.549	0.025
Other small phaeophytes	566.08	0.62081	0.772	0.019
Calcareous epiphytic rhodophytes	528.75	0.57912	0.78	0.018
Total SS (trace)	29745			

Table 5.22. Results of fitting a step-wise model to the fish community data, based on an adjusted R^2 selection criterion of the environmental variables.

Predictor variables	Adj. R^2	SS (trace)	Pseudo -F	P	Prop. of variation (adj. R^2)	Cumulative proportion of adj R^2	Resid. df
+Depth	0.274	8809.6	13.466	0.001	0.296	0.296	32
+Turf	0.365	3180.5	5.553	0.001	0.107	0.403	31
+Distance from shore	0.442	2654.1	5.273	0.001	0.089	0.492	30
+% Low relief	0.473	1326.9	2.794	0.001	0.045	0.537	29
+Calcified phaeophytes	0.499	1135.6	2.516	0.007	0.038	0.575	28
+Cymodoceans	0.523	1027.2	2.389	0.013	0.035	0.610	27
+Calcareous reds	0.546	963.1	2.352	0.005	0.032	0.642	26
+Zosteraceans	0.556	649.9	1.625	0.076	0.022	0.664	25
+Other branching phaeophytes	0.564	572.6	1.458	0.127	0.019	0.683	24
+*Scytothalia doryocarpa*	0.571	537.5	1.391	0.143	0.018	0.701	23
+Corals	0.578	519.3	1.365	0.168	0.017	0.719	22
+Foliose chlorophytes	0.583	472.9	1.258	0.247	0.016	0.735	21
+Hydrocharitaceans	0.593	565.2	1.542	0.094	0.019	0.754	20
+Crustose calc. rhodophytes	0.599	465.7	1.289	0.212	0.016	0.769	19
+*Caulerpa* spp.	0.607	481.4	1.357	0.179	0.016	0.785	18
+*Sargassum* spp.	0.610	409.9	1.167	0.297	0.014	0.799	17
-Cymodoceans	0.610	349.8	0.996	0.434	0.012	0.787	18
+Filamentous chlorophytes	0.615	426.9	1.231	0.259	0.014	0.802	17
+Other small phaeophytes	0.621	430.0	1.259	0.243	0.014	0.816	16
+Sand	0.624	379.9	1.120	0.343	0.013	0.829	15

A distance-based redundancy analysis ordination plot demonstrated that the first two axes explained 59.6 % of the variation in the fitted model and 49.3 % of the total variation in the fish composition data (Fig. 5.10). The first axis on the dbRDA plot shows a strong relationship with the environmental variables depth and distance from shore and reflects the separation from left to right of the plot of the groups of samples from each of the three reef locations. The second axis is strongly related to the variable turf, which, at least in part, was responsible for the spread of samples and thus variability in fish composition of mid- reefs (Fig. 5.10).
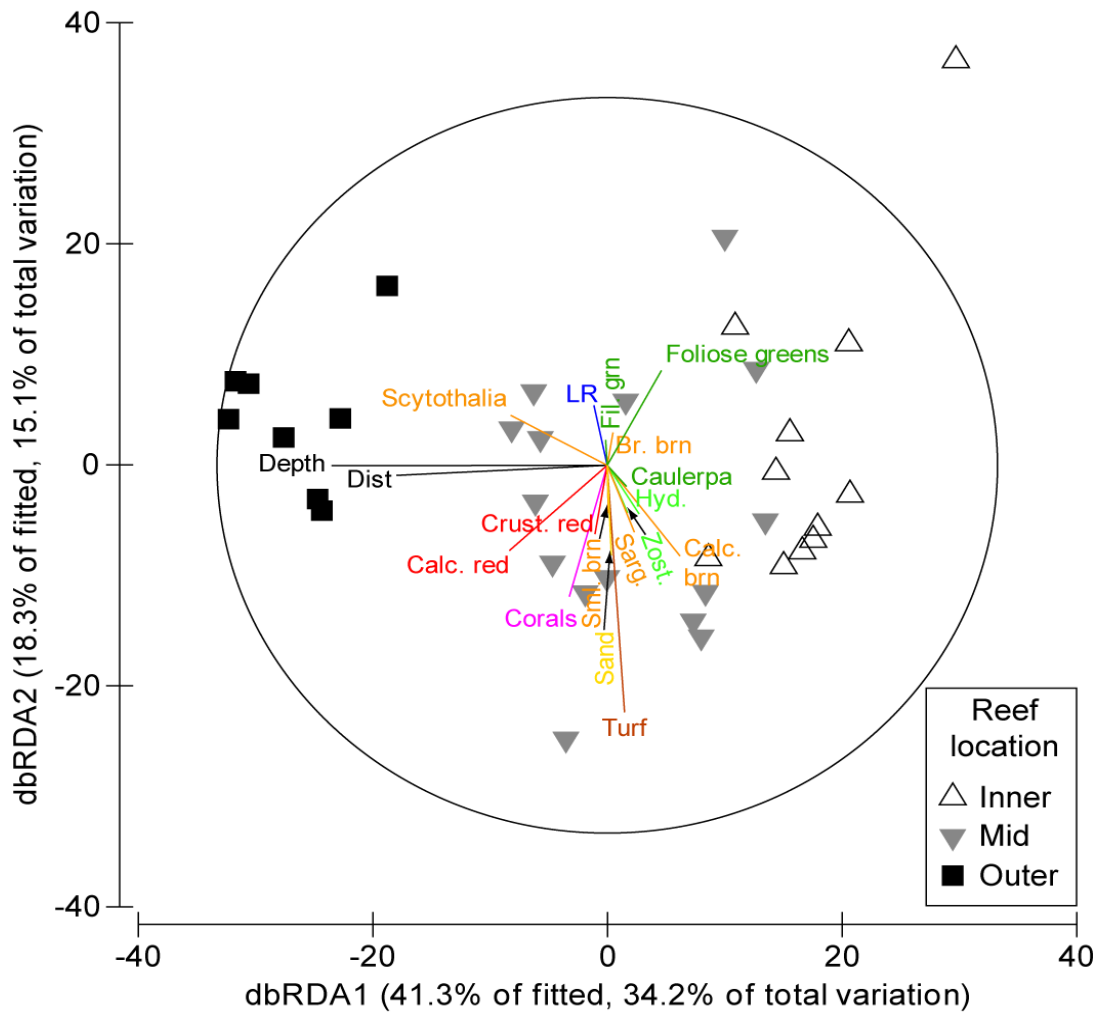
Figure 5.10. Distance-based constrained ordination plot for the fitted model of fish composition data *vs* environmental variables, showing symbols coded for reef location and overlaid vectors for each of the environmental variables.

Phaeophyceae
Br. brn - Unidentified branching phaeophytes
Calc. brn - Calcareous phaeophytes
Scytothalia - *Scytothalia doryocarpa*
Sarg. - *Sargassum* spp.
Sml. brn - Unidentified small phaeophytes

Seagrasses
Cym. - Cymodocean spp.
Hyd. - Hydrocharitaceans

Rhodophyta
Calc. red - Calcareous rhodophytes
Crust. red - Crustose calcareous rhodophytes

Chlorophyta
Fil. green. - Filamentous chlorophytes
Caulerpa - *Caulerpa* spp.

Other
Turf - Unidentified turf spp.
Dist. - Distance from shore
LR - % low relief

5.4 Discussion

5.4.1 Reef fishes of the Jurien Bay Marine Park

The majority of the 137 fish species recorded during underwater visual census of reef habitats in the JBMP have either temperate (86 spp.) or tropical (28 spp.) distributions. Twenty-five species of labrid were observed, while other speciose families were the Monacanthidae (10 spp.), Pomacentridae (9 spp.) and Epinephelidae/Serranidae (9 spp.). The labrids *Coris auricularis*, *Notolabrus parilus* and *Austrolabrus maculatus* and the pomacentrid *Parma mccullochi* were the most frequently observed species, *i.e.* recorded on 1310 to 1773 of 1821 transects, and numerically ranked 1st (n = 56,521), 5th (n = 10,898), 11th (n = 5,541) and 4th (n = 12,809), respectively. While *A. maculatus* and *P. mccullochi* occur exclusively over reefs, *C. auricularis* inhabits reefs and the sand associated with reefs and *N. parilus* occupies both reefs and seagrass. Other abundant species, that were less frequently observed, typically occurred in schools, *e.g.* the pempherid *Pempheris klunzingeri* (17,206 individuals on 542 transects), the clupeid *Spratelloides robustus* (15,340 individuals on 21 transects) and the kyphosid *Kyphosus cornelii* (10,843 individuals on 788 transects) and numerically ranked 2nd, 3rd and 6th, respectively.

Glaucosoma hebraicum and *Pagrus auratus*, which are targeted by recreational and commercial fishers, were rarely recorded during UVC, with only 61 and 14 individuals observed, respectively. This contrasts with the 921 observations of *Choerodon rubescens*, another target species. In New Zealand, Willis *et al.* (2000) found that baited remote underwater video stations (BRUVS) were more reliable than UVC for investigating the relative abundance of *P. auratus* in a marine reserve. However, during our study of the fish fauna of the JBMP over five seasons, using the same BRUVS method as that of Willis *et al*. (2000), we recorded very few of each of

those three species, *i.e.* 2, 11 and 6, respectively (see Chapter 8). This indicates that the behavioural response to both divers and BRUVS varies both within and among such demersal species and that *G. hebraicum* and *P. auratus* are not abundant in the areas of the JBMP surveyed. The much greater number of *C. rubescens* recorded by UVC than by BRUVS emphasises a well-known fact that the use of different methods to survey relative abundance can produce substantially different results (see *e.g.* Connell *et al.* 1998; Willis *et al.*, 2000; Watson *et al.* 2005; Bennett *et al.*, 2009). Other species of interest to fishers were recorded in moderate numbers, *e.g. Arripis georgianus* (1397), *Pseudocaranx* spp. (903) and *Epinephelides armatus* (505).

Although 921 *Choerodon rubescens* were observed during UVC, the total lengths of the vast majority of individuals (*ca* 91 %) were below the current minimum legal length of 400 mm (data not shown). Inner reefs were dominated by fish < 249 mm in length, while mid- and outer reefs comprised fish of mostly 50-349 mm and 300-499 mm, respectively. The small individuals (≤ 299 mm) recorded over inner and mid- reefs comprised both 0+ recruits and individuals with lengths that were less than that at which this species matures (*ca* 280 mm; Fairclough, 2005), but relatively few adults, and indicates that these shallower reefs are used as nursery habitats. The change in the dominant length classes also suggests that there is a size-related or ontogenetic shift from shallow, protected reefs to deeper, more exposed reefs, which was not discernible from the limited BRUVS data. Although such a movement from shallow to deep habitats during the life cycle of a species occurs among several other demersal species in Western Australia, *e.g. Sillago bassensis* and *Rhabdosargus sarba* (Hyndes *et al.*, 1999), it contrasts with the findings of Fairclough *et al.* (2008), who demonstrated that both juvenile and adult *C. rubescens* were relatively abundant over shallow reefs (< 5 m) in oceanic waters of South Passage in Shark Bay. The rarity of

large *C. rubescens* observed over shallow reefs may also be a function of historical fishing pressure having removed those larger fish.

5.4.2 Influence of reef location and marine park zone on the number of species and density of fishes

The number of fish species and relative density of fishes differed significantly among both reef location and marine park zone, when employing the data for the inner, mid- and outer reefs in the general use and scientific reference zones (GHGU, GHSR, JBGU and JBSR). While there was a marginal effect of those two factors on the density of fishes ($p < 0.05$), when the data for the inner and mid- reefs in all six zones were employed, *i.e.* the above four zones and the GHSZ and JBSZ, the number of species differed significantly only among zones. Using the first data set, the pseudo-F statistic indicated that the effect of reef location was substantially greater than that of zone on both variables. However, the interaction demonstrated that the reef location effect wasn't consistent among zones. Indeed, while the overall number of species and density of fishes were lower over outer reefs than either mid- or inner reefs, they did not differ in the case of the JBGU zone and only the inner and mid- reefs differed in the JBSR zone. Using the second data set, such a difference occurred only between inner and mid- reefs in the GHGU and JBSZ zones for the number of species. The significant differences among zones using the first data set could be explained by lower numbers of species and densities of fishes in the GHGU and GHSR zones *vs* those in the JBGU and JBSR zones. Using the second data set, the number of species in the JBSZ and the density of fishes in both the JBSZ and JBGU were lower than in the other zones.

The significantly lower number of species and density of fishes detected over outer reefs than inner and mid- reefs is likely to be influenced by a combination of the typically lower structural complexity and greater exposure of those locations. However, as a lower diversity and relative abundance of fishes wasn't detected in all four zones containing outer reefs, this indicated some variability in the effect of those factors. Indeed, the number of species was similar among the three reef locations in the JBGU and the density of fishes was greater over outer reefs than inner and mid-reefs in that zone. Thus, despite the increased exposure and depth of the outer reefs, the structural complexity of that habitat, reflected in a combination of its rugosity and substrate composition was sufficient to support similar diversity and abundance to the mid- and inner reefs in that zone (see Choat and Ayling, 1987; Newman *et al.*, 1997; Harman *et al.*, 2003; Anderson and Millar, 2004). Similarly, site to site variation in structural complexity would have been responsible for the differences detected among zones in the diversity and abundance of fishes at individual reef locations. It is unlikely that the different levels of management of fishes in the JBMP would have significantly influenced either of those variables in the time between when the marine park was gazetted (2003), the commencement of enforcement of rules associated with the different management zones (2005; K. Crane, Department of Environment and Conservation, pers. comm.) and the timing of these fish surveys (2005-2007) (Anon., 2005; *cf*. Edgar and Barrett, 1997).

5.4.3 Composition of fishes of the JBMP

The species composition of the fish faunas over reefs in the JBMP, employing the two data sets, *i.e.* inner, mid- and outer reefs in general use and scientific references zones and inner and mid- reefs in general use, scientific reference and

sanctuary zones, differed significantly both among reef location and zone and there was an interaction between the two. However, the effect of reef location was much greater than that of either zone or the interaction. The greatest difference, as reflected in the ANOSIM R-statistics, lay between inner and outer reefs and this was common to each of the general use and scientific reference zones. Moderate differences were also detected between inner *vs* mid- and mid- *vs* outer reefs. However, the difference in fish composition between inner and mid-reefs of the sanctuary zones was the weakest.

The relationship between the composition of the fish fauna at each reef location was reflected in the overall nMDS plots and those for each of the zones separately. The samples for outer reefs were always clearly separated from those of the inner and mid-reefs on each plot, but also were less dispersed on the overall nMDS plot, indicating less variability in the composition of fishes within and among individual reef sites at outer reefs than at inner or mid- reefs. When each of the general use and scientific reference zones was investigated separately, the nMDS plots demonstrated that the fish compositions at all three reef locations in each zone were distinct. However, the strength of those differences and variability in the composition of fishes differed in each zone and the proximity of the points for each reef location reflected the (dis)similarity in that composition on each sampling occasion at each site. While the samples for inner reefs in the GHSZ are separated from those of its mid- reefs, only one inner reef site was available for survey. In contrast to all other zones, the samples for inner reefs in the JBSZ overlapped those of its mid- reefs.

SIMPER demonstrated that, as *C. auricularis*, *N. parilus* and *P. mccullochi* were among the most abundant and frequently observed species, they typified almost

all of the reef locations and marine park zones. Variations in their relative abundance also often resulted in one or more of those species being responsible for distinguishing among reef locations or zones. *Austrolabrus maculatus* also typified mid- and outer reefs and distinguished them from inner reefs, while *Pomacentrus milleri* typified inner reefs and distinguished them from both mid- and outer reefs. Furthermore, the two labrids *Pseudolabrus biserialis* and *Ophthalmolepis lineolatus* were partly responsible for typifying outer reefs and distinguishing them from both inner and mid-reefs. Thus, while some of the above labrid and pomacentrid species were essentially ubiquitous, the occupation of specific reef locations by other confamilial and thus morphologically similar species, reflects the partitioning of available resources, such as food and space (Ross, 1986). This type of partitioning was visible among labrids within reef locations. For example, the dietary compositions of the three larger labrids, *C. auricularis*, *N. parilus* and *O. lineolatus*, are sufficiently different to demonstrate their occupation of slightly different niches (see Chapter 9; Lek *et al*., in press). Furthermore, while those larger labrids were observed to roam over the reef habitat, this did not apply to the far smaller *A. maculatus* and *P. biserialis*, which typically occupied small areas associated with rhodophytes and sponges found on reef ledges and/or in caves, suggesting they have a more specific habitat niche. These conclusions parallel those of Denny (2005) for abundant labrids in New Zealand, where several species occurred over reefs at a range of depths, but some were significantly more (*Pseudolabrus miles*) or less (*Notolabrus fucicola*) abundant as depth increased.

When the composition of fishes for each reef location was compared among zones, there was a greater difference between zones at inner reefs than at mid- reefs and essentially no difference among zones over outer reefs. The difference over inner

reefs would have been primarily due to the difference between the JBGU zone and the GHGU, GHSR and JBSR zones, which on the nMDS ordination plot for inner reefs showed the separation of points for the former zone from all other zones. This difference reflects not only the variation among zones, but also that of individual reef sites, which is indicated by the two groupings representing the JBGU. Such a difference in the composition of fishes would have been influenced by the vastly different environmental characteristics of those two sites.

5.4.4 Influence of environmental variables on the composition of fishes

Several of the environmental variables recorded during this study were shown to significantly influence the composition of fishes. In particular, the step-wise model indicated that depth described a much greater percentage (30 %) of the variation in the composition of fishes than any other variable, which corresponds with the distinction of the fish composition of outer reefs from both inner and mid-reefs, indicated by the dbRDA plot, and the fact that outer reefs are deeper on average than inner and mid-reefs. Other variables that were included in the model and the percentage variation that they explained were turf (11 %), distance from shore (9 %), the percentage of low relief recorded at each site (5 %), calcified phaeophytes (4 %), cymodocean seagrasses (3 %) and calcareous rhodophytes (3 %). The effect of depth and distance from shore was clearly reflected in the dbRDA plot, as the points representing the composition of fishes at each reef location essentially formed a gradient from left to right of the outer, mid- and then inner reefs. Furthermore, the effect of variations in the percentage cover of turf over individual reefs was responsible, at least in part, for the separation of sites along the second axis of the dbRDA plot and the dispersal of at

least the mid-reef sites. This would have contributed to the significant among zone effect on fish species composition.

5.4.5 Summary

This study demonstrated that reef location along a gradient of depth and distance from shore influenced the composition of fishes in the JBMP. The increase in depth was also correlated with changes in structural complexity, evidenced by differences in the abundance of, for example, seagrasses and algae, but also a decrease in rugosity. Although the study was not designed to detect whether the fish faunas differed among specific habitat types, such as algal reefs *vs* unvegetated sand (see *e.g.* Anderson and Millar, 2004; Williams *et al.*, 2008), it did show that there is substantial variability in the fish fauna among different reef habitats, but also within and among marine park zones of the JBMP. Furthermore, the detection of significantly different species compositions over outer reefs, which were distinguished by some species that were not present or occurred in lower abundances over mid- or inner reefs, *e.g.* *O. lineolatus*, or contained different life cycle stages of some species, *e.g.* *C. rubescens*, demonstrates that the current location of sanctuary zones, which do not encompass outer reefs, does not completely protect such species or stages from the effects of fishing. Although the scientific reference zones extend sufficiently offshore to encompass outer reefs, those zones still allow fishing for Western rock lobster *Panulirus cygnus*. Such fishing inadvertently captures fish species, including *Choerodon rubescens*, *Epinephelides armatus* and labrids (de Lestang *et al.*, 2008) that are known to suffer barotrauma-related mortality after capture in deeper water.

The above results demonstrate the need to consider the variation in fish fauna that occurs at both small and large spatial scales when designing a monitoring

program for reef fishes in the JBMP. Poorly designed surveys that do not take the substantial variation into account may produce spurious results, when, for example, comparing the fish fauna among marine park zones. This is particularly important if such studies are designed to detect positive or negative effects on the abundance of targeted and non-targeted species as a result of the closure of areas to fishing. Furthermore, consideration should be given to the likelihood that species composition and abundance may change as a result of such management and this may influence other parameters being measured, such as diversity and mean trophic level (Jennings and Polunin, 1997; Watson *et al.*, 2007).

6.0 Fish communities of seagrass and unvegetated habitats

Fairclough, D. V. and Potter, I. C.

6.1 Introduction

The abundance and diversity of fish species are typically greater in seagrass meadows than in nearby unvegetated sand habitats (see Bell and Pollard, 1989; Ferrell and Bell, 1991; Connolly, 1994; Jenkins and Wheatley, 1998; Travers and Potter, 2002). This difference has been attributed to the provision by the more structurally complex seagrass of greater protection from predators and a more diverse and abundant food supply (Howard *et al.*, 1989). However, the extent of this difference varies with factors such as the proximity of the two habitat types, distance from shore and thus depth, and seagrass type (Ferrell and Bell, 1991; Jenkins *et al.*, 1997; Hyndes *et al.*, 2003). For example, Ferrell and Bell (1991) found that the numbers of species and individuals were generally greater in seagrass than sand habitats when they were at least 100 m from seagrass, whereas such differences were less consistent when those two habitat types were far closer, *i.e.* within 10 m.

Seagrass meadows often have been considered to represent an important habitat for juvenile fishes in Australia and elsewhere, through providing shelter and, as a result of their high productivity, an abundant food supply (see Bell and Pollard, 1989; Jenkins *et al.*, 1997; Nagelkerken *et al.*, 2000; Lazzari and Stone, 2006). However, this conclusion has been routinely drawn from the presence of greater abundances of juvenile fishes in seagrass than in adjacent unvegetated habitats (see Beck *et al.*, 2001; Heck *et al.*, 2003 for reviews). It has been proposed that structure itself, whether it be in the form of seagrass, reef, macroalgae or mangroves, rather than the type of structure, can be more important as an indicator of the value of a habitat as a nursery (Beck *et al.*, 2001; Heck *et al.*, 2003). For example, Nagelkerken

et al. (2000) found that structure in the form of both seagrass and mangroves in the same location are important nurseries for a range of species. However, Chittaro *et al.* (2005) found this not to be the case for the same habitat types in a different location. Beck *et al.* (2001) state that for seagrass to be considered the most important nursery habitat for a species, there must be evidence, not only of the higher abundance of juveniles relative to other habitats, but of higher survival and growth rates in seagrass, as a result of the protection from predators and the abundant food resources, respectively, in that habitat, which ultimately result in more juveniles reaching the adult stage from that habitat.

The densities of fishes and composition of fish communities differ according to which seagrass species are dominant as this influences the physical characteristics of the seagrass meadow (Bell and Pollard, 1984; MacArthur and Hyndes, 2001; Travers & Potter, 2002; Hyndes *et al.*, 2003). For example, in south-western Australia, Hyndes *et al.* (2003) recorded more species and greater densities of fishes in seagrass meadows that were dominated by *Posidonia sinuosa* than by *Amphibolis griffithii* or *Posidonia coriacea* and attributed this variation to a combination of differential predation and recruitment levels of fish in habitats of different architecture, the movement of fish after settlement into favoured habitats and/or differences in food availability among seagrass habitats. The studies of Hyndes *et al.* (2003) and MacArthur and Hyndes (2001) also provided evidence that fish species are less abundant in seagrass beds of low density.

In the Jurien Bay Marine Park (JBMP), seagrass beds, which occur predominantly in the lagoonal areas, comprise *ca* 25 % of the park's area. Nine species have been recorded in the JBMP, with *Posidonia* and *Amphibolis* species being the most abundant (Anon, 2005). The Department of Environment and

Conservation have identified seagrass beds in the JBMP as an important habitat and nursery area for marine organisms, such as fishes, and as an important primary producer (Anon., 2005). The fish fauna of the seagrass beds of the JBMP has been studied for the first time only recently. Fromont *et al.* (2006) conducted a taxonomic study of the fish fauna using underwater visual census (UVC) and box trawls, while Vanderklift *et al.* (2007) employed UVC to investigate the abundance of predatory fishes in seagrass beds adjacent to reefs. Each of those studies were conducted during a single season in the JBMP. Collection of baseline spatial and temporal data on the diversity and abundance of fishes in the seagrass and adjacent unvegetated sand habitats of the JBMP and the development of an understanding of the value of these habitats as nurseries for fishes, will allow environmental and fisheries managers to monitor the status of those communities and thus ensure that management plans are effective in maintaining their health.

The aims of this study were to describe the numbers of fish species, numbers of individuals and compositions of fish species in seagrass and unvegetated sand habitats at a range of locations within the Jurien Bay Marine Park. Sites were chosen in those two habitat types in different marine park zones, *i.e.* those open to fishing (general use zones), those closed to fishing (sanctuary zones) and those where fishing is restricted (scientific reference zones), in both the Green Head to Sandy Point and Jurien to Black Rock regions, where each of those zones occur. Within each zone, site selection was limited by the presence of suitable habitat, which provided a range of different seagrass types and densities and different-sized areas of unvegetated sand among those zones. Thus, while the sampling regime was not designed to test *a priori* hypotheses regarding the effect of factors such as seagrass type and density, they could be explored with the data collected. Focus was also placed on investigating

whether the species that occupy those habitats are likely to be resident, *i.e.* complete their life cycle in those habitats, or occupy them only as juveniles, possibly prior to moving to alternative habitats, such as reef. The following specific hypotheses were tested.

(1) The number of species and density of fishes in the inshore seagrass beds are greater than in inshore unvegetated habitats and the compositions of fish species in those two habitats differ.

(2) The number of species and density of fishes are greater and the compositions of the fish faunas are different at sites in seagrass beds that have high seagrass densities than in those with lower densities, and that this is the case regardless of seagrass species composition.

(3) The numbers of species, density and compositions of fishes in seagrass beds change in each season due to the seasonal differences in immigration and emigration patterns of different species.

(4) There is no evidence of a serial change in the composition of the fish fauna in any of the marine park zones as a result of protection from fishing.

6.2 Materials and methods

6.2.1 Sampling regime and sample processing

The fishes of inshore seagrass ($\leq$ 9 m deep) were sampled by otter trawling in each season for two years from autumn 2005 to summer 2006/7 and, in the case of unvegetated sand habitats ($\leq$ 7 m deep), in each season for one year from autumn 2005 to summer 2005/6 (Table 6.1). Trawling in sand habitats was only conducted for one year as few fish were captured in that habitat (see Results). Trawling was conducted in each of the three main management zones, *i.e.* general use, scientific

reference and sanctuary zones, at two locations in the JBMP, *i.e.* from Green Head to
Sandy Point (referred to as Green Head) and Jurien Bay to Black Rock (referred to as
Jurien) (Figs 4.1, 4.2). However, sampling of unvegetated sand in the Green Head
scientific reference zone was not possible due to insufficient areas of that habitat type.
Trawling was not conducted in a third location, between Cervantes and Wedge Island,
due to difficulties accessing that location and the lack of habitat that could be trawled
effectively in each marine park zone in that location. For example, test trawls in
seagrass beds in the Nambung sanctuary zone and adjacent general use zone waters,
found that those beds emanated from a sand/rock substrate which prevented effective
trawling and caused frequent snagging of the net. A similar problem was encountered
in unvegetated sand habitats in that location.

Table 6.1. Habitat types sampled by trawling in general use, scientific reference and sanctuary zones at Green Head and Jurien in the Jurien Bay Marine Park and depth range at each site. ns = not sampled.

Region	Management zone	Habitat type and depth range (m)	
		Seagrass	*Unvegetated sand*
Green Head	General use	3-7	4-7
	Scientific reference	6-8	ns
	Sanctuary	4-6	5-6
Jurien	General use	5-8	3-6
	Scientific reference	4-8	3-5
	Sanctuary	4-9	2-3

Between the middle and end of each season of sampling, four replicate trawl
samples were obtained during the day in each habitat and zone in each location, *i.e.*
Green Head general use zone (GHGU), Green Head scientific reference zone
(GHSR), Green Head sanctuary zone (GHSZ), Jurien general use zone (JBGU), Jurien
scientific reference zone (JBSR) and Jurien sanctuary zone (JBSZ) (location/zone
combinations are referred to as sites, *i.e.* six sites in total) (Table 6.1). Replicates were
located at least 150 m apart, to prevent overlap of the areas trawled, and each trawl on

any individual day was towed in the same direction as the prevailing wind to ensure each trawl was in an approximately straight line. The net used was a small tri-net, which was 5 m long, 2.6 m wide and 0.5 m high at the mouth and had 50 and 13 m warp and bridle lengths, respectively. The net contained stretched mesh of 51 mm in its wings and 25 mm in its bunt. The net was towed at a speed of *ca* 3 - 4 km h^{-1} and for a distance of 150 m. The distance trawled during each replicate was measured using a Garmin GPS Map 178c global positioning system, which, together with the width of the mouth of the net, enables the approximate area of substrate trawled to be determined, *i.e. ca* 390 m^{-2} per trawl.

The net was sorted *in situ* and fish to be retained were immediately euthanased in an ice slurry, prior to being stored on ice in labelled plastic bags. Elasmobranchs were always identified *in situ* and their disk widths or total lengths measured to the nearest 1 mm. They were then returned to the water alive. Total lengths (to the nearest 1 mm) of individuals of the Common Sea Dragon, *Phyllopteryx taeniolatus*, were measured and also returned alive. In the laboratory, retained teleost fishes from each replicate sample were identified, their total lengths measured (mm). The total weight of the sample of each species was recorded to the nearest 0.1 g. The biogeographical distributions of species were derived from the information presented in Hutchins and Swainston (1986), Gomon *et al.* (2008) and Allen (1999).

An understanding of the composition of seagrass species and seagrass density at each seagrass site was derived from observations of the small amounts of the different types of live seagrass, *i.e. Posidonia sinuosa*, *Amphibolis griffithii*, *Amphibolis antarctica* and *Halophila* sp., collected in the net while trawling and from still images derived from the area of substrate visible in the field of view of the baited remote underwater video (BRUV) deployments (see Chapter 8), which were each

located in the area of each replicate trawl at each site. Seagrass density at each site was derived from each replicate BRUV drop at those sites and was considered as either low (> 50% sand), moderate (20-50 % sand) or high (< 20% sand).

6.2.2 Statistical analyses

Univariate analyses

The numbers of individuals of each species collected in each sample in each habitat were converted to a density, *i.e.* fish per trawl, which equates to fish 390 m^{-2}. Preliminary examinations of the relationships between the ln(x+1) transformed means and ln(x+1) transformed standard deviations of the number of species and total density of fishes at each site in both seagrass and sand in each sampling season were conducted, together with normal Q-Q and residual plots, to determine whether those data met the assumptions of analysis of variance (ANOVA), *i.e.* normality and homogeneity of variances, and thus whether they required transformation prior to ANOVA. Those examinations revealed that square-root transformations were appropriate for the above two variables.

The square-root transformed mean number of species and mean overall fish density in seagrass and unvegetated sand at each site in each season in the first year of sampling were subjected to one-way ANOVA to test the first hypothesis that there is a greater number of species and individuals in inshore seagrass than unvegetated sand. A one-way ANOVA is justified in this case, as habitat type is the main factor of interest and, as very few individuals were collected in the sand habitat, *i.e.* fish were caught in only 28 of the 80 replicate trawl net samples from that habitat, the use of the factor "season" would not produce particularly meaningful results. No further

univariate statistical analyses were carried out on data for the unvegetated sand habitat.

The transformed mean number of species and density of fishes at each site in each season and year in inshore seagrass beds were subjected to a three-way ANOVA to test the hypotheses outlined in section 8.1, using a factorial design of site (fixed, 6 levels), crossed with season (fixed, four levels), crossed with year (fixed, 2 levels).

Multivariate analyses

A one-way Analysis of Similarities test (ANOSIM; Clarke, 1993) was used in the Primer *v*6 statistical package with the Windows PERMANOVA+ module (Anderson *et al.* 2008) to determine whether the composition of the fish faunas of seagrass and unvegetated sand habitats differed significantly. Data used comprised the density of fishes derived from the first four seasons of sampling, when trawling was conducted in both habitats. The effects of site and season were not investigated in this test as "habitat" was the main factor of interest. Note that the effects of site and season in the seagrass habitat are investigated (see later). Prior to using ANOSIM tests, the densities of fishes in each season and habitat were square-root transformed, following an examination of a plot of the log of the means *vs* the log of the standard deviations of the densities of each fish species in each habitat (Clarke and Warwick, 2001). A Bray-Curtis similarity matrix was then constructed, incorporating a dummy variable of 0.1, as the number of samples with zero fish from the sand habitat was large, and this was then used for the ANOSIM test. The species that typified and distinguished the ichthyofaunas in the seagrass and sand habitats were determined using Similarity Percentages (SIMPER) on the original square-root transformed data set. The square-root transformed densities of fish were then averaged across each site and season and

a new Bray-Curtis similarity matrix constructed (including a dummy variable of 0.1), from which a non-metric multi-dimensional scaling (nMDS) plot was derived.

To test the hypothesis that the species composition at sites in seagrass beds with high density seagrass differed from those with low density and that fish faunas in seagrass beds undergo seasonal changes, the data were considered to represent a three factor crossed design of site (6 levels) × season (4 levels) × year (2 levels), each factor being fixed. The density of fishes in each replicate were square-root transformed and from which a Bray-Curtis similarity matrix was constructed (incorporating a dummy variable of 0.1), which was then subjected to 3-way PERMANOVA. When a factor was found to have a significant effect, pairwise permutational t-tests were used to explore the data for differences among the levels of that factor. Two-way crossed ANOSIM tests of site × season, site × year and season × year were conducted on the similarity matrix to investigate the strength of any significant results in the PERMANOVA in a fully non-parametric framework (*cf.* Fairclough *et al.*, 2008). SIMPER was used to determine which species were responsible for typifying and distinguishing significant factors. A nMDS plot was constructed from a Bray-Curtis similarity matrix, which was derived from the square-root transformed mean densities of fishes at each site in each season (pooled across years), as year was found to have no effect (see Results).

6.3 Results

6.3.1 Types and observed densities of seagrass

Observations of the species of seagrasses that had been trawled at each site in each replicate revealed that their compositions were highly variable and that between 50 and 77 % of replicates at any one site had trawled a mixture of the species

Amphibolis griffithii, *Amphibolis antarctica* and *Posidonia sinuosa*, with a small percentage also containing *Halophila* sp. (Table 6.2). A reasonable percentage of replicates contained a combination of only the two *Amphibolis* species at the Jurien general use and scientific reference zone sites, while 20% of trawls at the Green Head sanctuary zone site (GHSZ) and 44 and 41 % of trawls at the Green Head general use (GHGU) and the Jurien sanctuary zone (JBSZ) sites, respectively, covered only monospecific *P. sinuosa* beds (Table 6.2).

The composition of seagrasses recorded during each replicate drop of the baited remote underwater video (BRUV, see Chapter 8) demonstrated that *P. sinuosa* was the most frequently-recorded species at the GHGU and JBSZ sites (Tables 6.3, 6.4). Fifty percent of BRUV drops at the GHSZ site were located on *P. sinuosa*, while the remainder comprised *P. sinuosa* and small amounts of *A. antarctica*. The Green Head scientific reference (GHSR), Jurien general use (JBGU) and Jurien scientific reference (JBSR) zone sites were more variable in composition, although the majority of BRUV drops at the former site comprised either *P. sinuosa* or a combination of *P. sinuosa* and either *A. griffithii* or *A. antarctica* (Tables 6.3, 6.4). At the latter two sites, only a small number of BRUV drops comprised solely *P. sinuosa*, with seagrass in a majority of drops consisting of *A. griffithii*, *A. antarctica*, a combination of the two, or a combination of one or both *Amphibolis* spp. and *P. sinuosa* (Tables 6.3, 6.4).

The majority of BRUV drops at each site (> 71 %) were located on high density seagrass, except at the JBSZ, which was comprised mostly (71 %) of moderate densities of seagrass. Only a small percentage were located on low density seagrass, which were at the GHSR and JBGU sites (Table 6.5).

Table 6.2. Percentage frequency of observation of the different compositions of seagrasses trawled from all replicate trawls at each site in each season. Seagrass species: *Ps*, *Posidonia sinuosa*; *Ag*, *Amphibolis griffithii*; *Aa*, *Amphibolis antarctica*; *H, Halophila* sp. GH, Green Head; JB, Jurien; GU, general use zone, SR, scientific reference zone; SZ, sanctuary zone.

Site	Seagrass composition						
	Ps	*Ag*	*Aa*	*Ag, Aa*	*Ag, Aa, Ps*	*Ag, Aa, H*	*Ag, Aa, Ps, H*
GHGU	44				50	3	3
GHSR		16		16	68		
GHSZ	20				77		3
JBGU		12		19	56	13	
JBSR				32	54	14	
JBSZ	41	3	6		50		

Table 6.3. Percentage frequency of observation of the different compositions of seagrasses recorded in the camera's field of view during each baited remote underwater video replicate drop at each site in each season (Total 144 BRUV drops). Seagrass species: *Ps*, *Posidonia sinuosa*; *Ag*, *Amphibolis griffithii*; *Aa*, *Amphibolis antarctica*; *H, Halophila* sp. GH, Green Head; JB, Jurien; GU, general use zone; SR, scientific reference zone; SZ, sanctuary zone.

Site	Seagrass composition							
	Ps	*Ag*	*Aa*	*Ag, Aa*	*Ps, Ag*	*Ps, Aa*	*Aa, H*	*Ps, Ag, Aa*
GHGU	88				4	8		
GHSR	33	13		17	8	21	8	
GHSZ	50					50		
JBGU	13	59		8	8	8		4
JBSR	4	29	8	13	21	17		8
JBSZ	92					8		

Table 6.4. Typical dominant seagrass species and density recorded by baited remote underwater video at sites sampled by trawl netting in each season in the Jurien Bay Marine Park between Autumn 2005 and Summer 2006/2007. GU = general use zone, SR = scientific reference zone, SZ = Sanctuary zone.

GHGU, *P. sinuosa*

GHSR, *P. sinuosa*

GHSZ, *P. sinuosa*

JBGU, *A. griffithii*

JBSR, *A. griffithii*

JBSZ, *P. sinuosa*
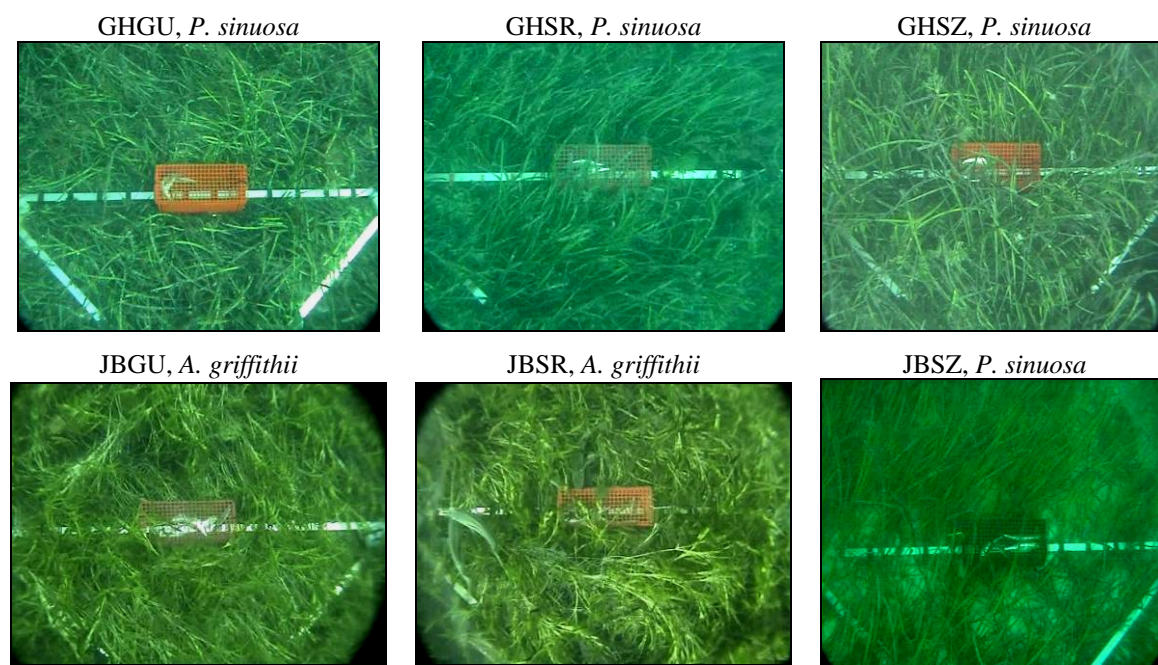
Table 6.5. Percentage frequency of observation of low, moderate and high density seagrass recorded in the camera's field of view during each baited remote underwater video replicate drop at each site in each season (Total 144 BRUV drops). Density: Low, > 50 % of field of view is sand; moderate 20-50 % sand; high, < 20 % sand. GH, Green Head; JB, Jurien; GU, general use zone, SR, scientific reference zone; SZ, sanctuary zone.

Site	Seagrass density		
	Low	*Moderate*	*High*
GHGU		13	88
GHSR	13	17	71
GHSZ		17	83
JBGU	17	4	79
JBSR		25	75
JBSZ		71	29

6.3.2 Numbers of species and density of fishes

A total of 1262 fish, representing 41 species from 24 families (20 teleost, 4 elasmobranch) were caught by trawling in inshore seagrass beds during the eight seasons of sampling (Table 6.5). During the four seasons when both seagrass and unvegetated sand were sampled, 694 fish comprising 37 species were caught in seagrass, while only 45 fish, comprising 22 species from 12 families (9 teleost, 3 elasmobranch) were caught in unvegetated sand (Table 6.6). Note that individuals of the Siganidae that were caught could not be identified to the species level, due to the similarity of their morphological characteristics, *e.g.* fin ray counts, and that two species are known to occur in the Jurien region, *i.e. Siganus fuscescens* and *S. canaliculatus*. Twenty nine and fifteen of the species collected in seagrass and sand, respectively, are distributed solely in temperate waters, while five and two species occurring in those two habitats, respectively, occur in temperate to subtropical waters and five and four in temperate to tropical waters. Two of the species collected in seagrass have tropical distributions, while six species in seagrass and three in sand are endemic to Western Australia. The wrasses (Labridae) and the leatherjackets (Monacanthidae) were the most diverse families in both habitats, with seven labrid and six monacanthid species being caught in seagrass and five monacanthids and three labrids being caught over unvegetated sand (Tables 6.5, 6.6).

Five species comprised 75 % of the total numbers of fish caught in seagrass, with *Scobinichthys granulatus* (29.2 %) and *Notolabrus parilus* (18.1 %) being the most abundant and most frequently caught, followed by *Apogon rueppellii* (13.1 %), *Heteroscarus acroptilus* (8.5 %) and *Acanthaluteres vittiger* (5.8 %; Table 6.5). The remaining 36 species each contributed less than 5 % to the total numbers of fish caught. Only six of the species caught in seagrass, three of which were Odacines, occur solely in that habitat, while 20 occur in seagrass and reef habitats, three in seagrass and sand and six in all three habitats. Two species caught in seagrass are reported to occur solely over reefs, *i.e. Scorpaena sumptuosa* and *Epinephelus rivulatus*, while three species typically occupy both reef and unvegetated sand habitats (*Upeneichthys vlamingii*, *Aploactisoma milesii* and *Trygonorrhina fasciata*) and one species occupies unvegetated sand habitats (*Cynoglossus broadhursti*) (Hutchins and Swainston, 1986; Table 6.5). Of the 10 most abundant species caught in seagrass and of those that commonly occur in seagrass, the catches contained at least the majority of the full length ranges and at least some fish with developing, mature, spawning and/or spent gonads, *e.g. N. parilus*, *H. acroptilus* and *Haletta semifasciata* (Table 6.5). Eighteen of the remaining species comprised fish that were mostly well below their recorded maximum lengths and each of those species is reported to occur either in seagrass and other habitats or solely other habitats, *e.g. Siganus* spp., *Enoplosus armatus* and *Choerodon rubescens*.

None of the 22 species caught by trawling over unvegetated sand were abundant, with *S. granulatus* and *Torquigener pleurogramma*, which were the most numerically abundant, contributing only 9 and 6 individuals to catches in that habitat (Table 6.6). Indeed, fish were caught in only 28 of the 80 trawls conducted over unvegetated sand. Only three of the species caught occupy solely unvegetated sand

habitats, while seven species typically occur in sand and a combination of seagrass and/or reefs and twelve are usually found in habitats other than sand (Table 6.6).

Nine of the species caught in seagrass and unvegetated sand are taken by recreational and/or commercial fishers, such as members of the Platycephalidae, Labridae and Plotosidae. However, only *C. rubescens*, of which only two individuals were caught, is an important target in those sectors in the Jurien region (Tables 6.5, 6.6).

The number of species and overall density of fishes were significantly greater in inshore seagrass beds than over inshore unvegetated sand (Table 6.7; Fig. 6.1). The number of species and overall density of fishes in seagrass differed significantly among sites, but not between seasons or years (Table 6.8; Fig. 6.2). There were significant two-way interactions between site and season for both the number of species and density of fishes in the seagrass habitat. However, there were no consistent trends at the different sites among seasons (Table 6.8, Fig. 6.2). In the case of density of fishes, there was a significant two-way interaction between season and year and a three-way interaction among site, season and year (Fig. 6.3a, b). However, the mean squares for each of the interactions for both variables were much smaller than those of the main effect "site" (Table 6.8). Furthermore, while there was a slight decline in the overall mean density of fishes from year one to year two, the confidence intervals for those means overlapped (Fig. 6.3a). Similarly, the mean density of fishes at most sites declined slightly from year one to year two, but their confidence intervals overlapped (Fig. 6.3b).

Table 6.5. Fishes collected during trawling of seagrass habitats of the JBMP between Autumn 2005 and Summer 2006/2007, interest to commercial and/or recreational fishers ([F]), biogeographical distributions in Australian waters (Distn; T, temperate; S, subtropical; Tr, tropical; *endemic to W.A.), typical marine habitats occupied (S, sand; G, seagrass; R, reef), total length range (maximum lengths on record in parentheses; disk widths and total lengths (TL) given for length range and maximum lengths, respectively, of urolophids and dasyatids; max. lengths derived from Hutchins and Swainston, 1986; Gomon *et al.*, 2008 and Allen, 1999), total numbers of individuals caught of each species (n), % contribution to total numbers of individuals caught, number of replicate trawls in which species was caught (Freq, total number of replicates = 192), and overall mean density (fish $116m^{-2}$) of each species from all sites.

Family	Species	Distn	Habitats	Length range (mm)	n	%	Freq	Mean density
Monacanthidae	*Scobinichthys granulatus*	T	GR	12-189 (345)	368	29.2	135	1.92
Labridae	*Notolabrus parilus*[F]	T	GR	91-272 (490)	228	18.1	98	1.19
Apogonidae	*Apogon rueppellii*	T/Tr	SGR	42-121 (120)	165	13.1	40	0.86
Labridae	*Heteroscarus acroptilus*	T	GR	41-189 (290)	107	8.5	63	0.56
Monacanthidae	*Acanthaluteres vittiger*	T	GR	24-170 (320)	73	5.8	40	0.39
Platycephalidae	*Leviprora inops*[F]	T	SG	155-423 (610)	50	4.0	37	0.26
Labridae	*Haletta semifasciata*	T	G	105-278 (410)	32	2.5	27	0.17
Apogonidae	*Apogon victoriae*	T/S*	GR	45-115 (140)	28	2.2	18	0.15
Monacanthidae	*Monacanthus chinensis*	T/Tr	GR	60-249 (381)	25	2.0	22	0.13
Plotosidae	*Cnidoglanis macrocephalus*[F]	T	SGR	68-445 (910)	23	1.8	19	0.12
Labridae	*Siphonognathus radiatus*	T	G	59-174 (220)	17	1.3	16	0.09
Siganidae	*Siganus* spp.	T/Tr	GR	52-122 (*ca* 410)	16	1.3	13	0.08
Enoplosidae	*Enoplosus armatus*	T	GR	52-198 (310)	15	1.2	12	0.08
Monacanthidae	*Acanthaluteres spilomelanurus*	T	GR	61-119 (140)	12	1.0	9	0.06
Tetraodontidae	*Torquigener pleurogramma*	T/S	SGR	111-178 (220)	12	1.0	9	0.06
Latidae	*Hypopterus macropterus*	T/Tr*	GR	114-208 (140)	12	1.0	10	0.06
Diodontidae	*Diodon nicthemerus*	T	GR	33-111 (300)	12	1.0	11	0.06
Clinidae	*Cristiceps australis*	T	G	64-168 (230)	11	0.9	11	0.06
Mullidae	*Upeneichthys vlamingii*[F]	T	SR	89-252 (420)	10	0.8	10	0.05
Scorpaenidae	*Scorpaena sumptuosa*	T/S	R	121-137 (400)	7	0.6	6	0.04
Monacanthidae	*Brachaluteres jacksonianus*	T	GR	23-60 (90)	5	0.4	5	0.03
Urolophidae	*Trygonoptera ovalis*	T*	SGR	145-300 (380TL)	4	0.3	4	0.02

Table 6.5 cont.

Family	Species	Distn	Habitats	Length (mm)	n	%	Freq	Mean density
Aploactinidae	*Aploactisoma milesii*	T	SR	74-86 (230)	3	0.2	3	0.02
Monacanthidae	*Meuschenia freycineti*	T	GR	120-192 (550)	3	0.2	3	0.02
Ostraciidae	*Aracana aurita*	T	GR	74-85 (250)	3	0.2	3	0.02
Plotosidae	*Paraplotosus albilabris*[F]	T/Tr	GR	158-311 (1340)	2	0.2	2	0.01
Latidae	*Psammoperca waigiensis*[F]	Tr	GR	234-291 (470)	2	0.2	2	0.01
Platycephalidae	*Platycephalus laevigatus*[F]	T	GR	423-445 (810)	2	0.2	2	0.01
Labridae	*Choerodon rubescens*[F]	T/S*	GR	87-92 (700)	2	0.2	2	0.01
Tetrarogidae	*Centropogon latifrons*	T	G	89 (110)	1	0.1	1	< 0.01
Labridae	*Siphonognathus argyrophanes*	T	G	441 (520)	1	0.1	1	< 0.01
Syngnathidae	*Stigmatopora argus*	T	G	226 (260)	1	0.1	1	< 0.01
Cynoglossidae	*Cynoglossus broadhursti*	T	S	230 (310)	1	0.1	1	< 0.01
Rhinobatidae	*Trygonorrhina fasciata*	T	SR	300 (1260)	1	0.1	1	< 0.01
Dasyatidae	*Dasyatis brevicaudata*	T	SGR	500 (4300TL)	1	0.1	1	< 0.01
Terapontidae	*Pelsartia humeralis*	T	SG	178 (390)	1	0.1	1	< 0.01
Heterodontidae	*Heterodontus portusjacksoni*	T	SGR	243 (1370)	1	0.1	1	< 0.01
Terapontidae	*Pelates octolineatus*	T	SG	161 (320)	1	0.1	1	< 0.01
Syngnathidae	*Phyllopteryx taeniolatus*	T	GR	220 (460)	1	0.1	1	< 0.01
Serranidae	*Epinephelus rivulatus*[F]	Tr*	R	170 (460)	1	0.1	1	< 0.01
Labridae	*Halichoeres brownfieldi*	T/S*	GR	94 (150)	1	0.1	1	< 0.01

Table 6.6. Fishes collected during trawling of unvegetated sand habitats of the JBMP between Autumn 2005 and Summer 2005/2006, interest to commercial and/or recreational fishers (^F), biogeographical distributions in Australian waters (Distn; T, temperate; S, subtropical; Tr, tropical; *endemic to W.A.), typical marine habitats occupied (S, sand; G, seagrass; R, reef; O, offshore), total length range (maximum lengths in parentheses; disk widths and total lengths given for length range and maximum lengths, respectively, of urolophids; max. lengths derived from Hutchins and Swainston, 1986; Gomon *et al.*, 2008 and Allen, 1999), total numbers of individuals caught of each species (n), % contribution to total numbers of individuals caught, number of replicate trawls in which species was caught (Freq, total number of replicates = 80), and overall mean density (fish $116m^{-2}$) of each species from all sites.

Family	Species	Distn	Habitats	Length (mm)	n	%	Freq	Mean density
Monacanthidae	*Scobinichthys granulatus*	T	GR	42-72 (345)	9	20.0	6	0.11
Tetraodontidae	*Torquigener pleurogramma*	T/S	SGR	86-162 (220)	6	13.3	5	0.08
Paralichthyidae	*Pseudorhombus jenynsii*^F	T/Tr	S	143-271 (550)	4	8.9	2	0.05
Labridae	*Heteroscarus acroptilus*	T	GR	94-175 (290)	4	8.9	2	0.05
Monacanthidae	*Chaetodermis penicilligera*	T/Tr	GR	41-125 (310)	3	6.7	2	0.04
Ostraciidae	*Anoplocapros amygdaloides*	T	R	130-140 (390)	2	4.4	2	0.03
Mullidae	*Upeneichthys vlamingii*^F	T	SR	121-143 (420)	2	4.4	1	0.03
Apogonidae	*Siphamia cephalotes*	T	GR	45 (50)	1	2.2	1	0.01
Urolophidae	*Trygonoptera mucosa*	T*	SG	200 (360TL)	1	2.2	1	0.01
Syngnathidae	*Filicampus tigris*	T/Tr	SG	250 (350)	1	2.2	1	0.01
Urolophidae	*Trygonoptera ovalis*	T*	SGR	150 (380TL)	1	2.2	1	0.01
Monacanthidae	*Brachaluteres jacksonianus*	T	GR	32 (90)	1	2.2	1	0.01
Gerreidae	*Parequula melbournensis*	T	SGR	79 (220)	1	2.2	1	0.01
Heterodontidae	*Heterodontus portusjacksoni*	T	SGR	300 (1370)	1	2.2	1	0.01
Tetraodontidae	*Polyspina piosae*	T	S	36 (80)	1	2.2	1	0.01
Monacanthidae	*Nelusetta ayraudi*	T	O	68 (710)	1	2.2	1	0.01
Cynoglossidae	*Paraplagusia bilineata*	T/Tr	S	245 (330)	1	2.2	1	0.01
Syngnathidae	*Urocampus carinirostris*	T	G	80 (100)	1	2.2	1	0.01
Syngnathidae	*Phyllopteryx taeniolatus*	T	GR	270 (460)	1	2.2	1	0.01
Labridae	*Notolabrus parilus*^F	T	GR	170 (490)	1	2.2	1	0.01
Labridae	*Halichoeres brownfieldi*	T/S*	GR	50 (150)	1	2.2	1	0.01
Monacanthidae	*Acanthaluteres spilomelanurus*	T	GR	23 (140)	1	2.2	1	0.01

Pairwise Scheffe's *a posteriori* tests demonstrated that in seagrass the number of species and overall density of fishes both differed significantly between pairs of sites in eight of the 15 cases (Table 6.9). Both variables were significantly greater at the Green Head general use (GHGU), Green Head sanctuary (GHSZ) and Jurien sanctuary zone sites (JBSZ) than at the Jurien general use (JBGU) and Jurien scientific reference zone sites (JBSR) (Fig. 6.2). However, the number of species and overall density of fishes at sites within each of those two groups were not significantly different from each other. Both variables were significantly greater at the GHGU and JBSZ sites than at the Green Head scientific reference zone site (GHSR). However, neither variable at the GHSR site was significantly different from those at the GHSZ, JBGU and JBSR sites (Table 6.9; Fig. 6.2).

Table 6.7. Mean squares and significance levels of one-way ANOVAs on the number of species and overall fish density in inshore seagrass and unvegetated sand habitats in the JBMP. *df* = degrees of freedom, p ≤ 0.05*, 0.01**, 0.001***.

| | Main effect | |
Source	Habitat	Residual
df	1	42
No. of species	18.881***	0.243
Overall fish density	40.206***	0.662

Table 6.8. Mean squares and significance levels of three-way crossed ANOVAs on the mean number of species and overall fish density in trawl net catches at sites (S) in inshore seagrass beds of the JBMP in each season (Sn) and year (Y). *df* = degrees of freedom. p ≤ 0.05*, 0.01**, 0.001***.

| | Main effects | | | |
Source	Site	Season	Year	Residual
df	5	3	1	144
No. of species	5.615***	0.206	1.044	0.326
Fish density	19.517***	0.534	2.365	
	Two-way interactions			
Source	S × Sn	S × Y	Sn × Y	
df	15	5	3	
No. of species	0.992***	0.216	0.817	
Fish density	1.922***	0.715	3.402**	
	Three-way interactions			
Source	S × Sn × Y			
df	15			
No. of species	0.563			
Fish density	2.128***			

Table 6.9. Significant results of Scheffe's *a posteriori* pairwise comparisons of both the numbers of species (grey cells) and overall density of fishes (white cells) between each site (pooled across seasons and years). $p \leq$ 0.05*, 0.01**, 0.001***. GH, Green Head; JB, Jurien; GU, general use zone; SR, scientific reference zone; SZ, Sanctuary zone.

Site	GHGU	GHSR	GHSZ	JBGU	JBSR	JBSZ
GHGU		**		***	***	
GHSR	***					**
GHSZ				***	**	
JBGU	***		***			***
JBSR	***		***			***
JBSZ		***		***	***	
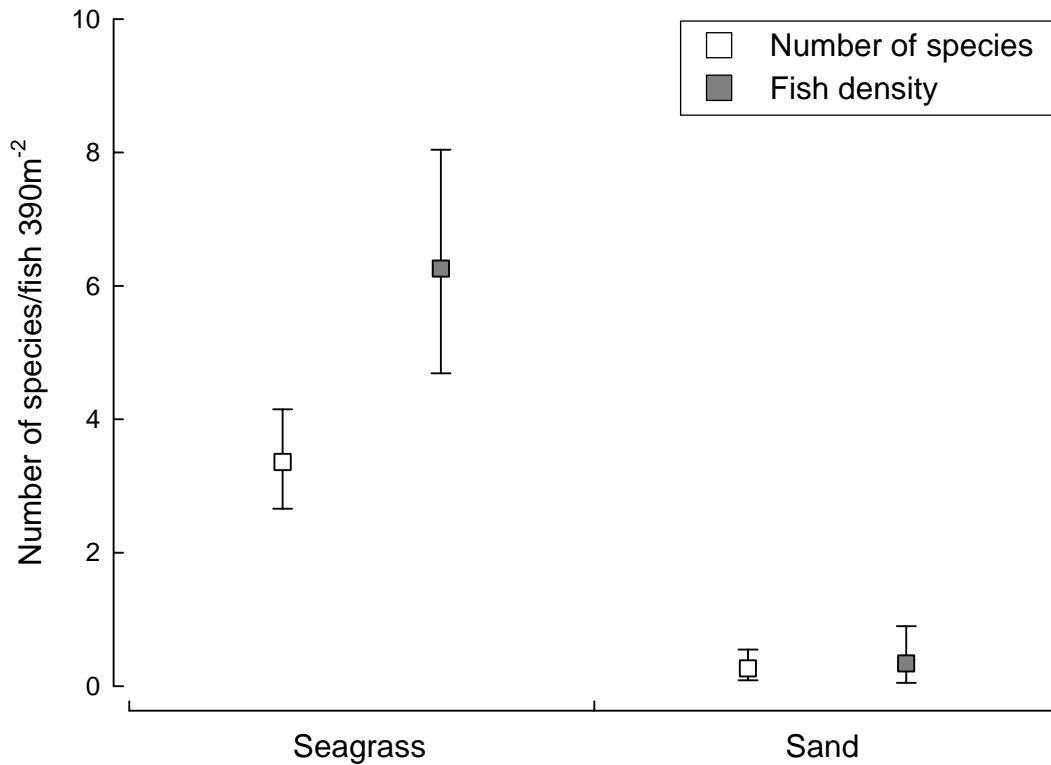
Figure 6.1. Back-transformed mean number of species and mean overall density of fishes (± 95 % confidence intervals) in inshore seagrass and unvegetated sand habitats.
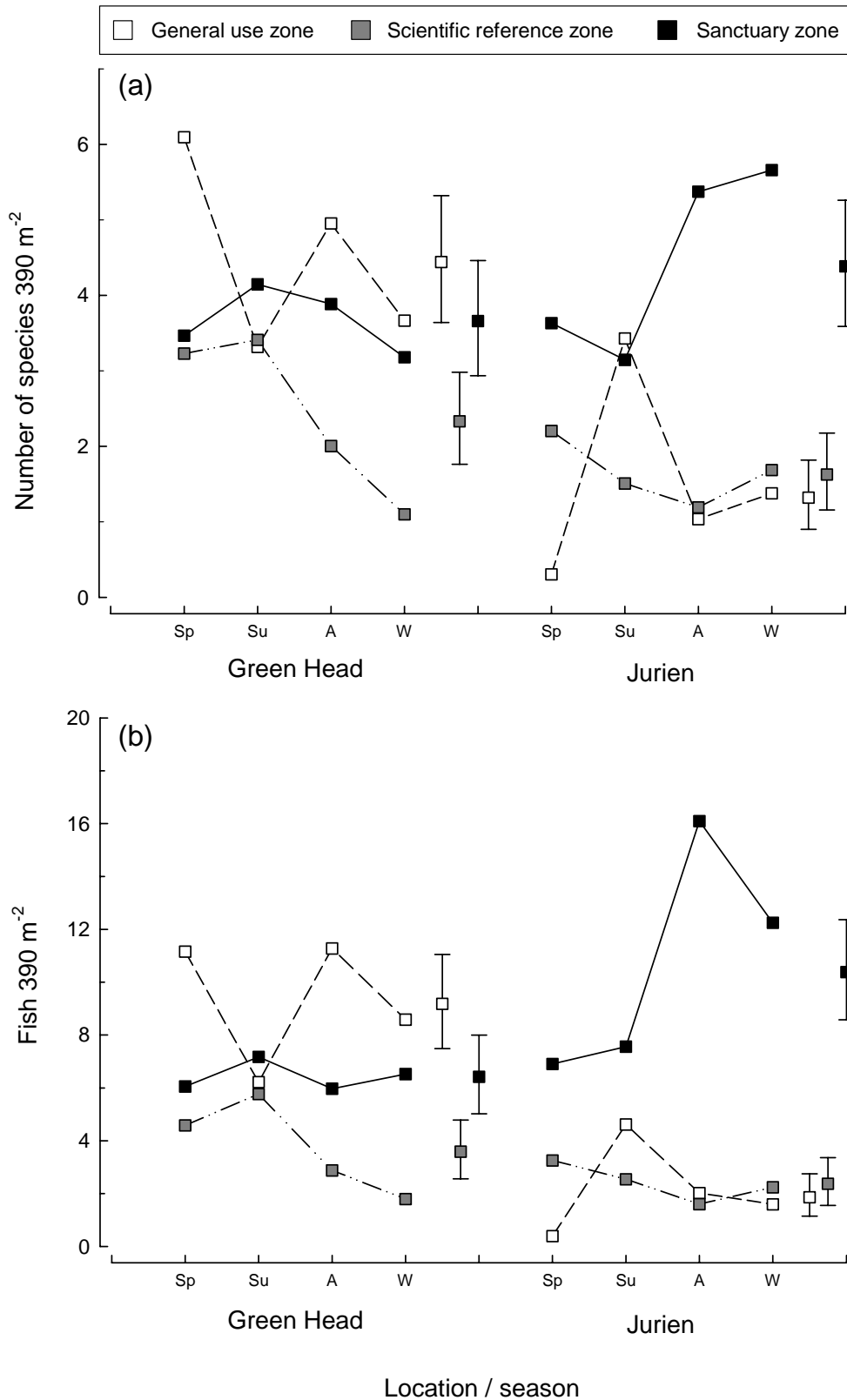
Figure 6.2. Back-transformed mean values for (a) number of species and (b) density of fishes at each inshore seagrass site in each location in the Jurien Bay Marine Park in each season. Overall back-transformed means (± 95 % CIs) are shown for each site. W, winter; Sp, spring; Su, summer; A, autumn.
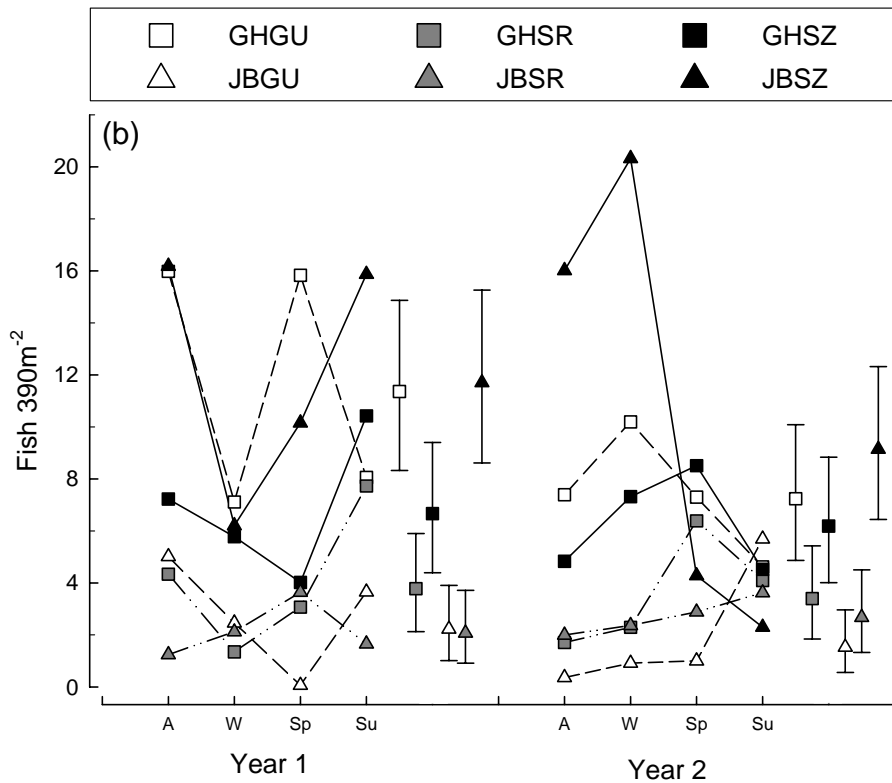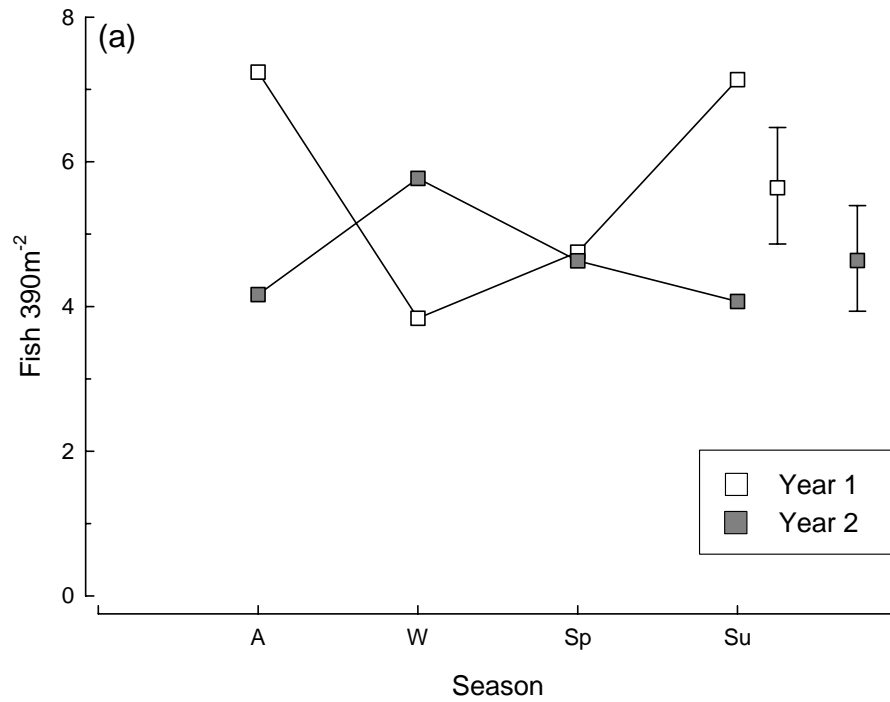
Figure 6.3. Back-transformed mean density of fishes in (a) each season and year and at (b) each inshore seagrass site in each season in each year in the Jurien Bay Marine Park. Overall back-transformed means (± 95 % CIs) are shown for each year. GH, Green Head; JB, Jurien; GU, General use zone; SR, Scientific reference zone; SZ, Sanctuary zone; W, winter; Sp, spring; Su, summer; A, autumn.

6.3.3 Abundant species

The mean densities of *Scobinichthys granulatus* were highest at the GHGU and JBSZ sites, with elevated values at the GHSZ site (Fig. 6.4). *Notolabrus parilus* was also abundant at those three sites, but was most abundant at the GHGU and GHSZ sites (Fig. 6.4). *Apogon rueppellii* was vastly more abundant at the JBSZ site than any other and was rarely recorded at the GHSZ and JBGU sites and never at either the GHSR or JBSR sites (Fig. 6.4). The highest mean densities of *Heteroscarus acroptilus* were recorded at the GHSR site, followed by the GHSZ and GHGU sites (Fig. 6.4).

The highest densities of *S. granulatus* were recorded in the first autumn and second winter of sampling at the two sites where it was most abundant, *i.e.* GHGU and JBSZ (Fig. 6.4). Densities remained relatively low between and immediately following those two seasons. The mean density of *N. parilus* was highly variable among seasons and this species did not display any consistent changes in abundance among seasons at different sites (Fig. 6.4). High densities of *A. rueppellii* were recorded in the first spring and summer and second autumn of sampling. However, matching elevated values were not recorded in the corresponding seasons during the two years of sampling (Fig. 6.4). Densities of *Heteroscarus acroptilus* were highly variable among seasons at the different sites (Fig. 6.4).
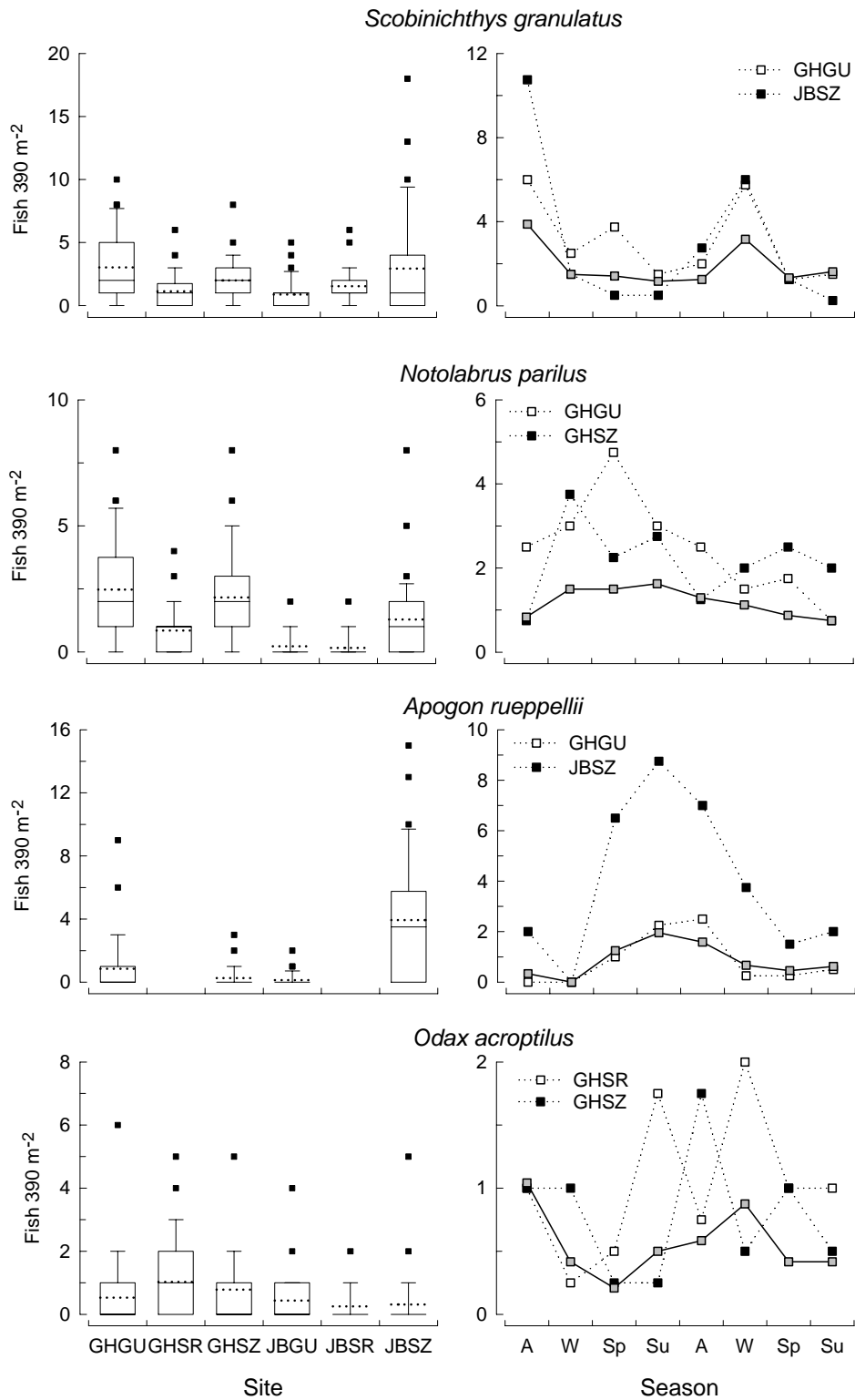
Figure 6.4. Box (25th, 50th [median] and 75th percentiles, including mean shown as dotted line) and whisker (10th and 90th percentiles) plots, with outliers, of the densities of *Scobinichthys granulatus*, *Notolabrus parilus*, *Apogon rueppellii* and *Heteroscarus acroptilus* at each site sampled in the Jurien Bay Marine Park (left column) and mean densities of each of those species at the two sites where they were most abundant (highest mean densities; right column) in each season with mean overall density at all sites shown in grey. Note error bars are not included on mean density plots to avoid any assumption about the distribution of the density data.

6.3.4 Composition of fish species

Composition of fishes in seagrass and sand

One-way ANOSIM demonstrated that the composition of the fish faunas of the inshore seagrass and unvegetated sand habitats were significantly different ($p = 0.1$, R = 0.58). While SIMPER detected that *Scobinichthys granulatus* and *Torquigener pleurogramma* typified the sand habitat, contributing 45 and 43 % to the similarity of the species compositions within that habitat type, they were recorded in very low abundances, as were all species present in that habitat. *Scobinichthys granulatus* was more abundant in seagrass than sand and was responsible for typifying the samples from that habitat, and, along with *Notolabrus parilus*, distinguished seagrass from sand. A non-metric multidimensional scaling (nMDS) plot demonstrated that the majority of the points that represent the composition of the fish fauna at each of the seagrass sites in each season are almost exclusively located on the right-hand side of the plot and do not overlap those from sand (Fig. 6.5). Furthermore, the greater dispersion of points for the sand sites (MVDISP, 1.233 for sand *vs* 0.84 for seagrass) indicates the greater variability in the composition of catches from that habitat.

