Differential responses and sensitivity to edge of seagrass fish and their primary prey faunal groups with respect to two distinct adjacent habitat edge types bordering *Posidonia australis* beds on the northern shores of Jervis Bay, NSW, Australia

by

Nikki Antonia Bramwell

Thesis submitted in fulfilment of requirements of the degree of Doctor of Philosophy at the University of Technology, Sydney

June 2016

School of Life Sciences

University of Technology, Sydney

Ultimo, NSW, Australia, 2007

Certificate of Original Authorship

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature of Student:

Date: October 25, 2016

Acknowledgements

I would like to thank my supervisors, Professor David Booth and Dr. Edd Hammill for their invaluable support and encouragement throughout the course of my candidature and thesis preparation. I am very grateful to them for providing different perspectives, ideas and suggestions towards the production of this piece of work.

I would like to especially thank my scholarship body, Australia Aid (AusAID) for providing me the opportunity to pursue this degree. Special thanks to Richard Lum and the staff of the Sponsored Students division of the UTS: International office, mediating the AusAID scholarship, for their full support throughout my candidature. I would also like to acknowledge Tim Glasby of the NSW Department of Primary Industries (Fisheries) for being so helpful in the initial stages and providing seagrass and rocky reef benthic mappings used for site selection and for presentation in this thesis. Special thanks to the NSW DPI (Fisheries) also for providing the permits necessary to conduct this research especially within the usually untouched Greenpoint, Hare Bay site. I would like to thank the staff of the Beecroft Weapons Range in Jervis Bay for allowing me access to Greenpoint and for granting me the necessary permit to conduct research from their compound.

Special thanks to Des Beechey of the Australian Museum (Sydney) for his assistance with mollusc identification and Frank Coman and staff at the CSIRO Marine and Atmospheric Research centre (Brisbane) for their assistance with identifying troublesome zooplankton samples from micrographs I had sent to them. I would also like to acknowledge the UTS lab technical staff, primarily Peter Jones, Gemma Armstrong and Susan Fenech for facilitating the smooth running of my lab work and manipulative aquarium experiments.

Special thanks to the volunteers who assisted with lab and field work including Cherryl Marsellina, James Laolada, Quinn Ollivier, Ian Dick, Ellery Johnson, Vicky von Bernard, Lucas Djurichkovic, Abigail Marcella Irwin, Jonathon Lee and Alice Pidd with special mention to James Laolada, who consistently made himself (and his friends) available, sometimes on short notice in the final stages of my fieldwork. Special thanks also to Quinn Ollivier, who started as an undergraduate intern, for his invaluable contribution in mollusc distribution evaluation at one of my sampling sites resulting in a publication.

I am very grateful to my fellow lab mates and post doctorates, past and present, for making my research experience a memorable one. I am grateful for their support and words of wisdom especially from Cian Foster-Thorpe, Gwenael Cadiou, Hayden Beck, Ashley Fowler, David Feary and Paloma Matis.

I would like to thank my family for their patience and support while pursuing this degree over 10,000 miles from home and for my friends both here and home for their words of encouragements and prayers. Thanks are also in order for the baristas of the Sydney CBD for helping me through the many months of thesis writing and Coldplay for their soothing effect in the process.

Greatest thanks go to my Heavenly Father for making all of this possible, bringing all things together and placing the above persons and opportunities in my life and all in perfect timing.

Table of Contents

Appendices

List of Tables

List of Figures

Thesis Abstract

Several studies over the past decade have examined “edge effects” on fauna within a focal habitat using a model consisting of two habitat types forming the edge. With regards to seagrass faunal studies this edge effect is more commonly investigated at seagrass-sand interfaces. These observed effects are in many cases largely biased towards the structure of the seagrass itself at the edge and not the type of adjacent with which the seagrass forms the edge. As real landscapes contain multiple edges with the structure of each determined by the type of adjacent habitat with which the focal one is forming the edge, it seems imperative to begin assessing the dynamics of edge effects under these conditions. As such this study investigates the spatial distribution of fish and their prey communities – zooplankton and benthic invertebrates, along with epiphyte load, within *Posidonia australis* seagrass beds in northern Jervis Bay, NSW, Australia with respect to two adjacent habitat edges i.e. rocky algal reef and bare sediment. Rocky reef habitats are common features in the nearshore environment of the south-east Australian coast. The relationship between the prey and fish distribution relative to both habitat edge types was examined along with the relative sensitivity to edge of the different seagrass fauna. Manipulative aquarium experiments were also performed to assess the role of predatory threat in the spatial distribution of selected seagrass species with respect to these habitat edges. Results illustrated (1) differing responses of seagrass fauna to different habitat edge types, with the rocky reef exhibiting an overall greater effect, (2) site-specific and species-specific and for fish taxa, functional guild-specific responses to the different edge types, (3) a close relationship between edge effects and sensitivity to edge exhibited by fish and their prey, (4) a greater sensitivity to edge displayed by the more sessile benthic invertebrate community compared to the more mobile zooplankton and fish taxa, and (5) that predatory threat influenced habitat position of certain fish taxa. Results of this study highlight the importance of adjacent habitat type in edge studies, illustrating different responses to the differently structured edge types, likely driven by differing microclimatic conditions experienced at each. As such, adjacent habitat type should feature more in the discussion of edge effects and the need exists to conduct more edge studies in landscapes representing real multiple edge conditions to better inform management and planning initiatives.

Chapter 1 – General Introduction:

Overview of theory

Habitats within the seascape rarely exist in isolation. They are oftentimes, at some point, closely associated and form boundaries with at least one and in many cases at least two other distinct habitat types. Additionally, at the border where habitat A meets habitat B, habitat A in this position cannot be considered equivalent to contiguous habitat A (Anderson et al. 2009). As they do not exist in isolation the fauna dwelling within a habitat are likely influenced by the presence of another unique habitat in close proximity, especially if this unique neighbouring or adjacent habitat provides resources not found within its own, i.e. it provides "complementary" resources (Ries et al. 2004; Ries & Sisk 2004). The influence that a habitat's edge with a neighbouring one may have on particular taxa, however, is dependent on several factors expounded on further in this thesis. These factors include the structure of the edge itself (Fagan, Cantrell & Cosner 1999) i.e. the habitats comprising the edge construction as well as intrinsic characteristics of the taxa i.e. their size, mobility, and perception of edge (Fagan, Cantrell & Cosner 1999; Ries et al. 2004; Ries & Sisk 2004), the latter taxa characteristic partially linked to the first two. Consequently, different taxa may exhibit different degrees of response or sensitivity to edge (Fagan, Cantrell & Cosner 1999; Jelbart, Ross & Connolly 2006; Ries et al. 2004; Sisk & Battin 2002) which may again be affected by the unique construction if the edge itself.

Seagrasses form a prominent feature of the New South Wales seascape (Roy et al. 2001). They host a wide array of fish and invertebrate species (Middleton et al. 1984; Valentine & Duffy 2007; Bell & Westoby 1986; Valesini et al. 2004; Franco et al. 2006; Franco et al. 2008), several of commercial and recreational importance. The structure of the seagrasses themselves offers stability to the benthos. While the blades serve to reduce wave energy, the roots hold the sediment in place (Kirkman 1987) providing an ideal habitat for settling for both benthic invertebrates and juvenile fish. Additionally, many larger mobile faunal species are known to exploit seagrass beds for their rich supply of fish and invertebrate prey (Elliot et al 2007). The importance of this ecosystem as such cannot be denied. Their inherent value and prevalence in the NSW seascape validates its selection as the ecosystem of choice in addressing the edge discussion.

Several studies in the past decade including a pilot study I conducted in conjunction with this thesis (See Appendix I for methods and summary of results) have examined the distribution of seagrass fauna in relation to a single adjacent habitat more commonly adjacent sand (Jelbart, Ross & Connolly 2006; Macreadie et al. 2010; Smith et al. 2008). The tone of discussions in many cases is somewhat biased towards the structure of the seagrass' "edge" itself with the sand being the determining factor behind species distribution (but see Smith et al. (2008)). While this is undoubtedly very useful, it will be important to determine how seagrass fauna may respond to seagrass edges of different structures formed as the seagrass borders more than one adjacent habitat as in nature most landscapes possess multiple edges (Ries et al. 2004). This would enable us to determine the varying sensitivities of individual fauna and communities to different edge types in the same location. Examining the effect on fauna with respect to different adjacent habitats allows the type of adjacent habitat to feature more in the equation of "edge effects" as the type of adjacent habitat type will determine the seagrass edge structure and hence the unique physical dynamics cascading into impacts on faunal assemblages (Ries & Sisk 2004) at the different edge types. Simply put, each unique adjacent habitat bordering a seagrass bed will provide a different edge structure at each boundary and hence influence seagrass fauna differently. It is this relationship that will be examined in this thesis.

Dual edge study model

Predictive models describing mechanisms involved in ecological responses to habitat edges (Fagan, Cantrell & Cosner 1999; Ries et al. 2004; Ries & Sisk 2004) stress the importance of regarding the change in resource distribution and local microclimate conditions towards edges (Ries & Sisk 2004) when assigning perceived edge effects to a particular faunal community. This is attempted in the current study, with the focal habitat being *Posidonia australis* seagrass beds and the fish community being the focal fauna. The seagrass fish community along with their potential prey communities i.e. benthic invertebrates, zooplankton and epiphyte load as well as seagrass blade morphological characteristics are examined from within the seagrass beds with increasing distance away from two distinct adjacent habitats – a rocky algal reef platform and unvegetated sediment. These two adjacent habitats bordered the extensive *P. australis* beds along the vertical and horizontal axes respectively at each location (Fig 1.1). These assessments are done on the mesoscale i.e. 10s m, mindful of the fact that considerable variation within the faunal community exists on this scale, the detection of which would be lost at larger scales i.e. 10s – 100s km (Banks & Skilleter 2007). Additionally, a scale measured in units of meters and centimetres would not have been appropriate in this study to adequately detect comparable distributional trends considering the high mobility of some of the sampled faunal groups (Connolly & Hindell 2006; also see Ries et al. 2004 for review of scale at which edge responses operate for varying fauna in terrestrial ecosystems). The appropriateness of the scale used will depend on the size, mobility and edge perception of the individual (Connolly & Hindell 2006). Larger more mobile organisms, such as fish fauna, will require a relatively large scale for proper detection of trends (Connolly & Hindell 2006) as they perceive an edge to a lower degree than less mobile organisms (Burel & Baudry 2003). As such, in order to preserve comparability of results and to adequately represent all faunal groups assessed a scale of tens of meters was deemed the best compromise.

The prey communities selected for investigation reflect the overwhelming occurrence of invertebrate and hyperbenthos-zooplankton fish feeding groups noted within estuaries (Elliott & Dewailly 1995; Franco et al. 2011) as well as the importance of the seagrass ecosystem for grazers of both seagrass and epiphytic material by herbivorous fauna including fish (McGlathery 1995; Statton et al. 2015; Valentine & Duffy 2007; van Montfrans, Wetzel & Orth 1984). Additionally, while resource distribution is highly likely to determine the fish's distribution, several studies have also cited the role of predatory risk in the assumed position of fauna in the ecosystem (Cheminée 2012; Gotceitas & Brown 1993; Grabowski et al. 2005; Grol et al. 2011; Lima & Dill 1990; Ljungberg et al. 2013). Accordingly, the change in habitat occupancy related to different edge constructions and positions from edge with and without the inclusion of a predatory stimulus was also investigated for select seagrass fish species.

Fig 1.1 Layout of habitat arrangement at sampling sites forming two different seagrass edge construction types.

The relative strength of an observed response with edge, termed "sensitivity" and the direction of this response (increasing or decreasing away from the edge) of the fish community and the varying fish prey communities are examined with respect to each adjacent habitat type. This was undertaken to help elucidate mechanisms that may be driving distributional trends with edge type for the fish, as well as the entire sampled seagrass ecosystem.

Scope of study – the biological community

The scope of this study does not include measurement of physical or physicochemical parameters at the edges or within the seagrass beds due to time constraints of a PhD study. The primary focus, however, lies in deciphering trends and relationships in the biological community. Knowledge of any variation in local physical environmental conditions at the edges and extending into the seagrass beds such as hydrodynamics and water flow was obtained from relevant published literature cited throughout the thesis. Focus and time was placed on sampling and processing different components of the biological community with measurement of physical and physicochemical parameters not being a practical venture.

Thesis structure

The thesis begins with the examination of fish fauna using two different sampling methods (Chapters 2 – Method #1; and Chapter 3 – Method #2) within the seagrass bed with increasing distance from both adjacent habitat types i.e. the rocky algal reef and bare sediment. Fish fauna was also assessed with increasing distance from the "general edge" region with the nature of both habitat types not taken into account. This is further explained in subsequent chapters and is included to help decipher if the edge effect being observed was driven by the specific edge construction, i.e. considering the adjacent habitat type, or just edge *per se*. Consequently, faunal distribution is assessed in three planes:

Plane 1: distance from rocky algal reef

Plane 2: distance from bare sediment

Plane 3: distance from "general edge" or edge *per se*

Towards the end of Chapter 3 fish assemblage data from both sampling methods are compared and then combined in a presence/absence matrix on several levels. The thesis then proceeds to examine the fish prey communities i.e. benthic invertebrates, zooplankton and epiphyte load measures (Chapter 4) along the same planes, in the same sampling positions. This was done to assess any relationship between the distribution of the fish community and its sensitivity to the varying edge types with that of its prey. Blade morphology metrics are also here examined to determine any direct or indirect effect on prey and fish fauna. The penultimate chapter (Chapter 5) seeks to support, in a controlled tank experiment, trends observed in the field as well as explore the role predatory threat on fish may have on its distribution with respect to habitat structure and by extrapolation edge type. The final culminating chapter (Chapter 6 – General Discussion) compares the distribution with respect to the different edge types and edge sensitivities of prey and fish communities at different levels. It also postulates possible mechanisms driving edge effects observed in all components of the biological community sampled based on data from this study and inferred relationships based on relevant published research.

To ensure proper flow and coherency of the text all ***data related tables and graphs*** *are positioned towards the end of each chapter in the order in which they are first referred.*

Use of functional group classifications

Throughout this study fish species are referred to as individual species or taxa as well as functional groups and their distribution with respect to each edge type analysed as such. Functional grouping ensures the relevancy of the study across other transitional habitats and geographical locations (Elliott et al. 2007; Franco et al. 2008) and gives a better understanding of the relative importance or function (Elliott et al. 2007; Franco et al. 2008) of varying positions within the seagrass bed with respect to the adjacent habitat edges. The functional group classifications used in this study follow closely those put forward in Elliott et al. (2007) and Franco et al. (2008) and include two classification schemes i.e. The **Feeding Mode Functional Grouping (FMFG)** and **Estuarine Use Functional Grouping (EUFG)**. The description of each functional group or “guild” as defined by this study is below presented with guild assignment to fish species or taxa done after consultation with literature along with stomach content analysis done in this research.

Feeding Mode Functional Grouping (FMFG):

Zooplanktivore (ZP):

Consuming predominantly zooplankton including copepods and other planktonic crustaceans, planktonic molluscs, annelids, hydroids, fish egg and larvae and other planktonic larvae

Non-piscivorous carnivores (CNP):

Feeding primarily on a range of mobile macroinvertebrates including crustaceans and molluscs

Piscivorous carnivores (CP):

Feeding primarily of finfish but may also take mobile invertebrates

Herbivores (HV):

Grazing predominantly on living plant material including macroalgae, macrophytes, epiphytic algae; whereas they may take other food items these individuals are morphologically adapted for grazing or based on literature have diets dominated by plant material

Omnivores (OV):

In this study this guild is not differentiated from the "Opportunist" guild (Elliot et al. 2007) and includes those fish feeding on a diversity of plant and animal material to varying degrees. Food items would include a combination of fish, filamentous algae, epifauna and infauna, macrophytes and periphyton.

Estuarine Use Functional Groups:

Following the classification of Elliott et al. (2007) there are two guilds of Estuarine species (ES) and two guilds of Marine species (MSp):

Estuarine Species (ES):

Estuarine Residents (ER)

Capable of completing their life cycle entirely within the estuary and are not found at sea at any stage of their life cycle

Estuarine Migrants (EM)

Have some stage/s of their life cycle completed or found outside of the estuary (marine or freshwater environments) or have discrete representative populations in marine or freshwater systems

Marine Species (MSp):

Marine Migrants (MM)

Spawn at sea and tend to enter estuaries in large numbers, usually in their juvenile stages; capable of traversing through the entire length of the estuary tolerating wide ranges of salinities encountered

Marine Stragglers (MS)

Usually associated with coastal waters, spawn at sea and customarily only enter estuaries in low numbers; restricted to the lower reaches of the estuary where salinities are highly reflective of marine coastal waters

Relevance of Study to New South Wales Seascape

The seascape of New South Wales, Australia is anything but homogeneous. As well as the seascape varying from estuary to estuary or from one coastal lagoon to the next, distinct habitats within are not found in isolation. Seagrass beds of various species, primarily, *Posidonia australis*, *Zostera capricorni*, *Zostera muelleri* and *Halophila australis* and *Halophila ovalis*, occur within the nearshore marine environment some occurring in monospecific stands as well as being mixed among other seagrass species (Refer to Figs 1.2 – 1.7). Adding to the diversity of seagrass habitats found in New South Wales is the presence of extensive sand patches adjacent to homogeneous seagrass beds or interspersed within the more patchily distributed seagrass configurations (Fig 1.4). Isolated rocky algal reefs of varying sizes are also in many cases found in close association with seagrass habitats in the nearshore marine benthic environment (Figs 1.3 – 1.5).

This diversity of habitats often found within units, tens or hundreds of meters of each other make it imperative and relevant to study fish assemblages within any one habitat in relation to its neighbouring habitat as free movement is often facilitated between adjacent habitats (Nagelkerken et al. 2008; Olds et al. 2012). This connectivity is highly likely to influence the fish fauna within any one habitat. It also becomes imperative to begin considering the influence and relative influences of one habitat type on another when the focal one is bordered by at least two unique habitat types, as is clearly the case in the NSW seascape.

Advantages of using the seagrass, Posidonia australis, as the focal habitat in this edge study model

Seagrasses, based on their proximity to sand habitats and isolated rocky reefs in the context of New South Wales, as well as its relatively easier degree of accessibility, often found in shallow coastal waters, make it a suitable focal environment from which to address the importance of and sensitivity of fish and prey fauna to differing habitat types and relate this to the structuring of the fish community itself. Additionally seagrasses offer a stable environment (Fonseca et al. 1983; Orth 1977; Peterson et al. 2004) for the establishment of a diverse prey community (Castel et al. 1989; Neckles, Wetzel & Orth 1993; Summerson & Peterson 1984) which is undoubtedly related to the heightened fish community (Bell & Westoby 1986a; Elliott et al. 2007; Franco et al. 2006; Gray, McElligott & Chick 1996; Pollard 1984; Valesini, Potter & Clarke 2004) of both permanent residents and transient marine species (Elliott et al. 2007), many of commercial importance found within. The moderate complexity of the seagrass beds also allows for a combination of fish sampling techniques to be employed with greater ease, as opposed to the prop root dominant, frequently turbid environment of the mangrove habitat or the craggy outcrops and crevices of the rocky reef that would make sampling within these habitats less profitable. The behaviour of cryptic sand dwelling fish which often burrow into the sediment to escape capture, along with the presence of faster swimming, larger species would also render the sand or mud habitat a more challenging one from which to get reliable fish assemblage and habitat use data.

Posidonia australis is also usually found in more oceanic waters, being intolerant of hyposaline conditions and typically restricted to open lagoons (Kirkman 1997). Its restricted distribution in this regard associates its presence with a more oligotrophic, less stagnant environment where the effect of eutrophication is to some degree minimized, hence eliminating a possible nuisance variable from the proposed study. *Posidonia australis'* higher tolerance of increased wave action over other seagrass taxa (Kirkman 1997) allows for its presence next to hydrodynamic rocky reef habitats (Barros, Underwood & Lindegarth 2001; Connell 1985) allowing for the assessment of the dual edge model described above. The lower occurrence of this seagrass species along the NSW coast of Australia (Kirkman 1997) along with its slower

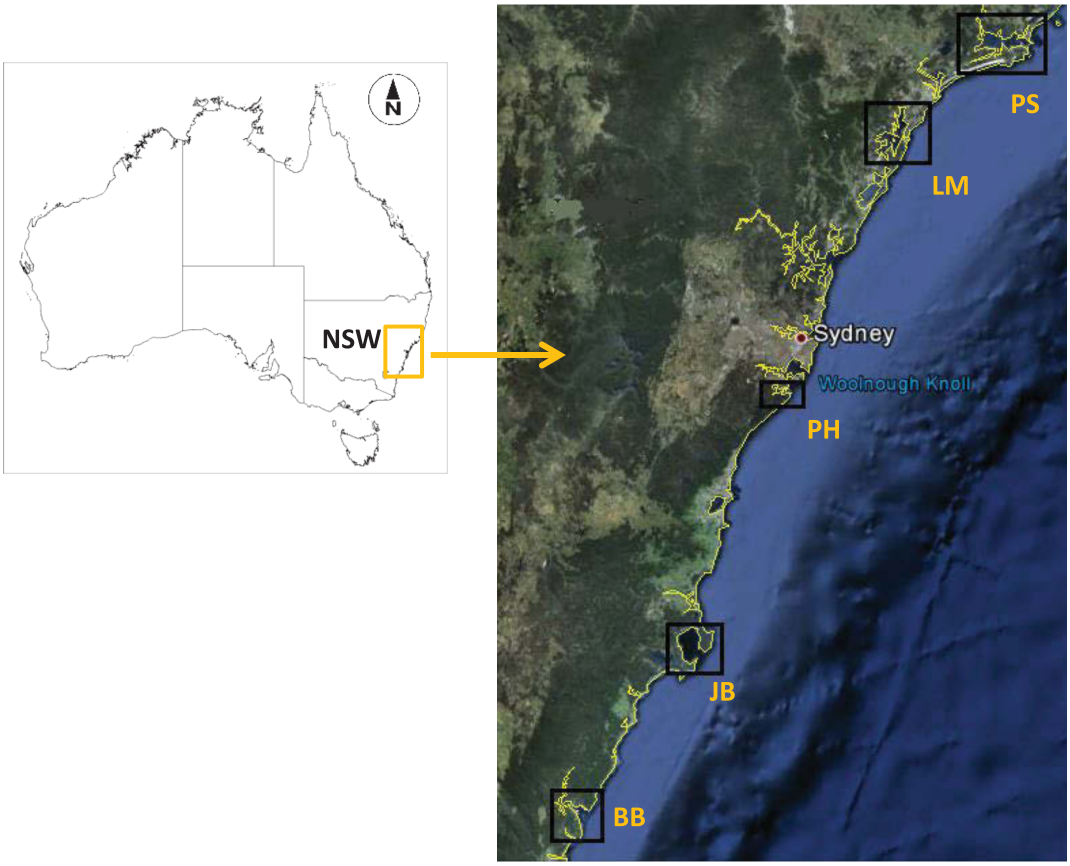
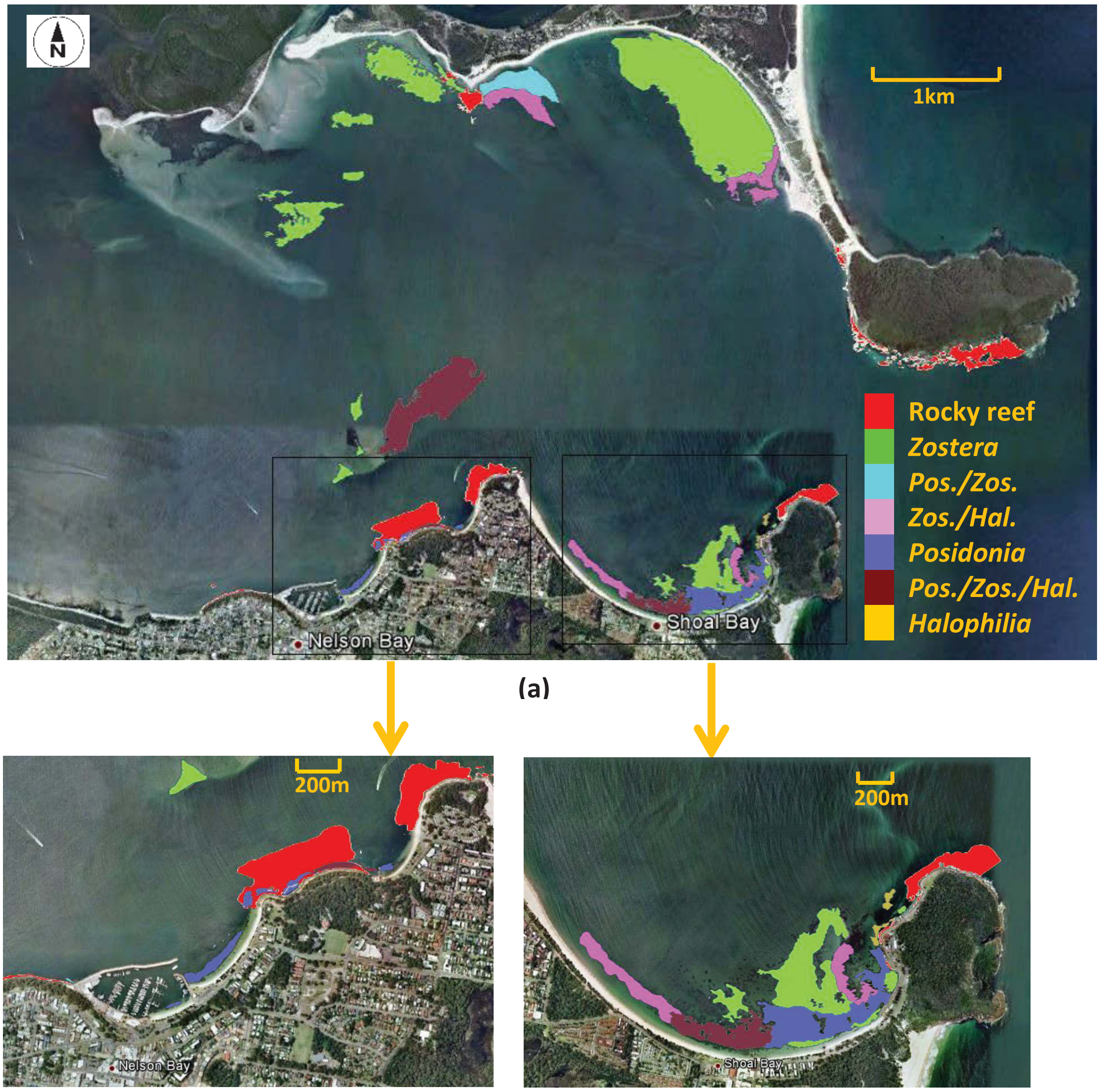


Fig 1.2 Position of selected estuaries along the New South Wales coast (inset)
PS – Port Stephens [32°41’22.81”S 152°04’01.24”E]; LM – Lake Macquarie [33°05’34.11”S 151°35’21.47”E]; PH – Port Hacking [34°04’03.68”S 151°07’33.95”E]; JB – Jervis Bay [35°08’21.49”S 150°43’42.56”E]; BB – Batemans Bay [35°42’30.17”S 150°10’39.41”E]. Image adapted from Google Earth (2014).

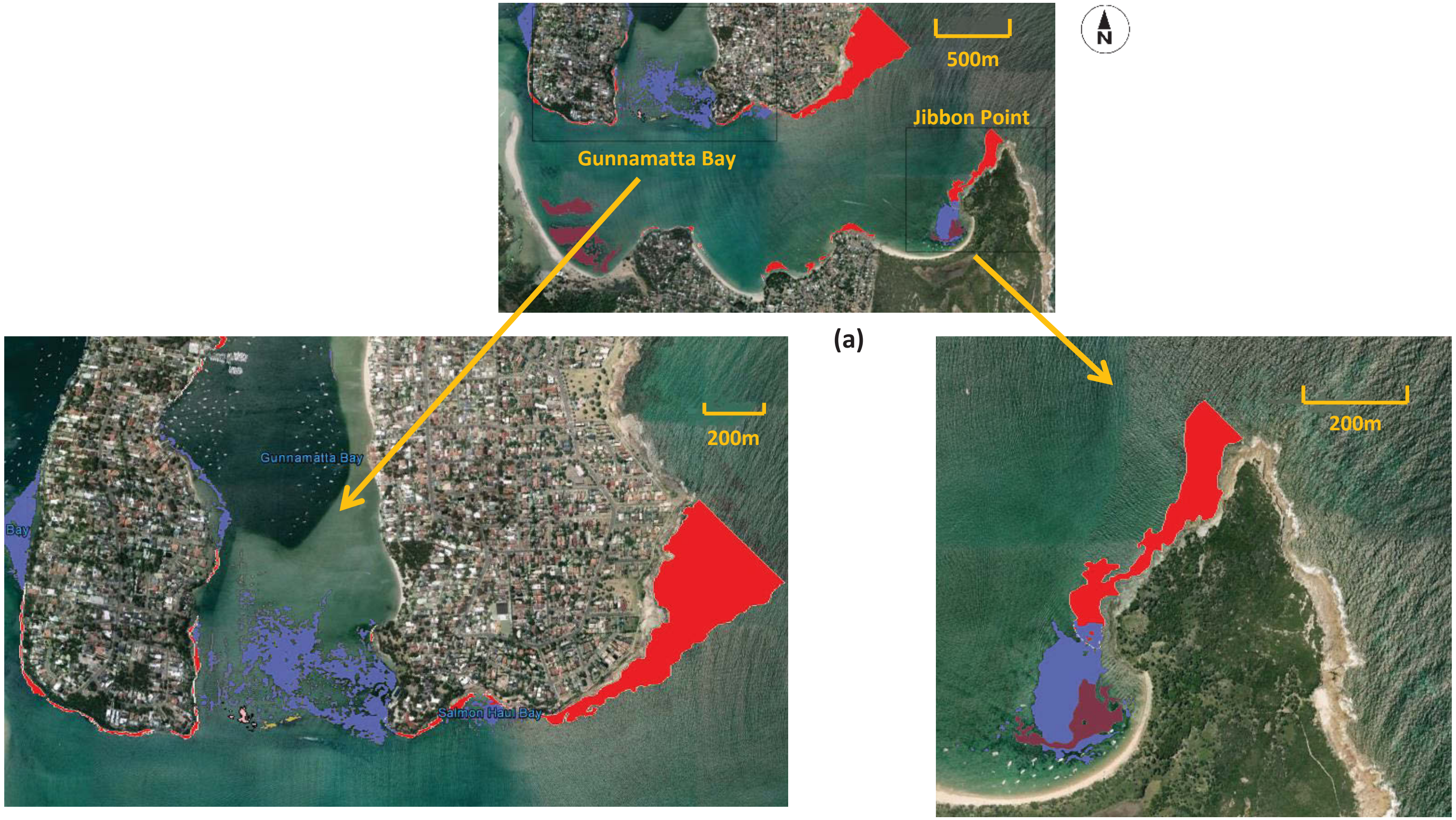


(a)

(b)

(c)

Fig 1.3 Benthic habitat mapping of (a) Port Stephens and select bays on its southern shores: (b) Nelson Bay and (c) Shoal Bay performed in 2004. *Adapted with permission from habitat maps provided by NSW Department of Primary Industries (Fisheries); Figs 1.4 – 1.7 follow the same benthic habitat colour key as illustrated in the current figure; colour note – bright red = rocky reef; maroon = Pos./Zos./Hal. mix.*

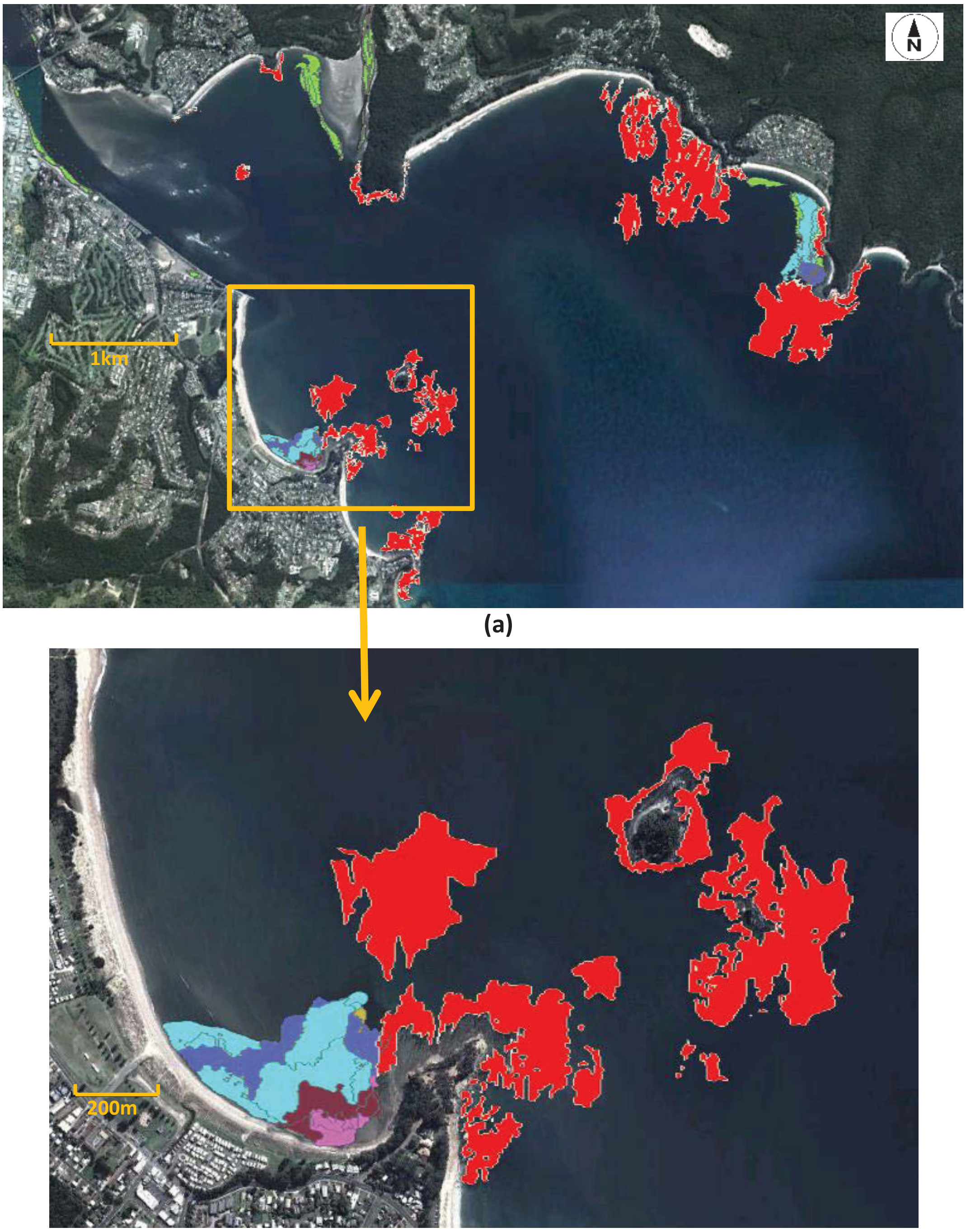


(a)

(b)

(c)

Fig 1.4 Benthic habitat mapping of (a) Port Hacking and select bays within: (b) Gunnamatta Bay and (c) Jibbon Point performed in 2008. *Adapted with permission from habitat maps provided by NSW Department of Primary Industries (Fisheries); benthic habitat colour key illustrated in the Fig 1.3.*



(a)

(b)

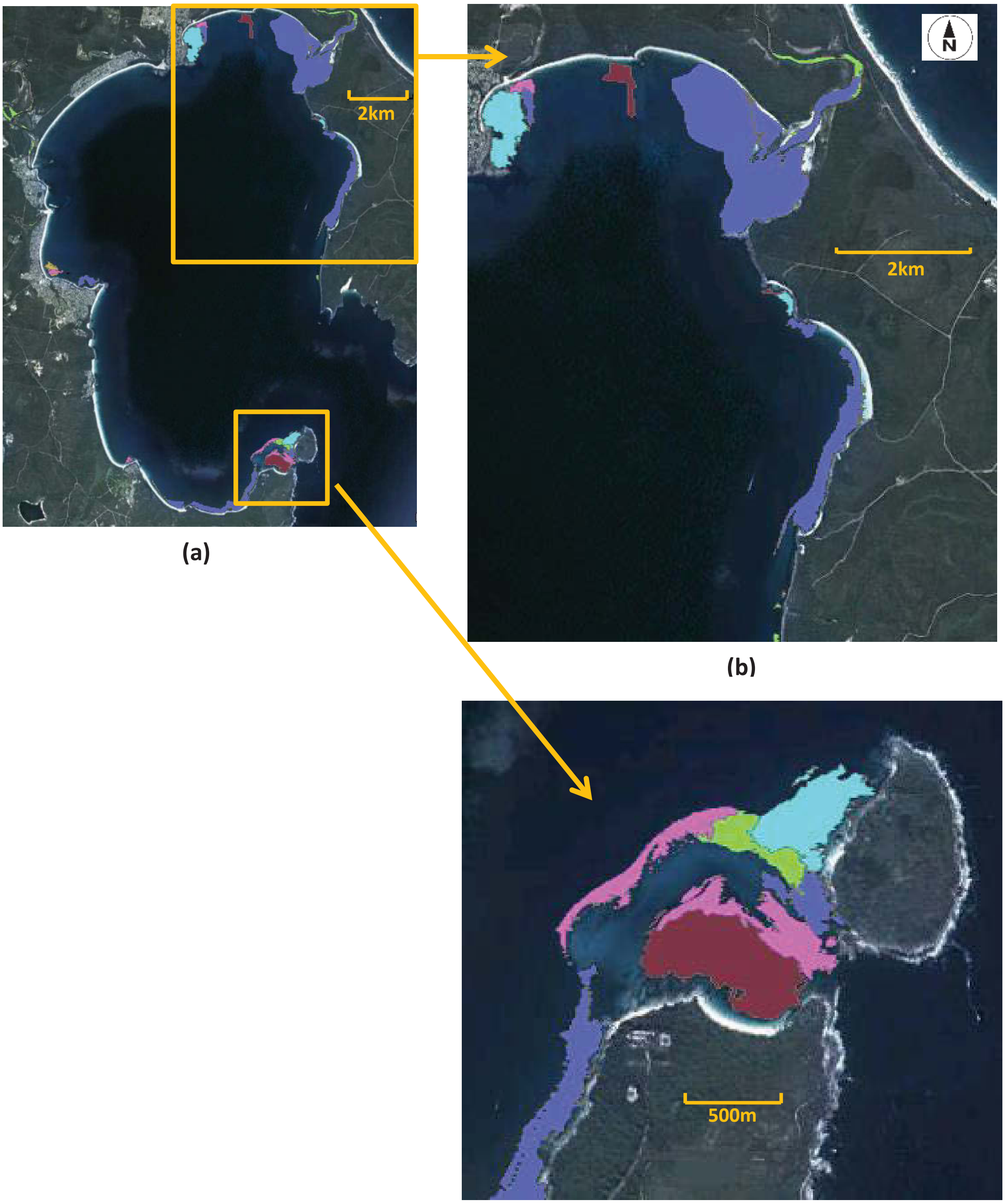
Fig 1.5 Benthic habitat mapping of (a) Batemans Bay and select region within: (b) Batehaven performed in 2005, 2009 and 2012. *Adapted with permission from habitat maps provided by NSW Department of Primary Industries (Fisheries); benthic habitat colour key illustrated in the Fig 1.3.*

regeneration times (Kirkman 1997) makes *P. australis* a good focal habitat candidate for at least two other reasons: first, most seagrass studies have focused on the more dominant *Zostera* species and hence more information on fish assemblages in *Posidonia* beds is required and second, the fragility of the species makes a study validating its importance useful to justify its continued conservation, in conjunction with habitats found adjacent to it, which may influence the distribution of faunal assemblage within.

Description of study sites

Jervis Bay is an oblong shaped, partially open embayment located 100 km south of Sydney and is 15 km long and 10 km wide (Bryant et al. 1997). The embayment is characterised by pristine waters with no influence of large rivers emptying within (Cho 1998). It possesses stands of *P. australis*, *Halophila* spp. and *Zostera* spp. seagrasses often present around rocky coastal outcrops (Fig 1.6, 1.7) with the *P. australis* meadows among the largest in New South Wales (Cho 1998). Two sites, Callala Bay (**CB**) – 34°59’53.47”S 150°43’37.89”E and Greenpoint (**GP**), Hare Bay – 35°00’34.37”S 150°46’04.24”E (Fig 1.7), were chosen having extensive completely homogenous monostands of *Posidonia australis* beds immediately adjacent to a rocky algal reef platform along one margin (perpendicular to shore) and unvegetated sediment at the other margin (parallel to shore) at each site. The sections of the seagrass beds sampled at both sites were in depths of up to 1.5m at mean low tide and consisted of continuous extensive stands of *P. australis*. Both reef platforms aligned perpendicular to the shoreward bare sediment were interspersed with sand patches containing patches of the seagrass species *Halophila ovalis* and rooted, upright canopy forming macroalgae, the latter themselves matted with filamentous and tufted algae. The reef structure at both sites was covered with numerous macroalgal species ranging from red coralline algae, mat-forming filamentous brown and green algae to upright, canopy forming, highly branching algal forms. Free floating detached mats of macroalgae were also present. A list of some of the more dominant macroalgae associated with the rocky reef habitat across both sites, obtained from field observation in this study, are outlined in Table 1.1.