Composition of fishes in seagrass

A three-way PERMANOVA, using data for the density of each species at each site (si) in each season (se) in the two years (yr) of sampling, detected significant differences among the composition of fish species for each of those three factors ($p \leq 0.019$; Table 6.10). However, the mean squares, Pseudo-F values and estimates of components of variation were much greater for site than for either season or year (Table 6.10). Similarly, although PERMANOVA detected significant si×se, se×yr and si×se×yr interactions, the mean squares, Pseudo-F values and estimates of components of variation for each were low. Two-way
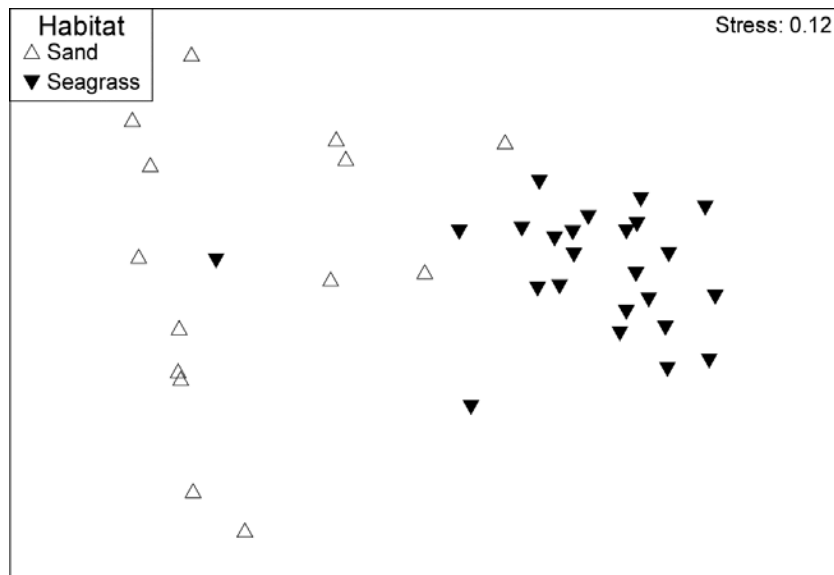
Figure 6.5. Non-metric multidimensional scaling plot derived from a Bray-Curtis similarity matrix constructed from the mean densities of each fish species at each site in unvegetated sand and seagrass habitats of the JBMP in each season in the first year of sampling.

crossed ANOSIM of si×se, si×yr and se×yr confirmed the greater effect of site than season or year. Thus, while the effect of site on the composition of fishes remained significant in the first two interactions (p = 0.1 %, R = 0.294, 0.228, respectively), the effects of season and year were either low, as indicated by very low R statistics, or not significant (si×se test, se: p = 0.1 %, R = 0.112; si×yr test, yr: p = 23 %, R = 0.012; se×yr test, se: p = 0.1 %, R = 0.063, yr: p = 0.3 %, R = 0.054). Furthermore, a nMDS plot of the composition of fish species in each season of the two years of sampling (pooled across all sites) provided no evidence of cyclicity or seriation among the points for each season and many of the points for each season overlapped (data not shown).

Results of pairwise permutational t-tests from the three-way PERMANOVA demonstrated that the compositions of the fish faunas differed significantly among the members of each pair of sites ($p \leq 0.005$), except in the case of the Green Head general use (GHGU) *vs* sanctuary zone (GHSZ) sites (p = 0.08) (Table 6.11). Furthermore, the compositions of the fish faunas at the Jurien general use (JBGU) and scientific reference zone sites (JBSR) were only just significantly different (p = 0.04). As the effect of year was

Table 6.10. Results of a three-way crossed PERMANOVA employing data for the densities of each species at each site (si) in each season (se) and year (yr) of sampling in seagrass habitat of the JBMP. df = degrees of freedom, MS = mean squares, $p \leq 0.05^*$, 0.01^{**}, 0.001^{***}. ECV = square root estimates of components of variation.

Main effects				
Source	*Site*	*Season*	*Year*	*Residual*
df	5	3	1	144
MS	12844	3964	3085	1222
Pseudo-F	10.5***	3.2***	2.5*	
ECV	19.1	7.6	4.4	
Two-way interactions				
Source	*Si × Se*	*Si × Yr*	*Se × Yr*	
df	15	5	3	
MS	2300	1245	3900	
Pseudo-F	1.8***	1.0	3.2***	
ECV	11.6	1.2	10.6	
Three-way interaction				
Source	*Si × Se × Yr*			
df	15			
MS	1748			
Pseudo-F	1.4*			
ECV	11.5			

limited, the fully non-parametric two-way ANOSIM of site crossed with season provided a better indication of the influence of site on the compositions of the fish faunas of the JBMP. Thus, the compositions of the fish faunas were significantly different among each pair of sites, except in the case of the GHSZ *vs* both the GHGU and the Green Head scientific reference zone (GHSR) sites (Table 6.11). However, the R-statistics were only considered to be sufficiently large in those tests, *i.e.* ≥ 0.4, to demonstrate strong among-site differences in the case of GHGU *vs* JBGU and JBSR, GHSR *vs* Jurien sanctuary zone (JBSZ), and JBSZ *vs* JBGU and JBSR sites. There was a moderate difference, *i.e.* R = 0.31-0.33, between the compositions of the fish faunas of the GHSZ *vs* JBGU, JBSR and JBSZ sites and a weaker difference between GHGU and both GHSR and JBSZ, *i.e.* R ≤ 0.25 (Table 6.11).

Table 6.11. Results of pairwise tests of the composition of fish species among sites in the JBMP. Results given of PERMANOVA t-tests (t test result and significance level, grey cells) and pairwise ANOSIM (R statistic and significance level, white cells) from two-way test of site crossed with season. R statistics considered to represent large differences in composition of fish species among sites in bold. $p \leq 0.05^*$, 0.01^{**}, 0.001^{***}.

Site	GHGU	GHSR	GHSZ	JBGU	JBSR	JBSZ
GHGU		2.82***	1.36	4.09***	4.08***	2.52***
GHSR	0.25***		1.88**	2.20***	2.65***	3.79***
GHSZ	0.03	0.06		3.53***	3.47***	3.12***
JBGU	**0.47*****	0.19***	0.31***		1.60*	4.51***
JBSR	**0.41*****	0.14**	0.33***	0.19***		4.87***
JBSZ	0.206***	**0.46*****	0.33***	**0.54*****	**0.54*****	

On the nMDS plot derived from a Bray-Curtis similarity matrix, constructed from data for the densities of each fish species at each site in each season (pooled across years), the points representing the samples in each season at the JBSZ site lay separately and at the top of the plot, but were closest to those for the GHGU site, followed by the GHSZ site (Fig. 6.6). The points for the GHSR site were more widely dispersed and lay among those for the GHSZ, JBGU and JBSR sites. Other than the point for the composition of fish species in winter at the GHSR, those for the JBSR and JBGU only overlapped each other and those for the JBGU were widely dispersed.

SIMPER demonstrated that the Rough Leatherjacket *Scobinichthys granulatus* was most responsible for typifying the species compositions at all sites except the JBSZ site, which was typified primarily by the Gobbleguts *Apogon rueppellii*, followed by *S. granulatus* and the Brown-spotted wrasse *Notolabrus parilus* (Table 6.12). The latter species also typified the GHGU and GHSZ sites. *Apogon rueppelli* distinguished the JBSZ site, where it was most abundant, from the other two Jurien sites, JBGU and JBSR, and the GHSR and GHSZ sites, where it occurred in lower abundance or was not caught (Table 6.12; Fig. 6.4). *Notolabrus parilus* and *S. granulatus* were also responsible for distinguishing between the JBSZ and the above sites, being more abundant at the JBSZ site, except in the case of JBSZ *vs* GHSZ, as *N. parilus* was more abundant at the latter site and *S. granulatus* was similarly abundant at both sites (Table 6.12; Fig. 6.4). The Rainbow Cale *Heteroscarus acroptilus* was also responsible for distinguishing the JBSZ from the GHSR site, being more abundant at the latter site (Fig. 6.4). *Scobinichthys granulatus* and/or *N. parilus* were primarily responsible for distinguishing the compositions of fish species at the GHGU and GHSZ sites from those of the JBGU and JBSR sites, being more abundant at the two Green Head sites than the Jurien sites (Table 6.12; Fig. 6.4).
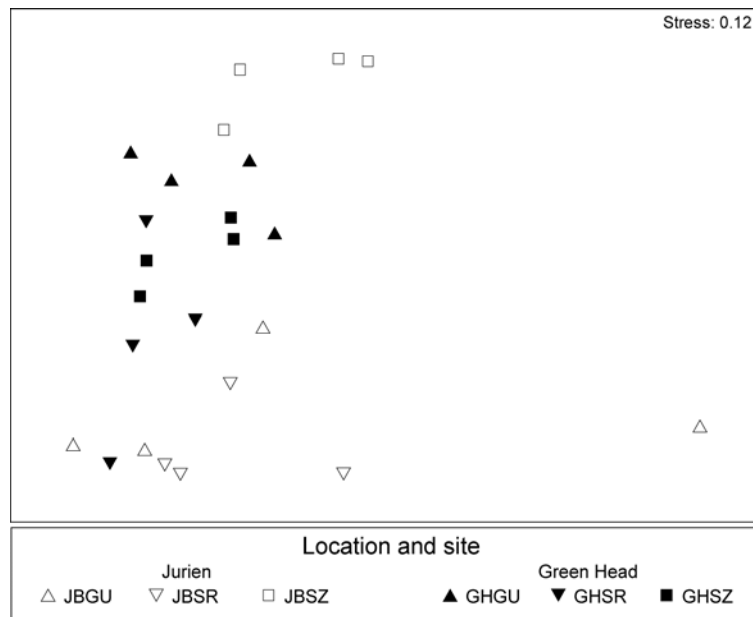
Figure 6.6. Non-metric multidimensional scaling plot derived from a Bray-Curtis similarity matrix constructed from the mean densities of each fish species at each site in each season (pooled across years). JB, Jurien; GH, Green Head; GU, general use zone; SR, scientific reference zone; SZ, sanctuary zone.

Table 6.12. Species detected by SIMPER as most responsible for typifying the species compositions of the six sites sampled by trawling in the JBMP (grey cells, in descending order of importance) and as most important for distinguishing between the composition of fish species in each pair of sites that were considered to differ significantly by ANOSIM (see Table 6.10; white cells, species arranged in descending order of importance according to the dissimilarity/SD ratio). The site at which distinguishing species were most abundant is given by the superscript, with 1 referring to the site in the left column and 2 to the site in the top row of the table. GH, Green Head; JB, Jurien; GU, general use zone; SR, scientific reference zone; SZ, Sanctuary zone.

Site	GHGU	GHSR	GHSZ	JBGU	JBSR	JBSZ
GHGU	*S. granulatus* *N. parilus*					
GHSR		*S. granulatus*				
GHSZ			*S. granulatus* *N. parilus*			
JBGU	*N. parilus*[2] *S. granulatus*[2]		*N. parilus*[2] *S. granulatus*[2]	*S. granulatus*		
JBSR	*N. parilus*[2] *S. granulatus*[2]		*N. parilus*[2]		*S. granulatus*	
JBSZ		*A. rueppellii*[1] *N. parilus*[1] *S. granulatus*[1] *H. acroptilus*[2]	*A. rueppellii*[1] *N. parilus*[2]	*A. rueppellii*[1] *N. parilus*[1] *S. granulatus*[1]	*A. rueppellii*[1] *N. parilus*[1] *S. granulatus*[1]	*A. rueppellii* *S. granulatus* *N. parilus*

6.4 Discussion

6.4.1 Fish communities of seagrass and unvegetated sand habitats in the JBMP

The samples of fish collected from the seagrass beds of the JBMP were significantly more speciose than those of the unvegetated sand habitats, *i.e.* 41 *vs* 22 species, and, during the four seasons when both habitats were sampled, contained a significantly greater number of individuals, *i.e.* 694 *vs* 45. This greater diversity and abundance of fishes in seagrass than sand parallels the results of several other studies that have compared the two habitat types (*e.g.* Connolly, 1994; Travers and Potter, 2002; Hyndes *et al.*, 2003), and presumably reflects the benefits offered by seagrass, such as protection from predators and increased food supply. Furthermore, the collection of *ca* 15 times more fish in seagrass than sand in the JBMP is similar to the ratio in the catches of Travers and Potter (2002), who used the same trawl net design in nearshore shallow waters of the subtropical embayment of Shark Bay. Those authors suggested that the presence of only a limited food supply for the predominantly carnivorous fish fauna in the nearshore shallow unvegetated habitats of that embayment was the likely cause of the depauperate nature of the fish assemblages.

The majority of the species caught in both seagrass (29 of 41) and unvegetated sand (15 of 22) habitats have temperate distributions and both habitats were numerically dominated by the Rough Leatherjacket *Scobinichthys granulatus*. This species is common in the seagrass beds of the southern half of Australia (Hutchins and Swainston, 1986; Hyndes *et al.*, 2003) and was recorded by Fromont *et al.* (2006) in their visual census of seagrass in the JBMP. Only six of the species collected in seagrass are reported to be restricted to that habitat, *e.g.* Blue Weed Whiting *Haletta semifasciata*, Long-rayed Weed Whiting *Siphonognathus radiatus* and Southern Crested Weedfish *Cristiceps australis*, with a large number of species collected (27) typically occupying seagrass and alternative habitats, such as reefs (Hutchins and Swainston, 1986). For example, the Brown-spotted Wrasse *Notolabrus parilus* was numerically the second most abundant species collected in seagrass of the JBMP, but was also

fourth or fifth in surveys of reefs (see Chapters 5, 8). Similarly, only three species caught in sand habitats of the JBMP are restricted to that habitat, *i.e.* Small Tooth Flounder *Pseudorhombus jenynsii*, Orange-barred Pufferfish *Polyspina piosae* and Lemon Tongue Sole *Paraplagusia bilineata*. Another seven species occupy sand and other habitats, *e.g.* Weeping Toadfish *Torquigener pleurogramma*, while 12 species, representing 25 of the 45 individuals collected, reportedly do not occur in unvegetated sand at all, including the most abundant species *S. granulatus*, among others, *e.g.* Rainbow Cale *Heteroscarus acroptilus* and Prickly Leatherjacket *Chaetodermis penicilligera*. This latter fact may be related to the size of the areas of sand trawled and the close proximity of other habitats, particularly seagrass beds (*cf.* Ferrell and Bell, 1991). While trawling was never conducted along the habitat boundaries, at least in the case of the sites in unvegetated sand at Green Head, there is the potential for an edge effect, due to the sand habitats in that region forming long narrow strips < *ca* 400 m wide. Thus, many of the individuals caught in sand that are not reported to occur in that habitat may have been foraging, displaced during storm events from the nearby habitat they typically occupy or associated with the detached macrophytes occasionally collected in trawls of sand.

6.4.2 Do the seagrass beds of the JBMP represent a nursery habitat?

Orth (1986) stated that although the method of trawling may underestimate the abundance of individuals in seagrass, it is appropriate for comparative studies of fishes among different habitats and for collecting small epibenthic fishes that may be closely associated with seagrass. Indeed fish as small as 12 mm were caught by trawling in the JBMP during this study, which thus provides relevant data on the types of fishes that occupy seagrass during their juvenile phase (*cf.* Wassenberg *et al.*, 1997; Travers and Potter, 2002).

The fact that both small and large individuals of the 11 most abundant species were caught in seagrass, *e.g. S. granulatus*, *N. parilus*, Gobbleguts *Apogon rueppellii* and

H. acroptilus, suggests that seagrass is an important habitat for them in the JBMP throughout their lives. Furthermore, individuals of seven of those 11 species, *e.g.* the labrids and apogonids, were collected with developing, mature, spawning and/or spent gonads, indicating that they complete their life cycles within seagrass, as also found for seagrass-dwelling labrids in Cockburn Sound (MacArthur and Hyndes, 2001). Only two of the eleven species, the labrids *H. semifasciata* and *S. radiatus*, reportedly occur only in seagrass. Thus, conclusions cannot be readily drawn that, other than unvegetated sand, which comprised a depauperate fish fauna, seagrass is a more important habitat than others, *e.g.* reefs, for the maintenance of the populations of all of those species in the JBMP. Beck *et al.* (2001) state that such a conclusion would require complementary studies of the growth and survivorship of individuals in the different habitats in which they occur. For example, while the majority of the length range and spawning females of the Red-striped cardinalfish *Apogon victoriae* were collected in seagrass in the JBMP, this species was also abundant during underwater visual census (UVC) of inner reef habitats (see Chapter 5) and its full length range was recorded in that habitat. Those facts, in combination with the consistent observation of both mouth-brooding adults and substantial numbers of new recruits in spring and/or summer in that habitat during those censuses, indicate that reefs are also an important habitat for this species.

The results of baited remote underwater video studies in the JBMP showed that length distributions of the labrid *N. parilus* in seagrass and reef habitats were significantly different (Chapter 8; Bivoltsis, 2007). While the full length range of this species was recorded in reef habitats, the assemblages observed in seagrass were dominated by individuals less than 240 mm. Studies of the biology of *N. parilus* in reef and seagrass habitats revealed that this protogynous hermaphrodite reaches sexual maturity, spawns, undergoes sex change and thus completes its life cycle in both habitats (see Chapter 9). As trawling was not conducted in close proximity to reefs, it appears that individuals of *N. parilus* that settle in seagrass beds may remain there throughout their life. However, it may not be advantageous to do so, as

indicated by the smaller maximum length and shorter life span in seagrass *vs* reef (see Chapter 9). The smaller maximum size of *N. parilus* in seagrass may be a result of the movement of individuals to other habitats when they reach too large a size for seagrass to provide protection from predators or from predation itself of those larger individuals that cannot find protection.

The catches of fishes in seagrass revealed few species that are of interest to recreational and/or commercial fishers and, apart from Baldchin Groper *Choerodon rubescens*, do not form an important part of west coast fisheries (Fletcher and Santoro, 2010; Sumner *et al.*, 2008). Furthermore, the seagrass beds of the JBMP do not form an important nursery habitat for *C. rubescens*, as only two individuals were caught in this habitat, while many juveniles were recorded during UVC of reef habitats of the JBMP (see Chapter 5).

6.4.3 Influence of seagrass type and density on fish fauna

The numbers of fish species, density of fishes and the compositions of the fish communities of the unvegetated surf zones of the JBMP differed significantly among the sites sampled. The numbers of fish species and density of fishes were significantly greater at the Green Head general use (GHGU) and the Jurien sanctuary zone (JBSZ) sites than at the Green Head Scientific reference zone (GHSR) site and Jurien general use (JBGU) and scientific reference zone (JBSR) sites. Furthermore, those two variables were significantly greater for the Green Head sanctuary zone (GHSZ) site than the two latter sites. Travers and Potter (2002) and Hyndes *et al.* (2003) found greater numbers of species and higher densities of fishes in seagrass beds comprising only *Posidonia sinuosa* than those comprising *Amphibolis antarctica* and *Amphibolis griffithii*, respectively. In the JBMP, *P. sinuosa* occurred most frequently as the only seagrass species collected in replicate trawls and observed in BRUVS at the GHGU and JBSZ sites, indicating that large monospecifc stands of that species were present at those sites. This may be partly responsible for the higher diversity and abundance

of fishes recorded at those two sites. However, the typically lower density of *P. sinuosa* at the JBSZ site than the GHGU apparently did not affect any of those variables.

The fact that *A. rueppellii* was most abundant at the JBSZ site, where *P. sinuosa* is common, parallels the findings of Travers and Potter (2002) and Hyndes *et al.* (2003). However, the densities of *A. rueppellii* were not as high at the GHGU site, where *P. sinuosa* was similarly common but of higher density than at the JBSZ site. A large percentage (68 %) of the catches obtained by Hyndes *et al.* (2003) of *S. granulatus* were from *P. sinuosa* beds, which contrasts, to some degree, with the fact that during this study, *S. granulatus* was relatively abundant at all sites and thus includes sites that also comprised substantial areas of *Amphibolis* spp. It is possible that, when the trawls covered seagrass of mixed composition, *S. granulatus* was caught only in the *P. sinuosa* stands that occurred adjacent to *Amphibolis*. However, although *S. granulatus* was not abundant in the catches of fishes by Travers and Potter (2002) in seagrass in Shark Bay, those authors found it to be more abundant in *Amphibolis* seagrass beds than *P. sinuosa*. The variability of occurrence of *S. granulatus* in different seagrasses may be a function of changes in predation or competition that occur as a result of the different fish faunas at the three latitudinally separated locations of Cockburn Sound, Jurien and Shark Bay.

The significantly greater species richness, density of fishes and different species composition that were recorded at the GHGU, GHSZ and JBSZ sites *vs* the JBGU and JBSR sites is likely to be a result, not only of the different architecture provided by the greater prevalence of *P. sinuosa* and *Amphibolis* spp. at the former three and latter two sites, respectively, but also due those latter seagrass beds often being interspersed with sand patches (pers. obs.). The physical structure of *P. sinuosa* thus provides greater opportunities than *Amphibolis* spp. in terms of protection from predators and availability of food to support greater diversity and abundance of fishes. Furthermore, the overall lower density of seagrass at those latter sites, as a result of the interspersed sand patches, may have a similar effect to

that of the low density *Posidonia coriacea* beds of Cockburn Sound, which were found by Hyndes *et al*. (2003) to contain a lower diversity and abundance of fish species and thus different species composition to nearby dense beds of *A. griffithii* and *P. sinuosa*.

6.4.4 Influence of season on biotic variables and species composition in seagrass

Although there were significant interactions between site and season for both the number of fish species and the density of fishes and for season × year and site × season × year for the density of fishes, there were no consistent seasonal patterns at each site across the two years of sampling that may reflect the repeated annual recruitment, immigration or emigration of particular species in the JBMP at different times of the year. In terms of the abundant species, the densities of *N. parilus* and *H. acroptilus* overall and at individual sites where they were relatively abundant did not display any consistent trends in comparable seasons of the two years of sampling. In the case of *H. acroptilus* this may be due to the fact that spawning females were collected between June and December and thus it is unlikely that a peak in abundance would be detected as a result of recruitment of juveniles at a particular time of year. The densities of *S. granulatus* and *A. rueppellii* were more variable among seasons overall, but produced distinct peaks at the two sites where they were most abundant, *i.e.* GHGU and JBSZ. The high densities of *S. granulatus* in the first autumn and second winter of sampling, followed by low densities in the intermittent seasons, parallels to some degree the results of Hyndes *et al.* (1999), who found high densities of small fish in autumn and/or winter in shallow sites in south-western Australia, followed by low densities in other seasons. Those authors also found a greater abundance of large individuals in spring and summer at deep sites and a lack of small individuals at deep sites and thus suggested that the change in densities and size differences of *S. granulatus* among depths may reflect a seasonal offshore migration from those shallow nursery grounds. The fact that *S. granulatus* reaches a maximum size of *ca* 345 mm and the largest individual collected in this study was 189 mm,

coupled with the changes in abundance of this species at specific sites in the JBMP, suggest that a similar migration occurs in this location.

High densities of *A. rueppellii* were recorded in the first spring and summer of sampling and the immediately ensuing autumn in the JBSZ, where it was abundant, but not during the second spring and summer. Furthermore, *A. rueppellii* was much more abundant in the second autumn and winter of sampling than the first. The presence of such high densities in the warmer seasons contrasts partially with the results of Hyndes *et al*. (2003), who found that the densities of that species were highest during autumn and winter in seagrass beds of Cockburn Sound.

7.0 Fish communities of unvegetated surf zone habitats

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7.1 Introduction

The factors that influence the compositions of the fish faunas of nearshore surf zone habitats and the roles that surf zones play in the life cycles of fish species have been studied on the lower west coast of Australia (*e.g.* Lenanton, 1982; Lenanton and Caputi, 1989; Ayvazian and Hyndes, 1995; Valesini *et al.*, 2004; Crawley *et al.*, 2006) and elsewhere in the world (*e.g.* Modde and Ross, 1981; Lasiak, 1981; Santos and Nash, 1995; Clark, 1997; Beyst *et al.*, 2001; Pessanha and Araujo, 2003). While the compositions of the fish communities in surf zones on the lower west coast of Australia are diverse, they are usually dominated numerically by a few abundant schooling species, *e.g.* members of the Atherinidae, Clupeidae and Mugilidae. Furthermore, many of those species use the surf zones as a nursery area and some are of commercial or recreational importance (Lenanton, 1982; Ayvazian and Hyndes, 1995; Valesini *et al.*, 2004).

Ayvazian and Hyndes (1995) found that the compositions of surf zone fish assemblages of south-western Australia changed over a large biogeographical scale, *i.e.* on the lower west coast *vs* the south coast. That difference was attributed primarily to the fact that seagrass beds and reefs were present and thus provided protection only on the west coast and that some of the species that typically occupy those habitats were also found in unvegetated surf zones. However, differences in the fish communities of surf zone habitats also occur at a much smaller geographical scale, *i.e.* 10s of kilometres. For example, fish faunal compositions have been found to differ among surf zone habitats that are subjected to varying degrees of exposure to wave activity and/or proximity to seagrass beds, with a greater number of species and individuals often occurring at more protected sites (Clark *et al.*, 1996; Clark, 1997; Valesini *et al.*, 2004).

The compositions of fish assemblages of coastal waters of south-western Australia have also been shown to change with season as a result of factors such as the recruitment of juveniles at particular times of the year, movements of species from nearshore nursery areas to offshore deeper waters, *e.g*. *Sillago bassensis* and *Scobinichthys granulatus*, migrations to spawning areas, *e.g. Sillago robusta,* and opportunistic movements to feed in areas where detached macrophytes accumulate in winter, *e.g. Pelsartia humeralis* and *Cnidoglanis macrocephalus* (Robertson and Lenanton, 1984; Lenanton and Caputi, 1989; Hyndes *et al*., 1999; Crawley *et al.*, 2006).

The majority of unvegetated surf zone habitats in the Jurien Bay Marine Park (JBMP) are not exposed to the direct impact of ocean swell. The small amount of surf that does occur on its beaches is a result of the moderation and refraction of ocean swells that approach from the west through the chain of offshore reefs, inshore reef patches and seagrass beds in that region and also due to their variable aspect, the presence of rocky headlands and the shallow nature of some of its embayments (Anon, 2005; pers. obs.). However, the size of the surf is exacerbated by along-shore fetch, created by strong prevailing southerly winds, which results in beaches with a range of exposure (pers. obs.).

Knowledge of the composition of the fish communities of the surf zone habitats of the JBMP and how their faunas change with the variations in exposure, the proximity of adjacent habitats and with season will allow environmental and fisheries managers to ensure that their spatial management plans, *e.g.* the size and location of sanctuary zones, take into account surf zone areas that contain the greatest diversity of fishes and/or provide suitable habitats for the juveniles and/or adults of important fishery species. The aims of this part of the project were (1) to determine the numbers of fish species, the densities of fishes and the compositions of the fish communities in unvegetated surf zones along the full length of the JBMP, and to elucidate the factors likely to influence those variables, *e.g.* exposure, season and volume of weed wrack, and (2) to determine whether the species that occupy the surf zones are either

residents, or use them as a nursery area prior to moving to alternative habitats, or are transient or opportunistic. The following specific hypotheses were explored.

(1) The fish faunas of the JBMP are numerically dominated by a few abundant species.

(2) The fish faunas at sites that have low exposure consist of greater numbers of both species and individuals and different species compositions to those at sites with higher exposure.

(3) The numbers of species, individuals and compositions of the fish faunas change in each season due to time-staggered recruitment pulses of different species at different times of the year.

(4) As *Cnidoglanis macrocephalus* and *Pelsartia humeralis* feed opportunistically in wrack accumulations, which are larger in winter due to large swell events and heavy seas, their densities in nearshore surf zones are greater in that season.

Note that hypotheses were not tested about the influence on fish communities of the different management zones, as, of the nine sites sampled in the different zones, only the Green Head sanctuary zone does not allow fishing from the beach. Furthermore, the along-shore boundaries of this zone are very close together, *i.e.* < 1 km apart, potentially reducing the effect of protection from fishing for species that occur there.

7.2 Materials and methods

7.2.1 Sampling regime and sample processing

The fishes of nearshore unvegetated surf zone habitats in the three main management zones, *i.e.* general use, scientific reference and sanctuary zones, at each of three locations in the JBMP, which were separated by at least 15 km were sampled by seine netting in each season for two years between Winter 2005 and Autumn 2007 (Figs. 4.1-4.3). The three respective locations encompassed waters from Green Head to Sandy Point (referred to as Green Head), Jurien Bay to Black Point (referred to as Jurien) and Cervantes to Wedge Island (referred to as Cervantes). Note that beach fishing is allowed in each of the three scientific

reference zones and, of the sanctuary zones sampled, only the Green Head sanctuary zone (Fig. 3.2), which extends along the beach for *ca* 0.8 km, does not allow fishing from the beach. Other sanctuary zones that are closed to fishing from the beach were available for sampling in the Jurien and Cervantes locations (Fig. 3.2). However, these zones were either too exposed to swell to allow effective seine netting or did not contain suitable habitat, *e.g.* comprised intertidal or subtidal rock platforms. The sites sampled were thus chosen to reflect the variations in exposure found along the length of the JBMP (Tables 7.1, 7.2).

Between the middle and end of each season, four replicate seine net samples were collected during the day in each zone at each location (referred to as sites, *i.e.* nine sites in total) (Tables 7.1, 7.2). The seine net, which was 21.5 m long and 1.5 m high comprised two 10 m long wings, each with 6 m of 9 mm mesh and 4 m of 3 mm mesh and a 1.5 m bunt consisting of 3 mm mesh. For sampling, the net was unravelled in a line parallel to the beach and then walked around in a circle, sweeping an area of 116 m^2, and then pulled onto the beach. The net was sorted *in situ* and fish to be retained were immediately euthanased in an ice slurry and then stored on ice in labelled plastic bags. In the first four seasons of sampling, the majority of teleost fishes were retained to ensure correct identifications and obtain biological measurements. In the second four seasons of sampling, most teleost fishes were identified and their total lengths (TL) measured to the nearest 1 mm *in situ*. They were returned alive to the water. Individuals of the Elasmobranchii (rays) were always identified *in situ* and their disc widths measured to the nearest 1 mm and returned to the water alive. When very large samples of schooling fish species were collected, subsamples were retained and the remaining fish returned to the water alive. An estimate of the volume of brown, red or green algae and seagrass collected in each sample was recorded. In the laboratory, teleost fishes from each replicate sample were identified and the total lengths of individuals were measured (to the nearest 1 mm) and the total weight of each species *in toto* was recorded to the nearest 0.1 g. Voucher specimens of some species have been provided to the Western Australian

Table 7.1. Location and description of physical characteristics of each site sampled by seine netting in the Jurien Bay Marine Park in each season between Winter 2005 and Autumn 2007. GU = general use zone, SR = scientific reference zone, SZ = Sanctuary zone. Degree of Exposure (subjective): Low, sites that are shallow and protected from long-shore fetch driven seas by adjacent headlands and/or very shallow seagrass beds (< 2 m); Moderate, sites that are exposed to fetch driven seas and have no adjacent headlands. Slope: Gentle, gradual slope, water depth always < 2 m within 50 m of shore; Steep, water depth reaches 2 m < 50 m from shore. Aspect (approximate): S, south; W, west

Site	Location	Average water depth (m)	Degree of exposure	Adjacent habitats (within 500 m, unless noted)	Slope	Aspect
1	Green Head GU	< 1.5	Moderate	Seagrass within 50 m, rocky headland	Gentle	S
2	Green Head SR	~ 1	Low	Seagrass within 50 m, rocky headlands	Gentle	W
3	Green Head SZ	~ 1	Low	Seagrass within 50 m, rocky headlands	Gentle	W
4	Jurien GU	≥ 1.5	Moderate	Seagrass	Steep	W
5	Jurien SR	≥ 1.5	Moderate	Seagrass	Steep	W
6	Jurien SZ	≥ 1.5	Moderate	Seagrass	Steep	SW
7	Cervantes GU	< 1.5	Moderate	None	Gentle	S
8	Cervantes SR	≥ 1.5	Moderate	Reef	Steep	WSW
9	Cervantes SZ	~ 1	Low	Seagrass within 50 m	Gentle	WSW

Table 7.2. Sites sampled by seine netting in each season in the Jurien Bay Marine Park between Winter 2005 and Autumn 2007. GU = general use zone, SR = scientific reference zone, SZ = Sanctuary zone.

1. Green Head GU	2. Green Head SR	3. Green Head SZ
4. Jurien GU	5. Jurien SR	6. Jurien SZ
7. Cervantes GU	8. Cervantes SR	9. Cervantes SZ

Museum (see Table 7.3). Each fish species was assigned to one of the following categories (from Ayvazian and Hyndes, 1995), according to their usage of nearshore habitats. (1) Resident species that occupy nearshore surf zone environments throughout their life cycle, (2) Nursery species that use those environments seasonally or opportunistically as a nursery ground and (3) Transient species that occur irregularly, *i.e.* are typically associated with other habitat types, use the nearshore environment opportunistically for food and/or shelter, or are beyond their normal distributional range. Those species not listed in Ayvazian and Hyndes (1995) were assigned to one of the above categories based on information presented in Hutchins and Swainston (1986), Gomon *et al.* (2008) and Allen (1999).

7.2.2 Statistical analyses

Univariate analyses

The numbers of individuals of each species in each sample were treated as a density, *i.e.* fish 116 m^{-2}. Examinations of the relationships between the ln(x+1) transformed means and ln(x+1) transformed standard deviations of the variables number of species and density of fishes at each site in each sampling season, together with their normal Q-Q and residual plots, were conducted to determine whether those data met the assumptions of analysis of variance (ANOVA), *i.e.* normality and homogeneity of variances and, if not, thus required transformation prior to ANOVA. Those examinations revealed that square root and ln(x+1) transformations were appropriate for those two variables, respectively. The transformed data for the number of species and density of fishes at each site in each season and year were subjected to ANOVA to test the hypotheses outlined in section 7.1, using a factorial design of site (fixed, 9 levels), crossed with season (fixed, four levels), crossed with year (fixed, 2 levels).

An examination of both the log-transformed variables height of swell (swell) and height of seas (seas; data provided by the Department of Planning and Infrastructure) showed

that square-root transformations of the data for both swell and seas were required for those variables to meet the assumptions of ANOVA. Following transformation, the mean swell and seas in each month in each season during the period of sampling were subjected to two-way ANOVA, using the fixed factors season (4 levels) and year (2 levels.). Similarly, following preliminary examination, the ln(x+1) transformed mean volumes of weed collected during each season and the mean densities of the two species of interest, *i.e. Cnidoglanis macrocephalus* and *Pelsartia humeralis*, were each subjected to two-way ANOVA (fixed factors: season, 4 levels; year, 2 levels).

Multivariate analyses

The densities of each species in the four seine net replicate samples at each site on each sampling occasion were dispersion-weighted using the PRIMER v6 statistical package, in conjunction with the Windows PERMANOVA+ module (Clarke and Gorley, 2006; Anderson *et al.*, 2008; see Chapter 8 for explanation of use of this method). Using that software, data were then analysed to investigate relationships among the species compositions at the nine sites and in the eight seasons of sampling. The dispersion-weighted data were (1) averaged across all sampling seasons at each site and (2) across all sites in each season of sampling, prior to constructing separate Bray-Curtis similarity matrices from those two data sets. Separate non-metric multidimensional scaling plots (nMDS) were derived from the respective matrices to examine the relationships between the compositions of fish species (1) at each site and (2) in each of the eight seasons of sampling. The original dispersion-weighted data were then averaged for each site in each of the eight sampling seasons and subjected to a two-way crossed Analysis of Similarities (ANOSIM; Clarke, 1993) of site (fixed, 9 levels) and sampling season (fixed, 8 levels). Subsequently, pairwise ANOSIM tests were used to examine differences in species compositions among pairs of sites and seasons and were only considered significant when the R-statistic was ≥ 0.4. Where significant differences were

detected among groups of a factor, Similarity Percentages (SIMPER) was then used to determine which species typified and distinguished each of those groups. To identify which species were most responsible for typifying a site or season, a minimum cut-off value of 20 % contribution to the average similarity within a group was used. In the case of determining which species were responsible for distinguishing among groups, a minimum cut-off value of *ca* 15 % and/or a dissimilarity/SD ratio of 0.7 were used. The RELATE procedure was used to investigate any evidence of cyclicity or seriation in the composition of fish species among the eight consecutive sampling seasons.

7.3 Results

7.3.1 Water temperatures

Mean water temperatures (calculated from temperatures recorded at all sites) in surf zone habitats increased from minima of 17.6 and 15.0 ℃ in the first and second winters of sampling, respectively, to maxima of 24.0 and 25.2 ℃ in the first and second summers (Fig. 7.1a). Note that water temperature could not be recorded in Spring 2005.

7.3.2 Numbers of species and density of fishes

A total of 22,996 fishes, representing 52 species from 34 teleost families and one elasmobranch family were collected from unvegetated nearshore surf zone habitats in the JBMP (Note that an eel larva could not be identified to species; Table 7.3). Thirty three of the species collected are distributed solely in temperate waters, seven occur in temperate and subtropical waters and 11 are found in temperate through to tropical waters. The capture of the tropical *Terapon jarbua* represents a southward extension to its known distribution, with its southern limit in Western Australia previously recorded as Carnarvon (24º53'S). Only four species caught are endemic to Western Australia, *i.e. Cirrhimuraena calamus, Kyphosus cornelii*, *Trygonoptera mucosa* and *Trygonoptera ovalis*. The most speciose teleost families
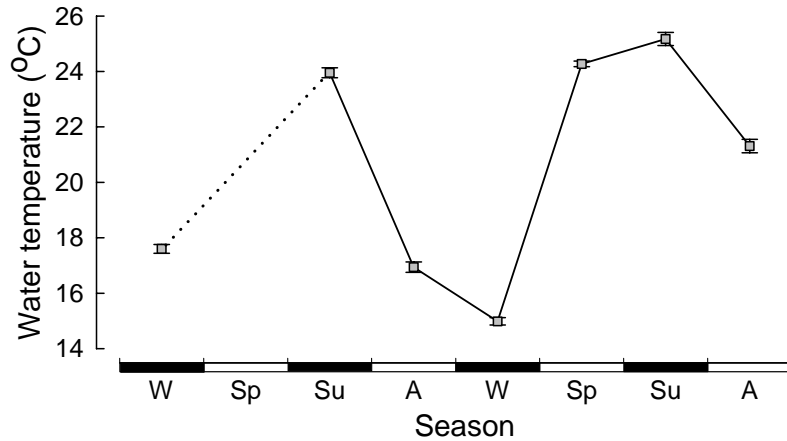
Figure 7.1. Mean seasonal water temperatures ± 1 S. E. determined from all measurements taken at all sites in the Jurien Bay Marine Park between Winter 2005 and Autumn 2007.

recorded were the Labridae, Monacanthidae, Syngnathidae and Terapontidae, each comprising three species, while the only elasmobranch family (Urolophidae) comprised two species (Table 7.3).

Three species contributed 81 % to the total numbers of individuals collected from nearshore surf zones, namely the atherinid species *Leptatherina presbyteroides* (37 %) and *Atherinomorus vaigiensis* (25 %) and the tetraodontid *Torquigener pleurogramma* (19 %). The remaining 49 identified species each contributed less than 5 % to the total numbers of individuals collected (Table 7.3). Seventeen species occur only in sandy environments, such as surf zones, with their full range of lengths being recorded, *e.g. L. presbyteroides*, *A. vaigiensis* and *Leseurina platycephala*, while only the juveniles of other sand-associated species, *e.g. Sillago bassensis*, were recorded in that habitat. A further 16 species occur in sandy environments in addition to seagrass and/or reef habitats, *e.g. Spratelloides robustus* and *Cnidoglanis macrocephalus*. Of those, the abundant species, *e.g. T. pleurogramma* and *Pelsartia humeralis*, were dominated by their juveniles. Nineteen of the 53 species collected typically occupy seagrass beds and/or reef habitats, *e.g. Siphamia cephalotes*, *Enoplosus armatus* and *Cristiceps australis*, each representing ≤ 0.2 % of the total numbers of fish caught (Hutchins and Swainston, 1986; Gomon *et al.*, 2008; Allen, 1999).

Leptatherina presbyteroides, *A. vaigiensis* and *T. pleurogramma* were obtained frequently in catches (83-132 of the 286 seine net replicates) and, when caught, were present in relatively large numbers (33-102 fish per net) (Table 7.3). *Spratelloides robustus* was also caught in large numbers when present (52 fish per net), but was only captured on 20 occasions. In contrast, *Lesueurina platycephala* was caught in small numbers (3 fish per net), but was the most frequently occurring species (152 seine net replicates) (Table 7.3).

The numbers of species and total density of fishes differed significantly among sites and seasons, but not between the two years of sampling (Table 7.4; Fig. 7.2). There were significant two-way interactions between site and season and between season and year for both the number of species and density of fishes and also between site and year for density of fishes. However, the mean squares for each of the interactions were much lower than those for the main effects. In the case of number of species, a significant three-way interaction was detected between site, season and year, but the mean squares were again much lower than any of those for the main effects or two-way interactions (Table 7.4).

Pairwise Scheffe's *a posteriori* tests demonstrated that both the number of species and density of fishes differed significantly between pairs of sites in 13 cases (Table 7.5). The number of species at the protected Green Head sanctuary zone (GHSZ) site was significantly greater than at all sites at Jurien and the Cervantes scientific reference zone site (CVSR), which are moderately exposed, but not the protected Green Head Scientific reference (GHSR) and Cervantes sanctuary zone (CVSZ) sites or the exposed Green Head (GHGU) and Cervantes (CVGU) general use zone sites. The number of species at the GHSR, GHGU and CVSZ sites were greater than those at the exposed Jurien general use zone (JBGU), Jurien sanctuary zone (JBSZ) and CVSR sites (Table 7.5; Fig. 7.2). The density of fishes in the GHSZ was significantly greater than all other sites except the GHSR site, which, along with the GHGU and CVSZ, were significantly greater than both the JBGU and CVSR sites (Table 7.5; Fig. 7.2). Pairwise Scheffe's *a posteriori* tests demonstrated that the number of species

Table 7.3. Fishes collected during seine netting of unvegetated surf zone habitats of the JBMP between Winter 2005 and Autumn 2007 ([a]deposited at WAM), interest to commercial and/or recreational fishers ([F]), biogeographical distributions in Australian waters (Distn; T, temperate; S, subtropical; Tr, tropical; *endemic to W.A.), typical marine habitats occupied (S, sand; G, seagrass; R, reef), use of nearshore surf zone habitats (R, resident; N, nursery; T, transient; from Ayvazian and Hyndes, 1999, italicised category derived from Hutchins and Swainston, 1986; Gomon *et al.*, 2008 and Allen, 1999), total length range (maximum lengths in parentheses; disk widths and total lengths given for length range and maximum lengths, respectively, of urolophids; max. lengths derived from Hutchins and Swainston, 1986; Gomon *et al.*, 2008 and Allen, 1999), total numbers of individuals caught of each species (n), % contribution to total numbers of individuals caught, number of replicate seines in which species was caught (Freq, total number of replicates = 286), average number of fish caught when species was caught (Avg catch) and overall mean densities (fish 116m^{-2}) from all sites.

Family	Species	Distn	Habitats	Use	Length (mm)	n	%	Freq	Avg. catch	Mean
Atherinidae	*Leptatherina presbyteroides*	T	S	R	20-75 (110)	8453	36.8	83	101.8	29.6
Atherinidae	*Atherinomorus vaigiensis*	T/S	S	R	23-172 (170)	5842	25.4	100	58.4	20.4
Tetraodontidae	*Torquigener pleurogramma*	T/S	SGR	N	20-172 (220)	4334	18.8	132	32.8	15.2
Clupeidae	*Spratelloides robustus*[F]	T/S	SR	R	24-104 (100)	1045	4.5	20	52.3	3.7
Sillaginidae	*Sillago bassensis*[F]	T	S	N	18-206 (360)	639	2.8	70	9.1	2.2
Mugilidae	*Aldrichetta forsteri*[F]	T	S	N	27-341 (500)	524	2.3	32	16.4	1.8
Terapontidae	*Pelsartia humeralis*	T	SG	N	13-162 (390)	463	2.0	57	8.1	1.6
Leptoscopidae	*Lesueurina platycephala*	T	S	R	21-117 (110)	461	2.0	152	3.0	1.6
Terapontidae	*Pelates octolineatus*	T	SG	N	17-105 (320)	302	1.3	19	15.9	1.1
Sillaginidae	*Sillago schomburgkii*[F]	T	S	R	81-382 (420)	211	0.9	29	7.3	0.7
Plotosidae	*Cnidoglanis macrocephalus*[F]	T	SGR	R	41-400 (910)	134	0.6	33	4.1	0.5
Apogonidae	*Apogon ruepellii*	T/Tr	SGR	R	24-90 (120)	101	0.4	7	14.4	0.4
Cynoglossidae	*Paraplagusia bilineata*	T/Tr	S	R	27-207 (330)	100	0.4	38	2.6	0.3
Mugilidae	*Mugil cephalus*[F]	T/Tr	S	N	24-125 (790)	90	0.4	15	6.0	0.3
Clupeidae	*Hyperlophus vittatus*[F]	T	S	N	32-68 (100)	52	0.2	6	8.7	0.2
Platycephalidae	*Platycephalus speculator*[F]	T	SG	N	25-332 (900)	50	0.2	38	1.3	0.2
Apogonidae	*Siphamia cephalotes*	T	GR	R	24-52 (50)	42	0.2	16	2.6	0.1
Enoplosidae	*Enoplosus armatus*	T	GR	R	20-80 (310)	29	0.1	8	3.6	0.1
Bothidae	*Pseudorhombus jenynsii*[F]	T/Tr	S	R	29-251 (550)	28	0.1	19	1.5	0.1
Pomatomidae	*Pomatomus saltatrix*[F]	T/Tr	SR	N	34-149 (1200)	9	<0.1	8	1.1	<0.1
Clinidae	*Cristiceps australis*	T	G	T	57-107 (230)	7	<0.1	5	1.4	<0.1
Terapontidae	*Terapon jarbua*[a]	Tr	S	*R*	16-41 (320)	7	<0.1	6	1.2	<0.1
Arripidae	*Arripis truttaceus*[F]	T	SGR	T	70-136 (960)	6	<0.1	3	2.0	<0.1
Monacanthidae	*Monacanthus chinensis*	T/Tr	GR	R	49-68 (381)	6	<0.1	5	1.2	<0.1
Carangidae	*Pseudocaranx georgianus*[aF]	T/S	SR	T	40-116 (940)	6	<0.1	4	1.5	<0.1
Sparidae	*Rhabdosargus sarba*[F]	T/S	GR	T	162-204 (800)	6	<0.1	2	3.0	<0.1
Labridae	*Haletta semifasciata*	T	G	R	66-129 (410)	4	<0.1	3	1.3	<0.1
Monacanthidae	*Scobinichthys granulatus*	T	GR	R	13-43 (345)	4	<0.1	4	1.0	<0.1

Table 7.3 cont.

Family	Species	Distn	Habitats	Use	Length (mm)	n	%	Freq	Avg. catch	Mean
Labridae	*Siphonognathus radiatus*[a]	T	G	R	56-72 (220)	4	<0.1	4	1.0	<0.1
Arripidae	*Arripis georgianus*[F]	T	SGR	T	235-256 (410)	3	<0.1	3	1.0	<0.1
Syngnathidae	*Histiogamphelus cristatus*[a]	T	G	R	80-157 (275)	3	<0.1	3	1.0	<0.1
Notocheiridae	*Iso rhothophilus*	T	S	T	42-52 (50)	3	<0.1	1	3.0	<0.1
Kyphosidae	*Kyphosus cornelii*[a]	T/S*	R	*T*	34-71 (600)	3	<0.1	3	1.0	<0.1
Pleuronectidae	*Ammotretis elongatus*[F]	T	S	R	58-94 (220)	2	<0.1	2	1.0	<0.1
Gobiidae	*Favonigobius lateralis*	T	S	R	23-25 (90)	2	<0.1	2	1.0	<0.1
Blenniidae	*Petroscirtes breviceps*[a]	T/Tr	GR	*T*	46-68 (150)	2	<0.1	2	1.0	<0.1
Tetraodontidae	*Polyspina piosae*[a]	T	S	N	33-53 (80)	2	<0.1	2	1.0	<0.1
Urolophidae	*Trygonoptera mucosa*	T*	SG	T	210-248 (360TL)	2	<0.1	2	1.0	<0.1
Monacanthidae	*Acanthaluteres vittiger*	T	GR	R	63 (320)	1	<0.1	1	1.0	<0.1
Cheilodactylidae	*Cheilodactylus rubrolabiatus*[a]	T/S	R	T	48 (750)	1	<0.1	1	1.0	<0.1
Triglidae	*Chelidonichthys kumu*[a]	T	S	*T*	42 (600)	1	<0.1	1	1.0	<0.1
Ophichthidae	*Cirrhimuraena calamus*[a]	T*	S	T	190 (620)	1	<0.1	1	1.0	<0.1
Platycephalidae	*Leviprora inops*[F]	T	SG	N	306 (610)	1	<0.1	1	1.0	<0.1
Labridae	*Notolabrus parilus*[F]	T	GR	R	114 (490)	1	<0.1	1	1.0	<0.1
Plotosidae	*Paraplotosus albilabrus*[F]	T/Tr	GR	T	31 (1340)	1	<0.1	1	1.0	<0.1
Mullidae	*Parupeneus spilurus*[aF]	T/Tr	SGR	T	47 (470)	1	<0.1	1	1.0	<0.1
Syngnathidae	*Phyllopteryx taeniolatus*	T	GR	*T*	240 (460)	1	<0.1	1	1.0	<0.1
Centropomidae	*Psammoperca waigiensis*[F]	T/Tr	GR	*T*	105 (470)	1	<0.1	1	1.0	<0.1
Monodactylidae	*Schuettea woodwardi*[a]	T	R	*T*	56 (240)	1	<0.1	1	1.0	<0.1
Sphyraenidae	*Sphyraena obtusata*[F]	T/Tr	SGR	*T*	240 (550)	1	<0.1	1	1.0	<0.1
Syngnathidae	*Stigmatopora argus*	T	G	R	118 (260)	1	<0.1	1	1.0	<0.1
Urolophidae	*Trygonoptera ovalis*	T*	SGR	*T*	300 (380TL)	1	<0.1	1	1.0	<0.1
Unknown	*Unid. eel* (larva)[a]	-	-	-	85	1	<0.1	1	1.0	<0.1

were significantly lower in winter than in spring, summer and autumn and that the density of fishes differed significantly among all seasons except for between spring and autumn (Table 7.6). While the number of species recorded at each site in each season was highly variable, the largest density of fishes at each site was recorded in spring and/or summer except for GHSZ, when more individuals were caught in winter and autumn.

Table 7.4. Mean squares and significance levels of three-way crossed ANOVAs on the number of species and total density of fishes at each site (S), in each season (Sn) and year (Y) in surf zone habitats of the JBMP. *df* = degrees of freedom, p ≤ 0.05*, 0.01**, 0.001***.

	Main effects			
Source	*Site*	*Season*	*Year*	*Residual*
df	8	3	1	214
No. of species	2.143***	2.466***	0.277	0.169
Density of fishes	27.602***	24.037***	1.079	1.538
	Two-way interactions			
Source	$S \times Sn$	$S \times Y$	$Sn \times Y$	
df	24	8	3	
No. of species	0.597***	0.296	1.239***	
Density of fishes	3.580***	4.719**	7.290**	
	Three-way interactions			
Source	$S \times Sn \times Y$			
df	24			
No. of species	0.288*			
Density of fishes	2.177			

Table 7.5. Significant results of Scheffe's a posteriori pairwise comparisons of both the numbers of species (grey cells) and density of fishes (white cells) between each site (pooled across seasons and years). *p* ≤ 0.05*, 0.01**, 0.001***. GH, Green Head; JB, Jurien; CV, Cervantes; GU, general use zone; SR, scientific reference zone; SZ, Sanctuary zone.

Site	GHGU	GHSR	GHSZ	JBGU	JBSR	JBSZ	CVGU	CVSR	CVSZ
GHGU				**		**		***	
GHSR				**		***		***	
GHSZ	**			***	*	***		***	
JBGU	*	***	***						**
JBSR			***						
JBSZ			***						**
CVGU			***						
CVSR	***	***	***						***
CVSZ			**	*				***	

Table 7.6. Significant results of pairwise comparisons of both the numbers of species (grey cells) and density of fishes (white cells) between each season (pooled across sites and years). *p* ≤ 0.05*, 0.01**, 0.001***.

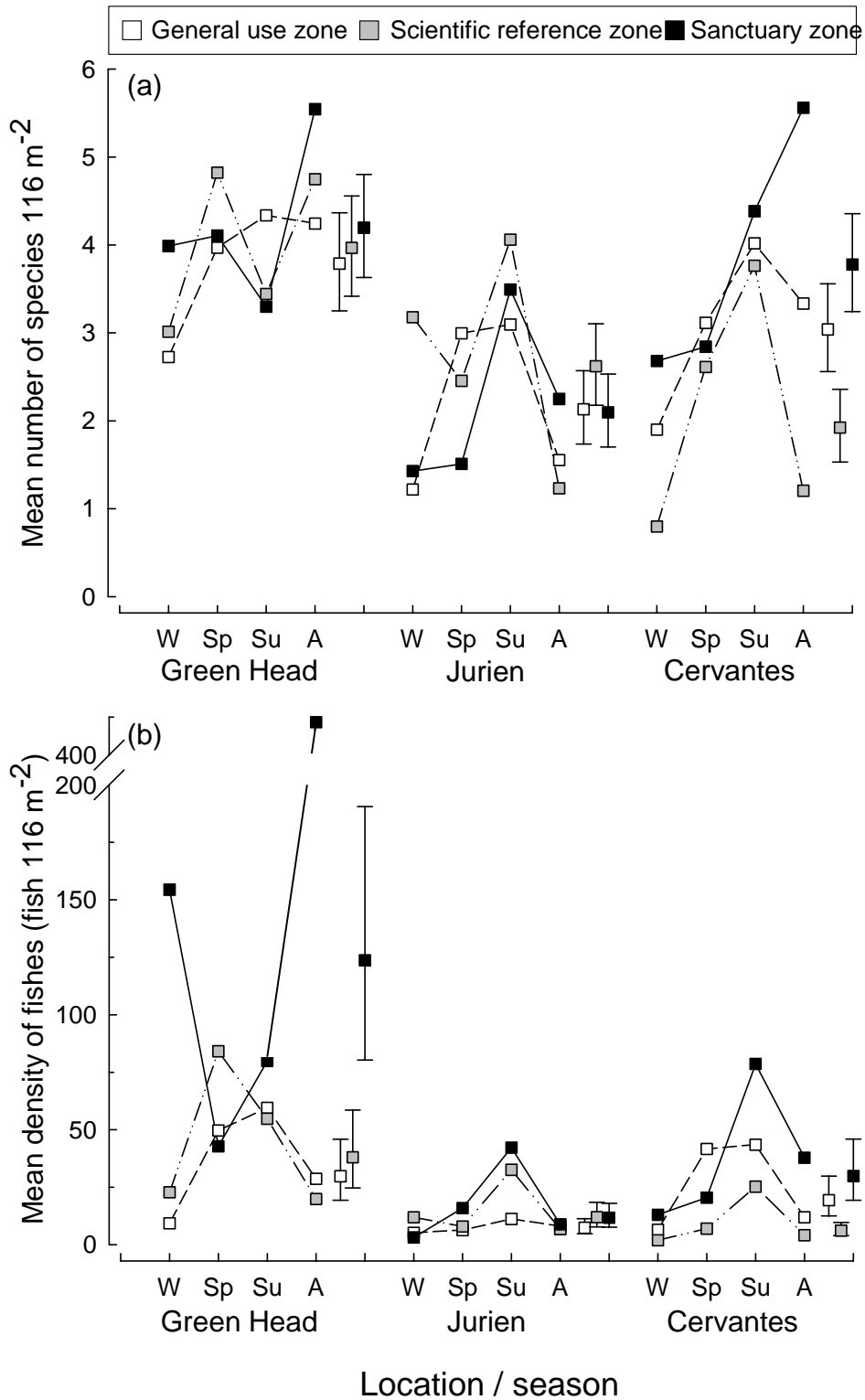| *Season*	Winter	Spring	Summer	Autumn
Winter		**	***	**
Spring	**			
Summer	***	*		
Autumn	*		**	

Figure 7.2. Mean (a) number of species and (b) density of fishes at each unvegetated surf zone site in each location in the Jurien Bay Marine Park for each season. Overall back-transformed means (± 95 % CIs) are shown for each site. W, winter; Sp, spring; Su, summer; A, autumn.

7.3.3 Effect of swell, seas and weed volumes on fish abundance

The square-root transformed mean height of both swell and seas at Jurien during the period of sampling, *i.e.* between Winter 2005 and Autumn 2007, differed significantly among seasons, but not between the two years of sampling (Table 7.3; Fig. 7.3.a). Pairwise Scheffe's *a posteriori* tests showed that mean swell was significantly greater in winter than in both autumn and summer, but not spring, which was significantly greater than summer (Fig. 7.3a). In contrast, pairwise tests demonstrated that mean seas were significantly greater in spring and summer than in autumn, but were not different from each other or from winter (Fig. 7.3a).

The log-transformed mean volume of weed collected during seine net sampling at all sites in each season did not differ significantly among those seasons. However, it did differ between the two years of sampling and there was a significant season × year interaction, although the mean squares for the interaction were much lower than those of the year effect (Table 7.3; Fig. 7.3b). Mean weed volumes were greater in winter, spring and summer of the first year of sampling than the second, while the reverse was true for Autumn (Fig. 7.3b).

The log-transformed mean volume of weed in each season (dependent variable) did not correlate well with either the square-root transformed mean swell or seas height (linear regression lines with slopes of $-0.02 \leq a \leq 0.01$ and $R^2 < ca$ 0.02 in each case; data not shown). Furthermore, the log-transformed mean densities of *C. macrocephalus* and *P. humeralis* did not differ significantly among season or year (Table 7.7). However, the log-transformed mean densities of both *C. macrocephalus* and *P. humeralis* in each season were positively and significantly correlated with mean log-transformed weed volume in those seasons (Table 7.8.; Fig. 7.4).

Table 7.7. Mean squares and significance levels of two-way crossed ANOVAs on the mean height of both swell and seas at Jurien and the mean volume of weed and densities of *Cnidoglanis macrocephalus* and *Pelsartia humeralis* from seine net catches in each season and year in surf zone habitats of the JBMP. *df* = degrees of freedom. Note that *df* for the residual in test of main effects on weed volume and densities of *C. macrocephalus* and *P. humeralis* are shown as a superscript. $p \leq 0.05^*, 0.01^{**}, 0.001^{***}$.

Main effects			
Source	*Season*	*Year*	*Residual*
df	3	1	16
Swell heights	0.092**	0.019	0.011
Seas height	0.028**	0.006	0.005
Weed volume	1.142	28.782**	3.075[64]
Cnidoglanis macrocephalus	0.107	0.285	0.246[64]
Pelsartia humeralis	0.456	0.431	0.622[64]
Two-way interaction			
Source	*Season × Year*		
df	3		
Swell heights	0.008		
Seas height	0.003		
Weed volume	8.778*		
Cnidoglanis macrocephalus	0.139		
Pelsartia humeralis	0.721		

Table 7.8. Parameters (± 95% confidence intervals in parentheses) for the linear regressions fitted to data for the ln *mean volume of weed* at all sites in each season *vs* ln *mean density* (fish 116 m^{-2}) of both *Cnidoglanis macrocephalus* and *Pelsartia humeralis* according to the relationships ln *mean fish density* = *a*ln *mean weed volume* + *b*. Results of t-tests on the slope *a* are shown, $p < 0.05^*, <0.01^{**}$.

Dependent variable	Parameters			
	a	*b*	T	R^2
ln mean density of Cnidoglanis macrocephalus	**1.13** (0.51, 1.75)	**-5.14** (-7.36, -2.91)	4.46**	0.77
ln mean density of Pelsartia humeralis	**1.27** (0.20, 2.33)	**-4.62** (-8.44, -0.79)	2.91*	0.59
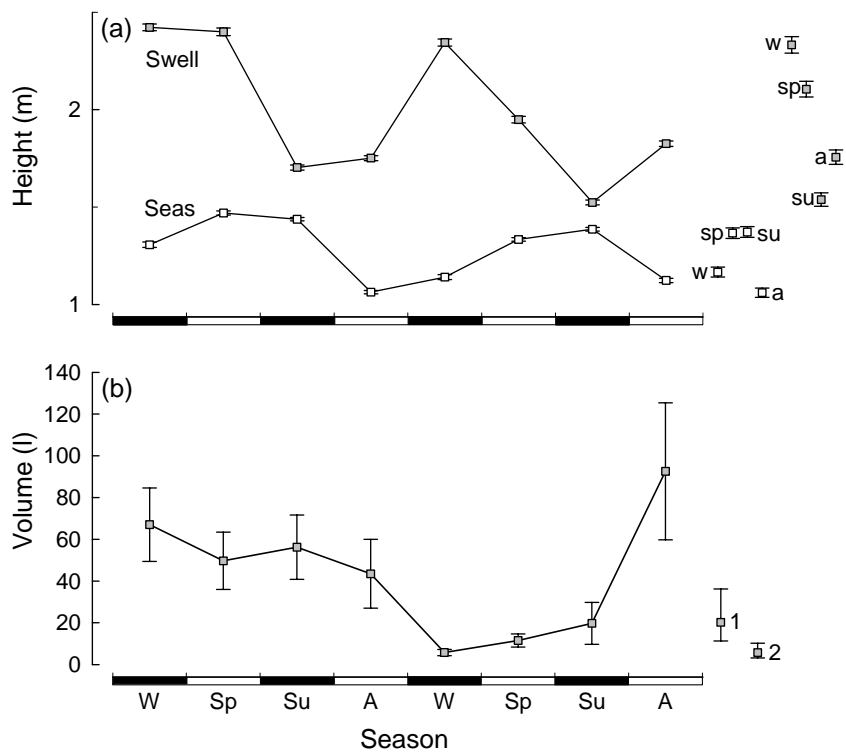
Figure 7.3. Mean (a) seasonal swell (grey) and sea heights (white) ± 1 S. E. determined from data recorded at the Jurien wave bouy, provided by the Department of Planning and Infrastructure, and (b) weed volume ± 1 S. E. determined from all replicate seines in each season of sampling between Winter 2005 and Autumn 2007 in the Jurien Bay Marine Park. Back-transformed mean swell and seas for each season and weed volume for each year of sampling shown at right of figure in (a) and (b), respectively.
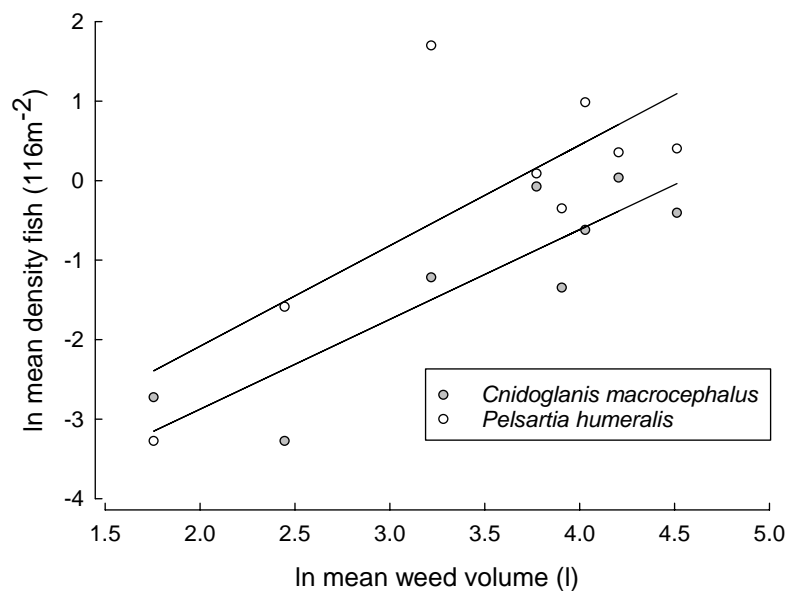
Figure 7.4. Correlation between log-transformed mean volume of weed collected during seine netting in each season and the mean densities in each season of *Cnidoglanis macrocephalus* and *Pelsartia humeralis* determined from all replicate seines in each season of sampling between Winter 2005 and Autumn 2007 in the Jurien Bay Marine Park.

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7.3.4 Composition of fish species

On the non-metric multi-dimensional scaling plot (nMDS) derived from the matrix constructed for the mean densities of each fish species at each site in each sampling season, the points for the Green Head and Cervantes sanctuary zone sites were located on the left-hand side of the plot and separated from the remaining seven sites, demonstrating that the compositions of fish species at those sites were similar (Fig. 7.5a). The points representing all other sites were located on the right-hand side of the plot in a dispersed group (Fig. 7.5a). When the mean densities of fish species at all sites in each season were subjected to nMDS, the resulting plot demonstrated evidence of a cyclical change in species compositions in each of the two years of sampling (Fig. 7.5b).

Two-way crossed ANOSIM of site and sampling season demonstrated that the compositions of the fish faunas of the nine sites in the JBMP were significantly different (Global R = 0.393, $p = 0.1$), but, while ANOSIM detected a significant difference among the eight seasons of sampling ($p = 0.1$), the global R statistic was lower (0.289). Furthermore, the RELATE procedure did not detect any evidence of either cyclicity or seriation among seasons ($\rho < 0.13$, $p > 5\%$ in each case).

Pairwise comparisons among sites demonstrated that the compositions of the fish species at the protected GHSZ and CVSZ were significantly different from each other (R = 0.423; $p = 0.1$) and from those at all other sites (R > 0.423; $p = 0.1$; Table 7.5). The GHSZ and CVSZ sites differed the least from the protected GHSR site (Table 7.5). The composition of fish species at the GHGU site differed from that of the JBGU sites and the CVGU and CVSR sites (R > 0.415, $p = 0.1$; Table 7.5). While the results of all other pairwise comparisons had p values < 5%, their R statistic values were less than 0.4, indicating less dissimilarity among their species

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compositions. The results of SIMPER demonstrated that *Lesuerina platycephala* was

most responsible for typifying the species compositions of the majority of sites

sampled in the JBMP, except for GHGU and GHSZ, which were typified by

Paraplagusia bilineata and *Leptatherina presbyteroides*, respectively, and CVSZ,

which was typified by both *Sillago bassensis* and *Platycephalus speculator* (Table

7.6). However, at the latter site, those species were in low abundance.

Pairwise ANOSIM comparisons among seasons demonstrated that the greatest

differences in composition of fish species occurred between winter 2005 and both

summer 2006/2007 (R = 0.576) and autumn 2007 (R = 0.402) and also between spring

2005 and those latter two seasons (R = 0.480, 0.412, respectively; all other R statistic

values < 0.389; Fig. 7.5b). SIMPER demonstrated that *Lesuerina platycephala* was

most responsible for distinguishing the species compositions among those seasons,

being most abundant in the winter and spring of 2005.

Table 7.5. R statistic values for pairwise ANOSIM comparisons of the composition of fish species at each surf zone site (pooled across the eight sampling seasons) sampled by seine netting in the JBMP. Boldface type represents those pairwise comparisons that are considered to be significant, *i.e.* R statistic ≥ 0.4. GH, Green Head; JB, Jurien; CV, Cervantes; GU, general use zone; SR, scientific reference zone; SZ, Sanctuary zone.

Site	GHGU	GHSR	GHSZ	JBGU	JBSR	JBSZ	CVGU	CVSR	CVSZ
GHGU									
GHSR	0.258								
GHSZ	**0.638**	**0.493**							
JBGU	**0.479**	0.307	**0.708**						
JBSR	0.392	0.381	**0.642**	0.255					
JBSZ	0.303	0.262	**0.563**	0.261	0.152				
CVGU	**0.415**	0.27	**0.645**	0.333	0.268	0.124			
CVSR	**0.526**	0.35	**0.724**	0.314	0.349	0.254	0.362		
CVSZ	**0.598**	**0.426**	**0.423**	**0.680**	**0.578**	**0.449**	**0.496**	**0.597**	
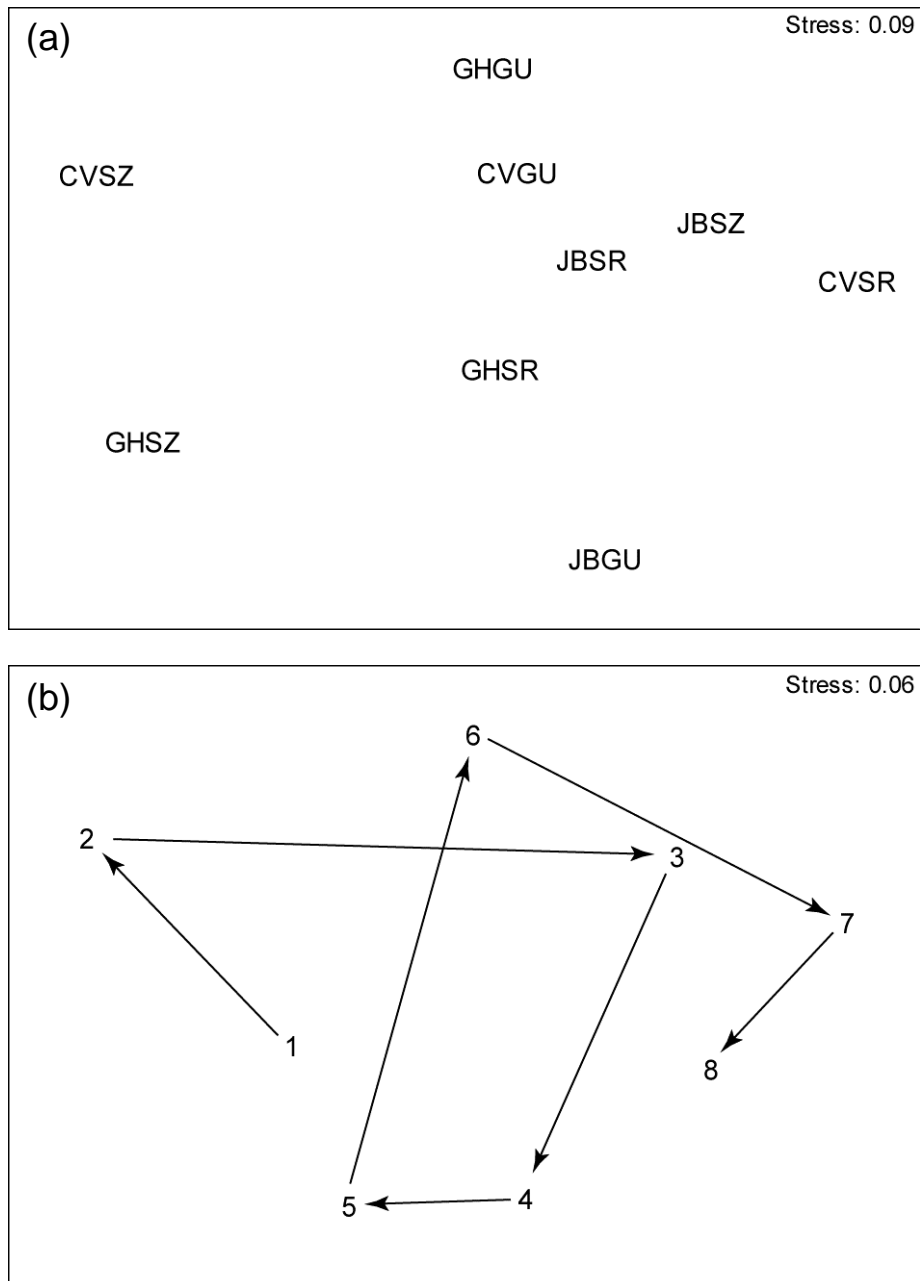
Figure 7.5. Non-metric multidimensional scaling plot derived from a Bray-Curtis similarity matrix constructed from (a) the mean densities of each fish species at each site pooled across all sampling seasons (GH, Green Head; JB, Jurien; CV, Cervantes; GU, general use zone; SR, scientific reference zone; SZ, sanctuary zone) and (b) the mean densities of each fish species in each season of sampling pooled across all sites. (1, winter 2005; 2, spring 2005; 3, summer 2005/2006; 4, autumn 2006; 5, winter 2006; 6, spring 2006; 7, summer 2006/2007; 8, autumn 2007).

Table 7.6. . Species detected by SIMPER as most responsible for typifying (grey cells) the species compositions of the nine sites sampled by seine netting in the JBMP and as most important for distinguishing between the composition of fish species in each pair of sites that were considered to differ significantly (see Table 6.5; white cells, containing species arranged in descending order of importance according to the dissimilarity/SD ratio). The site at which distinguishing species were most abundant is given by the superscript, with 1 referring to the site in the left column and 2 to the site in the top row of the table. GH, Green Head; JB, Jurien; CV, Cervantes; GU, general use zone; SR, scientific reference zone; SZ, Sanctuary zone.

Site	GHGU	GHSR	GHSZ	JBGU	JBSR	JBSZ	CVGU	CVSR	CVSZ
GHGU	*P. bilineata*								
GHSR		*L. platycephala*							
GHSZ	*L. presbyteroides*[1] *P. bilineata*[2]	*L. presbyteroides*[1] *L. platycephala*[2]	*L. presbyteroides*						
JBGU	*L. platycephala*[1] *P. bilineata*[2]		*L. platycephala*[1] *L. presbyteroides*[2]	*L. platycephala*					
JBSR			*L. presbyteroides*[2] *L. platycephala*[1]		*L. platycephala*				
JBSZ			*L. presbyteroides*[2] *L. platycephala*[1]			*L. platycephala*			
CVGU	*P. bilineata*[2] *L. platycephala*[1]		*L. presbyteroides*[2] *L. platycephala*[1]				*L. platycephala*		
CVSR	*P. bilineata*[2] *L. platycephala*[1]		*L. presbyteroides*[2] *L. platycephala*[1]					*L. platycephala*	
CVSZ	*P. bilineata*[2]	*L. platycephala*[2]	*L. presbyteroides*[2]	*L. platycephala*[2]	*L. platycephala*[2] *P. speculator*[1]	*L. platycephala*[2] *P. speculator*[1]	*L. platycephala*[2]	*L. platycephala*[2]	*S. bassensis* *P. speculator*

7.4 Discussion

7.4.1 Fish community of the surf zone habitat of the Jurien Bay Marine Park

The fish community of the unvegetated surf zone habitat of the Jurien Bay Marine Park (JBMP) was numerically dominated by three species with temperate to subtropical distributions, *i.e.* the Silverfish *Leptatherina presbyteroides*, Ogilby's Hardyhead *Atherinomorus vaigiensis* and the Weeping Toado *Torquigener pleurogramma*, which collectively accounted for 81% of the total numbers of individuals caught. Those species are common in nearshore waters of the west coast of Australia and they typically occur in schools, as indicated by the relatively large average catch (Table 7.3, Ayvazian and Hyndes, 1995; Valesini *et al.*, 2004). The presence of individuals covering the full length range of the two atherinids demonstrates that these species occupy the nearshore surf zone habitat of the JBMP throughout their life. In contrast, while large catches of juveniles of *T. pleurogramma* were recorded in winter and spring, indicating that they use this habitat as a nursery area, its adults were caught in the surf zones of the JBMP and were also caught by trawling in seagrass (see Chapter 6) and recorded by baited remote underwater video in unvegetated sand, seagrass and reef habitats (see Chapter 8).

Although the Blue Sprat *Spratelloides robustus* was numerically the fourth most abundant species it was caught relatively infrequently, but in very large numbers, indicating that it typically occurs only in large schools. In contrast, while the Flathead Sandfish *Leseuerina platycephala* was only the eighth most abundant species overall, it was the most frequently-caught species in samples overall, demonstrating that this species occurs regularly along the surf zone habitat of the JBMP, but in relatively low numbers. Catches contained the full length ranges of those two species, indicating that they also occupy surf zones throughout their life cycle, however *S. robustus* does also occupy turbulent waters around reefs (Chapter 5).