The submerged rocky reef habitat at Callala Bay displayed a more gradual slope towards the shoreward reef platform at all sections from the margin of the sampled *P. australis* bed compared to Greenpoint which possessed a more vertical reef structure along some sections of its interface with the *P. australis* bed. Additionally, Greenpoint was prone to stronger waves on several sampling occasions compared to the generally calm conditions at Callala Bay (pers.



(a)

(b)

(c)

Fig 1.6 Benthic habitat mapping of (a) Jervis Bay and select sections within (b,c) performed in 2004. *Adapted with permission from habitat maps provided by NSW Department of Primary Industries (Fisheries); benthic habitat colour key illustrated in Fig 1.3.*

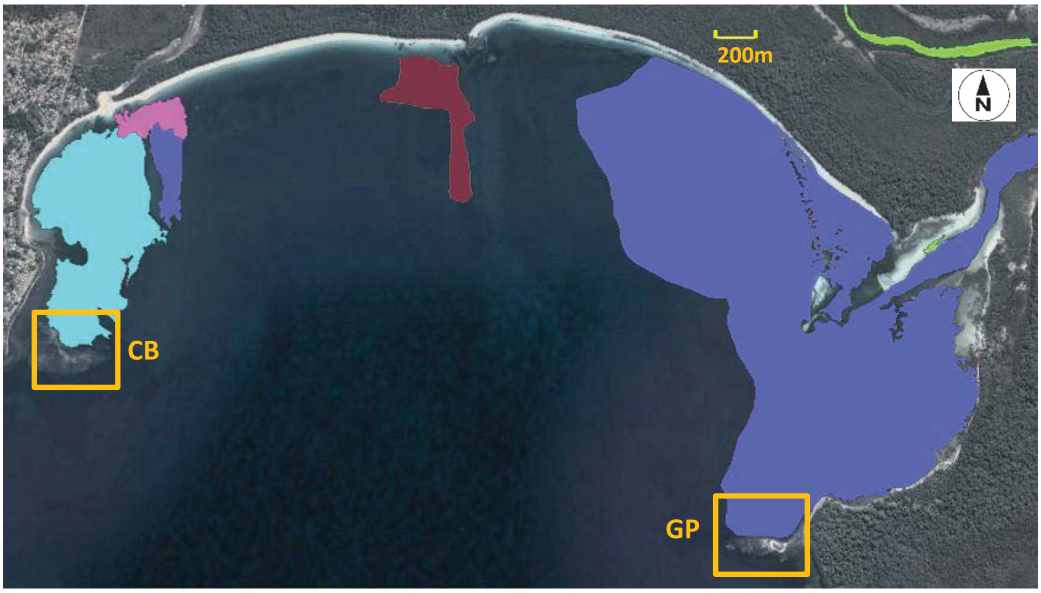


Fig 1.7 Benthic habitat mapping of northern most section of Jervis Bay including the sampling sites Callala Bay (CB) and Greenpoint, Hare Bay (GP) performed in 2004. *Adapted with permission from habitat maps provided by NSW Department of Primary Industries (Fisheries); benthic habitat colour key illustrated in Fig 1.3.Ground-proofing of CB during current research showed the sampling locations of this study to be monostands of P.australis.*

observ). All sampling locations within both sites on all sampling occasions had no human interference apart from that imposed by myself and assisting field volunteers during the sampling process. Nonetheless, Greenpoint is within a more secluded section of the Jervis Bay northern headlands, assessable through the Department of Defence's Beecroft Weapons Range occupied by the Royal Australian Navy, and is a sanctuary zone declared by the NSW Department of Industries (Fisheries) who granted me permission to conduct this research.

Several estuaries along the NSW coastline including Port Stephens, Lake Macquarie, Port Hacking and Batemans Bay were surveyed along with Jervis Bay in pilot studies associated with this research. Jervis Bay, however, for several reasons addressed here below and in subsequent chapters, was chosen as the main study estuary. Jervis Bay, unlike the other named estuaries, possessed sites with continuous monostands of *Posidonia australis* beds adjacent to both rocky reef and bare sediment ecosystems at appropriate depths as described above. While the other estuaries did possess *Posidonia australis* adjacent to sand and/ or rocky reef, the beds were often patchy distributed, contained a mixture of other seagrass species including *Zostera spp.* and were often not at practically assessable depths.

The uniform, appropriate depth at Jervis Bay was especially important as it allowed for the sampling of fish communities using two separate techniques, the importance of which is highlighted in Chapter 3. It also allowed for the proper sampling of the other biological components of the seagrass ecosystem i.e. the benthic invertebrates, zooplankton, epiphyte load and seagrass morphology. Uniformity of depth at Jervis Bay for all sample locations was also important as it avoided the possible confounding interactions with this factor. As such, this estuary was deemed the ideal location to study the dual edge model. As stated above, several biological components of the seagrass ecosystem are being measured, processed and assessed at each site over several distance categories in this research and in most cases over two seasons. This was done to gain a complete picture of fish and potential prey distribution with respect to edges and edge type over a consistent distance increment.

Due to the idiosyncrasies noted in literature for individual estuaries (Livingston 1987) choosing one estuary to focus the study would remove the effect of nuisance variables influencing results across estuaries which could only be reasonably addressed by including multiple estuaries. The latter would not have been a practical option given the breadth of the study i.e. the inclusion of several components of the biological community and the limited allotted time frame of a PhD research. As such this study forms the framework on which further studies can adopt and build on when investigating the impact of the dual edge model on different components of the seagrass ecosystem.

Table 1.1 List of common macroalgal taxa found associated with adjacent rocky reef habitat across both sampling sites – Callala Bay and Greenpoint, Jervis Bay

Common rocky reef associated macroalgal taxa
Brown algae – Division Heterokontophyta
Cladosiphon filum
Cladostephus spongiosus
Colpomenia sinuosa
Cystophora spp.
Dictyopteris muelleri
Dictyota spp.
Eklonia radiate
Hincksia mitchellidae
Hormosira banksia
Padina spp.
Sargassum lacerifolium
Green algae – Division Chlorophyta
Avrainvillea clavatiramea
Caulerpa racemose
Chaetomorpha spp.
Codium spp.
Entermorpha spp.
Red algae – Division Rhodophyta
Ceramium spp.
Gracilaria spp.
Jania microarthrodia
Family Corallinacea

Chapter 2: *Seagrass Fish Distribution with Respect to Different Habitat Edge Types based on Seine Net Collection*

2.1 Introduction

Seagrass beds provide an ideal habitat for estuarine and marine migrant fish (Bell, Steffe & Westoby 1988; Bell & Westoby 1986a; Franco et al. 2006; Gray, McElligott & Chick 1996; Guidetti 2000; Gullström et al. 2011; Jenkins, Keough & Hamer 1998; Jenkins & Wheatley 1998; McRoy & Helfferich 1980; Nagelkerken et al. 2000; Pollard 1984; Smith et al. 2011; Valesini, Potter & Clarke 2004). The blades themselves, particularly that of the wider strap-like *Posidonia australis* (Middleton et al. 1984) provide a microhabitat for plant and animal-based epiphytic organisms comprising an important component of their diet (Gullström et al. 2011). The blades also add complexity to the substrate, allowing smaller fish individuals and their prey such as macrocrustaceans and polychaetes (Whitlow & Grabowski 2012) to shelter from predation and greater water movement outside the canopy even in schools. Larger individuals may also shelter within the beds where the inter-blade spaces are large enough to accommodate their size (Bartholomew, Diaz & Cicchetti 2000).

Fish species generally found in seagrass beds are the cryptic syngnathids and gobiids with patterns of behaviour and morphologies suited for this habitat (Bell & Westoby 1986a; Valesini et al. 2004; Franco et al. 2006) as well as larger transient species in their juvenile stages (Franco et al. 2006). *Girella tricuspidata* (luderick) and *Pelates sexlineatus* (trumpeter) have also been associated with the seagrass ecosystem along with *Acanthopagrus australis* (Yellowfin bream), *Rhabdosargus sarba* (Tarwhine) and the prevalent *Ambassis jacksoniensis* (Port Jackson glassfish) (Gray, McElligott & Chick 1996). As aforementioned species such as the pipefish in particular, have morphologies specifically designed to dwell in these beds (Sheppard et al. 2011) wrapping their tails around the blades both for camouflage and physical support (Howard & Koehn 1985) and to enhance its filter feeding mode on passing copepods (Jenkins & Wheatley 1998). Stabilization of the sediment is another ecosystem service provided by the seagrass (Orth 1977) through the sediment-binding role played by the root system and current buffering action of the blades (Fonseca & Fisher 1986; Fonseca et al. 1983; Peterson et al. 2004). This allows for the proliferation of benthic epi- and infauna (Ca stel et al. 1989; Summerson & Peterson 1984), also forming a considerable part of the diet of seagrass fish.

Numerous studies over the past decades have attested to the non-homogeneous distribution of fish within the seagrass ecosystem. Numerous seagrass morphological characteristics

(Jenkins & Sutherland 1997; Jenkins & Wheatley 1998), small-scale local biotic and abiotic variations within the seagrass beds (Gullström et al. 2011; Jackson et al. 2006; Macreadie et al. 2010; Macreadie et al. 2009; Smith et al. 2008; Smith et al. 2011; Smith, Jenkins & Hutchinson 2012) and larger scale factors such as position of a seagrass bed relative to the estuary mouth (Bell, Steffe & Westoby 1988) have been noted to influence fish and other fauna abundances and measures of species diversity within the seagrass bed. Furthermore, within recent times an influx of studies based on habitat fragmentation (Macreadie et al. 2010; Macreadie et al. 2009; Warry et al. 2009) and landscape ecology (Smith et al. 2008; Smith et al. 2011) demonstrated the additional importance of the position of the seagrass bed itself with another habitat, albeit primarily with sand [but see (Tuya et al. 2010; Vanderklift et al. 2007)], with some fish and invertebrate taxa being more abundant at the seagrass-sand edge compared to the seagrass interior and others the reverse. These studies have on most occasions invariably alluded to the "edge effect" and reasonably so, but must now consider that this effect to a large degree may be an attribute of the type and hence structure of the adjacent habitat forming the edge with the seagrass (Ollivier et al. 2015).

The importance of the structure of adjacent habitats has been widely reported in the terrestrial ecosystem (Collinge 1996) more so than marine systems. At least one author reporting on the terrestrial landscape has regarded the adjacent habitat structure itself as being a stronger influencing factor on faunal assemblages compared to the habitat structure in which the fauna resides (Berg 2002). The importance of the habitat type comprising the edge is also highlighted in the predictive models of edge effects on species interactions of Fagan, Cantrell & Cosner (1999) and Ries & Sisk (2004) with both models stating that the potential sensitivity of taxa will be a function of the taxa itself and the type of edge. "Type of edge" here implies that the habitats constituting the edge will constitute a number of possible combinations leading to a different edge structure in each case with varying degrees of edge "permeability" (Fagan, Cantrell & Cosner 1999; Ries et al. 2004; Ries & Sisk 2004).

The seagrass-sand and seagrass-rocky reef habitat edges for instance, both highly prevalent along the NSW coast, have completely different architecture that will undoubtedly facilitate different microclimate and hydrodynamic conditions (Moore & Hovel 2010; Murcia 1995; Peterson et al. 2004; Ries & Sisk 2004) at each edge type. Additionally, whereas the rocky reef provides additional structure next to the seagrass the sand does not. The rocky reef also acts as a physical barrier to faunal movement and to that of nutrients limiting edge permeability (Fagan, Cantrell & Cosner 1999; Ries et al. 2004; Ries & Sisk 2004) while the sand habitat would not. The “novel interactions” (Fagan, Cantrell & Cosner 1999) formulated at both habitat edge types would therefore undoubtedly be different, likely resulting in different faunal response.

As many seagrass habitats along the NSW coast and undoubtedly other localities are surrounded by more than one adjacent habitat (Ries et al. 2004) it was the aim of this study to move away from the single adjacent habitat model and to investigate the effect on seagrass fauna in relation to two adjacent habitats, that of rocky reef and unvegetated sediment, for each seagrass bed studied.

Specific questions to be addressed by this chapter:

This chapter seeks to begin to address differences in trends observed in fish fauna with these two habitat edge types and answer the following research questions:

1. Is there a difference in fish community composition, fish taxa abundance or fish functional group abundance and taxa richness with distance away from the seagrass-rocky reef edge, seagrass-sand edge or edge *per se*?

2. Is the difference taxa-specific, functional group-specific or site-specific?

3. Do certain taxa or functional groups display differential or opposing distributional trends relative to the two types of edge i.e. the seagrass-reef and seagrass-bare sediment edges?

Null hypotheses tested:

1. There is no difference in a. fish community composition, b. fish taxa abundance, c. fish functional group abundances, d. taxa richness with distance away from either adjacent habitat type or edge *per se*.

2. There is no difference in the response of a. varying fish taxa and b. fish functional groups to increased distance from adjacent habitat types and edge *per se*.

3. There is no difference in a. taxa or b. functional group response to edge types or edge *per se* with site.

4. There is no difference in the response of a. individual fish taxa or b. functional groups relative to the two unique adjacent habitat types i.e. the rocky reef and bare sediment.

Rationale:

With regards to the demarcation of vulnerable habitats such as *Posidonia australis* seagrass beds (Kirkman 1997) for protection, this research will provide invaluable information concerning the particular sections of the seagrass beds hosting increasing species richness and abundance with respect to its position next to adjacent habitats. While this knowledge may only be applicable within the confines of this study's scale it gives insight into the differing distribution of fish species and functional groups to habitat edges of different types and paves the way for similar studies with a broader geographical range and time scale. This information will allow for small scale precision where demarcation for protection is concerned in a climate of limited capital. Protection at the finer scale (tens of meters) may also be more productive than large scale (kms) sanctuary zones as these oftentimes overlook the small scale fundamental interactions which may make or break the protection goal (Banks & Skilleter 2007; Cheminée 2012).

2.2 Methods

Seine net sampling

Four transects were lain perpendicular to and extending from an intertidal macroalgal-dominated rocky reef platform and parallel to the shoreward unvegetated sediment into a *Posidonia australis* seagrass (Fig 2.1) at two sites in Jervis Bay – Callala Bay (34°59'45.70"S 150°44'08.28"E) and Greenpoint, Hare Bay (35°08'05.99"S 150°43'25.97"E). Both sites contained extensive monostands of *Posidonia australis* seagrass immediately adjacent to and extending from the rocky algal reef (RAR). Fish assemblage data were collected at the following distances from the RAR along each of the four transects at both sites:

Distance 1 (D1): 0 – 15m

Distance 2 (D2): 15 – 30m

Distance 3 (D3): 30 – 45m

Distance 4 (D4): 45 – 60m

Each transect was 15m wide essentially creating sixteen 15 × 15 m replicate quadrants (Fig 2.1) per site. Within each quadrant a seine net (18.7m long, 2.3m high, 5mm mesh and attached 1.6m long cod end) was used to sample the fish within the seagrass. While along the vertical axis fish was sampled beginning at the immediate seagrass-reef interface (0-15m) the beginning of the first transect was approximately 5m from the nearby unvegetated sediment to ensure that sampling occurred in homogeneous seagrass. Each transect represented a set distance from the shoreward bare sediment as follows:

Transect 1 (T1): 0 – 15m+

Transect 2 (T2): 15 – 30m+

Transect 3 (T3): 30 – 45m+

Transect 4 (T4): 45 – 60m+

The "+" indicates the additional 5m from the bare sediment before the beginning of the first transect as described above. The net was extended beginning from the point of origin of the quadrant X, where one individual remained stationary holding one end of the net at this point X (Fig 2.1). A second individual extended the other end of the net, for instance at D1 in transect 1, up to the 15m-mark along the transect rope and made wide loop of diameter not greater than 15m bringing the net back to point X. Both ends of the net were then pulled in towards the point X keeping the base as close to the sediment as possible. This was repeated for all quadrants. The fish were kept in fresh seawater in labelled buckets to distinguish transect numbers and distances from the reef until all replicate seines were taken for the day. Each individual was subsequently identified, tallied, measured and returned to the seagrass bed. All fish were collected within two hours of either side of peak low tide and in daylight hours between 7:30 – 18:00. This was done for practical reasons as the seagrass beds would be too deep to seine outside of this time and also to reduce unnecessary variability in fish composition with tide. To avoid fish mortality and to keep within the two hour period of peak low tide, each site was done over a period of two days. Seine netting was done within each of the 16 sampling units or quadrants at each site repeated over two seasons – austral winter, August-September 2013 and austral summer, January-February 2014.

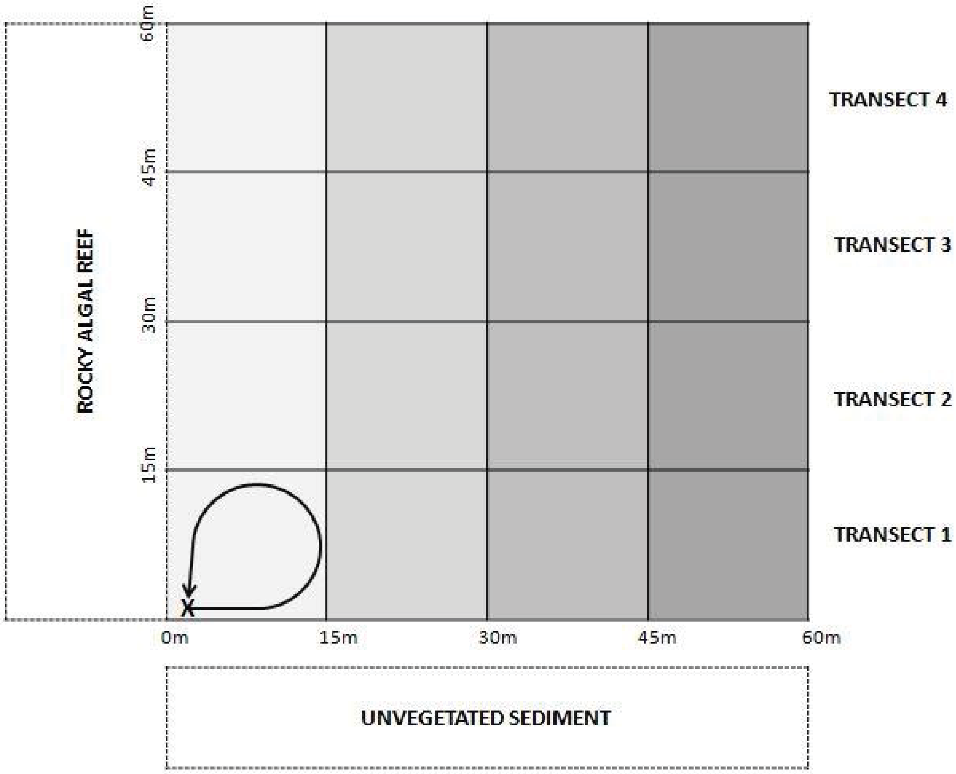


Fig 2.1 Layout of fish sampling matrix at both sites in Jervis Bay (Callala Bay and Greenpoint) showing direction of seine net deployment (X – origin). *Shaded region represents position of seagrass; greater intensity for further distances from reef.*

Functional group assignments

Individual fish species and taxa were assigned to functional guilds in two separate classification schemes i.e. Feeding Mode Functional Groups (FMFG) and Estuarine Use Functional Groups (EUFG) adapted from Elliott et al. (2007) and Franco et al. (2008) as outlined in Chapter 1: General Introduction. Assignment to guilds was accomplished by consultation with literature describing life strategies and diet of the relevant species from which the guild was allocated after confirmation from at least two sources. Stomach content analysis done in conjunction with this research (Appendix II) also guided guild assignment.

Statistical analysis

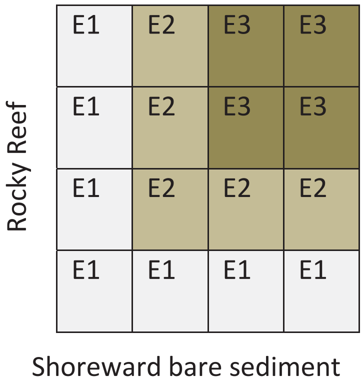
Multivariate PERMANOVA was performed on the community assemblage (i) of individual species and (ii) of feeding mode and estuarine use functional guilds, while univariate

PERMANOVAs were run on (iii) dominant individual fish species/taxa, (iv) individual functional guilds, (v) species richness and (vi) total abundance using two separate orthogonal designs in each case:

Design 1: “distance from reef” (fixed), “distance from bare sediment” (fixed), “site” (random) and “season” (fixed) along with their interactions *and*

Design 2: “distance from general edge” (fixed), “site” (random) and “season” (fixed) along with their interactions.

“General edge” was determined as outlined in Fig 2.2 with distances from the edge being considered disregarding the adjacent habitat type. In cases where there was a high non-significance ($p \geq 0.2$) for any one factor in each design it was removed from the design and the statistical test rerun. If removal of the highly non-significant factor did not change the p-values of the others the factor was retained. The factors retained in the model for each significant trend observed are noted in tables in the Results section. Pairwise comparisons between each combination of “distance from reef”, “distance from bare sediment” and “distance from general edge” was performed for each significant relationship. All abundance data, with the exception of species richness, which had already exhibited homogeneity of variances, was log transformed to achieve this requirement. Where homogeneity was not achieved even after log transformation the significance level was set at $p \leq 0.01$ (Underwood 1981).



E1	E2	E3	E3
E1	E2	E3	E3
E1	E2	E2	E2
E1	E1	E1	E1

Fig 2.2 “General edge” assignment of the sixteen 15×15m quadrat positions sampled at each site. *E1 = 0-15m from either edge (E0-15m); E2 = 15-30m (E15-30m); E3 = 30-60m (E30-60m).*

All significant differences illustrated in graphical representations of results represent analysis performed on log-transformed data with the exception of species richness as outlined above.

Bray-Curtis similarity matrices were applied to all community multivariate datasets prior to analysis while Euclidean distances were applied to univariate datasets. Principle Coordinate (PCO) analysis was performed on the log-transformed community data converted into a Bray-Curtis resemblance matrix in each case to visually evaluate compositional trends with distance from both adjacent habitats and general edge. SIMPER (similarity percentages) analysis was also performed on each significant community trend to ascertain the taxa or groups with the greatest contributions to observed significant trends (Clarke & Gorley 2006). The more commonly occurring taxa as well as those taxa or groups displaying the greatest contribution to community trends (in the event that the latter are also not commonly occurring) were then separately assessed in univariate analyses. This was done to determine each taxa's or group's own detailed response to the unique habitat edges. This selection would ensure that the more relevant interesting trends are here described to curtail the study findings. Use of this technique, applying SIMPER to highlight more highly contributing taxa to community variation and the subsequent focus on these taxa in univariate analysis, is applied in published research (Ollivier et al. 2015). Smith, Jenkins & Hutchinson (2012) also applies a similar procedure.

All analysis was done in PRIMER 6 version 6.1.13 and PERMANOVA+ version 1.0.3. P-value calculations in this package are done via random permutations to provide a *p(perm)* value for each test, along with p-values based on Monte Carlo simulations, *p(mc)*, useful in the event of low numbers of unique permutations i.e. <999 (Anderson, Gorley & Clarke 2008) . *P(perm)* is the p-value most commonly cited in this and subsequent chapters with *p(mc)* values only considered for the effect of "distance from reef"," distance from bare sediment" or "distance from general edge" and associated pairwise comparisons for instances of low numbers of unique permutations; in all other cases *p(perm)* is the value considered and cited. The PERMDISP p-value for homogeneity of multivariate dispersions is also cited herein for each significant effect, with p>0.05 indicating homogeneity of variances. As the package follows a non-parametric form of analysis (Clarke 1993) computing p-values from random permutations (set for all PERMANOVA tests at 9999 in this study), strict assumptions usually linked to ANOVA such as normality of distribution are not required to be met as the test is not affected by lack of normality (Anderson, Gorley & Clarke 2008). As such this criterion was not addressed with regards to this dataset. The PRIMER 6 & PERMANOVA + package proved a versatile statistical package allowing for the analysis of unbalanced designs (Clarke & Gorley 2006) appropriate for the analysis of data with respect to "general edge" in the current study. The ability to handle complex experimental designs, compute p-values for interacting terms, pooling of terms, and designs including datasets lacking replication, such as with repeated measures, are among the list of capabilities with the PERMANOVA+ add on (Clarke & Gorley 2006).

It should be noted that while interaction terms were computed in PERMANOVA in this and subsequent chapters unless otherwise stated these are not presented (Refer to Section 6.6.1). Where significant interaction terms would affect the proper interpretation of results these are presented in the relevant chapters. Additionally, non-significant interaction terms were at points highlighted to drive home the importance of particular data treatment procedures. Non-inclusion of interaction terms was primarily to steer the focus of the results towards the main effects in such a study involving several measured variables and independent factors. The results would otherwise be even more cumbersome and difficult to follow.

2.3 Results

2.3.1 Overall analysis

A total of 31 different taxa were sampled with the seine net over the two seasons – August/ September 2013 (end of Austral winter) and January/ February 2014 (Austral summer) with 20 species sampled in the winter and 19 in the summer. Ten (10) species were common to both seasons.

A total of approximately 3,570 individuals were counted over all positions over both seasons (Table 2.1) with approximately 95% of this figure owing to numbers counted in summer (3,389) compared to that in winter (181). Just over 90% of the total number of individuals sampled in summer was the schooling Atherinidae, *Atherinosoma microstomata* (small mouthed hardyhead) and *Atherinomorus vaigiensis* (Ogilby's hardyhead), which were grouped to from one taxonomic group in analysis. The winter fish community comprised mainly of more cryptic non-schooling seagrass species. To ensure the gregarious Atherinidae were not masking underlying trends and overshadowing the statistical analysis, the statistical designs described in Section 2.2 (Methods) above were applied to the fish community including and excluding the Atherinidae (Table 2.2). The statistical designs were also applied to the fish community metrics in separate seasons to determine any season-specific distributional trends especially for taxa that were more abundant or only present in one season over the other. This was only applied to the community of individual fish taxa, species richness and total abundance and the results of this additional analysis are cited throughout the text.

2.3.2 Fish taxa distribution

2.3.2.1 Both seasons

Fish community composition

There was a significant effect of “distance from reef” (*pseudo*-F = 2.0891; p = 0.0498) with pairwise analysis showing a significant difference in community between the 0-15m and the 45-60m distances (p = 0.044; pairwise comparison) (Table 2.2a). SIMPER analysis indicated that six taxa contributed to just over 60% of the difference found at these two extremes of distances from reef with respect to this study namely – the Atherinidae (20.57%), *Stigmatopora argus* (10.88%), the weed whitings – *Neoodax balteatus* and *Haletta semifasciata* (9.39%), *Brachaluteres jacksonianus* (7.39%), *Siphaemia cephalotes* (7.31%) and *Pelates sexlineatus* (6.51%). Due to *H. semifasciata* (blue weed whiting) being mistakenly included with *N. balteatus* (little weed whiting) in the winter season for consistency and accuracy both species were grouped as “weed whitings” throughout the analysis. No significant relationship was found with “distance from bare sediment” or “distance from general edge” for the fish community (Table 2.2b,c).

Individual species

Of the main taxa contributing predominantly to the significant difference in community assemblage with “distance from reef” and with distance in the other two planes, two species – *Stigmatopora argus* (spotted pipefish) and *Siphaemia cephalotes* (wood’s siphonfish) displayed a significant variation in abundance, without significant variation between site ($0.0692<p<0.0729$: *S. argus* and $0.8975<p<0.9194$: *S. cephalotes*) or season ($0.4905<p<0.5097$: *S. argus* and $0.2483<p<0.251$: *S. cephalotes*). Additionally, the weed whitings displayed a consistent but non-significant trend with distance in two directional planes. While *S. argus* and the weed whitings were among the most commonly occurring of the taxa observed, *S. cephalotes* was not.

Stigmatopora argus

Stigmatopora argus varied significantly away from the shoreward bare sediment edge (pseudo-F =29.027; p = 0.03) with the abundance falling significantly from the first transect closest to the bare sediment (T1) to the next distance category (T2) (p = 0.01; pairwise comparison) (Table 2.2b; Fig2.3b). The pipefish species also displayed a trend of increasing abundance away from the immediate seagrass-reef edge, peaking at the 15-30m from reef distance and declining thereafter (Fig 2.3a). This trend, however, was not statistically significant. A non-significant trend of decreasing abundance at the furthest general edge seagrass position (E30-60m) compared to E0-15m and E15-30m was also displayed (Fig 2.3c).

Siphaemia cephalotes

Siphaemia cephalotes was absent from seagrass positions at the immediate edge of both habitats, that is at the 0-15m distance from the reef and at 0-15m+ from the shoreward bare sediment and consequently from E0-15m (Fig 2.4). The species increased steadily in abundance away from both edge types (Fig 2.4a-b), significantly so from the reef (pseudo-F = 26.361; p = 0.01) (Table 2.2a). Due to its absence at the 0-15m distance from reef pairwise comparison revealed a significant difference in abundance at this position compared to that at 30-45m location (p = 0.04; pairwise comparison) (Table 2.2a). The trend of increasing abundance away from the general edge was more pronounced at Callala Bay, in which case there was a significant effect of this factor (pseudo-F = 32.395; p = 0.0006). Pairwise comparison at Callala Bay only showed significant differences in *S. cephalotes* abundances between the E0-15m and E30-60m (p = 0.0027) and E15-30m and E30-60m (p = 0.0019) general edge positions (Fig 2.4d). This more pronounced increase at Callala Bay explained the highly significant Si × Ed interaction (*pseudo-F* = 6.453; p = 0.0019) for this species.

Weed Whitings – *Neoodax balteatus* and *Haletta semifasciata*

The weed whitings, which were only encountered at Greenpoint, displayed a homogeneous distribution along seagrass positions with distance from the bare sediment but showed a gradual increase in abundance away from reef and general edge (Fig 2.5b).

Species richness

Species richness differed significantly with “distance from reef” (*pseudo*-F =9.303; p = 0.04), with pairwise comparisons showing significant differences between distances 0-15m and 45-60m (p = 0.02; pairwise comparison) and between 15-30m and 45-60m (p = 0.02; pairwise comparison) (Table 2.2a; Fig 2.6a,b). There was no significant variation with distance from the bare sediment or general edge, although there was a general increase in the number of species/taxa sampled with “distance from general edge” (Fig 2.6e,f).

Total abundance

No significant variation was found with total abundance including or excluding Atherinidae. There was, however, a notable trend of increasing total abundance, excluding the Atherinidae, with “distance from reef” (Fig 2.7a) and “distance from general edge” (Fig 2.7b). These trends of increasing total abundance, however, were more pronounced at Callala Bay compared to Greenpoint, where total abundance increased with distance from the reef only (Fig 2.7b).

2.3.2.2 Winter season

Fish community composition

There was no significant difference in fish community composition with increasing distance in any plane i.e. with distance from the reef, bare sediment or general edge, in this season. There were, however significant trends in distribution of two leatherjacket species namely *Scobinichthys granulatus* (rough leatherjacket) and *Brachaluteres jacksonianus* (pygmy leatherjacket) which displayed similar trends across both sites.

Both species increased in abundance away from the general edge with this being significant for *S. granulatus* (*pseudo-F* = 112.32; p=0.0102) whose abundance was significantly higher at E30-60m compared to E0-15m (p = 0.04; pairwise comparison) (Table 2.2c; Fig 2.8e,f). Additionally, *B. jacksonianus* increased significantly with distance from the reef (*pseudo-F* = 12.799; p=0.0296) (Table 2.2a; Fig 2.8a). There was no significant variation in abundance of either species with “distance from bare sediment”, however, for both species there was an increase in abundance from the T1 (0-15m+) to T3 (30-45m+) and a decrease thereafter at T4 (45-60m+) (Fig2.8e).

Species richness

There was a general increase in number of taxa with increasing distance from the reef and general edge for both sites although statistically non-significant (Fig 2.9a,c – left panels). With regards to distance from bare sediment, the number of species/taxa sampled at both sites peaked at T3 (30-45m+) and declined thereafter during the winter season Fig 2.9b.

Total abundance

There was no consistent or significant trend in total fish abundance with increasing distance in any plane during this season with only Callala Bay showing a consistent but non-significant increase in total abundance with distance from the reef and general edge.

2.3.2.3 Summer season

Fish community composition

There was no significant variation in fish community composition across both sites with increasing distance from either habitat type or general edge.

Species richness

As in the winter there was a trend of increasing species richness with distance from the reef and general edge for the seagrass positions sampled at both sites. There was a significant effect of distance from reef at Callala Bay (*pseudo-F* = 3.6309; p = 0.0357) with the mean species richness at the two furthest distances, 30-45m and 45-60m, being significantly higher (p = 0.0081 and p = 0.0123 respectively: pairwise comparison) than at the immediate edge i.e. 0-15m from the rocky reef (Fig 2.9a – right panel).

Total abundance

There was no significant variation in total fish abundance with distance from either adjacent habitat or general edge or was there a consistent meaningful distribution for any individual fish species with increasing distance in any plane in this season. There was, however, a notable consistent trend of low total fish numbers at the immediate reef edge (0-15m) (Fig 2.10a) and a bell-shaped curve distribution with “distance from general edge”, peaking at the E15-30m position and decreasing again at the most interior position i.e. at E30-60m (Fig 2.10b). This was highly driven by the distribution of the schooling Atherinidae sampled during the summer season.

2.3.3 Functional group distribution

The percentage contribution of each functional group in each of the two classification schemes considered, i.e. the Feeding Mode Functional Grouping (FMFG) and Estuarine Use Functional Grouping (EUFG) is found in Tables 2.3 and 2.4 respectively, along with the percent contribution to each guild of each species sampled. Due to the influx of the Atherinidae in the summer which would impact the percentage contributions of each guild, the percentages were calculated per season. Percentages were also calculated with and without the Atherinidae in the summer sampling season. Additionally while the community of individual fish species/taxa during the summer sampling period was significantly different between sites ($0.0001<p<0.001$), this was not the case in winter ($0.0514<p<0.068$). As such the percentages were calculated pooling both sites for winter and separately for both sites for the summer fish data. While the distribution of guilds in both functional classifications revealed interesting trends, the most consistent, meaningful and statistically significant ones with distance from the adjacent habitats and general edge from this seine net sampling data across sites and seasons were encountered with the FMFG. As such it is this grouping that will be the focus for the remaining portion of this chapter. With the overwhelming contribution made by the estuarine guilds across both sites and seasons (90.48 – 99.9%) compared to the marine guilds likely being an artefact of the seine net sampling method (Franco et al. 2011) the trends of the EUFG is later discussed when both GoPro and seine net data are combined (Chapter 3).

Feeding Mode Functional Groups (FMFG)

Rationale for treatment and presentation of FMFG distributional trends

The Atherinidae sampled were primarily juveniles (99.2%; 3124 individuals) along with 25 adults (0.8%). From stomach content analysis I conducted in conjunction with this research (See Appendix II) these adults were classed as omnivores (OV). The juveniles fell into two size classes, juvenile class 1 (juv 1) generally below 50mm TL (85.7% of Atherinidae; 2699 individuals) and juvenile class 2 (juv 2) falling between 55 – 75 mm TL (13.5% of Atherinidae; 425 individuals). Stomach content analysis showed juv 1 to be zooplanktivores (ZP) feeding primarily on copepods and planktonic bivalves and juv 2 to be non-piscivorous carnivores (CNP) with a diet of primarily molluscs and devoid of copepods (Appendix IIA).

To ensure that the influx of Atherinidae was not masking an underlying distributional trend with the cryptic seagrass species, the community of functional guilds as assigned to the five trophic groupings were performed including and excluding the Atherinidae. This exclusion, however did not take into account the 25 omnivorous adults. As the juvenile Atherinidae only fell in the CNP and ZP guilds, analysis with their exclusion was only done on the FMFG community and the ZP and CNP guilds.

Regardless of their presence in the statistical designs, analysis of the FMFG community i.e. community distribution and that of individual functional guilds, rendered the factors “season” highly non-significant ($0.24<p<0.5019$) and allowed the whole data set to be analysed without splitting into separate seasons. The effect of “site” was also non-significant for the community of FMFG and individual guilds primarily with the inclusion of Atherinidae ($0.0629<p<0.9097$). With the Atherinidae excluded there was a low significance of “site” for the FMFG community distribution and ZP guild for statistical design 1 only (both $p = 0.04$). There was a high significance of “site” and “site × season” for the CNP guild (excluding Atherinidae) distribution for all models ($0.002\geq p\leq 0.0013$ and $0.002\geq p\leq 0.0004$ respectively) which is dealt with accordingly in the relevant section below.

FMFG community distribution

Including Atherinidae

The fish community as classified in the five feeding mode functional groups varied significantly with “distance from reef” (*pseudo-F* = 2.1599; p=0.0092) (Table 2.2a) and “distance from general edge” (*pseudo-F* = 2.8176; p=0.0029) (Table 2.2c). Significant differences in FMFG community distribution was found between the 0-15m and 45-60m (p = 0.0091; pairwise comparison) and 15-30m and 45-60m (p = 0.001; pairwise comparison) distances from the reef (Table 2.2a) and between the E0-15m and E30-60m (p = 0.0002; pairwise comparison) “distance from general edge” positions (Table 2.2c). PCO plots also show a clear separation of the FMFG community distribution at the 45-60m distance from the reef especially so from the 0-15m distance (Fig 2.11).

SIMPER analysis puts the major contributors to the significant pairwise comparisons of “distance from reef” positions i.e. 0-15m vs 45-60m and 15-30m vs 45-60m and of “distance from general edge” positions i.e. E0-15m vs E30-45m, to be the CNP (33.16%, 35.71%and 36.15% respectively), ZP (27.49%, 31.07% and 22.68% respectively), OV (20.13%, 16.4% and 16.33% respectively) and CP (11.01%, 11.12% and 15.76% respectively) with very low contribution made by herbivores (HV) which were also represented by very few species.

Excluding Atherinidae

There was no significant difference in FMFG community distribution, excluding the Atherinidae, with distance from either adjacent habitat with only a low non-significance with “distance from reef” (pseudo-F = 2.1755; p=0.0787) (Table 2.2a) There was a marginal significance with distribution from the general edge but this was at the $p<0.05$ level. As the abundance data was not homogeneous around the general edge factor in this instance disregarding the Atherinidae this was not considered statistically significant (Table 2.2c).

FMFG individual guild distribution

Non-Piscivorous Carnivores (CNP)

Regardless of the inclusion of the schooling Atherinidae in the summer season, which was comprised of 60% CNP (juv 2) based on stomach content analysis (Appendix II), there was a steady increase in abundance of the CNP guild with “distance from reef” and “distance from general edge” (Fig 2.12). This was statistically significant in both cases with exclusion of the school (“distance from reef”: *pseudo-F* = 38.35; p = 0.0074 and “distance from general edge”: *pseudo-F* = 110.66; p = 0.0091) (Table 2.2a,c). Pairwise comparisons show significantly higher abundances of CNP at the 45-60m distance compared to 0-15m (p = 0.04; pairwise comparison) (Table 2.2a; Fig 2.12b) and at the E30-60m distance compared to E0-15m (0.04; pairwise comparison) (Table 2.2c; Fig 2.12f). There was a high “site” and “site × season” interaction for this variable disregarding the school in both statistical designs. As such these individuals were analysed using the same statistical model for each site separately (excluding “site” from the model). This showed a statistically significant increase in abundance with “distance from reef” (pseudo-F = 3.9761; p = 0.0181) at Callala Bay with the 45-60m distance hosting statistically greater abundances of this guild than at all other distances (0-15m, p = 0.03; 15-30m, p = 0.02; 30-45m, p = 0.03; pairwise comparisons) (Fig 2.13a). Abundances of this guild showed a similar trend at Greenpoint, however without statistical significance. There was no apparent trend with distance from bare sediment i.e. with increasing transect number at either site.