Other relatively abundant species in catches and which have been reported to reside in surf zone habitats throughout their lives included Yellowfin Whiting *Sillago schomburgkii*, Estuary Catfish *Cnidoglanis macrocephalus*, Gobbleguts *Apogon rueppellii* and Lemon Tongue Sole *Paraplagusia unicolour* (*cf.* Ayvazian and Hyndes, 1995). Catches of *C. macrocephalus* were dominated, however, by individuals of less than 180 mm in length, implying that this large species (max length = 910 mm) uses the nearshore surf zone primarily as a nursery in the JBMP. Catches of Southern School Whiting *Sillago bassensis*, Yellow-eye Mullet *Aldrichetta forsteri*, Sea Trumpeter *Pelsartia humeralis* and Western Striped Grunter *Pelates octolineatus* also comprised mainly small individuals, as members of these species typically occupy other habitats as they increase in size (Hyndes *et al.*, 1999; see Chapter 5).

Catches of *C. macrocephalus* and *P. humeralis* in surf zones of the JBMP were correlated with the presence of weed wracks and this finding is thus in agreement with those of Lenanton *et al.* (1982), Hyndes *et al.* (1999) and Crawley *et al.* (2006). Lenanton *et al.* (1982) and Crawley *et al.* (2006) showed that the amphipods that are abundant in such accumulations are an important food source for the juveniles of *C. macrocephalus* and *P. humeralis*. Although the volume of detached macrophytes collected in seine net samples would be expected to be greatest in winter, as shown by Lenanton *et al.* (1982), when the destructive force of large storm-related swell events is greatest (Lemm *et al.* 1999), this was not always the case on the beaches sampled in the JBMP. Indeed, comparably large samples of weed wrack were collected in the other three seasons in the first year of sampling, while the volume of weed collected in the second year of sampling was least during winter. This of course may be related to the timing of sampling in relation to the timing of storm events. However, large accumulations can occur at other times of the year, as found by Lenanton *et al.* (1982), presumably as a result of the senescence of seagrasses

and some algal species, *e.g. Sargassum* spp. Indeed, *Sargassum* spp. die back in early to mid-summer at Rottnest Island, to the south of the JBMP (Kendrick and Walker, 1994). Dead algae and seagrass would be transported into the surf zones of the JBMP by swell and seas created by the strong prevailing onshore winds that occur on the mid-west coast of Australia between early spring and early autumn. This would account for the fact that *C. macrocephalus* and *P. humeralis* were captured in large numbers when weed was present in the surf zones of the JBMP in those other seasons. However, Hyndes *et al.* (1999) found that *C. macrocephalus* was most abundant in winter in nearshore habitats when the largest volumes of detached macrophytes were recorded.

Nineteen of the 54 species captured in seine net samples from the surf zones of the JBMP are reported to occur predominantly in habitats other than nearshore surf zones, *e.g.* seagrass and reef, and were recorded in those habitats in the JBMP (see Chapters 5, 6; *cf.* Ayvazian and Hyndes, 1995). Apart from the moderate catches of Woods Siphon Fish *Siphamia cephalotes* (n = 42) and Old Wife *Enoplosus armatus* (n = 29), the numbers of such species, *e.g.* Blue Weed Whiting *Haletta semifasciata* and Sand Bass *Psammoperca waigiensis*, in catches were very low, *i.e.* ≤ 7 fish. Furthermore, in most cases, the individuals caught were juveniles. Thus, at least in the case of *S. cephalotes* and *E. armatus*, such species may use the surf zone opportunistically, *e.g.* when there are weed accumulations which provide abundant food, or they may have been removed from their typical adjacent habitats during periods of heavy swell and seas.

7.4.2 Influence of site and season on biotic variables and species composition

The numbers of fish species, density of fishes and the compositions of the fish communities of the unvegetated surf zones of the JBMP differed significantly among the sites sampled. This was mainly due to differences between sites that were shallow (< 1.5 m)

and had low or moderate exposure and a gentle slope below the waterline, *e.g.* GHSZ, GHSR, CVSZ, GHGU and CVGU, and those that were deeper (> 1.5 m) and were moderately exposed and steeply sloping, *e.g.* JBSZ, JBSR, JBGU, CVSR. Thus, the former sites presumably provided a more favourable overall combination of physical features that allowed for a greater diversity of species and numbers of individuals. Indeed, Valesini *et al*. (2004) demonstrated that, on the lower west coast of Australia, sites that could be distinguished statistically, based on a range of enduring physical characteristics, such as the direction of fetch, the distance from shore to the 2 m depth contour and the proximity of nearby alternative habitats, *e.g.* reef and seagrass, differed significantly in terms of the numbers of fishes recorded. Valesini *et al* (2004) recorded the greatest number of species in the most protected habitat type, which was dominated numerically by *Leptatherina presbyteroides*, while the greatest numbers of individuals were recorded in moderately sheltered and moderately exposed habitat types, and which consisted predominantly of the small clupeids *Hyperlophus vittatus* and *S. robustus*. In the JBMP, the catches at the three most protected and relatively shallow sites, *i.e.* GHSZ, GHSR and CVSZ, were dominated in terms of numbers by the small atherinid *L. presbyteroides* or the tetraodontid *Torquigener pleurogramma*, while at the slightly more exposed shallow sites, *i.e.* GHGU and CVGU, catches were dominated by the larger-bodied atherinid *Atherinomorus vaigiensis*. In contrast, catches at the exposed and deeper sites, *i.e.* JBSZ, JBGU, JBSR and CVSR, were dominated in terms of numbers by *A. vaigiensis*, *L. platycephala* and/or *P. humeralis*. Indeed, *L. platycephala* was responsible for typifying the species compositions at those exposed sites and also at the Cervantes general use zone and Green Head scientific reference zone sites, due to its consistency in seine net catches. *Leseuerina platycephala* and *A. vaigiensis*, for example, are presumably well adapted to the greater turbulence that occurs at the more exposed sites.

The number of species and density of fishes differed significantly among seasons, but while there were no consistent patterns in the number of species recorded at the different sites in each season, this was not the case for the density of fishes. Indeed, the number of individuals recorded at each site tended to be greatest during the spring and/or summer, except in the case of the Green Head sanctuary zone site. The high values for the density of fishes at that site were recorded during winter and autumn, which was caused by large catches of juvenile *T. pleurogramma* in winter 2005 and of *L. presbyteroides* in both autumns. Overall, higher numbers of the abundant *A. vaigiensis* were recorded in both springs and summers, while for *L. presbyteroides*, this occurred in both summers and both autumns. The lengths of fish in the catches of those two species showed that their juveniles first recruited into the surf zones of the JBMP in summer and spring, respectively. Other abundant species, such as *T. pleurogramma*, *Sillago bassensis* and *S. robustus*, were recorded sporadically, thus not revealing any consistent seasonal trends and this presumably reflects their schooling nature and/or their movement from the nearshore surf zone to alternative habitats as they increase in size (Hyndes *et al.*, 1999). However, the overall increased density of fishes recorded in spring and summer at most sites may have been caused predominantly by the recruitment of juveniles of a range of species at that time of year, when environmental conditions, such as water temperature, are favourable for increased food supply and growth.

8.0 Fish communities of reef, seagrass and unvegetated sand habitats, surveyed by baited remote underwater video

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(This chapter derived from honours thesis submitted by A.K. Bivoltsis, November 2007)

8.1 Introduction

8.1.1 Estimating fish community structure in marine protected areas

Non-destructive and non-extractive methods for sampling fish communities, *e.g.* underwater visual census (UVC) and the use of video, play a vital role in sampling within marine protected areas (MPAs), where traditional sampling tools may be prohibited, *e.g.* trawling. The use of both single and stereo remote underwater stationary video sampling techniques offer a way of gaining quantitative measures of species richness, diversity, relative abundance, density and length composition of fishes without the presence of a diver and thus overcome some of the biases inherent to UVC (*see* Lincoln-Smith, 1988; Cole, 1994; Harvey & Shortis, 1996; 1998; Willis *et al.*, 2000; Willis & Babcock, 2000; Harvey *et al.*, 2001; Willis, 2001; Cappo *et al.*, 2004; Watson *et al.*, 2005).

Video sampling methods can be used in complex topographies, sensitive habitats and at greater depths for longer periods, than UVC by divers. Harvey (1998) demonstrated that an assemblage of temperate New Zealand reef fish did not alter their behaviour in response to a stationary camera system. However, video techniques do have some associated biases, such as conservative relative abundance estimates, reliance on good visibility and difficulties determining the "area" sampled (Priede & Merrett, 1996; Cappo *et al.*, 2004). More specifically, baited remote underwater video systems (BRUVS) introduced bias towards the species that are attracted to the bait (Willis *et al.,* 2000). Although this

may be advantageous to fisheries managers, as it provides information on the targeted species which are typically carnivorous, it can also produce potentially misleading results in the discrimination of fish assemblages among different habitat types, *e.g.* between habitats that contain different proportions of species from various trophic levels. Baited remote underwater video systems have, however, been identified to attract a greater diversity and abundance of fish into the field of view as opposed to unbaited systems and, while they are designed to sample carnivorous fish communities, they do not prevent the additional sampling of other "non-carnivorous" species that are attracted to either the bait or fish activity (Watson *et al.*, 2005; Harvey *et al.*, 2007).

8.1.2 Types of baited remote underwater video systems (BRUVS)

Baited video techniques successfully suit a variety of applications, such as assessing the effects of areas closed to fishing, indexing abundances of species of interest, comparing fish assemblages over varying spatial and temporal scales and in different habitats and providing information on the length composition of fishes.

Several studies have employed a single downward-facing camera system to estimate the relative abundance of carnivorous reef fishes and measure the performance of MPAs (*e.g.* Babcock *et al.*, 1999; Willis & Babcock, 2000; Willis *et al.*, 2000; 2003; Kleczkowski *et al.*, 2008). Those studies detected differences in the relative abundance and length of targeted fish species such as the Pink Snapper *Pagrus auratus*, between fished and non-fished areas in temperate regions of Australia and New Zealand. Furthermore, the downward facing BRUVS identified shifts in fish community structure as a result of an increased abundance of *P. auratus* within protected areas (Babcock *et al.*, 1999).

A single forward-facing camera system has been demonstrated to detect variation in overall fish assemblages across varying spatial scales (Westera *et al.*, 2003; Cappo *et al.*,

2004; Malcolm *et al*., 2007). However, the use of forward-facing stereo-video techniques greatly improve the information gained from such studies, by allowing for accurate definition of sample boundaries and improved accuracy and precision of distance measures and fish length estimates (Harvey *et al*., 2002, 2004). Through the use of a stereo-video system, the abundance of the exploited species, *i.e. Glaucosoma hebraicum*, was demonstrated to be greater within than outside protected areas in a Western Australian MPA (Watson *et al*., 2007). Similarly, Watson *et al*. (2007) recorded higher abundances of several common non-targeted species inside MPAs at the Abrolhos Islands, Western Australia. This technique has also allowed the detection of variation in fish assemblages among different habitats (Harvey *et al*., 2005; Watson *et al*., 2005).

8.1.3 Rationale and hypotheses

Relatively few studies have compared the characteristics of fish communities in reefs with those in other very different habitat types in Western Australia, and most studies that have compared fish faunas in different habitats have concentrated on comparing those in seagrass with those over sand (*e.g*. Jenkins *et al*., 1997; Travers & Potter, 2002; Heithaus, 2004; Valesini *et al*., 2004). Furthermore, previous published studies of the fish fauna of the central west coast of Western Australia, in particular the region encompassing the JBMP, are restricted to those of Hutchins (2001), which focused on assessing the species diversity of reef habitats and did not yield strictly quantitative data, and of Vanderklift *et al*. (2007), who surveyed the composition and abundance of predatory species of fish in seagrass meadows immediately adjacent to reefs. Thus, the present study is the first on the central west coast of Australia to use a method, *i.e*. BRUVS, which will provide comparable quantitative data on the numbers of species, numbers of individuals and species compositions in multiple habitats, *i.e*. reef, seagrass and sand.

The establishment of the Jurien Bay Marine Park in 2003, and subsequent operation from October 2005, presents the opportunity to determine whether, at this very early stage, there is evidence that the fish faunas in the different sanctuary zones in this marine park are showing the effects of not being exposed to fishing. This information can be used now and in the future to assess the performance of the current JBMP zonation scheme against its objectives.

As the vast majority of fish species detected using BRUVS are carnivorous, the objective of this study was to investigate patterns in the numbers of species, numbers of individuals and species compositions of this group of fishes, and the size compositions of selected species, within the Jurien Bay Marine Park using a non-destructive and non-extractive baited remote underwater video system similar to that of (Willis & Babcock, 2000; Willis *et al.*, 2000). In particular, this study has focused on understanding how those fish communities varied (1) among major habitat types, *i.e.* reefs, seagrass and unvegetated sand, (2) among reef locations with different degrees of exposure, *i.e.* inner reefs, mid reefs and outer reefs, (3) between management zones that allow differing levels of protection from fishing, (4) across varying spatial scales, and (5) among seasons.

The following hypotheses were tested:

1. The numbers of species, numbers of individuals and species compositions in reefs, seagrass and sand habitats are different, due predominantly to the fact that those habitats differ in structural complexity and each fish species is to some degree morphologically and/or behaviorally adapted to certain habitat characteristics. Furthermore, numbers of species and numbers of individuals will be greatest in those habitats which are the most structurally complex, *i.e.* reefs, followed by seagrass and then sand.

2. The composition of the fish communities on inner, mid and outer reefs are different, due to those reefs occurring along a gradient of increasing distance from shore and thus experiencing changes in depth, degree of exposure and the composition of their algal communities.

3. The numbers of species, numbers of individuals and species compositions of the fish communities among and within management zones do not differ because restrictions on fishing activities have not been in force for a long enough period of time and available data only spans two years.

4. The number of species, number of Individuals and composition of the fish communities do not differ between seasons because the chosen sampling methodology, *i.e.* BRUVS, records larger, more aggressive fish and not the smaller juveniles that appear seasonally due to recruitment pulses, as is typically the case with other bait based sampling methods, *e.g.* line fishing.

5. As the outer reef habitat is exposed to heavier wave action than the inner and mid reef habitats, and thus represents a harsher environment, this will be reflected in a difference in the length compositions of selected abundant species in those environments. Furthermore, as seagrass restricts occupancy by large fish more than do reefs, this will be reflected in the structure of the length-frequency distributions of *Notolabrus parilus* in those two habitat types.

Attention is also paid to determining whether the biotic variables for the fish assemblages in corresponding habitats in two regions, *i.e.* Green Head and Jurien Bay, are similar.

8.2 Materials and methods

8.2.1 Study area

The study area in the Jurien Bay Marine Park (JBMP) extended approximately 39 km from Green Head (30° 4.18' S) to the southern boundary of the Hill River Scientific Reference zone (30° 27.47' S) (see Fig. 3.2). The study area contained three main marine park management zones, *i.e.* (1) general use zones; open to all types of fishing, (2) scientific reference zones; open to rock lobster fishing and most forms of shore based-fishing and (3) sanctuary zones; closed to all types of fishing (Fig. 3.2).

8.2.2 Sampling design

A spatially and temporally-stratified design was developed to study the carnivorous fish communities of reef, seagrass and unvegetated sand habitats in the study area. Sampling was conducted using a baited remote underwater video system (BRUVS; see later for description of the system and method of operation) and incorporated three factors, *i.e.* habitat type, management zone and season. The fish communities of the JBMP were sampled during the day using the BRUVS in summer 2005/2006, autumn 2006, spring 2006, summer 2006/2007 and autumn 2007. Sampling was carried out in each of the three main marine park management zones, within the defined study area, which thus provided replication of those zones, *i.e.* Green Head general use, Green Head scientific reference, Green Head sanctuary, Jurien Bay general use, Jurien Bay scientific reference and Jurien Bay sanctuary zones. Within each replicate zone, five habitat types were sampled where possible, *i.e.* inner reefs, mid reefs, outer reefs, seagrass and unvegetated sand (see below for site descriptions).

Reef habitats

In each season, sampling was conducted at up to 42 reef sites covering the six marine park zones described above and three reef locations, *i.e.* inner, mid and outer reefs. Reef locations were subjected to different degrees of exposure to wave action as a result of their increasing distances from shore. (Table 8.1; Figs 4.1, 4.2). For a detailed description of the reef locations sampled within the JBMP, see section 4.1.1.

The choice of sampling sites was constrained by the numbers of distinct reefs available at the different locations in each zone and by the size and shape of the zones. Where possible, two replicate sites for each reef location, *i.e.* inner, mid and outer reefs, in each zone were sampled (Table 8.2; Figs 4.1, 4.2). Four replicate outer reef sites were sampled within scientific reference and general use zones when possible. However, this habitat type could not be sampled when there were high swells. Note that outer reef sites were not present in the sanctuary zones, and thus this habitat type was not represented in each zone. Furthermore, the small area of available inner reef habitat in the Green Head sanctuary zone meant that it only contained a single site. For the same reason, the two replicates of the Jurien Bay inner reef sanctuary zone were spread across two separate sanctuary zones. While sites were initially chosen based on distance from shore, as an indicator of the degree of exposure, and this led to a virtually balanced design, it was apparent from the preliminary field trip that some "outer" reef sites did not have the same degree of exposure as others, *i.e.* they were not exposed to ocean swell and did not possess high wave action and/or strong wave surge (Table 8.1). Thus, for analysis, these sites were reclassified as "mid" reef sites. Inner, mid and outer reef sites were separated, on average, by a distance of approximately 2 km, while replicate sites within each reef location were at least 500 m apart and represented by distinct reef units.

Table 8.1. Depth range, distance from shore and degree of exposure of inner reef, mid reef and outer reef sites sampled within the Jurien Bay Marine Park.

	Reef location		
	Inner	*Mid*	*Outer*
Depth range (m)	2 – 9	3 - 10	8 - 14
Distance from shore (km)	0.5 – 1.8	2.5 – 5.8	4.8 – 7.2
Exposure	Protected from ocean swell. No to low wave action.	Protected from ocean swell. No to low wave action	Exposed to ocean swell. High wave action or strong surge.

Table 8.2. Number of replicate sites sampled in each season within each zone and habitat type in the Jurien Bay Marine Park. *Zone*: GHGU = Green Head general use, GHSR = Green Head scientific reference, GHSZ = Green Head sanctuary zone, JBGU = Jurien Bay general use, JBSR = Jurien Bay scientific reference and JBSZ = Jurien Bay sanctuary zone (see Fig. 2.1).

	Reef habitat					
Zone	*Inner*	*Mid*	*Outer*	*Total*	*Seagrass*	*Sand*
GHGU	2	2	4	8	4	4
GHSR	2	2	4	8	4	4
GHSZ	1	4	-	5	4	4
JBGU	2	2	4	8	4	4
JBSR	2	3	4	9	4	4
JBSZ	2	2	-	4	4	4
Total	**11**	**15**	**16**	**42**	**24**	**24**

Seagrass and unvegetated sand

Within each of the six management zones in each season, four replicate video samples were obtained in both seagrass and unvegetated sand habitats (Table 8.2). Replicates in each habitat in each zone were separated by at least 300 m and typically obtained within the same day. Sites in seagrass and sand habitats within the study area were located in less exposed waters that were up to 8 m deep and within 3 km of shore. Although the seagrass meadows sampled within the Green Head zones were typically dominated by *Posidonia sinuosa*, areas of *Amphibolis antarctica* and *Amphibolis griffithii* were interspersed within the beds of this seagrass. By comparison, seagrass meadows within the Jurien Bay zones contained a mixture of the above three species, which, in the open and scientific reference zones were interspersed with small sand patches (Fairclough, pers.

obs.). All unvegetated habitat comprised a bare sand substratum. Note that the sand areas within the Green Head zones were smaller than in the Jurien Bay zones and were surrounded by seagrass meadows (see Fig. 3.1).

8.2.3 Baited remote underwater video system

System design configuration and equipment description

The baited remote underwater video system (BRUVS) used in this study was a single camera system similar to that developed by Willis & Babcock (2000). This system was chosen in preference to a stereo-video system, *sensu* Harvey & Shortis (1996), as it can be operated from a small boat (< 5 m) and rapidly deployed without the need for heavy-lifting equipment and regular recalibration of cameras.

A single downward-facing video camera in a custom-made waterproof housing (see later) was mounted on a horizontal strut extending from the apex of a near vertical rod, such that the front lens was 135 cm from the bottom of a triangular base stand (Fig. 8.1a). The upright held the downward-facing camera such that it pointed vertically toward the base of the stand. The resulting field of view was approximately 125 x 95 cm (Fig. 8.1b). Each video stand, which was built to be as light and manoeuverable as possible, was constructed from hollow, stainless steel, 25 mm square pipe, consisted of a triangular base (103 × 103 × 150 cm) with two support bars that held the upright rod and was fully collapsible for transport (Fig. 8.1a). Weights of 2-4 kg were attached, using stainless steel hose clamps, to all three corners of the base of the stand to provide extra stability, and ensure that the stand remained in an upright position on the substratum. Marks were placed along the base of the stand at 100 mm intervals from the inside marking, using PVC tape, to allow spatial calibration of digitised images for accurate estimation of fish lengths (Fig. 8.1b). A wire mesh bait holder in the shape of a rectangular prism (29 x 11 x 13 cm)

was attached, using cable ties, to the hypotenuse of the base of the stand so that it lay approximately in the centre of the camera's field of view (Fig. 8.1a,b). The bait consisted of three Australian Sardines, *Sardinops neopilchardus*, which were replaced on each drop. Two identical systems were used to facilitate the sampling of more than one site at any one time.

The cameras used were Sony digital miniDV cameras (model DCR-HC15E) that had a resolution of 800,000 pixels. Each camera was fitted with a wide-angle lens (Cokin 0.5 x magnification) and was set on landscape view, wide angle, long play, auto exposure and auto focus. Cameras were powered with Lithium-ion batteries that provided up to 500 min of recording time. Video footage was collected remotely and recorded on mini DV tapes with date/time codes overlaid on footage. Each camera was encased in a custom-built waterproof housing, which was made from a piece of sewer pipe (16.7 cm long, 10.7 cm in diameter and 2 cm thick) (Fig. 8.2). The housings had clear perspex lenses (1.5 cm thick) at their front and back, which were each mounted on an 11 cm diameter rubber o-ring to prevent water leaks. The rear lens was removable to allow access to the cameras to change tapes and batteries (Fig. 8.2). Sufficient tapes were used to store a full season of replicate video footage encompassing all habitat types.

Method of deployment of BRUVS

For each replicate, the video assembly was lowered over the side of an unanchored vessel and left for the predetermined period of time (see Section 2.3.3), commencing from the time the system was stationary and in an upright position on the bottom. A 12 mm polypropylene rope, with a marked float attached to the end, was secured to the apex of the stand for lowering and later retrieval.
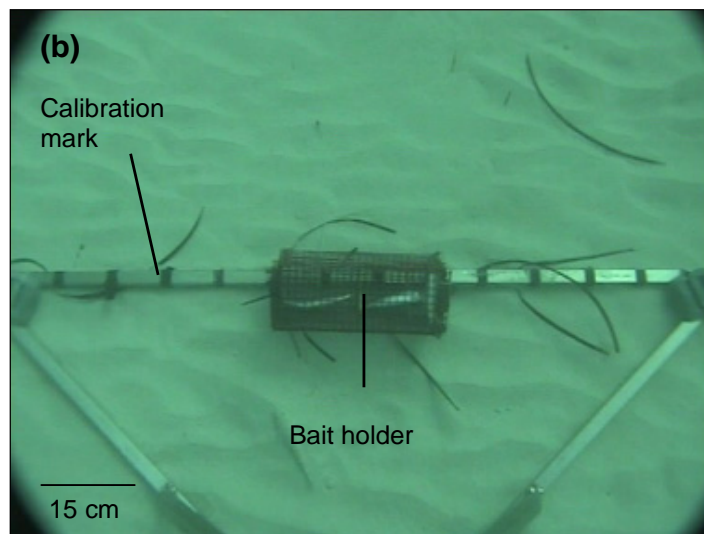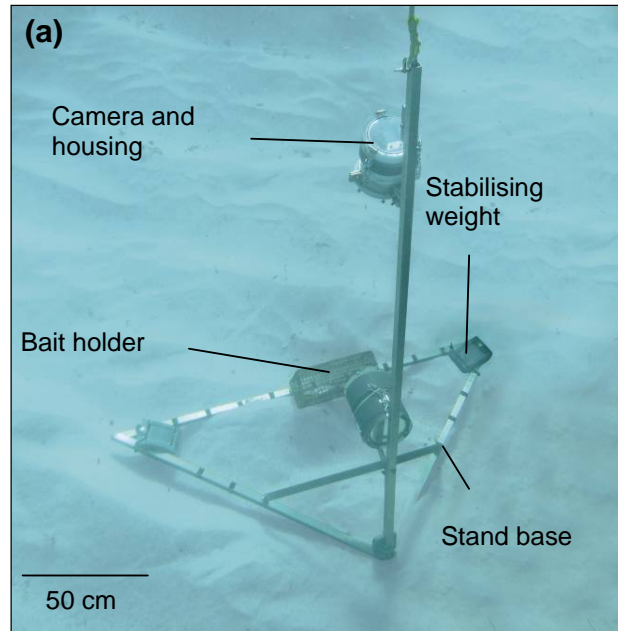
Figure 8.1. (a) Posterior oblique view of the design configuration of the submerged BRUVS stand used in this study and (b) image of the field of view of the downward-facing camera.
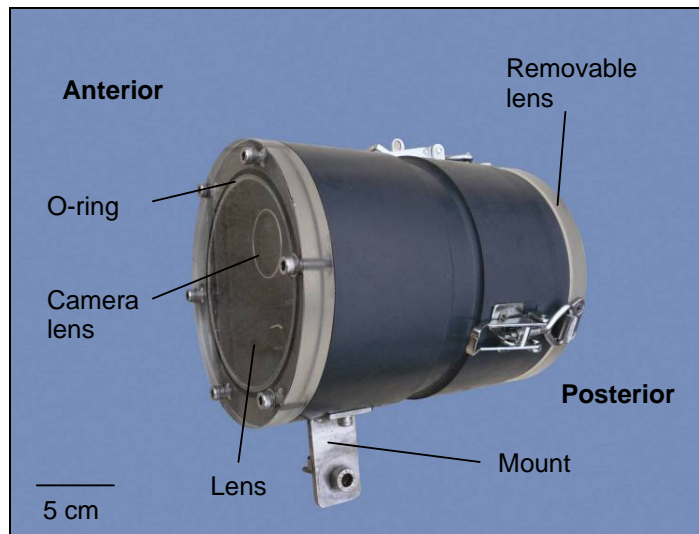
Figure 8.2. Oblique view of the waterproof camera housing encasing the Sony digital miniDV camera.

The point of deployment at each site was located within the area surveyed by UVC (see chapter 5), but, in the case of reef habitat, was constrained by bottom topography and prevailing weather conditions. For reef sites, drops were placed on reefs or at the reef edge, if necessary, in order to avoid snagging the gear. The points of deployment within each habitat were located using a Garmin GPS Map 178c and the video was deployed as close as possible to those points on each sampling occasion.

Determination of duration of deployment of BRUVS

In their study, Willis & Babcock (2000) restricted the BRUVS deployment time to 30 min, as the time that the bait plume persisted was unknown and the study was focused on only two species. Harvey *et al*. (2004) used a 60 min deployment time for assessing fish communities and found that the arrival of new species of fish plateaued within approximately 40 min. The optimum duration of deployment of the BRUVS in this study was determined during a preliminary analysis of video footage employing a subsample of 18 replicates of 60 min deployments in reef habitats. Each video sample was analysed to

determine the composition of fish species observed during the 60 min of footage (see section 8.2.4). The cumulative number of species observed over reefs increased with BRUVS deployment time, with the highest rate of accumulation of new species occurring within the first 10 min of deployment (Fig. 8.3). The cumulative number of species, since initial deployment, plateaued at *ca* 45 min. On average > 80 % of species recorded, from a total of 18 sites, were observed within the first 45 min, thus this was considered a sufficient deployment time in terms of recording maximum diversity.
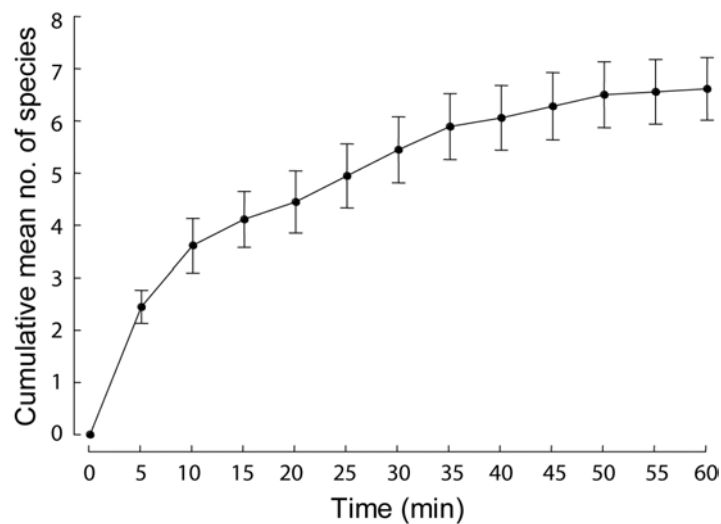
Figure 8.3. Cumulative mean number of species (± 1 S.E.) at five min intervals in 18 replicate 60 min BRUVS deployments in reef habitat.

The maximum number (MaxN) and the time at which MaxN (tMaxN) occurred for each observed species was simultaneously recorded (see Section 8.2.4. for video footage analysis method). The mean time at which the maximum abundance of fish (tMaxN) occurred was determined for each of the nine most frequently observed species from all 18 BRUVS deployments. Mean tMaxN for each species was always less than 45 min indicating that this was a sufficient deployment time (Table 8.3). Given that species

diversity was consistently greater in the reef than seagrass and unvegetated sand habitats, based on preliminary analysis and previous studies (Harvey *et al.*, 2005) and that tMaxN for each observed species was always reached in less than 45 min on seagrass and unvegetated sand (Bivoltsis, pers. obs.), a comparable deployment time of 45 min for those habitats was considered appropriate.

Table 8.3. Mean time of MaxN (tMaxN) for the nine most frequently observed species during 60 min BRUVS deployments (n = 18) in reef habitat.

Species	Mean tMaxN
Parma mccullochi	33
Pomacentrus milleri	33
Epinephelides armatus	24
Pseudolabrus biserialis	21
Coris auricularis	20
Labracinus lineatus	15
Pseudocaranx dentex	14
Ophthalmolepis lineolatus	13
Notolabrus parilus	9

8.2.4 Data analysis

Analysis of video footage

Video footage was analysed via tape playback on a television monitor during and at the completion of each season of sampling. Footage could be analysed frame-by-frame, if necessary, to ensure accurate species identification and abundance counts. Video footage that could not be analysed prior to the commencement of the next sampling season was stored on DVD disks in MPEG2 format and later analysed via VLC media player, v. 0.8.6c, on a computer monitor. In each replicate video sample, all fish observed during the 45 min of footage were identified and a count of the maximum number of fish of each species at any one time (MaxN), *i.e.* in any one video frame, during that 45 min and the time at which that occurred (tMaxN) was recorded (Ellis & DeMartini, 1995; Willis & Babcock, 2000; Willis *et al.*, 2000). While the use of MaxN provides a conservative estimate of the

abundance of a species, it has the advantage of avoiding recounting the same individuals (Willis & Babcock, 2000).

It has been demonstrated that an average of several MaxN values, taken at intervals throughout a video sample, produce results that usually correlate to a single MaxN value (Willis & Babcock, 2000). This was confirmed in the present study by comparing the single MaxN (described above) for a selection of abundant species during four reef habitat video deployments, with an average MaxN for each of those species in each video. The average MaxN for each species was determined from the MaxNs observed in each consecutive five min interval of each 45 min video, *i.e.* 9 replicate MaxN values for each species in each video. Since those values obtained for individual species within a sample were not considered to be independent of each other, the RELATE procedure in PRIMER v6 (Clarke and Gorley, 2006) was used to quantify the extent to which the two complementary matrices paralleled each other and test for any significant match ($p \leq 0.05$) in the pattern of rank orders among samples. Prior to analysis, data were fourth root-transformed and the underlying resemblance matrices were constructed using the Bray-Curtis similarity measure. The Ho: there is no agreement in the rank order pattern between matrices, was rejected based on $p = 0.04$ and a spearman rank correlation coefficient of 1. Therefore, one single MaxN yielded an appropriate relative abundance count for all species observed.

Length compositions

The lengths of three abundant, *i.e. Coris auricularis*, *Notolabrus parilus* and *Ophthalmolepis lineolatus*, and one recreationally/commercially important teleost species, *i.e. Epinephelides armatus*, were determined during each video replicate. At the time of MaxN, for each of those species in each video replicate, a still image was captured by

taking a screen shot and imported into the image analysis software program ImageJ. The total length (TL) of each fish of each species at tMaxN was measured to the nearest 1 mm.

Accurate length measurements were obtained from images by calibrating each image in the horizontal and vertical planes from known measurements on the base of the video stand. Thus, measurements of fish could only be made when they were on or very close to the seabed and in approximately the centre of the field of view. Note that measuring fish that were not on the substrate would result in an increase in the estimated length of a fish, which would continue to increase as a fish came closer to the camera lens, thus excluding the measurement of several species, *e.g. Pseudocaranx georgianus* which do not typically occur on the substrate. Testing demonstrated that, at a distance of *ca* 10 cm above the base of the stand, estimated fish length increased by *ca* 12 %, *e.g.* a 150 mm fish would be estimated as having a length of 168 mm. This is sufficient to produce a significantly different distribution of lengths (based on using a two-sample Kolmogorov-Smirnov (KS) test) if all fish were measured at that height (hypothetical sample of 241 fish; KS test, $p = 0.004$). Although measuring fish at tMaxN resulted in some fish that were observed during the 45 min deployment not being measured, this method had the advantage of avoiding repeated measurements of the same individual (Willis & Babcock, 2000). On a few occasions, measurements were made of individuals of those abundant species that were observed at times other than tMaxN in the video, when they were obviously different fish, by virtue of their size or sex to increase the sample size of measured fish. These length measurements were combined with those from tMaxN for analysing length data.

8.2.5 Statistical analyses

Overall fish assemblages

All the identified species of fishes were classified into geographic distributions, *i.e.* tropical, subtropical, temperate and species endemic to Western Australia, based on Hutchins (1994; 2001), Hutchins & Swainston (2001) and Allen (2000). Each species was also placed in a trophic group based on the associated habitat over which it fed, *i.e.* reef, seagrass or sand, and whether it was a carnivore (zooplankton, zoobenthos or nekton), herbivore or omnivore (Ayvazian & Hyndes, 1995; Froese & Pauly, 2006).

Number of species and number of individuals

The total number of species and total number of individuals (derived from the sum of all MaxN values for each species of fish in each replicate sample) at each site were both analysed in a three-way crossed Permutational Multivariate Analysis of Variance (PERMANOVA) (Anderson, 2001; McArdle & Anderson, 2001) on a Euclidean distance based similarity matrix of the single variable, *i.e.* number of species or number of individuals. The factors included in the design were zone (Green Head general use, Green Head scientific reference, Green Head sanctuary, Jurien Bay general use, Jurien Bay scientific reference and Jurien Bay sanctuary), habitat (inner reef, mid reef, outer reef, seagrass and sand) and season (summer 2005/2006, autumn 2006, spring 2006, summer 2006/2007 and autumn 2007). Each factor was considered to be fixed and each reef site was treated as a replicate sample, along with the replicates from seagrass and unvegetated sand, with up to four levels (Table 2.2). Prior to analysis, the total number of species was square-root transformed and the total number of individuals was fourth-root transformed to reduce the amount of variability among groups. Although PERMANOVA makes no formal assumptions on homogeneity of variance it is sensitive to spread, thus, transforming the

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data will reduce the likelihood of differences between groups being the result of spread (Anderson, 2001). Appropriate transformations for each variable were determined from the relationship of the natural log of both the standard deviation and the mean of the replicates for each habitat type in each zone from each season (Clarke & Warwick, 2001). All analyses were performed using type III sums of squares, as recommended for unbalanced, multifactorial designs (Quinn & Keough, 2002). Hence, PERMANOVA was chosen as it produces outputs from a test statistic that is derived by permutation and thus avoids the stringent assumptions of ANOVA (see Fairclough *et al*., 2008). To overcome a missing level in the sampling design, *i.e.* outer reef sanctuary zone (see section 8.2.2), two PERMANOVA tests were performed on each variable. Firstly, all outer reef samples were excluded to allow for a comparable test among zones. Secondly, all sanctuary zone samples were excluded to allow for a comparable test across reef habitat types, *i.e.* inner reefs, mid reefs and outer reefs, since outer reef sites were not represented in sanctuary zones. When a significant difference was detected, *i.e.* the null hypothesis of no difference was rejected based on $p \leq 0.05$, pairwise comparisons using PERMANOVA pairwise tests were conducted to determine which levels of each factor differed significantly. The back-transformed geometric means $\pm$ 95 % confidence intervals are presented graphically for all significant univariate results.

Fish community compositions

The relative abundance counts (MaxN) of each fish species in each replicate sample from each zone, habitat and season were pre-treated by dispersion weighting to down-weight highly variable species. However, this technique does not affect group-to-group differences and the relative abundances of consistent species remain virtually unchanged (Clarke & Gorley, 2006). Following this, an overall square-root transformation was applied

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to down-weight consistent, highly abundant species. Since there were more than two samples which contained all zero values, a dummy variable of 0.1 was added to the data matrix. The complete pre-treated data were used to create a Bray-Curtis similarity matrix for further analysis. Two complementary but fundamentally different multivariate approaches were used for identifying differences among fish assemblages, *i.e.* PERMANOVA, a semi non-parametric method that constructs a test statistic analogous to Fisher's *F*-ratio and provides a subsequent *p*-value that is derived by permutation (Anderson, 2001; McArdle & Anderson, 2001), and Analysis of Similarity (ANOSIM) as described in PRIMER v6 (Clarke, 1993; Clarke and Gorley, 2006) which is a completely non-parametric routine that also produces a test statistic by permutation, but does not partition variation. Similar results from the two techniques would provide confidence that any identified among group differences in the species assemblages were robust and correctly interpreted.

Based on the hypothesis that there are differences in the composition of fish assemblages from different main habitat types, *i.e.* reef, seagrass and sand, and supported by preliminary analysis (see results section 3.3.1), the data set was initially separated into those habitat types to explore in greater detail the influence of the remaining factors, *i.e.* zone, reef location and season. PERMANOVA was employed to test for significant differences in the composition of *a priori* groups of samples within each habitat type and was chosen over ANOSIM for its ability to handle multifactorial designs, preventing the need for successive two-way tests. Reef habitat data were analysed using a three-way PERMANOVA design, which included the factors zone (6 levels), habitat (3 levels, *i.e.* inner reefs, mid reefs and outer reefs) and season (5 levels). All factors were fixed and considered crossed because they were all of equal importance and levels of each factor were directly comparable across levels of other factors. However, as described previously,

to overcome an imbalance in the sampling design (see section 2.2.1.), two tests were performed on the reef data. Firstly, all outer reef samples excluded and secondly, all sanctuary zone samples were excluded. Samples from seagrass and sand habitats were each analysed separately using a two-way PERMANOVA design where the factors zone (6 levels) and season (5 levels) were fixed and again considered to be crossed and of equal importance. Results were considered significant based on p values < 0.05, mean squares (MS) and pseudo-F values. Where statistically significant differences were detected, PERMANOVA pair-wise tests were performed to further explore the patterns of variation, interpret interactions between factors and isolate where those differences laid. On a few occasions, fully non-parametric ANOSIM was also employed to aid interpretation of significant PERMANOVA results that had relatively low mean squares. Such results were considered significant based on p values < 0.05 and the R-statistic being sufficiently large, *i.e.* > 0.4, thereby demonstrating that among group differences were always greater than within group differences.

Non-metric multidimensional scaling (nMDS) ordination plots and multivariate dispersion (MVDISP) were used, according to the appropriate routines in PRIMER v6 (Clarke, 1993; Clarke and Gorley, 2006), to visualise the patterns among samples representing the *a priori* groups and measure the relative dispersion of those groups, respectively. Similarity Percentages (SIMPER) (Clarke, 1993) was used to determine which species distinguished each of those groups considered to be significantly different, *i.e.* contributed the most to any significant dissimilarity between groups, using a ratio of dissimilarity to standard deviation greater than 0.7, unless otherwise stated.

Length compositions

Comparative analyses of length-frequency compositions for *C. auricularis* and *N. parilus* were conducted using KS tests, as those species both occurred in sufficient numbers in more than one habitat type to allow meaningful comparisons. A Bonferroni correction, calculated by dividing the significance level (0.05) by the number of comparisons being conducted (2) using the same data, was applied to the tests for *C. auricularis* to reduce the chances of a Type 1 error. Thus, a difference in the length compositions was only accepted when $p < 0.025$. In the case of *N. parilus*, three comparisons were made and thus the cut-off significance level was 0.017. Prior to any statistical or graphical analysis, the lengths of each species were pooled across zone and season and, in the case of *Ophthalmolepis lineolatus* and *Epinephelides armatus*, also across habitat type.

Habitat variables

A complementary multivariate data matrix derived from the average percentage contributions of identified macrophyte species, broad morphological macrophyte groups, sponges and coral for each reef site sampled, derived from UVC (see Ch. 5), was compared to the overall fish community matrix, derived using the BRUVS method, using BVSTEP in PRIMER v6 (Clarke & Gorley, 2006) in order to determine how well the sampled habitat variables match the distributional patterns of fish assemblages. This routine was chosen for its ability to cater for large numbers of variables, *i.e.* > 15, in the second data matrix. Based on the stepwise approach employed in the BVSTEP routine, the procedure was restarted several times to ensure the best solution possible was reached. The test was considered significant based on a p value < 0.05 and the rho value being sufficiently large.

8.3 Results

8.3.1 Overall fish assemblages

A total of 6689 individuals were recorded during analysis of the 433 replicate video samples. This included 80 teleost species and 10 elasmobranch species that collectively belonged to 44 families (Table 8.4). However, some individuals in the genera *Pseudocaranx*, *Acanthaluteres*, *Sphyraena, Sillago*, *Mustelus*, *Acanthistius* and the families Monacanthidae, Orectolobidae and Ophichthidae were not able to be assigned to a particular species because they were either videoed at a distance or an aspect which made their diagnostic features difficult to detect or they belonged to such morphologically similar species that identification was not possible from video footage alone. In such cases, individuals were recorded at the genus or family level. The most diverse families were the Labridae with 14 species, the Monacanthidae with eight species and the Serranidae and Pomacentridae with six and five species, respectively.

Twenty-one species accounted for 90 % of the total number of fish recorded (Table 8.4). In terms of numbers of individuals, the fish assemblages were dominated by the Labridae family, which accounted for 58 % of the total number of fish recorded. The relatively most abundant species were *Coris auricularis* (47 % of the total number of fish recorded), *Torquigener pleurogramma* (6 %), *Pentapodus vitta* (6 %), *Notolabrus parilus* (5 %), and *Pseudocaranx georgianus* (3 %). Furthermore, *N. parilus, C. auricularis, T. pleurogramma* and *P. vitta* were each seen in over 25 % of the video samples.

Sixty one percent of all species recorded were temperate in origin (Table 8.4). Subtropical and tropical species contributed 23 and 16 % to the total number of species,

Table 8.4. Sum of MaxN (total of MaxN values recorded for each species in each sample in which they occurred), frequency of occurrence (number of samples in which a species was sighted) and the percentage contributions to the total number of fish recorded (%) from each major habitat type, for all species sampled within the Jurien Bay Marine Park between Summer 2005/2006 and Autumn 2007 using BRUVS. ● indicates a commercially or recreationally important species. *Habitat*: R = reef, G = seagrass, S = sand. *Geographic range*: S = subtropical, Te = temperate, Tr = tropical, WA = endemic to Western Australia. *Trophic group*: 1 ZP = reef associated zooplankton, 1 ZB = reef associated zoobenthos, 2 ZB = seagrass associated zoobenthos, 3 ZP = sand associated zooplankton, 3 ZB = sand associated zoobenthos, C = carnivore, 1 C = reef associated carnivore (nekton), 3 C = sand associated carnivore, 1 O = reef associated omnivore, 2 O = seagrass associated omnivore, 1 H = reef associated herbivore, BP C = benthopelagic carnivore, P C = pelagic carnivore.

Family	Scientific name	Common name	Sum MaxN	Frequency	R (%)	G (%)	S (%)	Geographic Range	Trophic group
Labridae	*Coris auricularis*	Western King Wrasse	3131	190	60.3	1.1	0.3	S/WA	1ZB
Tetraodontidae	*Torquigener pleurogramma*	Weeping Toadfish	437	135	1.6	26.9	9.1	Te	BP C
Nemipteridae	*Pentapodus vitta*	Western Butterfish	385	107	1.3	17.5	33.8	Te/WA	2 ZB
Labridae	*Notolabrus parilus*	Brownspotted Wrasse	324	243	4.5	7.4	-	Te	1 ZB
Carangidae	●*Pseudocaranx georgianus*	Silver Trevally	218	77	2.8	3.2	10.7	Te/WA	1/3 C
Terapontidae	*Pelates octolineatus*	Western Striped Grunter	174	17	1.9	6.3	-	Te	2 O/ZB
Pseudochromidae	*Labracinus lineatus*	Lined Dottyback	141	80	2.7	-	-	Tr	1 C
Terapontidae	*Pelsartia humeralis*	Sea Trumpeter	141	49	0.3	10.6	-	Te	2 O/ZB
Labridae	*Ophthalmolepis lineolatus*	Southern Maori Wrasse	140	75	2.7	-	-	Te	1 ZB
Apogonidae	*Apogon rueppellii*	Western Gobbleguts	133	52	1.2	5.6	0.9	Te	1 ZB
Labridae	*Pseudolabrus biserialis*	Redband Wrasse	127	83	2.5	-	-	Te/WA	1 ZB
Myliobatidae	*Myliobatis australis*	Southern Eagle Ray	116	101	0.6	2.8	16.4	Te	1 ZB
Scorpididae	*Neatypus obliquus*	Footballer Sweep	107	30	2.1	-	-	S/WA	1 ZB
Serranidae	●*Epinephelides armatus*	Breaksea Cod	82	63	1.6	-	-	S/WA	1 C/1 ZB
Labridae	*Austrolabrus maculatus*	Blackspotted Wrasse	61	56	1.2	-	-	Te	1 ZB
Tetraodontidae	*Lagocephalus sceleratus*	Silver Toadfish	60	42	0.1	2.3	8.8	Tr	1 ZB
Pempherididae	*Pempheris klunzingeri*	Rough Bullseye	58	1	1.1	-	-	S	1 ZB
Muraenidae	*Gymnothorax woodwardi*	Woodward's Moray	55	53	1.1	-	-	S/WA	1 C
Pomacentridae	*Parma mccullochi*	McCulloch's Scalyfin	51	38	1.0	-	-	Te/WA	1 O
Dasyatidae	*Dasyatis brevicaudata*	Smooth Stingray	48	31	0.6	1.4	0.3	Te	BP C
Kyphosidae	*Kyphosus cornelii*	Western Buffalo Bream	33	22	0.6	-	-	S/WA	1 H
Labridae	*Thalassoma lutescens*	Green Moon Wrasse	32	26	0.6	-	-	Tr	1 ZB
Monacanthidae	*Scobinichthys granulatus*	Rough Leatherjacket	29	25	0.1	1.9	-	Te	1/2 O

Table 8.4. Cont.

Family	Scientific name	Common name	Sum MaxN	Frequency	R (%)	G (%)	S (%)	Geographic Range	Trophic group
Carangidae	*Pseudocaranx sp.*	Trevally	29	14	0.4	0.4	0.6	Te	1 C/S C
Arripidae	●*Arripis georgianus*	Australian Herring	28	15	<0.1	1.4	3.2	Te	BP C
Monacanthidae	*Monacanthus chinensis*	Fanbelly Leatherjacket	24	20	<0.1	1.8	0.3	Tr	1/2 O
Monacanthidae	*Acanthaluteres sp.*	Unid Leatherjacket	24	12	-	2.0	-	Undefined	2 ZB
Mullidae	*Parupeneus spilurus*	Blacksaddle Goatfish	23	18	0.4	-	-	Tr	1 ZB
Pempherididae	*Pempheris multiradiata*	Bigscale Bullseye	23	3	0.4	-	-	Te	1 O
Platycephalidae	●*Platycephalus speculator*	Southern Bluespotted Flathead	22	19	-	-	6.9	Te	3 C
Scorpididae	*Scorpis georgianus*	Banded Sweep	21	17	0.4	-	-	Te	1 ZP
Monacanthidae	●*Meuschenia hippocrepis*	Horseshoe Leatherjacket	20	18	0.4	0.1	-	Te	1 C
Chaetodontidae	*Chelmonops curiosus*	Western Talma	19	17	0.4	-	-	Te	1 ZB
Kyphosidae	*Kyphosus sydneyanus*	Silver Drummer	19	5	0.4	-	-	Te	1 H
Muraenidae	*Gymnothorax prasinus*	Green Moray	16	16	0.3	-	-	Te	1 ZB
Labridae	*Pictilabrus laticlavius*	Senator Wrasse	16	14	0.3	-	-	Te	1 ZB
Apogonidae	*Apogon victoriae*	Western Striped Cardinalfish	16	12	0.3	-	-	S/WA	1 ZB
Labridae	*Halichoeres brownfieldi*	Brownfield's wrasse	16	8	-	1.3	-	S/WA	2 ZB
Pomacentridae	*Chromis westaustralis*	West Australian Puller	16	6	0.3	-	-	S/WA	1 O
Haemulidae	*Plectorhinchus flavomaculatus*	Goldspotted Sweetlip	14	11	0.2	0.2	-	Tr	1 ZB
Sphyraenidae	●*Sphyraena sp*	Unid Pike	14	8	-	1.2	-	Undefined	P C
Sparidae	*Rhabdosargus sarba*	Tarwhine	14	4	0.3	-	-	S	1 O
Carangidae	●*Seriola hippos*	Samsonfish	13	13	0.2	-	0.3	Te	BP C
Urolophidae	*Trygonoptera ovalis*	Striped Stingaree	13	13	0.2	0.2	-	Te/WA	BP C
Labridae	*Thalassoma lunare*	Moon Wrasse	13	12	0.3	-	-	Tr	1 ZB
Pomacentridae	*Pomacentrus milleri*	Miller's Damsel	12	6	0.2	-	-	Tr	1 O
Monacanthidae	Monacanthidae	Unid Leatherjacket	11	10	<0.1	0.8	0.3	Te	2 ZB
Pinguipedidae	*Parapercis haackei*	Wavy Grubfish	11	9	0.1	0.2	0.9	Te	1 ZB
Sparidae	●*Pagrus auratus*	Pink Snapper	11	7	0.2	-	-	Te	1 ZB
Heterodontidae	*Heterodontus portusjacksoni*	Port Jackson Shark	10	10	<0.1	0.5	0.9	Te	C

Table 8.4. Cont.

Family	Scientific name	Common name	Sum MaxN	Frequency	R (%)	G (%)	S (%)	Geographic Range	Trophic group
Sphyraenidae	●*Sphyraena obtusata*	Striped Seapike	9	7	-	0.8	-	Tr/WA	1 C
Pomacentridae	*Chromis klunzingeri*	Black-headed Puller	9	4	0.2	-	-	Te/WA	1 O
Carangidae	*Trachurus novaezelandiae*	Yellowtail Scad	9	2	<0.1	0.7	-	Te/WA	1 ZB
Rhinobatidae	*Trygonorrhina fasciata*	Southern Fiddler Ray	8	8	-	0.7	-	Te	1/2 ZB
Siganidae	*Siganus sp.*	Siganid sp.	7	2	0.1	-	-	Tr	1 O
Chaetodontidae	*Chaetodon assarius*	Western Butterflyfish	6	6	0.1	-	-	S/WA	1 O
Enoplosidae	*Enoplosus armatus*	Old Wife	6	6	0.1	-	-	Te	1 ZB
Labridae	●*Choerodon rubescens*	Baldchin Groper	6	4	<0.1	0.1	-	S/WA	1 C/ZB
Monacanthidae	*Meuschenia galii*	Bluelined Leatherjacket	5	5	0.1	-	-	Te	1 C
Labridae	●*Bodianus frenchii*	Western Foxfish	4	4	<0.1	-	-	Te	1 C/ZB
Rhinidae	*Rhynchobatus australiae*	Whitespotted Guitarfish	4	4	-	-	1.3	Tr	3 ZB
Mullidae	*Parupeneus chrysopleuron*	Rosy Goatfish	4	3	0.1	-	-	Tr	1 ZB
Sillaginidae	●*Sillago sp.*	Whiting	4	3	-	-	1.3	Te	1 ZB
Orectolobidae	*Orectolobidae sp*	Unid Wobbegong	4	2	0.1	-	-	Te	1 C
Clupeidae	*Hyperlophus vittatus*	Sandy Sprat	4	1	-	-	1.3	S	3 ZP
Labridae	*Olisthops cyanomelas*	Herring Cale	3	3	<0.1	-	-	Te	1 ZB
Monacanthidae	*Meuschenia freycineti*	Sixspine Leatherjacket	3	3	-	0.3	-	Te	1/2 O
Pomatomidae	●*Pomatomus saltatrix*	Tailor	3	3	-	0.3	-	S	P C
Scyliorhinidae	*Aulohalaelurus labiosus*	Blackspotted Catshark	3	3	<0.1	0.2	-	Te	C
Triakidae	●*Mustelus sp*	Gummy shark	3	3	<0.1	0.2	-	S	C
Urolophidae	*Trygonoptera mucosa*	Western Shovelnose Stingaree	3	3	<0.1	-	0.3	Te	1 ZB
Lethrinidae	*Lethrinus nebulosus*	Spangled Emperor	3	2	<0.1	-	-	Tr	1 C
Serranidae	●*Epinephelus rivulatus*	Chinaman Rockcod	3	2	<0.1	-	-	Tr	1 C
Glaucosomatidae	●*Glaucosoma hebraicum*	West Australian Dhufish	2	2	<0.1	-	-	S/WA	1 C
Labridae	*Eupetrichthys angustipes*	Snakeskin Wrasse	2	2	<0.1	-	-	Te	1 ZB
Labridae	*Thalassoma septemfasciatum*	Sevenband Wrasse	2	2	<0.1	-	-	S/WA	1 ZB
Monacanthidae	*Nelusetta ayraudi*	Ocean Jacket	2	2	-	0.1	0.3	Te	1/2 O

Table 8.4. Cont.

Family	Scientific name	Common name	Sum MaxN	Frequency	R (%)	G (%)	S (%)	Geographic Range	Trophic group
Mullidae	*Upeneichthys vlamingii*	Bluespotted Goatfish	2	2	<0.1	-	0.3	Te	1 ZB/3 C
Pleuronectidae	*Ammotretis elongatus*	Elongate Flounder	2	2	-	-	0.6	Te	3 ZB
Serranidae	*Hypoplectrodes nigroruber*	Blackbanded Seaperch	2	2	<0.1	-	-	Te	1 C
Serranidae	*Acanthistius sp*	Unid Wirrah	2	1	<0.1	-	-	Te	1 C
Latidae	*Psammoperca waigiensis*	Sand Bass	1	1	<0.1	-	-	Te	1 C
Monacanthidae	*Acanthaluteres spilomelanurus*	Bridled Leatherjacket	1	1	<0.1	-	-	Te	2 ZB
Ophichthidae	*Ophichthid sp.*	Unid Eel	1	1	-	-	0.3	Undefined	3 ZB
Orectolobidae	*Orectolobus hutchinsi*	Western Wobbegong	1	1	<0.1	-	-	S	1 C
Ostraciidae	*Anoplocapros amygdaloides*	Western Smooth Boxfish	1	1	-	-	0.3	S	BP C
Pomacentridae	*Parma occidentalis*	Western Scalyfin	1	1	<0.1	-	-	S/WA	1 C
Serranidae	*Acanthistius serratus*	Western Wirrah	1	1	<0.1	-	-	Te/WA	1 C
Serranidae	●*Othos dentex*	Harlequin Fish	1	1	<0.1	-	-	Te	1 C
Sillaginidae	●*Sillaginodes punctatus*	King George Whiting	1	1	<0.1	-	-	Te	3 ZB
Total number of species			**90**		**75**	**33**	**25**		
Total number of individuals				**6689**	**5173**	**1199**	**317**		

respectively, while those species that are endemic to W.A. contributed 25 % to the total number of species recorded (Table 8.4). However, subtropical endemic species were numerically the most abundant, comprising 52 % of the total number of individuals, due mainly to the large numbers of *C. auricularis* (Table 8.4). In terms of numbers, temperate species were the next most abundant, comprising 41 % of the total number of fish while a small component of the assemblage was tropical in origin (5 % of the total abundance).

The BRUVS sampling method successfully detected a suite of commercially and recreationally important species, including *P. georgianus* and *Epinephelides armatus*, which were relatively abundant (Table 8.4). The remaining commercially and/or recreationally targeted species, *e.g*. *Arripis georgianus, Meuschenia hippocrepis, Platycephalus speculator, Seriola hippos* and *Pagrus auratus*, were observed in relatively low abundances (sum of MaxN was ≤ 28; Table 8.4).

Of the two most abundant commercially and recreationally important species, *P. georgianus* was observed in all five habitats, but was most abundant on mid reef sites. Further inspection of the data revealed that *P. georgianus* showed a fine scale preference for mid reef sites from within the sanctuary zone at Green Head. *E. armatus* was only recorded in reef habitat and was most frequently sighted at outer reef sites. Although *E. armatus* was also observed on mid reef sites, it was rarely recorded on inner reef sites. On the few occasions when *E. armatus* was recorded at inner reef locations, those sightings were always at the same site in the general use zone at Green Head.

The chosen method of BRUVS sampled species from a range of trophic groups, the majority of which were carnivorous. In particular, zoobenthic feeders, such as *C. auricularis, N. parilus* and *P. vitta*, were the most prevalent and characterised the overall assemblage (Table 8.4). Some omnivorous species, *e.g*. *Parma mccullochi* and

Monacanthus chinensis, and herbivorous species, *e.g. Kyphosus cornelii* and

Kyphosus sydneyanus, were also detected.

The fish assemblages of reef, seagrass and sand habitats

The fish assemblages from the three main habitat types, *i.e.* reef (inner, mid and

outer locations combined), seagrass and sand, differed markedly in their composition,

number of species and number of individuals. The reef assemblage comprised 75

species, representing as much as 83 % of the total number of species observed. The reef

habitat was dominated numerically by *C. auricularis,* which accounted for 60.3 % of

the total number of individuals recorded in that habitat (Table 8.4). Reefs contained 77

% of the total number of individuals recorded in all habitats. In contrast, the 33 species

recorded from seagrass represented 37 % of the total number of species and 18 % of the

total number of individuals recorded. Seagrass meadows were numerically dominated

by *T. pleurogramma, P. vitta* and *Pelsartia humeralis*, which collectively accounted for

55 % of the total number of fish recorded from seagrass (Table 8.4). The fish

assemblage of the unvegetated sand habitat contained only 25 species representing 28 %

of the total number recorded and contributing only 5 % to the total number of fish.

In contrast to the situation with reefs and seagrass, some of the samples from

over sand contained no fish. Thus, fish were not observed in 33 of the 117 (28 %)

individual sand samples, which helped account for the low overall number of species

and number of individuals in that habitat. Numerically, the fish fauna of the unvegetated

sand was dominated by *P. vitta* and *Myliobatis australis,* which collectively contributed

50 % to the total number of fish recorded in that habitat.

Of the 90 species recorded in total, 47 were exclusively found on reefs and

seven were unique to each of the seagrass and sand habitats. Twenty nine species were

observed in more than one habitat type. The fish fauna of the reef habitat contained 17

species that were also found over sand and 25 species that were also observed over seagrass. One species was observed in both seagrass and sand but not on reefs.

8.3.5 Number of species and number of individuals

Three-way crossed PERMANOVA demonstrated that the number of species and the number of individuals differed significantly among the following four habitat types in the six zones and five seasons sampled, *i.e.* inner reefs, mid reefs, seagrass and sand, thus excluding outer reef sites (for rationale see section 8.2.5). To a far lesser extent, for both number of species and number of individuals, there were significant differences detected among seasons and zones and significant two-way interactions between zone x habitat and zone x season. There was also a significant interaction for habitat x season for number of species (Table 8.5). In the case of both number of species and number of individuals, the mean squares were far greater for habitat than for either season or zone, which in turn were greater than those for the zone x habitat, zone x season and habitat x season interactions. PERMANOVA pairwise tests revealed there were significant differences between the mean number of species and mean number of individuals in each pair of habitat types ($p \leq 0.001$), except for between inner reefs and mid reefs. The mean number of species and mean number of individuals was greatest on mid reefs followed by inner reefs, seagrass and sand, respectively (Fig. 8.4 a, b).

PERMANOVA pairwise tests revealed the only differences in the mean number of species and mean number of individuals among season was between autumn 2006 and each of the other sampling seasons ($p \leq 0.02$). This was due to a lower mean number of species and individuals in autumn 2006 in the three Jurien Bay zones compared with the other sampling seasons. This pattern was also driving the zone x season interaction in both the number of species and number of individuals (Fig. 8.4 c, d). PERMANOVA pairwise tests indicated the overall zone effect, for both the number

of species and number of individuals, was driven by a lower number of species and individuals in the Jurien Bay sanctuary and Green Head scientific reference zone compared with the other Jurien Bay zones. In addition, there was a lower number of species and individuals in the Jurien Bay sanctuary zone compared with the Green Head sanctuary zone (Fig. 8.4 a, b). The zone x habitat interaction for both variables was due to a lower number of species and individuals in the Jurien Bay sanctuary zone from inner and mid reef habitats, whereas the habitat x season interaction for the number of species was due to a greater number of species in the seagrass habitat during summer 2006/2007 (plot not shown).

PERMANOVA detected a significant overall habitat effect for the number of species and number of individuals when the data for all five habitat types, *i.e.* inner reefs, mid reefs, outer reefs, seagrass and sand, in the general use and scientific reference zones, were analysed (Table 8.6). There was also a significant zone effect and a two-way interaction between zone x season for number of species and number of individuals (Table 8.6). For both number of species and number of individuals, the mean squares were far greater for habitat than zone, which in turn were greater than for the interaction.

PERMANOVA pairwise tests demonstrated that the number of species differed between each pair of habitat types except between inner *vs* mid and mid *vs* outer ($p \leq 0.001$), while the number of individuals differed between habitat pairs except those involving inner reefs, mid reefs and outer reefs ($p \leq 0.001$) (Fig. 8.5 a, b). The mean number of species and individuals for all five habitat types, *i.e.* inner reefs, mid reefs, outer reefs, seagrass and sand, was greater in Jurien Bay zones than Green Head zones in each season except autumn 2006, which was responsible for the zone x season interaction (Fig. 8.5 c, d).

Table 8.5. Results of a three-way crossed PERMANOVA on the number of species and number of individuals from inner reef, mid reef, seagrass and sand habitats in each zone and in each season. *df* = degrees of freedom, *MS* = mean squares, $p \leq 0.05^*$, 0.01^{**}, 0.001^{***}. *ECV* = estimates of components of variation.

Source	Number of species				Number of individuals			
	df	*MS*	*Pseudo-F*	*ECV*	*df*	*MS*	*Pseudo-F*	*ECV*
Zone (Z)	5	1.158	4.274**	0.0169	5	0.536	2.598*	0.0063
Habitat (H)	3	51.052	188.410***	0.5899	3	31.780	154.010***	0.3668
Season (S)	4	1.271	4.692**	0.0159	4	0.945	4.580**	0.0118
Z x H	15	0.555	2.048*	0.0194	15	0.383	1.855*	0.0120
Z x S	20	0.547	2.017*	0.0262	20	0.371	1.798*	0.0156
H x S	12	0.561	2.070*	0.0168	12	0.173	0.840	-0.0019
Z x H x S	60	0.342	1.262	0.0241	60	0.223	1.080	0.0056
Residual	249	0.271		0.2710	249	0.206		0.2060

Table 8.6. Results of a three-way crossed PERMANOVA on the number of species and number of individuals from general use and scientific reference zones, in each habitat and in each season. *df* = degrees of freedom, *MS* = mean squares, $p \leq 0.05^*$, 0.01^{**}, 0.001^{***}. *ECV* = estimates of components of variation.

Source	Number of species				Number of individuals			
	df	*MS*	*Pseudo-F*	*ECV*	*df*	*MS*	*Pseudo-F*	*ECV*
Zone (Z)	3	1.669	6.784***	0.0211	3	0.527	3.294*	0.0059
Habitat (H)	4	33.063	134.360***	0.5672	4	17.575	101.110***	0.3008
Season (S)	4	0.316	1.283	0.0013	4	0.183	1.053	1.70E-4
Z x H	12	0.236	0.960	-6.84E-4	12	0.185	1.065	1.77E-4
Z x S	12	0.527	2.143*	0.0206	12	0.378	2.173*	0.0149
H x S	16	0.399	1.622	0.0129	16	0.221	1.274	0.0040
Z x H x S	48	0.288	1.169	0.0140	48	0.203	1.167	0.0098
Residual	208	0.246		0.2461	208	0.174		0.1738

8.3.6 Fish community compositions

Comparisons of fish community compositions in the three main habitats

Following non-metric multidimensional scaling (nMDS) ordination of the resemblance matrix derived from the mean abundances of each fish species in each zone, habitat type and season, the groups of samples belonging to reef, seagrass and sand habitats each formed well defined and virtually separate groups (Fig. 8.6). Thus, on the ordination plot, reef habitat samples lay in a tight group on the left, while those for sand lay on the right and those for seagrass occupied an intermediate and generally lower position. The value for MVDISP was greatest for sand (1.347), followed by seagrass (1.191) and reef (0.926).
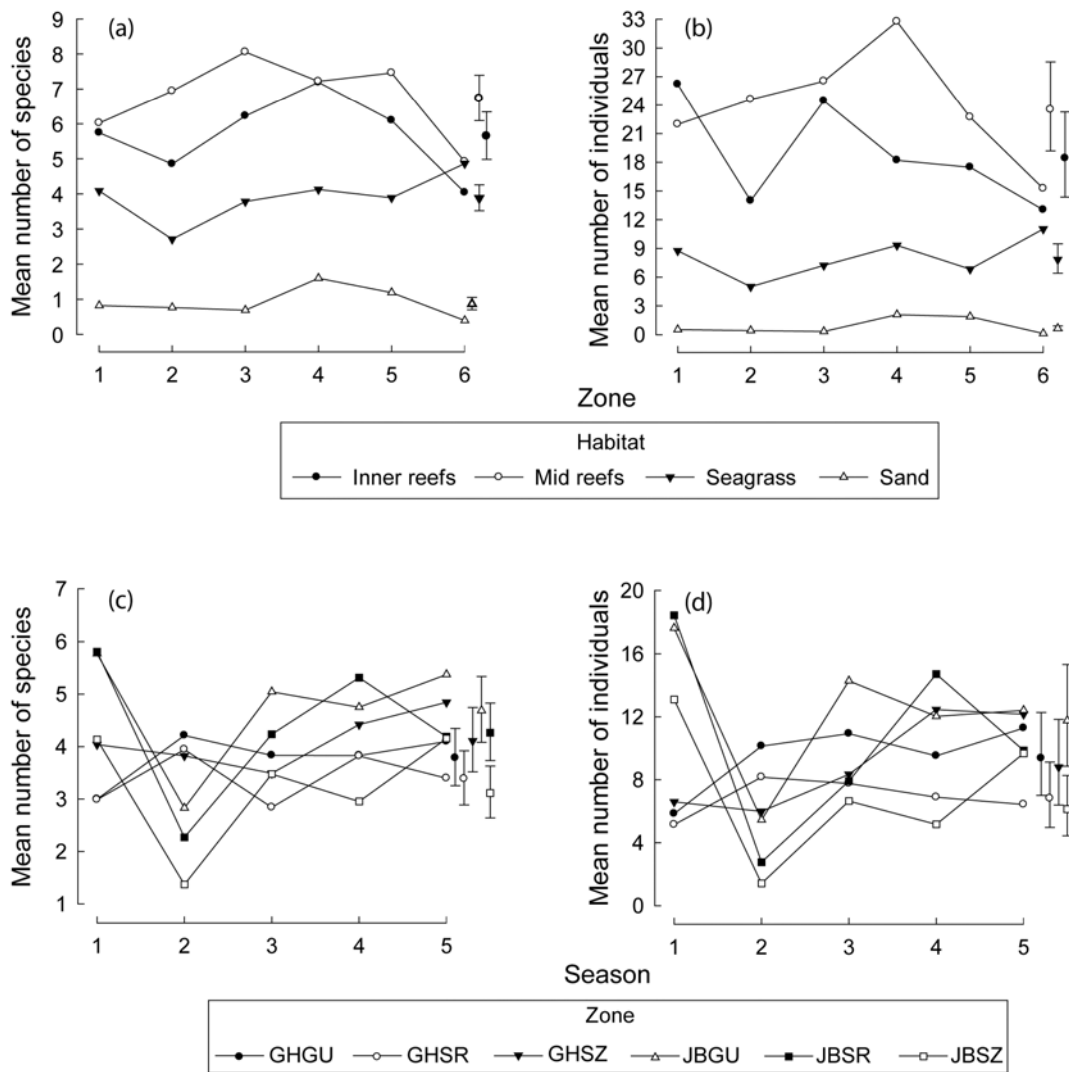
Figure 8.4. (a) Mean number of species and (b) mean number of individuals in each zone; 1 = GHGU, 2 = GHSR, 3 = GHSZ, 4 = JBGU, 5 = JBSR and 6 = JBSZ, from inner reefs, mid reefs, seagrass and sand, pooled across season including the overall mean ± the 95 % confidence interval for habitat type. (c) Mean number of species and (d) mean number of individuals in each zone and season, pooled across habitat including the overall mean ± the 95 % confidence intervals for each zone; GHGU = Green Head general use, GHSR = Green Head scientific reference, GHSZ = Green Head sanctuary zone, JBGU = Jurien Bay general use, JBSR = Jurien Bay scientific reference, JBSZ = Jurien Bay sanctuary zone; 1 = summer 2005/2006, 2 = autumn 2006, 3 = spring 2006, 4 = summer 2006/2007 and 5 = autumn 2007.
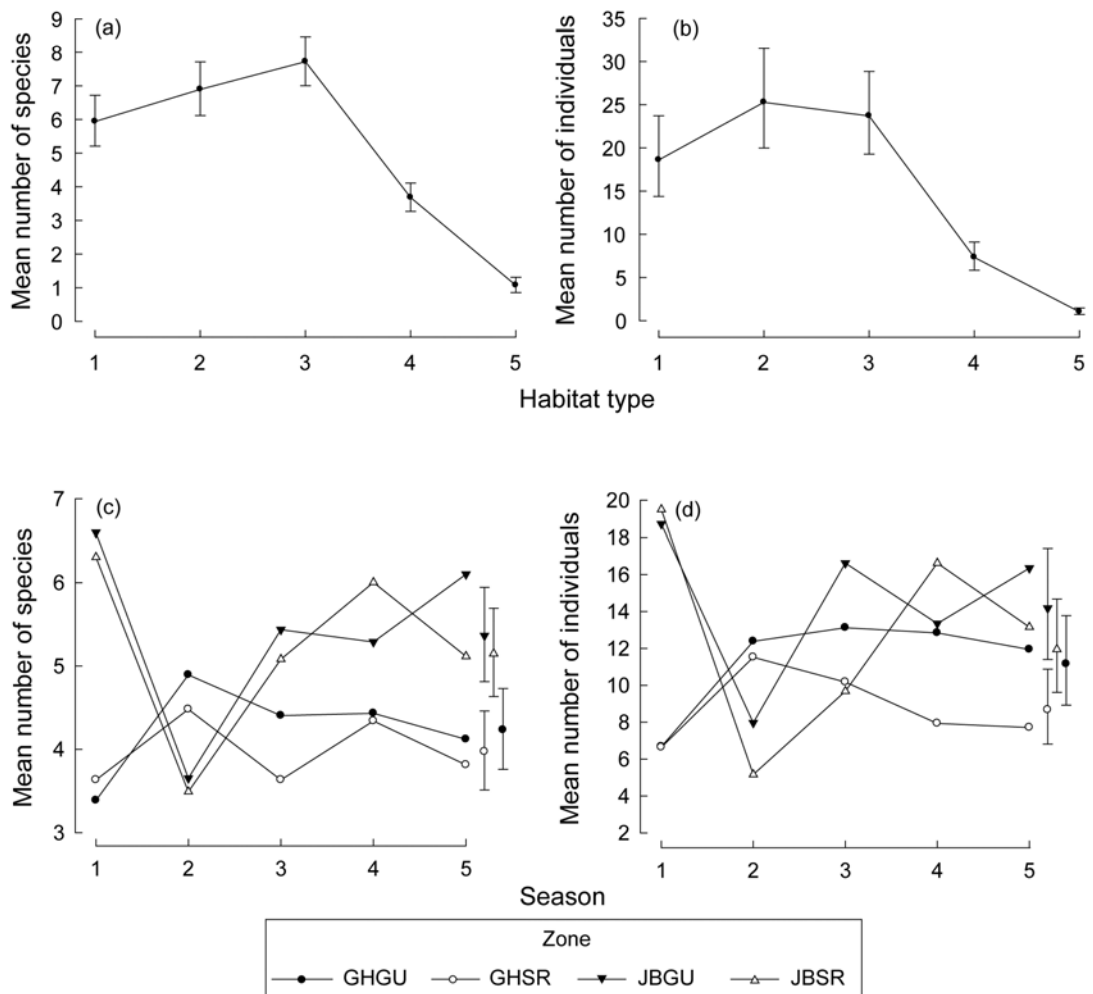
Figure 8.5. (a) Mean number of species and (b) mean number of individuals in each habitat type ± the 95 % confidence interval; 1 = inner reefs, 2 = mid reefs, 3 = outer reefs, 4 = seagrass and 5 = sand, from general use and scientific reference zones in each season. (c) mean number of species and (d) mean number of individuals in each zone and season, pooled across habitat including the overall mean ± the 95 % confidence intervals for each zone; GHGU = Green Head general use, GHSR = Green Head scientific reference, JBGU = Jurien Bay general use, JBSR = Jurien Bay scientific reference zones; 1 = summer 2005/2006, 2 = autumn 2006, 3 = spring 2006, 4 = summer 2006/2007 and 5 = autumn 2007.
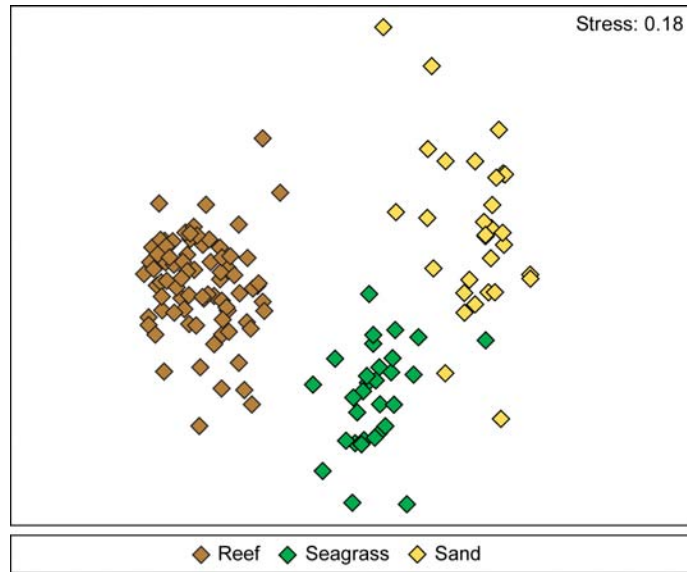
**Figure 8.6.** Non-metric multidimensional scaling (nMDS) ordination of the resemblance matrix derived from the mean abundances of each fish species in each zone, habitat type and season. Data coded for habitat type.

One-way ANOSIM demonstrated that the composition of the samples from reef, seagrass and sand were significantly different ($p = 0.001$, R-statistic = 0.682). Pairwise comparisons showed that the difference was greatest for reef *vs* sand habitats, followed by reef *vs* seagrass and then seagrass *vs* sand ($p = 0.001$ in each case, R-statistic = 0.885, 0.634, 0.494, respectively).

SIMPER demonstrated that the main typifying species for reef were *C. auricularis* and *N. parilus*, while for seagrass they were *T. pleurogramma* and *N. parilus* and for sand were *M. australis* and *P. speculator* (Table 8.7). Thus, *N. parilus* was a main typifying species for both reef and seagrass. Furthermore, SIMPER demonstrated that reef samples were distinguished from seagrass and sand samples by relatively greater numbers of *C. auricularis* and, in the case of reef *vs* seagrass, relatively lower numbers of *T. pleurogramma*. Seagrass samples were distinguished from sand samples by relatively greater numbers of *T. pleurogramma, N. parilus,* and *P. vitta* and relatively lower numbers of *M. australis* (Table 8.7).

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Table 8.7. Species identified by SIMPER as consistently typifying the fish assemblages (shaded) of reef (R), seagrass (G) and sand (S) habitats and those species that distinguished between the assemblages in each pair of habitat types. Species are arranged in descending order of importance. The habitat type in which each distinguishing species was relatively most abundant is shown in brackets.

	Reef	Seagrass	Sand
Reef	*C. auricularis* *N. parilus*		
Seagrass	*C. auricularis*(R) *T. pleurogramma* (G) *N. parilus*(R) *P. vitta*(G) *L. lineatus*(R)	*T. pleurogramma* *N. parilus*	
Sand	*C. auricularis*(R) *N. parilus*(R) *P. biserialis*(R) *L. lineatus*(R)	*T. pleurogramma* (G) *N. parilus* (G) *P. vitta*(G) *M. australis*(S)	*M. australis* *P. speculator*

Comparisons of fish community compositions in reef habitats - influence of reef location

Results of PERMANOVA using samples from inner and mid reef habitats demonstrated that reef location, *i.e.* inner *vs* mid reefs, was the most important factor affecting the composition of fishes on those reef habitat sites (Table 8.8). A two-way crossed location x zone SIMPER revealed that inner reef sites were distinguished from mid reef sites by higher abundances and frequencies of occurrence of *L. lineatus* and *P. vitta*, and lower abundances and frequencies of occurrence of *C. auricularis*, *P. biserialis* and *E. armatus.*

Table 8.8. Results of a three-way crossed PERMANOVA employing MaxN abundance data for fish species in each zone, from inner and mid reef locations in each season. *df* = degrees of freedom, *MS* = mean squares, $p \leq 0.05^*$, 0.01^{**}, 0.001^{***}. *ECV* = estimates of components of variation.

Source	*df*	*MS*	*Pseudo-F*	*ECV*
Zone (Z)	5	6076	3.051***	211.290
Location (L)	1	10777	5.412***	153.350
Season (S)	4	3271	1.643**	55.782
Z x L	5	3331	1.673**	138.660
Z x S	20	1773	0.890	-56.073
L x S	4	2070	1.040	6.886
Z x L x S	20	1598	0.803	-202.100
Residual	68	1991		1991

Results of PERMANOVA on reef samples from replicate general use and scientific reference zones again demonstrated that reef location, *i.e.* inner, mid and outer, was the most important factor affecting the composition of fishes on reef habitats (Table 8.9). With the data for the outer reef sites included in the analysis, the significant difference among reef locations was increased and evident by the larger mean squares and pseudo-F value for reef location (*cf*. Tables 8.8, 8.9).

PERMANOVA pairwise tests revealed that the greatest differences lay between inner and outer reefs (t = 5.379, *p* = 0.001) followed by mid *vs* outer (t = 3.664, *p* = 0.001), then inner *vs* mid reefs (t = 2.221, *p* = 0.001). A two-way crossed location x zone SIMPER demonstrated that outer reefs were distinguished from both inner and mid reefs through a greater abundance and frequency of occurrence of *Ophthalmolepis lineolatus, P. biserialis, E. armatus, Gymnothorax woodwardi, P. georgianus* and *Austrolabrus maculatus* and a lower abundance and frequency of occurrence of *L. lineatus*. *Coris auricularis* was also a distinguishing species between reef locations and was most abundant on mid reef sites followed by outer then inner reef sites. *Notolabrus parilus* showed the reverse pattern, being most abundant on inner, outer then mid reefs. Inner and mid reefs were distinguished by the same species previously identified from the above SIMPER on mid and inner reef samples only, in addition to *A. maculatus*, *P. georgianus* and *Parma mccullochi*, which were also identified as distinguishing species, and were more abundant on mid reefs.

Based on the fact that reef location was the most significant factor in both of the above tests, the data for all reef samples were combined and subjected to nMDS ordination. The corresponding plot, coded for reef location, showed that samples from the outer reef sites were the most tightly grouped and did not overlap with those from the other two reef locations (Fig. 8.7). Inner and mid reef samples were more dispersed and showed some overlap with each other.

Table 8.9. Results of a three-way crossed PERMANOVA employing MaxN abundance data for fish species in samples from replicate scientific reference and general use zones in inner reef, mid reef and outer reef locations in each season. df = degrees of freedom, MS = mean squares, $p \leq 0.05*$, $0.01**$, $0.001***$. ECV = estimates of components of variation.

Source	df	MS	Pseudo-F	ECV
Zone (Z)	3	4934	2.970***	98.034
Location (L)	2	25593	15.405***	533.780
Season (S)	4	2109	1.270	16.560
Z x L	6	3461	2.083***	159.470
Z x S	12	1641	0.988	-2.921
L x S	8	1804	1.086	15.482
Z x L x S	24	1539	0.926	-52.621
Residual	88	1661		1661

Figure 8.7. Non-metric multidimensional scaling (nMDS) ordination of the resemblance matrix derived from the mean abundances of each fish species in each zone, reef location and season. Data coded for habitat type, *i.e.* reef location.

Comparisons of fish community compositions in reef habitats - influence of zone

PERMANOVA performed on the samples from inner and mid reefs detected a significant zone effect (Table 8.8) and to a lesser extent a location x zone interaction. The MS for the zone effect was relatively small in comparison to that of the factor location (Table 8.8), indicating that the majority of the differences among reef samples were explained by the factor location. In addition, PERMANOVA pairwise tests revealed that only certain pairs of zones differed, the most significant being between the Green Head and the Jurien Bay scientific reference zones, Jurien Bay sanctuary and scientific reference zones and the Green Head and Jurien Bay sanctuary zones ($p \leq$

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0.001 in each case; t = 2.2722, 2.2622 and 2.1125, respectively). The nMDS ordination plot demonstrated that the samples from the above pairs of zones showed some degree of separation (Fig. 8.8a), yet this was most likely confounded by the factor location. Furthermore, the significant location x zone interaction was explained by a complete separation of samples between the Green Head and Jurien Bay management zones from the inner reef location, while this separation was less apparent in mid reef samples (Fig. 8.8b, c respectively). SIMPER revealed that samples from inner reef sites within zones from Green Head were consistently distinguished from those from Jurien Bay zones by relatively greater abundances of *C. auricularis* and *L. lineatus* and relatively lower abundances of *P. vitta*.

Similarly, PERMANOVA performed on the reef samples from replicate scientific reference and general use zones, detected a significant zone effect and to a lesser extent a location x zone interaction (Table 8.9). However, the MS and pseudo-F values were much lower than those for reef location and indicated that location was by far the most important factor influencing the fish community composition as it explained the majority of among group variation. When the corresponding nMDS ordination plot for these latter data was coded for zone, there were no conspicuous patterns between samples from the four zones (see Fig. 8.8a) and this was most likely due to the confounding location factor. Therefore, the significant interaction between reef location and zone was driving the zone difference. The estimates of components of variation were also greater for the location x zone interaction than for zone, indicating that the two-way interaction was responsible for explaining a greater amount of among group variation than zone alone. Thus, there was a complete separation of samples from the inner reef location from Green Head and Jurien Bay zones, some degree of separation of samples from the outer reef location from Green Head and Jurien Bay zones, but considerable overlap of samples from the mid reef location

from all four zones (Fig. 8.8b, d, c, respectively). SIMPER revealed that inner reef samples from Green Head zones were consistently distinguished from those in Jurien Bay zones by relatively greater abundances of *C. auricularis* and *L. lineatus* and relatively lower abundances of *P. vitta*.
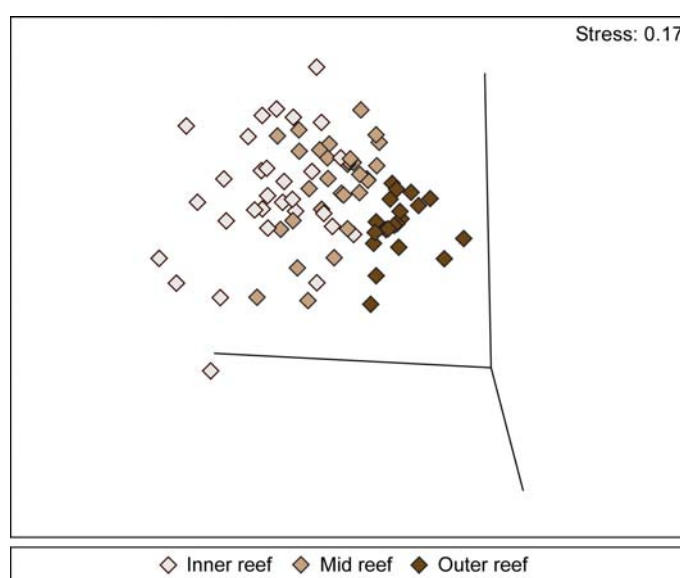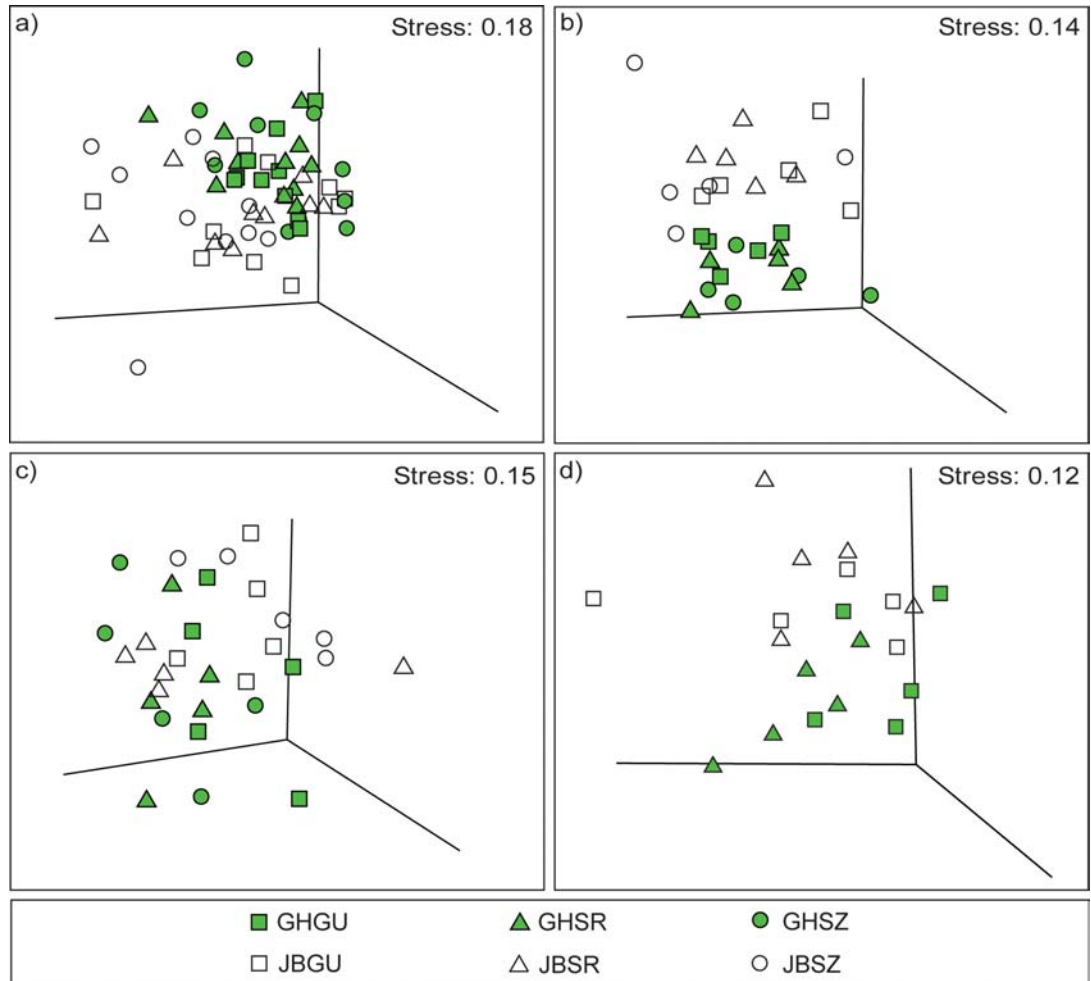

Figure 8.8. Non-metric multidimensional scaling (nMDS) ordination of the resemblance matrix derived from the mean abundances of each fish species from reef samples in each zone and season from, (a) inner and mid reefs, (b) inner reefs, (c) mid reefs and (d) outer reefs. Data coded for zone; GHGU = Green Head general use, GHSR = Green Head scientific reference, GHSZ = Green Head sanctuary zone, JBGU = Jurien Bay general use, JBSR = Jurien Bay scientific reference, JBSZ = Jurien Bay sanctuary zone.

Comparisons of fish community compositions in reef habitats - influence of season

Season was detected as a significant factor influencing the fish community composition of samples from inner and mid reef locations (Table 8.8), although the combination of low mean squares, low pseudo-F value and a considerably lower ECV indicated a low amount of among season difference. The nMDS ordination plot of inner and mid reef samples coded for season revealed no obvious trends in the distinction between samples from the five sampling periods (plot not shown).

Comparisons of fish community compositions in seagrass - influence of zone

PERMANOVA revealed that seagrass samples were significantly influenced far more by zone than by season (Table 8.10). There was an additional zone x season interaction. Following nMDS ordination of the matrix derived from the mean data for seagrass samples in each zone and season, coded for zone, the samples from Green Head and Jurien Bay zones showed no overlap on the resultant ordination plot (Fig. 8.9). SIMPER revealed that seagrass samples from Green Head zones were distinguished from those from Jurien Bay zones by relatively greater abundances and frequency of occurrences of *N. parilus* and *T. pleurogramma* and relatively lower abundances and frequency of occurrences of *P. vitta* and *P. humeralis*. Furthermore, zones from Jurien Bay showed some degree of separation, in particular, samples from the Jurien Bay sanctuary zone sat alone on the bottom of the plot (Fig. 8.9). SIMPER revealed that samples from the Jurien Bay sanctuary zone were consistently distinguished from those of the Jurien Bay scientific reference and general use zones by relatively greater abundances and frequency of occurrences of *P. vitta* and *N. parilus* and relatively lower abundances and frequency of occurrences of *P. humeralis*.

Table 8.10. Results of a two-way crossed PERMANOVA employing MaxN abundance data for fish species from seagrass samples in each zone and season. df = degrees of freedom, MS = mean squares, $p \leq$ 0.05*, 0.01**, 0.001***. ECV = estimates of components of variation.

Source	df	MS	Pseudo-F	ECV
Zone (Z)	5	20381	12.255***	935.90
Season (S)	4	6402	3.850***	197.47
Z x S	20	2172	1.306*	127.17
Residual	90	1663		
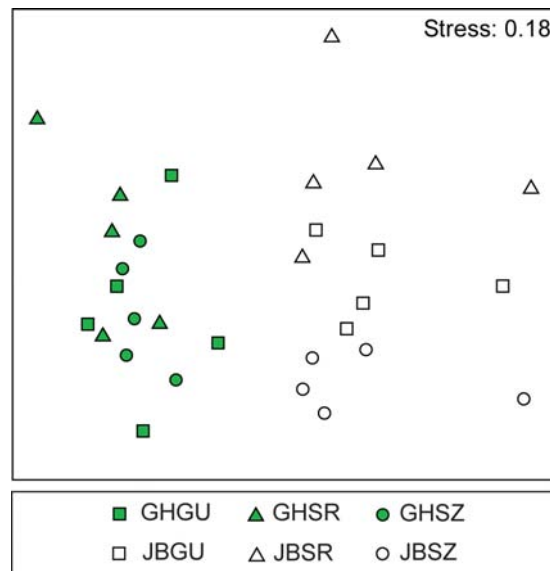
Figure 8.9. Non-metric multidimensional scaling (nMDS) ordination of the resemblance matrix derived from the mean abundances of each fish species from seagrass samples in each zone and season. Data coded for zone: GHGU = Green Head general use, GHSR = Green Head scientific reference, GHSZ = Green Head sanctuary zone, JBGU = Jurien Bay general use, JBSR = Jurien Bay scientific reference, JBSZ = Jurien Bay sanctuary zone.

Comparisons of fish community compositions in seagrass - influence of season

The samples representing the other significant factor season (Table 8.10), did not show conspicuous patterns of distribution on an nMDS ordination plot consistent with those significant differences (plot not shown). The relatively low MS and pseudo-F values for this factor compared with that for zone (Table 8.10), emphasises that the effect of season on the composition of the fish fauna in seagrass is weak and the majority of among season difference detected by PERMANOVA was attributed to the high amount of dispersion and overlap among samples from the five seasons. Furthermore, the zone x season interaction was attributed to the outlying samples from Jurien Bay in autumn 2006, seen on the far right of the nMDS coded for zone (Fig. 8.9).

Comparisons of fish community compositions in sand - influence of zone

PERMANOVA demonstrated that zone was the most significant factor influencing the composition of the fish assemblages over sand (Table 8.11). However, on the nMDS ordination plot derived from data for samples from the sand habitat, the samples from Green Head and Jurien Bay zones showed little tendency to form discrete groups (Fig. 8.10). PERMANOVA pairwise comparisons revealed that the greatest differences lay between samples from the Jurien Bay general use zone with those from the Green Head scientific reference, Green Head general use and Jurien Bay sanctuary zones ($p < 0.01$; t = 2.216, 1.891 and 2.006, respectively). Further analysis, using a supporting two-way crossed zone x season ANOSIM on data for samples from the sand habitat, produced a similar result indicating the composition of the fish assemblages were significantly influenced by zone only ($p = 0.003$; Global R-statistic = 0.115). However, this difference is considered to be weak due to the very low R-statistic. Pairwise tests revealed the greatest significant differences were between the same zone pairs detected by PERMANOVA ($p < 0.02$; R-statistic = 0.335, 0.228 and 0.225, respectively). According to SIMPER, a greater abundance and frequency of occurrence of *M. australis* in samples from the Jurien Bay general use zone consistently distinguished them from those of the Green Head scientific reference, Green Head general use and Jurien Bay sanctuary zones.

Table 8.11. Results of a two-way crossed PERMANOVA employing MaxN abundance data for fish species from sand samples in each zone and season. *df* = degrees of freedom, *MS* = mean squares, $p \leq$ 0.05*, 0.01**, 0.001***. *ECV* = estimates of components of variation.

| Source	df	MS	Pseudo-F	ECV
Zone (Z)	5	6648	2.321***	189.17
Season (S)	4	3656	1.276	32.95
Z x S	20	3531	1.232	166.51
Residual	90	2865		
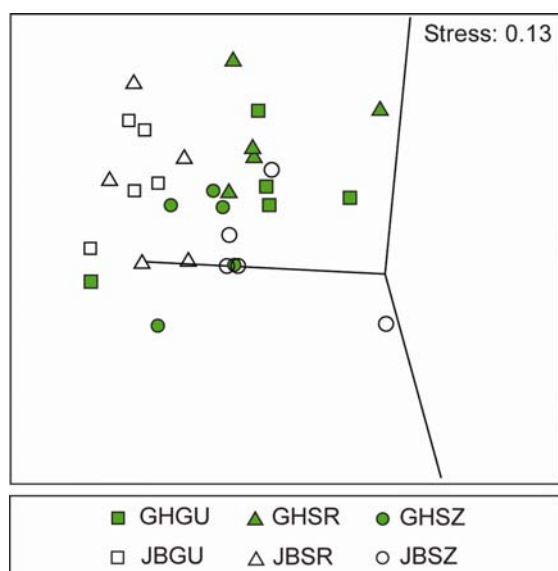
Figure 8.10. Non-metric multidimensional scaling (nMDS) ordination of the resemblance matrix derived from the mean abundances of each fish species from sand samples in each zone and season. Data coded for zone: GHGU = Green Head general use, GHSR = Green Head scientific reference, GHSZ = Green Head sanctuary zone, JBGU = Jurien Bay general use, JBSR = Jurien Bay scientific reference, JBSZ = Jurien Bay sanctuary zone.

Although the significant zone effect detected by PERMANOVA can be sufficiently explained in conjunction with ANOSIM through examination of pairwise tests, the residual MS value (Table 8.11) is comparatively high in relation to the small MS value for the factor zone, indicating a large amount of within group variation. In addition, the pseudo-F value (Table 8.11) and R-statistic value (see above) were both comparatively low, demonstrating that significant differences were weak. Therefore, detected group variation within the sand was largely attributed to a high amount of dispersion among samples driven by variability in the composition of sand samples.

8.3.7 Length compositions

The length-frequency distributions for *Coris auricularis* in the inner and mid reef locations were not significantly different (KS test; $p = 0.33$). However, those of inner and mid reef locations both differed significantly from that of the outer reefs (KS test; $p < 0.001$). Yet, the range of lengths in the inner and mid reefs combined was similar to those at the outer reefs, *i.e.* 47 to 356 *vs* 62 to 344 mm (Fig. 8.11a). The

majority of individuals observed in the inner/mid reef group and the outer reefs were less than 160 mm in length and both length distributions had a modal length class of 100-119 mm. However, the numbers of *C. auricularis* in the 120-139 and 140-159 mm length classes in the inner/mid reefs were greater than those of the outer reefs, while the outer reefs were represented by greater numbers in the 60-79 and 80-99 mm length classes (Fig. 8.11a).

As the length-frequency compositions of *Notolabrus parilus* in the three reef locations were not significantly different (KS test; $p \gg 0.017$), the data for the reef locations were pooled. The length distributions in the two main habitats in which this species was recorded, *i.e.* reefs and seagrass, ranged from 80 to 355 and 78 to 303 mm, respectively (Fig. 8.11b). The KS test demonstrated that the length distributions in these two habitats were significantly different ($p = 0.01$). Substantial numbers of individuals in the 140-159 and 220-239 mm length classes were observed in reef habitats while, in seagrass, the 100-119 and 180-199 mm length classes dominated. Greater numbers of large *N. parilus*, *i.e.* > 220 mm, were recorded in the reef habitat than in the seagrass.

The lengths of *Ophthalmolepis lineolatus* recorded in the different regions, zones, reef locations and seasons ranged from 95 to 378 mm, but did not produce an obvious mode (Fig. 8.11c). The majority of individuals of this species, which occurs almost exclusively in outer reef habitats, were between 120 and 239 mm in length. A wide length range of the recreationally and commercially important reef species, *Epinephelides armatus*, was recorded, *i.e.* 117 to 523 mm, producing a modal length class of 240-259 mm (Fig. 8.11d).
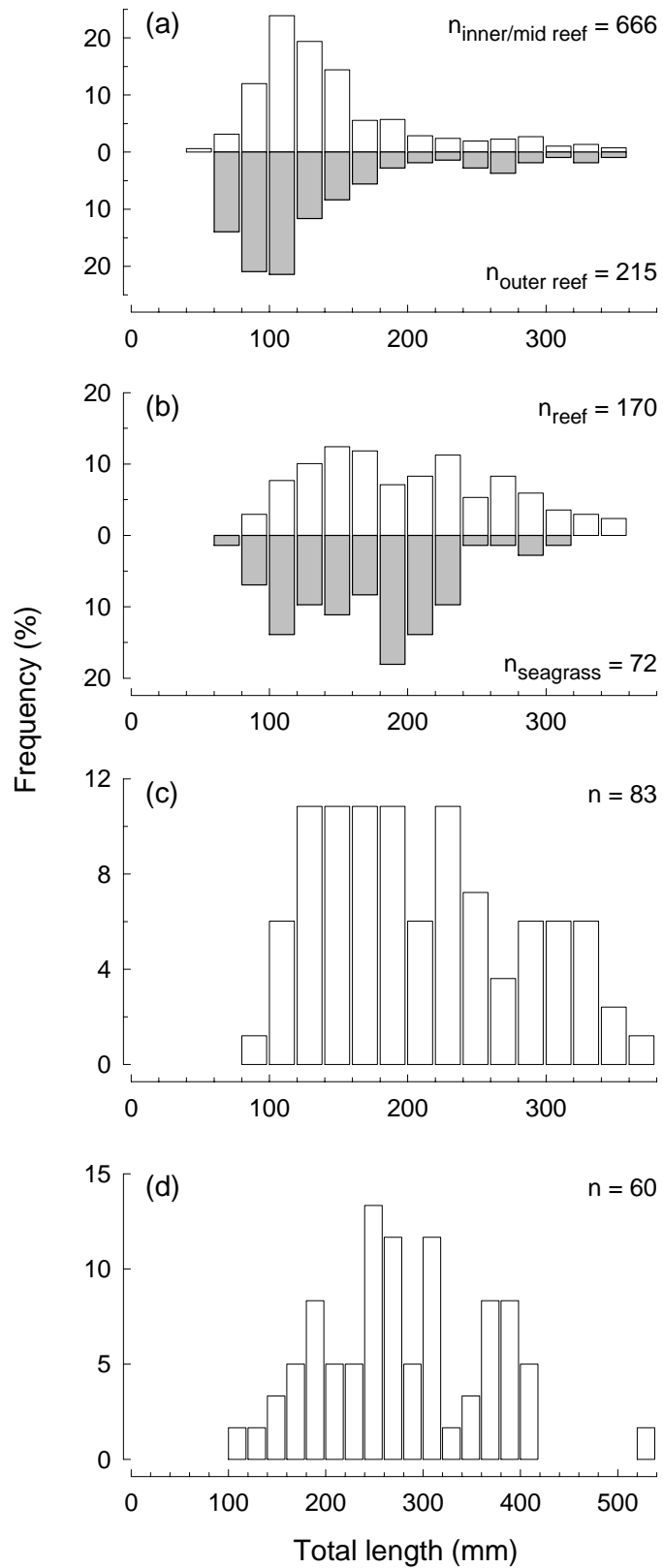
Figure 8.11. Length frequency histograms for (a) inner/mid *vs* outer reef habitats for *Coris auricularis*, (b) reef *vs* seagrass habitats for *Notolabrus parilus*, and reef habitats for (c) *Ophthalmolepis lineolatus* and (d) *Epinephelides armatus*. Sample sizes (n) are shown on each graph.

8.3.8 Habitat variables

A total of 24 reef habitat variables were identified, which were used to characterise the overall percentage contributions of macrophyte species, coral and sponges at each reef site (Table 8.12). Analysis using BVSTEP demonstrated a significant match ($p = 0.01$, rho value = 0.355) between the fish community composition at each reef site sampled and the percentage contributions of the 24 habitat variables identified. Following repeated re-runs of the procedure, variables 8, 11, and 15 were consistently identified as being the most influential in explaining the spatial patterns in the composition of fish species among the various reef sites. Further exploration revealed there was a distinct difference in the algal composition between those reef sites from Green Head and those from Jurien Bay. Non-metric multidimensional scaling (nMDS) ordination of the resemblance matrix derived from the percentage contributions of the 24 reef habitat variables, coded for region, showed sites from Jurien Bay lay at to the bottom of the plot, while sites from Green Head were situated towards the top of the plot (Fig. 8.12). Outer reef sites were generally characterised by a dominant canopy cover of large brown algae, comprising either *Ecklonia radiata, Scytothalia doryocarpa* or *Sargassum* spp., the contributions of which varied between regions. In addition, outer reef sites contained a heterogeneous understorey of algal species, usually dominated by red algal species and, in particular, calcareous reds. By comparison, inner and mid reef sites were more commonly dominated by low turfing species and green algal species, in particular, filamentous species and *Caulerpa* spp.

Table 8.12. Reef habitat variables, employed by BVSTEP, for characterising the percentage contributions of macrophyte species at each reef site.

	Habitat variable		Habitat variable
1	Calcified browns	13	Branching foliose reds
2	Filamentous browns	14	Calcareous epiphytic reds
3	Other branching browns	15	Calcareous reds
4	Other small browns	16	Crustose calcareous reds
5	*Ecklonia radiata*	17	Filamentous reds
6	*Sargassum* spp.	18	Cymodoceans
7	*Scytothalia doryocarpa*	19	Hydrocharitaceans
8	*Scaberia agardhii*	20	Posidonians
9	*Caulerpa* spp.	21	Zosteraceans
10	*Codium* spp.	22	Turf
11	Filamentous greens	23	Corals
12	Foliose greens	24	Sponges

Figure 8.12. Non-metric multidimensional scaling (nMDS) ordination of the resemblance matrix derived from the mean percentage contributions of the 24 reef habitat variables at each reef site. Data coded for region.

8.4 Discussion

8.4.1 The fish communities of reef, seagrass and unvegetated sand habitats

The fish communities of reef, seagrass and unvegetated sand habitats within the study area, covering the six management zones (GHGU, GHSR, GHSZ, JBGU, JBSR and JBSZ) in the Jurien Bay Marine Park, which were derived from samples obtained using baited remote underwater video stations, were collectively dominated by individuals and species of the Labridae. Thus, the members of this family comprised

58 % of the total number of fish and 14 of the 90 species. The most abundant species by far was *Coris auricularis*, which dominated the overall assemblage. The next three most diverse families were the Monacanthidae, with eight species, and the Serranidae and Pomacentridae with six and five species, respectively. The above four families were also the most speciose in samples recorded in Jurien Bay during the same period by trawling of seagrass beds (Chapter 6) and underwater visual census (UVC; Chapter 5) of reefs and by Hutchins (1994; 2001) using UVC in the Jurien Bay area. As in the current study, the subtropical labrid *C. auricularis*, which is endemic to Western Australia, was the most abundant species in those and other studies conducted within the JBMP (Hutchins, 1994; 2001; Vanderklift *et al.*, 2007). Reduced predation from piscivorous species, removed by fishing, can lead to an increase in the abundance of prey species (Hixon & Beets, 1993), thus the large dominance of *C. auricularis* could be due to a release from predation. Furthermore, Watson *et al.* (2007) recorded a reduced mean relative abundance of *C. auricularis* inside MPAs at the Abrolhos Islands, Western Australia, following ten years of protection from fishing and suggested this could be directly related to an increased abundance of and subsequent predation by piscivorous species otherwise targeted by fishers.

On the basis of the current study using BRUVS, the fish fauna of Jurien Bay comprises far more temperate species (61 %) than either subtropical (23 %) or tropical (16 %). In contrast, in terms of number of individuals, the subtropical species contribute more than the temperate species, *i.e.* 52 *vs* 41 %, and tropical species contribute only 5 %. However, the increased importance of subtropical species is largely due to the huge contribution (47 %) made by a single species, namely *C. auricularis*. Hutchins (1994; 2001) considered the region from Port Denison to Perth as being dominated by temperate and subtropical species.

From the above it follows that, although, in terms of numbers of individuals, the JBMP has a largely temperate fish fauna, as would be expected from its latitude (Hutchins, 1994; 2001), there is a substantial contribution made by subtropical and tropical species. This can be attributed to the fact that the Leeuwin current disperses a number of subtropical and tropical species further south (Hutchins and Pearce, 1994), thereby extending the ranges of those species southwards. However, small resident communities of tropical species, *e.g. Thalassoma lutescens*, are found in isolated coral reefs, within the JBMP (Anon., 2005).

During the present study, the BRUVS sampled a higher proportion of carnivorous species, in particular zoobenthic feeders, compared to herbivorous and omnivorous species. The dominance of carnivorous species is assumed to be a function of the use of bait in the sampling methodology. Yet, the use of bait did not prevent the method from successfully detecting significant differences in the numbers of species, numbers of individuals and species compositions among habitats, a result that is comparable to other studies (Harvey *et al*., 2007). Harvey *et al*. (2007) sampled higher species diversity and more individuals of the herbivorous group using baited as opposed to unbaited video stations. This result is likely due to their forward facing stereo-video system, which recorded herbivorous species in the far field of view grazing or swimming, indicating that a downward facing BRUVS is largely restricted to sampling carnivorous species that are attracted directly to the bait.

8.4.2 Comparisons of fish communities in reef, seagrass and sand habitats

Few studies have employed the same technique to obtain data that can be used to compare the numbers of species, numbers of individuals and species compositions in reef, seagrass and unvegetated sand habitats in the same area and at different times of the year (see *e.g.* Howard, 1989; Jenkins & Wheatley, 1998; Guidetti, 2000; Harvey *et*

al., 2005 and Gratwicke & Speight, 2005). The data collected during the present study using BRUVS demonstrated that the number of species and individuals and community composition in fish assemblages all differed markedly among the three main habitats found in the JBMP. Furthermore, as hypothesised, the number of species and individuals were greatest in the habitat that showed the greatest amount of structural complexity and were lowest in the habitat exhibiting the least structural complexity. Thus, the number of species and individuals were both highest on reefs and lowest on unvegetated sand.

Results of the present study demonstrated that the number of species and individuals on reefs were significantly greater than on seagrass, which contrasts directly with the results of Jenkins & Wheatley (1998) and Guidetti (2000). However, the possibility that the type of sampling in the latter two studies may have been more biased in one habitat than the other cannot be excluded. In contrast, Harvey *et al*. (2005) found that, as in the present study and when likewise using a baited underwater video system, the number of species and individuals was greater over reefs than seagrass and also over sand habitats. This result is possibly related to the fact that reefs possess a greater array of microhabitats due to changes in rugosity and a greater diversity of macrophyte species, thus enabling them to support more species and more individuals than seagrass meadows.

The greater number of species and individuals found in seagrass than over sand habitats in the JBMP parallel the results of numerous other studies (Howard, 1989; Sogard & Able, 1991; Jenkins *et al*., 1997; Jenkins & Wheatley, 1998; Guidetti, 2000; Travers & Potter, 2002; Harvey *et al*., 2005; Heithaus, 2004; Valesini *et al*., 2004; Gratwicke & Speight, 2005). As hypothesised, this is due in part to the shelter from predators provided by the more complex seagrass habitat than the unvegetated sand (Howard *et al*., 1989; Hindell *et al*., 2000). However, such a conclusion is at variance

with the results of Levin *et al*. (1997), who detected no difference in the rates of predation on fish in sand and seagrass habitats. Yet, it must be recognised that seagrass habitats provide other benefits to fish species, *e.g.* a diverse community of invertebrates and epiphytic algae that can provide a greater supply of food to resident fish fauna (Bell & Pollard, 1989; Levin *et al*., 1997).

The community compositions of the three main habitats were shown by ANOSIM to be significantly different from each other. Indeed, *C. auricularis* was very largely restricted to reefs, on which it was extremely abundant, and sightings of *Pseudolabrus biserialis* and *Labracinus lineatus* were also confined to this habitat type. While *Platycephalus speculator*, *Ammotretis elongatus* and *Meuschenia freycineti* were not consistently found throughout this study, they were reasonably abundant and the first two were found exclusively on sand and the third was observed only on seagrass. These species thus show a preference for a specific habitat type to which they are morphologically and behaviourally well adapted. Species such as *Pentapodus vitta* and *Myliobatis australis* were observed in all three main habitats indicating they utilise each of these different environments opportunistically.

8.4.3 The fish communities of reef habitats

Variation among inner, mid and outer reef locations

During the present study, the number of species and individuals were not found to differ among the three reef habitats, *i.e.* inner, mid and outer reefs, using BRUVS, reflecting the very considerable variation exhibited by these variables among sites in the same reef habitat. Significant spatial variation in fish assemblage structure at small scales, *i.e.* kilometres, has been demonstrated elsewhere in other studies using BRUVS (Malcolm *et al*., 2007). It is thus relevant that, as identified in previous studies (*e.g.* Harman *et al*., 2003), the characteristics of the sites within each reef habitat, *e.g.* algal

composition and rugosity (Chapter 5), vary markedly, and it is these which are considered to be playing a major role in accounting for the variability in the number of species and individuals within the sites of a habitat type. Although the number of individuals and species of reef fishes have been recorded by Harvey *et al*. (2005) as forming a gradient from sheltered to exposed reefs, this difference from the results of the present study probably reflects the fact that the depth differences between regions of the reef were greater in the study by Harvey *et al.* (2005) than in the present study.

PERMANOVA demonstrated that, in contrast to the situation with numbers of species and numbers of individuals, the species compositions in the three reef habitats were significantly different from each other. Thus, the abundances and frequencies of occurrence of *L. lineatus* and *P. vitta* were relatively greater in inner than mid reefs, while the reverse was true for *C. auricularis*, *P. biserialis* and *Epinephelides armatus*. Outer reef sites were distinguished from inner and mid reefs by greater abundances and frequencies of occurrence of *Ophthalmolepis lineolatus, P. biserialis* and *E. armatus* and relatively lower abundances and frequencies of occurrence of *L. lineatus* and *C. auricularis*.

Although *P. vitta* was a distinguishing species for inner reef *vs* mid reef faunas, it made a relatively greater contribution to the faunas of seagrass and unvegetated sand areas than to those of reefs. Indeed, *P. vitta* contributed only 1.3 % to the total number of individuals on reefs, but was so abundant over seagrass and sand that it ranked as high as second and first in terms of abundance in those two habitats, respectively. It is thus likely that the reason why *P. vitta* was responsible for distinguishing between inner and mid reef locations was because inner reef sites were located in areas close to both seagrass and unvegetated sand. The relatively large numbers of *L. lineatus* in inner reefs probably reflects the protected nature of those sites and their possession of microhabitat

characteristics, such as caves and holes, in which this species was observed to seek refuge (see *e.g*. Santin & Willis, 2007).

Coris auricularis and *N. parilus* could both be considered generalists in terms of habitat utilisation as they were both relatively abundant on inner, mid and outer reefs. In contrast, *O. lineolatus* was largely restricted to outer reefs and, together with *P. biserialis* and *E. armatus,* typified the fauna of that habitat type. The greater abundance of at least the latter three species on outer reefs may reflect a combination of physical adaptations, *e.g*. greater swimming performance (Gust *et al*., 2001; Fulton & Bellwood, 2004; Denny, 2005; Harvey *et al*., 2005), and habitat partitioning among closely related species (Fairclough *et al*., 2008) that allows those species to exist successfully in a habitat with high wave exposure. Furthermore, the restriction of *O. lineolatus* to outer reefs may also be partly diet related (Chapter 9).

Variation among zones

Although the compositions of fish assemblages were significantly influenced by zone, this variation was far less than those between their inner, mid and outer reefs. The fish fauna of Jurien Bay zones was relatively more speciose than in Green Head zones. The variation among zones in fish community composition on reefs was most apparent in inner reef sites followed by outer then mid reef sites. Variation in those sites between Green Head and Jurien Bay zones is most likely driven by differences in their fine-scale habitat characteristics.

Underwater visual census of the percentage contributions of the various macrophyte species at each reef site revealed that the composition of the algal communities in the Green Head zones and Jurien Bay zones differed. A similar result has been found by Babcock *et al*. (2006) in the JBMP. *Ecklonia radiata* was the dominant canopy species on reefs at Jurien Bay, whereas *Sargassum* spp. were the

dominant canopy-forming brown algae on Green Head reefs. There is considerable variation in the composition of algal species at the site level within zones, resulting in a variety of distinct algal habitats being identified (Babcock *et al.*, 2006). Fish assemblages are known to vary with changes in algal structure and species composition, which provide a refuge from predation and associated diverse sources of invertebrate food which change accordingly (Levin, 1994; Levin & Hay, 1996; Chemello & Milazzo, 2002).

Seasonal variation

The fish faunas in the different reef locations exhibited a low level of change among the five seasons sampled across the two years, which parallels the findings of Howard (1989) further north on the mid-west coast of Australia and of Malcolm *et al.* (2007) in New South Wales. Therefore, as hypothesised, there was no detected seasonal variation as a result of either the substantial recruitment of juveniles following spawning or the immigration and emigration of particular species at different times of the year. During their study using a similar BRUVS, Willis & Babcock (2000) observed that fish often became aggressive and defended the bait, preventing other individuals and particularly juveniles from approaching it. Similar behaviour was observed in the present study, with larger individuals and certain species, *e.g*. *L. lineatus*, aggressively defending the bait cage. This lack of difference among seasons may also reflect the fact that sampling was conducted in consecutive summer and autumn periods (with the exception of one season in spring) and not in winter, when water temperatures are colder in the JBMP, than in summer and autumn (Chapter 5).

8.4.4 The fish communities of seagrass habitats

Overall, the fish assemblages observed in seagrass habitats were numerically dominated by *T. pleurogramma*, *P. vitta* and *Pelsartia humeralis*. In contrast, *Scobinichthys granulatus*, *N. parilus* and *Apogon rueppellii* were most abundant in seagrass sites sampled in the JBMP by trawling, whereas *T. pleurogramma* and *P. vitta* were relatively less abundant (Chapter 6). The high prevalence of *T. pleurogramma* and *P. vitta* observed by BRUVS in the present study is likely to be due to a combination of their behavioural characteristics and attraction to the bait, whereas *N. parilus* and *A. rueppellii* were less conspicuous and did not readily approach the bait cage. Although *N. parilus* ranked fourth in abundance in seagrass in the present study, this may still have been an underestimate due to its tendency to hide among foliage and not always approach the bait cage. Those species which are omnivorous or herbivorous were less likely to be attracted to the BRUVS. There is evidence to suggest that certain species that are resident in seagrass habitats, *e.g.* species of the family Monacanthidae and *Pelates octolineatus*, consume epiphytic algae and/or seagrass (MacArthur & Hyndes, 2007), thereby indicating they are not strictly carnivorous. Although the BRUVS sampled species of the family Monacanthidae, *e.g.* *S. granulatus*, they were not as abundant in the current study as in previous studies of fish in seagrass habitats (Scott, 1981; Jenkins *et al*., 1997; Travers & Potter, 2002; Chapter 6). Furthermore, variation in the dominance of certain species in samples between the current study and other studies in seagrass habitats are similarly attributed to the methods used, with the BRUVS detecting aggressive species and typically not smaller cryptic species and juveniles of larger species (*cf*. Bell & Pollard, 1989; Jenkins *et al*., 1997; Travers & Potter, 2002).

Variation among zones

The composition of the fish faunas in seagrass habitats from Green Head zones and Jurien Bay zones differed markedly. Furthermore, SIMPER revealed that the fish

fauna of seagrass in Green Head zones was distinguished from that in Jurien Bay zones by relatively greater abundances and frequencies of occurrence of *N. parilus* and *T. pleurogramma* and lower abundances and frequencies of occurrences of *P. vitta* and *P. humeralis*. This difference in fish community composition probably reflects differences in the seagrass species present in those zones and thus their physical structure and density and consequently their associated epifaunal and epiphytic species (Bell & Pollard, 1989; Travers & Potter, 2002; Hyndes *et al.*, 2003). Seagrass meadows sampled in the Green Head zones were relatively dense and typically dominated by *Posidonia sinuosa*, interspersed with small patches of *Amphibolis antarctica* and *Amphibolis griffithii*. By comparison, seagrass meadows within the Jurien Bay zones were less dense and contained a mixture of the above three species, which, in the general use and scientific reference zones, were interspersed with small sand patches (pers. obs; Anon., 2005).

Travers & Potter (2002) found that, in Shark Bay, the seagrass meadows of *P. australis* contained almost exclusively small fish species, whereas those of *A. antarctica* housed a number of larger fish species. This was attributed to the fact that the foliage of *P. sinuosa* is dense and thus restricts colonisation by larger fish species, whereas there is an open area underneath the canopy of *A. antarctica* which can readily be entered by larger fish species. Hyndes *et al.* (2003) similarly demonstrated that the composition of the fish faunas sampled in *A. griffithii, P. sinuosa* and *Posidonia coriacea* differed significantly and that this would have been partly attributable to inter-specific differences in fish body size. A similar trend was apparent in the present study, with dense seagrass meadows of *P. sinuosa* in Green Head zones supporting smaller individuals of *N. parilus* and *T. pleurogramma*, while schooling and larger individuals of *P. vitta* and *P. humeralis* were more abundant in the less dense meadows of *A. griffithii* and *A. antarctica* in Jurien Bay zones.

8.4.5 The fish communities of unvegetated sand habitats

Overall, the fish assemblages in sand habitats were numerically dominated by the teleost *P. vitta* and the elasmobranch *Myliobatis australis*, whose individuals collectively comprised just over half of the total number of fish recorded in this habitat type. Again, this is presumably related, in part, to the fact that BRUVS detect those species that are most attracted to bait. BRUVS have been previously recognised as an effective method for sampling large carnivorous elasmobranchs (Cappo *et al*., 2004). Other studies in bare sand habitats have recorded very different suites of species, which is likely due to those studies being conducted in nearshore waters using seine netting, which is more effective at sampling juveniles and abundant small fish species (Ayvazian & Hyndes, 1995; Valesini *et al*., 2004; Chapter 7).

Twenty-eight percent of the samples from sand habitats contained no fish and thus complements the results of trawling in sand in the JBMP (Chapter 6), which demonstrated that the fish fauna in this habitat was depauperate. These results are also consistent with many previous studies, which demonstrated that the number of species and number of individuals in the fish faunas of unvegetated sand habitats are less than in other habitats (Howard, 1989; Sogard & Able, 1991; Jenkins *et al*., 1997; Jenkins & Wheatley, 1998; Guidetti, 2000; Travers & Potter, 2002; Harvey *et al*., 2005; Heithaus, 2004; Valesini *et al*., 2004; Gratwicke & Speight, 2005).

8.4.6 Length-frequency distributions

The length-frequency data derived for the labrids *Coris auricularis*, *Notolabrus parilus* and *Ophthalmolepis lineolatus* from BRUVS demonstrated that this method sampled a wide length range of individuals of each species, from very small individuals < 100 mm to close to their respective maxima recorded during biological studies in the JBMP, *i.e.* 365, 346 and 310 mm for *C. auricularis*, *N. parilus* and *O. lineolatus*,

respectively (Chapter 9). Furthermore, the maximum length of *Epinephelides armatus* in the present study approached the greatest length recorded for this serranid in Western Australia, *i.e.* 550 mm (Hutchins & Swainston, 1986).

Although the length ranges of *C. auricularis* in the different reef locations were similar, the "mode" produced by the two most abundant length classes in the outer reefs (80-119 mm) lay to the left of the two most abundant in the mid and inner reefs combined (100-139 mm). This difference may reflect the presence of slower growth in the harsher environment of the exposed outer reefs and limited movement between reef locations, at least during the early part of life.

The length-frequency distribution of *N. parilus* in the reefs combined was significantly different to that in the seagrass, with larger individuals more prevalent in the reef habitat. This may be due to the proposal that large individuals have greater difficulty penetrating seagrass than small individuals (Travers & Potter, 2002; Hyndes *et al*., 2003; Fairclough *et al*., 2008).

There are difficulties associated with gaining accurate length measurements using the downward-facing BRUVS employed in the present study. This is particularly important to bear in mind if the aim is to detect changes in the size composition of commercially and recreationally important species. As noted, an *ca* 12 % overestimation error results when measurements are made of fish at a height of only 10 cm above the bottom. Thus, restrictions were placed on which species could be measured due to the need for fish to be on the bottom when measured. For example, although *Pseudocaranx georgianus* was relatively abundant among the BRUVS samples, the lengths of its individuals could rarely be recorded, as this species was almost never observed close to the base of the camera stand, from which fish measurements are calibrated. A similar situation applied to other, typically pelagic

recreationally/commercially important species, *e.g. Seriola hippos* and *Arripis georgianus*.

The ability to record measurements may also be hindered by the fact that, even when individuals were on the bottom, they were not always clearly visible and in a horizontal position relative to the bottom. For example, individuals of *N. parilus* were often hidden in the seagrass or obscured by macrophytes. Limitations imposed by poor water clarity and light levels may also restrict the recording of measurements.

8.4.7 The Jurien Bay Marine Park

The effect of fishing restrictions

Most published studies that have assessed the effects of fishing restrictions have focused on a few commercial and recreationally important species (Willis & Babcock, 2000; Willis *et al*., 2000; 2003). The current study surveyed the wider fish community and recorded no detectable effect of the influence of the fishing restrictions *per se* in certain zones where fishing restrictions are in place.

The Jurien Bay Marine Park (JBMP) had only been established for a limited time, *i.e*. 28 months, and enforcement of zones closed to fishing had only been in operation for three months, before the current study commenced in January 2006. Those finfish species most targeted on the mid-west coast and potentially within the JBMP, *i.e. Glaucosoma hebraicum*, *Pagrus auratus* and *Choerodon rubescens* (Anon., 2005), are recognised as top-level predators and are usually the first type of species exploited in marine fisheries (Pauly *et al*., 1998a, b) and are therefore expected to respond the most rapidly to protection from fishing. Such species were detected in relatively low abundances, probably reflecting their naturally low densities in the survey area or their failure to be detected via the BRUVS. Cappo *et al*. (2004) noted the difficulties in

assessing rare species using BRUVS because the sampling unit cannot match their distribution and low abundance.

Similar studies using BRUVS have detected differences in the abundance of targeted fish species in reserve *vs* fished areas after longer periods of time than that in the present study (Willis & Babcock, 2000; Watson *et al*., 2007; Kleczkowski *et al.*, 2008). A slow recovery rate of such species is consistent with the results of other studies (Russ & Alcala, 2004), which is related to the slow growth rate of those targeted finfish species and is hence an attribute that places them as most vulnerable to fishing pressure. Previous studies have indicated that the earliest detected effects of fishing restrictions in MPAs result after a period of three years (Halpern & Warner, 2002). This is often an exception and the majority of studies do not report statistically significant differences between fished and unfished areas until much later. Barrett *et al*. (2007) detected no change in the abundance of the majority of fishes upon analysis of the fish communities in four no-take marine reserves in Tasmania after a period of ten years.

8.4.8 Summary: Implications of surveying fish communities using a downward facing BRUVS

In summary, the downward facing BRUVS used in this study is recognised as having certain advantages and disadvantages.

Disadvantages

1. Although it is not surprising that the downward facing BRUVS method detected predominantly carnivorous species, forward-facing baited systems (*sensu* Harvey & Shortis, 1996) often detect a greater number of omnivorous and/or herbivorous species due to its much larger field of view. This enables detection of species that are attracted to the "commotion" caused by feeding and aggregation at the bait cage, and species indifferent to the above but are merely

passing through the field of view by chance (Cappo *et al*., 2004; Harvey *et al*., 2005).

2. The identification of fish to the species level is occasionally restricted by the subtle morphological differences that exist between closely related species, *e.g.* the *Pseudocaranx* complex. Identification of more cryptic species is also restricted by the obscuring of the field of view by macrophytes and by poor visibility.

3. Fish relative abundances can be underestimated, *e.g.* when large schools of a species are present, as it is unlikely that all fish would be viewed in the field of view at one time, thus reducing the accuracy of the MaxN value. The MaxN of other species may be underestimated when there are several individuals in an area, but only one or a small number are viewed in one frame. Note that positive correlations between MaxN and the densities of particular species recorded using UVC have been demonstrated (Willis & Babcock, 2000; Willis *et al*., 2000).

4. Species composition and relative abundance of species may be influenced by fish behaviour (see Armstrong *et al*., 1992). Aggressive species and larger individuals are more likely to be recorded at the bait. Thus, the abundance of less aggressive species and juveniles is likely to be underestimated, *e.g.* the relative abundance of *Choerodon rubescens* detected using BRUVS was much lower than that recorded during UVC in the same area (Chapter 5).

5. While the downward facing BRUVS method could be used to estimate the lengths of species that were observed close to calibration marks on the BRUVS stand, several species could not be measured as they were rarely recorded in that position.

6. High vertical relief of some reefs and strong currents can lead to the camera stand falling over and thus preventing the successful recording of fish samples. Variation in the direction and distance in which the bait plume is dispersed as a result of currents and wave action can contribute to variation in the species compositions, numbers of species and numbers of individuals within a treatment group, which is an unknown variable attributable to all baited video methods.

Advantages

1. This method successfully detected differences in the numbers of species, numbers of individuals and species compositions among three main habitat types, *i.e.* reefs, seagrass and sand, with a focus on carnivorous species.

2. The BRUVS detected changes in the composition of fish assemblages in reef habitats that had different degrees of exposure to wave action. While sampling was not designed specifically to test for changes in species composition according to changes in reef characteristics, such as algal composition, this method was capable of detecting such changes.

3. The BRUVS method was successfully employed to detect changes in the abundance of individual species in different habitats.

4. The length compositions of selected species were successfully derived from video footage and were of sufficient quality to allow comparisons among habitat types and to detect differences among the length distributions.

5. The BRUVS method detects predominantly carnivorous species and can therefore be used to study these species, of which many are of commercial/recreational interest, and for which fishery independent abundance/biomass data is required.

6. The downward-facing camera system used restricts the field of view, thus reducing the potential impact that reduced water clarity may have on the numbers of species and individuals recorded if a forward-facing video system was used.

7. The use of downward-facing BRUVS provides a record of the substrate and associated habitat variables, *e.g.* algal species, within a known area, while simultaneously sampling the fish assemblages. This allows correlations to be drawn between the fish species composition and such habitat variables.

9.0 The biology of *Coris auricularis*, *Notolabrus parilus* and *Ophthalmolepis lineolatus*

Lek, E., Fairclough, D. V. and Potter, I. C.

9.1 Introduction

The Labridae is the second largest family of marine fishes (Parenti and Randall, 2000; Allen *et al.*, 2006) and, in various parts of the world, many of its larger species are the focus of fisheries, *e.g. Semicossyphus pulcher, Tautoga onitis* and *Cheilinus undulatus*. The last of the above species is listed as "endangered" on the IUCN red list, having suffered from heavy fishing for the live reef fish trade (Sadovy *et al.*, 2003; White *et al.*, 2003; Russell, 2004; Topping *et al.,* 2005). In south-eastern Australia in the 1990s, moderately-sized labrids, *i.e. Notolabrus tetricus* and *Notolabrus fucicola*, became the focus of a live reef fish trade for restaurants. Commercial catches of those species expanded rapidly with little initial management and fishers raised concerns about declining catch rates and decreasing maximum size (Smith *et al*., 2003).

Increasing fishing effort in the demersal scalefish fishery of the west coast of Australia led to overfishing occurring in the stocks of some of the traditionally-targeted demersal fish species, including those of the large labrid *Choerodon rubescens* (Wise *et al.*, 2007). This has led to the introduction of a suite of changes to the management of that multi-species fishery, which will reduce substantially the effort and catch by the recreational and commercial sectors (Department of Fisheries, 2007a; b; 2011). The decline in abundance of targeted demersal species in traditional fishing grounds, such as the metropolitan region of the west coast of Australia, has led to a change in the behaviour of fishers. For example, recreational fishers travel greater distances, both offshore and along the coast, to catch large fish (Wise *et al.*, 2007; Sumner *et al.*, 2008; Harvey and Beckley, in prep). Furthermore, a recent study in the metropolitan region indicated that the numbers of small species, such as the labrids *Coris auricularis*,

Notolabrus parilus and *Ophthalmolepis lineolatus* are being caught and/or retained more frequently in that region, which may represent an example of "fishing down the food web" (Pauly *et al.*, 1998a; Harvey, 2004; Harvey and Beckley, in prep). As these small species on the west coast of Australia can be caught relatively easily (*pers. obs.*) and are abundant (Hutchins, 2001), they could also become the focus of a local live reef fish trade, like that of south-eastern Australia, if it is economically viable. Thus, data on important biological parameters for such species are urgently required by managers for developing appropriate management plans for those species.

Many labrids, including *S. pulcher* and *Pseudolabrus celidotus*, are protogynous hermaphrodites, *i.e.* individuals change sex from functional females to functional males, and they often have social hierarchies, which determine when sex change occurs, *e.g.* when the male of a haremic group dies (Robertson, 1972; Warner, 1975; Jones, 1980; Sadovy *et al.*, 2003; Candi *et al.*, 2004). Although some species with this type of life history may be able to respond to heavy fishing pressure by modifying aspects of their life history, *e.g.* their length at sex change (Bannerot *et al.*, 1987; Ross, 1990; Alonzo & Mangel, 2005), that response would be undesirable. For example, in areas of eastern Australia where the labrid *Choerodon venustus* is heavily fished, its maximum length has been reduced and this has been accompanied by a reduction in the length and age at sex change to levels below those in areas of low fishing pressure (Platten *et al.*, 2002; see also Heppell *et al.*, 2006). As fishers retain larger fish preferentially, they would not only be removing the large males of protogynous species, but also the largest and most fecund females. Sex ratios in "reproductive" groups of a protogynous species are rarely 1♀:1♂. For example, the sex ratio of adult *C. rubescens*, *i.e.* fish ≥ the length at which 50 % of individuals reach sexual maturity, is *ca* 10♀:1♂ on the central west coast of Australia (Fairclough, 2005). However, the sex ratio of *C. rubescens* in commercial catches, which are restricted to fish > 400 mm (minimum legal length), is *ca* 1♀:1♂,

indicating that male fish are being removed disproportionately from the population. If the females in social groups of the species in areas of heavy fishing are unable to respond quickly to the removal of males, by changing sex, then reductions in spawning potential are likely. This fact coupled with the removal of the most fecund females may have serious implications for the stocks of such a species.

There are, at present in Western Australia, no minimum legal lengths for the retention of the Western King Wrasse *C. auricularis*, the Brown-spotted Wrasse *N. parilus* and the Southern Maori Wrasse *O. lineolatus*. These species are included in the low risk category in the west coast bioregion fishing regulations, which allows a combined catch of up to 30 fish to be retained by each angler (Department of Fisheries, 2011). The research undertaken for the above three labrids on the west coast of Australia was aimed at providing the types of biological data required by fisheries managers, *i.e.* lengths and ages at maturity and sex change, length and age compositions and growth patterns, spawning periods and diets, for developing appropriate plans for conserving the stocks of those species, before they become a more important focus of fishers in the region.

The realisation that an excessive removal of fish that belong to specific trophic levels, *e.g.* top predators, has positive or negative flow-on effects to other trophic levels, has resulted in a "push" for a greater understanding of the trophic linkages between species and the implementation of "ecosystem" management, in conjunction with traditional single species management (Walters *et al.*, 1997; Pauly *et al.*, 1998b; Carscadden *et al.*, 2001; Fu *et al.*, 2001). The now widely-used ecosystem model programs, ECOPATH and ECOSIM, employ estimates of abundance and biomass of aquatic species, such as fish, and also of the types and quantities of food that they eat. Those models can be used to gain an understanding of the potential quantitative effect on the stock size of a species through decreases or increases in those of other species

and the influence of changes in those parameters with time and space (Polovina, 1984; Walters *et al.*, 1997; Pauly *et al.*, 2000; Morissette *et al.*, 2003; Christensen and Walters, 2004). Dietary data are essential for these models because, for example, they enable species to be assigned to functional groups designed to elucidate the links to other groups and also permit the construction of consumption to biomass ratios used in those models (Pauly *et al.*, 2000). The type of dietary data collected during the present study, and for many other species by the Centre for Fish and Fisheries Research at Murdoch University, along with other previously published biological parameters, such as mortality rates, are essential for the construction of the ecosystem models being produced by Loneragan *et al.* for the JBMP (FRDC project 2006/038[1]).

Coris auricularis, *N. parilus* and *O. lineolatus* are abundant (Hutchins, 2001) and thus ecologically important species on the west coast of Australia and have the potential to form the basis of recreational and/or commercial fisheries. Thus, the aims of this study were to test the following hypotheses.

1. As with many labrids that have been studied, *C. auricularis*, *N. parilus* and *O. lineolatus* are functional protogynous hermaphrodites. If this is the case, the study will also determine whether they are of the monandric or diandric type (Sadovy and Shapiro, 1987), the lengths and ages at which their females reach maturity and the lengths and ages at which 50 % of functional females change to functional males.

2. As with the assemblages of other reef species, including labrids that occur at different spatial scales representing environments that would provide different opportunities, such as changes in competition or food supply, (see *e.g.* Gust *et al.*, 2002; Fairclough, 2005), the length and age compositions of *C. auricularis* and *N. parilus* each differ among the habitats in which they occur, *i.e.* between

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[1] FRDC 2006/038 "Evaluating how food webs and the fisheries they support are affected by fishing closures in Jurien Bay, temperate Western Australia."

reef habitats that are sheltered from and exposed to ocean swell and also between reef and seagrass habitats with *N. parilus*. This is reflected in different length-at-age compositions and thus von Bertalanffy parameters in those different habitats. Note that such comparisons were not made for *O. lineolatus*, as it occurs almost exclusively over outer exposed reefs.

3. Because the three species are morphologically similar and co-exist in reef habitats, they partition their resources by (a) spawning at different times of the year, thus reducing competition among larvae and juveniles at this critical period in their life history, and (b) consuming different types and amounts of prey. The diets of each species also differ among seasons, length classes and habitats, *e.g.* sheltered *vs* exposed reefs.

9.2 Materials and methods

9.2.1 Sampling regime and morphometric measurements

Coris auricularis, *Notolabrus parilus* and *Ophthalmolepis lineolatus* were collected from the reef habitats described in Chapter 4 (shown in Fig. 3.1) by line fishing, using coral prawns as bait, by using small rectangular traps (400x240x240 mm) baited with crushed Australian sardines (*Sardinops neopilchardus*) and by spear fishing. The traps had a mesh size of 1.5 mm and a circular entrance at each end of 50 mm diameter. Samples of *N. parilus* from seagrass were obtained from the trawl sampling regime described in Chapter 6. After their capture, all fish were immediately euthanased in an ice slurry. Fish were taken to the laboratory where their total lengths (TL) and total wet weights (W) were recorded to the nearest 1 mm and 0.1 g, respectively. Length-weight relationships were calculated for each species from line and trap caught fish and used to estimate the weights of speared and thus damaged fish, for which accurate weights could not be obtained from the sample.

9.2.2 Reproductive biology

Laboratory procedures and analysis

The sex of each fish was determined by examining its gonads. On the basis of their morphology, the gonads of almost all fish could be macroscopically distinguished as either ovaries or testes (Tables 9.1, 9.2). These gonads were removed, weighed to the nearest 0.01 g and their stage of development recorded, following a modified scheme from Laevastu (1965) (Tables 9.1, 9.2). At least 10 ovaries and 10 testes from a wide length range of fish in each calendar month were preserved in Bouin's fixative for *ca* 24 h, after which they were dehydrated in a series of increasing concentrations of ethanol. The mid-region of each gonad was embedded in paraffin wax and cut into 6 µm thick transverse sections. Each section was then stained with Mallory's trichrome and mounted on a microscope slide with DePeX under a cover slip. Subsamples of gonads were sectioned transversely at their anterior and posterior ends to confirm that ovarian and testicular development occurred consistently along the length of the gonad. Sections were examined under a compound microscope to confirm the accuracy of the macroscopic staging.

The gonads of several individuals of each species of intermediate length, which could not be clearly defined as ovaries or testes, were also removed, weighed to the nearest 0.01 g and sectioned histologically as described above. Sections were examined

Table 9.1 Macroscopic characteristics of the stages of development of the ovaries of *Coris auricularis*, *Notolabrus parilus* and *Ophthalmolepis lineolatus*. Scheme adapted from Laevastu (1965).

Stage	Macroscopic characteristics
I – *Sexually immature*	Ovarian lobes extend 1/4 of body cavity length. Strand like, transparent and colourless.
II – *Maturing virgin/ resting adult*	Ovaries occupy up to 1/4 of body cavity length. Translucent, pale yellow to pink. Ovarian lobe rounded. Small clearish eggs can be seen through ovary wall with magnifying glass.
III – *Developing*	Ovaries occupy approximately 1/3 of body cavity length. Lobe-like, with few to many small white granular oocytes visible through ovarian wall.
IV – *Maturing*	Ovaries occupy approximately 1/3 of body cavity length. Ovarian lobes becoming enlarged, with few to many cream-coloured oocytes visible through ovarian wall.
V – *Prespawning*	Ovaries occupy 1/2 to 2/3 of body cavity length. Ovaries packed with many large cream-coloured oocytes, visible through ovarian wall.
VI – *Spawning*	Ovaries occupy about 2/3 length of body cavity. Swollen, packed with many large cream-coloured oocytes. Clear hydrated oocytes visible through the ovary wall.
VII - *Spent*	Ovaries occupy up to 2/3 of body cavity length. A few large cream-coloured oocytes visible through ovarian wall. Large spaces among oocytes. Flaccid and reddish in colour.
VIII – *Recovering spent*	Ovaries occupy approximately 1/3 of body cavity length. Ovaries flaccid and red to brown.

Table 9.2 Macroscopic characteristics of the stages of development of the testes of *Coris auricularis*, *Notolabrus parilus* and *Ophthalmolepis lineolatus*. Scheme adapted from Rhodes and Sadovy (2001).

Stage	Macroscopic characteristics
I – *Inactive/ resting*	Testes occupy 1/3 of body cavity length. Essentially flat and string like, but may be triangular in cross-section towards cloaca. Translucent and pinkish.
II – *Mature/ active*	Testes 1/3 to 1/2 of body cavity length. Flat to partially enlarged, tapering in size towards anterior end. Partially translucent with some cream coloured areas, to opaque and cream in colour in more developed testes.
III – *Mature/ ripe*	Testes 2/3 of body cavity length. Swollen in appearance, almost triangular in shape at posterior end and tapering towards anterior end. Opaque and cream to white in colour. Sperm rarely extruded when pressure is applied to testes. May have brown tinges at anterior ends.
IV – *Spent/ recovering*	Testes 1/3 to 2/3 of body cavity length. Flaccid, reddish brown in colour

to determine whether those gonads contained solely ovarian or testicular tissue or both tissue types simultaneously. In the latter case, those gonads were categorised as transitional, bisexual or male, depending on the type and amount of ovarian and testicular tissue present (Sadovy and Shapiro, 1987; Sadovy de Mitcheson and Liu, 2008). Transitional individuals contain gonads with degenerating vitellogenic or later stage oocytes and proliferating testicular tissue. The gonads of bisexual individuals contain immature ovarian tissue, *i.e.* previtellogenic oocytes, and immature testicular tissue, *i.e.* spermatogonia and sometimes spermatocytes (see Results), which are intermixed. Individuals of intermediate length with gonads containing both ovarian and testicular tissue simultaneously were classified as male when their gonads comprised maturing and/or mature testicular tissue, *i.e.* spermatids and spermatozoa, and varying amounts of (Rhodes and Sadovy, 2002).

Additional subsamples of the gonads of small juveniles of each species were sectioned histologically to allow investigation of the pattern of sexual development in their early part of life. Longitudinal sections were obtained following the procedure described earlier for transverse sections. Small juveniles that contained immature ovarian tissue and small amounts of immature testicular tissue and sometimes maturing testicular tissue, *i.e.* spermatids, are referred to here as bisexual juveniles. As all three species of labrid were shown to be protogynous hermaphrodites and those individuals occurred at lengths and ages well below those of first maturation of females and the occurrence of males, they are not considered to be functional at that stage in life.

Gonadosomatic indices (GSI) were calculated for females $\geq L_{50m}$, *i.e.* the length at which 50 % of females reach sexual maturity (see later), and for all male fish. The GSI of each fish was calculated from the equation $W_G/(W-W_G)\times100$, where W_G = wet weight of the gonad and W = wet weight of the whole fish. The frequencies of the

different gonadal development stages in each month were determined for females $\geq L_{50m}$ at maturity only.

The mean monthly GSIs and frequencies of occurrence of the different gonadal development stages of each species in each month were analysed to determine the timing of the spawning periods of the three labrids (see Figure 9.3 and 9.4 in Results). The main spawning period of each species was considered to represent those months where ≥ 50 % of the ovaries of the females of each species were at stages III to VIII (Fairclough, 2005; Moore *et al.*, 2007), *i.e.* they were either developing, about to spawn, spawning or had recently spawned, and were thus considered to be sexually mature.

The lengths at which 50 and 95 % of females of each labrid species reached sexual maturity, *i.e.* L_{50m} and L_{95m}, respectively, and their 95 % confidence limits were determined using logistic regression analysis to fit logistic curves to the probability that, during their respective spawning periods, a female fish at a specific length would possess gonads at stages III to VIII (see Figure 9.4 in Results). Calculations of lengths at maturity for each species were conducted on the combined data set derived from samples collected from all reef habitats during their spawning periods, as insufficient samples of each species were obtained from each of the different reef habitats during their spawning periods to allow separate analyses. Furthermore, limited samples of *N. parilus* were obtained from seagrass during the spawning period to fit logistic curves. The form of the logistic equation used for this analysis is $P = 1/\{1+\exp[-\log_e(19)(L-L_{50m})/(L_{95m}-L_{50m})]\}$, where $P =$ the predicted proportion of mature females at a particular total length, L (mm), and L_{50m} and $L_{95m} =$ the total lengths in mm at which 50 and 95 % of fish reached sexual maturity, respectively. On the basis of its length, the likelihood of the jth fish possessing or not possessing gonads at stage III to VIII was calculated as P_j or $1-P_j$, respectively. Setting $X_j = 0$ if the jth fish did not possess gonads at such stages, and $X_j = 1$ if it did possess such gonads, the overall log-likelihood was calculated as

$\Sigma_j\{X_j\ln P_j+(1-X_j)\ln(1-P_j)\}$. The logistic equation was fitted by maximizing this log likelihood, using SOLVER in Microsoft Excel. The data for the lengths of immature and mature individuals of each species were randomly resampled and analysed to create 1000 sets of bootstrap estimates for the parameters of the logistic equation and of the probability of maturity for a range of specified lengths. The 95 % confidence limits of the probability of maturity at each specific length were taken as the 2.5 and 97.5 percentiles of the corresponding predicted values resulting from this resampling analysis. The medians of the bootstrap estimates were used as the point estimates of each parameter and of the probability of maturity at each specified length.

Ages at which 50 and 95 % of females of each species reach sexual maturity were not calculated using logistic regression analysis as described for length, as, at the time of the spawning periods, the data for the ages of each species are essentially discrete. Thus, during their spawning periods, *i.e.* the time of year when it is appropriate to use the status of sexual maturity of fish to determine their ages at sexual maturity, fish are approximately 1 year old, 2 years old *etc.* and a decimal age at sexual maturity of, for example 2.5 years, does not strictly make sense. Thus, for example, fish mature at the end of their second year or third year *etc*.

The lengths at which 50 (L_{50c}) and 95 % (L_{95c}) of individuals of each species had become males, *i.e.* had changed sex, and their 95 % confidence intervals were estimated by fitting logistic curves to the probability that a fish at a specific length was male. The same logistic equation was employed as described earlier for determining length at sexual maturity and was fitted by maximising the log-likelihood and using bootstrap resampling. In this case, P = the predicted proportion of males at a particular total length, L (mm); L_{50m} and L_{95m} are replaced with L_{50c} and L_{95c}, which are the total lengths in mm at which 50 and 95 % of fish had become male. The ages at which 50 and 95 % of fish become male, *i.e.* A_{50c} and A_{95c}, and their associated 95 % confidence intervals

were determined using the same data as for length at sex change and the above bootstrap resampling procedure and again replacing parameter labels where appropriate in the logistic equation.

Likelihood ratio tests were used to test whether the L_{50c} and A_{50c} of *C. auricularis* and *N. parilus* caught over shallow protected and deeper exposed reefs, and of *N. parilus* caught over reefs and seagrass, differed significantly. The null hypothesis that the data for a species in the two habitats could be described by a common logistic curve was compared with the alternative hypothesis that the data for each habitat would be better described by separate logistic curves (Cerrato, 1990). The test statistic was calculated as twice the difference between the log-likelihood obtained by fitting a common logistic curve to the data for both habitats and by fitting separate logistic curves to the data for each habitat. The null hypothesis was rejected at the $\alpha = 0.05$ level of significance if the test statistic exceeded $\chi^2_\alpha(q)$, where q is the difference between the numbers of parameters in the common curve and the separate curves (Cerrato, 1990).

9.2.3 Ageing studies

Laboratory procedures and analysis

The two sagittal otoliths of each fish were removed, cleaned, dried and stored in paper envelopes. The otoliths of each labrid species were small (< 5 mm long) and increased in thickness with increasing fish size, preventing accurate counts of opaque growth zones near the margins of the otoliths. Thus, the otoliths of each species were sectioned to improve the resolution of their opaque zones (*e.g.* see Hyndes *et al.*, 1992; Smith *et al.*, 2003; Fairclough, 2005). The left otolith of each fish was mounted in clear epoxy resin, which was then allowed to harden for *ca* 24 h. An approximately 300 μm thick section was cut through the primordium of the otolith along its dorso-ventral axis

using an Isomet low-speed diamond saw (Buehler). The resultant sections were polished using fine wet and dry carborundum paper (Grade 1200), cleaned and mounted on microscope slides using DePeX mounting medium and a cover slip was placed over the top of the section and allowed to dry.

Sectioned otolith slides were placed on a black background under a dissecting microscope (Wild Leitz M3Z) and examined using reflected light. The number of opaque zones in the sectioned otolith of each fish was counted by the senior author on two occasions, without knowledge of the date of capture or length of that fish. Any discrepancies in the number of zones recorded in an otolith for an individual fish were investigated and, in the few cases where the numbers of zones still could not be confidently determined, because the readability of the zones in the otolith was poor, those fish were not included in further analyses. The number of opaque zones in the sectioned otoliths of all *C. auricularis* (n = 1012) and random subsamples (*ca* 200 fish) of *N. parilus* and *O. lineolatus* were counted by a second experienced reader of labrid otoliths (D. Fairclough). The limited number of discrepancies between his counts and those of the senior author (96 % for *C. auricularis*, 89 % for *N. parilus* and *O. lineolatus*) were due either to the senior author's failure to detect in a small number of otoliths the recently delineated opaque zones or the low readability of the otoliths due to poor distinction between opaque and translucent growth zones. As an accurate and precise count could not be determined confidently for the latter otoliths, they were removed from further analysis. In the former case, those fish were collected during the time of year when opaque zones typically delineate for these species (see section 9.3.3) and were re-examined together by both readers to reach a consensus on the number of zones. In the very few cases where agreement was still not reached on the numbers of opaque zones, which was always due to poor readability of the otolith, those individuals were not included in further analyses.

Validation of growth zone formation

Marginal increment analysis was employed to determine whether the opaque zones in the otoliths of *C. auricularis* are formed annually, irrespective of the size and thus life stage of the fish. Note that a validation of the annual formation of opaque zones in the otoliths of *N. parilus* and *O. lineolatus* was not conducted for the following reasons. (1) The annual formation of opaque zones in the otoliths of several labrids of a variety of genera has been successfully demonstrated in sub-tropical to warm temperate waters of Western Australia (Fairclough, 2005; Cossington *et al.*, 2010; Coulson *et al.*, 2009). This has now also been demonstrated for *C. auricularis* in the warm temperate environment of the JBMP (see Results). Thus it is highly likely that this pattern also occurs in the otoliths of *N. parilus* and *O. lineolatus*. (2) Validation of the annual formation of opaque zones in otoliths has been conducted successfully for two congeners of *N. parilus*, *i.e. Notolabrus fucicola* and *Notolabrus tetricus*, in temperate waters of Tasmania and Victoria (Ewing *et al.*, 2003; Smith *et al.*, 2003). (3) Validation of the annual formation of opaque zones in otoliths has been conducted successfully for *O. lineolatus* at a similar latitude to the JBMP on the east coast of Australia (Morton *et al.*, 2008). Sectioned otoliths of *N. parilus* and *O. lineolatus* were examined to determine the time of year when new opaque zones delineate, which is required to calculate the ages of individual fish (see section 9.3.3).