Piscivorous Carnivores (CP)

The CP guild showed significant variation with “distance from general edge” (*pseudo-F* = 11.124; p = 0.0002) and increased gradually towards the seagrass interior in all planes (Fig

2.12). Due to its absence at the immediate edge position pairwise comparison showed significant increase in its abundance at the E15-30m and E30-60m positions compared to that at E0-15m (p = 0.0009; p = 0.0001 respectively: pairwise comparisons) (Table 2.2c; Fig 2.12 e,f). The effect of “distance from reef” (*pseudo-F* = 3.0329; p = 0.037) and “distance from bare sediment” (*pseudo-F* = 3.5588; p = 0.0191) were not significant at the set p<0.01 level, however, pairwise comparisons show the all “distance from reef” categories beyond 15m to be significantly different from that at the 0-15m position (p≤0.01; pairwise comparisons) (Table 2.2a) and the 45-60m+ “distance from bare sediment” position to differ significantly from abundances of this guild at the 0-15m+ position (p = 0.0015; pairwise comparison) (Table 2.2b).

Zooplanktivores (ZP)

Zooplanktivores showed an increase in abundance towards the bare sediment and general edge with the Atherinidae included in the model (Fig 2.12c,e). This trend was generally held with Atherinidae exclusion with a more obvious stepwise decrease in abundance away from the general edge (Fig 2.12f). With Atherinidae exclusion, zooplanktivore abundances were also generally lower at the furthest “distance from reef” and “distance from bare sediment” (Fig 2.12b,d). These trends were however not statistically significant.

Omnivores (OV)

Omnivore abundance showed no meaningful trend with “distance from reef” but generally greater abundances of this guild were observed towards the bare sediment and the general edge. These trends were, however, statistically non-significant.

Herbivores (HV)

There was a significant effect of “distance from reef” only on herbivore abundance (pseudo-F = 10.333; p = 0.0398) (Table 2.2a) with their distribution skewed towards distances further from the reef especially at the furthest two distance categories i.e. at 30-45m and 45-60m (Fig 2.12a) . The herbivores were also found in higher numbers at the furthest “distance from bare sediment” and the furthest general edge position (Fig 2.12c,e). The latter two trends, however, were not statistically significant.

2.4 Discussion:

Distribution of fish species: community composition and individual taxa

Whereas total abundance of fish individuals did not prove to be a consistent indicator of change in fish distribution with distance from either adjacent habitat type or general edge, species richness, fish community composition and the abundance of individual species did. There was, however, a non-significant increase in the total number of fish (disregarding the gregarious Atherinidae sampled in the summer session) caught in the seagrass beds with distance away from the rocky reef habitat and general edge with the latter being observed for Callala Bay only. The number of fish taxa sampled, however, consistently increased at both sites and seasons taken together and independently considered with distance from reef and general edge with no consistent pattern with distance form bare sediment. With both sites and seasons considered the furthest distance from reef category (45-60m) hosted significantly higher numbers of taxa compared to the first two distance categories (0-15m and 15-30m).

Although other authors have found a similar increase in fish species richness e.g. Jelbart, Ross & Connolly (2006) along with higher fish abundances e.g. Moore & Hovel (2010) in macrophyte beds with distance from the edge other research have reported higher fish abundances at seagrass edges compared to distances further away (Tuya et al. 2010; Valentine et al. 2007; Vanderklift et al., 2007). This is however not surprising due to two important factors. Firstly, while the latter studies involved seagrass-reef edges, Jelbart, Ross & Connolly (2006) and Moore & Hovel (2010) investigated seagrass-bare sediment interfaces while the current study involved both interfaces at right angles. This underscores the importance of the edge interface structure i.e. the structure of the habitat adjacent to the focal seagrass bed in determining faunal distribution relative to the edge. Secondly, different sampling methods were employed in both groups of studies resulting in the observation of taxa occupying different components of the seagrass ecosystem. While the latter group of studies captured more pelagic fish taxa employing visual censuses, the former represents cryptic species hidden among the blades of the macrophytes sampled with nets dragged through the seagrass blades. The different niches occupied will undoubtedly determine where the fish will be distributed with respect to the edge both in terms of their response to the distribution of their potential prey and the degree to which they employ predator evasion strategies.

The fish community exhibited a weak but significant effect with distance from the reef only with the community at 45-60m distance category from the reef being significantly different from that encountered at the immediate seagrass-reef edge position i.e. at 0-15m likely due in part to the absence and/or low numbers of particular taxa at the edge compared to the interior. Dominant individual species displayed notable distributional trends with distance into the seagrass bed primarily with respect to the rocky reef and general edge which undoubtedly contributed to this change in community structure between the immediate seagrass-reef edge and seagrass interior. *Siphaemia cephalotes*, the weed whitings, *B. jacksonianus* (winter) and *S. granulatus* (winter) all increased steadily in abundance with distance away from the reef being statistically significant for *S. cephalotes* and *B. jacksonianus*. *Scobinichthys granulatus* also displayed a non-significant increase with increasing distance from the reef, however, only up to the 30-45m distance. This species' abundances nonetheless increased significantly with distance away from the general edge. *Stigmatopora argus* displayed an interesting trend of apparently avoiding the immediate seagrass-reef edge, increasing at the 15-30m distance and decreasing thereafter. A general but non-significant decrease at the last general edge for this species was also noted. A differential preference for the general edge and differentially distributional responses to particularly the seagrass-reef edge habitat is therefore apparent among the species sampled, a phenomenon highlighted in literature (Fagan, Cantrell & Cosner 1999; Ries et al. 2004; Ries & Sisk 2004). Understanding the reasoning behind the distributional trends in these species which determine community composition with respect to habitat edges is hardly possible without first examining the resources utilized by them and how these are distributed with respect to the habitat edges (Ries et al. 2004). As such, this is addressed in Chapter 4.

The differing microclimate, local hydrodynamics (Barros, Underwood & Lindegarth 2001; Pattiaratchi et al. 1995; Sorokin 1993; Van Elven, Lavery & Kendrick 2004) and fish prey distribution (Chapter 4) with distance from the reef edge likely creates at least two unique "micro-ecosystems" – one typical of the edge, dominated by species who thrive best under the prevailing conditions therein and one typical of the interior, dominated by species whose optimum conditions are found away from the edge. This would account for the significantly different fish communities at the extreme of distances with respect to the reef habitat. It is interesting to note that this difference was only observed with respect to the reef edge and not the bare sediment indicating a greater influence of this habitat type in structuring community assemblage within the *Posidonia australis* seagrass beds when both adjacent habitat types were present for the two sites and over the two seasons under investigation. The harsher, more turbulent conditions at the immediate seagrass-reef edge experienced as the waves make contact with this physical barrier (Barros, Underwood & Lindegarth 2001; Pattiaratchi et al. 1995; Sorokin 1993; Van Elven, Lavery & Kendrick 2004) may prove unfavourable for some fish species and/or their prey that thrive best in the less hydrodynamic interior and more favourable to others which may actually be a function of their feeding mode (Bustamante & Branch 1996).

Apart from assuming positions with respect to the adjacent habitats based on their prey distribution, the difference in fish community and differential preference of the edge community by different species may be similar to that noted in the terrestrial ecosystems. It has been noted in the latter case, for instance, where pioneer species, able to withstand the harsher conditions at the edge would be found there (Ranney, Bruner & Levenson 1981) placing themselves in a position to access resources from both habitats at the border (Ries et al. 2004). Conversely, more delicate, specialized species and/or life stages may opt for a more stable environment at the interior.

Distribution of FMFG: community and individual guilds

Fish and other marine organisms tend to orientate themselves in an environment where they can survive best (Bell & Westoby 1986; Cocheret de la Morinière et al. 2004; Levin et al. 2000; Pérez-Matus & Shima 2010) – that is where they can gain optimum nutrition, avoid prey and reproduce, with the first two being the ones heralded as the more important in literature. There is often also the notion of a trade-off between optimum nutrition and predator avoidance, where a sub-standard but sufficient food supply, whether by actual food source or position in the environment (Werner & Hall 1988) is accepted to avoid being eaten themselves (Schmitz et al. 2008; Schmitz, Krivan & Ovadia 2004).

The optimum physical ecosystem position for a particular organism will most likely depend on its feeding mode functional group as it would depend on their desirable prey and where those may be had in the environment. Hence the effect of an adjacent habitat or general edge on that prey in the ecosystem is likely to influence the distribution of the fish itself relative to the adjacent habitat or edge.

The distribution of feeding mode functional groups with the Atherinidae included in this study varied significantly with increasing distance from the reef and general edge only with the combination and/or number of individuals within the five assigned grouping being significantly different at 45-60m from the reef compared to the distances below 30m from the reef as illustrated in the PCO plot in Fig 2.11. This separation points to a possible change in the ecological function of the seagrass beds sampled within 30m of the reef and that beyond the

45m distance with respect to the prey community, which in turn helps to influence the distribution of different fish feeding guilds. This difference in FMFG distribution with respect to the reef habitat likely translated to the observed significant difference with distance from the general edge, with the interior positions i.e. 30-60m away from both edges, hosting a significantly different feeding guild combination and/or number of individuals within each guild compared to the immediate general edge position ($p<0.001$). With no significant variation with distance from the bare sediment ($0.076<p<0.1944$), this difference is likely more driven by FMFG community distribution with respect to the reef.

CNP guild:

With and without consideration of the Atherinidae (60 % CNP and 40 % ZP by composition), “distance from reef” had an obvious effect on CNP abundance which likely translated to the observed effect with general edge. These non-piscivorous carnivores were preferentially distributed towards the bed interior with respect to the reef and general edge with no meaningful trend with distance from the shoreward bare sediment edge. This is likely in part due to the distribution of the benthic invertebrate prey distribution with respect to the reef which is discussed in Chapter 3. Rocky intertidal reefs having great structural complexity and the availability of coral rubble and refuge ditches are known to be a great source for molluscs (Kohn & Leviten 1976) in particular and hence the prevalence of fish that utilize them for prey in these seagrass beds bordered by reef. This may also partially account for the significant effect of the reef edge as opposed to the bare sediment edge for this CNP group as their prey may be distributed relative to the reef by prevalent environmental factors including wave energy, current direction and wind (Boström & Bonsdorff 2000) rather than the bare sediment which may be a less significant prey source.

CP guild:

The piscivorous carnivores which made up one of the smallest feeding mode guilds showed a significant effect of “distance from reef” and “distance from general edge” and showed a consistent trend of increasing numbers away from the shoreward bare sediment being absent from all 0-15m and all 0-15m+ positions from the reef and bare sediment respectively. The trends observed by this group were highly driven by that of the wood siphonfish, *Siphaemia cephalotes*, a cryptic, piscivorous (Fishelson et al. 2005), seagrass small-bodied species, which occurred in low numbers. This species’ diet is also reported to be comprised of benthic invertebrates as well as fish and it is likely that they may be utilizing the molluscs, dominant in this system. Their low numbers, however, especially in summer did not allow for meaningful stomach content analysis of this species.

ZP guild:

Zooplanktivores showed a consistent trend of decreasing abundance at the furthest general edge position (E30-60m) with and without consideration of the schooling Atherinids and were generally found in greater numbers closer to the shoreward bare sediment edge. This is consistent with previous findings of *Stigmatopora argus* (which in this study was the primary ZP excluding the Atherinidae) being found in greater abundances in seagrass closer to the sand edge than away which was related to higher zooplankton abundances, particularly copepods, at the seagrass edge (Macreadie et al. 2010). In this reef-seagrass-sand system bordered by another habitat apart from only sand that trend may be rendered less obvious as the species may be influenced by the reef as well. The physical structure of the reef and the back wash taken away from it as the waves break on its structure may in fact carry the zooplankton a distance away from the reef resulting in less at the immediate edge. This may be counteracting the reported trapping of zooplankton at the seagrass-sand interface (Macreadie et al. 2010).

Due to the presence of the reef and the dominance of molluscs found in the environment (see Chapter 4) it is likely that depending on the fish's zooplankton prey of choice a finer scale distribution trend may be occurring. Stomach content analysis showed the schooling zooplanktonic Atherinidae (juv 1) to have primarily planktonic larval gastropods and bivalves constituting their diet followed in importance by copepods (Appendix II), whereas *Stigmatopora argus* is a primary copepod feeder (Howard & Koehn 1985; Macreadie et al. 2010; Payne, Rippingale & Longmore 1998). If these zooplankton groups are differentially distributed with respect to the reef it may result in differences even within the zooplankton feeding mode guild resulting in a slightly wider distribution explaining it's more bell-shaped curve distribution in this plane. This may also account for the slight shift in ZP distribution towards the reef noticed when the Atherinidae were excluded from the analysis. Zooplankton group distribution relative to the adjacent habitats and edge and correlation with fish distribution is evaluated and discussed in Chapter 4.

OV guild:

Omnivores, which by their nature are more generalists in their food preferences, showed no meaningful trend with distance from the reef but were found in greater abundance towards the shoreward bare sediment edge which translated to higher numbers within 30m of the immediate general edge. This may be explained in part by the presence of the river garfish, constituting by abundance approximately 51% of the omnivore group where sampled. Although classed as an omnivore in literature this species is reported to utilize zooplankton when available (Gomon 2011), and hence may be following the distributional trend of the zooplanktivores closer to the general edge and bare sediment. It is more challenging to explain the distribution of generalist feeders as it would depend largely on the food item they may be currently utilizing based on its relative abundance in the ecosystem and confounded by any trade-off strategies being employed by this feeding guild to ensure minimal predation risk to themselves while feeding.

HV guild:

The herbivores which consisted of two *Acanthaluteres* species (were found in significantly higher abundances away from the reef and were more commonly associated with the furthest shoreward bare sediment and general edge distances. This may be reflective of the distribution of epiphytic algae with respect to the adjacent habitat, especially to the reef, a potential source of epiphytic algae (Van Elven, Lavery & Kendrick 2004) which is investigated in Chapter 4.

Edge vs Adjacent Habitat

Multi-edge research is highly uncommon in literature and understandably so due to its complex interactions. One other research study in conjunction to this dissertation (Ollivier et al., 2015) addresses this with regards to total abundances of benthic invertebrates only at one of the two study sites (Callala Bay). It is, however, of great importance in understanding trends in distribution of marine organisms. When a habitat, in this case the seagrass bed, is bordered by more than one adjacent habitat type the benefits or attributes of one adjacent habitat may be outweigh the other depending on the species and more generally on the species' niche for instance, its feeding mode functional group. As such the type of edge involved, i.e. the type of adjacent habitat forming the edge with the seagrass bed, is important and not just the fact that there is an edge. Results from this study indeed demonstrate that the specific identity of the adjacent habitat, and not merely the fact that there is an edge, helped to determine the magnitude of the edge effect and distribution with respect to the edge. As discussed above some functional feeding groups showed meaningful consistent trends (statistically significant and non-significant) with general edge but only showed distribution trends with regards to one over the other adjacent habitat. This adjacent habitat specific edge effect should therefore be considered especially in nearshore environments where these three habitats commonly occur together (rocky reef, seagrass and bare sediment) and border each other. This is essential as the presence of an additional habitat over the primarily studied dyads i.e. considering only one adjacent habitat, may completely shift the distribution of organisms present in the focal environment. This is as the additional habitat may offer unique benefits over the other, including but not restricted to potential prey. Differently put, the impact on faunal distribution within the focal habitat of one other unique adjacent habitat may either shift slightly or be markedly different in the presence of a third unique adjacent habitat. Fletcher (2005) for instance demonstrated increased edge effects on bird populations when considering the presence of two adjacent habitat edges opposed to the commonly studied dyad system. This would call for a change in the way ecosystems are monitored and how population models are constructed.

Conclusion

Results of this study validates the rejection of the null hypotheses 1 – 4 set at the beginning of this chapter. A clear difference is illustrated in fish community composition as comprised of individual fish taxa and feeding mode functional guilds with respect to distance from the habitat edged. This is accompanied by the abundance of certain dominant fish taxa and individual functional guilds along with increased species richness with distance away from at least one adjacent habitat type. The dataset also pointed towards a greater influence of the reef habitat over the bare sediment in structuring fish assemblages away from its edge into the seagrass bed interior. This difference was seen to be more pronounced with some fish taxa and individual feeding mode functional guilds over others and in some instances depended on the site. While there were no clear opposing trends in distribution away from both adjacent habitat type by any fish taxa or feeding mode functional guild, there was a general increase in zooplanktivores with distance away from the reef into the seagrass interior but a decrease in abundance of this same guild away from the bare sediment. These results illustrate the importance of the identity of the habitat forming the edge with the focal seagrass bed in structuring seagrass fish assemblages in relation to that edge. This falls in line with published literature indicating edge structure as an important factor influencing species distribution with respect to the edge (Fagan, Cantrell & Cosner 1999). Additionally, as each feeding functional mode has a different prey source, their distribution will likely differ with respect to any one particular edge type, as illustrated in this study, based on the differential distributional trend of its potential prey. As the response of the predator to the edge is influenced by the prey's own edge response (Ries & Sisk 2004), each feeding mode will tend to respond differently to the edge. Reasons for this variation in edge response among the different feeding mode guilds are discussed in Chapter 6 as this can only be validly addressed after investigating the prey's response to the edges (Ries et al. 2004) . The latter is presented in Chapter 4.

As I have demonstrated above in this chapter and in the ones to follow, the distribution of fauna within the seagrass beds sampled is not homogeneous. Not all sections of a seagrass bed, even of the same seagrass species and within tens of meters of each other, are equal in value to particular fish species likely having implications at the community level. This value has been here shown to be affected by its distance from a particular habitat which has serious implications for nearshore management and so should be taken into consideration.

Table 2.1 Fish taxa sampled in seine netting across both Greenpoint and Callala Bay, Jervis Bay, across both seasons

Fish Taxa	**Total Abundance**
Atherinosoma microstomata	3150
Stigmatopora argus	120
Weed whitings: *Neoodax balteatus* + *Haletta semifasciata*	69
Pelates sexlineatus	31
Hyporhamphus regularis	31
Siphaemia cephalotes	27
Scobinichthys granulatus	25
Acanthaluteres spilomelanurus	24
Brachaluteres jacksonianus	19
Atypichthys strigatus	13
Microcanthus strigatus	12
Sillago ciliata	9
Myxus elongates	7
Rhabdosargus sarba	6
Bathygobius kreffti	4
Spratelloides robustus	4
Scorpis aequipinnis	3
Abudefduf sexfasciatus	3
Tetractenos glaber	2
Meuschenia freycineti	2
Enoplosus armatus	2
Gymnapistes marmoratus	1
Aldrichetta forsteri	1
Upeneichthys lineatus	1
Cheilodactylus spectabilis	1
Urolophus sp.	1
Acanthaluteres vittiger	1
Mugil cephalus	1
Centropogon australis	1
Total	**3571**

Table 2.2 (a) Summary of PERMANOVA results of the effect of “Distance from reef” on indicated community, individual taxa and functional group distribution across both sites and seasons, except where indicated – W (winter only). *“Di” denotes “Distance from reef”, “Tr” – distance from bare sediment / transect; D1=0-15m, D2=15-30m, D3=30-45m, D4=45-60m; significant permdisp (in bold) indicate non-homogeneity of variances; Permdisp values of significant relationships only reported (*^{1} *– including and* ^{2} *– excluding Atherinidae); n.s. – not significant.*

		Distance from Reef			**Factors Included in Model**				**Pairwise Comparisons**						
	df	**MS**	**pseudo-F**	**p**	**Di**	**Tr**	**Site**	**Seas**	**D1-D2**	**D1-D3**	**D1-D4**	**D2-D3**	**D2-D4**	**D3-D4**	**Permdisp**
Community^1	3	4733	2.0891	**0.0498**	*	*	*		n.s.	n.s.	**0.044**	n.s.	n.s.	n.s.	0.896
Community^2	3	4672.4	1.7668	0.0782	*	*	*		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	
Species Richness	3	12.792	9.303	**0.0423**	*	*	*	*	n.s.	n.s.	**0.0193**	n.s.	**0.0223**	n.s.	0.899
Total Abundance^1	3	3.7544	0.76724	0.5663	*	*	*	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	
Total Abundance^2	3	0.57292	0.84551	0.5865	*	*	*	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	
Stigmatopora argus	3	0.67079	0.53904	0.6732	*	*	*	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	
Siphaemia cephalotes	3	0.50929	26.361	**0.0102**	*	*	*	*	n.s.	**0.0361**	n.s.	n.s.	n.s.	n.s.	**0.001**
Brachaluteres jacksonianus (W)	3	0.17209	12.799	**0.0296**	*	*	*		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	
Scobinichthys granulatus (W)	3	0.13722	1	0.5042	*	*	*		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	
Feeding Mode Functional Groups (Including Atherinidae)															
Community	3	5139.4	2.1599	**0.0092**	*	*			n.s.	n.s.	**0.0091**	n.s.	**0.001**	n.s.	0.343
Non-piscivorous carnivores (CNP)	3	3.4131	1.5143	0.4069	*	*	*	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	
Zooplanktivores (ZP)	3	0.70678	0.34444	0.8075	*	*			n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	
Piscivorous carnivores (CP)	3	0.5361	3.0329	0.0368	*	*			**0.005**	**0.01**	**0.0072**	n.s.	n.s.	n.s.	**0.001**
Omnivores (OV)	3	0.54087	0.84937	0.5972	*	*	*		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	
Herbivores (HV)	3	0.4017	10.333	**0.0398**	*	*	*	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	0.14
Feeding Mode Functional Groups (Excluding Atherinidae)															
Community	3	4849.4	2.1755	0.0787	*	*	*		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	
Non-piscivorous carnivores (CNP)	3	1.2952	38.35	**0.0074**	*	*	*	*	n.s.	n.s.	**0.04**	n.s.	n.s.	n.s.	0.894
Zooplanktivores (ZP)	3	0.78721	0.58494	0.6527	*	*	*	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	