To measure the marginal increments, the sectioned otoliths of *C. auricularis* were placed on a black background under a Leica Mz7.5 dissecting microscope, with a reflecting light source, and viewed on computer via a Leica DC300 camera and the computer imaging package Leica IM 1000 (Leica Microsystems Pty Ltd). The measurements described below were then made to the nearest 0.01 mm, perpendicular to the opaque zones and without knowledge of the date of capture of the fish from which that otolith had been removed, using the Leica IM 1000 measurement module.

The marginal increment in each otolith, *i.e.* the distance between the outermost opaque zone and the edge of that otolith, was measured and expressed as a proportion of the distance between the primordium and the outer edge of the opaque zone, when only one opaque zone was present, or as a proportion of the distance between the outer edges of the two outermost opaque zones, when two or more opaque zones were present.

Length and age frequency compositions and analysis of growth

The approximate mid-point of the main spawning periods of *C. auricularis*, *N. parilus* and *O. lineolatus*, which was estimated from the trends shown throughout the year by the gonadosomatic indices (see Figure 9.3 in Results) and gonadal maturity stages of their females (see Figure 9.4 in Results), was considered to correspond to the average birth date of the individuals of each species. Thus, *C. auricularis*, *N. parilus* and *O. lineolatus* were assigned birth dates of 1 June, 1 September and 1 November, respectively. This birth date was then used, in conjunction with the time of year when the opaque zones (annuli) in the otoliths become delineated and counts of the numbers of opaque zones in the otoliths of each fish, to determine the age of individual fish on their date of capture.

Using the Statistical Package for the Social Sciences for Windows *v*15.0 (SPSS Inc., 2006), Kolmogorov-Smirnov (K-S) tests were used to test the null hypotheses that there were no significant differences among either the length or age frequency distributions of both females and males of *C. auricularis* and of *N. parilus* in the different reef habitats, *i.e.* shallow *vs* deep, in which they each occur. Note *O. lineolatus* occurred almost exclusively in deep reefs and thus tests were not conducted for that species. Test were conducted using length and age composition data derived from fish caught only by line fishing, as this method was used consistently in the two habitat types and would have the same selectivity in each habitat. Other methods, *e.g.*

spearfishing and trapping, were used opportunistically to collect specific length and age classes of fish and would thus bias the results of any statistical tests. Similarly KS tests were not used to compare statistically the length and age frequency distributions of *N. parilus* caught by line over reefs with those caught by trawling n seagrass, because of the different selectivities of the two methods of capture. Note that length and age frequency distributions of each species, derived from fish collected in different management zones of the JBMP, were not compared, as any effect of closures to fishing would be unlikely to have manifested in the short time since enforcement of closures commenced and when sampling occurred.

Since the three labrids are protogynous hermaphrodites (see section 9.3.2), a single von Bertalanffy growth curve was fitted, for each species, to the combined data set of the lengths at age of females, bisexual individuals and males, using non-linear regression in SPSS. The von Bertalanffy equation is $L_t = L_\infty(1\text{-}\exp(-k(t\text{-}t_0)))$, where L_t = the total length (mm) at age t (years), L_∞ = the asymptotic total length (mm), k = the growth coefficient (year^{-1}) and t_0 = the hypothetical age (years) at which fish would have zero length. Composite von Bertalanffy growth curve equations for *C. auricularis* and *N. parilus* in the different reef habitats, *i.e.* shallow protected *vs* deep exposed, and, in the case of *N. parilus*, also in seagrass, were compared using likelihood ratio tests (in a similar manner to that described earlier for comparing the L_{50}s at sex change – see section 9.2.2) (Cerrato, 1990).

9.2.4 Dietary studies

Laboratory procedures and analysis

In each season, the whole intestine was removed from subsamples of at least 12 individuals, when available, of *C. auricularis*, *N. parilus* and *O. lineolatus* in each length class, *i.e.* $\leq$ 149, 150-199, 200-249 and $\geq$ 250 mm, and in each habitat in which

they occur and then preserved in 70 % ethanol. Note that *C. auricularis* occurs and was collected over shallow protected and deeper exposed reefs, *N. parilus* over shallow and deep reefs and in shallow protected seagrass beds and *O. lineolatus* over only deep reefs. A small incision was made in the wall of each intestine to facilitate the preservation of its contents, following which, samples were stored for at least 5 days prior to examination.

As these labrids do not have a distinct stomach, only the foregut (the first third of the intestine) of each fish was examined. This avoided over-representation of dietary items that contain hard structures, which are difficult to digest and thus remain in the lower part of the intestine, *e.g.* echinoid spines. The fullness of each foregut was estimated visually on a scale of 0 to 10, with 0 being empty and 10 being fully distended. Contents of the foreguts were examined under a dissecting microscope (Wild Leitz M3Z) and dietary items were identified to the lowest possible taxonomic level (Shepherd and Thomas, 1989; Wilson *et al.*, 1993; Coleman, 1994; Wilson *et al.*, 1994; Edgar, 2003; Wells and Bryce, 2000; Wilson, 2002; Jones and Morgan, 2002). Bait used to catch fish (*Metapenaeopsis* spp. or *Sardinops neopilchardus*), which occurred frequently in the foreguts, was not recorded as it does not represent part of the natural diet. The percentage volume (%V) that each dietary item, contributed to the overall contents of each foregut was visually estimated.

The percentage frequency of occurrence (%F) and mean percentage volumetric contribution (%V) of each dietary item for each of the three labrid species in each habitat in which they were collected were calculated in SPSS for Windows *v*15.0 (SPSS Inc., 2006) (see Table 9.8 in Results). The percentage volumetric contributions of unidentifiable material, which probably contained representatives of more than one of the different dietary items, and sand, which is presumably ingested accidentally during feeding, were excluded from further analyses. For each species, the remaining data for

the percentage volumetric contribution of each dietary item, unidentifiable material and sand, were then adjusted up to 100 % for each individual. As the foregut contents comprised up to 304 individual dietary items, that could be identified to varying taxonomic levels, each item was aggregated into one of 22 broader taxonomic groups, which are subsequently referred to as dietary categories (see Table 9.8; Platell *et al.*, 1997). The mean percentage volumetric contribution of each dietary category (Table 9.8) was calculated for each length class, *i.e.* $\leq$ 149, 150-199, 200-249 and $\geq$ 250 mm, for each of the three labrid species across all seasons and in each season separately in each of the habitat types in which they were collected.

Multivariate analyses

Multivariate analyses were carried out in the Primer *v*6 statistical package (Clarke and Gorley, 2006), in conjunction with the Windows PERMANOVA+ module (Anderson and Gorley, in prep.), to test the following hypotheses. (1) The dietary compositions of *C. auricularis*, *N. parilus* and *O. lineolatus* differ in the deep reef habitat in which they co-occur. (2) The dietary compositions of *C. auricularis* and *N. parilus* differ in the shallow reef habitat in which they co-occur. (3) The dietary composition of *C. auricularis*, *N. parilus* and *O. lineolatus* differs among the habitats in which they occur and in with body size and season within each habitat. Prior to multivariate analyses, the mean percentage volumetric contribution of the different dietary categories for each species in each season in each length class was square-root transformed, as is considered appropriate for percentage data (Platell and Potter, 2001).

To test the first hypothesis, the data were considered to represent a 3-way crossed design of species (3 levels) × length class (3 levels) × season (4 levels), each factor being fixed. The test used dietary data only for the length classes that were represented for each species in all seasons in the deep reef habitat, *i.e.* 150-199, 200-249

and ≥ 250 mm, to avoid missing cells in the analysis. The dietary data were randomly sorted into groups of three fish for each length class and in each season, with the means for each dietary category for each group being calculated and used in the analysis to represent replicates within each length class. A Bray-Curtis similarity matrix was constructed from the square-root transformed mean percentage volumetric contribution of each dietary category to the groups of fish in each length class of each species in the deep reef habitat in each season. The resultant matrix was employed by (1) PERMANOVA in the three-way design to test for differences among species in the deep reef habitat and (2) complementary two-way Analysis of Similarities (ANOSIM) of species × length class and species × season to compare the results of the PERMANOVA and, in particular, the effect of "species", in a non-parametric framework (Clarke, 1993). While the factors length class and season were included in the tests, to investigate any interactions, species was the main factor of interest and the effect of length class and season are investigated further for each species individually (see later). Any significant effects of the factor species were investigated further using pairwise results in the 2-way ANOSIM tests.

To display the relationships among samples of each species over deep reefs, the percentage volumetric contributions of the 22 dietary categories in the diets of each species were meaned for each of the three length classes in each season and a Bray-Curtis similarity matrix was constructed and then subjected to non-metric multidimensional scaling ordination (nMDS). A one way Similarity Percentages (SIMPER) analysis was conducted on the original transformed data set, comprising the groups of three fish for each length class in each season used in the above statistical tests, to determine which of the dietary categories typified and distinguished the composition of the diet of the three species in the deep reef habitat (Clarke, 1993).

To test the second hypothesis that the composition of the diets of *C. auricularis* and *N. parilus* in shallow reefs are different, the same statistical designs were used in PERMANOVA and ANOSIM as described for the above test. However, all four length classes were represented in each season for both species and thus there were four levels for length class, *i.e.* ≤ 149, 150-199, 200-249 and ≥ 250 mm. Species was again the main factor of interest in these tests and thus pairwise tests were not required. A Bray-Curtis similarity matrix was constructed from the square-root transformed mean percentage volumetric contribution of each dietary category to groups of three fish in each length class of each species in the shallow reef habitat in each season (as in the first test), from which the PERMANOVA and ANOSIM tests were conducted. A nMDS plot was constructed from a Bray-Curtis similarity matrix, which was derived from the square-root transformed mean volumetric contribution of each dietary category in each length class (meaned across all groups of three fish in each class) and season for *C. auricularis* and *N. parilus* collected over shallow reefs. A one way SIMPER test was used to investigate typifying and distinguishing dietary categories for *C. auricularis* and *N. parilus*.

The square-root transformed percentage volumetric contributions of the different dietary categories for each species were then used separately to test the effect of habitat, length class and season on the diet of each species. As above, dietary data were randomly sorted into groups of three fish for each length class in each season and habitat, each group then being treated as a replicate. A similarity matrix was constructed for each species from the transformed data. In the case of *C. auricularis* and *N. parilus*, a 3 factor design (habitat × length class × season) was used in PERMANOVA to test for differences among those three *a priori* groups. The factor habitat consisted of two levels (shallow and deep reefs) for *C. auricularis* and three levels (shallow and deep reefs and seagrass) for *N. parilus*. Length class comprised 3 levels (150-199, 200-249 and

≥ 250 mm) for the former species and two (150-199, 200-249) for the latter and season comprised four levels. Complementary two-way ANOSIM tests (habitat $\times$ length class and habitat $\times$ season) were again used, followed by nMDS and SIMPER. Note that only the length classes that were represented in each habitat and season for each species were included in the PERMANOVA tests to avoid having missing cells. The complementary ANOSIM tests were first run using the same data sets and similarity matrices as for the PERMANOVA to be directly comparable, following which they were run using the full set of length classes to provide complete analyses using all data for each species. The full data sets were also then used to produce nMDS plots and to conduct SIMPER tests. As *O. lineolatus* was collected only over deep reefs, a two-way ANOSIM was used to investigate whether the dietary composition differed for this species among length classes and seasons and when significant differences were detected, nMDS plots were constructed to display those differences and SIMPER was used to determine which dietary categories typified and distinguished the *a priori* groups.

9.3 Results

9.3.1 Reproductive biology

Histological characteristics of the gonads

Examination of the histological sections of the gonads of small individuals, *i.e.* < 120 mm, of *C. auricularis*, *N. parilus* and *O. lineolatus* collected over reefs, demonstrated that the majority of individuals of the former species and each of those of *N. parilus* and those in the small sample of the latter species contained undifferentiated germ cells (protogonia *sensu* McPherson, 1977) and previtellogenic ovarian tissue and were thus female (Fig. 9.1). These gonads are categorised as stage I of ovarian development and the ovarian tissue comprised oocyte development in different stages of meiosis, including the zygotene and diplotene phases, and also chromatin nucleolar

oocytes and sometimes perinucleolar oocytes (Fig. 9.1; Table 9.3). The gonads of two small *C. auricularis* (89 and 90 mm) collected over reefs, that were examined histologically, were found to contain ovarian tissue, similar to the above small females of those species, and some small areas of testicular tissue, which comprised late stage spermatocytes and/or very small amounts of spermatids, and were thus considered to be bisexual juveniles (Fig. 9.2).

The gonads of all fish collected over reefs that were between 120 mm and, for *C. auricularis*, 180 mm (n = 18), for *N. parilus*, 160 mm (n = 12), and for *O. lineolatus*, 220 mm (n = 83), that were macroscopically identified to be females at stages I or II and were later examined histologically, were confirmed to be female. The lamellae in the ovaries were organised and extended from the ovarian wall into the lumen. The lamellae contained protogonia and oocytes at different stages of development, including meiotic stages of oogenesis and also chromatin nucleolar and some perinucleolar oocytes. These ovaries represented either stage I or II of ovarian development (Table 9.3; Fig. 9.3a). Protogonia and the different stages of meiosis were commonly visible in all later stages of ovarian development, *i.e.* III-VIII (see Table 9.3). The gonads of almost all *N. parilus* $\leq$ 160 mm in length that were caught in seagrass (n=18) were identified as females when examined histologically. Three small *N. parilus* from seagrass (107, 115 and 135 mm) were determined by histological analysis of their gonads to be bisexual, while one small *N. parilus* (124 mm) from seagrass was male.
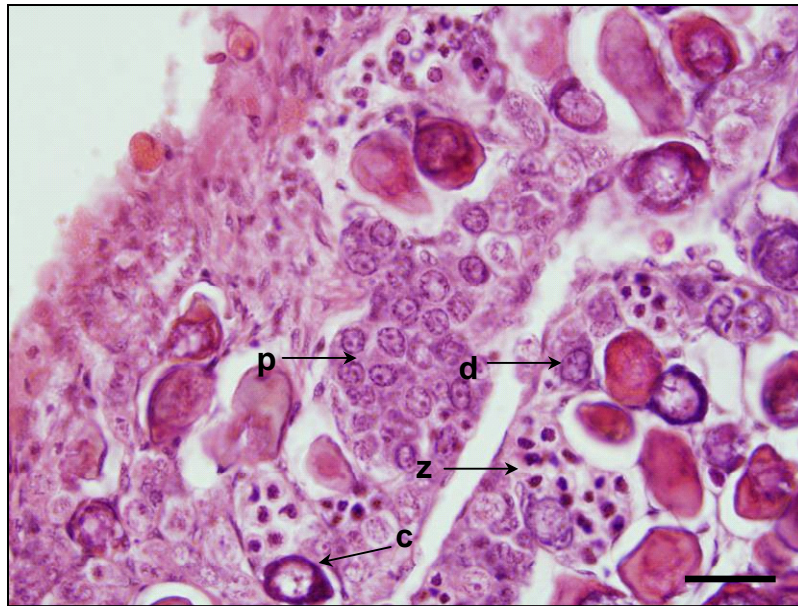
Figure 9.1 Histological section of the gonad of a small female *C. auricularis* (89 mm). c, chromatin nucleolar oocyte; d, diplotene phase, p, protogonium; z, zygotene phase. Scale = 20 µm.
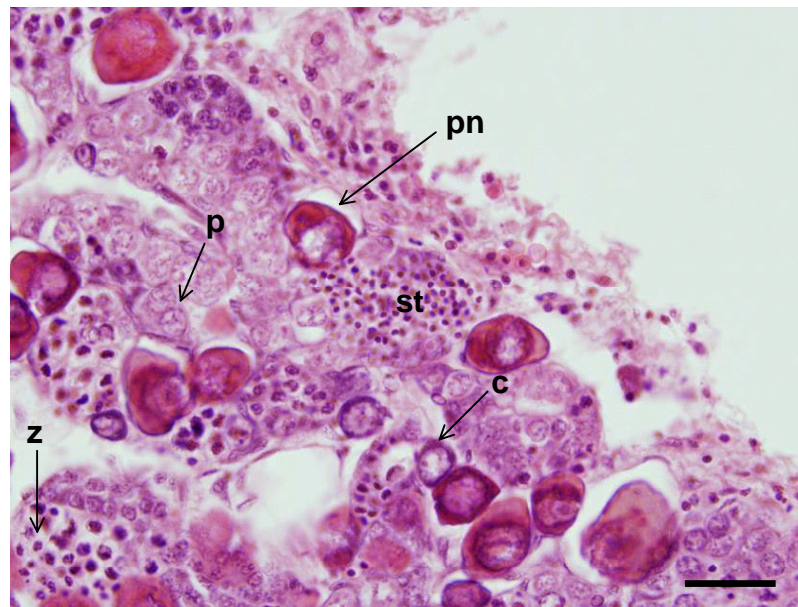

Figure 9.2. Histological section of a small bisexual *C. auricularis* (89 mm). c, chromatin nucleolar oocyte; p, protogonia; pn, perinucleolar oocyte; st, spermatids; z, zygotene oocyte. Scale = 20 µm.

Examination of histological sections of the ovaries and testes of individuals of

C. auricularis, *N. parilus* and *O. lineolatus* that were at each of the different

macroscopic stages of development, *i.e.* I-VIII for females and I-IV for males (see Table

9.2), demonstrated that the macroscopic identification of the different sexes was valid

and the ovaries and testes of each of those species at each stage had essentially the same

characteristics (Tables 9.3 and 9.4). Examination of additional transverse sections from the anterior and posterior ends of both testes and ovaries, derived from subsamples of each species, demonstrated that gonadal development was consistent along their length.

Ovaries of each species that were at stages I and II, which were found in larger juveniles and small resting adults, respectively, are difficult to distinguish, as they have similar macroscopic and histological characteristics. Thus, they each comprise early stages of oocyte development, *i.e.* oogonia, chromatin nucleolar and perinucleolar oocytes, albeit in different amounts. As only subsamples of ovaries were sectioned histologically, the numbers of those two stages were pooled for the purpose of analysis of the frequencies of the different stages of development of ovaries in each month (see Fig. 9.4). Similarly, ovaries identified macroscopically as developing (stage III) and maturing (stage IV) differ only by the greater number and degree of development of yolk vesicle and cortical alveolar oocytes in the latter stage when examined histologically. Thus, the numbers of those two stages were pooled for the analysis described above (Table 9.3).

Ovaries that were either at stage V or VI, *i.e.* prespawning or spawning, respectively, for each of the three species, could only be distinguished macroscopically when hydrated oocytes were visible through the ovary wall, which indicates that spawning is imminent. Those latter ovaries are thus classed as spawning. Histological sections of the two stages revealed that while prespawning ovaries are tightly packed with yolk granule oocytes, spawning ovaries can also be tightly packed with yolk granule oocytes, but also contain either hydrated oocytes, migratory nucleus oocytes and/or post-ovulatory follicles, which provide evidence of approaching or recent spawning (Table 9.3; Hunter and Goldberg, 1980). Migratory nucleus oocytes cannot be distinguished from yolk granule oocytes in macroscopic examinations of the ovaries and post-ovulatory follicles are not visible at all. For these reasons, the numbers of those

two stages were pooled for analysis of the frequency of the different stages of development in each month. Ovaries that were spent, *i.e.* stage VII, and recovering, *i.e.* stage VIII, are considered to be post-spawning and were pooled for the above analysis. Histological sections of those stages showed varying numbers of degenerating yolk granule and cortical alveolar oocytes and scar tissue was sometimes visible. None of the gonads that were identified macroscopically as ovaries that were at stages V-VIII contained any testicular tissue in conjunction with degeneration of vitellogenic oocytes. Thus no individuals were identified as being "transitional" *sensu* Sadovy and Shapiro (1987), *i.e.* undergoing functional sex change.

A small number of individuals of *C. auricularis* (11) and *O. lineolatus* (2) that were of intermediate length, *i.e.* 202-275 mm for the former species and 225 and 251 mm for the latter, contained gonads that were reddish to brown in colour, flaccid and occupied one half to two thirds of the length of the body cavity and macroscopically could not be readily classified as either ovaries or testes. Histological sections of those gonads demonstrated that they comprised gonial cells and a combination of previtellogenic oocytes, *i.e.* chromatin nucleolar and perinucleolar oocytes, and immature testicular tissue, *i.e.* predominantly spermatogonia with some spermatocytes. (Fig. 9.3). These individuals were thus classified as "bisexual" *sensu* Sadovy de Mitcheson and Liu (2008). The bisexual individuals of *C. auricularis* that were of intermediate length were collected in January, April, June and July, while those of *N. parilus* in seagrass were collected in October and December and of *O. lineolatus* were caught in March. In the case of two individuals of each of *C. auricularis*, *N. parilus* and *O. lineolatus*, immature ovarian tissue was present in conjunction with immature and small amounts of mature testicular tissue, *i.e.* spermatids, and thus these individuals are considered to be functional males.

Histological sections demonstrated that the testes of male *C. auricularis*, *N. parilus* and *O. lineolatus* each contained a lamellar structure, membrane-lined lumen and external wall (Fig. 9.3c). Inactive or resting testes, *i.e.* stage I, contained predominantly undifferentiated protogonia and spermatogonia and also some spermatocytes in small crypts (Table 9.4). Mature/active testes, *i.e.* stage II, comprised mainly spermatocytes and spermatids, with some spermatozoa in crypts (Table 9.4). Mature/ripe testes, *i.e.* stage III, consisted of mostly spermatids and spermatozoa, each located in crypts. However, many crypt walls surrounding spermatozoa had broken down and spermatozoa were often found in sperm sinuses in the outer wall of the testes, which are presumably used in transport of sperm to the cloaca during spawning (Table 9.4). Testes never contained a centralised or singular sperm duct. Spermatogonia were either absent or present in very low numbers in the latter two stages. Spent testes, *i.e.* stage IV, contained obvious crypts, which appeared empty apart from remnant spermatids or spermatozoa and early stages of development, *i.e.* protogonia and/or spermatogonia. Spermatozoa were rare in the sperm sinuses of those testes (Table 9.4).

Table 9.3. Histological sections and characteristics of the macroscopic stages of development (from Table 9.1) of the ovaries of *Coris auricularis*, *Notolabrus parilus* and *Ophthalmolepis lineolatus*. Terminology used for characteristics of oocyte development from Wallace and Selman (1981).
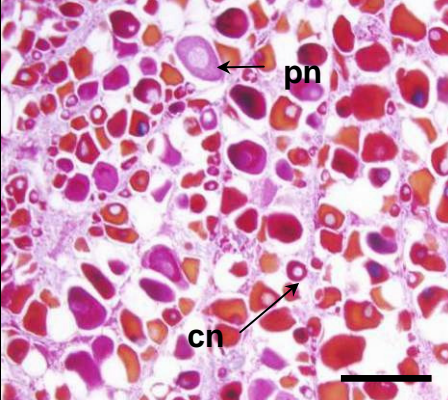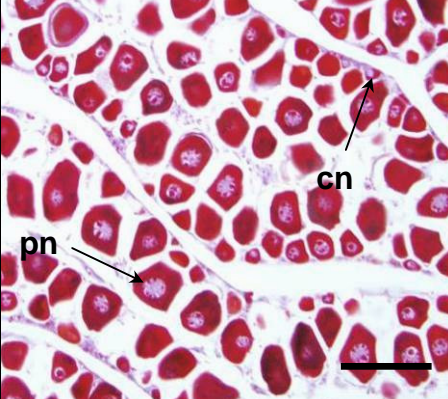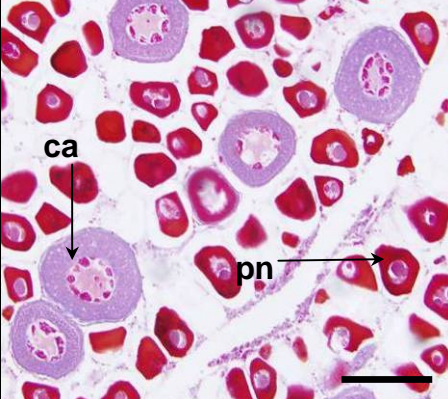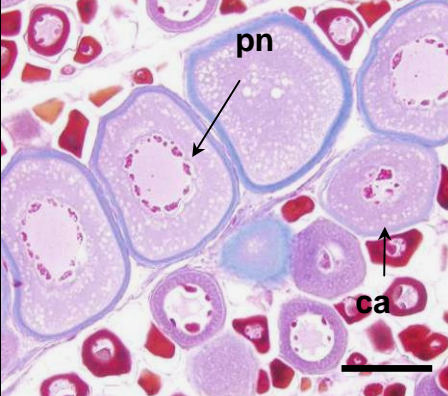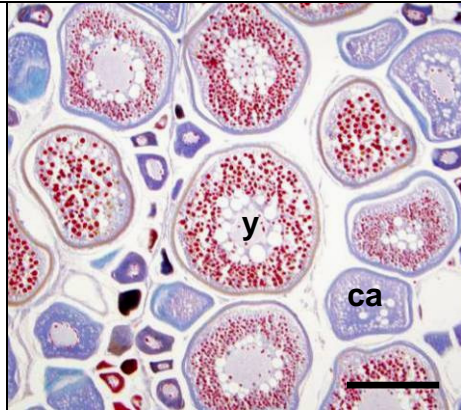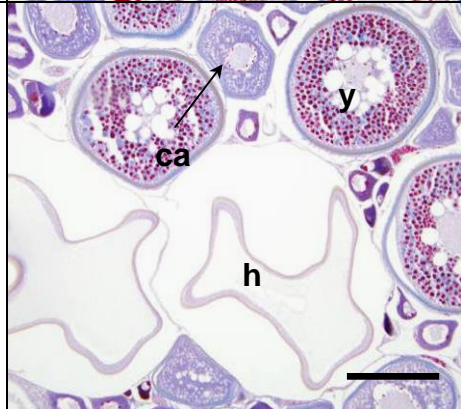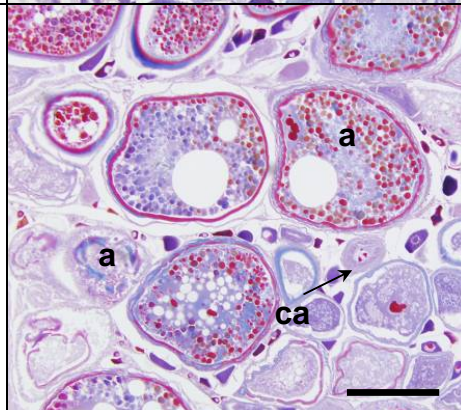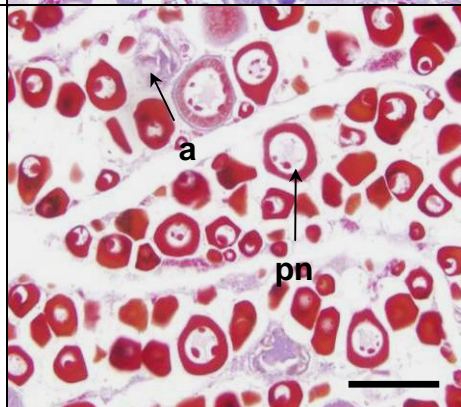
Macroscopic stage	Histological section	Histological characteristics
I – *Sexually immature*		Well organised ovarian lamellae, with oogonia, chromatin nucleolar (cn) and some perinucleolar (pn) oocytes present. Scale = 100 μm.
II – *Resting*		Well organised ovarian lamellae, with oogonia, chromatin nucleolar (cn) and early to late perinucleolar (pn) oocytes present. Note: these oocyte stages are found in all subsequent stages of development. Scale = 100 μm.
III – *Developing*		Highly organised lamellae with few to many predominantly small cortical alveolar (ca) oocytes. Scale = 100 μm.
IV – *Maturing*		Oogonia, chromatin nucleolar and perinucleolar (pn) oocytes present. Many small to large cortical alveolar (ca) oocytes. Scale = 100 μm.

Table 9.3 cont.

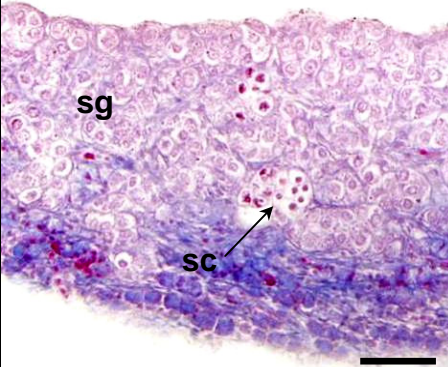| V – *Prespawning* | | Previtellogenic and vitellogenic oocytes present. Cortical alveolar (ca) and yolk granule (y) oocytes abundant and at different stages of development. Ovary tightly packed. Scale = 200 µm. |
VI – *Spawning*		Cortical alveolar oocytes (ca) and yolk granule (y) oocytes abundant, along with a combination of hydrated (h, collapsed) oocytes, migratory nucleus oocytes and/or post-ovulatory follicles (not shown). Scale = 200 µm.
VII – *Spent*		Ovary disorganised, containing cortical alveolar (ca) and yolk granule oocytes. Greater than 50% of those oocytes atretic (a). Scale = 200 µm.
VIII – *Recovering*		Ovarian lamellae disorganised, consisting of chromatin nucleolar (cn) and perinucleolar (pn) oocytes and dark-staining connective tissue (t). Few remnants of atretic (a) oocytes may be present. Scale = 100 µm.
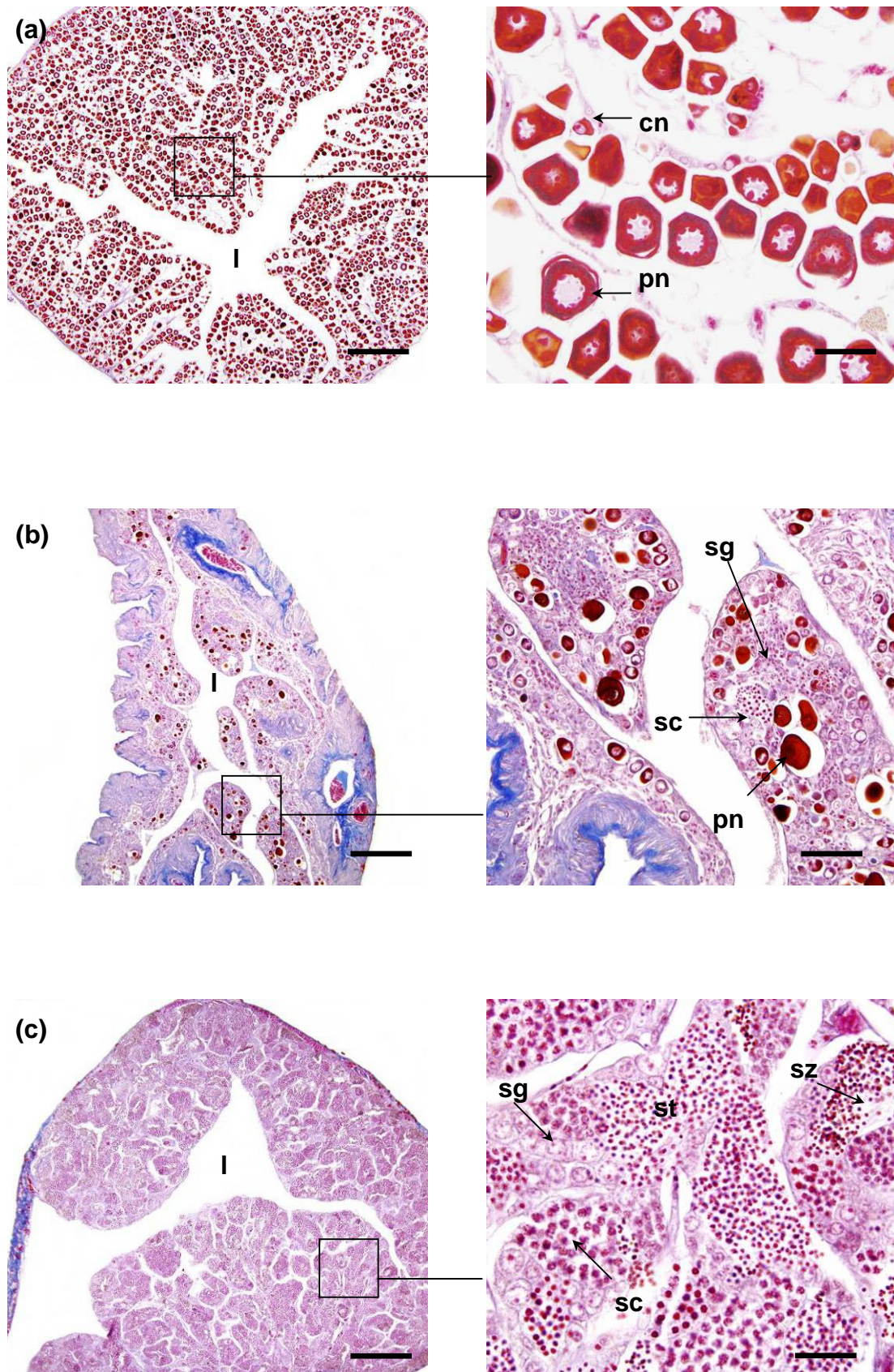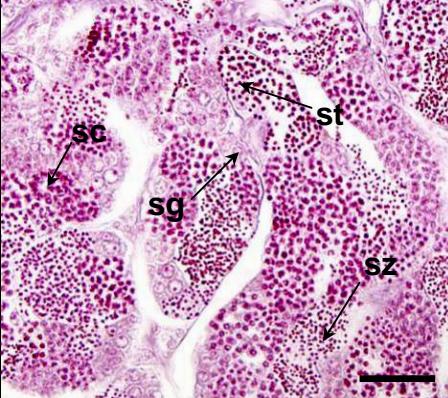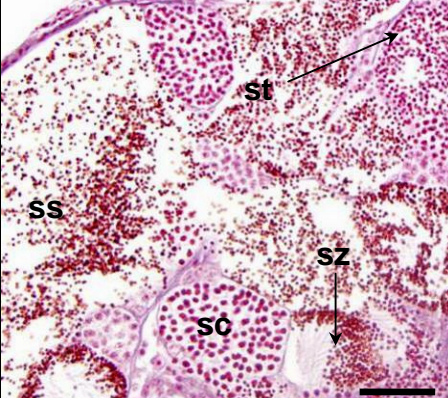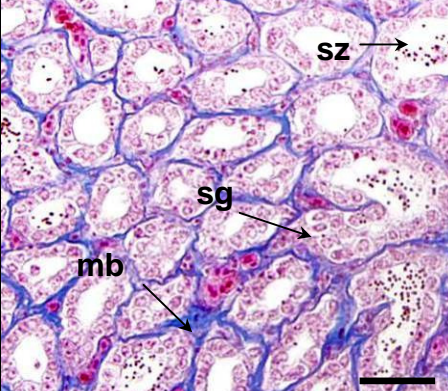
Figure 9.4. Histological section of gonads representing (a) resting females, (b) bisexual individuals and (c) mature/active males of the three labrid species at low (left column) and high (right column) magnification. Low magnification scale bars: (a) 1 mm; (b,c) 200 µm; high magnification scale bars: (a) 100 µm; (b,c) 200 µm. cn, chromatin nucleolar oocyte; pn, perinucleolar oocyte; l, lumen; sg, spermatogonia; sc, spermatocytes; st, spermatids; sz, spermatozoa.

Table 9.4 Histological sections and characteristics of the macroscopic stages of development (from Table 9.2) of the testes of *Coris auricularis*, *Notolabrus parilus* and *Ophthalmolepis lineolatus*. Histological characteristics of each of the stages of development of the testes modified from Rhodes and Sadovy (2002).

Macroscopic stage (from Table 9.2)	Histological sections	Histological characteristics
I – *Inactive/ resting*		Spermatogonia (sg) abundant, some primary and secondary spermatocytes (sc). Scale = 25 µm.
II – *Mature/ active*		Some spermatogonia (sg) present. Spermatocytes (sc) and spermatids (st) abundant in crypts. Some crypts may contain spermatozoa (sz). Secondary spermatocytes, spermatids and spermatozoa represent < 50 % of the volume of the testes. Scale = 25 µm.
III – *Mature/ ripe*		Few spermatogonia and spermatocytes present. Seminiferous lobules extensive and filled with spermatocytes, spermatids (st) and spermatozoa (sz), which are abundant, representing > 50% of the volume of the testes. Spermatozoa visible in sperm sinuses (ss) in the outer wall of the testes. Scale = 25 µm.
IV – *Spent/ recovering*		Sperm sinuses and seminiferous lobules largely empty with little or no spermatozoa (sz). Muscle bundles (mb) abundant and gonad contains early stages of spermatogenic development (spermatogonia, sg). Scale = 25 µm.

Gonadosomatic indices

Mean monthly GSIs of female *C. auricularis* $\geq L_{50m}$ at sexual maturity (see later) increased gradually from *ca* 0.1 in January to *ca* 0.15 in March and then to a peak of *ca* 0.5 in June, before declining precipitously to *ca* 0.1 in July and remaining < 0.1 during the ensuing months (Fig. 9.4a). The mean monthly GSIs of female *N. parilus* $\geq L_{50m}$ were low, *i.e.* < 0.3, between January and June, following which they increased rapidly to *ca* 1.4 in August and *ca* 1.5 in September and then declined precipitously to 0.2 in October. They then remained $< ca$ 0.2 in November and December (Fig. 9.4b). The mean monthly GSIs of female *O. lineolatus* $\geq L_{50m}$ remained < 0.3 between April and August and then increased to *ca* 0.5 in September and to a peak of *ca* 2.5 in October, before declining gradually to *ca* 0.3 in March (Fig. 9.4c). The trends exhibited by the mean monthly GSIs of the males of *C. auricularis*, *N. parilus* and *O. lineolatus* were essentially the same as those of their females (Fig. 9.4). However, the values for the GSIs of their males were substantially smaller than those of their females, indicating the much smaller testis weights in comparison to ovaries.

Analysis of stages of development in ovaries

All females of *C. auricularis* that were $\geq L_{50m}$ and were caught between August and February contained resting ovaries, *i.e.* stage II (Fig. 9.5a; Table 9.2). Female *C. auricularis* $\geq L_{50m}$ that possessed developing ovaries, *i.e.* stages III/IV, were first recorded in March and were found until June (Fig. 9.5a). Female *C. auricularis* with ovaries at stages V/VI, which were thus prespawning or spawning, were collected between April and June and were most abundant in fish caught in the latter month. By July, sexually mature female *C. auricularis* had ovaries that were either spent, recovering or resting, *i.e.* stages VII/VIII or II.
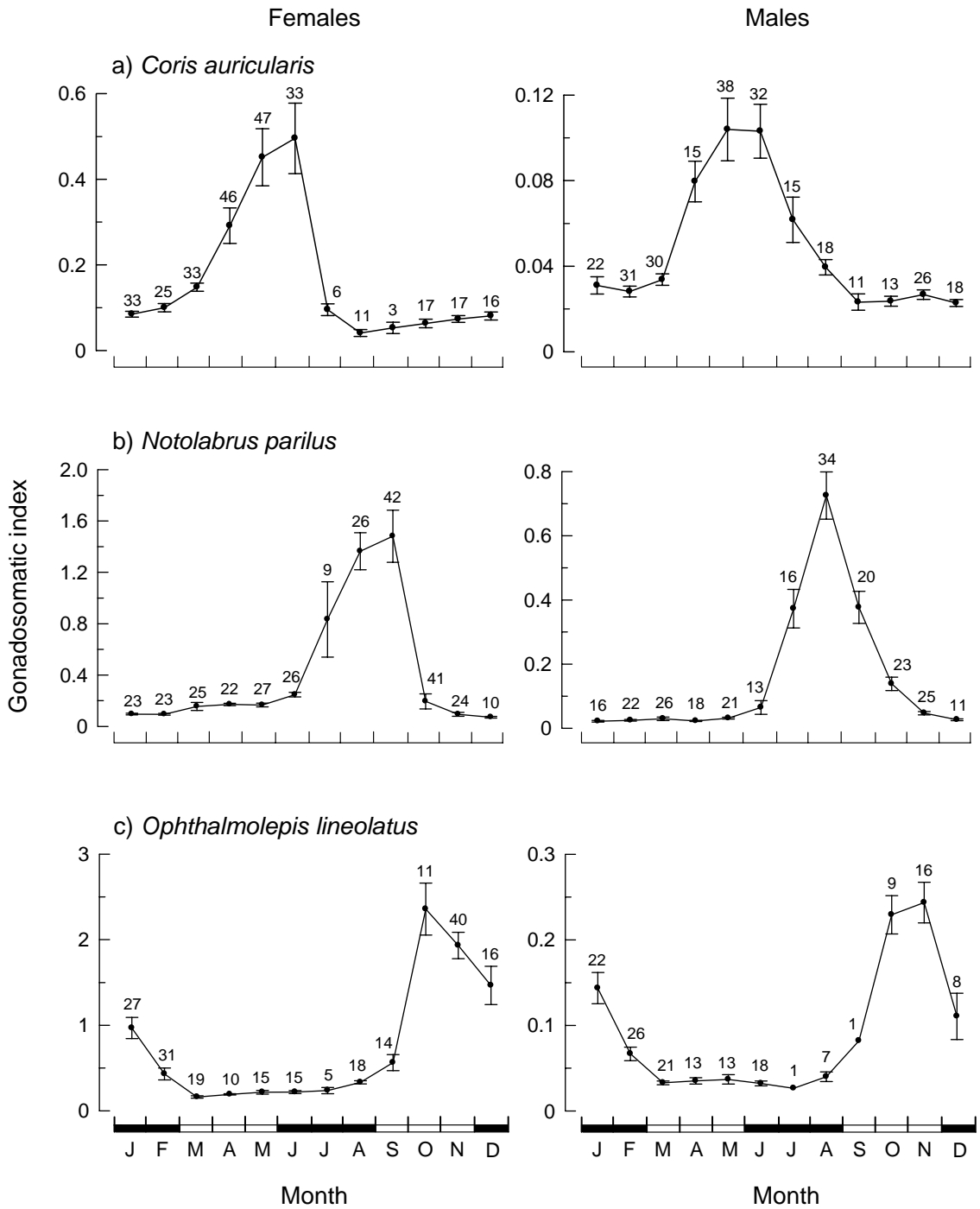
Figure 9.4. Mean monthly gonadosomatic indices ± 1 S. E. for females and males of (a) *Coris auricularis*, (b) *Notolabrus parilus* and (c) *Ophthalmolepis lineolatus*. Data derived from females ≥ their respective lengths at sexual maturity (L_{50m}s), *i.e.* 215, 170 and 181 mm, and from all males collected from reefs in the Jurien Bay Marine Park between January 2005 and October 2007, pooled for each month of the year. Sample sizes (n) are shown above each mean.

The ovaries of all female *N. parilus* that were $\geq L_{50m}$ in length and were caught between December and May were resting, *i.e.* stage II (Fig. 9.5b). Females with developing ovaries, *i.e.* stages III/IV, were collected between June and November. *Notolabrus parilus* females that contained either prespawning ovaries (stage V) or ovaries in spawning condition (stage VI) were collected between July and October, but were most prevalent in August (62 %) and September (60 %), while females with spent/recovering ovaries were caught between September and November.

Females of *O. lineolatus* $\geq L_{50m}$ caught between March and July contained ovaries at stages II, *i.e.* resting (Fig. 9.5c). Female *O. lineolatus* with stages III/IV and V/VI ovaries were present between August and January and September and February, respectively. The majority (> 67 %) of sexually mature female *O. lineolatus* contained ovaries that were either prespawning (stage V) or in spawning condition (stage VI) between October and January. Spent (stage VII) and recovering (stage VIII) ovaries were recorded in low numbers between October and February (Fig. 9.5c).

Lengths and ages at maturity

The months during which ≥ 50 % of the ovaries of female *C. auricularis*, *N. parilus* and *O. lineolatus* were at stages III – VIII, *i.e.* were considered to be sexually mature, and for which the data could thus be used to determine the lengths and ages at sexual maturity, were from April to June, August to October and September to February, respectively (see Fig. 9.5). The minimum lengths at which sexually mature female *C. auricularis*, *N. parilus* and *O. lineolatus* were recorded over reefs were 139, 132, and 164 mm, respectively (Fig. 9.6). The lengths at which 50 % of female *C. auricularis*, *N. parilus* and *O. lineolatus* were sexually mature (L_{50m}) were 215, 170 and 181 mm, respectively (Table 9.5). The majority, *i.e.* > 75 %, of female *C. auricularis*, *N. parilus* and *O. lineolatus* over reefs were mature at lengths > 260, 200
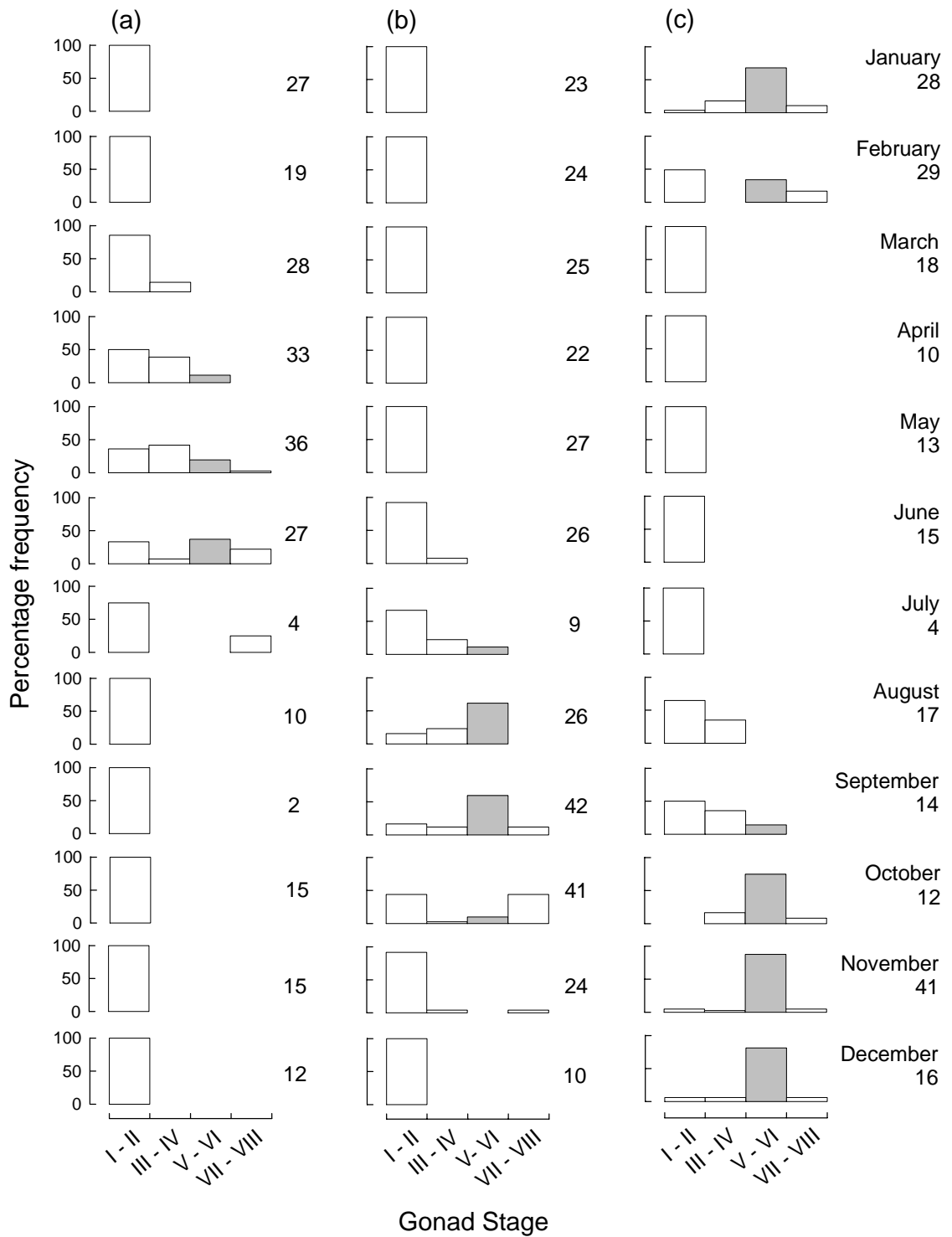
Figure 9.5. Monthly percentage frequencies of occurrence of sequential stages in ovarian development of female a) *Coris auricularis*, b) *Notolabrus parilus* and c) *Ophthalmolepis lineolatus* ≥ their respective lengths at sexual maturity (L_{50m}), *i.e.* 215, 170 and 181 mm, pooled for each month of the year for samples collected from reefs in the Jurien Bay Marine Park between January 2005 and October 2007. Sample sizes (n) are shown for each month on each figure.

Table 9.5. Lengths (L_{50m}, L_{95m}) at sexual maturity and their lower and upper 95 % confidence limits for female *Coris auricularis*, *Notolabrus parilus* and *Ophthalmolepis lineolatus* collected over reefs in the Jurien Bay Marine Park.

		Length (mm)					
	n	L_{50m}	Lower	Upper	L_{95m}	Lower	Upper
Coris auricularis	139	215	202	229	307	274	349
Notolabrus parilus	145	170	158	179	233	211	268
Ophthalmolepis lineolatus	135	181	173	189	230	211	249

and 180 mm, respectively (Fig. 9.6). While *N. parilus* were not collected in seagrass beds at lengths < 120 mm, 77 and 92 % of females were mature in the 120-139 mm and 160-179 mm length classes and all individuals between 180 and 239 mm were mature (data not shown).

The youngest mature females of *C. auricularis*, *N. parilus* and *O. lineolatus* obtained over reefs were two years old (Fig. 9.6). Greater than 50 % of female *C. auricularis*, *N. parilus* and *O. lineolatus* were sexually mature by 4, 3 and 3 years of age, respectively. In seagrass, 60 and 85 % of female *N. parilus* were mature at the ages of 2 and 3 years, respectively, and all females ≥ 4 years were mature (data not shown). Note that no one year old *N. parilus* were obtained while trawling in seagrass.

Lengths and ages at sex change

The smallest male *C. auricularis* from shallow reefs was 186 mm in length (Fig. 9.7a). The percentage of males in consecutive length classes collected over shallow reefs increased progressively from 2 % in the 180-199 mm length class to 55 % in the 240-259 mm length class and to 100 % in all fish ≥ 300 mm in length (Fig. 9.7a). Over deep reefs, the smallest male was 228 mm in length and the percentage of males increased from *ca* 15 % in the 220-239 mm length class to *ca* 63 % in the 260-279 mm length class and to 100 % in all fish ≥ 340 mm (Fig. 9.7b). The lengths at which 50 % of
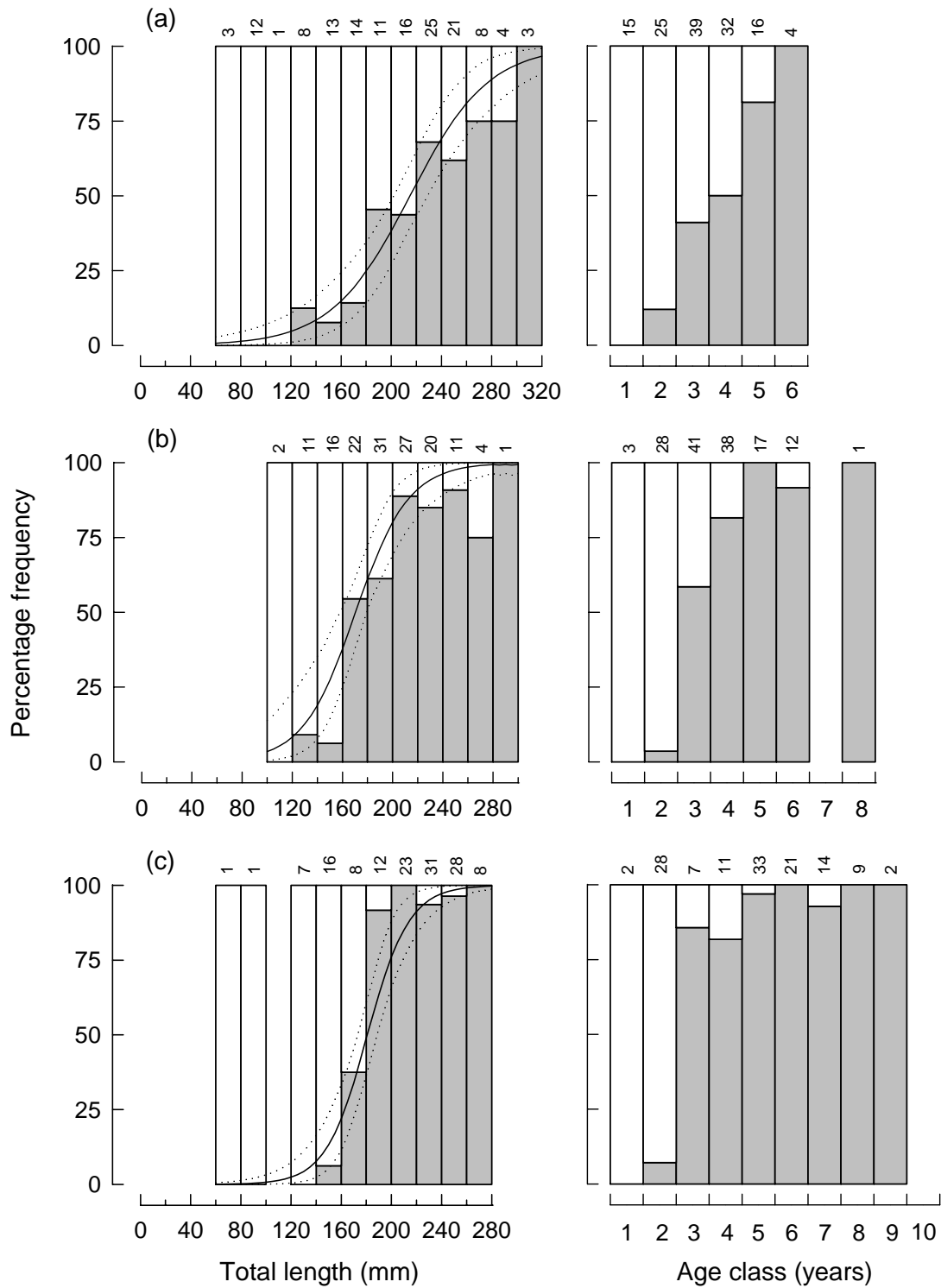
Figure 9.6. Percentage frequencies of occurrence of sexually mature females (grey bars) in each 20 mm length class and each age class for a) *Coris auricularis*, b) *Notolabrus parilus* and c) *Ophthalmolepis lineolatus* during their spawning periods, with the curves predicted using logistic regression analysis on the length and status (immature or mature) of individual fish and from which lengths at sexual maturity were determined (see Table 9.4). Sample sizes (n) shown on each figure.

individuals had changed to males, *i.e.* L_{50c}, derived from logistic regression analyses, were 252.3 and 267.2 mm over shallow and deep reefs, respectively (Table 9.6). A likelihood ratio test demonstrated that the logistic regression equations were significantly different for those two habitats ($p < 0.05$).

The youngest male *C. auricularis* collected over shallow reefs was 3.1 years old (Fig. 9.7a). The percentage frequency of male *C. auricularis* in that habitat increased from *ca* 33 % in the 3+ age class to *ca* 95 % in the 5+ age class and all fish ≥ 6 years of age were male (Fig. 9.7a). The youngest male *C. auricularis* collected over deep reefs was 3.7 years old and the percentage of males in each age class increased more gradually than over shallow reefs, with *ca* 48 % and 100 % of individuals being male in the 5+ age class and that were ≥ 8 years old, respectively (Fig. 9.7b). The ages at which 50 % of individuals of *C. auricularis* had changed sex to male (A_{50c}) over shallow and deep reefs were 4.1 and 5.4 years, respectively (Table 9.6). A likelihood ratio test found that the logistic regression equations for those two habitats were significantly different ($p < 0.05$).

The smallest male *N. parilus* from shallow reefs was 167 mm in length (Fig. 9.8a). The percentage of males collected over shallow reefs increased from *ca* 1.6 % in the 180 – 199 mm length class to *ca* 44 % in the 220-239 mm length class and all fish ≥ 280 mm were males (Fig. 9.8a). Over deep reefs, the smallest male *N. parilus* was 162 mm in length. The percentage of males increased from *ca* 3 % in the 160-179 mm length class to *ca* 74 % for fish in the 240-259 mm length class and all fish ≥ 300 mm were male (Fig. 9.8b). The lengths at sex change (L_{50c}) of *N. parilus* in shallow and deep reef habitats were 236.0 and 236.1 mm, respectively, (Table 9.6) and the logistic curves derived from the percentage of males at each length in those two habitats were not significantly different ($p > 0.05$). Thus, the length at sex change data for *N. parilus*

Figure 9.7. Percentage frequencies of occurrence of female (white bars) and male individuals (grey bars) in each length and age class for *Coris auricularis* in a) shallow reefs and b) deep reefs. The logistic curve (solid line) and its 95 % confidence intervals (dotted lines) were derived using logistic regression analysis of the length (left-hand side) and age (right-hand side) and sex of individual fish. Sample sizes (n) shown on each figure.

from the two reef habitats were pooled and the L_{50c} derived from the combined data set

was 236.4 mm (Fig. 9.8c, Table 9.6).

The youngest male *N. parilus* collected over shallow reefs was 2.1 years old.

The percentage frequency of male *N. parilus* from shallow reefs increased from *ca* 2 %

in the 2+ age class to *ca* 65 % in the 5+ age class and all fish ≥ 8 years old were male

(Fig. 9.8a). Over deep reefs, the youngest male *N. parilus* was 3.2 years old and the

percentage of males in each age class increased from *ca* 4 % in the 3+ age class to *ca*

49 % in the 5+ age class and all fish ≥ 9 years of age were males (Fig. 9.8b). The ages at

which 50 % of individuals of *N. parilus* caught over shallow and deep reefs changed to

male (A_{50c}) over shallow and deep reefs were 5.3 and 5.6 years, respectively (Table 9.6).

Logistic curves fitted to the percentage of male *N. parilus* at each age in shallow and

deep reefs were not significantly different (likelihood ratio test, $p > 0.05$). Thus, data for

the ages of females and males of *N. parilus* from the two habitats were pooled and the

A_{50c} derived from a logistic curve fitted to the percentage of males at each age in the

combined data set was 5.4 years (Fig. 9.8c, Table 9.6).

The smallest male *N. parilus* from seagrass was 124 mm long (Fig. 9.8d). The

percentage of male *N. parilus* increased from *ca* 7 % in the 100 – 119 mm length class

to *ca* 61 % in the 200 – 219 mm length class and to 100 % by 240 mm (Fig. 9.8d). The

length at which 50 % of individuals in seagrass had changed to males, *i.e.* L_{50c}, was

203.3 mm (Table 9.6). The youngest male *N. parilus* in seagrass was 1.9 years old and

the percentage of male *N. parilus* caught in seagrass increased from *ca* 5 % in the 1+

age class to *ca* 65 % in the 4+ age class and to 100 % by 6 years of age (Fig. 9.8d). The

ages at which 50% of individuals of *N. parilus* from seagrass habitats had changed sex

to male (A_{50c}) was 4.4 years old (Table 9.6). The logistic curves fitted to the percentages

of male *N. parilus* at each length and age in seagrass were significantly different from

the corresponding curves fitted to the data for reef habitats (Likelihood ratio test, p

0.05).

The smallest male *O. lineolatus* was 223 mm in length and the youngest male

was 4.7 years old (Fig. 9.9). The percentage frequency of male *O. lineolatus* increased

from *ca* 4 % in the 220-239 mm length class to *ca* 85 % in the 260-279 mm length class

and to 100 % for all fish $\geq$ 280 mm. The length at which 50 % of individuals were male

(L_{50c}) was 254.2 mm (Fig. 9.9; Table 9.6). The percentage of males increased

progressively from *ca* 4 % in the 4+ age class to *ca* 70 % in the 7+ age class and only

reached 100 % in the oldest age class, *i.e.* 10+ (Fig. 9.9). The age at which 50 % of
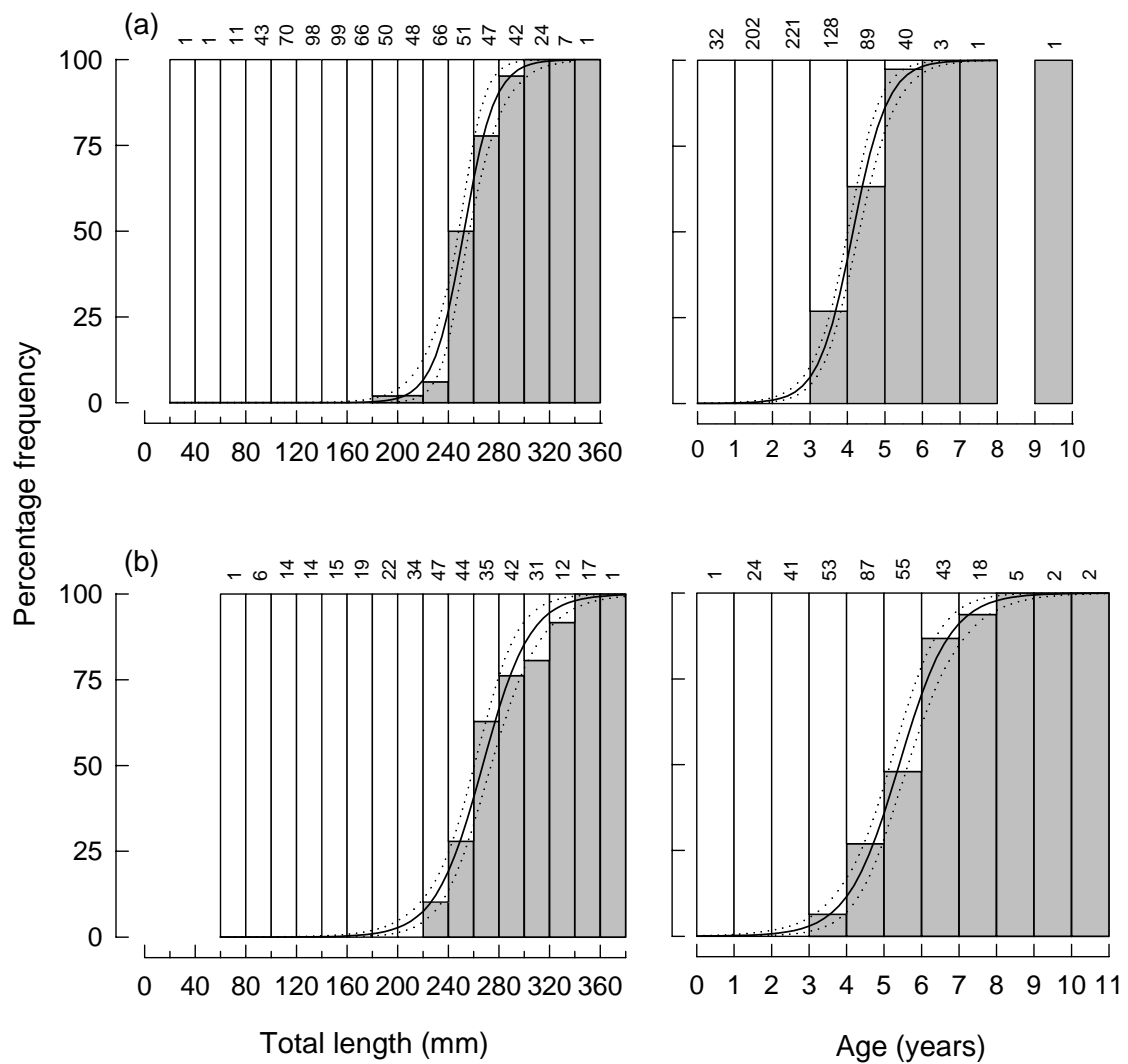
O. lineolatus were male was 7.1 years (Table 9.6).

Figure 9.8. Percentage frequencies of occurrence of female (white bars) and male individuals (grey bars) in each length and age class for *Notolabrus parilus* in a) shallow reefs, b) deep reefs, c) all reefs and d) shallow seagrass. The logistic curve (solid line) and its 95 % confidence intervals (dotted lines) were derived using logistic regression analysis for the length (left-hand side) and age (right-hand side) and sex of individual fish. Sample sizes (n) shown on each figure.

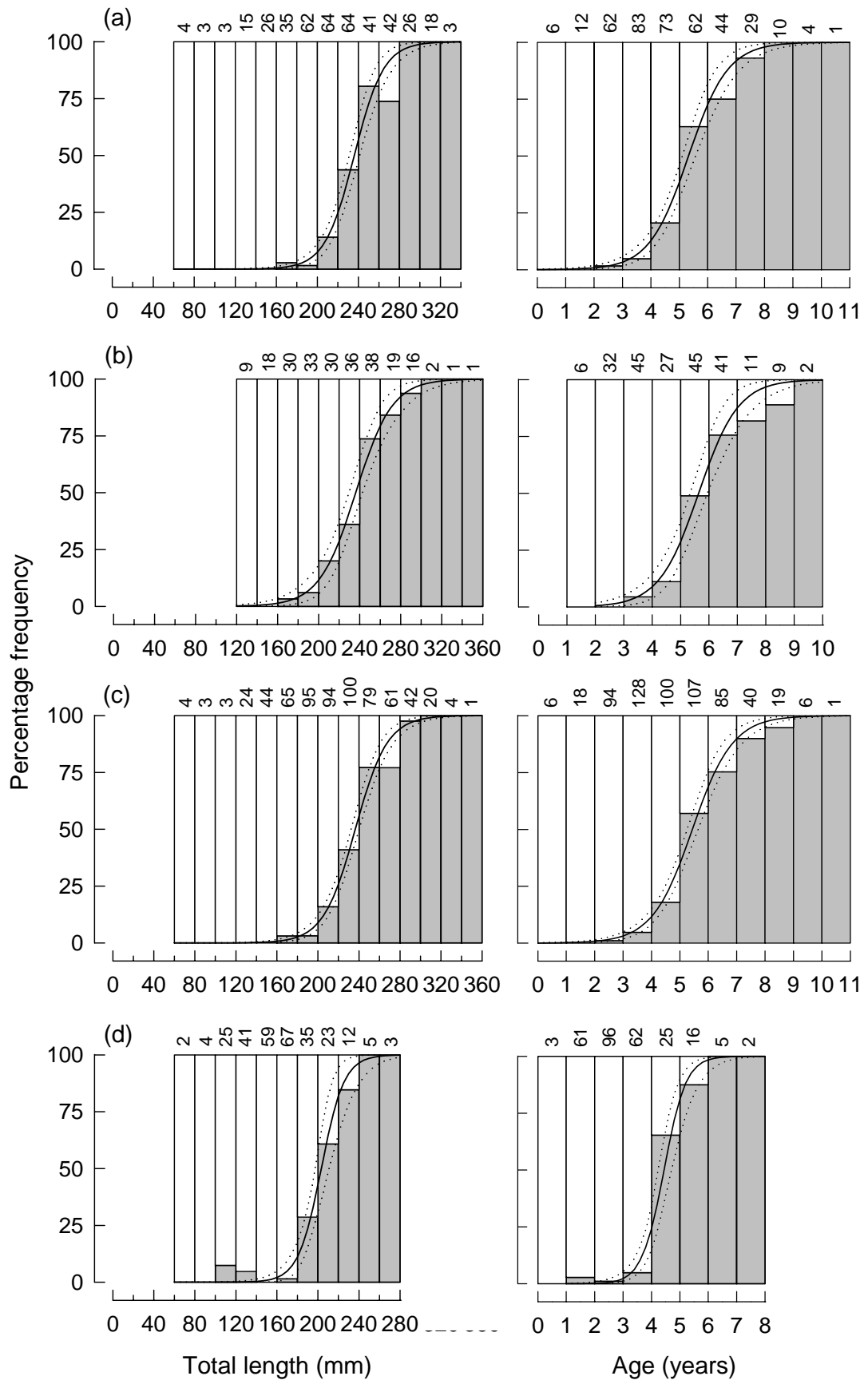**Figure 9.9.** Percentage frequencies of occurrence of female (white bars) and male individuals (grey bars) in each length and age class for *Ophthalmolepis lineolatus*. The logistic curve (solid line) and its 95 % confidence intervals (dotted lines) were derived using logistic regression analysis for the length (left-hand side) and age (right-hand side) and sex of individual fish. Sample sizes (n) shown on each figure.
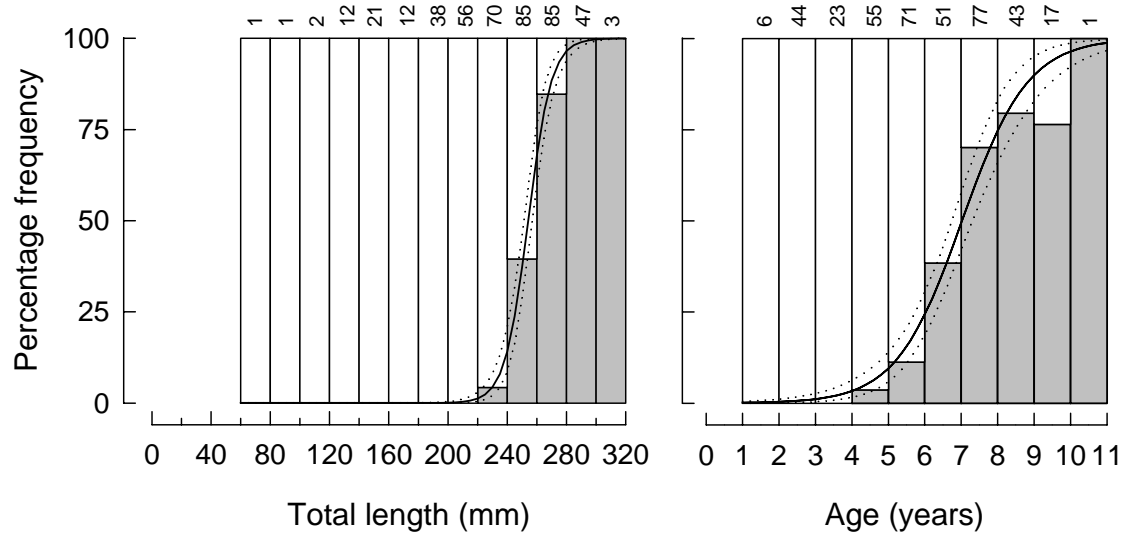
Table 9.6. Lengths (L_{50c}, L_{95c}, $\pm\,95\%$ CI) and ages (A_{50c}, A_{95c}, $\pm\,95$ % C.I.) at sex change of *Coris auricularis*, *Notolabrus parilus* and *Ophthalmolepis lineolatus* in different habitats in the Jurien Bay Marine Park, derived using logistic regression analyses of the percentage of bisexual and male individuals at each length and age, respectively.

	Length (mm)						Age (years)						
	n	L_{50c}	- 95 %	+ 95 %	L_{95c}	- 95 %	+ 95 %	n	A_{50c}	- 95 %	+ 95 %	A_{95c}	- 95 %	+ 95 %
Coris auricularis														
Shallow reef	734	252.3	248.4	256.5	288.5	275.9	301.6	726	4.1	4.0	4.3	5.5	5.2	5.8
Deep reef	358	267.2	260.5	273.8	321.8	307.9	335.9	335	5.4	5.2	5.7	7.5	7.0	8.0
Notolabrus parilus														
Shallow reef	400	236.0	231.2	241.3	278.1	267.1	289.9	386	5.3	5.1	5.6	7.4	6.8	7.9
Deep reef	233	236.1	229.7	242.7	288.2	273.0	306.6	218	5.6	5.3	5.9	7.7	7.0	8.5
Shallow and deep reefs combined	639	236.4	232.4	240.3	282.5	273.4	290.9	604	5.4	5.3	5.6	7.5	7.1	8.0
Shallow seagrass	280	203.3	197.2	210.8	236.0	221.1	255.3	275	4.4	4.2	4.7	5.6	5.3	6.2
Ophthalmolepis lineolatus														
Deep reef	435	254.2	251.3	256.9	277.0	272.3	281.8	390	7.1	6.8	7.4	9.7	9.0	10.5

9.3.2 Ageing studies

Validation of growth zone formation in sectioned otoliths

The smallest *Coris auricularis*, of 28 mm in length, was collected in November and its otoliths were very small and contained a diffuse opaque primordium and core (Fig. 9.9a). The otoliths of small individuals (53 - 65 mm) collected in February also contained an opaque primordium and diffuse opaque core. However they also comprised a narrow translucent edge (Fig 9.9 b). As the average birth date of this species is 1 June (see section 9.3.2), those small fish had presumably formed the opaque primordium and core and translucent periphery in the immediately ensuing cold winter/early spring and warmer spring/summer months, respectively, after birth and were thus *ca* 5 and 8 months old, respectively, at the date of capture (Fig. 9.9a). The otoliths of other individuals in the corresponding cohort (67 – 124 mm) in the immediately ensuing months (March to November) also did not contain any opaque annuli in their otoliths. The first delineated opaque zones in the otoliths of *C. auricularis* were detected in December, when the fish collected were 98 - 115 mm in length and thus *ca* 18 months old (Fig. 9.9c).

The mean monthly marginal increments in the otoliths of *C. auricularis* with one opaque zone rose from a minimum of 0.03 in March to a maximum of 0.35 in November and then subsequently declined (Fig. 9.10). The mean monthly marginal increments for otoliths of *C. auricularis* with 2-3, 4-5 and ≥ 6 opaque zones followed a similar pattern, *i.e.* rose from their minima of *ca* 0.2-0.3 in March to their maxima of *ca* 0.8-0.9 in October and November and then declined (Fig. 9.10). This single distinct rise and fall in the mean marginal increments in a calendar year for fish with different numbers of opaque zones in their otoliths indicates that an opaque zone is formed annually in the otoliths of *C. auricularis* throughout life and that the numbers of those opaque zones can thus be used for ageing individuals of this species.
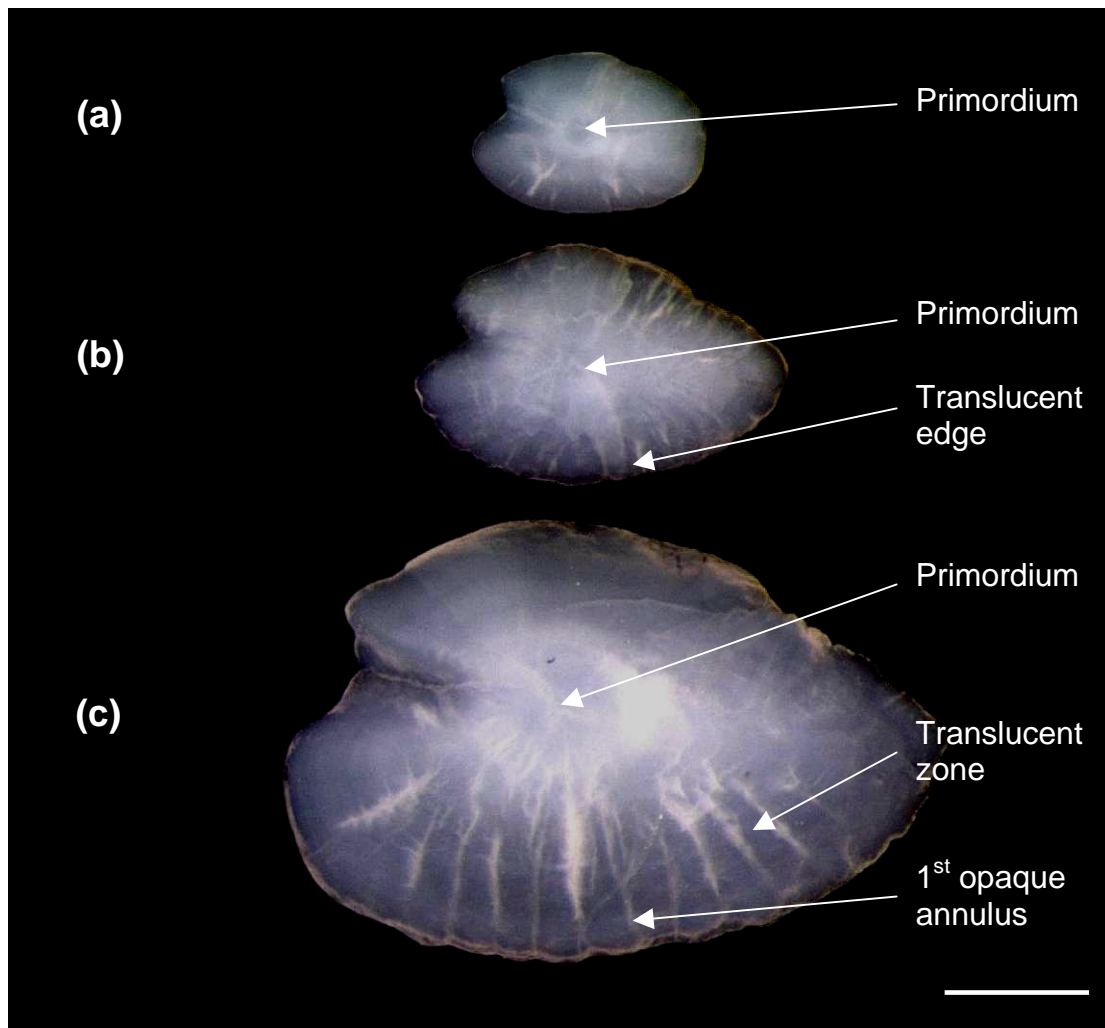
Figure 9.9. A whole otolith of a (a) 28 mm *Coris auricularis* caught in November with an opaque core and no opaque annuli, (b) 53 mm *C. auricularis* caught in February with a narrow translucent edge and no opaque annuli and (c) 115 mm *C. auricularis* caught in December with the 1st opaque annulus visible at the otolith edge, having recently delineated. Scale bar = 500 µm.

The otoliths of small *N. parilus* (68 – 74 mm), which were collected in February, had a small opaque core and a large translucent edge and contained no opaque annuli. The large translucent zone had presumably formed in the warm months immediately after birth (1st September) and prior to capture in February. Thus, those individuals would be *ca* 5 months old (see section 9.3.2). The otoliths of other individuals in the corresponding cohort that were collected in the ensuing months also did not contain any opaque annuli in their otoliths. The first annulus became delineated in otoliths by approximately February in the second summer of life, when the fish collected were 101 - 139 mm in length and *ca* 16 months old.

Figure 9.10. Mean monthly marginal increments ±1 S.E. in sectioned otoliths of *Coris auricularis* collected in the Jurien Bay Marine Park between January 2005 and June 2007. Samples are pooled for each calendar month and sample sizes are shown above each mean.

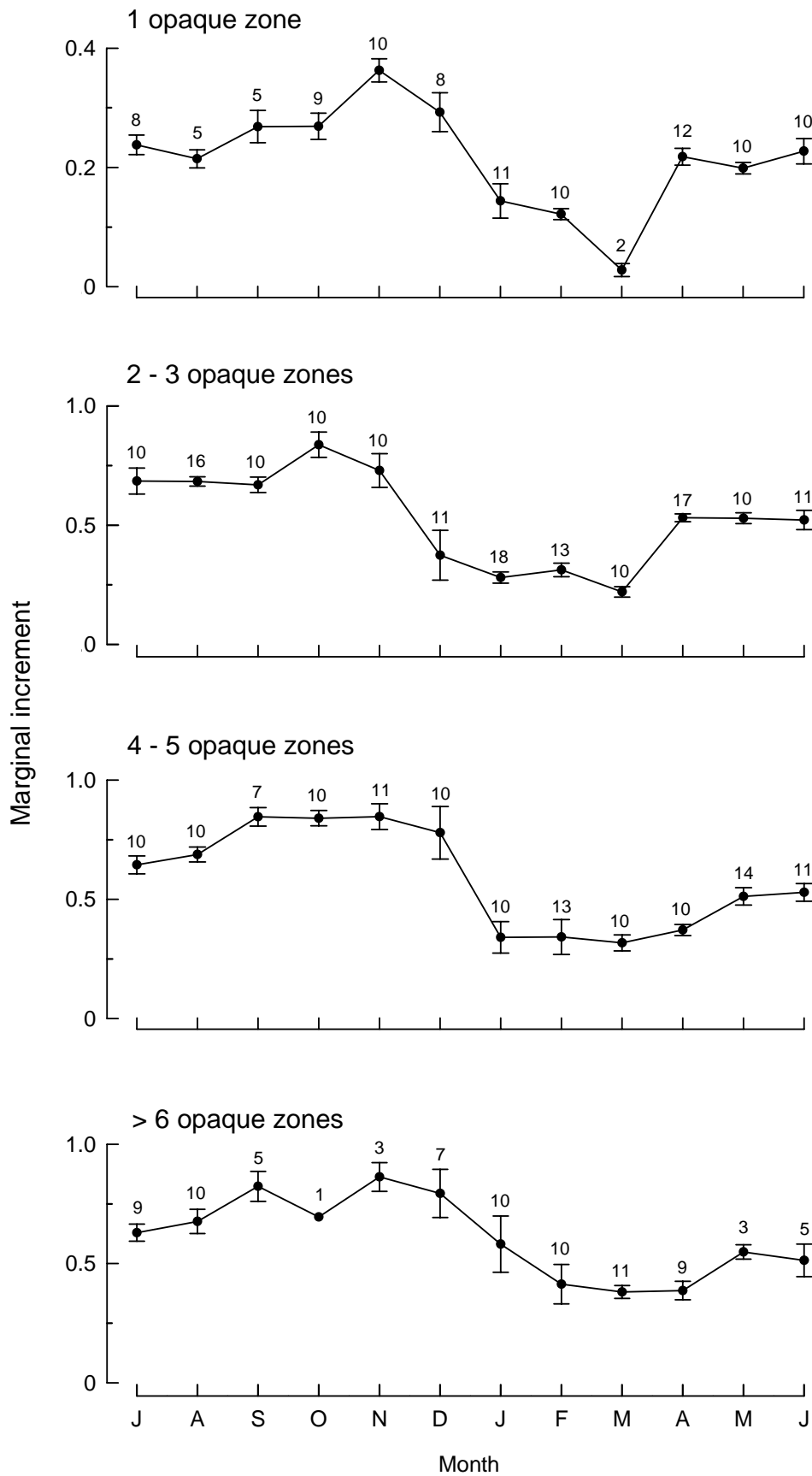The smallest *O. lineolatus*, which was 77 mm in length, was collected in January. The otoliths of this fish contained a small opaque core followed by a large translucent centre and one opaque annulus on the edge of the otolith, which would have thus recently delineated. The large translucent centre and single opaque zone would have formed during the warm and cold months immediately ensuing birth (based on the average birth date of 1 November, see section 9.3.2) when this fish was thus *ca* 14 months old. The otoliths of other individuals in the corresponding cohort in subsequent months also had a delineated opaque annulus on the edge of the otolith.

Length and age frequency compositions in different habitats

The lengths of female *C. auricularis* collected over shallow and deep reefs ranged from 28 - 295 and 70 - 329 mm, respectively, while the males occurred only in the upper length classes and ranged from 186 - 352 and 228 - 365 mm in those two habitats, respectively (Fig. 9.11a, b). Two bisexual juveniles (89 and 90 mm) were collected over shallow reefs, while larger bisexual individuals were of intermediate length and ranged from 202 to 275 mm (Fig. 9.11a, b). Separate Kolmogorov-Smirnov (KS) tests for *C. auricularis* identified to be female and male demonstrated that the length-frequency distributions of each sex, that were collected only by line fishing in shallow and deep reef habitats and thus provided comparable data sets, were significantly different ($p < 0.05$) among habitats, reflecting a greater frequency of occurrence of females and males in the larger length classes over deep reefs (Fig. 9.11).

Female *C. auricularis* from the shallow and deep reefs ranged from 0.5 - 5.2 and 0.8 - 7.6 years old, respectively, while the males ranged from 3.1 - 9.2 and 3.7 - 10.5 years old, respectively (Fig. 9.11a, b). The two small bisexual juveniles (89-90 mm) belonged to the 0+ age class and were collected from the shallow reefs, while the larger bisexual individuals (202-275 mm) were collected from both water depths and were

Figure 9.11. Length and age frequency compositions of female (white bars), bisexual (numbers above white bars denote bisexual individuals in those length and age classes) and male (black bars) *Coris auricularis* collected by line and spear fishing and trapping over (a) shallow and (b) deep reefs of the Jurien Bay Marine Park between January 2005 and October 2007. Sample sizes (n_f, females; and n_m, males) are shown on each figure.

intermediate in age, ranging from 2.6 – 6.7 years old (Fig. 9.11a). The age frequency distributions of both female and male *C. auricularis* over shallow reefs were significantly different from those over the deep reefs (KS test; $p < 0.001$), as indicated by the greater frequency of occurrence of older females and males over deep reefs (Fig. 9.11).

The lengths of female *N. parilus* collected over shallow and deep reefs ranged from 68 - 278 and 126 - 290 mm, respectively, while males were restricted to the upper length classes and in those two habitats and ranged from 167 - 331 and 162 - 346 mm, respectively (Fig. 9.12a, b). The pattern exhibited by the age-frequency distributions of female and male *N. parilus* parallelled those of their length- frequency distributions.
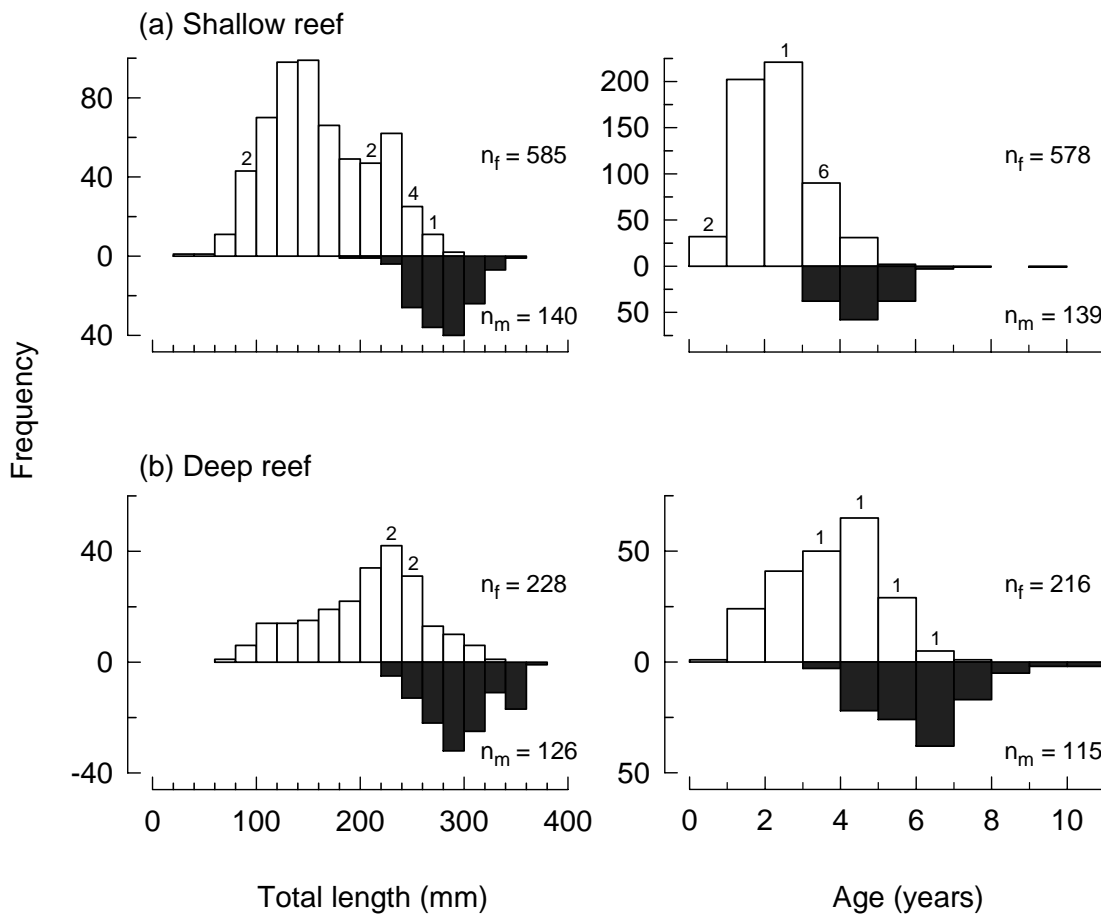
Figure 9.12. Length and age frequency compositions of female (white bars), bisexual (numbers above white bars denote bisexual individuals in those length and age classes) and male (black bars) *Notolabrus parilus* collected by line and spear fishing and trapping over (a) shallow and (b) deep reefs and (c) by trawling in seagrass of the Jurien Bay Marine Park between January 2005 and October 2007. Sample sizes (n_f, females; and n_m, males) are shown on each figure.

Thus, the females of *N. parilus* from the shallow and deep reefs ranged from 0.5 - 7.9

and 1.6 - 8.3 years old, respectively, while the males ranged from 2.1 - 10.4 and 3.2 -

9.2 years old, respectively (Fig. 9.12a, b). The length and age frequency distributions of

the females and males of *N. parilus* collected over shallow reefs were not significantly

different from those of the corresponding sex over deep reefs (KS test; $p > 0.05$).

Female *N. parilus* caught in shallow seagrass ranged from 62 - 238 mm in length and

0.7 - 5.3 years of age, while males ranged from 124 - 272 mm and 1.9 - 7.7 years (Fig.

9.12c). Thus the maximum lengths and ages of females and males caught in seagrass were smaller than those from reef habitats. Three bisexual individuals were collected ranging from 107 to 135 mm and were between 1.3 and 2.1 years old (Fig. 9.12c).

Female *O. lineolatus* collected over deep reefs ranged from 77 - 275 mm in length, while male *O. lineolatus* only occurred in the upper length classes in that habitat and had a relatively small length range of 223 - 310 mm (Fig. 9.13). Female *O. lineolatus* were recorded in almost all age classes, ranging from 1.3 - 9.7 years old (Fig. 9.13), while the males ranged from 4.7 - 10.4 years old. The two bisexual *O. lineolatus* caught were of intermediate length (225 and 251 mm) and age (6.3 and 8.3 years old) (Fig. 9.13).
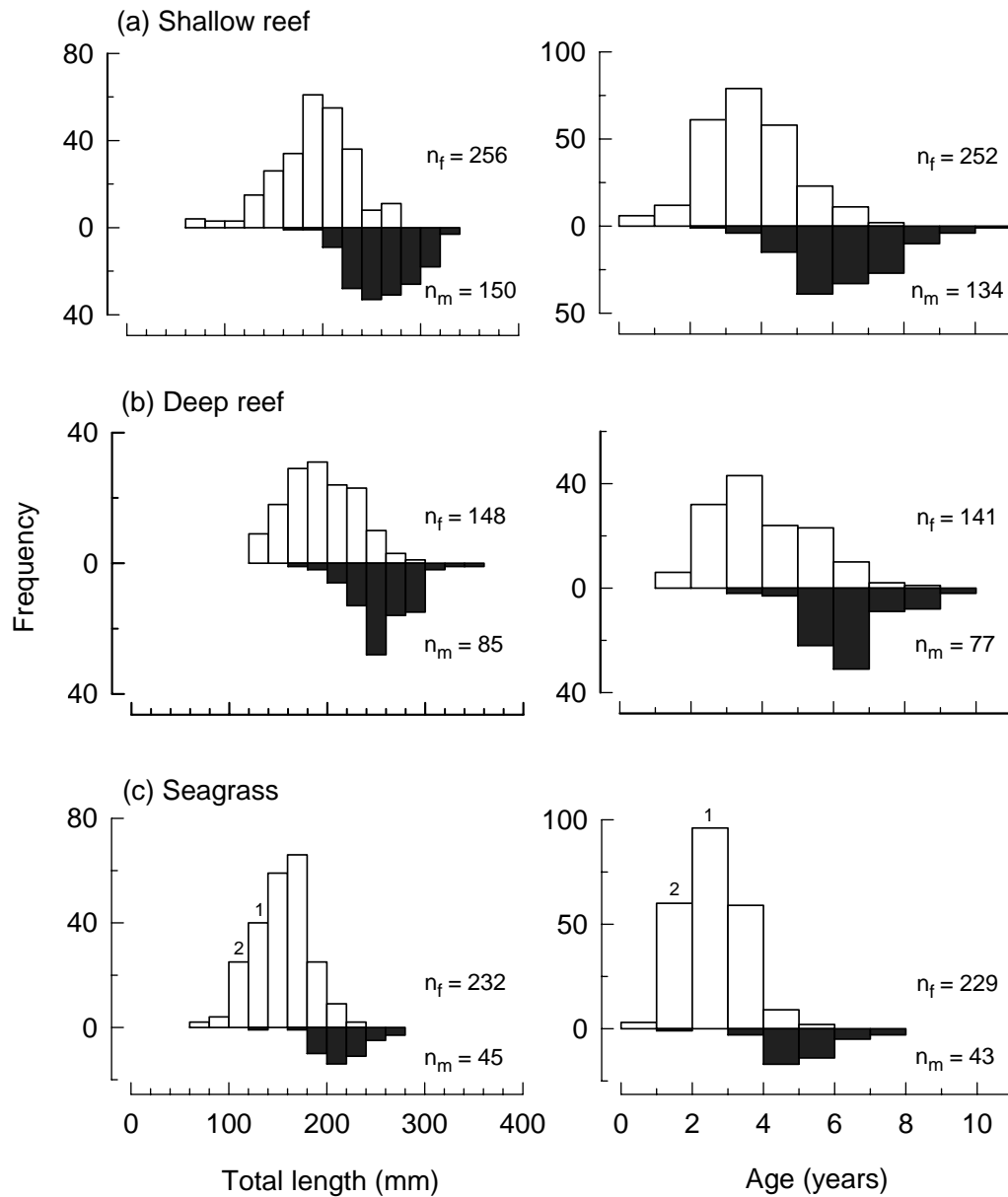

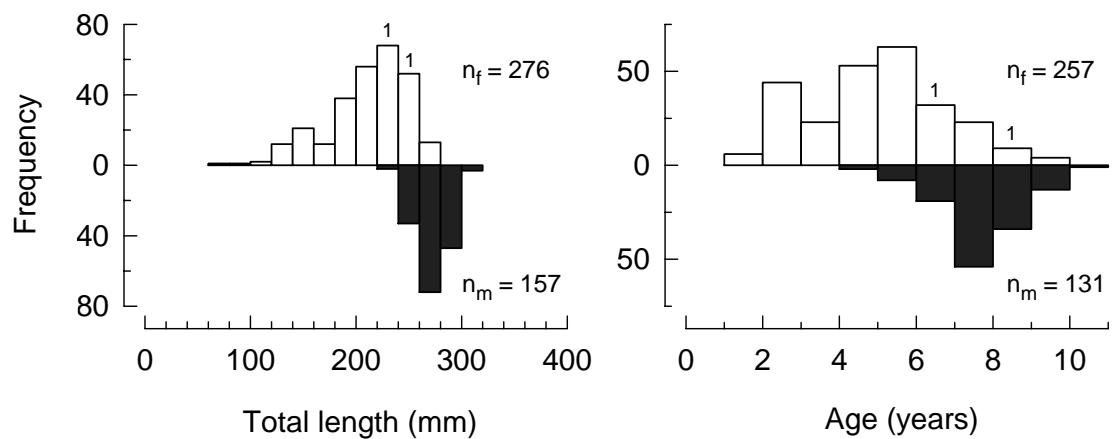**Figure 9.13.** Length and age frequency compositions of female (white bars), bisexual (numbers above white bars denote bisexual individuals in those length and age classes) and male (black bars) *Ophthalmolepis lineolatus* collected by line and spear fishing over deep reefs of the Jurien Bay Marine Park between January 2005 and October 2007. Sample sizes (n_f, females; and n_m, males) are shown on each figure.

Growth

The separate von Bertalanffy growth curves fitted to the lengths at age of *C. auricularis* caught over shallow and deep reefs provided good fits to those data, as demonstrated by their high coefficients of determination (Fig. 9.14 a, b; Table 9.6) and residual plots (not shown). The asymptotic length (L_∞) was greater for fish collected over shallow reefs (460 mm) than over deep reefs (397 mm), whereas the reverse applied to the growth coefficient (*k*), *i.e.* 0.19 *vs* 0.21 year^{-1} and the von Bertalanffy growth curves were significantly different (Likelihood ratio test; $p < 0.01$) (Table 9.6, Fig. 9.14c). On the basis of the von Bertalanffy growth equation, *C. auricularis* caught over shallow reefs at ages 1, 5 and 9 years attain, on average, lengths of 78, 284 and 379 mm, respectively, while those caught over deep reefs attain lengths, on average, of 67, 257 and 338 mm, respectively. Males reached larger lengths and older ages than the females in both habitats.

High values for the coefficients of determination and residual plots (data not shown) demonstrated that the separate von Bertalanffy growth curves fitted to the lengths at age of *N. parilus* caught over shallow and deep reefs provided good fits to those data (Fig. 9.15 a, b; Table 9.6). The asymptotic length (L_∞) was slightly greater for *N. parilus* caught over deep reefs (381 mm) than over shallow reefs (326 mm), whereas the reverse applied to *k*, *i.e.* 0.14 *vs* 0.22 year^{-1} (Table 9.6). However, the von Bertalanffy growth curves were not significantly different ($p > 0.05$), thus a composite von Bertalanffy growth curve was produced for the lengths at age of *N. parilus* from both reef habitats (Fig. 9.15c, Table 9.6). For the pooled data, *N. parilus* at ages 1, 5 and 10 years, on average, attain lengths of 103, 230 and 297 mm, respectively. Male *N. parilus* reached larger lengths and older ages than their females.

Figure 9.14. Composite von Bertalanffy growth curves fitted to the lengths at age of female (white circles), bisexual (black circles) and male (grey circles) *Coris auricularis* collected over (a) shallow reef, (b) deep reef and (c) both reef habitats in the Jurien Bay Marine Park. Sample sizes (n) shown on each figure.

Table 9.6. von Bertalanffy growth curve parameters, L$_\infty$, k and t_0 (in bold ± 95% CIs in parentheses), for *Coris auricularis*, *Notolabrus parilus* and *Ophthalmolepis lineolatus* collected in different habitats in the Jurien Bay Marine Park. r^2 is the coefficient of determination and n is the sample size.

		von Bertalanffy parameters			
	L_∞ (mm)	k (year^{-1})	t_0 (years)	r^2	n
Coris auricularis					
All reef	**377**	**0.26**	**0.11**	**0.88**	**1047**
	(360, 395)	(0.23, 0.28)	(0.01, 0.21)		
Shallow reef	**460**	**0.19**	**0.04**	**0.89**	**726**
	(412, 506)	(0.16, 0.23)	(-0.08, 0.20)		
Deep reef	**397**	**0.21**	**0.13**	**0.86**	**335**
	(362, 432)	(0.17, 0.26)	(-0.14, 0.40)		
Notolabrus parilus					
All reef	**336**	**0.2**	**-0.85**	**0.79**	**604**
	(312, 361)	(0.16, 0.24)	(-1.22, -0.47)		
Shallow reef	**326**	**0.22**	**-0.70**	**0.80**	**386**
	(303, 349)	(0.18, 0.27)	(-1.08, -0.33)		
Deep reef	**381**	**0.14**	**-1.29**	**0.78**	**218**
	(285, 478)	(0.06, 0.22)	(-2.24, -0.19)		
Seagrass	**266**	**0.27**	**-0.68**	**0.84**	**275**
	(242, 290)	(0.21, 0.34)	(-1.01, -0.35)		
Ophthalmolepis lineolatus					
Deep reef	**296**	**0.27**	**-0.34**	**0.79**	**390**
	(282, 311)	(0.22, 0.32)	(-0.75, 0.07)		

The von Bertalanffy growth curve fitted to the lengths at age of *N. parilus* collected by trawling in seagrass habitats (Fig. 9.16a) had a smaller asymptotic length (*L$_\infty$*), *i.e.* 266 mm, than that of the data for the shallow and deep reef habitats combined (336 mm), while the growth coefficient (*k*) was greater, *i.e.* 0.20 *vs* 0.27 year^{-1} (Fig. 9.16b, Table 9.6). Note that a likelihood ratio test was not used to test for differences in the lengths at age of *N. parilus* in seagrass *vs* reef habitats, as fish were caught using two different methods in each habitat, which have different selectivities. On average, at ages, 1, 5 and 7 years, this species in seagrass attains lengths of 98, 210 and 233 mm, respectively.
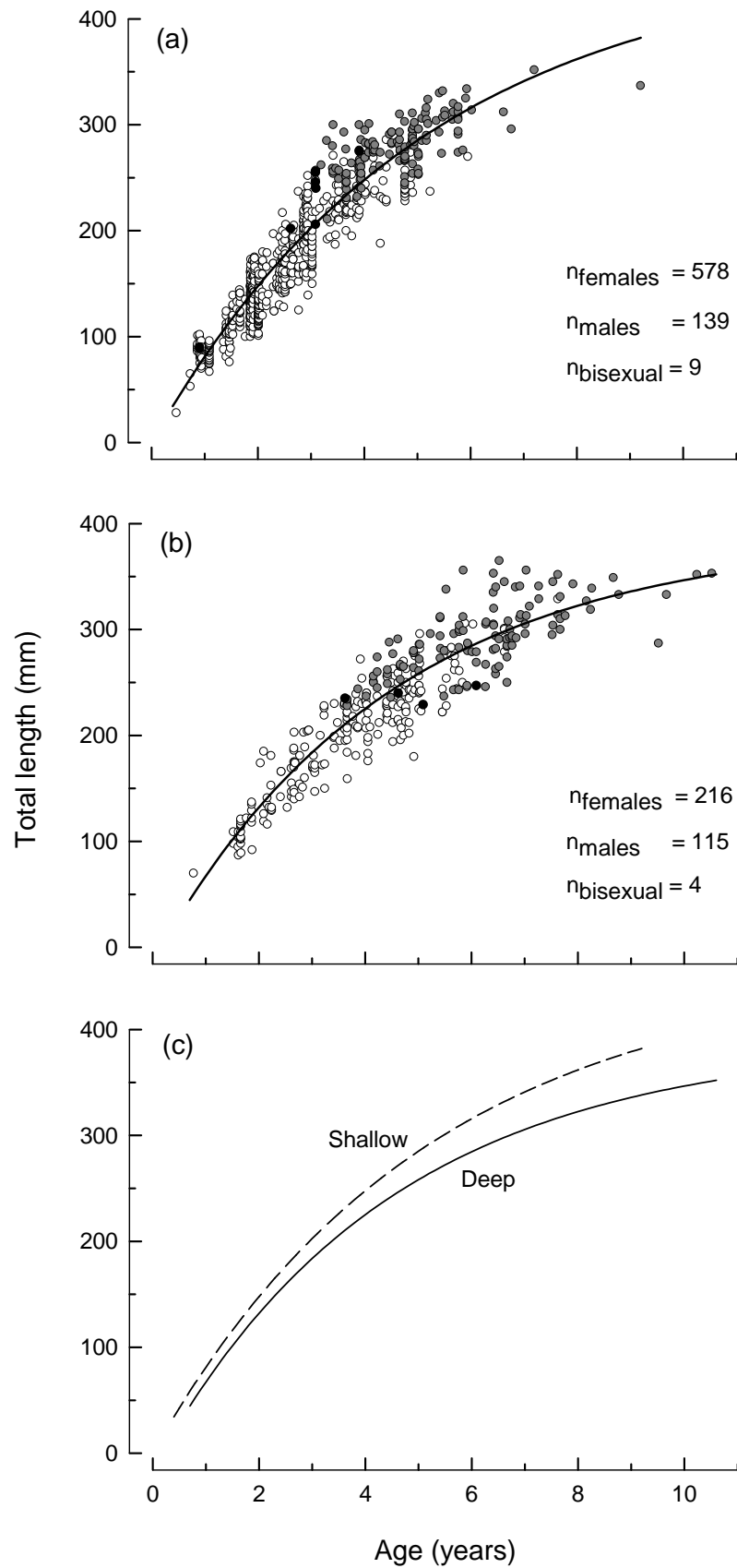
Figure 9.15. Composite von Bertalanffy growth curves fitted to the lengths at age of female (white circles), bisexual (black circles) and male (grey circles) *Notolabrus parilus* collected over (a) shallow reef, (b) deep reef and (c) both reef habitats combined in the Jurien Bay Marine Park. Sample sizes (n) shown on each figure.

Figure 9.16. Composite von Bertalanffy growth curves fitted to the lengths at age of female (white circles), bisexual (black circles) and male (grey circles) *Notolabrus parilus* in (a) seagrass and (b) shallow and deep reefs combined and seagrass in the Jurien Bay Marine Park. Sample sizes (n) are shown for seagrass.

The von Bertalanffy growth curve fitted to the composite length at age data of female, bisexual and male individuals of *O. lineolatus* collected over deep reefs provided a good fit to those data (Table 9.6; residuals plot not shown). The asymptotic length (L_∞) was 296 mm and the growth coefficient (k) was 0.27 year^{-1} (Fig. 9.17a; Table 9.6). Based on this growth curve, individuals of *O. lineolatus* would have reached average lengths of 89, 225 and 278 mm by 1, 5 and 10 years of age. The mean length at age of males at

any particular age was greater than that of females (not shown). However, females reached essentially the same maximum age as males.

von Bertalanffy growth curves fitted to length at age data for *C. auricularis* that were caught over deep reefs, *N. parilus* over both shallow and deep reefs and *O. lineolatus* over deep reefs demonstrated that, while all three species reached similar maximum ages, the growth curves indicated that *C. auricularis* reached larger lengths at the different ages than both *N. parilus* and *O. lineolatus*. The latter two species had similar maximum lengths at age (Fig. 9.18).
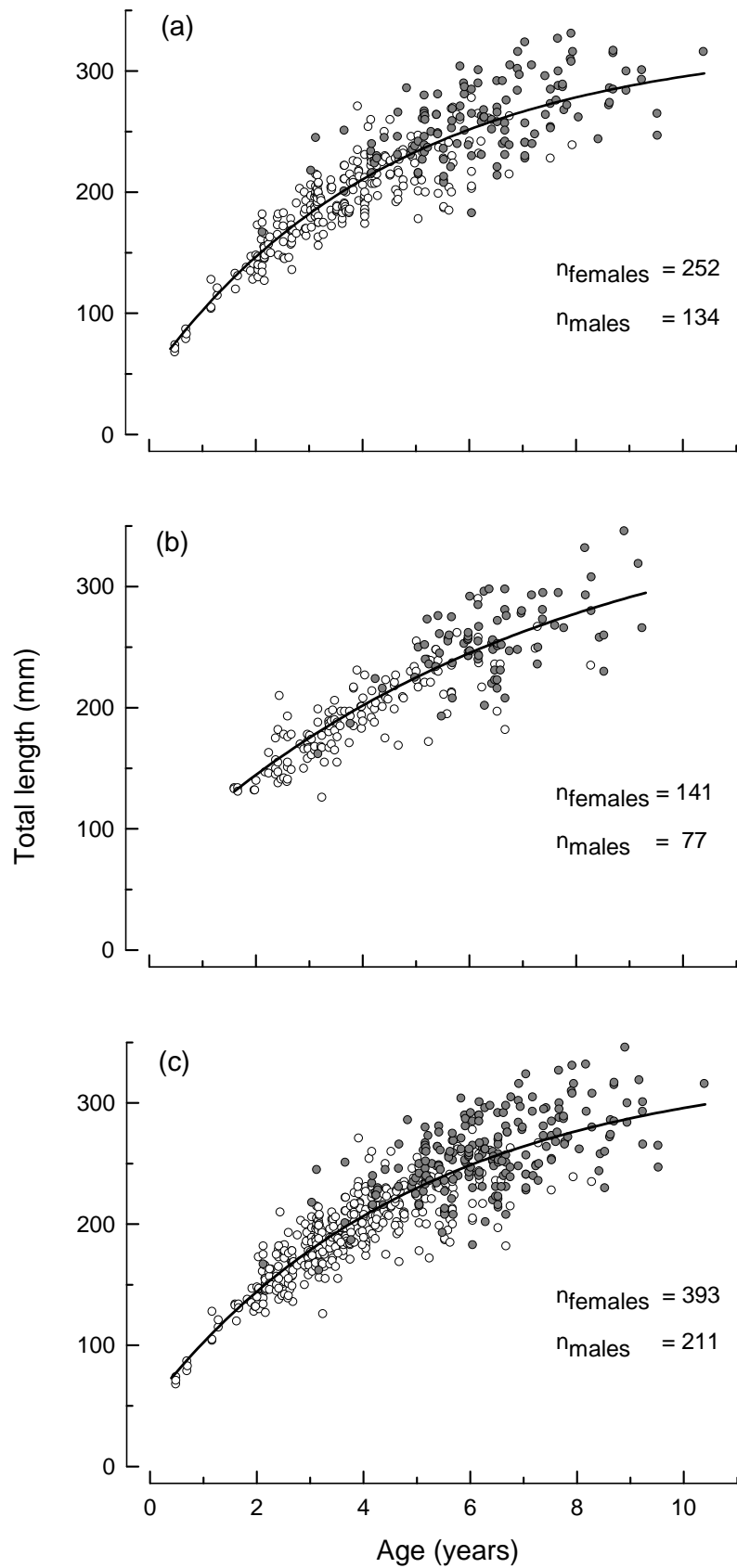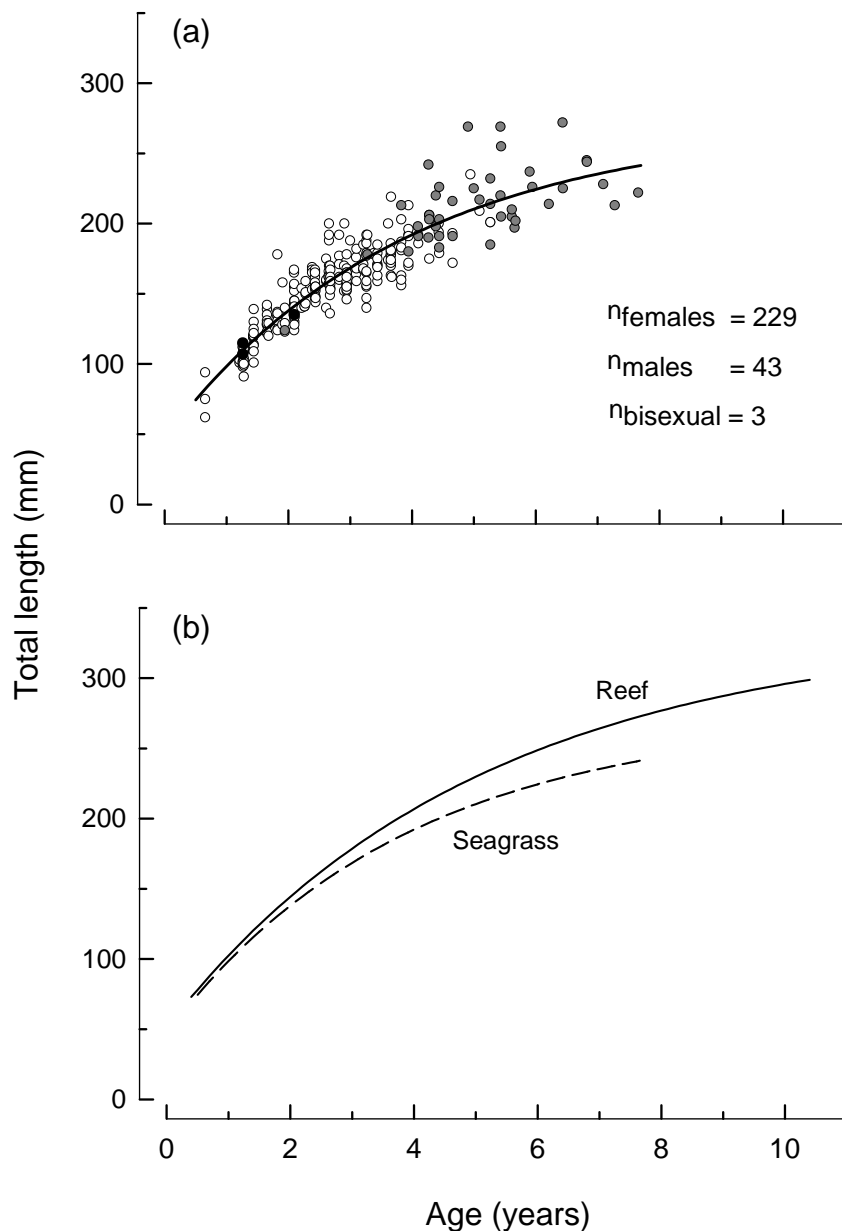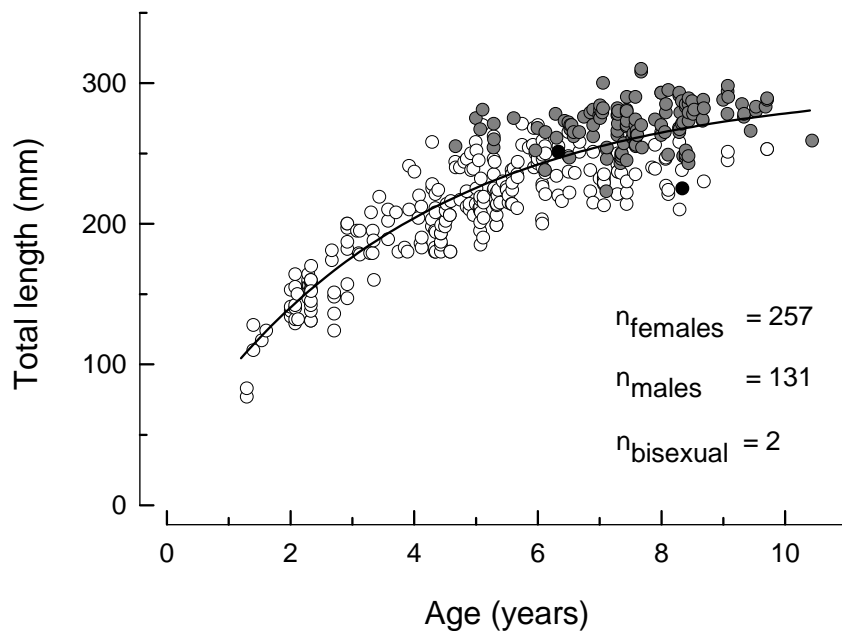

Figure 9.17. Composite von Bertalanffy growth curve fitted to the lengths at age of female (white circles), bisexual (black circles) and male (grey circles) *Ophthalmolepis lineolatus* collected over deep reefs in the Jurien Bay Marine Park. Sample sizes (n) are shown.
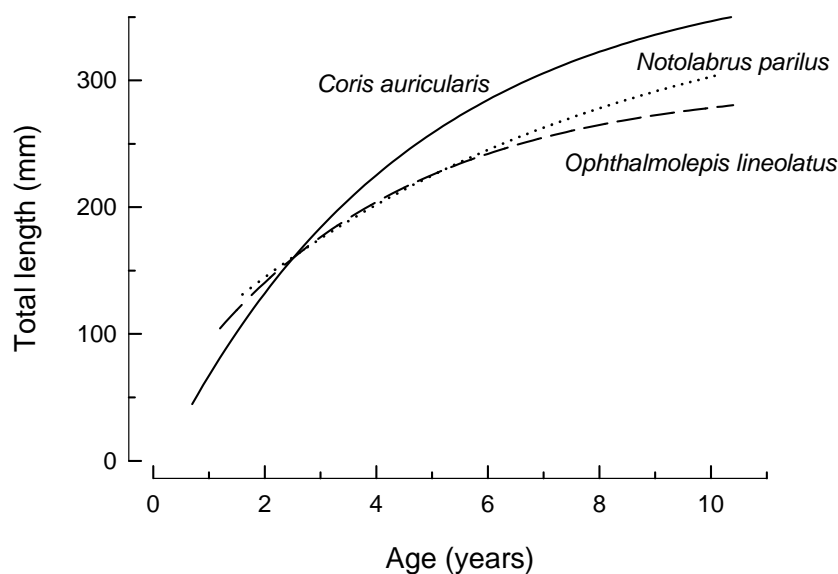
Figure 9.18. von Bertalanffy growth curves fitted to the lengths at age of *Coris auricularis* over deep reefs (black line), *Notolabrus parilus* over both shallow and deep reefs (dotted line) and *Ophthalmolepis lineolatus* (dashed line) collected over deep reefs in the Jurien Bay Marine Park.

9.3.3. Dietary compositions of *Coris auricularis*, *Notolabrus parilus* and

Ophthalmolepis lineolatus

9.3.3.1. Description of taxa consumed by the three labrids

Coris auricularis *in shallow and deep reef habitats*

All of the foreguts of *C. auricularis* collected contained food and the overall

mean foregut fullness (± 1 S.E.) in shallow and deep reef habitats was 6.5 ± 1.9 and 6.1

± 2.3 (Table 9.8). Forty major taxonomic groups were identified in the diets of

C. auricularis collected over deep reefs, while 34 identifiable groups were recorded in

those from shallow reefs. Crustaceans were the most frequently ingested taxa in shallow

(92 % of foreguts) and deep reefs (87 %), followed by gastropods, which occurred in 84

and 76 % of stomachs in those two habitats, respectively (Table 9.8). Crustaceans and

gastropods contributed the most to the total volume of the overall diet of *C. auricularis*

in shallow (38% and 22%, respectively) and deep reefs (39% and 18%). Amphipods

were the most frequently consumed crustacean in shallow (77 % of foreguts) and deep

reefs (74%), and contributed 18 and 17 % to the overall dietary volume in those two

Table 9.8 Percentage frequency of occurrence (%F) and mean percentage volumetric contribution (%V) of different taxa to the diets of *Coris auricularis*, *Notolabrus parilus* and *Ophthalmolepis lineolatus* in different habitats in the Jurien Bay Marine Park. Taxa grouped as dietary categories and used in multivariate analyses are marked with an asterisk. Total number of identifiable taxa includes macrophytes and sand. Crustaceans were grouped as small[a] and large[b] for multivariate analyses

| Major taxa and dietary categories | *Coris auricularis* | | | | *Notolabrus parilus* | | | | | | *Ophthalmolepis lineolatus* | |
| | Shallow | | Deep | | Shallow | | Deep | | Seagrass | | Deep | |
	%F	%V	%F	%V	%F	%V	%F	%V	%F	%V	%F	%V
Foraminifera*	**19.6**	**1.0**	**2.5**	**1.0**	**1.4**	**1.0**	**-**	**-**	**3.1**	**0.2**	**-**	**-**
Bryozoa*	**1.3**	**<0.1**	**3.4**	**0.4**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Porifera*	**13.9**	**1.0**	**8.4**	**0.5**	**2.0**	**1.0**	**-**	**-**	**0.8**	**<0.1**	**0.8**	**0.8**
Cnidaria*	**0.6**	**0.1**	**0.8**	**<0.1**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Sipunculida*	**5.7**	**0.7**	**0.8**	**0.1**	**2.0**	**0.6**	**-**	**-**	**1.6**	**0.4**	**0.8**	**0.1**
Nemertea*	**1.9**	**0.2**	**-**	**-**	**-**	**-**	**-**	**-**	**0.8**	**<0.1**	**1.6**	**1.2**
Annelida*	**47.5**	**7.2**	**31.9**	**5.4**	**19.7**	**3.2**	**14.3**	**3.0**	**10.9**	**2.8**	**9.8**	**3.5**
Polychaeta	**47.5**	**7.1**	**31.9**	**5.4**	**19.7**	**3.2**	**14.3**	**3.0**	**10.9**	**2.8**	**9.8**	**3.5**
Oligochaeta	**0.6**	**0.1**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Mollusca	**86.7**	**23.9**	**76.5**	**20.6**	**85.0**	**39.9**	**87.8**	**38.5**	**80.6**	**41.8**	**63.1**	**27.7**
Polyplacophora*	**4.4**	**0.5**	**3.4**	**0.6**	**4.8**	**1.8**	**8.8**	**4.6**	**17.1**	**6.5**	**6.6**	**4.7**
Bivalvia*	**17.1**	**2.1**	**10.1**	**1.3**	**19.0**	**5.1**	**15.6**	**3.8**	**19.4**	**5.0**	**9.0**	**2.6**
Gastropoda*	**84.2**	**22.2**	**76.5**	**18.0**	**82.3**	**32.3**	**84.4**	**29.4**	**67.4**	**30.3**	**54.1**	**20.4**
Fissurellidae, Patellidae	1.9	0.1	4.2	0.4	4.1	1.4	8.8	1.2	-	-	2.5	0.5
Haliotidae	-	-	-	-	0.7	<0.1	2.0	0.3	-	-	0.8	0.3
Mitridae	0.6	0.1	1.7	0.3	8.8	1.8	10.9	1.8	-	-	-	-
Naticidae	3.2	0.2	0.8	<0.1	2.0	0.2	-	-	1.6	0.7	-	-
Columbellidae	10.8	0.9	2.5	0.2	27.2	7.6	23.8	4.1	0.8	0.1	11.5	2.3
Cypraeidae	1.3	0.1	-	-	-	-	-	-	-	-	-	-
Turbinidae	27.8	3.5	19.3	2.1	30.6	6.2	23.1	6.2	33.3	12.0	12.3	3.3
Trochidae	24.7	3.4	16.0	1.6	39.5	8.0	36.1	9.1	40.3	14.4	6.6	1.7
Buccinidae	9.5	0.6	7.6	0.9	2.0	0.1	2.7	1.0	-	-	6.6	1.5
Terebridae	-	-	-	-	0.7	<0.1	-	-	0.8	0.1	-	-
Unidentifiable gastropods	73.6	13.3	65.5	12.6	41.5	6.9	38.1	5.7	21.7	2.9	32.0	11.0
Scaphopoda*	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**3.9**	**0.2**	**-**	**-**
Cephalopoda*	**0.6**	**1.0**	**1.7**	**0.8**	**1.4**	**0.7**	**2.0**	**0.7**	**-**	**-**	**-**	**-**
Arthropoda	**92.4**	**39.0**	**87.4**	**39.3**	**80.3**	**32.7**	**83.0**	**41.0**	**75.2**	**37.3**	**68.0**	**38.3**
Pycnogonida*	**4.4**	**0.5**	**0.8**	**<0.1**	**-**	**-**	**0.7**	**0.1**	**0.8**	**<0.1**	**0.8**	**0.6**
Crustacea*	**91.8**	**38.5**	**87.4**	**39.2**	**80.3**	**32.7**	**83.0**	**40.9**	**75.2**	**37.2**	**67.2**	**37.7**
Nebaliidae[a]	3.2	0.1	-	-	-	-	-	-	-	-	-	-
Cumacea[a]	2.5	0.1	1.7	0.1	-	-	-	-	-	-	-	-
Copepoda[a]	2.5	0.5	0.8	0.3	-	-	-	-	-	-	-	-

Major taxa and dietary categories	Coris auricularis				Notolabrus parilus						Ophthalmolepis lineolatus	
	Shallow		Deep		Shallow		Deep		Seagrass		Deep	
	%F	%V	%F	%V	%F	%V	%F	%V	%F	%V	%F	%V
Ostracoda[a]	14.6	0.9	7.6	0.4	0.7	0.1	-	-	0.8	0.2	-	-
Amphipoda[a]	77.8	18.2	74.8	17.3	38.8	8.0	37.7	8.0	10.1	1.0	8.2	2.4
Isopoda[a]	31.0	3.1	21.0	2.8	1.4	0.2	11.6	2.0	3.9	2.0	5.7	1.8
Tanaidacea[a]	34.8	2.7	26.9	2.0	4.1	0.3	-	-	-	-	-	-
Mysidae[a]	3.2	0.3	4.2	0.8	0.7	<0.1	0.7	<0.1	-	-	-	-
Penaeidae[b]	5.1	0.4	12.6	1.2	14.3	2.2	12.2	1.7	2.3	0.7	-	-
Stomatopoda[b]	1.3	0.2	-	-	0.7	0.3	2.0	0.8	-	-	1.6	0.8
Alpheidae[b]	-	-	-	-	-	-	0.7	0.1	1.6	0.8	-	-
Palinuridae[b]	-	-	-	-	-	-	0.7	0.5	-	-	0.8	0.5
Paguroidea[b]	5.7	0.4	4.2	0.4	24.5	4.6	29.3	5.7	11.6	2.1	4.1	0.7
Portunidae[b]	-	-	-	-	-	-	-	-	0.8	0.8	0.8	0.7
Majidae[b]	5.1	1.1	5.0	2.6	4.8	2.9	16.3	7.3	2.3	1.1	1.6	1.4
Hymenosomatidae[b]	3.2	0.3	1.7	0.2	2.7	0.7	-	-	-	-	-	-
Leucosiidae[b]	-	-	-	-	-	-	0.7	0.1	1.6	0.7	-	-
Unidentifiable brachyuran[b]	13.9	1.9	21.8	4.7	25.9	8.8	23.1	8.1	25.6	11.7	30.3	17.9
Unidentifiable crustaceans	39.2	8.4	41.2	6.6	21.8	4.6	17.7	6.5	34.9	16.4	26.2	11.6
Echinodermata	**38.6**	**6.9**	**22.7**	**4.4**	**25.9**	**9.6**	**33.3**	**9.0**	**23.3**	**6.3**	**18.9**	**6.1**
Asteroidea*	**0.6**	**0.1**	**0.8**	**0.1**	**0.7**	**0.3**	**-**	**-**	**-**	**-**	**-**	**-**
Echinoidea*	**13.3**	**2.8**	**9.2**	**1.4**	**23.1**	**8.2**	**32.7**	**8.9**	**18.6**	**5.0**	**16.4**	**5.7**
Crinoidea*	**4.4**	**1.1**	**2.5**	**1.2**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Ophiuroidea*	**26.6**	**2.7**	**11.8**	**1.7**	**2.7**	**0.8**	**0.7**	**<0.1**	**5.4**	**1.2**	**2.5**	**0.3**
Holothuroidea*	**0.6**	**0.1**	**-**	**-**	**0.7**	**0.3**	**0.7**	**0.2**	**-**	**-**	**-**	**-**
Chordata	**5.1**	**2.3**	**8.4**	**4.3**	**16.3**	**8.8**	**8.2**	**4.7**	**9.3**	**5.6**	**11.5**	**6.4**
Ascidiacea	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**2.5**	**1.5**
Teleostei*	**5.1**	**2.3**	**8.4**	**4.3**	**16.3**	**8.8**	**8.2**	**4.7**	**9.3**	**5.6**	**9.0**	**4.9**
Macrophytes*	**48.7**	**5.0**	**29.3**	**4.2**	**21.1**	**3.1**	**14.3**	**1.7**	**35.7**	**4.3**	**7.4**	**2.6**
Other Material	**50.6**	**11.8**	**55.5**	**20.8**	**6.8**	**2.0**	**6.1**	**2.1**	**3.9**	**1.2**	**11.5**	**5.1**
Sand	34.2	4.5	31.1	5.7	-	-	0.7	<0.1	2.3	0.5	3.3	0.7
Unidentified material	23.4	7.3	28.6	15.2	6.8	2.0	5.4	2.1	1.6	0.7	9.8	4.4
Total number of stomachs	158		119		146		147		129		133	
Number of stomachs with food (%)	158 (100%)		119 (100%)		146 (100%)		147 (100%)		129 (100%)		121 (91.0%)	
Stomach fullness (mean ± S.E.)	6.5 ± 1.9		6.1 ± 2.3		6.1 ± 2.3		6.2 ± 2.3		4.8 ± 2.1		4.3 ± 2.6	
Total number of identifiable taxa	40		34		32		27		27		25	

habitats, respectively (Table 9.8). Although turbinid and trochid gastropods were the most frequently consumed identifiable gastropods, they each constituted less than 4 % of the overall volume of the diet in each reef habitat. Gastropods,which could not be identified due to their being crushed by the pharyngeal plates of *C. auricularis*, occurred in a large proportion of their foreguts in shallow (73 %) and deep reefs (66 %) and comprised 13 % of the volume of their diets in each habitat (Table 9.8). Polychaetes were recorded in 48% of *C. auricularis* foreguts in shallow reefs and comprised 7 % of the volume of their diets, while in the deep reef habitat they occurred less frequently (32 %) and contributed less to their overall volume (5 %). Echinoderms were more frequently ingested in shallow (39 %) than deep reefs (23 %) and contributed more to the dietary volume of *C. auricularis* in the former habitat (7 *vs* 4 %). The echinoderm classes Ophiuroidea and Echinoidea were the most frequently consumed and provided the greatest contribution in terms of volume of echinoderms to the diet of *C. auricularis* in both reef habitats (Table 9.8). Macrophytes, such as seagrass, red and brown algae were consumed frequently, more so in shallow reefs than deep, and constituted *ca* 4-5 % of the volume of the diet of *C. auricularis*. Similarly, sand was ingested frequently by *C. auricularis* and comprised *ca* 5 % of the diet in those two habitats (Table 9.8).

Length-related changes in dietary compositions of Coris auricularis

Small crustaceans, *e.g.* amphipods and isopods, and gastropods, *e.g.* turbinids and trochids, together comprised a substantial proportion or the majority of the volume of the diet of each length class of *C. auricularis* in both shallow and deep reef habitats (Fig. 9.18). In shallow reefs, small crustaceans were more important for individuals in the smaller length classes (≤ 149 and 150 to 199 mm), representing 33 and 42 % of the volume of their diets, than the 200 to 249 mm and ≥ 250 mm length classes, in which they comprised *ca* 23 and

22 % of their diets (Figure 9.18a). The percentage contribution of small crustaceans to the diets of *C. auricularis* over deep reefs was more variable, constituting between 24 and 42 % of their volume. The volume of the diets comprised by gastropods was also variable among the length classes of *C. auricularis* in both shallow and deep reef habitats, ranging from *ca* 19 to 30 % and 20 to 34 %, respectively (Figs 9.18). The volume of large crustaceans consumed, *e.g.* paguroids and majids, increased progressively with increasing length, and represented $\geq$ 10 and 19 % in the $\geq$ 250 mm length class in both shallow and deep reefs, respectively. Similarly, the volume of echinoderms in the diets and annelids increased with increasing length in both reef habitats (Figure 9.18a).

Notolabrus parilus *in shallow and deep reef and seagrass habitats*

All of the foreguts of *N. parilus* collected in shallow and deep reefs and in seagrass contained food. The overall mean foregut fullness was higher in shallow and deep reefs, *i.e.* 6.1 ± 2.3 and 6.2 ± 2.3, respectively, than in seagrass, *i.e.* 4.8 ± 2.1. Similar numbers of major taxonomic groups were identified in the diets of *N. parilus* collected over deep reefs and seagrass, *i.e.* 27 groups each, while slightly more identifiable groups (32) were recorded in the foreguts of fish from shallow reefs.

Gastropods and crustaceans were the most frequently ingested taxa by *N. parilus* in all three habitats and also comprised the majority of the volume of their diets (Table 9.8). However, they were consumed less frequently by individuals in seagrass. Although similar amounts of crustaceans and gastropods were consumed by *N. parilus* in shallow reefs (33% and 32%, respectively), greater volumes of crustaceans than gastropods were present in the diets of *N. parilus* in deep reefs (41 *vs* 29 %) and seagrass (37 *vs* 30 %) (Table 9.8). Brachyuran crustaceans, including identifiable taxa, such as paguroids and majids, and unidentifiable brachyurans, comprised the largest proportion of the volume of crustaceans in
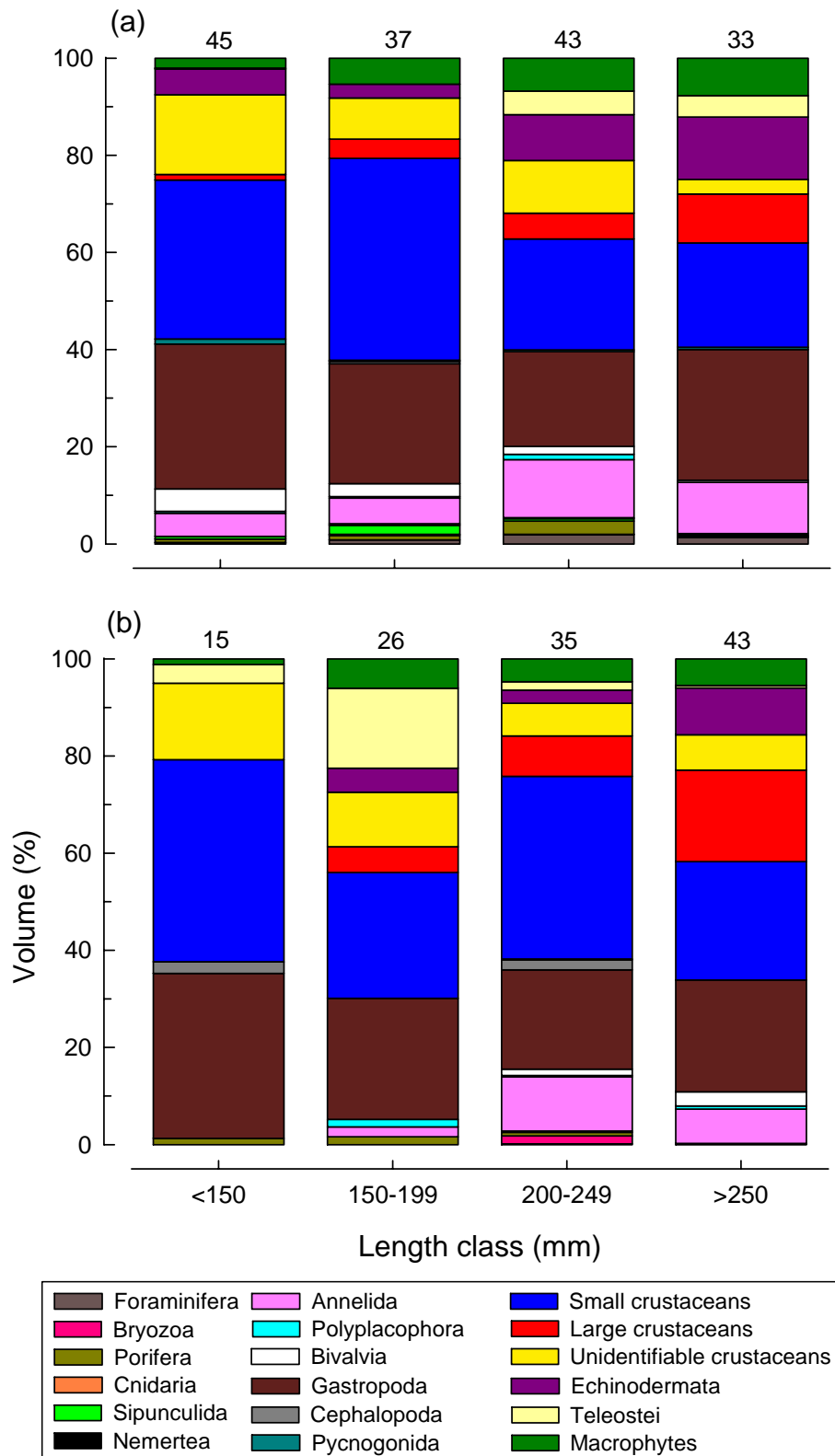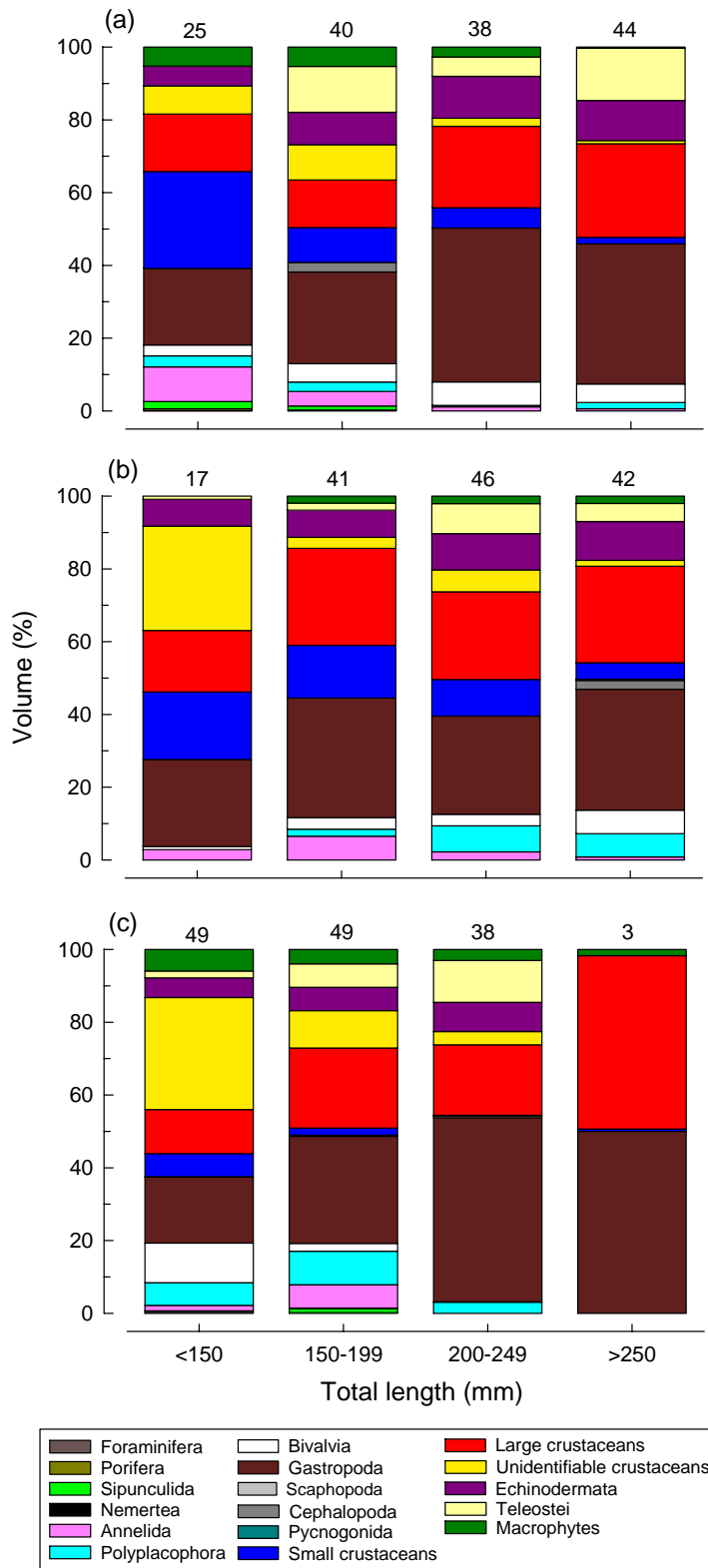
Figure 9.18 Mean percentage volumetric contributions of the different dietary categories and other material in the diets of individuals of *Coris auricularis* in sequential length classes collected from (a) shallow and (b) deep reef habitats in the Jurien Bay Marine Park between 2005 and 2007. Sample size for each length class shown above bar.

the diets of *N. parilus* in shallow (12 %) and deep (15 %) reefs and in seagrass (14 %).

Amphipods also comprised a large proportion of the identifiable crustaceans in the diets of

N. parilus in shallow and deep reefs, *i.e.* 8 % of total volume, and were much more abundant

than in seagrass (1 %). Paguroid and majid crustaceans were more prevalent in the foreguts of

fish collected in deep (6 and 7 %, respectively) than shallow reefs (5 and 3 %) and seagrass

(2 and 1 %) (Table 9.8). Collumbellid gastropods were most important in the diets of

N. parilus in shallow reefs, while turbinid and trochid gastropods and also polyplacophoran

molluscs were more important in the diets of those collected in seagrass and least abundant in

deep reefs. Echinoids comprised a greater proportion of the diet in shallow and deep reefs

than in seagrass (> 8 % *vs* 5 %), while teleosts provided the greatest volumetric contribution

to the diet of *N. parilus* in deep reefs (9 %) (Table 9.8).

Length-related changes in dietary compositions of Notolabrus parilus

Crustaceans and gastropods formed the majority of the volume of the diets of

N. parilus in each length class (Fig. 9.18). The greatest volumes of small crustaceans, such as

amphipods, were consumed by small *N. parilus* (≤ 149 mm) in shallow and deep reefs and in

seagrass and in each habitat the volume declined with increasing length (Fig. 9.18). Similarly,

annelids, such as errant and sedentary polychaetes, were most abundant in either of the two

smallest length classes in each habitat. Bivalves, such as mytilids, were more abundant in the

smallest length class of *N. parilus* caught in seagrass, than in shallow or deep reefs, while

they comprised a greater, albeit small, proportion of the volume of the diet in the larger

length classes in reef habitats than seagrass (Fig. 9.18). In contrast, gastropods, *e.g.* trochids

and turbinids, large crustaceans, echinoids and teleosts typically increased in volumetric

contribution to diet with length in each habitat (Fig. 9.18). For example, gastropods,

consisting of predominantly columbellids, turbinids and trochids, comprised 21, 24 and 18 %

of the diets of *N. parilus* ≤ 149 mm in shallow and deep reefs and in seagrass, respectively, with more diversity in species occurring on reefs, and increased to 42, 27 and 51 % for fish in the 200-249 mm length class in each of those three habitats (Fig. 9.18).

Ophthalmolepis lineolatus *in deep reef habitats*

Of the *O. lineolatus* foreguts examined, virtually all contained food (91 %), the mean stomach fullness (± 1 S.E.) for those stomachs containing food was 4.3 ± 2.6 and 25 identified major taxa were consumed in deep reef habitats (Table 9.8). Crustaceans were the most frequently ingested taxa (67 % of foreguts) and comprised the largest proportion (38 %) of the total volume of the diets of *O. lineolatus* (Table 9.8). Brachyurans comprised the majority of the volume of those crustaceans, however a large proportion of those were not identifiable beyond the infraorder Brachyura level (33 %). Amphipods, isopods and paguroids were the most frequently ingested identifiable crustaceans, occurring in 8, 6 and 4 % of foreguts, respectively and contributed 2, 2 and 0.7 %, respectively, in terms of the total volume of the diets. Molluscs also comprised a significant proportion of the diets of *O. lineolatus*, occurring in 63 % of foreguts and representing 28 % of their volume (Table 9.8), with gastropods comprising the majority of that volume, *i.e.* 21 %. Columbellids and turbinids were the most frequently consumed gastropods, each occurring in 12 % of the foreguts and constituting 2 and 3 % of the volume, respectively. A large
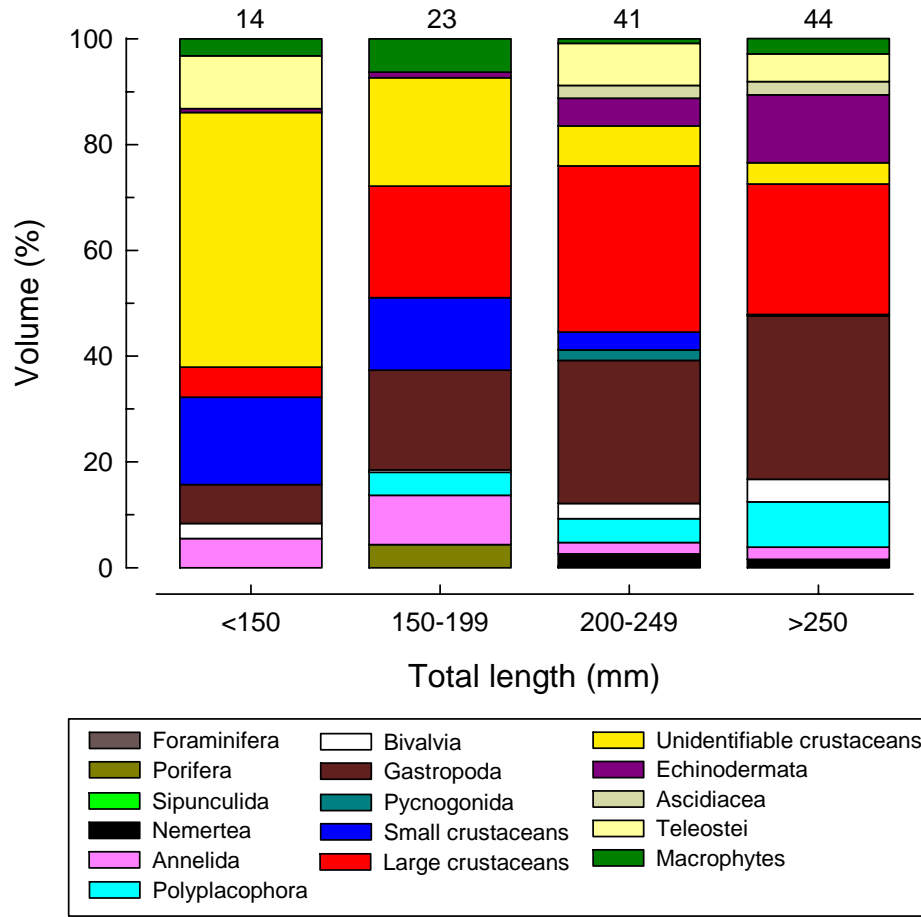
Figure 9.18 Mean percentage volumetric contributions of the different dietary categories and other material to the diets of sequential length classes of *Notolabrus parilus* in coastal waters from (a) shallow reefs, (b) deep reefs and (c) shallow seagrass in Jurien Bay Marine Park between 2005 and 2007. Numbers above each histogram denotes number of fish.

percentage of the gastropods (11 % of volume) comprising the diet of *O. lineolatus* were not identifiable beyond class (Table 9.8). Polyplacophorans and bivalve molluscs, echinoids, teleosts and macrophytes each comprised at least *ca* 3 % of the total volume of the diets.

Length-related changes in dietary compositions of Ophthalmolepis lineolatus

      Crustaceans comprised the majority (71 %) of the dietary volume of small *O. lineolatus* $\leq$ 149 mm, but their contribution to the diets declined with increasing length (Fig. 9.19). The volume of small crustaceans, such as amphipods and isopods, in the diets of *O. lineolatus* decreased progressively with increasing length, *i.e.* 17 % in the $\leq$ 149 mm length class to 0.3 % in the $\geq$ 250 mm length class, while large crustaceans, such as majids, increased from 6 % in the $\leq$ 149 mm length class to values between 21 % and 31 % in the 150-199 mm to 25 % in the $\geq$ 250 mm length classes (Fig. 9.19). Gastropods, such as turbinids and trochids, and echinoderms, *e.g.* urchins, each comprised gradually increasing percentages of the diets of *O. lineolatus* with increasing length, *i.e.* 7 to 31 % of volume in the $\leq$ 149 mm and $\geq$ 250 mm length classes, respectively, for gastropods, and 6 to 13 %, respectively, for echinoderms (Fig. 9.19).

9.3.3.2 Multivariate analyses of dietary compositions

Coris auricularis*,* Notolabrus parilus *and* Ophthalmolepis lineolatus *over deep reefs*

      The compositions of the diets of *C. auricularis*, *N. parilus* and *O. lineolatus* collected over deep reefs, where they co-occur, were significantly different (PERMANOVA: p = 0.001; Table 9.9). PERMANOVA also detected significant differences among the compositions of the diets in each length class and season (p = 0.017; 0.012, respectively; Table 9.9). However, the mean squares, pseudo-F values and estimates of components of variation were much lower for length class and season than for species.

Figure 9.19 Mean percentage volumetric contributions of the different dietary categories and other material to the diets of sequential length classes of *Ophthalmolepis lineolatus* in coastal waters from deep reefs in Jurien Bay Marine Park between 2005 and 2007. Numbers above each histogram denotes number of fish.

Furthermore, there were no two or three-way interactions (Table 9.9). Complementary two-way ANOSIM tests of species × length class and species × season confirmed a significant difference among the composition of the diets of each species in both tests ($p = 0.1$ %, R = 0.31, 0.25, respectively). While the effect of length class was significant in the first two-way ANOSIM ($p = 1.4$ %), the low R statistic (0.063) indicated that variation within and among groups of length classes was similar. ANOSIM did not detect a seasonal effect ($p = 56$ %, R = -0.005).

Table 9.9. Results of a three-way crossed PERMANOVA employing data for the densities of each dietary category of *Coris auricularis*, *Notolabrus parilus* and *Ophthamolepis lineolatus* in each represented length class (L) in each season (se) in deep reef habitat of the JBMP. *df* = degrees of freedom, *MS* = mean squares, $p \leq$ 0.05*, 0.01**, 0.001***. *ECV* = square root estimates of components of variation.

	Main effects			
Source	**Species**	**Length class**	**Season**	**Residual**
df	2	2	3	68
MS	9527	2583	2402	1148
Pseudo-F	8.30**	2.25*	2.09*	
ECV	16.79	6.86	7.47	
	Two-way interactions			
Source	*Sp* ×*L*	*Sp* ×*Se*	*L* ×*Se*	
df	4	6	6	
MS	1081	945	1100	
Pseudo-F	0.94	0.82	0.96	
ECV	-2.54	-5.14	-2.48	
	Three-way interaction			
Source	*Sp* ×*L* ×*Se*			
df	12			
MS	1085			
Pseudo-F	0.95*			
ECV	-4.84			

Pairwise comparisons from the two-way ANOSIM tests (species length × class, species × season) demonstrated that the compositions of the diets of *C. auricularis* were significantly different from those of *N. parilus* (p = 0.1 %; R = 0.42 and 0.31, respectively) and *O. lineolatus* (ANOSIM: p = 0.1 %, R = 0.44, 0.38). However, those of *N. parilus* and *O. lineolatus* were not significantly different ($p \leq 0.8\%$, R < 0.122).