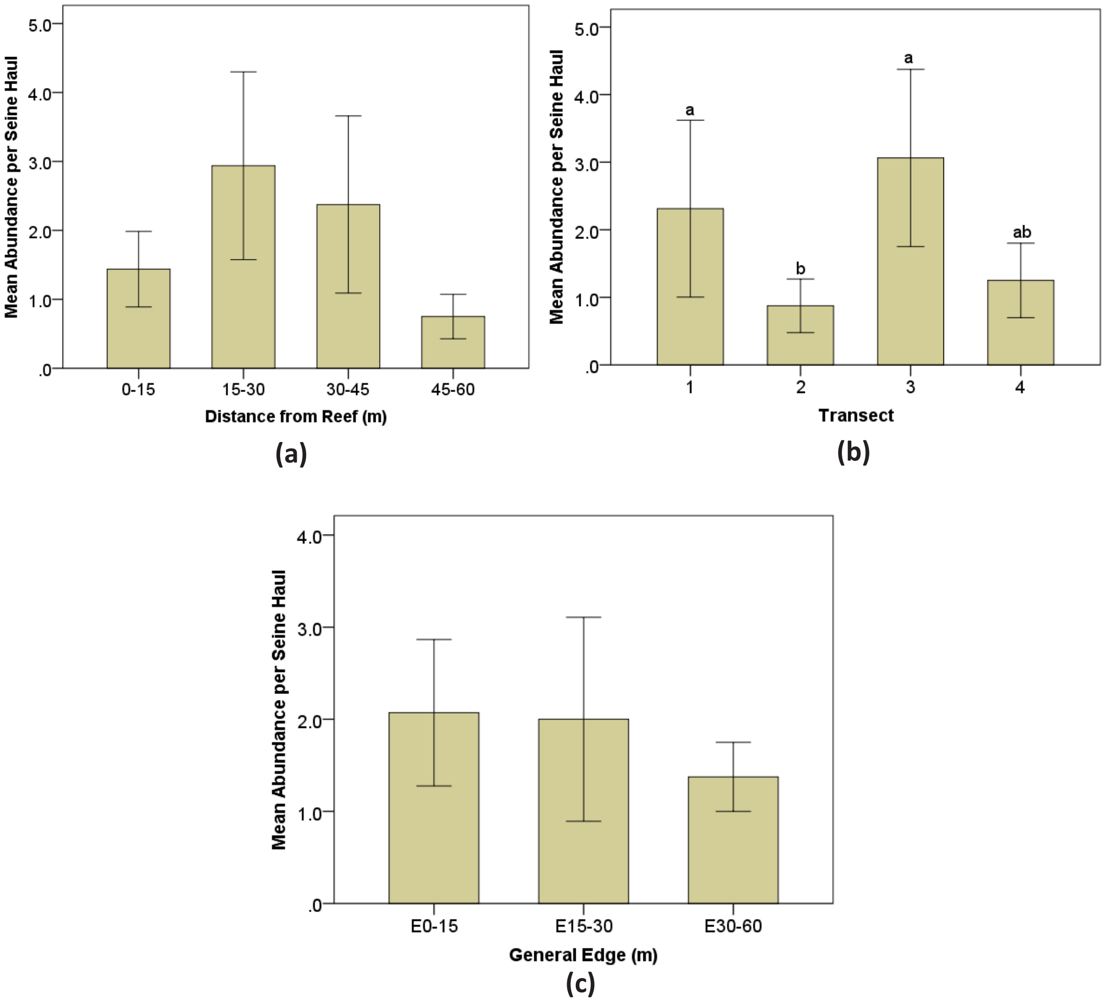
Table 2.2 (b) Summary of PERMANOVA results of the effect of “Distance from bare sediment” on indicated community, individual taxa and functional group distribution across both sites and seasons, except where indicated – W (winter only).*“Di” denotes “Distance from reef”, “Tr” – distance from bare sediment / transect; T1=0-15m+, T2=15-30m+, T3=30-45m+, T4=45-60m+; significant permdisp (in bold) indicate non-homogeneity of variances; Permdisp values of significant relationships only reported ([1] – including and [2] – excluding Atherinidae); n.s. – not significant.*

	Distance from bare sediment				**Factors included in Model**				**Pairwise Comparisons**						
	df	**MS**	**pseudo-F**	**P**	**Di**	**Tr**	**Site**	**Seas**	**T1-T2**	**T1-T3**	**T1-T4**	**T2-T3**	**T2-T4**	**T3-T4**	**Permdisp**
Community[1]	3	4733	1.5153	0.1792	*	*	*		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	
Community[2]	3	5176.9	1.2484	0.2927	*	*	*		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	
Species Richness	3	2.2083	2.7895	0.2077	*	*	*	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	
Total Abundance[1]	3	2.8063	2.3309	0.2362	*	*	*	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	
Total Abundance[2]	3	0.41404	0.65284	0.6169	*	*	*	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	
Stigmatopora argus	3	1.0963	29.027	**0.01**		*	*		**0.0143**	n.s.	n.s.	**0.0457**	n.s.	n.s.	0.8
Siphaemia cephalotes	3	0.55578	4.2997	0.13	*	*	*	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	
Brachaluteres jacksonianus (W)	3	6.86E^{-2}	0.58658	0.662	*	*	*		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	
Scobinichthys granulatus (W)	3	0.48871	2.8018	0.2081	*	*	*		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	
Feeding Mode Functional Groups (Including Atherinidae)															
Community	3	3757.3	1.5791	0.076	*	*			n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	
Non-piscivorous carnivores (CNP)	3	1.1968	1.3901	0.3959	*	*	*	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	
Zooplanktivores (ZP)	3	2.8962	1.4114	0.2519	*	*			n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	
Piscivorous carnivores (CP)	3	0.62906	3.5588	0.0191	*	*			n.s.	n.s.	**0.0015**	n.s.	n.s.	n.s.	**0.002**
Omnivores (OV)	3	0.86033	3.1905	0.1586	*	*	*		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	
Herbivores (HV)	3	0.1336	3.4365	0.1836	*	*	*	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	
Feeding Mode Functional Groups (Excluding Atherinidae)															
Community	3	4445.3	1.5454	0.1944	*	*	*		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	
Non-piscivorous carnivores (CNP)	3	0.17782	1.7036	0.3299	*	*	*	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	
Zooplanktivores (ZP)	3	0.8257	5.9317	0.1133	*	*	*	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	

Table 2.2 (c) Summary of PERMANOVA results of the effect of “Distance from general edge” on indicated community, individual taxa and functional group distribution across both sites and seasons, except where indicated – W (winter only). *“Ed” denotes “Distance from general edge”; E1=E0-15m, E2=E15-30m, E3=E30-60m; significant permdisp (in bold) indicate non-homogeneity of variances; Permdisp values of significant relationships only reported (*^{1} *– including and* ^{2} *– excluding Atherinidae); n.s. – not significant.*

		Distance from general edge			Factors Included			Pairwise Comparisons			
	df	**MS**	**pseudo-F**	**p**	**Ed**	**Site**	**Season**	**E1-E2**	**E1-E3**	**E2-E3**	**Permdisp**
Community^1	2	5826.2	2.1111	0.0708	*	*	*	n.s.	n.s.	n.s.	
Community^2	2	6508.2	1.6798	0.2054	*	*	*	n.s.	n.s.	n.s.	
Species Richness	2	16.717	15.668	0.0652	*	*	*	n.s.	n.s.	n.s.	
Total Abundance^1	3	2.4813	1.2739	0.436	*	*	*	n.s.	n.s.	n.s.	
Total Abundance^2	3	1.2598	1.2856	0.4292	*	*	*	n.s.	n.s.	n.s.	
Stigmatopora argus	2	0.12616	0.82078	0.5508	*	*	*	n.s.	n.s.	n.s.	
Siphaemia cephalotes	2	1.7393	4.6472	0.1876	*	*	*	n.s.	n.s.	n.s.	
Brachaluteres jacksonianus (W)	2	0.24269	8.4419	0.1019	*	*		n.s.	n.s.	n.s.	
Scobinichthys granulatus (W)	2	0.35522	112.32	**0.0102**	*			n.s.	**0.04**	n.s.	0.525
Feeding Mode Functional Groups (Including Atherinidae)											
Community	2	6784.1	2.8176	**0.0029**	*			n.s.	**0.0002**	n.s.	**0.007**
Non-piscivorous carnivores (CNP)	2	5.2755	1.1796	0.4446	*	*	*	n.s.	n.s.	n.s.	
Zooplanktivores (ZP)	2	1.979	1.0558	0.3592	*	*		n.s.	n.s.	n.s.	
Piscivorous carnivores (CP)	2	1.768	11.124	**0.0002**	*			**0.0009**	**0.0001**	n.s.	**0.001**
Omnivores (OV)	2	4.94E^{-2}	2.1148	0.3292	*	*	*	n.s.	n.s.	n.s.	
Herbivores (HV)	2	3.898E^{-2}	0.9956	0.5072	*	*	*	n.s.	n.s.	n.s.	
Feeding Mode Functional Groups (Excluding Atherinidae)											
Community	2	4976.2	3.1307	0.0465	*	*		0.0182	n.s.	n.s.	**0.027**
Non-piscivorous carnivores (CNP)	2	1.0827	110.66	**0.0091**	*	*	*	n.s.	**0.04**	n.s.	0.915
Zooplanktivores (ZP)	2	0.49622	1.656	0.4816	*	*	*	n.s.	n.s.	n.s.	

Interaction terms not presented in table for logistics purposes. As described in General Discussion (6.6.1) interaction terms were evaluated to determine statistical approach and/ or cited in the text and subsequently discussed where highly significant terms may influence valid interpretation of data.

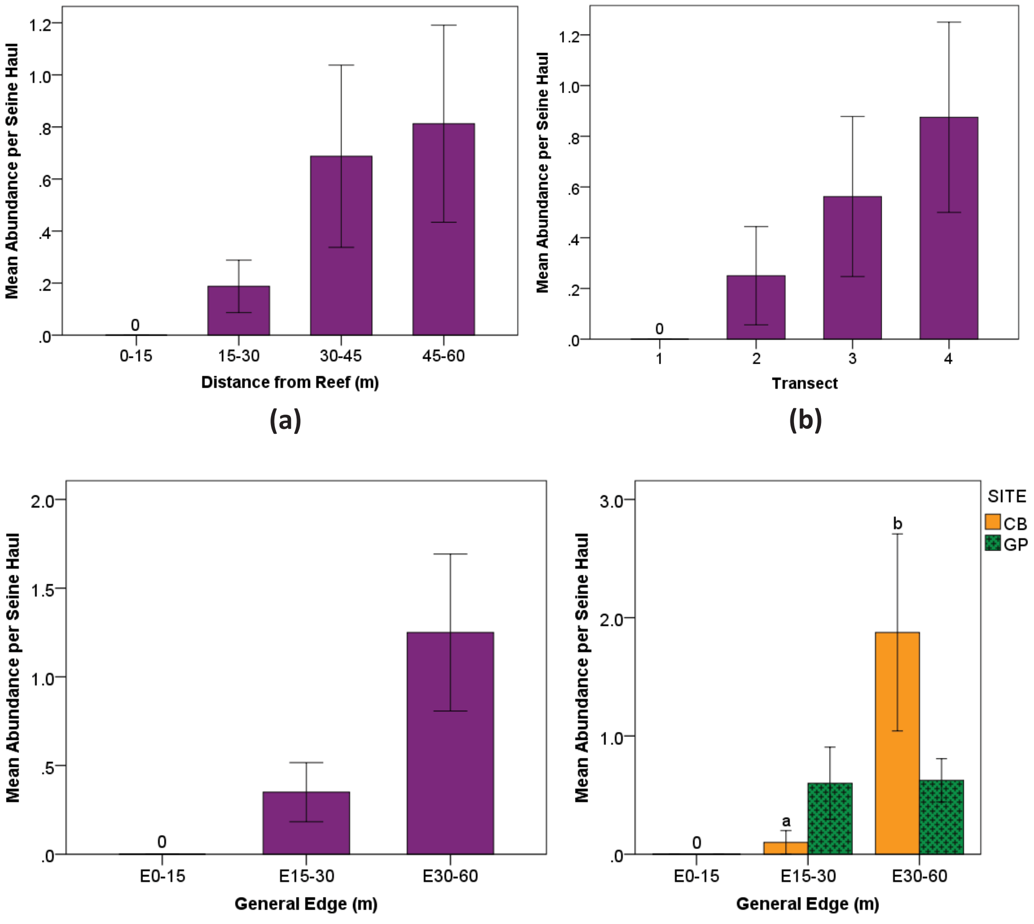


(a)

(b)

(c)

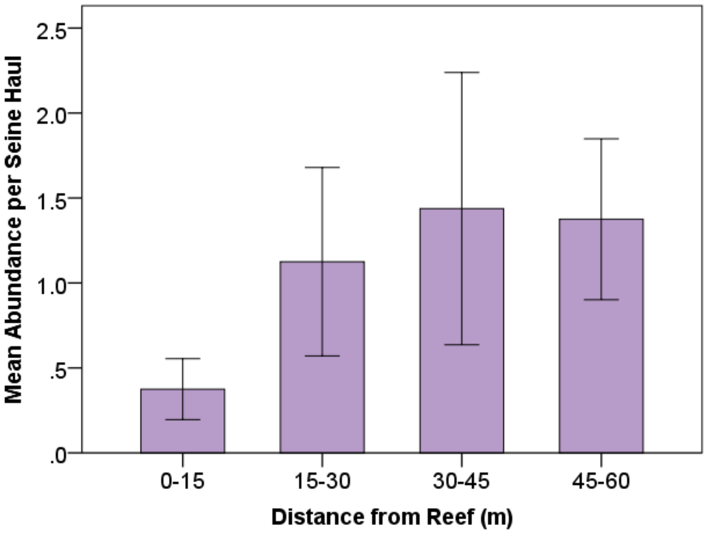
Fig 2.3 Abundance of *Stigmatopora argus* with increasing distance from (a) rocky reef, (b) bare sediment (increasing transect number) and (c) general edge across both sites and seasons. *Letters above bars represent the results of pairwise comparisons of log-transformed data with distance categories lacking similar letters being significantly different from each other.*



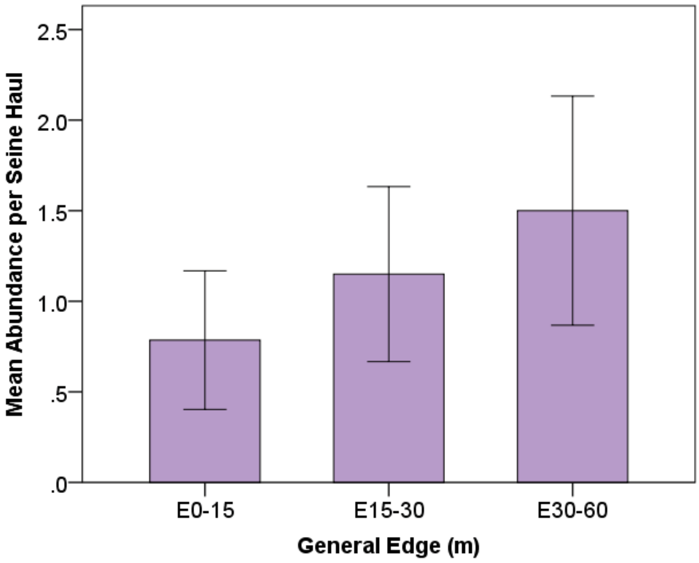
(a) **(b)**

(c) **(d)**

Fig 2.4 Abundance of *Siphaemia cephalotes* with increasing distance from (a) rocky reef, (b) bare sediment (increasing transect number), (c) general edge across both sites and seasons and (d) general edge across both seasons at individual sites (species not encountered in winter at GP). *Letters above bars represent the results of pairwise comparisons of log-transformed data with distance categories lacking similar letters being significantly different from each other; CB=Callala Bay, GP=Greenpoint.*



(a)



(b)

Fig 2.5 Abundance of weed whitings – *Neoodax balteatus* and *Haletta semifasciata* with increasing distance from (a) rocky reef and (b) general edge across both seasons at Greenpoint only.

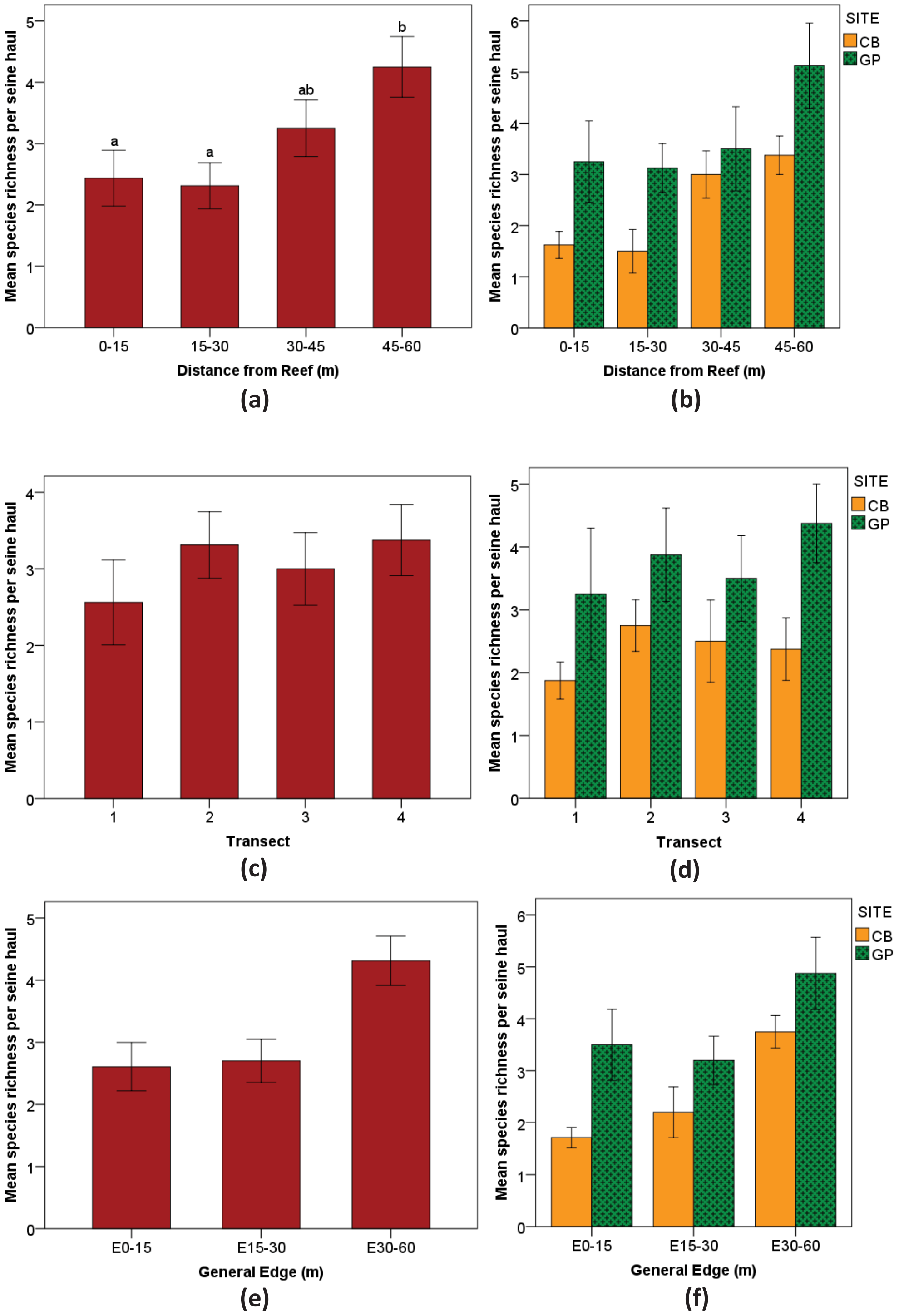
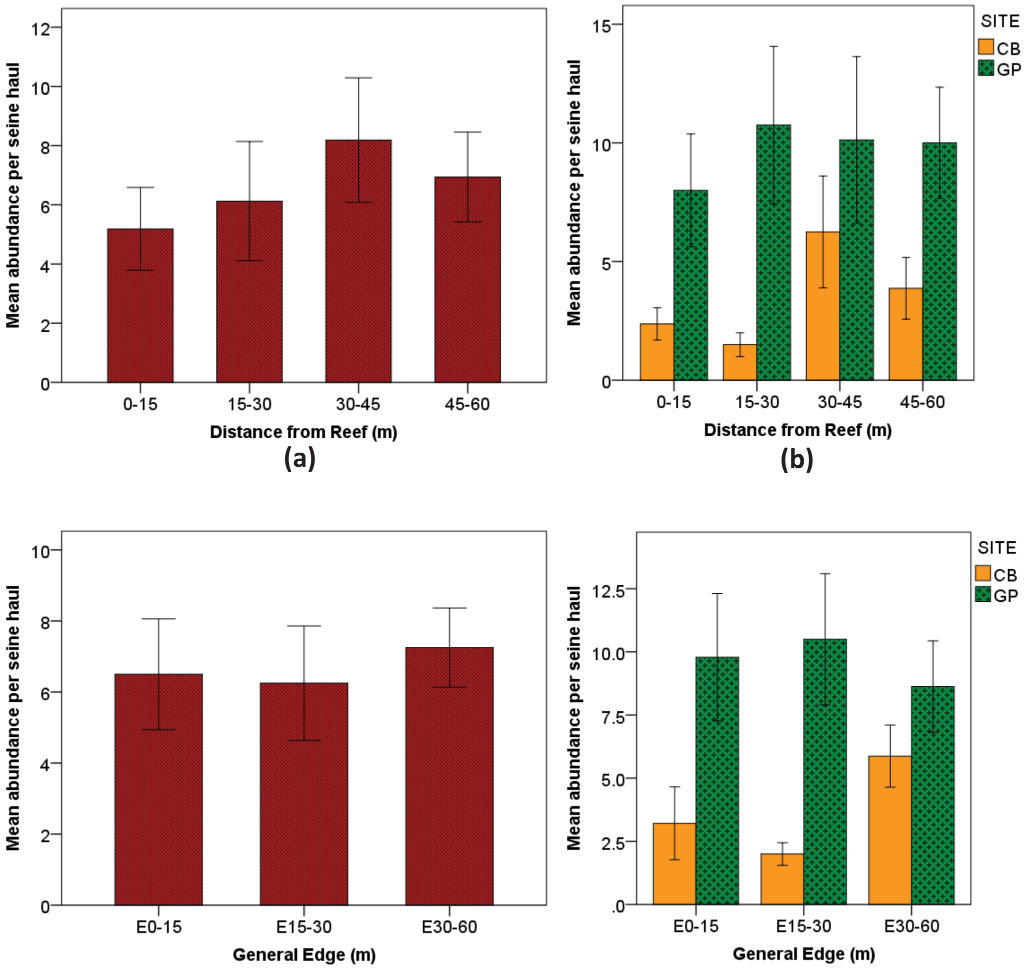