A non-metric multi-dimensional scaling (nMDS) plot demonstrated that the samples for *C. auricularis* and *N. parilus* formed relatively discrete clusters and there was almost no overlap in the points for each species (Fig. 9.21). There was also limited overlap in the points for *C. auricularis* with those of *O. lineolatus*, which were widely dispersed. The points for *O. lineolatus* overlapped completely those for *N. parilus*, reflecting the lack of difference detected by pairwise ANOSIM tests between the dietary composition of those two species in the deep reef habitat (Fig. 9.21).
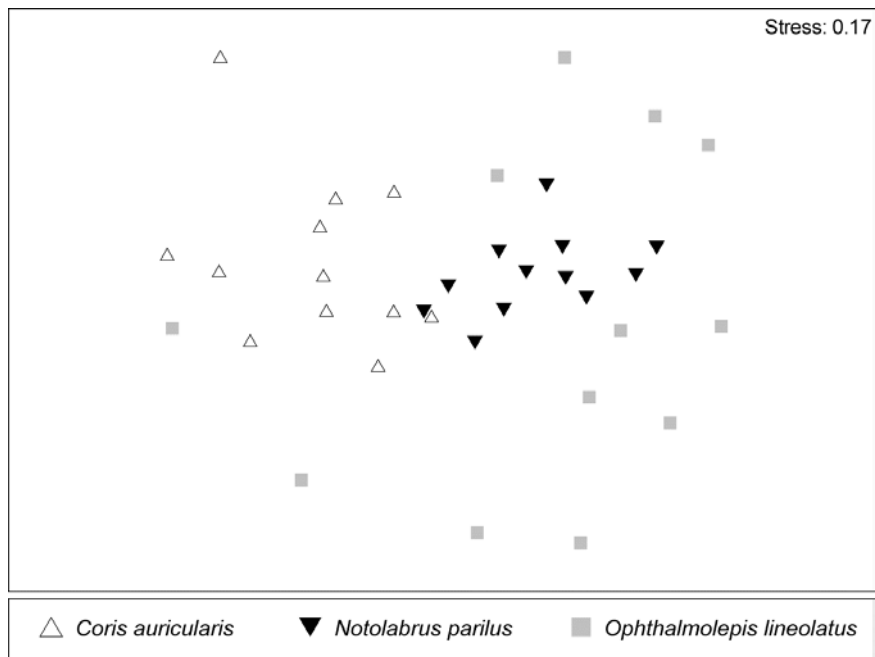
Figure 9.21. Non-metric multi-dimensional scaling plot, constructed from a Bray-Curtis similarity matrix, which was derived from the square-root transformed mean densities of each dietary category in each length class (150-199, 200-249, ≥ 250 mm) and season for *Coris auricularis*, *Notolabrus parilus* and *Ophthalmolepis lineolatus* caught over deep reefs in the Jurien Bay Marine Park.

SIMPER demonstrated that the dietary compositions of *C. auricularis* over deep reefs were typified by small crustaceans and gastropods, while those of both *N. parilus* and *O. lineolatus* were typified by gastropods and large crustaceans. The diets of *C. auricularis* were distinguished from those of *N. parilus* and *O. lineolatus* primarily by a greater abundance of small crustaceans in the diets of the former species and of large crustaceans in the latter two species.

Coris auricularis *and* Notolabrus parilus *over shallow reefs*

The compositions of the diets of *C. auricularis* and *N. parilus* collected in the shallow reef habitat were significantly different (PERMANOVA: $p = 0.001$; Table 9.10). PERMANOVA also detected significant differences among the compositions of the diets in each length class ($p = 0.001$), but not among seasons ($p = 0.857$; Table 9.10). The mean squares, pseudo-F values and estimates of components of variation

Table 9.10. Results of a three-way crossed PERMANOVA employing data for the densities of each dietary category of *Coris auricularis* and *Notolabrus parilus* in each length class (L) and season (se) in shallow reef habitat of the JBMP. *df* = degrees of freedom, *MS* = mean squares, $p \leq 0.05^*$, 0.01^{**}, 0.001^{***}. *ECV* = estimates of components of variation.

	Main effects			
Source	**Species**	**Length class**	**Season**	**Residual**
df	1	3	3	58
MS	17666	2914	532	1158
Pseudo-F	20.64***	3.41***	0.62	
ECV	415.87	99.83	-15.84	
	Two-way interactions			
Source	*Sp ×L*	*Sp ×Se*	*L ×Se*	
df	3	3	9	
MS	2953	1592	691	
Pseudo-F	3.45***	1.86*	0.81	
ECV	203.42	71.99	-31.36	
	Three-way interaction			
Source	*Sp ×L ×Se*			
df	9			
MS	668			
Pseudo-F	0.78			
ECV	-71.43			

were much lower for the factor length class than species and although two-way interactions were detected for species × length class ($p = 0.001$) and species × season ($p = 0.019$), those statistics were also much lower than for the main factor species (Table 9.10). There was no interaction between length class and season or between species, length class and season. Complementary two-way ANOSIM tests of species × length class (data meaned across seasons) and species × season (data meaned across length classes) showed that the composition of the diets of *C. auricularis* and *N. parilus* over shallow reefs differed significantly in each case ($p < 0.1$ %, R = 0.48, 0.38, respectively). The two-way ANOSIM tests detected a weak significant difference among length classes across species groups ($p = 0.1$ %, R = 0.19), but no difference among seasons ($p = 17.1$ %, R = 0.023). Further investigation of the effect of length class is conducted for each species separately (see later).

A non-metric multi-dimensional scaling (nMDS) plot demonstrated that the points for the two species formed almost completely separate groups and thus reflects the significant difference, detected by PERMANOVA and ANOSIM, between the composition of the diets of *C. auricularis* and *N. parilus* over shallow reefs. However, the points for the ≤ 149 mm

length class of *N. parilus* in each of the four seasons lay among those for *C. auricularis* and thus the similarity in the composition of their diets is presumably responsible for the interaction between species and length class.   SIMPER demonstrated that the dietary compositions of *C. auricularis* over shallow reefs were typified by small crustaceans and gastropods, while those of *N. parilus* were typified by gastropods and large crustaceans. The diets of *C. auricularis* were distinguished from those of *N. parilus* by a greater abundance of small crustaceans and annelids in the diets of the former species and of large crustaceans and gastropods in the latter species.
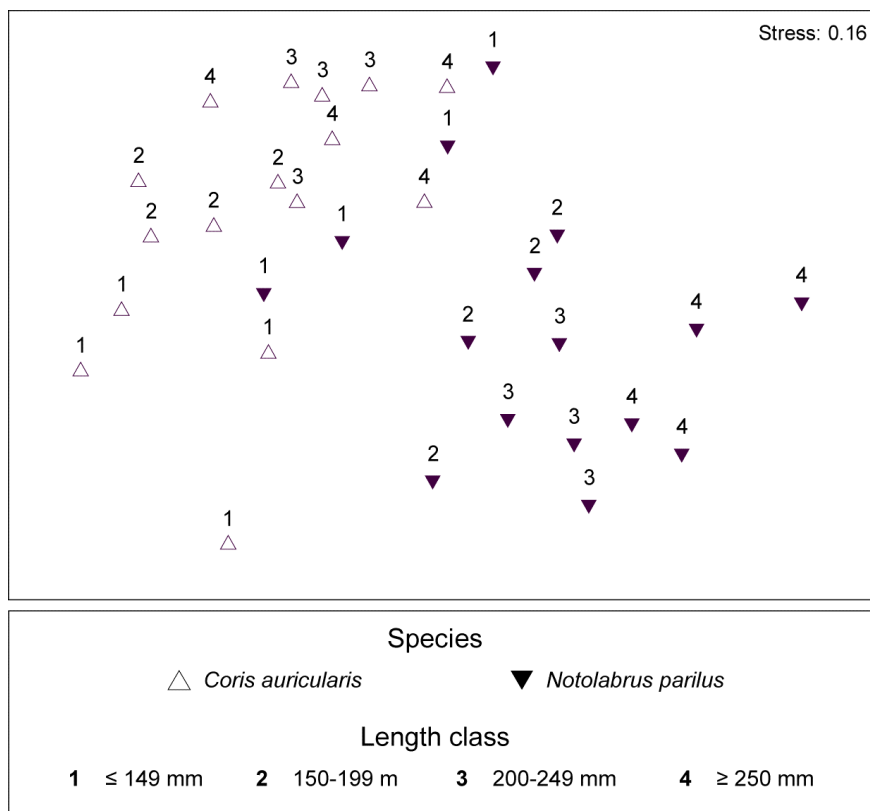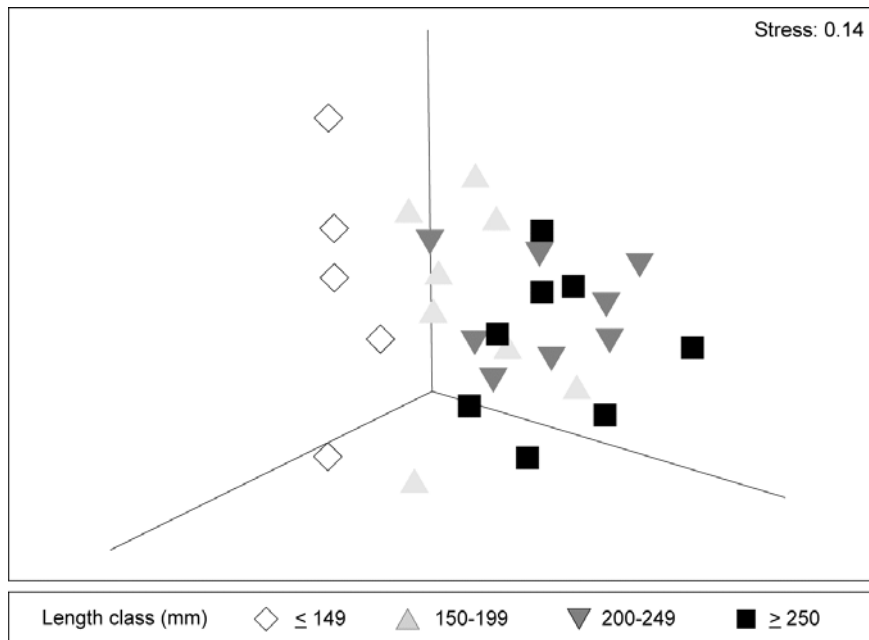

Figure 9.22. Non-metric multi-dimensional scaling plot, constructed from a Bray-Curtis similarity matrix, which was derived from the square-root transformed mean densities of each dietary category in each length class (≤ 149, 150-199, 200-249, ≥ 250 mm; pooled across seasons) for *Coris auricularis* and *Notolabrus parilus* caught over shallow reefs in the Jurien Bay Marine Park.

Dietary composition of Coris auricularis *in shallow and deep reef habitats*

A 3-way PERMANOVA demonstrated that the composition of the diets of *C. auricularis* differed significantly among both shallow and deep reef habitats and in each length class ($p \leq 0.01$), but not among seasons ($p = 0.18$; Table 9.11). Both the mean squares and pseudo-F values were slightly greater for habitat than length class, while the reverse was true for the estimates of components of variation. There were no significant two or three-way interactions (Table 9.11). Complementary two-way ANOSIM tests of habitat × length class, habitat × season and length class × season only detected significant differences among habitats and length classes in the first test (habitat: $p = 0.2$ %, length: $p = 0.1$ %). However, the R statistics were low in each case (R = 0.17 and 0.14, respectively). When each of the above two-way tests were re-run using the full set of length classes (Note: as ANOSIM does not suffer when cells are missing), the effect of habitat was even less or not significant ($p = 4.7$ %, R = 0.11; $p = 45.7$ %, R = 0.001), while that of length was greater ($p = 0.1$ %, R = 0.18) or similar ($p = 0.1$, R = 0.14). Season remained not significant ($p > 0.05$).

Pairwise comparisons from the two-way ANOSIM tests of habitat × length class and length class × season, using the data for all four length classes, showed that the overall significant differences in the dietary composition of the different length classes were a result of the strong difference ($p = 0.1$ %, R statistic range: 0.37-0.44) between the smallest (≤ 149 mm) and the two largest length classes (200-249 mm and ≥ 250 mm). The pairwise comparisons between the 150-199 mm and both the 200-249 mm and ≥ 250 mm length classes produced relatively weak differences in the habitat × length class test ($p \leq 0.2$ %, R = 0.19, 0.24, respectively), and no difference in the length class × season test ($p > 0.05$). There were no significant differences in

Table 9.11. Results of a three-way crossed PERMANOVA employing data for the densities of each dietary category of *Coris auricularis* in each represented length class (L, 150-199, 200-249, ≥ 250 mm) in each season (Se) in shallow and deep reef habitats (Ha) of the JBMP. *df* = degrees of freedom, *MS* = mean squares, $p \leq$ 0.05*, 0.01**, 0.001***. *ECV* = square root estimates of components of variation.

	Main effects			
Source	**Habitat**	**Length class**	**Season**	**Residual**
df	1	2	3	36
MS	1996	1637	885	697
Pseudo-F	2.87**	2.35**	1.27*	
ECV	6.94	7.18	3.71	
	Two-way interactions			
Source	**Ha × L**	**Ha × Se**	**L × Se**	
Df	2	3	6	
MS	1109	807	484	
Pseudo-F	1.59	1.16	0.69	
ECV	6.73	4.02	-6.78	
	Three-way interaction			
Source	**Ha × L × Se**			
Df	6			
MS	730			
Pseudo-F	1.05			
ECV	3.82			

either test between the adjacent length classes of ≤ 149 *vs* 150-199 mm and 200-249 *vs* ≥ 250 mm.

A nMDS constructed from the similarity matrix derived from the mean percentage volumetric contribution of each dietary category for each of the four length classes of *C. auricularis* in each season and reef habitat showed that a large number of points from the two reef habitats overlapped, reflecting the weak difference among reefs indicated by the low R statistic results described above (plot not shown). When the same nMDS was coded for length class, the points for the smallest length class, *i.e.* ≤ 149 mm, were dispersed vertically, lay to one side of the plot and did not overlap those of the other length classes (Fig. 9.23). Specifically, the points for that length class lay furthest from those of the two largest length classes, *i.e.* 200-249 and ≥ 250 mm, which reflects the greater dissimilarity, detected by pairwise ANOSIM tests, among those groups than among any other. The points for the 150-199 mm length class mostly lay towards the same side of the plot as those of the ≤ 149 mm

Figure 9.23. Non-metric multi-dimensional scaling plot, constructed from a Bray-Curtis similarity matrix, which was derived from the square-root transformed mean densities of each dietary category in each length class and season for *Coris auricularis* in both shallow and deep reef habitats, coded for length class, in the Jurien Bay Marine Park.

class. However, many of the pints for that length class overlapped those of the 200-249 mm and $\geq$ 250 mm length classes, which also overlapped each other (Fig. 9.23).

SIMPER (habitat $\times$ length class) demonstrated that the diets of *C. auricularis* in both the shallow and deep reef habitats and in each length class were typified primarily by gastropods and small crustaceans. The diets of small *C. auricularis* ($\leq$ 149 mm) were distinguished from those of individuals in the two largest length classes (200-249, $\geq$ 250 mm) by containing greater abundances of small crustaceans, gastropods and bivalves and lower abundances of annelids, macrophytes, ophiuroids, large crustaceans and echinoderms.

Dietary composition of Notolabrus parilus *in reef and seagrass habitats*

The three factor PERMANOVA found the composition of diets of *N. parilus* to differ significantly among habitats, length classes and seasons ($p < 0.05$; Table 9.12). The mean squares, pseudo-F values and estimates of components of variation were greatest for the

factor habitat. There were no significant two or three-way interactions among factors. Complementary and comparative two-way ANOSIM tests on the same similarity matrix, using habitat × length, habitat × season and length × season designs, found a weak difference among habitats in the two tests comprising that factor ($p \leq 0.2$ %, R = 0.15, 0.17). There were no significant differences among length classes in those tests ($p > 0.05$) and although the difference between season in the habitat × season test was significant ($p = 3.8$ %), it was very weak (R = 0.08) and not significant in the latter test ($p > 0.05$). Note that only the 150-199 and 200-249 mm length classes were included in the above tests as they were represented in each season in each habitat and thus avoided having missing cells in the PERMANOVA test, *i.e.* particular length classes in individual seasons.

Further two-way ANOSIM tests (habitat × length class, habitat × season and length class × season) were conducted using the data for all length classes, *i.e.* ≤ 149, 150-199, 200-249 and ≥ 250 mm. Those tests detected a similarly weak significant effect of habitat ($p = 0.2$, R = 0.11-0.12), the difference being driven by the compositions of diets in deep reefs *vs* seagrass ($p = 0.1$, R = 0.23 in both cases). ANOSIM also detected a weak difference among the diets of the different length classes in both 2-way tests ($p = 0.1$ %, R = 0.1, 0.13), which was a result of the difference among the diets of fish in the ≤ 149 mm length class and those of the 200-249 and ≥ 250 mm classes ($p \leq 0.8$ % in each case, R = *ca* 0.22-0.23 for ≤ 149 *vs* 200-249 mm and *ca* 0.32-0.40 for ≤ 149 *vs* ≥ 250 mm). Although the effect of season was significant in both of the two-way tests, in which it was a factor, the R statistic in each case was close to zero (R ≤ 0.06).

Table 9.12. Results of a three-way crossed PERMANOVA employing data for the densities of each dietary category of *Notolabrus parilus* in each represented length class (L, 150-199, 200-249 mm) in each season (Se) in shallow and deep reef habitats and seagrass (Ha) in the JBMP. *df* = degrees of freedom, *MS* = mean squares, *p* ≤ 0.05*, 0.01**, 0.001***. *ECV* = square root estimates of components of variation.

Main effects				
Source	*Habitat*	*Length class*	*Season*	*Residual*
df	2	1	3	52
MS	3840	2591	2351	995
Pseudo-F	3.86***	2.60*	2.36**	
ECV	11.0	6.80	8.82	
Two-way interactions				
Source	*Ha × L*	*Ha × Se*	*L × Se*	
Df	2	6	3	
MS	1527	1419	909	
Pseudo-F	1.53	1.42	0.91	
ECV	6.73	8.43	-3.15	
Three-way interaction				
Source	*Ha × L × Se*			
Df	6			
MS	640			
Pseudo-F	0.64			
ECV	-10.92			

A nMDS plot, derived from the similarity matrix, which was constructed from the data set comprising all length classes, showed that the points for the shallow and deep reefs overlap completely, while those for the seagrass lay predominantly to one side of the plot and are more widely dispersed (Fig. 9.24). The fact that the points for the deep reefs mostly form a tight cluster and lay separate to those of seagrass reflects the higher R statistic in the pairwise ANOSIM tests among those two habitats.

SIMPER demonstrated that the diets of *N. parilus* in each habitat were typified by gastropods and also by large crustaceans in the two reef habitats. The composition of the diet in deep reef habitats was distinguished from that of seagrass by greater abundances of small and large crustaceans, gastropods and echinoids. In contrast macrophytes were more abundant in those of *N. parilus* in seagrass.
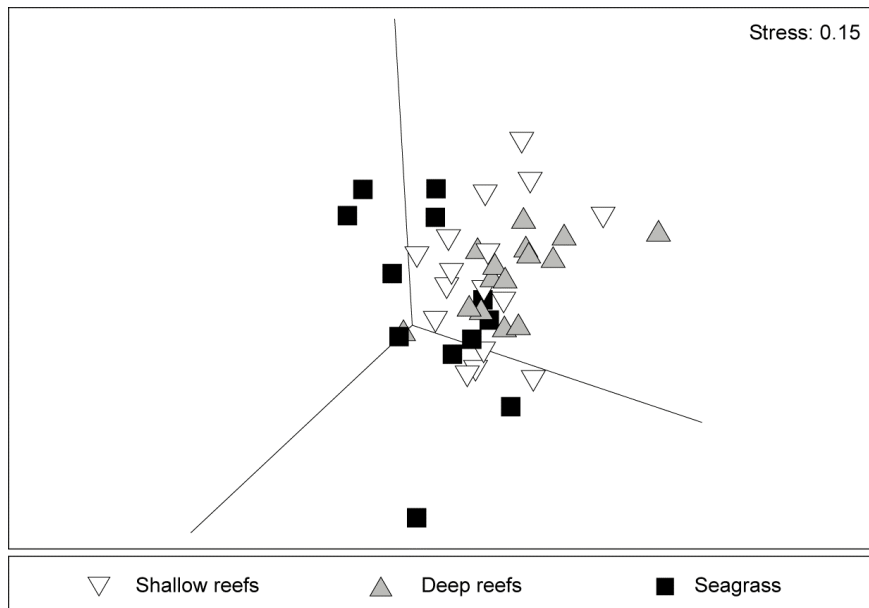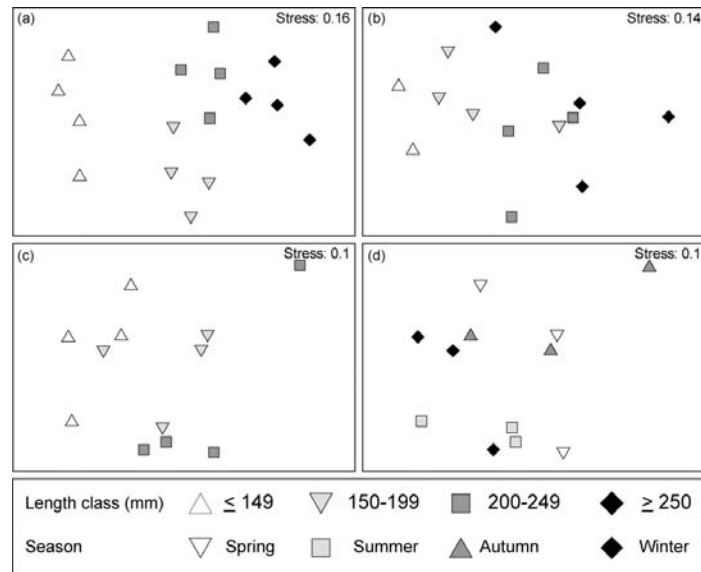
Figure 9.24. Three dimensional non-metric multi-dimensional scaling plot constructed from a Bray-Curtis similarity matrix, which was derived from the square-root transformed mean densities of each dietary category in each length class and season for *Notolabrus parilus* in shallow and deep reef habitats and in seagrass in the Jurien Bay Marine Park.

When the dietary data for *N. parilus* in each of the three habitats were treated separately and each of the similarity matrices constructed from the transformed data sets were subjected to ANOSIM tests of length class × season, the effect of length class was significant in both shallow reefs (p = 3.6 %, R = 0.16) and in seagrass (p = 3.7 %, R = 0.18), but not in deep reefs (p > 0.05). However, the R statistics in the former two tests were relatively low. An effect of season was only detected in the diets of *N. parilus* in seagrass (p = 1.1 %, R = 0.22).

Pairwise ANOSIM tests showed that the difference among length classes in shallow reefs lay between the ≤ 149 and both the 200-249 and ≥ 250 mm length classes (p = 3.7, 1 %; R = 0.36, 0.50, respectively). SIMPER detected that the smallest length class was typified by small crustaceans, while the two largest classes were typified by gastropods and large crustaceans. Furthermore, the greater abundance of small crustaceans in the diets of the ≤ 149 mm length class distinguished that class from those of the 200-249 and ≥ 250 mm length classes.

In seagrass, the composition of the diets differed significantly between the ≤ 149 mm class and the largest class represented in that habitat, *i.e.* 200-249 mm ($p = 3$ %, R = 0.31). The results of SIMPER indicated that the diets of the ≤ 149 mm length class were typified by gastropods and macrophytes, while those of the latter length class were typified primarily by gastropods. Furthermore, the diets of those two length classes were distinguished by greater abundances of bivalves in the former class and gastropods in the latter class. Pairwise ANOSIM tests showed significant differences among the diets of *N. parilus* in summer *vs* both spring ($p = 1.9$ %, R = 0.31) and autumn ($p = 1.3$ %, R = 0.36). While gastropods typifed the diets of *N. parilus* in spring and summer, gastropods and macrophytes typified those of autumn. Summer was distinguished from both spring and autumn by greater abundances of gastropods in the diets of *N. parilus* in that former season and by lower abundances of large crustaceans.

nMDS plots for each of three habitats demonstrate that in the case of shallow reefs and seagrass, the points for each length class essentially formed a progression from the left to the right hand side of the plot (Fig. 9.25a, b, c). There was evidence of a progression for the diet of *N. parilus* over deep reefs. The points for the different length classes in shallow reefs each formed relatively tight groups, as opposed to those in deep reefs or seagrass, indicating greater similarity of diets within length groups in the former habitat than was the case for the two latter habitats. On the nMDS plot for the composition of the diets of *N. parilus* in seagrass in each season, the points representing the samples collected in summer lay together at the left-hand side of the plot, while those for each of the other seasons were more widely dispersed. Furthermore, the points
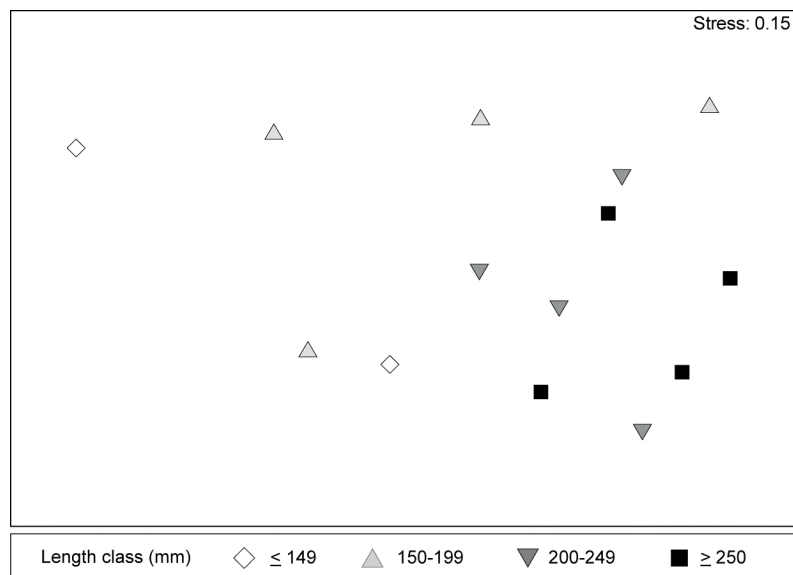
Figure 9.25. Non-metric multi-dimensional scaling plots, constructed from Bray-Curtis similarity matrices, which were derived from the square-root transformed mean densities of each dietary category in each length class and season for *Notolabrus parilus* collected in the Jurien Bay Marine Park in (a) shallow and (b) deep reefs, coded for length class, and in seagrass habitats coded for (c) length and (d) season.

for summer did not overlap those of spring and autumn, thus reflecting the significant

differences among the diets of *N. parilus* in those seasons in the seagrass habitat.

Dietary composition of Ophthalmolepis lineolatus *in deep reef habitats*

The results of a 2-way ANOSIM on the composition of the diets of *O. lineolatus*

collected over deep reefs demonstrated that they differed significantly among length classes

($p = 1.5$ %), however, the R statistic was relatively low, indicating limited overall difference

among length classes (R = 0.22). There were no differences in the diets among seasons

($p > 5$ %). Pairwise ANOSIM tests found a strong significant difference between the

composition of the diets of the ≤ 149 mm and the 200-249 mm length class ($p = 3.3$ %, R =

0.616), but not the ≥ 250 mm length class ($p > 5$ %). Significant differences were also

detected between the 150-199 mm and both of the two largest length classes ($p = 3.6, 3.1$ %,

R = 0.30, 0.36, respectively).

The nMDS plot constructed from the similarity matrix used for the above ANOSIM showed that, although there were few samples for the smallest length class, there was evidence of a progressive change in the dietary composition with increasing length (Fig. 9.26). Thus, the points for the ≤ 149 mm length class lay at one side of the plot and did not overlap those of the 200-249 mm and ≥ 250 mm length class, which lay clustered together at the right-hand side. While the points for the 150-199 mm length class were widely dispersed, they were also essentially separated from those of the two largest length classes (Fig. 9.26).

Figure 9.26. Non-metric multi-dimensional scaling (nMDS) plot, constructed from a Bray-Curtis similarity matrix, which was derived from the square-root transformed mean densities of each dietary category in each length class and season for *Ophthalmolepis lineolatus* collected in the Jurien Bay Marine Park, coded for length class.

SIMPER demonstrated that the diets of small *O. lineolatus* ≤ 149 mm were distinguished from those of the 200-249 mm and ≥ 250 mm length classes by a vastly greater percentage volume of small crustaceans in the foreguts of fish in the former length class and of large crustaceans and gastropods in the case of the 200-249 mm length class and of large crustaceans, gastropods and echinoids in the largest length class (≥ 250 mm). The diets of the

150-199 mm length class of *O. lineolatus* were distinguished primarily from those of the 200-249 mm class by greater abundances of gastropods in the latter length class, but also by large crustaceans and echinoids in that large length class, while echinoids, large crustaceans and gastropods, in that order, were responsible for distinguishing the diets of individuals in the former length class from the ≥ 250 mm length class.

9.4 Discussion

9.4.1 Reproductive biology

Evidence for protogynous hermaphroditism

The data collected on the biology of *Coris auricularis*, *Notolabrus parilus* and *Ophthalmolepis lineolatus* provides strong evidence that they are each protogynous hermaphrodites. However, there were some differences among the characteristics of the hermaphroditic sexual patterns of the three species.

Ophthalmolepis lineolatus

Histological examination of the gonads of small and young *O. lineolatus*, < 164 mm and three years of age (the length and age at which sexually maturing individuals were first recorded), showed that their gonads comprised solely ovarian tissue and they were thus all female. This, coupled with the fact that males were not recorded below 223 mm and 4.9 years of age among all samples, indicates that *O. lineolatus* commence life as female.

Ophthalmolepis lineolatus were shown to reach sexual maturity as females at 181 mm (L_{50m}) and between approximately 3 and 4 years of age, and 95 % of females were mature by 230 mm, when they were *ca* 6 years old. Only a very small number of males were recorded at lengths less than the upper 95 % C.I. of the L_{95m} (249 mm) and there was no overlap in the 95 % confidence intervals of the L_{95m} (211-249 mm) and the length at which 50 % of females

had changed to male (L_{50c}, 251-257 mm). Indeed, as the vast majority of female *O. lineolatus* were mature by the age of 6 years, this is below the age at which 50 % of females had changed to male (A_{50c}), *i.e.* 7.1 years. This implies that individuals would mature first as females and only change sex to male at some point later in life and *O. lineolatus* would be monandric, *i.e.* have only one pathway of development for males.

Sex change in this species appears to be strongly linked to length (size), rather than age, as males only occurred in the largest length classes and the logistic curve fitted to the length data for males was very steep, producing similar L_{50c} and L_{95c} parameters, *i.e.* 254 and 277 mm, respectively. In contrast, males occurred over a wide range of ages, *i.e. ca* 4.9 – 10.2 years. Furthermore, the oldest females were mostly smaller than males of the same age. Thus, physical size is an important factor that influences when to change sex and supports the size advantage hypothesis of Ghiselin (1969). The length and age distributions of *O. lineolatus* in this study parallel those for the same species on the east coast of Australia, indicating similar reproductive strategies in different populations (Morton *et al.*, 2008).

The large size of males and their different colour patterns to those of females, indicates that this species would have a social hierarchy, *e.g.* harems. As females were recorded in the oldest age classes, not all females will change sex during their life. For a protogynous species, this indicates that sex change occurs only when reproductive value will increase as a result of that change (Munday *et al.*, 2006). Specific cues to change sex, such as the loss of a dominant male from a social group, or the sex ratio becoming too female-biased, which, following sex change would have increased reproductive value of those older females, thus did not present themselves during their life (Munday *et al*., 2006).

Histological examination of the testes of male *O. lineolatus* demonstrated that they each comprised secondary testes, *i.e.* the testes contained ovarian characteristics, such as a lumen, a lamellar structure and a gonad wall, indicating that those males had previously been

female. During the spawning period, sperm sinuses that contained spermatozoa were also visible in the testis wall, which would have presumably been used to transport sperm to the cloaca during spawning. Testes did not contain a single centralised sperm duct, which is typical of gonochoristic males and primary males of diandric protogynous hermaphrodites. While all of the above evidence suggests that *O. lineolatus* is monandric, it cannot be disproven that some males may also originate from immature females, indicating an alternative pathway for development of males. This presumably would be only a small number of individuals if it occurs, as the vast majority of females had reached sexual maturity by the size and age at which males were recorded. This type of diandry has been found in several species, where the males are termed prematurational (Warner and Robertson, 1978; Kobayashi and Suzuki, 1990).

Bisexual *O. lineolatus*, *i.e.* individuals with gonads that contain immature ovarian and testicular tissue (Sadovy de Mitcheson and Liu, 2008), were recorded in the intermediate length and age ranges (251-269 mm, 6.0-7.2 years) and it is likely that those individuals were in the process of changing sex to male. However, it is not possible to determine whether the bisexual individuals had previously functioned as females or would have functioned as males in the future, as both tissue types were immature. Thus, there is a notable difference between gonadal structure and reproductive function and function can only be inferred rather than proven from the type of evidence presented above (see Sadovy de Mitcheson and Liu, 2008). Furthermore, the strongest type of evidence for functional protogynous sex change, which is absent here, comes from the capture of transitional individuals, which contain, in their gonads, degenerating vitellogenic oocytes and developing testicular tissue (Sadovy and Shapiro, 1987; Sadovy de Mitcheson and Liu, 2008). However, this appears to be a rare occurrence among the many studies of the reproductive biology of labrids and bisexual individuals are more commonly encountered (*cf.* Ebisawa *et al.*, 1995; Fairclough, 2005;

Sadovy *et al.*, 2003; Coulson *et al.*, 2009). The fact that very few *O. lineolatus* gonads were obtained, comprising both ovarian and testicular tissue, implies that, if they were undergoing sexual inversion, it occurs relatively rapidly. This thereby reduces the chances of encountering bisexual individuals and presumably also true transitional individuals in samples.

Coris auricularis

Examination of histological sections of the gonads of small and young *C. auricularis*, < 135 mm and two years of age (the length and age at which sexually maturing individuals were first recorded), collected over both shallow and deep reefs, showed almost all of those fish were female as their gonads comprised only ovarian tissue. In the gonads of two of those small individuals, *i.e.* 89 and 90 mm, which were both less than one year old and were collected over shallow reefs, small amounts of testicular tissue were observed. This suggests that *C. auricularis* could undergo a bisexual phase in early life. Although the testicular tissue observed in the gonad of one of those fish comprised small amounts of spermatids, *i.e.* maturing sperm cells, it is unlikely that such a small fish would take part in any spawning activity and thus be a functional male. The fact that (1) only a very small number of bisexual individuals were collected, (2) all other 0 and 1+ individuals were female and (3) the smallest male obtained was 186 mm in length, demonstrates that if there is a bisexual phase, it occurs in the early life history, *i.e.* the first year of life, and all individuals then revert to being female prior to maturation. Such an early bisexual phase has been recorded for other labrids, *e.g Cirrhilabrus temmincki* (Kobayashi and Suzuki, 1990). Further histological studies of the gonads of very small 0+ *C. auricularis* would be required to confirm the prevalence of bisexual individuals in the population.

Sexual maturation of female *C. auricularis* occurred over a wide length and age range. While the smallest and youngest maturing female was 139 mm and 1.9 years old over shallow reefs and 181 and 2.8 years old over deep reefs, the proportion of mature females only reached one in the largest length and oldest age class of females collected during the spawning period, *i.e.* 300-319 mm and 6-6.9 years. The length at which 50 % of females reached sexual maturity (determined from pooled data for shallow and deep reefs), *i.e.* 215 mm, was smaller than the length at which females changed to males over both shallow (252 mm) and deep reefs (267 mm) and the 95 % C.I. of each parameter did not overlap, indicating that, on average, it is likely that individuals will mature as females prior to changing to male. However, the fact that the length at which 95 % of females became mature (307 ± *ca* 33 mm) is greater than the L_{50c} over both shallow (252 ± *ca* 4 mm) and deep (267 ± c*a* 7 mm) reefs, overlaps the respective L_{95c}s for shallow and deep reefs (289 ± 13 mm, 322 ± 14 mm) and that the age at which the majority of females become mature (4-5 years) overlaps the age at which 95 % of females over shallow reefs and 50 % over deep reefs, suggests that some females may not mature prior to becoming male.

Several reasons have been elucidated in other studies as to why females may not mature in every spawning season, which may explain why not all female *C. auricularis* in each length and age class were mature. Such reasons include edge of range effects, where the environmental cues are not suitable to initiate gonadal recrudescence (Pollock, 1984; Fennessy and Sadovy, 2002). However, this would not apply in the case of *C. auricularis*, as the location of the JBMP is essentially in the middle of its Western Australian distribution. Social inhibition of sexual maturation by intrasexual aggression by large individuals was found to occur in *Pseudolabrus celidotus*. The fact that mature and/or spawning individuals were collected in many different locations indicates that there are no migrations taking place to specific spawning locations that may have contributed to the low frequency of mature

females. It is possible that, according to life-history theory, individuals hedge their bets as to whether to mature each year, but also that some individuals may not mature as females at all, which thus introduces the possibility of two pathways for male development, *i.e.* diandry. As *C. auricularis* is not particularly long-lived, reaching a maximum age of *ca* 10 years, and some males were recorded as young as three to four years of age, there may be advantage in putting energy into somatic growth to reach a size at which they can be successful as a male. Thus, it is noteworthy that the majority of male *C. auricularis* occurred in the upper length classes and that this species is sexually dichromatic, implying that there are social hierarchies.

Notolabrus parilus

Similar to *O. lineolatus*, histological sections of the gonads of small and young *N. parilus*, < 132 mm and 1.9 years old (the length and age at which sexually maturing individuals were first recorded), collected over both shallow and deep reefs revealed that their gonads comprised solely ovarian tissue and they were thus all female. Furthermore, the length and age of the smallest and youngest male collected over reefs was 162 mm and 2 years old, respectively. Those two facts demonstrate that individuals of this species in reef habitats commence life as females.

Female *N. parilus* over reefs reached sexual maturity on average at 170 mm (L_{50m}) and *ca* 3 years of age and the majority of females were mature by 233 mm (L_{95m}) and *ca* 4-5 years old. While some females had changed sex to male below the L_{95m}, the L_{50c} for *N. parilus* collected over shallow and deep reefs was similar (236 mm), when they were *ca* 5.3-5.6 years of age (A_{50c}). However, the majority of female *N. parilus* do not change sex until they are *ca* 283 mm (L_{95c}) and 7.5 years old (A_{95c}), which is thus well above the length and age at which most *N. parilus* reach sexual maturity. The fact that the lengths and ages at

which 50 and 95 % of *N. parilus* reached sexual maturity did not overlap those of the lengths and ages at which 50 and 95 % of females changed sex, respectively, and that all males contained secondary testes, implies that *N. parilus* would be monandric, as implied for the congeneric *N. gymnogenis* (McPherson, 1977; Morton *et al.*, 2008). However, as there is some overlap in the length and age classes of maturing females and of males of *N. parilus*, and as only bisexual *N. parilus* of intermediate length and age, rather than transitional individuals were obtained, such a conclusion cannot be proven, as it does not discount the possibility of males being derived from immature females (see Sadovy de Mitcheson and Liu, 2008).

The vast majority of small and young *N. parilus*, *i.e.* < 160 mm and 3 years old, collected in seagrass beds were females and most fish ≥ 200 mm and 4 years old were male, providing evidence for functional protogyny of this species in seagrass also. Three small bisexual individuals (107-135 mm), which ranged from 1.2-2.0 years of age were identified during histological analysis and one very small male was obtained of 124 mm and 1.9 years of age. This may provide evidence of a bisexual phase in the early life history of this species and the possibility that some individuals change to males from immature females or an early bisexual phase. However, this appears to be rare, as the majority of sex change occurred at lengths ≥ 180 mm and 4 years of age.

In comparison to *N. parilus* collected over reefs, female *N. parilus* in seagrass reached sexual maturity at a smaller length, *i.e.* > 50% were mature in the 120-139 mm length class and at 2 years of age *vs* 170 mm (L_{50m}) and 3 years in reefs. Furthermore, sex change (L_{50c}) in seagrass also occurred at smaller lengths and ages than in reef habitats, *i.e.* 203 mm and 4.4 *vs* 236 mm and 5.4 years. This latter fact may be a function of different growth patterns of *N. parilus* in seagrass, which influence when maturation and sex change take place, based on life history theory and the fact that this species is apparently smaller and shorter lived in

seagrass than reef (see Allsop and West, 2003). The patterns of maturity and sex change may also be influenced by emigration from seagrass habitats when individuals reach a size that is too large for seagrass to provide sufficient protection from predators.

Spawning periods and strategies

The spawning periods of *C. auricularis*, *N. parilus* and *O. lineolatus*, which occurred between April and June, July and October and September and February, respectively, in the JBMP, had little or no overlap. The fact that *C. auricularis* and *N. parilus* are the two most abundant labrids over reefs in the JBMP and that they co-occur with *O. lineolatus* over deep reefs, provides strong evidence that, as each of these labrids spawns at different times of year, they partition their food and spatial resources to reduce potential competition among larvae and juveniles during that crucial period of life.

The sub-tropical Western Australian endemic *Coris auricularis* spawns at a time of year when water temperatures have peaked and are declining (see Ch. 5), while the temperate *N. parilus* spawns when water temperatures are at their lowest and *O. lineolatus* when they are increasing towards the annual maximum in late summer/early autumn. The spawning period of *C. auricularis* also contrasts with the spring/summer spawning period of *Choerodon rubescens*, another sub-tropical W.A. endemic (Fairclough, 2005). While it would not be apparently beneficial to spawn immediately prior to winter, as declining water temperatures would presumably reduce food availability and growth rates, *C. auricularis* is the most abundant fish species recorded over reefs, by both underwater visual census (UVC) and baited remote underwater video (see Chapters 5 and 8), in the JBMP and is thus very successful. Indeed, during UVC, *C. auricularis* was three times more abundant than any other fish species and five times more abundant than *N. parilus*, the second most abundant labrid. It is thus relevant that the vast majority of *C. auricularis* recorded during UVC were small

juveniles < 100 mm in length, indicating that this species may have adapted to the high juvenile mortality rates likely over the winter months by adopting a reproductive strategy of flooding the environment with juveniles.

The timing of the spawning period of *N. parilus* is similar to several other temperate Australasian labrids, including its congeners, *i.e. N. tetricus*, *N. fucicola* and *N. gymnogenis*, and other species, *e.g. Pseudolabrus celidotus* and the large *Achoerodus gouldii* and *Achoerodus viridis*. A recent study of *O. lineolatus* on the east coast of Australia showed that this species spawns at a similar time of year to its conspecifics on the west coast (Morton *et al.*, 2008). In this study, the spawning period of *N. parilus* overlaps those of other labrids in temperate waters, *e.g. N. tetricus* and *Achoerodus viridis*, which occurs from around winter to spring (Barrett, 1995; Gillanders, 1995; Denny and Schiel, 2002). Female *N. parilus* caught over seagrass were found to also have similar spawning periods, *i.e.* from July to October, with spawning peaks in August and September (data not shown). The spawning period of *O. lineolatus* from Western Australia is comparable to that of the same species occurring in Eastern Australia (Morton *et al.*, 2008).

Each of the three labrids is sexually dichromatic, *i.e.* the sexes have different colour patterns, and the males occur typically in the upper length classes, indicating that their assemblages have social structures, which may include harems. In addition, the weights of mature/ripe testes were much smaller than ovaries that were in prespawning and spawning condition. This is a common trait of protogynous labrids, *e.g.* members of the *Choerodon* genus, and of some gonochoristic species, *e.g. Glaucosoma hebraicum* (Hesp *et al.*, 2002; Fairclough, 2005) and indicates that males produce only small amounts of sperm during any one spawning and thus are likely to spawn with only one female at a time (*cf.* Jones, 1981; Adreani *et al.*, 2004). The fact that the spawning periods of *C. auricularis*, *N. parilus* and *O. lineolatus* occur over protracted periods and that the ovaries of their spawning females

contained a combination of yolk granule oocytes, migratory nucleus oocytes, hydrated oocytes and/or post-ovulatory follicles indicates that individual females will spawn on more than occasion during the spawning period, *i.e.* they are multiple spawners. Furthermore, assuming that the mature females of each species are part of a social group, such as a harem, they will spawn on more than one occasion with the same male.

9.4.2 Comparisons of length and age compositions and growth patterns in different habitats

The length and age compositions of *C. auricularis* differed between the shallow and deep reefs, while those of *N. parilus* were similar. Thus, there were a greater number of larger and older male *C. auricularis* collected over deep reefs and the maximum and modal ages in that habitat (10.5 and 6 years) were greater than those over the shallow reefs (9.2 and 5 years). While this may indicate a movement of *C. auricularis* from shallow to deep reefs during their life, it would be unlikely, as labrids are often site attached and occupy a home range, *e.g. Halichoeres bivittatus*, *Notolabrus tetricus*, *Tautoga onitis*, *Thallasoma bifasciatum* (Barrett, 1995; Arendt *et al.*, 2001). Furthermore, although there were greater densities of *C. auricularis* over shallow protected reefs, this species reached larger lengths at age in that habitat, which implies that growth is not inhibited by density and which contrasts with the findings of Gust *et al.* (2002). Those authors demonstrated that, for example, *Scarus frenatus* had greater longevity and larger lengths at age over shallow protected reefs than deeper exposed reefs, where densities of scarids were much greater. Indeed, Gust (2004) found that the protogynous *S. frenatus* also underwent sexual maturation and sex change at smaller lengths and ages in those deep reef habitats. While length and age at sexual maturation of female *C. auricularis* could not be determined separately for shallow and deep reefs, the data did indicate that some individuals were maturing at smaller lengths and

younger ages in shallow reef habitats and sex change did take place at a lower length (L_{50c} 252 vs 267 mm) and younger age (A_{50c} 4 vs 5.4 years) in that habitat. The above facts indicate that a combination of the different availability of resources, competition and predation may be influencing the life history and growth patterns of *C. auricularis* in the different reef habitats. However, it would seem most likely that a greater availability of food resources would contribute most to the greater length at age of this species in shallow reefs and since they reach similar maximum lengths in that environment, the shorter life span merely indicates the completion of their life cycle at a younger age as a result of faster growth and possibly a different natural mortality regime.

This potential difference in resources that *C. auricularis* appears to take advantage of was not evident in the length and age distributions or growth rates of *N. parilus* in reef habitats. However, a difference was detected between those parameters in reef vs seagrass environments. Indeed, the maximum and modal length and age and the lengths at age of *N. parilus* were smaller in seagrass habitats. Although different methods were used to sample seagrass and reef, *i.e.* trawling vs line fishing, and trawling is considered to sample more effectively smaller and slower swimming fish (see Wassenberg *et al.*, 1997; Travers and Potter, 2002), baited remote underwater video employed in seagrass habitats in the JBMP recorded *N. parilus* of similar length to those obtained by trawling (see Chapter 6). This indicates that trawling did sample well the lengths of that species. In addition to the smaller lengths and ages in seagrass, sexual maturation and sex change occurred at a smaller length and younger age in that habitat. While the possibility remains that larger, older individuals emigrate from seagrass to reefs when they reach a size that prohibits the effective use of seagrass as a refuge, such migration would presumably be minimal as (1) labrids commonly occupy home ranges and (2) sampling of seagrass habitats was conducted at substantial distances from reef habitats. Thus, the different degrees of competition and predation and

types and amounts of resources available in seagrass presumably influence the life-history of *N. parilus* in seagrass. Evidence for lower availability of resources was provided by the lower average gut-fullness of *N. parilus* collected in seagrass than reefs.

The three moderately sized labrid species, *C. auricularis*, *N. parilus* and *O. lineolatus*, had similar longevities in the deep reef habitat where they co-occur, *i.e.* 10.5, 9.2 and 10.4 years, respectively, but with the latter species reaching a slightly smaller maximum length, *i.e.* 310 mm *vs* 365 mm for *C. auricularis* and 346 mm for *N. parilus*. In addition, the growth patterns of *N. parilus* and *O. lineolatus* over deep reefs were similar, while that of *C. auricularis* differed by reaching larger lengths at age and by its growth asymptoting less than the former two.

9.4.3 Dietary compositions of *Coris auricularis*, *Notolabrus parilus* and *Ophthalmolepis lineolatus*

Interspecific differences in dietary composition of the three labrids over reefs

The results of stomach content analysis of *C. auricularis*, *N. parilus* and *O. lineolatus* over deep reefs, where they co-occur, demonstrated that they each fed on a large number of prey taxa. However, of the identifiable taxa in their diets, which were primarily invertebrates, *C. auricularis* consumed the greatest variety of taxa, followed by *N. parilus* and then *O. lineolatus*, inferring that the *C. auricularis* is more of a generalist than the latter two. The diets of each of the three species over deep reefs were typified by crustaceans and gastropods, albeit in differing amounts. For example, the composition of the diets of *C. auricularis* was significantly different from those of *N. parilus* and *O. lineolatus*, which did not differ. The diet of the former species was distinguished from the latter two by comprising a greater abundance of small crustaceans, such as amphipods and isopods, while *N. parilus* and *O. lineolatus* consumed more large crustaceans, *e.g.* majids and/or brachyurans. Differences

in the diets of each species are not surprising, given some of the methods that they regularly use to obtain food (pers. obs.). For example, during underwater visual census of the reefs of the JBMP, small to medium-sized *C. auricularis* were commonly seen biting at the reef substrate and ingesting, filtering and spitting out sand from adjacent to the reef, which is indicative of the way it presumably seeks its small crustacean prey. Thus, the diets of *C. auricularis* very frequently contained sand, which occurred in larger volumes than individuals of the other two species. A large amount of sediment is incidentally consumed by the closely-related seagrass-dwelling omnivorous odacine *Haletta semifasciata* during its search for an important prey, *i.e.* polychaetes (MacArthur and Hyndes, 2007). Larger *C. auricularis* and *O. lineolatus* were observed to roam at 1 - 2 m above the substrate, seeking larger more mobile prey. In contrast, *N. parilus* were typically closely associated with the substrate and reef algae, using both as camouflage, prior to ambushing prey (*pers. obs.*), similar to observations by Morton *et al.* (2008) of *Notolabrus gymnogenis*. The diets of *C. auricularis* and *N. parilus* over shallow reefs were similarly different to those of the same species over deep reefs. Thus, *C. auricularis* consumed greater volumes of small crustaceans and gastropods, while *N. parilus* consumed more gastropods and large crustaceans.

The diets of the three species comprise similar taxa to those of other small to moderately-sized temperate labrids of Australia and New Zealand, *e.g. Notolabrus fucicola* (Denny and Schiel, 2001), *Notolabrus tetricus* (Shepherd and Clarkson, 2001), *O. lineolatus* on the east coast of Australia, *N. gymnogenis* and *Pictilabrus laticlavius* (Morton *et al.*, 2008). Morton *et al.* (2008) found that the diet of *O. lineolatus* on the central east coast of Australia was typified by trochid gastropods, bivalves and decapods, which contrasts slightly with the results of this study. For example, of the gastropods *O. lineolatus* consumed, turbinids contributed the most to the dietary volume. Echinoderms and chordates (teleosts) also represented more than 5 % of the volume of their diet. It is noteworthy that soft-bodied

prey items, such as the flesh of teleosts and crustaceans with soft exoskeletons, are digested more rapidly and completely and may therefore be under-represented.

Influence of habitat, season and body size on the diet of each labrid species

The diets of both *C. auricularis* and *N. parilus* differed little among the shallow and deep reef habitats of the JBMP, which does not support the hypothesis that diets differ among those habitats because of the very different environments that they represent. Vanderklift *et al.* (2006) found that, in the JBMP, there was a general increase in the standing crop of the macroalgae *Ecklonia radiata* with increasing distance from shore and a greater abundance of canopy forming algae has been associated with declines in the abundance of invertebrates (Murphy *et al.*, 2006a). Thus, the combination of a denser algal canopy and the harsh environment of the deep reef habitat, which is exposed to the direct force of ocean swell and breaking waves, may lead one to expect, at least, a partially different invertebrate fauna. However, although Murphy *et al.* (2006b) detected dissimilarity in the invertebrate fauna among sites in the JBMP, it was not apparently depth-related and may have been partly a function of the broad groupings of taxa used in their analysis, *i.e.* crustaceans, molluscs, *etc*. The fact that only weak dissimilarity was detected in the diets of both *C. auricularis* and *N. parilus* among the shallow protected and deeper exposed reef habitats is presumably a reflection of the homogeneity of invertebrate fauna that occurs among those reefs. Such homogeneity would be driven by the high potential for dispersal of invertebrate larvae in an environ that consists of strong swell and wind driven water movement. Furthermore, the fact that many prey items comprised fragments of, for example, gastropod or crustacean shell or legs, meant that individual prey items often were not identifiable beyond a high level taxa, such as class or order. This is a result of how labrids crush their food with pharyngeal plates and may have contributed, at least in part, to the limited difference in the dietary composition

of *C. auricularis* and *N. parilus* in different habitats that may actually be occurring at the species level.

While the diets of *N. parilus* were similar among reef habitats, some dissimilarity was detected among individuals in deep reef and seagrass habitats. Gastropods and crustaceans contributed equally to the volume of the diet of this species in each habitat, although there was a greater diversity of gastropods in the diets of reef-dwelling *N. parilus*. Furthermore, the greater volume of macrophytes in the diet of *N. parilus* in seagrass contributed to the dissimilarity between that habitat and the deep reefs. Seagrass was ingested frequently by *N. parilus* in the former habitat, presumably as a consequence of their prey occurring among seagrass leaves and detritus. Such a finding was also demonstrated by MacArthur and Hyndes (2007), who showed that while *N. parilus* and the closely related *Neoodax balteatus* in seagrass are carnivorous, consuming mostly molluscs and crustaceans, low volumes of macrophytes are also accidentally, but frequently consumed. The diet of *N. parilus* caught in seagrass also varied seasonally, unlike any of the three labrids in reef habitats. However, the nMDS plot of *N. parilus* obtained from seagrass demonstrated that the difference was not apparently driven by cyclical changes in the abundance of prey items that typified those seasons, *e.g.* gastropods and large crustaceans. However, the fact that their diets in Autumn were typified by macrophytes, as well as gastropods, may be related to a greater abundance of dead macrophytes occurring in seagrass beds following their annual senescence, *e.g.* that of *Sargassum* spp. in summer (Kendrick and Walker, 1994).

The composition of the diets of each of the three labrids demonstrated length and thus body-size related shifts. Dissimilarity among the dietary composition of different length classes of each species in each habitat was typically due to the difference between the smallest and the largest represented length classes, *i.e.* ≤ 149 mm *vs* 200-249 mm and/or ≥ 250 mm. In the case of *C. auricularis*, *N. parilus* and *O. lineolatus* in reef habitats, the diets

of the small individuals were typified by small crustaceans, such as amphipods and isopods. Large *C. auricularis* were distinguished from those small individuals by consuming a greater volume of a wider variety of prey items, including large crustaceans, echinoderms, annelids and ophiuroids, while large *N. parilus* consumed more gastropods and large crustaceans and *O. lineolatus* consumed gastropods, large crustaceans and echinoids. The diets of small *N. parilus* in seagrass differed from small individuals in reefs by being typified primarily by gastropods, but were distinguished from the largest length class in seagrass by containing greater volumes of bivalves in their diet and less gastropods than the largest length class.

Length or size-related shifts occur commonly in dietary compositions (see Hyndes *et al.*, 1997; Platell *et al.*, 2007; St John, 1999). This is a reflection of a combination of increasing mouth and body size, an improved ability to handle larger and different types of prey and the ability to swim faster and thus capture larger mobile prey, but can also be linked to size-related changes in habitats occupied (Gerking, 1994, Reñones *et al.*, 2002; Schafer *et al.*, 2002; Platell *et al.*, 2007). Such size-related changes in the diet of species that remain in one habitat type throughout their life are commonly detected among their smallest and largest length classes (Platell *et al.*, 1998; MacArthur and Hyndes, 2007; Morton *et al.*, 2008). In contrast to our findings for *N. parilus* in seagrass, MacArthur and Hyndes (2007) did not detect significant size-related shifts in the diets of that species. This may be related to the fact that their samples were obtained from only one seagrass type, *i.e. Amphibolis griffitthii*, while *N. parilus* in this study were collected from a range of seagrass types, *i.e. A. griffitthii*, *A. amphibolis* and *P. sinuosa*, which may have provided a different combination of prey types in the different seagrass structures.

10.0 Movements of Silver Trevally *Pseudocaranx georgianus* and Snapper *Pagrus auratus*, estimated using acoustic telemetry

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10.1 Introduction

The closure of areas to fishing is one method of managing fish stocks that, at least within those areas, will result in an increase in the relative abundance, average length, biomass and/or spawning output of targeted species (Lester *et al.*, 2009). Certain species have been shown to have benefited in some of those ways through such closures, including particular species in Western Australia (see *e.g.* Nardi *et al.*, 2004; Watson *et al.*, 2007). However, spatial management areas in marine waters are often introduced with multiple aims and/or levels of restriction to fishing, which may not have consistently positive effects for all targeted species. For example, Denny and Babcock (2004) found that, 18 years after the establishment of a New Zealand marine park, which allows recreational but not commercial fishing, the abundance and size of the demersal sparid *Pagrus auratus* in that park did not differ from those in areas open to all types of fishing, while the densities of a less targeted species, the benthopelagic carangid *Pseudocaranx dentex*, were greater within the park.

Many marine parks in Western Australia were established with the broad objective of protecting aspects of marine biodiversity through containing areas with different levels of restrictions on their use. However, within those parks, the locations and size of areas closed to fishing and/or their habitat compositions may not be beneficial to targeted fish species. While closed areas with characteristics appropriate for a particular species or phase(s) of a species' life cycle may provide benefits to their stocks, they are unlikely to benefit equally all targeted or non-targeted species in that geographical location. Furthermore, individuals may not always remain inside the boundaries of the closed areas and may use other habitats beyond those boundaries and thus be susceptible to fishing at particular times of the day or

year. For example, Meyer *et al.* (2007) showed that the carangid *Caranx ignobilis* demonstrated both diel variation in habitats occupied and seasonal movements to and from a specific location to spawn.

Site attachment, or the use of geographically-limited areas, *i.e.* home ranges, is a characteristic of many demersal species, *e.g.* labrids and serranids, and some more mobile species, such as the kyphosid *Kyphosus sectatrix* and carangid *Caranx melampygus* (Holland *et al.*, 1996; Zeller, 1997; Eristhee and Oxenford, 2001; Jones, 1984; 2005). Thus, closed areas that encompass the typical home ranges of such species are likely to provide constant protection from fishing to individuals in a particular location and thus potentially allow the benefits of closed areas to be realised. In New Zealand, *P. auratus*, an important target of fishers, have been found in greater numbers in some closed areas than in unprotected areas and in some cases to possess home ranges (Willis and Babcock, 2000; Willis *et al.*, 2001; Parsons *et al.*, 2003; Egli and Babcock, 2004). However, their behaviour is variable, as individuals of that species are known to travel long distances in some parts of Australia (see Fowler *et al.*, 2005; Hamer *et al.*, 2011; Wakefield *et al.*, 2011).

Despite the detailed knowledge of the biology of many targeted fish species in south-western Australia (*e.g.* Hesp *et al.*, 2002; Fairclough, 2005; Moore *et al.*, 2007), an understanding of the movements of their individuals and thus connectivity among stocks is limited. Data on length and age distributions from a range of locations/habitats may reveal that different locations are occupied at different stages of the life cycle. However, they don't provide information on home ranges in those locations or the pathways of movement within and among them (*e.g.* Hesp *et al.*, 2004; Wakefield *et al.*, 2011). Mark-recapture studies in south-western Australia have shown that many individuals of the coastal Australian herring *Arripis georgianus*, migrate long-distances of 100s to 1000s of kilometres, while the demersal *Glaucosoma hebraicum* moves only short distances of 1 to 10 kilometres (Ayvazian

et al., 2004; St John *et al.*, 2009a). However, these types of studies only provide information on the location where fish were tagged and recaptured and not on their specific movements between those times, or, for example, if their movements have a diurnal pattern. The collection of data on whether targeted species in the JBMP have home ranges would allow prediction of whether that marine park's existing "no fishing" zones are located appropriately or are of a suitable size to provide protection to individuals of such species.

Concurrent surveys of the fish fauna of different habitats in the JBMP (see Chapters 5 & 8) demonstrated that many of the species important to fisheries, *e.g. Glaucosoma hebraicum*, *Choerodon rubescens* and *P. auratus*, were relatively rare in that park, including within areas now closed to fishing. However, the Silver Trevally *Pseudocaranx georgianus*, which is an important species in the boat-based recreational fishing sector on the west coast of Australia (Sumner *et al.*, 2008), was found to be abundant in reef, seagrass and sand habitats of the JBMP during the above surveys. This thus provided an opportunity to investigate the movements of a highly mobile, targeted carangid, both within and among areas open and closed to fishing, which each contain different habitats. This study employed acoustic telemetry to investigate the movements of adult *P. georgianus*, which are of a length that would be retained by fishers, and to determine if possible the locations and sizes of their home ranges. The data were used to investigate whether individuals cross the boundary of an area closed to fishing and to test the hypotheses that individual *P. georgianus* occupy multiple habitat types and that their home ranges during the day and night differ in location and size. We also investigated the movements of a few juvenile Snapper *P. auratus*, which were occasionally caught in the same area.

10.2 Materials and methods

Location of tagging sites

The acoustic tagging study was conducted immediately to the south of Jurien Bay (Figs 3.2, 10.1a). Two rocky reef sites among other small inshore reef patches in the Jurien Bay Marine Park were chosen for tagging fish. One reef site, which was located in a marine park zone that is closed to fishing (referred to as a closed area), was located *ca* 500 m from shore in waters of *ca* 5 m depth (Fig. 10.1b). The second site was *ca* 1.4 km further south, in a large area of the marine park that is open to fishing and was 800 m from shore in waters 2-7 m in depth (Fig. 10.1b). Other small reef patches that were closer to shore and to the north of the first site and to the south of the second site, as well as intertidal platforms were present in the area, each being interspersed with expanses of sand and/or seagrass (Fig. 10.1b). Large areas of reef habitat were present only to the west of the tagging locations at a distance of at least 1 km from the most westerly located receiver. Those reef habitats were separated from the tagging sites by large areas of sand and/or seagrass (Fig. 10.1a, b).

Array design

An acoustic receiver array, using 19 Vemco VR3-UWM receivers, was deployed. The array, which had a potential detection area of *ca* 4 km^2, was designed to cover as large an area as possible around the reef habitats and to detect fish movements not only among the reef patches and into adjacent sand and seagrass habitats, but also across the boundary between the areas closed and open to fishing. Each receiver was attached, using rope, between a concrete mooring and float, such that, when deployed, the receiver was *ca* 1.5 m from the substrate and the top float was *ca* 2 m below the surface (Fig. 10.2). Silicone grease was coated over the receiver and underwater modem components to reduce marine fouling.
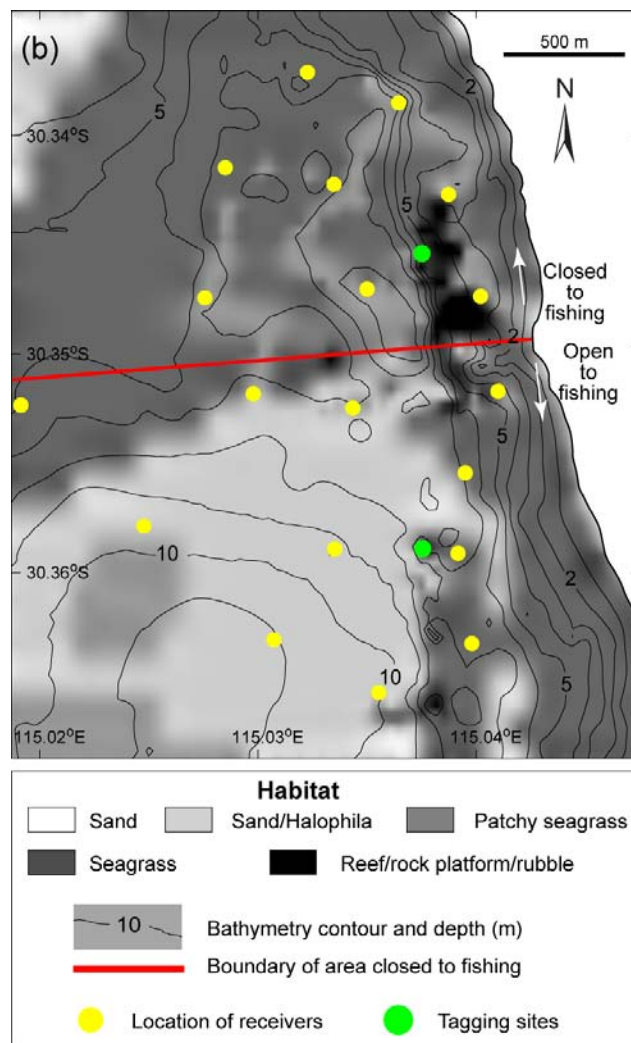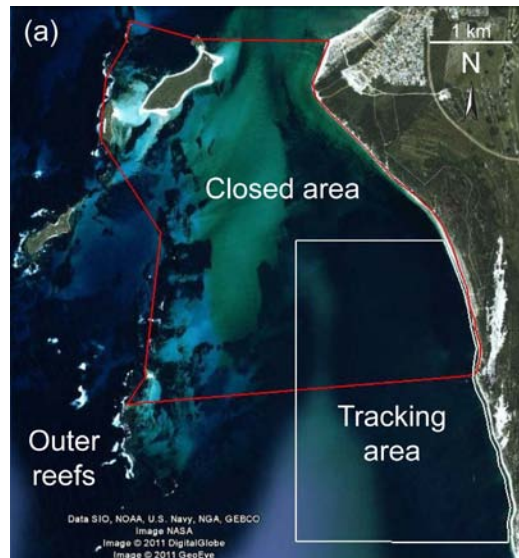
Figure 10.1. (a) Satellite image (Google Earth) of area of the Jurien Bay Marine Park where movement studies were conducted, showing the boundary of the zone closed to fishing (red) and the tracking area, where acoustic receivers were deployed (white). (b) Bathymetric contour map, representing the tracking area and showing locations where acoustic receivers were deployed (yellow) and the reef sites inside and outside the area closed to fishing where fish were tagged (green).

Each receiver was deployed on sand or seagrass substrate away from reef to minimise abrasion of the ropes and any acoustic shadow caused by reef. Receivers were placed *ca* 500 m apart, such that there would be overlap of the theoretical range at which they could detect the lower powered of the two tag types used (V9-2H). An approximately north-south line of inshore receivers (1-7) was deployed in waters of *ca* 2-7 m depth to encompass movements along the isolated reef patches at those depths (Fig. 10.1b). Another line (8-13) was placed to the west of the above line below *ca* the 6 m bathymetric contour, while receivers 14-19 were placed further to the west in waters of 5-10 m, comprising sand/seagrass substrate (Fig. 10.1b). Those receivers were placed such that they could detect movements to the west of the inshore reefs and into deeper seagrass or sand habitats.

Range testing

Tests by VEMCO indicate that VR3-UWM receivers should detect the tags used, *i.e.* Vemco V9-2H-R04K and V13-1H-R04K at 69kHz, at distances of 282 and 406 m, respectively (http://www.vemco.com/education/range.php), in environmental conditions with wind strengths of 28-34 knots. Such wind strengths are similar to the average of at least 30 knots that occurs on the mid-west coast of Australia during summer (http://www.bom.gov.au/cgi-bin/climate/cgi_bin_scripts/windrose_selector.cgi). However, other environmental conditions, *e.g.* turbidity or marine noise, may also influence the detection range (Heupel *et al.*, 2006; Payne *et al.*, 2010). Thus, range testing was conducted with the lower powered tag type (V9-2H). A V9-2H tag was attached to a mooring rope at *ca* 2 m above the substrate and placed at consecutive distances, *i.e.* 0, 100, 200, 300, 400, 500, 600 and 700 m, from each of three receivers for periods of at least 3 h, such that three replicate data sets were obtained for the number of tag detections at each distance. There were no physical obstructions between the

298
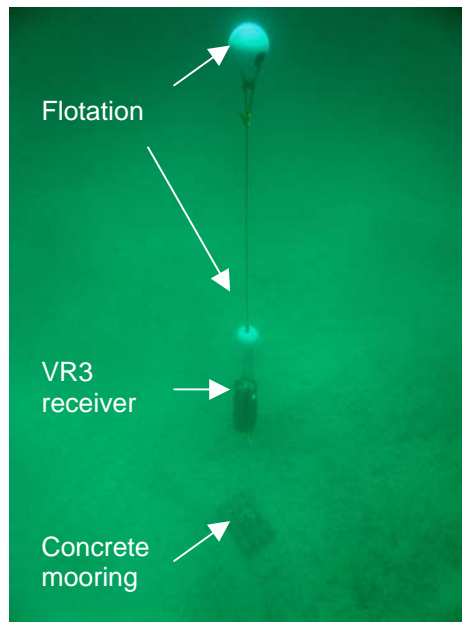
Figure 10.2. Design of mooring system for Vemco VR3 acoustic receivers.

location of the tag and any of the receivers. However, environmental conditions did vary during range testing.

Fish tagging

Fish were caught by line fishing, using barbless hooks, between late September and early December 2006. Two *P. georgianus* and three *P. auratus* were tagged at the reef site in the closed area, while 10 *P. georgianus* and one *P. auratus* were tagged at the reef site in the area open to fishing (Table 10.1). The *P. georgianus* were ≥ the lengths at sexual maturity (L_{50}) of both females (328 mm TL) and males (256 mm TL) on the mid-west coast (Farmer *et al*., 2005), while the four juvenile *P. auratus* were ≤ the L_{50}s of females and males on the lower west coast (585 and 566 mm, respectively; Wakefield, 2006).

Following capture, individual fish were immediately placed in a 130 L round plastic tank (58 cm diameter × 46 cm high), containing 80 L of aerated sea water at ambient

Table 10.1. Species tagged, tagging site ("closed" to fishing; "open" to fishing), date and time of tagging, total/fork lengths, calculated total weights (TW, from length-weight relationships) and Vemco tag type used.

Species	Fish number	Tagging Site	Date	Time (24 hr)	Total/fork length (mm)	Calculated total weight (g)	Tag type
P. georgianus	1	Closed	9/10/06	7:50	345	470.1	V9
P. georgianus	2	Closed	9/10/06	7:50	350	490.8	V9
P. georgianus	3	Open	10/10/06	18:28	420	846.8	V9
P. georgianus	4	Open	27/10/06	6:50	355	512	V9
P. georgianus	5	Open	14/11/06	16:45	350	490.8	V9
P. georgianus	6	Open	15/11/06	18:40	330	411.5	V9
P. georgianus	7	Open	15/11/06	16:30	370	579.5	V9
P. georgianus	8	Open	15/11/06	16:49	380	627.7	V9
P. georgianus	9	Open	15/11/06	17:35	423	846.8	V13
P. georgianus	10	Open	4/12/06	8:08	379	627.7	V13
P. georgianus	11	Open	4/12/06	7:34	386	652.7	V13
P. georgianus	12	Open	4/12/06	7:51	390	678.4	V13
P. auratus	13	Closed	20/9/06	7:10	309	613	V9
P. auratus	14	Closed	8/10/06	17:46	233	278	V9
P. auratus	15	Closed	8/10/06	17:30	286	491	V9
P. auratus	16	Open	15/11/06	17:50	264	393	V9

temperature and the anaesthetic clove oil at a concentration of 0.27 ml L^{-1} water (Munday and Wilson, 1997; Fig. 10.3a). Fish took approximately 60 sec to reach stage II anaesthesia, *i.e.* fish had total loss of equilibrium, floated upside down on the surface and did not respond to physical stimulation, but their operculae still opened and closed regularly at a reduced rate (Summerfelt and Smith, 1990 cited in Carter *et al.*, 2011; Munday and Wilson, 1997). Fish were removed from the anaesthetic and the total and fork lengths of *P. georgianus* and *P. auratus*, respectively, were measured to the nearest 1 mm. Weights of *P. georgianus* and *P. auratus* were estimated from their lengths using the existing length-weight relationships of Farmer *et al.* (2005) and Wakefield (2006). Fish were then placed ventral-side-up in a v-shaped channel cut into a foam block, which was covered in wet plastic. A sterile No 4 scalpel dipped in Betadine® (10% w/v Povidone-Iodine; FH Faulding & Co. Ltd.) was used to make a 2 cm incision through the abdominal wall approximately 2 cm anterior of the cloaca and 1 cm to the right of the ventral mid-line. Vemco V9-2H coded transmitters (30 mm length, 3.1 g weight in water) were inserted into the abdominal cavities of eight *P. georgianus* and the four *P. auratus*, while four *P. georgianus* received Vemco V13-1H

transmitters (36 mm length, 6 g weight in water) (Table 10.1). Incisions were closed with two square knots (Wagner *et al.* 2011) using size 3.0 metric ETHICON Inc. coated VICRYL* violet braided (Polyglactin 910) 90 cm absorbable sutures with a 36 mm reverse cutting needle (Note, the first *P. auratus* was stitched with a non-absorbable suture). During this process, the gills were irrigated with fresh sea water. After surgery, fish were tagged with a T-bar anchor tag (Hallprint) in the dorsal musculature and given an intra-peritoneal injection of the antibiotic ALAMYCIN LA-200 (200 mg/mL Oxytetracycline; Norbrook Laboratories Ltd., U.K.) at a dose of 50 mg kg^{-1} fish (McFarlane and Beamish, 1987). Tagged fish were placed in a recovery tank (dimensions as described above) of aerated seawater for an average of 6 min, after which time, all fish had regained equilibrium and were swimming strongly. Fish were immediately released to minimise stress associated with confinement in a restricted space. Note that one *P. auratus* was recaptured 2 weeks after tagging. The incision in the abdomen of that fish was clean and had healed over and the fish appeared healthy (Fig. 10.3b). The V9-2H and V13-1H tags each had a random delay of 20-60 s (average 40 s) between when they each emitted a consecutive signal and the two tag types had effective battery lives of 50 and 150 days, respectively.

Figure 10.3. (a) Tank used to hold fish for anaesthetising and recovery process. (b) *Pagrus auratus* recaptured two weeks after surgery displaying extent of healing at incision location.

Collection of data

The underwater modem system of the VR3-UWM receivers is designed for downloading data *in situ*. This system was trialled during this study and found to have problems in the shallow waters of the study location (mostly < 7 m). As the boat would swing widely on anchor, because of prevailing strong winds, and it is too difficult, if not at anchor, to hold a constant position in the rough seas caused by those winds, the modem could only rarely connect to receivers *in situ*, which occurred during good weather conditions. The modem has a 120° arc, under which it can detect the receivers in the water. In rough seas and shallow water it is too difficult to maintain that arc and thus prevents the modem connecting. Furthermore, large quantities of data were recorded by some receivers and the time required to download those data was very substantial, *i.e.* >> 1 h. Thus, on most occasions, receivers were removed from the water to download data.

Analysis of range test data

Data collected by the three receivers during the range test were downloaded. The number of detections per hour from the three receivers, at each distance, *i.e.* 0, 100, 200, 300, 400, 500, 600 and 700 m, was determined to gain an understanding of the attenuation of sound emitted from a V9 tag in relation to distance from the tag in the Jurien environment.

Analysis of patterns of tag detections

The "tracking period" of each tagged fish, *i.e.* the number of days between the date of release of the tagged fish and the date of last detection on any receiver of that fish, was determined. The percentage of time that each fish was present within the array during its tracking period was calculated (number of days that the fish was detected within the array/tracking period). Means of the number of detections per day or night were determined

for data collected during the first 50 or 150 days for fish tagged with V9 and V13 tags, respectively, *i.e.* during the expected life of the tags (hereafter referred to as "tag-life"). Day was considered to include the time from one hour after sunrise to one hour before sunset, while night comprised the time from one hour after sunset to one hour before sunrise and thus did not include the crepuscular period. For each fish, the number of detections of its tag at each receiver during each day and night, was determined for the period of its tag-life.

Home range estimation

For each fish, a weighted average estimate of its position (mean latitude and longitude) was determined for each hour during its tag life, *i.e.* 50 days for V9 tags and 150 days for V13 tags, using the method of Simpfendorfer *et al.* (2002), as follows:

$$Mean\ latitude = \left[\sum_{i=1}^{n} (d \times Latitude) \right] / D,$$

$$Mean\ longitude = \left[\sum_{i=1}^{n} (d \times Longitude) \right] / D,$$

where n = the number of receivers which, during each hour, detected the tag, d is the number of detections at each receiver, D is the total number of detections at all receivers in that hour and *Latitude* and *Longitude* are in decimal degrees.