Fig 2.6 Mean species richness (number of fish species) with increasing distance from (a,b) rocky reef, (c,d) bare sediment (increasing transect number) and (e,f) general edge across both sites and seasons. *Letters above bars represent the results of pairwise comparisons with distance categories lacking similar letters being significantly different from each other; CB=Callala Bay, GP=Greenpoint: Left panel graphs represent sites pooled.*



(a) (b)

(c) (d)

Fig 2.7 Mean total fish abundance (excluding Atherinidae) with increasing distance from (a,b) rocky reef and (c,d) general edge across both sites and seasons; *CB=Callala Bay, GP=Greenpoint; left panel graphs represent sites pooled.*

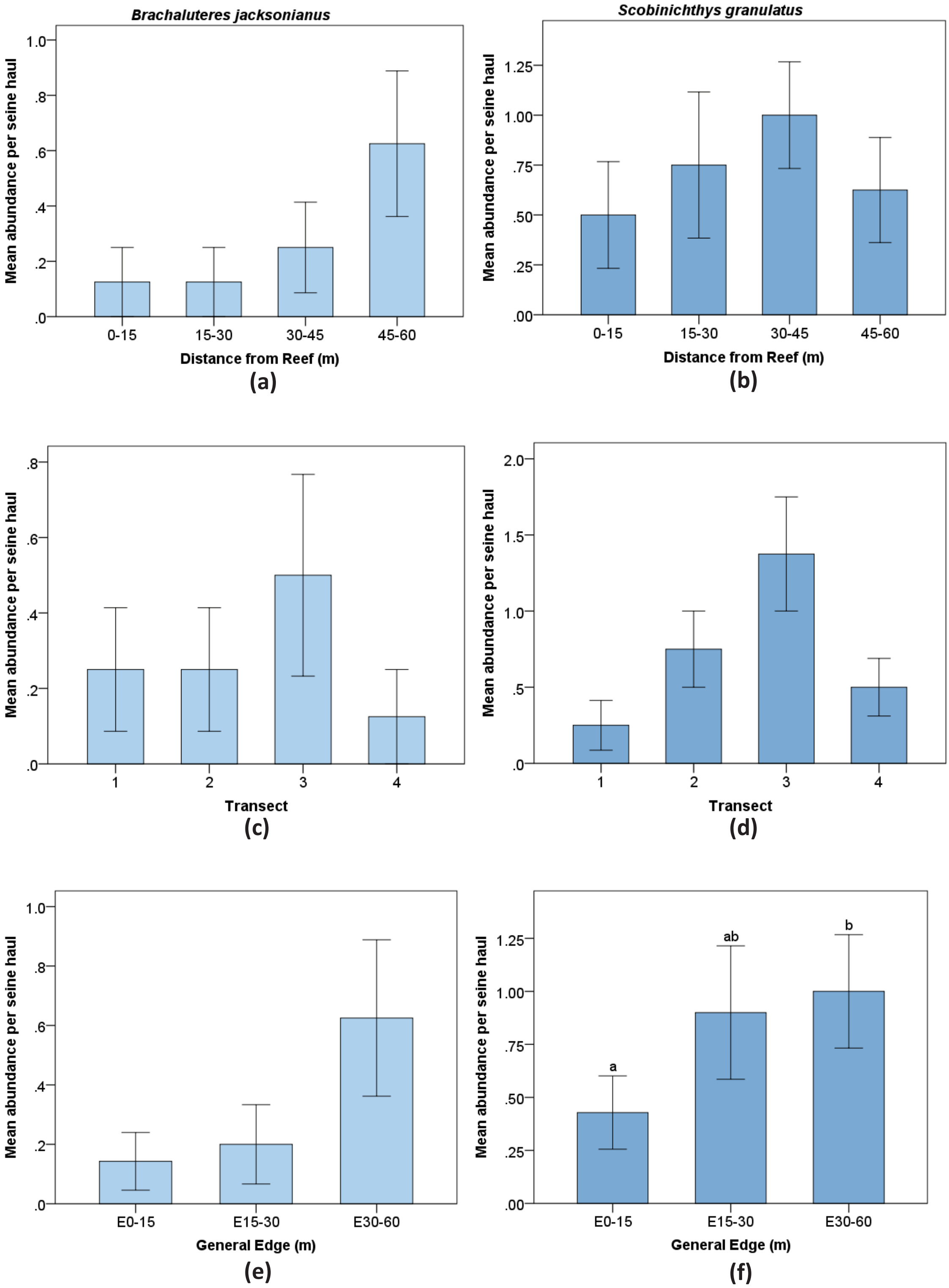
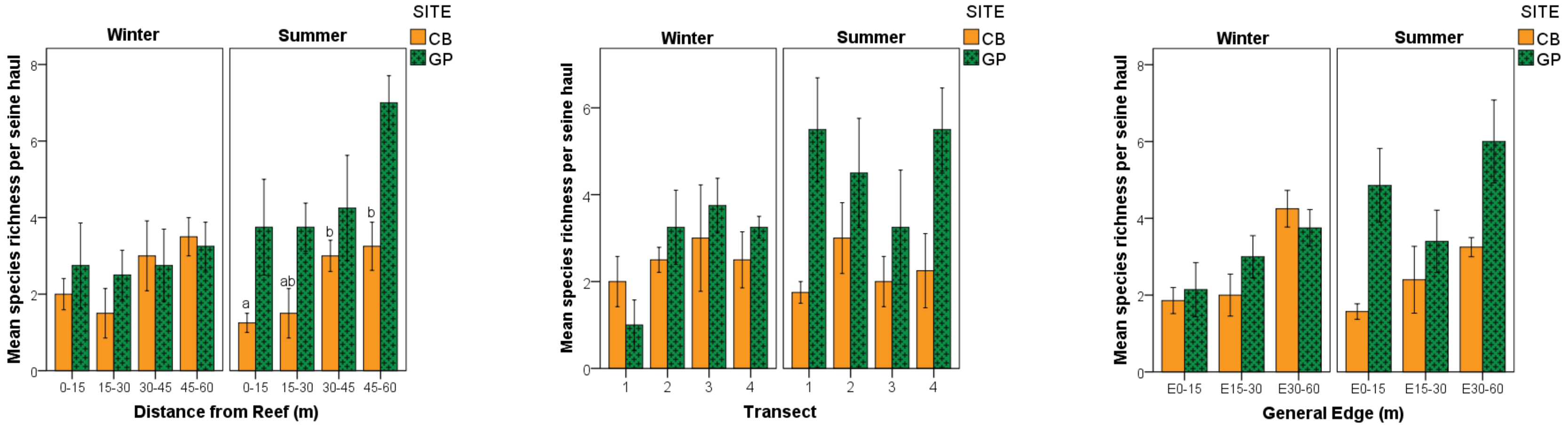
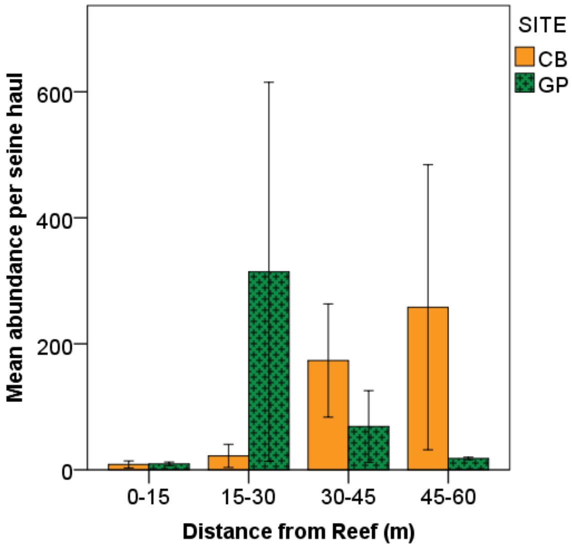


Fig 2.8 Abundance of the leatherjackets *Brachaluteres jacksonianus* (left panel) and *Scobinichthys granulatus* (right panel) with increasing distance from (a,b) rocky reef, (c,d) bare sediment (increasing transect number) and (e,f) general edge across both sites during winter only. *Letters above bars represent the results of pairwise comparisons of log-transformed data with distance categories lacking similar letters being significantly different from each other.*

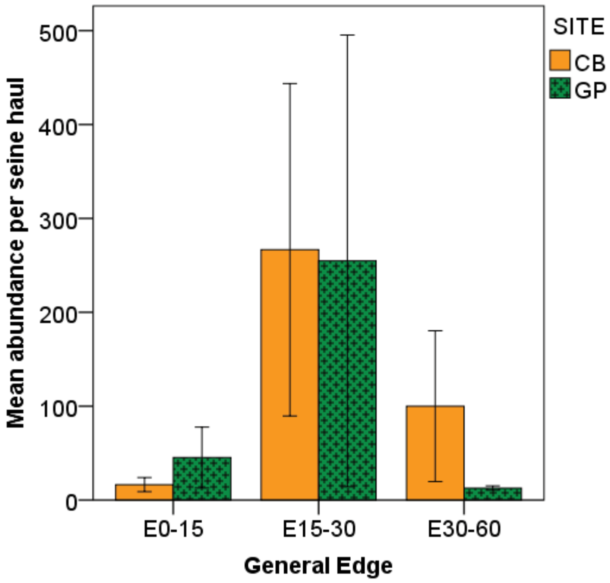


(a) (b) (c)

Fig 2.9 Mean species richness (number of fish species) with increasing distance from (a) rocky reef, (b) bare sediment (increasing transect number) and (c) general edge at both sites during the winter and summer seasons independently. *Letters above bars represent the results of pairwise comparisons with distance categories lacking similar letters being significantly different from each other; CB=Callala Bay, GP=Greenpoint.*



(a)



(b)

Fig 2.10 Mean total fish abundance with increasing distance from (a) rocky reef and (b) general edge across both sites during the summer season only; *CB=Callala Bay, GP=Greenpoint.*

Table 2.3 Feeding Mode Functional Groups: Overall percentage contribution per functional group and percent contribution by taxa of each group

SEASON 1			**CNP**	**CP**	**ZP**	**OV**	**HV**
	Overall Percentage:		**18.80%**	**14.36%**	**46.96%**	**16.57%**	**3.31%**
Scientific names	**Common names**	***Site**					
Tetractenos glaber	smooth toadfish	CB	5.88				
Brachaluteres jacksonianus	pygmy leatherjacket	CB,GP	26.47				
Atherinidae (juv 2)	hardyheads[1]	CB	5.88				
Bathygobius kreffti	fray finned goby	CB,GP	2.94				
Upeneichthys lineatus	blue striped goatfish	CB	2.94				
Cheilodactylus spectabilis	banded morwong	CB	2.94				
Neoodax balteatus	little weed whiting	GP	38.24				
Pelates sexlineatus	eastern striped trumpeter	CB,GP	11.76				
Urolophus sp.	stingaree	GP	2.94				
Siphaemia cephalotes	wood's siphonfish	CB,GP		96.15			
Gymnapistes marmoratus	soldierfish	CB		3.85			
Scorpis aequipinnis	sea sweep	CB,GP			3.53		
Stigmatopora argus	spotted pipefish	CB,GP			81.18		
Atypichthys strigatus	mado	GP			15.29		
Scobinichthys granulatus	rough leatherjacket	CB,GP				76.67	
Aldrichetta forsteri	yellow eye mullet	CB				3.33	
Hyporhamphus regularis	river garfish	GP				13.33	
Meuschenia freycineti	sixspine leatherjacket	GP				6.67	
Acanthaluteres spilomelanurus	bridled leatherjacket	CB,GP					83.33
Acanthaluteres vittiger	toothbrush leatherjacket	GP					16.67

**CB=Callala Bay, GP=Greenpoint*

Table 2.3 (cont'd) Feeding Mode Functional Groups: Overall percentage contribution per functional group and percent contribution by taxa of each group

SEASON 2		*Including Atherinidae[3]*				*Excluding Atherinidae[3]*			
CALLALA BAY		**CNP**	**ZP**	**OV**	**HV**	**CNP**	**ZP**	**OV**	**HV**
	Overall Percentage:	**23.97%**	**73.97%**	**1.60%**	**0.46%**	**14.29%**	**21.43%**	**50%**	**14.29%**
Pelates sexlineatus	eastern striped trumpeter	1.19				62.5			
Atherinidae (juv 2)	hardyheads[1]	98.09							
Brachaluteres jacksonianus	pygmy leatherjacket	0.72				37.5			
Stigmatopora argus	spotted pipefish		0.85				91.67		
Atherinidae (juv 1)	hardyheads[1]		99.07						
Spratelloides robustus	blue sprat		0.08				8.33		
Atherinidae (adult)	Ogilby's hardyhead			89.29				89.29	
Meuschenia freycineti	sixspine leatherjacket			7.14				7.14	
Scobinichthys granulatus	rough leatherjacket			3.57				3.57	
Acanthaluteres spilomelanurus	bridled leatherjacket				100				100

Table 2.3 (cont'd) Feeding Mode Functional Groups: Overall percentage contribution per functional group and percent contribution by taxa of each group

SEASON 2		*Including Atherinidae*[3]					*Excluding Atherinidae*[3]				
GREENPOINT		**CNP**	**ZP**	**CP**	**OV**	**HV**	**CNP**	**ZP**	**CP**	**OV**	**HV**
	Overall Percentage:	**93.05%**	**2.86%**	**0.18%**	**3.23%**	**0.67%**	**45.71%**	**22.38%**	**1.43%**	**25.24%**	**5.24%**
Sillago ciliata	sand whiting	0.59					9.38				
Weed whitings[2]		3.67					58.33				
Pelates sexlineatus	eastern striped trumpeter	1.44					22.92				
Atherinidae (juv 2)	hardyheads[1]	93.71									
Brachaluteres jacksonianus	pygmy leatherjacket	0.46					7.29				
Enoplosus armatus	old wife	0.13					2.08				
Stigmatopora argus	spotted pipefish		85.11					85.11			
Abudefduf sexfasciatus	scissortail sergeant		6.38					6.38			
Spratelloides robustus	blue sprat		6.38					6.38			
Mugil cephalus (juv)	*sea mullet*		2.13					2.13			
Siphaemia cephalotes	wood's siphonfish			66.67					66.67		
Centropogon australis	Eastern Fortescue			33.33					33.33		
Myxus elongatus	sand mullet				13.21					13.21	
Hyporhamphus regularis	river garfish				50.94					50.94	
Microcanthus strigatus	stripey				22.64					22.64	
Rhabdosargus sarba	tarwhine				11.32					11.32	
Scobinichthys granulatus	rough leatherjacket				1.89					1.89	
Acanthaluteres spilomelanurus	bridled leatherjacket					100					100

[1] – hardyheads include *Atherinosoma microstomata* (small mouthed hardyhead) and *Atherinomorus vaigiensis* (Ogilby's hardyhead); [2] – weed whitings include *Neoodax balteatus* (little weed whiting) and *Haletta semifasciata* (blue weed-whiting); [3] – refers to Atherinidae juveniles only

Table 2.4 Estuarine Use Functional Groups: Overall percentage contribution per functional group and percent contribution by taxa of each group

SEASON 1			**EM**	**ER**	**MS**	**MM**
		Overall Percentage:	**72.93%**	**23.20%**	**3.31%**	**0.55%**
Scientific names	**Common names**	***Site**				
Tetractenos glaber	smooth toadfish	CB	1.52			
Brachaluteres jacksonianus	pygmy leatherjacket	CB,GP	6.82			
Scobinichthys granulatus	rough leatherjacket	CB,GP	17.42			
Stigmatopora argus	spotted pipefish	CB,GP	52.27			
Acanthaluteres spilomelanurus	bridled leatherjacket	CB,GP	3.79			
Upeneichthys lineatus	blue striped goatfish	CB	0.76			
Pelates sexlineatus	eastern striped trumpeter	CB,GP	3.03			
Hyporhamphus regularis	river garfish	GP	3.03			
Atypichthys strigatus	Mado	GP	9.85			
Urolophus sp.	stingaree	GP	0.76			
Acanthaluteres vittiger	toothbrush leatherjacket	GP	0.76			
Atherinidae	hardyheads[1]	CB		4.76		
Siphaemia cephalotes	wood's siphonfish	CB,GP		59.52		
Gymnapistes marmoratus	soldierfish	CB		2.38		
Bathygobius kreffti	fray finned goby	CB,GP		2.38		
Neoodax balteatus	little weed whiting	GP		30.95		
Scorpis aequipinnis	sea sweep	CB,GP			50	
Cheilodactylus spectabilis	banded morwong	CB			16.67	
Meuschenia freycineti	sixspine leatherjacket	GP			33.33	
Aldrichetta forsteri	yellow eye mullet	CB				100

**CB=Callala Bay, GP=Greenpoint*

Table 2.4 (cont'd) Estuarine Use Functional Groups: Overall percentage contribution per functional group and percent contribution by taxa of each group

SEASON 2		*Including Atherinidae*[3]				*Excluding Atherinidae*[3]			
CALLALA BAY		**EM**	**ER**	**MS**	**MM**	**EM**	**ER**	**MS**	**MM**
	Overall Percentage:	**1.60%**	**98.23%**	**0.11%**	**0.06%**	**50%**	**44.64%**	**3.57%**	**1.79%**
Stigmatopora argus	spotted pipefish	39.29				39.29			
Pelates sexlineatus	eastern striped trumpeter	17.86				17.86			
Acanthaluteres spilomelanurus	bridled leatherjacket	28.57				28.57			
Scobinichthys granulatus	rough leatherjacket	3.57				3.57			
Brachaluteres jacksonianus	pygmy leatherjacket	10.71				10.71			
Atherinidae (juv 1 & 2)	hardyheads[1]		98.54						
Atherinidae (adults)	hardyheads[1]		1.46				100		
Meuschenia freycineti	sixspine leatherjacket			100				100	
Spratelloides robustus	blue sprat				100				100