The home range (km^2) of each *P. georgianus* and *P. auratus* was determined during the day and night for the period of its tag-life using kernel-based utilisation distribution methods, employing the *kernelUD* function in the *adehabitat* package in R (R Development Core Team, 2005; Calenge, 2006; Worton, 1995). Hourly mean estimates of the latitude and longitude position of each fish were converted to eastings and northings and using the smoothing parameter of $h = 140$ (which produced continuous home ranges in almost all cases), 95 % probability estimates of its home range size and location were estimated. The 95 % probability estimate of the home range of each fish (95 % utilisation distribution or

95 % UD) during the day and night were overlaid on habitat maps of the tracking area to gain

an understanding of area and habitat use. The extent (%) of overlap of the 95% UDs for each

fish during the day and night were determined using the *kerneloverlaphr* function in R and

Bhattacharyya's affinity method (Fieberg and Kochanny, 2005; Kochanny *et al.*, 2009). The

extent to which the 95 % UD of each fish during both the day and night overlapped that of

each other fish was determined using the same method.

10.3 Results

Range testing

During range testing, the number of tag detections recorded by each of the three

receivers, when the tag was placed consecutively at each receiver, *i.e.* at 0 m, varied from

$34 - 86$ h^{-1} (Fig. 10.4). At a distance of 100 m from the receivers, the number of

detections h^{-1} varied widely ($1 - 73$ h^{-1}), while very few detections were recorded at 200 m

($0 - 18$ h^{-1}). At 300 m, only nine detections were recorded by all three receivers and none was

recorded beyond 300 m (Fig. 10.4). Environmental conditions, *e.g.* wind strength,
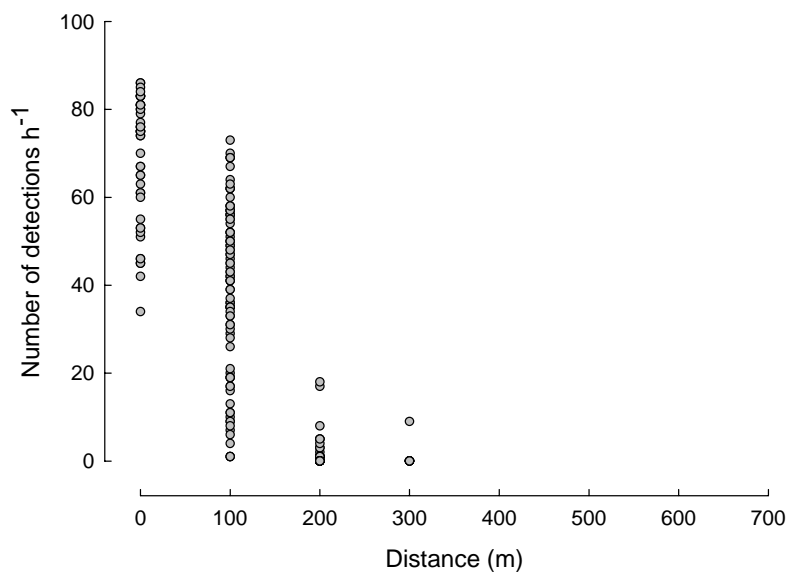
Figure 10.4. Combined number of detections h^{-1} for a V9 tag recorded by three receivers when placed at 100 m intervals, from 0 to 700 m, from each receiver.

varied while the tag was at each distance from each receiver. The number of detections recorded per hour at each distance for all three receivers indicated the variability in range likely to be experienced during the fish movement study. The low number of detections at 200 m indicates that fish would be detected primarily at distances less than 200 m from a receiver.

Summary of fish detections and diel pattern of detections

  Pseudocaranx georgianus, tagged with V9 and V13 tags, were tracked for between 44 and 306 days and between 269 and 356 days, respectively, while *P. auratus* tagged with V9 tags were tracked for between 134 and 356 days (Table 10.2). The total tracking period for all but one fish was much greater than the expected tag life. However, the number of detections per day typically declined following the expiration of the expected tag life. Individuals of *P. georgianus* were detected on 42 - 100 % of the days and 36 - 100 % of the nights during their tracking periods. The majority of individuals were detected on at least 88 % of days and 70 % of nights. *Pagrus auratus* were recorded on 98 - 100 % of days and 52 - 100 % of nights during their tracking periods (Table 10.2). The mean number of detections per day of individual *P. georgianus* and *P. auratus* varied widely, *i.e.* 12-313 d^{-1} and 129-364 d^{-1}, respectively. The mean number of detections per night for both species was typically less than per day. However, a greater mean number of detections were recorded at night for two *P. georgianus* (Table 10.2).

  Throughout their tracking periods, individuals were always detected at more receivers during the day than at night. *Pseudocaranx georgianus* was detected at between 5 and 10 of the total 19 receivers during the day and at between one and 7 at night, while *P. auratus* was detected at 7-9 and 5-7 receivers during the day and night, respectively. The majority of detections (≥ 95 %) of each fish was recorded at between one and five receivers during both

the day and night (Table 10.2). For two of the 12 *P. georgianus*, ≥ 95 % of their detections were recorded at only one receiver during the day throughout their tracking periods, while at night, ≥ 95 % of detections of eight fish were recorded at only one receiver.

Home range areas

Estimated home range sizes of individual *P. georgianus* tagged in "open" waters varied from 0.49 to 1.29 km^2 during the day, while at night, they were typically smaller, ranging from 0.37 to 1.61 km^2 (Table 10.3; Fig. 10.5). The two *P. georgianus* tagged in the closed area had 95 % utilisation distributions (UD) during the day and night similar in size to those from the area open to fishing (Table 10.3; Fig. 10.5). The estimated 95 % UDs during the day of the four *P. auratus* ranged from 0.86-1.38 km^2 and similar, but typically slightly smaller 95 % UDs were occupied at night (Table 10.3; Fig. 10.6). The area (95 % UD) occupied by each *P. georgianus* during the day overlapped the area it occupied at night by 19-93 %, with the majority overlapping by ≥ 67 % (see *e.g.* Fig. 10.5). Similarly, the areas occupied by the four *P. auratus* during the day overlapped that at night by ≥ 59 % (Table 10.3; Fig. 10.6).

The area of the 95 % UDs occupied during the day by the ten *P. georgianus* tagged at the reef site open to fishing, overlapped that of each other by 4 to 93 %, with most pairs of fish overlapping by at least 60 % (Table 10.4). There was a 93 % overlap of the UDs of the two *P. georgianus* tagged in the area closed to fishing. However, there was little overlap (0-29 %) of the UDs of those two fish with the *P. georgianus* tagged at the reef open to fishing. The 95 % UDs of the three *P. auratus* tagged at the reef site closed to fishing overlapped each other by 51-82 %, and that of the *P. auratus* tagged at the site open to fishing by 20-64 % (Table 10.4).

Table 10.2. Species tagged, tagging site ("closed" to fishing; "open" to fishing), tracking period (days) of each fish and, for the expected tracking period, the percentage of days/nights that the fish was detected within the receiver array, the mean number of detections of each fish per day/night, the number of receivers that detected the fish during the day/night and the minimum number of receivers that, combined, detected ≥ 95 % of total detections per fish during the day/night.

Species	Fish no	Tagging Site	Tag type (expected tracking period, days)	Tracking period (days)	% days within array during tracking period	% nights within array during tracking period	Mean no. detections day^{-1}	Mean no. detections night^{-1}	Number of receivers detecting fish during the day	Number of receivers detecting fish during the night	Min. no. of receivers detecting ≥ 95 % of total detections during the day	Min. no. of receivers detecting ≥ 95 % of total detections during the night
P. georgianus	1	Closed	V9 (50)	44	95	36	39	2	10	5	5	4
P. georgianus	2	Closed	V9 (50)	181	88	98	265	73	9	5	4	3
P. georgianus	3	Open	V9 (50)	222	98	100	313	340	8	6	3	1
P. georgianus	4	Open	V9 (50)	126	42	42	47	44	6	1	3	1
P. georgianus	5	Open	V9 (50)	306	88	96	12	8	5	1	1	1
P. georgianus	6	Open	V9 (50)	105	74	70	47	26	7	3	4	2
P. georgianus	7	Open	V9 (50)	148	100	100	101	210	9	7	3	1
P. georgianus	8	Open	V9 (50)	221	100	90	54	41	8	7	3	5
P. georgianus	9	Open	V13 (150)	356	74	74	53	35	8	5	3	1
P. georgianus	10	Open	V13 (150)	269	100	100	57	53	9	5	4	1
P. georgianus	11	Open	V13 (150)	278	100	100	77	50	9	4	5	1
P. georgianus	12	Open	V13 (150)	338	100	100	74	80	9	6	1	1
P. auratus	13	Closed	V9 (50)	260	100	92	130	68	9	5	5	3
P. auratus	14	Closed	V9 (50)	134	100	98	250	43	9	7	4	3
P. auratus	15	Closed	V9 (50)	204	98	52	129	5	9	6	4	3
P. auratus	16	Open	V9 (50)	356	100	100	364	70	7	5	2	3

During the night, the area of the 95 % UDs for the ten *P. georgianus* tagged at the reef

site open to fishing overlapped each other by at least 85 %, except in the case of one fish

(#8), whose 95 % UD overlapped the others by 43-63 % (Table 10.5). The 95 % UDs of the

two *P. georgianus* tagged in the area closed to fishing overlapped each other by 89 %, but did

not overlap those of nine of the *P. georgianus* tagged at the reef open to fishing. They did

overlap, however, that of fish #8 by 41 and 45 %. The 95 % UDs of the three *P. auratus*

tagged at the reef site closed to fishing overlapped each other by 65-84 %, and that of the

P. auratus tagged at the site open to fishing by 36-61 % (Table 10.5).

Table 10.3. 95 % probability estimates of home range area (km^2) for each *Pseudocaranx georgianus* and *Pagrus auratus* during the day (UD_{95d}) and night (UD_{95n}) based on and kernel utilisation distributions. *fish tagged in area closed to fishing, #fish only detected on one receiver either during the day or night.

Species	Fish number	Tagging Site	UD_{95d}	UD_{95n}	% overlap
P. georgianus	1*	Closed	1.15	0.58	19
P. georgianus	2*	Closed	1.07	0.77	42
P. georgianus	3	Open	1.19	0.42	81
P. georgianus	4	Open	1.10	0.37[#]	86
P. georgianus	5	Open	0.49	0.37[#]	93
P. georgianus	6	Open	1.28	0.75	72
P. georgianus	7	Open	0.89	0.40	82
P. georgianus	8	Open	0.75	1.61	67
P. georgianus	9	Open	1.29	0.40	61
P. georgianus	10	Open	1.03	0.42	84
P. georgianus	11	Open	1.28	0.37	81
P. georgianus	12	Open	0.61	0.37	91
P. auratus	13*	Closed	1.26	1.12	82
P. auratus	14*	Closed	1.38	0.94	59
P. auratus	15*	Closed	1.33	1.26	76
P. auratus	16	Open	0.86	1.10	84

Locations of home ranges and habitat use

During the day, the estimated home ranges of the two *P. georgianus* tagged in the

area closed to fishing extended southwards from the tagging site into the area open to fishing

and almost as far south as the tagging site in that latter area (Fig. 10.5a, b). Those home

ranges comprised reef, seagrass and some sand habitats in waters of *ca* 1-8 m. In contrast, at

night the home ranges of those fish were estimated to be smaller, almost exclusively south of

the area closed to fishing and extending further westwards than during the day. While the habitats occupied at night were in similar depths and also comprised reef and/or rock substrate, the habitat further to the west comprised more patchy seagrass and sand with some *Halophila* seagrass. During the day, the home ranges of the 10 *P. georgianus* tagged at the site open to fishing comprised reef/rock, seagrass and/or sand to the north, south, east and/or west of that site and were thus located in waters of *ca* 2 to 10 m deep (see *e.g.* Fig. 10.5c, d). However, the home range of all but two of those *P. georgianus* at night was less than during the day and was located immediately to the west of the tagging site, which comprised predominantly patchy seagrass and/or sand in waters > *ca* 7-11 m deep (see *e.g.* Fig. 10.5d). In fact, ≥ 95 % of detections of those fish were recorded at the one receiver to the west of that reef site.

The estimated home ranges during the day of each of the three *P. auratus* tagged at the site in the area closed to fishing were similar in location and size and, like the *P. georgianus* tagged at that site, extended southwards into the area open to fishing, but also, in some cases, extended slightly northwards (Fig. 10.6a-c). The data indicated that this species also used a variety of habitats in waters *ca* 1-8 m deep. During the night, the home ranges of those three fish were similar in location and size to those occupied during the day and also extended both north and south of the closed area boundary. However, one individual's home range at night was smaller and mainly south of the closed area boundary (Fig. 10.6a-c). The *P. auratus* tagged at the site open to fishing remained almost exclusively south of the closed area boundary both during the day and night, occupying a variety of habitats in *ca* 2-10 m of water (Fig. 10.6d).

Table 10.4. Percentage overlap, calculated using the Bhattacharyya method, of the 95 % kernel utilisation distributions during the day of each *Pseudocaranx georgianus* and *Pagrus auratus*. *P. g*, *P. georgianus*, *P. a*, *P. auratus*. *tagged in the area closed to fishing.

Species	Fish no.	P. g 1*	P. g 2*	P. g 3	P. g 4	P. g 5	P. g 6	P. g 7	P. g 8	P. g 9	P. g 10	P. g 11	P. g 12	P. a 13*	P. a 14*	P. a 15*	P. a 16
P. g	1*																
P. g	2*	0.93															
P. g	3	0.25	0.23														
P. g	4	0.00	0.00	0.80													
P. g	5	0.00	0.00	0.82	0.88												
P. g	6	0.11	0.09	0.60	0.68	0.54											
P. g	7	0.00	0.00	0.76	0.91	0.83	0.76										
P. g	8	0.00	0.00	0.09	0.29	0.04	0.61	0.41									
P. g	9	0.29	0.26	0.79	0.62	0.64	0.73	0.61	0.14								
P. g	10	0.10	0.08	0.84	0.82	0.85	0.67	0.76	0.04	0.82							
P. g	11	0.13	0.11	0.87	0.80	0.85	0.68	0.76	0.06	0.85	0.92						
P. g	12	0.01	0.00	0.82	0.87	0.93	0.59	0.82	0.04	0.70	0.89	0.88					
P. a	13*	0.70	0.69	0.26	0.01	0.00	0.07	0.00	0.00	0.27	0.08	0.12	0.00				
P. a	14*	0.83	0.82	0.32	0.01	0.00	0.14	0.00	0.00	0.37	0.13	0.18	0.01	0.82			
P. a	15*	0.46	0.46	0.10	0.00	0.00	0.03	0.00	0.00	0.11	0.03	0.05	0.00	0.71	0.51		
P. a	16	0.53	0.50	0.70	0.31	0.33	0.38	0.30	0.01	0.69	0.49	0.54	0.35	0.49	0.64	0.20	

Table 10.5. Percentage overlap, calculated using the Bhattacharyya method, of the 95 % kernel utilisation distributions during the night of each *Pseudocaranx georgianus* and *Pagrus auratus*. *P. g*, *P. georgianus*, *P. a*, *P. auratus*. *tagged in the area closed to fishing, [#]fish detected on only one receiver during the night.

| Species	Fish no.	P. g 1*	P. g 2*	P. g 3	P. g 4	P. g 5	P. g 6	P. g 7	P. g 8	P. g 9	P. g 10	P. g 11	P. g 12	P. a 13*	P. a 14*	P. a 15*	P. a 16
P. g	1*																
P. g	2*	0.89															
P. g	3	0.00	0.00														
P. g	4[#]	0.00	0.00	0.94													
P. g	5[#]	0.00	0.00	0.94	0.95												
P. g	6	0.00	0.00	0.85	0.85	0.85											
P. g	7	0.00	0.00	0.94	0.94	0.94	0.85										
P. g	8	0.41	0.45	0.43	0.43	0.43	0.63	0.43									
P. g	9	0.00	0.00	0.94	0.94	0.94	0.85	0.94	0.43								
P. g	10	0.00	0.00	0.94	0.94	0.94	0.85	0.94	0.43	0.94							
P. g	11	0.00	0.00	0.94	0.94	0.94	0.85	0.94	0.43	0.94	0.94						
P. g	12	0.00	0.00	0.94	0.94	0.94	0.85	0.94	0.43	0.94	0.94	0.95					
P. a	13*	0.80	0.89	0.00	0.00	0.00	0.00	0.00	0.41	0.00	0.00	0.00	0.00				
P. a	14*	0.87	0.90	0.00	0.00	0.00	0.00	0.00	0.48	0.00	0.00	0.00	0.00	0.84			
P. a	15*	0.67	0.65	0.00	0.00	0.00	0.00	0.00	0.31	0.00	0.00	0.00	0.00	0.73	0.65		
P. a	16	0.43	0.54	0.55	0.55	0.55	0.50	0.55	0.63	0.55	0.55	0.55	0.55	0.53	0.61	0.36	
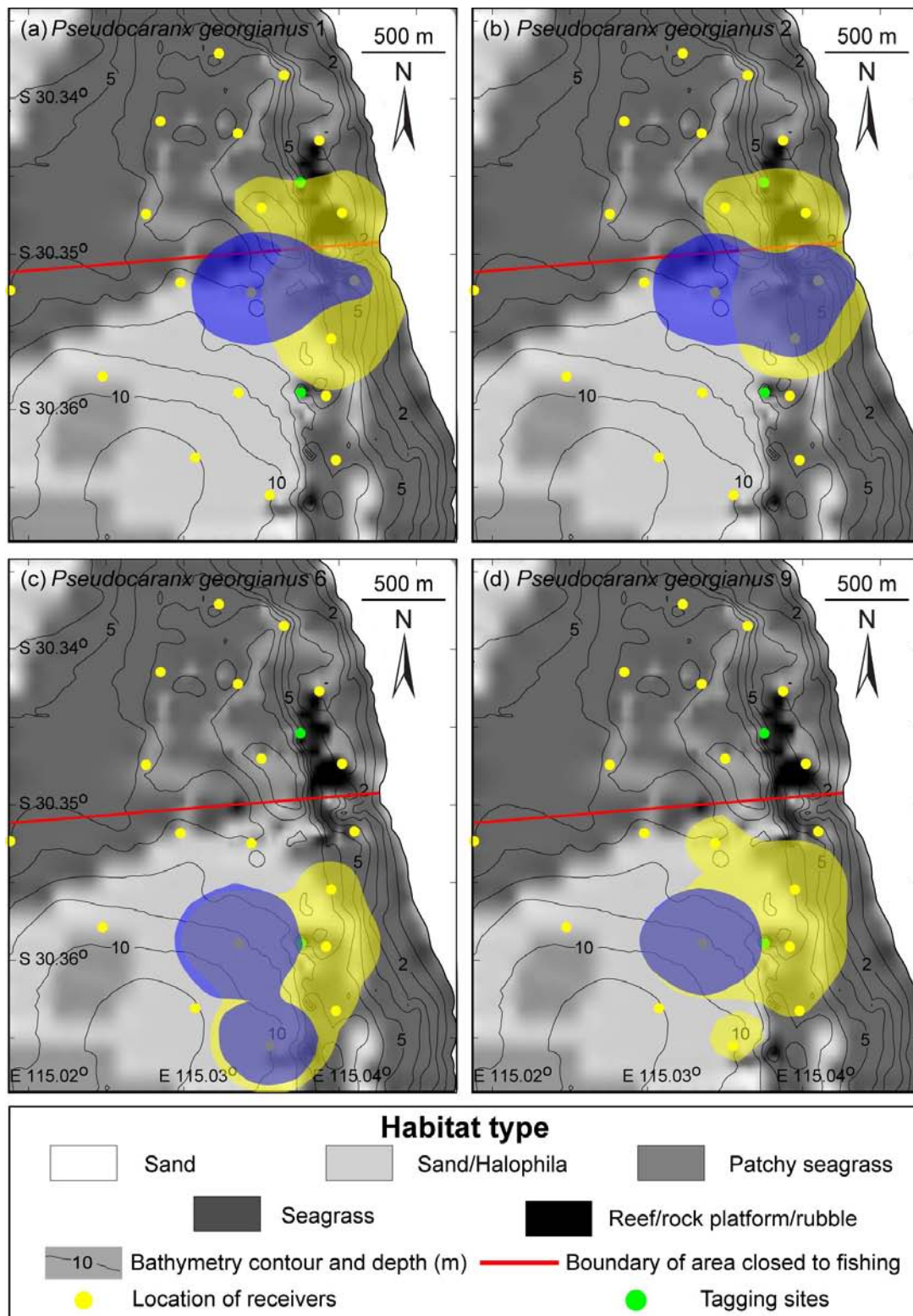
Figure 10.5. Area of estimated 95 % probability distributions (home ranges) during the day (yellow) and night (blue) of two *Pseudocaranx georgianus* tagged in the area closed to fishing (a, b) and two in the area open to fishing (c, d).
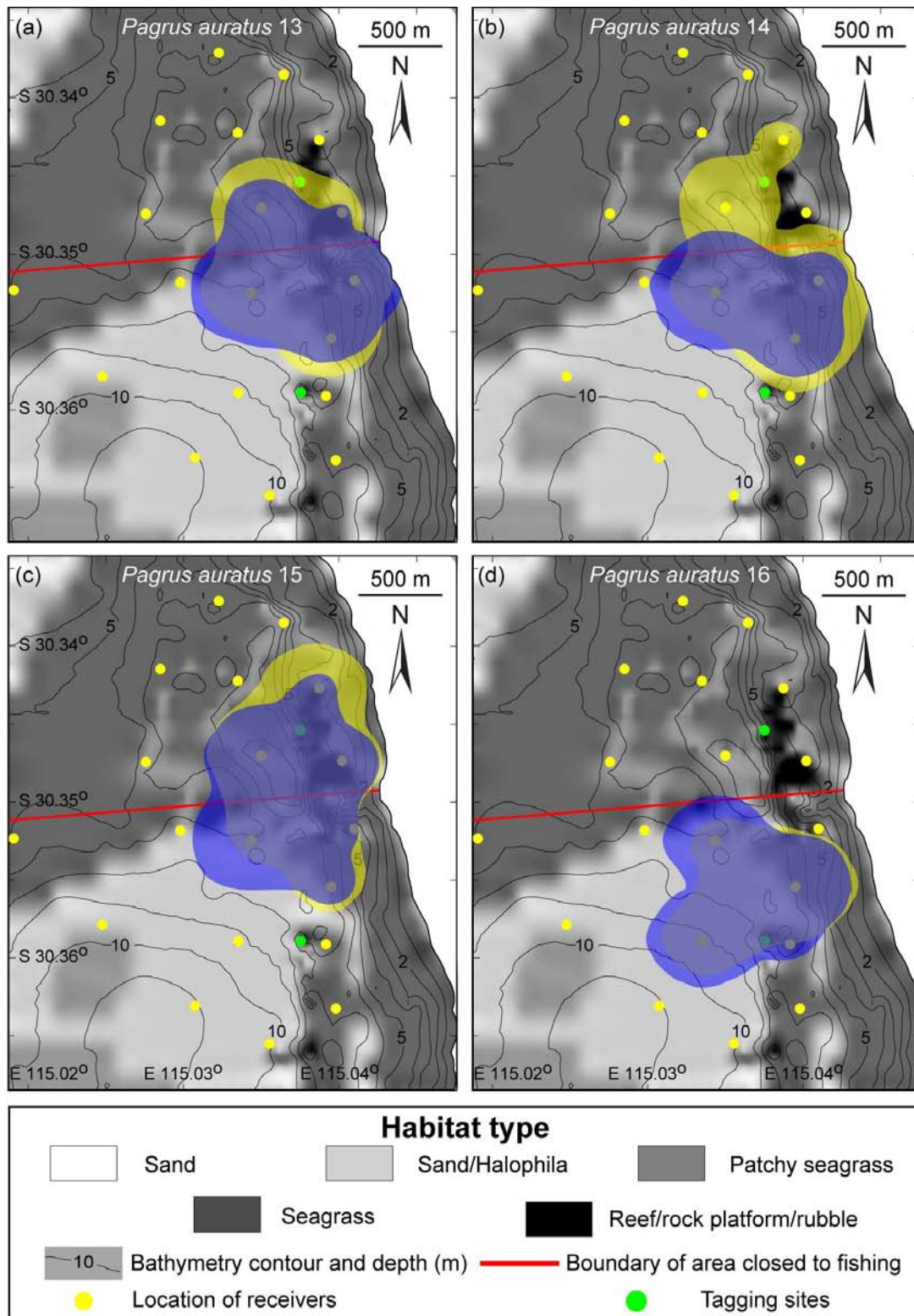
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Figure 10.6. Area of estimated 95 % probability distributions (home ranges) during the day (yellow) and night (blue) of three *Pagrus auratus* tagged in the area closed to fishing (a, b) and one in the area open to fishing (c, d).

10.4 Discussion

This study investigated the movements of adults of the benthopelagic carangid *Pseudocaranx georgianus* and juveniles of the demersal sparid *Pagrus auratus*. The two tag types used allowed us to track eight *P. georgianus* for 50 days and four for 150 days, while four *P. auratus* were tracked for 50 days. The data showed that the adults of *P. georgianus* and the juveniles of *P. auratus* occupied small home ranges during the day and night, *i.e.* $\leq ca$ 1.6 km^2. Although the two tag types, *i.e.* V9 and V13, had an expected life of only 50 and 150 days, respectively, they continued to function after those time periods. Fish with V9 tags were detected for between 105 and 356 days, except in one case (44 days), while those with V13 tags were detected for 269-356 days. The continued functioning of the tags revealed that fish remained within the area of the receiver array for a much longer period than the expected tag life and may have maintained the home range estimated during the 50 or 150 day period. The detections of only one *P. georgianus* (#1, Table 10.2) indicated that it had left the array after a limited time, *i.e.* 44 days. The last few detections of that fish were recorded sequentially from within the array southwards to the most southern receiver, suggesting that that fish moved in a southerly direction out of the array.

Pseudocaranx georgianus

Although the home ranges during the day of each *P. georgianus* were $\leq$ 1.3 km^2, encompassed a range of habitat types, including reef/rock, seagrass (*Posidonia sinuosa* and/or *Amphibolis* spp.) and sand with *Halophila* sp. seagrass and were located in depths of *ca* 1-11 m. This indicates that individuals are likely to forage opportunistically in different habitats during the day. The data also demonstrated that, at least in the case of the *P. georgianus* tagged at the reef site open

to fishing, each individual remained relatively close to the reef where they were tagged and that during the day their movements remained centralised around that reef. Furthermore, their home ranges did not extend long distances into expanses of either seagrass or sand or as far as the reefs, which lay a few kilometres to the west.

In most cases, the home ranges at night of each *P. georgianus* tagged at the reef site open to fishing were not only smaller than during the day, but were also often in deeper water to the west of the tagging sites. Most of those fish were detected only at one receiver that lay immediately to the west of the reef site, in habitats comprising patchy seagrass and/or sand, which may be related to their avoidance at night of habitats, such as reef, that may be occupied by nocturnal predators. Another carangid, *Caranx melampygus*, was shown to undertake predictable movement in Hawaii (Holland *et al.*, 1996). However, in contrast to *P. georgianus*, the location occupied by *C. melampygus* at night was separate to that occupied during the day. As movement studies have shown that tag detection can be reduced at night, due to noise from marine organisms, estimates of home ranges at night may not always be accurate (Payne *et al.*, 2010). However, although the home ranges estimated at night for *P. georgianus* in this study may be underestimated for the above reason, range testing demonstrated that the V9 tags could be detected at no more than 100-200 m away, which implies that fish had to swim relatively close to receivers to be detected during the day. Fish would not have been detected during the day by a range of receivers if they had remained in the same small area estimated to be their home range at night, as the receivers were located *ca* 500 m away from that location and thus beyond the range of the tags. This provides strong evidence that the smaller estimated home ranges at night are essentially valid, but may represent a slight underestimation.

The home range areas of the 10 *P. georgianus* tagged at the reef site open to fishing did not overlap the boundary of the area closed to fishing, which thus demonstrates that those fish were not protected at any time. Furthermore, during the day the home ranges of the fish tagged at the reef site closed to fishing extended into the area open to fishing and during the night were almost exclusively south of that closed area, thus also providing limited protection. The reef site at which they were tagged essentially represented the northern extent of their home range and thus may provide limited resources for *P. georgianus*. Their estimated home ranges only partly overlapped those of the fish tagged at the reef open to fishing, indicating there are other suitable reef habitats in the area. However, the presence of few reefs within the boundaries of the closed area demonstrates that it may provide limited benefit to *P. georgianus*.

The data collected demonstrate that large closed areas are probably not required to protect individuals of *P. georgianus*, but their locations need to encompass the types of habitats that this species occupies, if the stocks of this species require greater protection. However, although large areas may not be required for *P. georgianus*, it is not known what carrying capacity a small closed area would have and thus whether such closed areas would provide benefits at the stock level. The small home ranges of *P. georgianus* contrasts with those of the much larger carangid, *Seriola hippos*, in south-western Australia. Thus, while spawning aggregations of *S. hippos* occur at the same location each year and thus the species may have a restricted home range during that period, they can travel very long distances (> 2000 km) outside the spawning period (Rowland, 2009). The tagging experiments of Afonso *et al.* (2009) showed that the behaviour of *Pseudocaranx dentex* was highly variable, with fish on offshore reef pinnacles having small home ranges, while home

ranges of those found along inshore coastal reefs were much larger and also much greater than those of *P. georgianus* in this study. This raises the question of whether the movements and sizes of the home ranges of *P. georgianus* that occupy the small discrete inshore reef patches, where this study was focused, differ from those of this species on the long continuous offshore reefs of the JBMP. However, the results of this study on *P. georgianus* and of Afonso *et al.* (2009) on *P. dentex* and of Holland *et al.* (1996) on *C. melampygus* and Meyer *et al.* (2010) on *Caranx ignobilis* indicate that carangids often have predictable home ranges and/or movements to predictable locations that may be associated with specific activities, *e.g.* spawning.

Pagrus auratus

  Pagrus auratus is known to occupy different habitats at different stages of its life cycle. Thus, early juveniles (< *ca* 1.5 years old) typically occupy embayments or habitats that provide a nursery function, such as Cockburn Sound, on the lower west coast of Australia (Wakefield *et al.*, 2011). In that region, those individuals leave those nurseries after approximately 1.5 years and are then often found in deeper waters. However, it is also thought that, during the sub-adult phase of their life cycle, they may travel long distances before maturing, as occurs in South Australia and Victoria (Fowler *et al.* 2005, Hamer *et al.*, 2011). The few *P. auratus* tagged in this study were sub-adults and may have thus been moving along the coast as part of that phase. Those individuals remained in the array for a substantial amount of time (134-356 days) and occupied a relatively small area of up to 1.4 km^2. As with *P. georgianus*, the *P. auratus* tagged in the area closed to fishing occupied reef, seagrass and sand with *Halophila* sp., both inside and outside that area, while the one fish tagged outside that area occupied similar habitats, but essentially remained

outside. The home ranges occupied during the day and night were similar in size for three of the fish, suggesting that sub-adult *P. auratus* may forage both during the day and night in a variety of habitats.

It is not strictly relevant that small *P. auratus* < the minimum legal length for retention (41 cm north of Lancelin) remain in a small area that can be protected, given that they must be returned to the water (St John *et al.*, 2009b). However, although this may not be an issue in shallow waters, such individuals may suffer from barotrauma when caught in deeper waters (St John *et al.*, 2009b). If sub-adult *P. auratus* also occupy limited home ranges in deep water, then individuals may be more at risk from the effects of fishing in such waters.

11.0 Long-term monitoring of fish communities in the Jurien Bay Marine Park

Fairclough, D. V. and Potter, I. C.

11.1 Introduction

This study was designed to determine aspects of the diversity, richness and composition of fish species in reef, seagrass and sand habitats in the Jurien Bay Marine Park (JBMP). A range of sampling techniques were used to sample the fish fauna in the different habitats, some of which were used in more than one habitat, as different sampling methods can have different biases. For example, Wassenberg *et al.* (1997) demonstrated that fish and shrimp trawl nets caught predominantly small fishes, whereas Orth (1986) indicated that such a method provided good comparison of fishes across habitats. Although having the advantage of being non-destructive, underwater visual census (UVC) has been criticised for its biases, such as poor estimation by divers of transect width, underestimation of density of cryptic fishes and lower accuracy and precision of length estimates than stereo-video methods (Watson and Quinn, 1997; Harvey *et al.*, 2001; Willis, 2001). Langlois *et al.* (2006) found that UVC performed better than baited video in their study, recording greater abundances and diversity of fishes.

The evolution of video methods for remotely or actively obtaining estimates of fish abundance and accurate length data has provided a new approach to such surveys. However, the different video methods in use, *e.g.* baited stereo-video, diver-operated stereo video and downward-facing video produce different results (Watson *et al.*, 2010; Willis and Babcock, 2000; Langlois *et al.*, 2006). One major issue with baited video methods is that the sampling area cannot be defined, because the area influenced by the bait plume, which would influence the preciseness of relative

abundance measures, is unknown. To ensure replicates are independent, the video system is placed a minimum distance apart, often at least 250 m (*e.g.* Watson *et al.*, 2010). However, independence may be difficult to achieve in small areas closed to fishing.

When the aim of fish community studies is to determine the diversity of fish species that occupy different habitats, the use of appropriate and complementary sampling methods is essential. This study used both UVC and baited underwater video to survey the fish fauna of reef habitats, whereas trawling and baited video were employed to survey seagrass and unvegetated sand habitats and seine netting to survey the fish fauna of surf zones (see previous chapters for methodology). The data examined in previous chapters were collated to test the hypothesis that different fish communities were detected using different sampling methods both within and among habitats and the nature of the differences. In particular, the comparison of different methods in the same habitat will allow scientists to consider what methods to use in long-term monitoring programmes, depending on their focus.

11.2 Materials and methods

The number of each fish species in each replicate sample derived from underwater visual census (UVC), trawling and seine netting and the MaxN values derived from baited remote underwater video stations (BRUVS) was expressed as a percentage of the total number of fish in that sample and then $\ln(x+1)$ transformed. Note that the number of fish species presented in this chapter differ from those reported in previous chapters in the case of BRUVS and trawling in seagrass, as some fishes were not identifiable to species in both methods and thus were pooled in to species groups so that their abundances could be compared across methods. The

following analyses were conducted using the PRIMER $v6$ statistical software (Clarke and Gorley, 2006). A Bray-Curtis similarity matrix was constructed from the replicates from all methods, with the addition of a dummy variable of 0.1, as a reasonable number of samples in sand habitats comprised all zero values. To compare the composition of fishes among sampling methods and habitats sampled, the two factors, *i.e.* method and habitat, were flattened to create a single factor of method/habitat, which comprised seven levels (UVC reef, BRUVS reef, BRUVS seagrass, BRUVS sand, Trawl seagrass, Trawl sand, Seine beach). A one-way Analysis of Similarities (ANOSIM; Clarke, 1993) was then conducted to test the hypothesis that there was no difference in the composition of fishes among the combinations of method/habitat. Note that a two-way crossed design of method $\times$ habitat could not be used, as not all levels of one factor were present in every level of the other factor, *i.e.* not every method was used in each habitat. Pairwise tests were used to examine which pairs of method/habitat combinations were responsible for any difference. A second one-way ANOSIM, using the factor of method/habitat, was conducted on a Bray-Curtis similarity matrix constructed from the data for inner, mid and outer reefs to compare the results obtained using UVC and BRUVS within and among those reef habitats.

The data were averaged across the sites sampled by each method and a new Bray-Curtis similarity matrix constructed, which was subjected to non-metric multidimensional scaling ordination. Plotting the nMDS at the site level allowed visualization of the among-site variability within each method/habitat combination. The level of stress on the 2D nMDS was high (0.2, see results) and, while plotting the nMDS in 3D reduced the stress and thus provided a better representation of the relationships among samples, the data for each pairwise comparison of interest were

replotted to confirm the representation in the above 2D nMDS plot. Similarity Percentages (SIMPER; Clarke, 1993) was used to identify which species typified each method/habitat combination and distinguished between them.

11.3 Results

Comparison of fishes recorded by different methods in the same habitats

UVC and BRUVS of reef habitats detected 137 and 74 fish species, respectively, of which 67 were common to both methods and comprised 78 and 99 %, respectively, of the total numbers of fishes recorded by those two methods (Table 11.1). Thus, 71 species were unique to UVC and seven to BRUVS. Of the 31 species recorded by BRUVS and 40 by trawling in seagrass, 15 were common to both methods, which represented 59 and 77 % of the total number of fishes recorded, respectively. Thus, 16 and 25 species were unique to BRUVS and trawling, respectively. In sand habitats, only six of the 24 species recorded by BRUVS and 22 of those caught in trawls were common to both methods, representing 11 and 29 % of numbers, respectively.

Seventeen species, each representing ≥ 1 % numerically, contributed 86 % to the total number of fishes recorded by UVC over reefs (Table 11.1), and comprised 12 carnivores (*e.g. Coris auricularis*), three omnivores (*e.g. Parma mccullochi*) and two herbivores (*e.g. Kyphosus cornelii*). Fifteen species contributed 89 % to the total number recorded by BRUVS over reefs, all of which are carnivorous (*e.g. C. auricularis* and *Notolabrus parilus*). Over seagrass and unvegetated sand, 17 and 11 species, respectively contributed 96 and 93 % to the total numbers recorded by BRUVS in those habitats (Table 11.1). Fifteen of those recorded in seagrass and all of those in sand are carnivorous, *e.g. Torquigener pleurogramma* and *Pentapodus vitta*.

Thirteen and 22 species caught by trawling in seagrass and sand, respectively, represented 92 and 100 % of fishes caught in those habitats (Table 11.1). In seagrass, seven of those species are carnivorous (*e.g. N. parilus*), while six are omnivorous (*e.g. Scobinichthys granulatus*), whereas in sand, 16 are carnivorous (*e.g. T. pleurogramma*) and six omnivorous (*e.g. S. granulatus*).

Comparison of fish communities derived using different methods

ANOSIM detected a strong significant difference in the composition of fishes among method/habitat combinations ($p = 0.1$ %; Global R statistic = 0.877). Furthermore, pairwise comparisons revealed strong significant differences among method/habitat combinations in all but one case ($p = 0.1$ % in each case; Table 11.2). The comparisons of most interest, *i.e.* those between the compositions of fishes determined using different methods in the same habitat, produced R statistics which indicated substantial differences in the fish fauna detected in reefs by UVC *vs* BRUVS (R = 0.46) and in seagrass by BRUVS *vs* trawling (R = 0.497), but negligible difference between that detected by BRUVS and trawling in sand (R = 0.097). The compositions of fishes determined by UVC and BRUVS over inner, mid and outer reef habitats differed significantly between methods and between each pair of method/reef location combinations ($p = 0.1$ %; Table 11.3). In particular, strong differences were detected between the compositions of fishes determined by UVC and BRUVS at both inner (R = 0.611) and mid reefs (R = 0.528) and to a lesser extent over outer reefs (R = 0.387).

The locations of samples on the nMDS representing different sites surveyed using the different methods in different habitats reflected the strength of the pairwise differences revealed by ANOSIM (Fig. 11.1a). Thus, there was almost no overlap of

Table 11.1 Relative abundance (%) of each fish species recorded by each method in each habitat in which it was used. Species comprising ≥ 1 % numerically and thus in total the majority of numbers of fishes recorded by that method are in bold. See relevant chapter for full genus names.

Species	UVC	BRUVS reef	BRUVS seagrass	BRUVS sand	Trawl seagrass	Trawl sand	Seine sand
A. aureus	0.0030						
A. aurita	0.0045				0.2377		
A. bengalensis	0.0010						
A. dussumieri	0.0005						
A. elongatus	0.0005			0.6309			0.0044
A. forsteri							**2.2769**
A. geographicus	0.1688						
A. georgianus	0.6866	0.0193	**1.4178**	**3.1546**			0.0131
A. gouldii	0.0035						
A. labiosus	0.0005	0.0193	0.1668				
A. lenticularis	0.0153						
A. maculatus	**2.6136**	**1.1792**					
A. milesii					0.2377		
A. pardalotus	0.0015						
A. robustus	0.0361			0.3155		**4.4444**	
A. rueppellii	0.0827	**1.2179**	**5.5880**	0.9464	**13.0730**		0.4397
A. serratus	0.0010	0.0193					
A. truttaceus							0.0261
A. vaigiensis	0.0010						
A. victoriae	**3.5353**	0.3093			**2.2977**		
Acanthaluteres sp.	0.0059	0.0193	**2.0017**		**6.8138**	**2.2222**	0.0044
A. waigiensis							**25.4332**
A. westralis	0.0010						
Acanthistius sp.		0.0387					
Atherinid sp.	0.0990						
B. frenchii	0.2643	0.0773					
B. jacksonianus	0.0005				0.3962	**2.2222**	
C. assarius	0.0609	0.1160					
C. auricularis	**27.4099**	**60.2552**	**1.0842**	0.3155			
C. broadhursti					0.0792		
C. calamus							0.0044
C. curiosus	0.7400	0.3673					
C. gibbosus	0.0223						
C. hutchinsi	0.0624						
C. klunzingeri	0.4603	0.1740					
C. kumu							0.0044
C. latifrons					0.0792		
C. macrocephalus	0.0010				**1.8223**		0.5834
C. penicilligera	0.0015					**6.6667**	
C. rubescens	0.4465	0.0967	0.0834		0.1585		
C. rubrolabiatus	0.0678						0.0044
C. theagenes	**3.2591**						
C. westaustralis	**1.6300**	0.3093					
Ca. australis	0.0010						
Cr. australis	0.0005				0.8715		0.0305
D. alleni	0.3945						
D. brevicaudata	0.0015	0.5799	**1.4178**	0.3155	0.0792		
D. nichthemerus	0.0040				0.9508		
D. nigricans	0.0168						
E. angustipes	0.0030	0.0387					
E. cyanoura	0.0005						
E. rivulatus	0.0134	0.0580			0.0792		
En. armatus	0.4668	0.1160			**1.1885**		0.1263
Ep. armatus	0.2317	**1.5852**					
F. lateralis							0.0087
F. tigris						**2.2222**	
G. hebraicum	0.0386	0.0387					
G. prasinus		0.3093					
G. tephraeops	0.0084						
G. woodwardi	0.0015	**1.0632**					
G. zebra	0.0079						

Species	UVC	BRUVS reef	BRUVS seagrass	BRUVS sand	Trawl seagrass	Trawl sand	Seine sand
H. acroptilus	0.1332				**8.4776**	**8.8889**	
H. brownfieldi	**3.3175**		**1.3344**		0.0792	**2.2222**	
H. cristatus							0.0131
H. decurrens	0.0604						
H. macropterus					0.9508		
H. nigrorubrum	0.0129	0.0387					
H. portusjacksoni	0.0005	0.0193	0.5004	0.9464	0.0792	**2.2222**	
H. semifasciata					**2.5354**		0.0087
H. vittatus				1.2618			0.2264
H. wilsoni	0.0005						
I. rhothophilus							0.0131
K. cornelii	**5.3643**	0.6379					0.0131
K. sydneyanus	**1.3682**	0.3673					
L. dimidiatus	0.0005						
L. inops	0.0005				**3.9615**		0.0044
L. lineatus	0.8054	**2.7257**					
L. nebulosus	0.0069	0.0580					
L. platycephala							**2.0070**
L. presbyteroides							**36.8002**
L. sceleratus	0.0005	0.0967	**2.2519**	**8.8328**			
L. vaigiensis	0.0040						
M. australis	0.0005	0.5799	**2.8357**	**16.4038**			
M. cephalus							0.3918
M. chinensis	0.0035	0.0387	**1.7515**	0.3155	**1.9808**		0.0261
M. flavolineata	0.0312						
M. freycineti			0.2502		0.2377		
M. galii	0.0342	0.0967					
M. hippocrepis	0.0480	0.3673	0.0834				
M. strigatus	0.2208						
Monacanthid sp.	0.0010	0.0193	0.7506	0.3155			
Mustelus sp.		0.0193	0.1668				
N. ayraudi			0.0834	0.3155		**2.2222**	
N. obliquus	0.5984	**2.0684**					
N. parilus	**5.2638**	**4.5428**	**7.4229**		**18.0645**	**2.2222**	0.0044
O. cyanomelas	0.4801	0.0580					
O. dentex	0.0109	0.0193					
O. hutchinsi		0.0193					
O. lineolatus	0.4034	**2.7064**					
Ophicthid sp.				0.3155			
Orectolobid sp.		0.0773					
P. albilabrus					0.1585		0.0044
P. auratus	0.0084	0.2126					
P. bilineata						**2.2222**	0.4354
P. biserialis	**1.2969**	**2.4551**					
P. breviceps							0.0087
P. chrysopleuron	0.0208	0.0773					
P. flavomaculatus	0.2312	0.2320	0.1668				
P. haackei	0.1376	0.1160	0.1668	0.9464			
P. humeralis	0.0005	0.2706	**10.5921**		0.0792		**2.0113**
P. jenynsii						**8.8889**	0.1219
P. klunzingeri	**8.4907**	1.1212					
P. laevigatus					0.1585		
P. laticlavius	0.3326	0.3093					
P. lineatus	0.2138						
P. mccullochi	**6.1627**	0.9859					
P. melbournensis						**2.2222**	
P. meleagris	0.1252						
P. milleri	**5.0727**	0.2320					
P. multiradiata	0.4361	0.4446					
P. occidentalis	0.7029	0.0193					
P. ornata	0.0005						
P. piosae						**2.2222**	0.0087
P. saltatrix	0.0010		0.2502				0.0392
P. schwenkii	0.0040						
P. octolineatus	0.0990	**1.9138**	**6.2552**		0.0792		**1.3148**

Species	UVC	BRUVS reef	BRUVS seagrass	BRUVS sand	Trawl seagrass	Trawl sand	Seine sand
P. rhinorhynchos	0.0025						
P. speculator				**6.9401**			0.2046
P. spilurus	0.2143	0.4446					0.0044
P. taeniolatus	0.0010				0.0792	**2.2222**	0.0044
P. tapeinosoma	0.0005						
P. teira	0.0005						
P. victoriae	0.0094						
P. viridis	0.2836						
P. vitta	0.0614	**1.3145**	**17.5146**	**33.7539**			
P. volitans	0.0005						
P. waigiensis	0.1153	0.0193			0.1585		0.0044
Pa. elongatus	**1.3939**						
Ps. elongatus	0.0010						
Pseudocaranx sp	0.4351	**3.2476**	**3.5863**	**11.3565**			0.0261
R. australiae				**1.2618**			
R. sarba	0.0307	0.2706					0.0261
S. aequipinnis	0.0010						
S. argus					0.0792		0.0044
S. argyrophanes					0.0792		
S. bandanensis	0.0054						
S. bassensis							**2.7819**
S. beddomei	0.3153						
S. caninus	0.0178						
S. cephalotes	0.2237					**2.2222**	0.1828
S. cyanolaemus	0.0678						
S. georgianus	0.2099	0.4060					
S. gobbhan	0.0540						
S. granulatus	0.0124	0.1160	**1.9183**		**29.1681**	**20.0000**	0.0174
S. hippos	0.0153	0.2320		0.3155			
S. lalandi	0.0005						
S. obreptus	0.2109						
S. obtusata	0.6430		**1.9183**				0.0044
S. punctata		0.0193					
S. radiatus					**1.3469**		0.0174
S. robustus	**7.5932**						**4.5494**
S. schomburgkii							0.8925
S. sumptuosa					0.5546		
S. woodwardi	**1.5795**						0.0044
Siganus sp.	0.3321	0.1353			**1.2677**		
Sillago sp.				**1.2618**			
T. amblycephalum	0.0025						
T. brauni	0.0010						
T. fasciata	0.0010		0.6672		0.0792		
T. jarbua							0.0305
T. lunare	0.1431	0.2513					
T. lutescens	0.3505	0.6186					
T. mucosa		0.0387		0.3155		**2.2222**	0.0087
T. noarlungae	**1.1301**						
T. novaezelandiae	0.0084	0.0193	0.6672				
T. ovalis	0.0436	0.2126	0.1668		0.3169	**2.2222**	0.0044
T. purpureum	0.0015						
T. septemfasciata	0.0540	0.0387					
T. sexfasciatum	0.0005						
T. pleurogramma	0.0337	**1.6431**	**26.9391**	**9.1483**	0.9508	**13.3333**	**18.8158**
U. carinirostris						**2.2222**	
U. circularis	0.0005						
U. vlamingii	0.0134	0.0193		0.3155	0.7923	**4.4444**	
Unid eel							0.0044
Total no. species	**137**	**74**	**31**	**24**	**40**	**22**	**53**

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the samples for each method/habitat combination. The relatively lower R statistic of 0.46 derived for the pairwise comparison between UVC and BRUVS in reef was reflected in the proximity of the samples for each of the method/habitat combinations. However, they still did not overlap. Furthermore, the points representing trawl samples from sand, which were collected a few kilometres from shore, did overlap to some extent those from seine netting in surf zones and the lower R statistic indicated some degree of similarity. In the case of BRUVS and trawl in sand, the majority of samples for those two method/habitat combinations lay separate (Fig. 11.1a). However, those for trawling in sand were widely dispersed and partially overlapped the far less dispersed points for BRUVS in sand, which was responsible for the low pairwise R statistic.

The level of stress was high when all method/habitat combinations were plotted together (Fig. 11.1a). Thus, the plotting of data from reef habitats by UVC and BRUVS (Fig. 11.1b) and from seagrass by trawling and BRUVS (Fig. 11.1c) by nMDS ordination reduced the stress and retained the separation of samples from the different methods in each habitat type, indicating that the nMDS ordination plot in Fig. 11.1a provided a good representation of the relationship between each of those method/habitat combinations. However, the samples for BRUVS in sand *vs* trawl in sand were more clearly separated in the 3D nMDS ordination plot when restricted to those method/habitat combinations (Fig. 11.1d). The different representation of the relationship of those points between the two methods in Fig. 11.1d and Fig. 11.1a may reflect the fact that many of the samples from those two methods in sand contained zero fishes.

Table 11.2. Pairwise ANOSIM R statistics for comparisons of the composition of fishes in the different method/habitat combinations. UVC, UVC reef; VR, BRUVS reef; VSG, BRUVS seagrass; VSD, BRUVS sand; TSG, trawl seagrass; TSD, trawl sand; SSD, seine sand. Comparisons of different methods used in the same habitat in bold.

Method/habitat	UVC	VR	VSG	VSD	TSG	TSD	SSD
UVC							
VR	**0.460**						
VSG	0.961	0.745					
VSD	0.998	0.884	0.465				
TSG	0.968	0.772	**0.497**	0.659			
TSD	0.997	0.951	0.671	**0.095**	0.505		
SSD	0.998	0.857	0.449	0.453	0.711	0.373	

Table 11.3. Pairwise ANOSIM R statistics for comparisons of the composition of fishes in the different method/reef location combinations. UVC, underwater visual census; BRUVS, baited remote underwater video stations; inner, inner reefs; mid, mid reefs; outer, outer reefs.

Method/habitat	UVC inner	UVC mid	UVC outer	BRUVS inner	BRUVS mid	BRUVS outer
UVC inner						
UVC mid	0.125					
UVC outer	0.510	0.258				
BRUVS inner	**0.611**	0.626	0.730			
BRUVS mid	0.607	**0.528**	0.615	0.127		
BRUVS outer	0.730	0.616	**0.387**	0.466	0.28	
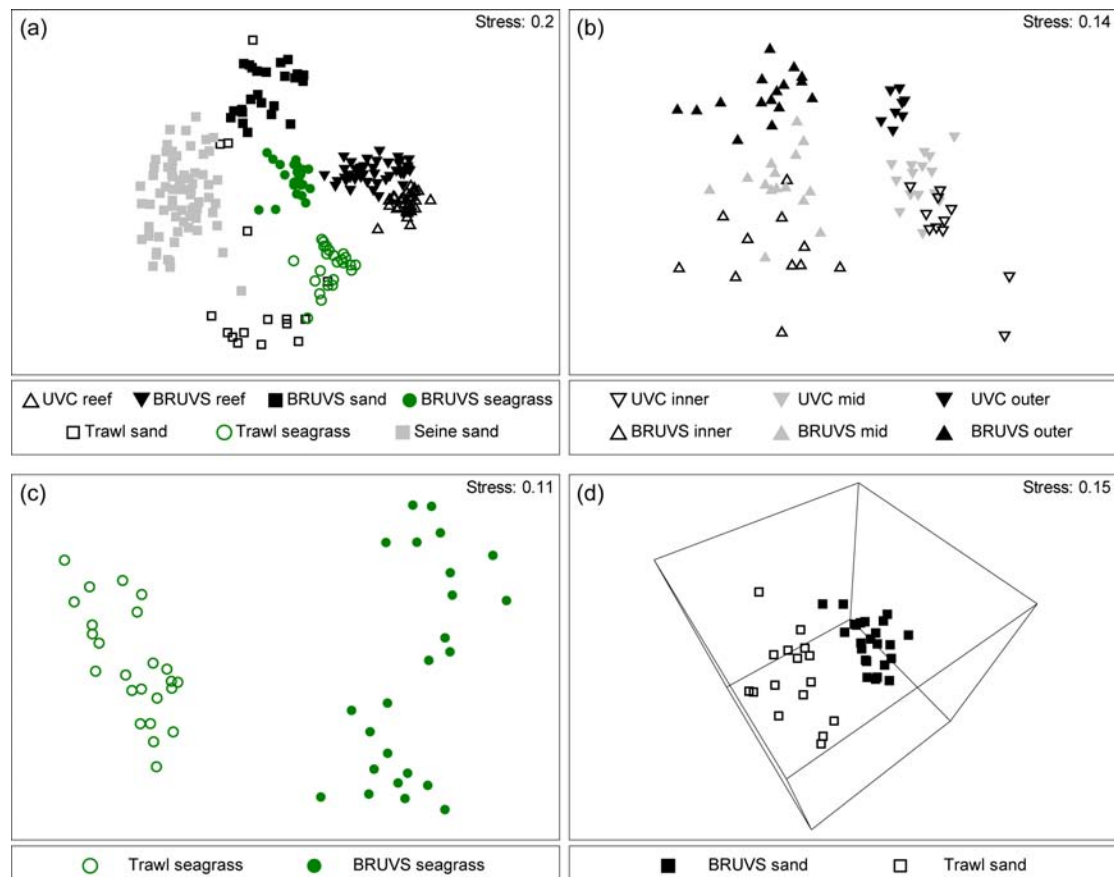
Figure 11.1. Non-metric multidimensional scaling plots demonstrating the relationships between the composition of fishes at each site in (a) all habitat/method combinations, (b) reefs derived by UVC and BRUVS, (c) seagrass derived by BRUVS and trawl and (d) sand derived by BRUVS and trawl.

SIMPER demonstrated that *Coris auricularis* and *Notolabrus parilus* typified the samples collected over reefs by both UVC and BRUVS and that *Parma mccullochi* also typified UVC over reef (Table 11.4). *Parma mccullochi* was also the most important species for distinguishing between those two methods over reef, being very much more abundant in UVC samples. *Austrolabrus maculatus* and *N. parilus* also contributed to the distinction between those two methods, being relatively more abundant in UVC samples, while *Pseudolabrus biserialis* was relatively more abundant in BRUVS samples (Table 11.4). When the samples for UVC and BRUVS were separated into inner, mid and outer reef habitats, *C. auricularis* and *N. parilus* typified each method at each reef location (Table 11.5). However, although *P. mccullochi* also typified samples collected by UVC at each reef location, and *Pomacentrus milleri* and *A. maculatus* also typified inner and outer reefs, respectively, they did not typify samples collected by BRUVS in those habitats. BRUVS samples from inner reefs were also typified by *Labracinus lineatus* and from outer reefs by *Ophthalmolepis lineolatus* and *Pseudolabrus biserialis*. The compositions of fishes over inner reefs obtained by different methods were distinguished from each other by greater abundances of *P. milleri*, *Apogon victoriae* and *P. mccullochi* in UVC samples and of *C. auricularis* in BRUVS samples (Table 11.5). Mid reefs were distinguished by greater abundances of *P. mccullochi*, *Halichoeres brownfieldi* and *Kyphosus cornelii* in UVC samples and of *L. lineatus* in BRUVS samples. Outer reefs were distinguished by greater abundances of *P. mccullochi* and *A. maculatus* in UVC samples and of *O. lineolatus* and *P. biserialis* in BRUVS samples (Table 11.5).

In seagrass habitats, *Torquigener pleurogramma*, *N. parilus* and *Pentapodus vitta* typified samples collect by BRUVS, while *Scobinichthys granulatus* and

N. parilus typified those collected by trawl. The two methods were distinguished by relatively greater abundances of *S. granulatus* and *N. parilus* in trawl samples and of *T. pleurogramma* in BRUVS samples (Table 11.4).

Although depauperate, BRUVS samples in unvegetated sand habitats were typified by *Myliobatis australis*, *Platycephalus speculator* and *Lagocephalus sceleratus*, while those of trawling were typified by *S. granulatus* and *T. pleurogramma*. Those two methods were distinguished primarily by greater abundances of *M. australis* in BRUVS samples, but also of *T. pleurogramma*, *P. speculator* and *L. sceleratus*. The surf zone sand habitats sampled by seine net were typified by *Leseurina platycephala*, *T. pleurogramma*, *Atherinomorus waigiensis* and *Leptatherina presbyteroides*, and each of those species were responsible for distinguishing seine net samples from those of trawling in unvegetated sand. Similarly, the first three of those species, with the addition of *M. australis* distinguished seine net samples from BRUVS samples in unvegetated sand.

Table 11.4. Results of SIMPER analyses showing the major species that typified each method/habitat combination (grey cells) and those that were primarily responsible for distinguishing between each pair of method/habitat combinations (white cells). Superscripts indicate in which method/habitat combination distinguishing species were relatively more abundant ([1] refers to the method/habitat combination in the column heading and [2] to the row heading). UVC, UVC reef; VR, BRUVS reef; VSG, BRUVS seagrass; VSD, BRUVS sand; TSG, trawl seagrass; TSD, trawl sand; SSD, seine sand

Method/habitat	UVC	VR	VSG	VSD	TSG	TSD	SSD
UVC	***C. auricularis*** *N. parilus* *P. mccullochi*						
VR	*P. mccullochi[1]* ***A. maculatus[1]*** ***N. parilus[1]*** ***P. biserialis[2]***	***C. auricularis*** *N. parilus*					
VSG			***T. pleurogramma*** *N. parilus* *P. vitta*				
VSD				***M. australis*** *P. speculator* *L. sceleratus*			
TSG			*S. granulatus[2]* ***T. pleurogramma[1]*** ***N. parilus[2]***		***S. granulatus*** *N. parilus*		
TSD				***M. australis[1]*** ***T. pleurogramma[1]*** ***P. speculator[1]*** ***L. sceleratus[1]***		***S. granulatus*** *T. pleurogramma*	
SSD				***L. platycephala[2]*** *T. pleurogramma[2]* *M. australis[1]* *A. waigiensis[2]*		***L. platycephala[2]*** *T. pleurogramma[2]* *A. waigiensis[2]* *L. presbyteroides[2]*	***L. platycephala*** ***T. pleurogramma*** *A. waigiensis* *L. presbyteroides*

Table 11.5 Results of SIMPER analyses showing the major species that typified each method/reef location combination (grey cells) and those that were primarily responsible for distinguishing between each pair of method/reef location combinations (white cells). Superscripts indicate in which method/reef location combination distinguishing species were relatively more abundant ([1] refers to the method/habitat combination in the column heading and [2] to the row heading). UVC, underwater visual census; BRUVS, baited remote underwater video stations; inner, inner reefs; mid, mid reefs; outer, outer reefs.

Method/habitat	**UVC inner**	**UVC mid**	**UVC outer**	**BRUVS inner**	**BRUVS mid**	**BRUVS outer**
UVC inner	*C. auricularis* *N. parilus* *P. milleri* *P. mccullochi*					
UVC mid		*C. auricularis* *N. parilus* *P. mccullochi*				
UVC outer			*C. auricularis* *A. maculatus* *N. parilus* *P. mccullochi*			
BRUVS inner	*P. milleri*[1] *A. victoriae*[1] *C. auricularis*[2] *P. mccullochi*[1]			*C. auricularis* *N. parilus* *L. lineatus*		
BRUVS mid		*P. mccullochi*[1] *H. brownfieldi*[1] *K. cornelii*[1] *L. lineatus*[2]			*C. auricularis* *N. parilus*	
BRUVS outer			*P. mccullochi*[1] *A. maculatus*[1] *O. lineolatus*[2] *P. biserialis*[2]			*C. auricularis* *O. lineolatus* *N. parilus* *P. biserialis*

11.4 Discussion

Different methods of sampling fish communities, when used in the same habitats, are known to record different species compositions and relative abundances (see *e.g.* Cappo *et al.*, 2004). Thus, in this study, complementary methods were used in each of reef, seagrass and unvegetated sand habitats to describe the diversity of fishes in the main habitats of the JBMP. The results demonstrated that substantially more species were recorded by underwater visual census (UVC) than by baited remote underwater video stations (BRUVS) in reef habitats, *i.e.* 137 *vs* 74, and ANOSIM detected a significant difference among those species compositions. While both methods were typified by the carnivorous labrids *Coris auricularis* and *Notolabrus parilus*, UVC samples were also typified by the herbivorous pomacentrid *Parma mccullochi*, which was the most important species for distinguishing between UVC and BRUVS over reefs. Indeed, the 17 species that each contributed ≥ 1 % to the numbers of fish recorded by UVC, and together contributed 86 % to the total numbers, belonged to a variety of trophic groups, *i.e.* carnivores, herbivores or omnivores. In contrast, although a similar number of species (15) recorded by BRUVS each represented more than 1 % numerically and together comprised 89 % of the total numbers of fishes recorded by that method, all 15 are carnivorous. While some omnivores and herbivores were recorded by BRUVS, *e.g. P. mccullochi* and *Kyphosus cornelii*, they each represented < 1 % of the total number of fishes recorded.

The most abundant fishery species recorded during UVC was *Arripis georgianus*. However, that species only ranked 21st numerically and represented < 1 % of total numbers. *Pseudocaranx* spp. were the most abundant species of interest to fishers in BRUVS samples over reefs (3rd), but they only ranked 29th numerically in UVC samples. Similarly, although *Epinephelides armatus* ranked 9th in BRUVS

samples over reefs, it was only 38th in UVC samples. These results are most likely related to the tendency for BRUVS to record primarily carnivorous species.

The numbers of species and compositions of fishes recorded in sand by BRUVS and trawling were similar. However, the similarity between fish compositions was presumably driven by the fact that a reasonable number of samples from both methods contained no fishes. Of the species sampled, only six of the 24 and 22 species observed and caught by those two methods, respectively, were common to both methods. Furthermore, the two methods were typified by very different species, *i.e. Myliobatus australis*, *Platycephalus speculator* and *Lagocephalus sceleratus* typified BRUVS samples and *Scobinichthys granulatus* and *Torquigener pleurogramma* typified the trawl. Of the species that contributed ≥ 1 % to the numbers of fishes caught by each method in seagrass and sand, the vast majority recorded by BRUVS were carnivorous, while *ca* 50 and 73 % of those caught by trawl in seagrass and sand, respectively, belonged to the same trophic group. The greater number of carnivores recorded in sand habitats may reflect the absence of macrophytes, other than drifting detached macroalgae, to provide food for herbivores and which would also provide habitat for the types of organisms that omnivores would consume. Indeed, when fish were caught in trawls over sand habitats, those samples typically also contained some detached macrophytes, such as *Ecklonia radiata* or seagrasses. In seagrass habitats, *T. pleurogramma* and *S. granulatus* typified BRUVS and trawls respectively, but *N. parilus* ranked 4th and 2nd in samples collected by both methods and thus typified both methods. *Pseudocaranx* spp. were again the most abundant species of interest to fishers in BRUVS over seagrass (7th), but were not caught by trawl. In contrast the platycephalid *Leviprora inops* was relatively abundant in trawls (6th), but was not recorded by BRUVS.

Recommendations for future monitoring

The most important consideration when designing future monitoring regimes depends on the aims of that monitoring. The results of the data collected during surveys of the fish fauna of the JBMP reiterated the fact that the use of different sampling methods will produce different species compositions and relative abundances. The vision for the JBMP in the management plan (Anon., 2005) was that "In the year 2025, the marine flora and fauna, habitats and water quality of the Jurien Bay Marine Park will be in the same or better condition than in the year 2005. The area will support viable and ecologically sustainable fishing, aquaculture, recreation and nature-based tourism and the marine park will be considered an important asset by the local community". Given that there are now quantitative "baseline" surveys of the fish fauna in specific habitats of the JBMP from the years of *ca* 2005-2007, *i.e.* at about the time the marine park was established, future studies can then determine whether the fish fauna is in "the same condition". However, it may be difficult to determine whether it is in "better condition" if there is no knowledge of it's original condition. The only historical information on the relative abundance of fish species in the area of the JBMP is that of Hutchins (2001). His surveys were designed to investigate species diversity primarily, using a timed method of visual census, rather than relative abundance and thus are not directly comparable. Furthermore, at the time of those surveys, it is unclear to what extent fishing may have impacted stocks of target species.

The data collected during this study indicated that the most targeted demersal species are in relatively low or very low abundance. That may reflect the current status of their stocks and thus that overfishing has been occurring (Fairclough et al., 2010), or it may demonstrate that the habitats within the areas surveyed are not

important for such species. However, UVC provided evidence that all life cycle stages of at least some demersal species, *e.g. Choerodon rubescens*, *Epinephelides armatus* and *Bodianus frenchii*, occupy reef habitats of the JBMP, while BRUVS provided data on the relative abundance of *Pseudocaranx* spp. in different habitats. Thus, their relative abundance and size structure could be monitored, using the appropriate method, into the future. Otolith microchemistry studies have demonstrated that juvenile and adult *C. rubescens* are both unlikely to move far (Fairclough *et al.*, 2011) and thus, as they are also a single genetic stock (M. Gardiner, unpublished data), mixing occurs predominantly during the larval phase. This is also the case for *Glaucosoma hebraicum* (Berry *et al.*, in press). Thus, any contribution to broader stocks by adults of such demersal species within the JBMP will depend on the size of the stock within the JBMP. The amount contributed by assemblages of such species in the JBMP could be compared to that of others elsewhere by investigating size structure and relative abundance, to gauge the relative importance of the JBMP. For example, do individuals within the JBMP represent adults of such species and thus provide spawning output or are there significant nurseries within the JBMP, both of which could be monitored? However, only age structure data will provide the types of data necessary to conduct stock assessments of targeted species.

Another aspect of the vision indicates that the JBMP will support recreation, nature-based tourism and that the local community will place a value on the marine park. In terms of fishes, this aim implies that biodiversity should be maintained, which simplistically could be considered to be a diverse fish fauna that is maintained in such a way that it supports the correct ecosystem functioning in the JBMP. The methods used in this study provide data on the relative abundance of species in different habitats, comprising different trophic groups. There was a tendency for

BRUVS to survey carnivorous species primarily, while UVC, trawling and seine netting surveyed a broader range of trophic groups. Thus, to determine in the future, whether the aims of the JBMP are being met, would require the use of multiple methods to survey, not only the species of interest to fishers, but also all of those that contribute to ecosystem function. The maintenance of such biodiversity will also require monitoring and maintenance of existing habitats that provide niches for particular species. The data collected by UVC demonstrated substantial variability in algal compositions among inner, mid and outer reef locations, and also among management zones. Indeed, the relative abundances of some fish species were correlated to changes in algal composition, reflecting the link between habitat and fish assemblages. Furthermore, the different seagrass compositions at different locations also supported different fish assemblages. Thus monitoring of fishes will need to take into account that spatial variability in macrophyte assemblages and resultant structural complexity in order to correctly account for variations in species diversity and abundance that are influenced by both habitat and by the different management regimes in the JBMP.

12.0 References

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13.0 Dissemination

The following dissemination of results from this project has occurred.

1. Presentation by David Fairclough of preliminary data on the fish faunas of the Jurien Bay Marine Park recorded in Autumn 2005 during underwater visual census of reef habitats to stakeholders and members of the scientific community, involved in the collaborative SRFME project in Jurien Bay, at a workshop at CSIRO on the 7th to 9th of June 2005, co-ordinated by Dr Russ Babcock.

2. Presentation by David Fairclough at the final Strategic Research Fund for the Marine Environment Symposium, 22nd February 2007 at CSIRO.

Sampling regime

Green Head to Sandy Point   Jurien Bay to Hill River

Marine park zone
- Open to fishing
- Sanctuary zone
- Scientific reference zone

Netting/BRUVS sites
TS = trawling sand
TG = trawling seagrass
S = seine netting

UVC/BRUVS sites
- Inner
- Mid
- Outer

Results

Reef fish communities

Underwater visual census

Silver drummer   Black throated threefin   Western blue devil

Results

Reef fish communities

Underwater visual census

Number of species recorded = 125

73 warm-temperate, 29 subtropical, 23 tropical

21 labrids (wrasses)
9 pomacentrids (damselfishes)

Reef fish communities. Most abundant species.

Western king wrasse
Coris auricularis

Rough bullseye
Pempheris klunzingeri

Brown-spotted wrasse
Notolabrus parilus

McCulloch's scalyfin
Parma mccullochi

Reef fish communities. Recreational and/or commercial species.

Rank	Species	n
20	Australian herring	980
26	Silver trevally	641
29	Baldchin groper	619
39	Western foxfish	333
41	Breaksea cod	324
66	West Australian dhufish	46
67	Silver bream	43
74	Samson fish	25
81	Spangled emperor	14
86	Pink snapper	8
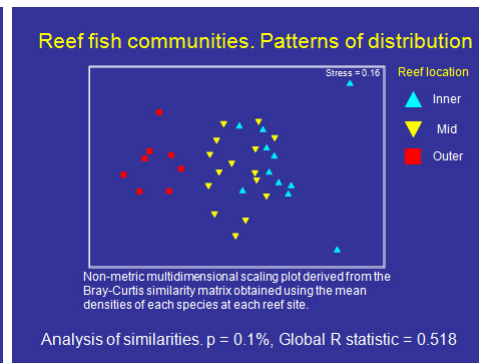
Reef fish communities. Patterns of distribution

Stress = 0.16

Reef location
- Inner
- Mid
- Outer

Non-metric multidimensional scaling plot derived from the Bray-Curtis similarity matrix obtained using the mean densities of each species at each reef site.

Analysis of similarities. p = 0.1%, Global R statistic = 0.518

Species distinguishing between the compositions of inner and outer reef fish assemblages (SIMPER)

Inner	Outer
Lined dottyback	Maori wrasse
Miller's damselfish	Red-banded wrasse
Red-striped cardinalfish	Black-spotted wrasse

Species distinguishing between the compositions of inner and outer reef fish assemblages

Scale (fish/125m²)
- 0.2
- 0.6
- 1.4
- 2

Lined dottyback *Labracinus lineata*

1 = Inner reef, 2 = Mid reef, 3 = Outer reef

3. Presentation given by Dr Russ Babcock at a meeting of the Ecological Effects of Fishing Scientific Reference Group, 8-10th August 2007 at the Department of Fisheries' Hillarys research laboratories, to outline the research being conducted in the Jurien Bay Marine Park. Some of the results of this project, in the form of two powerpoint slides (see below), were presented as part of that talk. The slides demonstrate examples of the ways in which resources are partitioned among abundant species in the JBMP, which are important findings in the context of ecological interactions and ecosystem modelling.
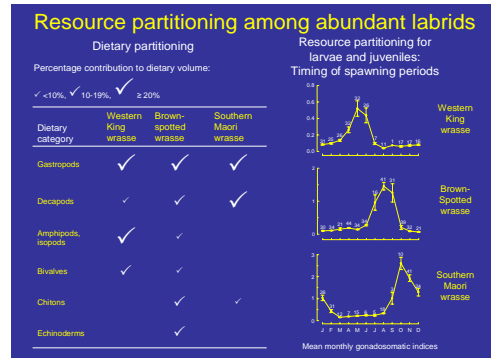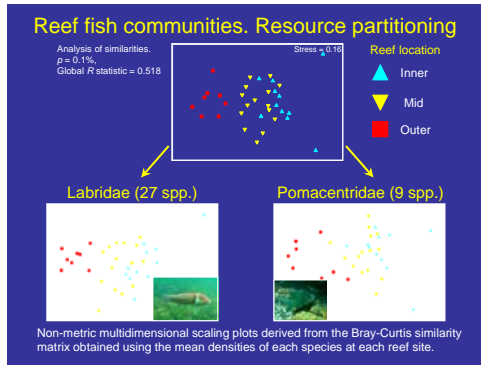
4. Presentations by David Fairclough and PhD candidate Elaine Lek at the WAMSI Show and Tell 2008, an opportunity to demonstrate current research in Western Australia.

5. Presentation by Elaine Lek at the 8th Indo-Pacific Fish Conference (June 2009)

6. Poster presented at the 8th Indo-Pacific Fish Conference in June 2009.

7. Chapter 9 (The biology of *Coris auricularis*, *Notolabrus parilus* and *Ophthalmolepis lineolatus*; Lek, E., Fairclough, D. V. and Potter, I. C.) forms part of a PhD thesis that is in preparation. Papers published and currently in prep from that work:

Lek, E., Fairclough, D. V., Platell, M. E., Clarke, K. R., Tweedley, J. R. and Potter, I. C. (2011). To what extent are the dietary compositions of three abundant, co-occurring labrid species different and related to latitude, habitat, body size and season? *Journal of Fish Biology*, in press.

Lek, E., Fairclough, D. V., Hesp, S. A., Hall, N. G. and Potter, I. C. (in prep). Do the patterns of differences between the lengths, ages, growth and recruitment characteristics of three labrid species at two latitudes differ consistently within and among species?

8. Chapter 8 (Fish communities of reef, seagrass and unvegetated sand habitats, surveyed by baited remote underwater video; Bivoltsis, A. K., Fairclough, D. V. and Potter, I. C.) was produced as an honours thesis by Alexia Bivoltsis. Alexia was awarded first class for her honours project.

9. CSIRO have collated the data collected during our part of the study with those obtained from the other SRFME collaborative studies in the JBMP by CSIRO, Edith Cowan University, the Western Australian Museum and the Department of Fisheries to develop predictive ecosystem models for the region (Loneragan *et al.*, FRDC project 2006/038[1]). [1]Loneragan, N., Dambacher, J., Okey, T. and Babcock, R. FRDC Project 2006/038. Evaluating how food webs and the fisheries they support are affected by fishing closures in Jurien Bay, temperate Western Australia.

10. Samples of fishes were provided to the Western Australian Museum for their collections and to Drs Christine Hanson and Glenn Hyndes of Edith Cowan University for concomitant studies of trophic interactions using stable isotope analyses.

14.0 Benefits to the State

This project has determined the diversity, density and species compositions of the fish that occupy reefs, seagrass and unvegetated sand habitats in three different management zones in the Jurien Bay Marine Park. These zones are (1) General use zones, where all types of fishing are allowed, (2) Scientific reference zones, where recreational and commercial rock lobster fishing and selected shore-based fishing activities are allowed, and (3) Sanctuary zones, where no fishing is permitted. The results of this study have provided the types of data that are necessary for ecosystem models produced for the Jurien Bay region and can also be used to assess whether or not scientific reference and sanctuary zones provide protection and benefits to fish species from the impacts of fishing. The results of this project will be of value to managers in other waters of Western Australia in which there are spatially managed areas. The biological data for three labrid species will be of value to fisheries managers as the members of this fish family become increasingly targeted. Furthermore, data provided on the movements of Silver Trevally and Pink Snapper will provide important information on the usefulness of protected areas in the management of these two species.