Table 2.4 (cont'd) Estuarine Use Functional Groups: Overall percentage contribution per functional group and percent contribution by taxa of each group

SEASON 2		*Including Atherinidae*^{3}				*Excluding Atherinidae*^{3}			
GREENPOINT		**EM**	**ER**	**MS**	**MM**	**EM**	**ER**	**MS**	**MM**
	Overall Percentage:	**8.04%**	**90.74%**	**0.18%**	**1.04%**	**62.86%**	**27.62%**	**1.43%**	**8.10%**
Stigmatopora argus	spotted pipefish	30.30				30.30			
Sillago ciliata	sand whiting	6.82				6.82			
Pelates sexlineatus	eastern striped trumpeter	16.67				16.67			
Acanthaluteres spilomelanurus	bridled leatherjacket	8.33				8.33			
Hyporhamphus regularis	river garfish	20.45				20.45			
Microcanthus strigatus	stripey	9.09				9.09			
Scobinichthys granulatus	rough leatherjacket	0.76				0.76			
Brachaluteres jacksonianus	pygmy leatherjacket	5.30				5.30			
Enoplosus armatus	old wife	1.52				1.52			
Centropogon australis	Eastern Fortescue	0.76				0.76			
Weed whitings[2]			3.76				96.55		
Atherinidae (juv 2)	hardyheads[1]		96.10						
Siphaemia cephalotes	wood's siphonfish		0.13				3.45		
Abudefduf sexfasciatus	scissortail sergeant			100				100	
Spratelloides robustus	blue sprat				17.65				17.65
Myxus elongatus	sand mullet				41.18				41.18
Mugil cephalus (juv)	*sea mullet*				5.88				5.88
Rhabdosargus sarba	tarwhine				35.29				35.29

[1] – hardyheads include *Atherinosoma microstomata* (small mouthed hardyhead) and *Atherinomorus vaigiensis* (Ogilby's hardyhead); [2] – weed whitings include *Neoodax balteatus* (little weed whiting) and *Haletta semifasciata* (blue weed-whiting); [3] – refers to Atherinidae juveniles only

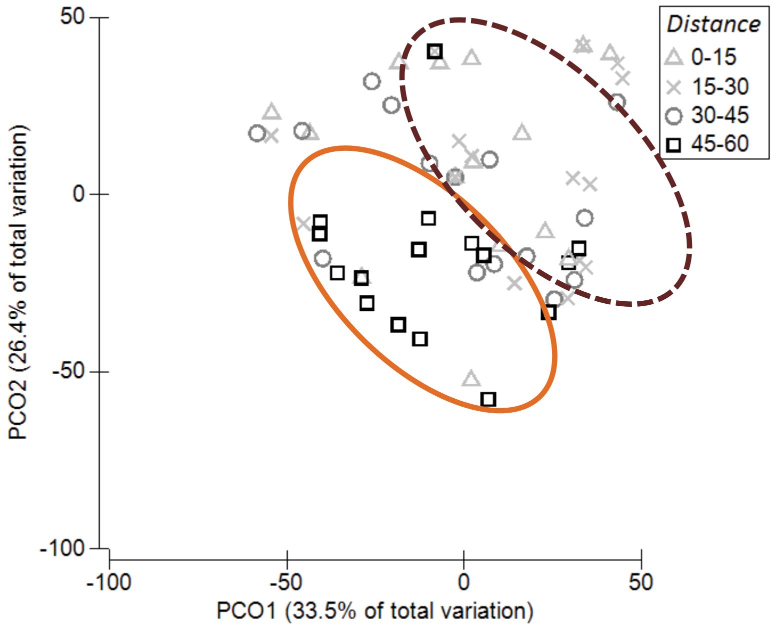


Fig 2.11 PCO plot of Feeding Mode Functional Group community distribution with "distance from reef" created from a Bray-Curtis resemblance matrix on log-transformed guild abundances including both sites and seasons in PRIMER 6 & PERMANOVA+. *Ellipses highlight the separation of data point into two main groups – distance categories below 30m from reef (broken line) and beyond 30m (solid line)*

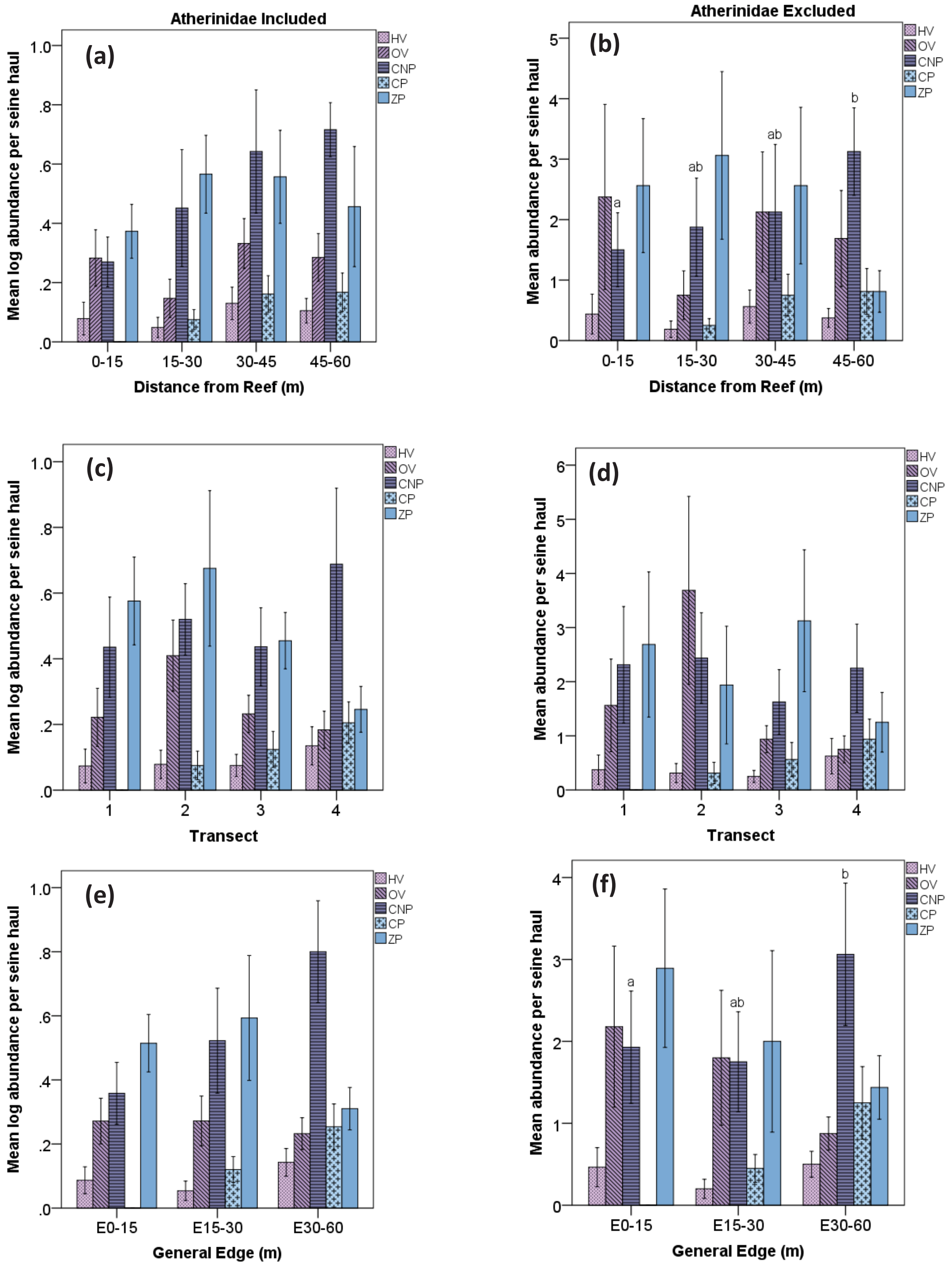
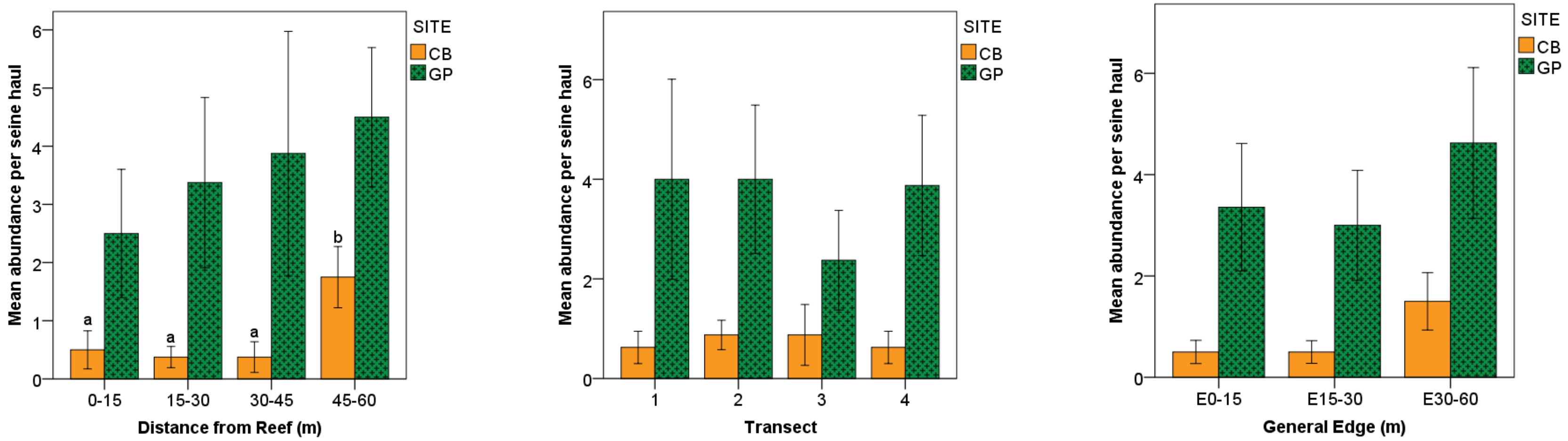


Fig 2.12 Distribution of feeding mode functional groups including (left panel) and excluding Atherinidae (right panel) with increasing distance from (a,b) rocky reef, (c,d) bare sediment (increasing transect number) and (e,f) general edge across both sites and seasons. *Letters above bars represent the results of pairwise comparisons of log-transformed data with distance categories lacking similar letters being significantly different from each other.*



(a) (b) (c)

Fig 2.13 Distribution of the CNP guild (excluding Atherinidae) with increasing distance from (a) rocky reef, (b) bare sediment (increasing transect number) and (c) general edge at both sites across both seasons. *Letters above bars represent the results of pairwise comparisons of log-transformed data with distance categories lacking similar letters being significantly different from each other; CB=Callala Bay, GP=Greenpoint.*

Chapter 3: ***Seagrass Fish Distribution with Respect to Different Habitat Edge Types based on GoPro Video Footage and Combination of Both Sampling Methods***

3.1 Introduction

Importance of more than one sampling method: Use of video footage

To gain a complete understanding of the fish community within the seagrass ecosystem and hence decipher any trends in relative occurrence, abundance and species richness relative to adjacent habitats it becomes imperative to employ more than one fish sampling method (Franco et al. 2011). The seine net (employed in data collection presented in Chapter 2) gives a more accurate account of cryptic seagrass canopy species; species that represent small-bodied and slower moving fish (Franco et al. 2011; Jenkins & Sutherland 1997; Smith, Jenkins & Hutchinson 2012) typically of the Estuarine Species functional group. It, however, fails to adequately sample larger, more mobile, pelagic, transient fish primarily of the Marine Species functional group that also exploit seagrass beds for prey material they supply.

Underwater video procedures better sample this more motile group (Smith, Jenkins & Hutchinson 2012) while simultaneously not providing an adequate account of cryptic canopy species that would be hidden from view (Smith, Jenkins & Hutchinson 2012). This underscores the importance of using a combination of fish sampling methods. For the case of species that may be adequately sampled by both techniques i.e. seine nets and underwater video cameras, such as gregarious schooling species common within NSW seagrass beds often occupying both the water column and canopy, use of both techniques may safeguard against erroneous conclusions from possible sampling artefacts if both techniques reveal similar trends in distribution.

Use of unbaited video cameras deployed within the seagrass bed would also adequately capture fish occurrences at varying positions undisturbed by human interference which may alter their movement, position and behaviour, the latter especially beyond the scope of the seine net. Video analysis have been successfully used in literature (Becker, Cowley & Whitfield 2010; Smith et al. 2011) to give an account of the relative abundances and habitat use of fish species across several habitat types using different units of measure such as MaxN, AvrMaxN (Smith et al. 2011) and %TiV (percent time in view). The latter measure (%TiV) is a straightforward metric calculating the time spent within the habitat location by a particular individual, functional group or total fish observations as a percentage of the total video footage. This is employed in fish video analyses to compare the frequency of occurrence of the relevant groups across space and/ or time (Smith et al. 2011; Smith, Jenkins & Hutchinson 2012). MaxN and AvrMaxN, however, provide an indication of numerical abundance rather than frequency of occurrence. The widely used MaxN metric (Becker, Cowley & Whitfield 2010; Harvey et al. 2013; Santana-Garcon, Newman & Harvey 2014) involves the use of the maximum number of individuals of a species of functional group viewed within a single frame of the entire video footage. This maximum number is then registered as the abundance of the species or group for that collected sample unit. This method, however, has its limitations and is very conservative (Becker, Cowley & Whitfield 2010; Smith et al. 2011). A schooling species, for instance, appearing in high numbers in a single frame and absent or very rarely observed throughout the remaining footage is highly overestimated. To address this AvrMaxN may be used (Smith et al. 2011). Here the author averages the five video footage frames containing the highest fish abundances to given a more representative value. Hence if the schooling individuals were found in only one frame that absolute value would still be divided by five. This metric will also not underestimate those non-schooling fish that are in relatively high abundances throughout the footage. Using both metrics would allow a broader range of interpretation i.e. understanding trends in abundances as well as frequency of occurrence.

Behavioural data important

While knowledge of fish species richness, abundance and community structure are good indicators of the relative preference of certain positions (Anderson et al. 2009; Bell & Westoby 1986b) within the seagrass bed and possibly extrapolated to infer its relative “health”, how fish actually use different sections of the habitat is also equally important. For instance, an individual or school may be simply passing through a certain section of the seagrass habitat and using it as an escape route or travel path on its way to another destination on its capture by the sampling method as opposed to sheltering, feeding or meandering slowly within and through the seagrass canopy. Being able to differentiate between the two, which may be accomplished by use of unbaited underwater video cameras, provides more information on the use and importance of the seagrass bed in different positions by different fish species and functional groups.

Specific questions being addressed by this chapter

This chapter’s focus is two-fold and seeks to answer the following research questions below in each focus (section):

Focus (Section) 1: Video (GoPro) footage only

1. Is there a difference in (i) fish taxa total abundance, (ii) taxa richness, (iii) community composition of individual taxa, (iv) functional group community composition and (v) individual functional guild abundance with distance away from the seagrass-rocky reef edge, seagrass-sand edge or edge *per se*?

2. Is the difference noted in #1 above taxa-specific or functional group-specific?

3. Do certain taxa or functional groups (guilds) display differential or opposing trends relative to the two habitat edges i.e. the seagrass-reef and seagrass-bare sediment edges?

4. Is there a difference in the use of the seagrass habitat with increasing distance from the habitat edges with respect to (i) physical position occupied (ii) swim speed and (iii) foraging?

In comparison with seine net catch data (Chapter 2)

5. Are trends in fish distribution with respect to the two adjacent habitats and general edge (edge *per se*) consistent between the two sampling methods?

6. Do the individual sampling methods capture trends equally efficiently across fish taxa and fish functional groups?

Focus (Section) 2: Complete picture (combination of GoPro and seine net data)

7. Combining all data from both sampling methods is there a difference in (i) fish taxa richness, (ii) community composition of individual taxa, (iii) functional group community composition and (iv) individual functional guild abundance with distance away from the seagrass-rocky reef edge, seagrass-sand edge or edge *per se*?

Null hypotheses tested (Focus 1):

1. There is no difference in a. fish taxa total abundance, b. taxa richness, c. community composition of individual taxa, d. community composition of functional groups, and e. individual functional guild abundance with distance away from either adjacent habitat type and/ or edge *per se*.

2. There is no a. fish taxa-specific and b. fish functional group-specific response to either habitat edge type or edge *per se*.

3. There is no difference in response displayed by a. individual fish taxa and b. individual fish functional groups relative to either adjacent habitat type and/ or edge *per se*.

4. There is no difference in the overall fish a. physical position occupied, b. swim speed and c. foraging within the seagrass habitat with increasing distance from the adjacent habitat types and edge *per se*.

5. There is no consistency in the trends observed with respect to each adjacent habitat type and edge *per se* between the two sampling methods.

6. There is no difference in the ability of each sampling method in efficiently capturing trends displayed by sampled fish taxa and functional groups.

Null hypothesis tested (Focus 2):

7. Incorporating both sampling methods, there is no difference in a. taxa richness, b. community composition of individual taxa, c. community composition of functional groups and d. individual functional group abundance with increasing distance from either adjacent habitat type and/ or edge *per se*.

The main and ultimate objective of the chapter is to access fish distribution in the sampled seagrass beds with respect the two adjacent habitats (rocky reef and seagrass) and general edge using another sampling method i.e. GoPro video cameras and to obtain an overall picture of fish distribution combining data from both GoPro deployment and the seine net employed in the same sampling locations.

Rationale:

This chapter builds on the previous one and provides a more complete picture of fish distribution along with habitat use with distance from the two adjacent habitats and edge *per se*. It also compares the relative effectiveness of different fish sampling methods in capturing trends by certain fish taxa and functional groups which will help to inform future research in this area depending on the scope and aims of the intended study.

3.2 Methods

Unbaited GoPro underwater video cameras were fixed to a stake each which was driven into the sediment and positioned with the lens perpendicular to the stake and just above the seagrass canopy. Each stake with one camera affixed was placed in the centre of each 15 × 15 m sampling unit or quadrant, as described in Chapter 2, and pointed away from the rocky reef (Fig 3.1). Each camera was deployed for approximately ten minutes and then retrieved. The central placement of the camera was to best facilitate the observation of any fish that may moving within the entire quadrant over the ten-minute period. As only one camera was deployed per quadrant, this position was deemed the best position to capture fish abundances within the given 225 m^2 sampled. Placement, for instance, at the zero mark or beginning of each quadrant may not represent some individuals at the further end of the quadrant due to the restricted visibility of the seagrass water column from preliminary video analysis. In order to keep the quadrant (sampling unit) the same size throughout the study for comparability of data, the central position was the best compromise.

A ten-minute period was chosen after a preliminary experiment was done using twenty minute footage. Upon analysis of the video footage after 5, 10 and 20 minutes, the 10-minute period captured more species and higher MaxN values than the 5-minute period but did not differ considerably enough from the 20-minute period to warrant the additional time. Pointing the camera away from the reef helped to ensure that after deployment and retrieval the investigator was never in the field of view and would not directly interfere with the fish community being observed. All video footage at each site and on each sampling occasion was collected within the same tidal range as with seine netting (Chapter 2) and was generally done at least one day before seine netting began as the latter would disrupt the seagrass bed. Additionally, all video footage collected at each site and sampling occasion was completed within one hour with four video cameras being positioned at a time. Each group of four was generally synchronised to begin videoing simultaneously beginning at D1 (Fig 3.1). Unbaited video cameras were used in order to get a true representation of the fish within each 15 × 15m quadrant without an attracting mechanism. Due to the scale of the study, use of baited cameras is highly likely to attract individuals from neighbouring quadrants. This would render sample replication and the differentiation between assemblages at varying distance categories within tens of meters meaningless.

Video footage was collected over two seasons (austral winter: August-September 2013 and austral summer: January-February 2014) corresponding with seine netting (Chapter 2) in the same beds. Whereas in the Austral winter season, video footage was collected on one occasion in each quadrant at each site (n=32), in the summer season, footage was collected once weekly in each quadrant at each site over three consecutive weeks (n=96), with both sites sampled within the same week on each of the three occasions.

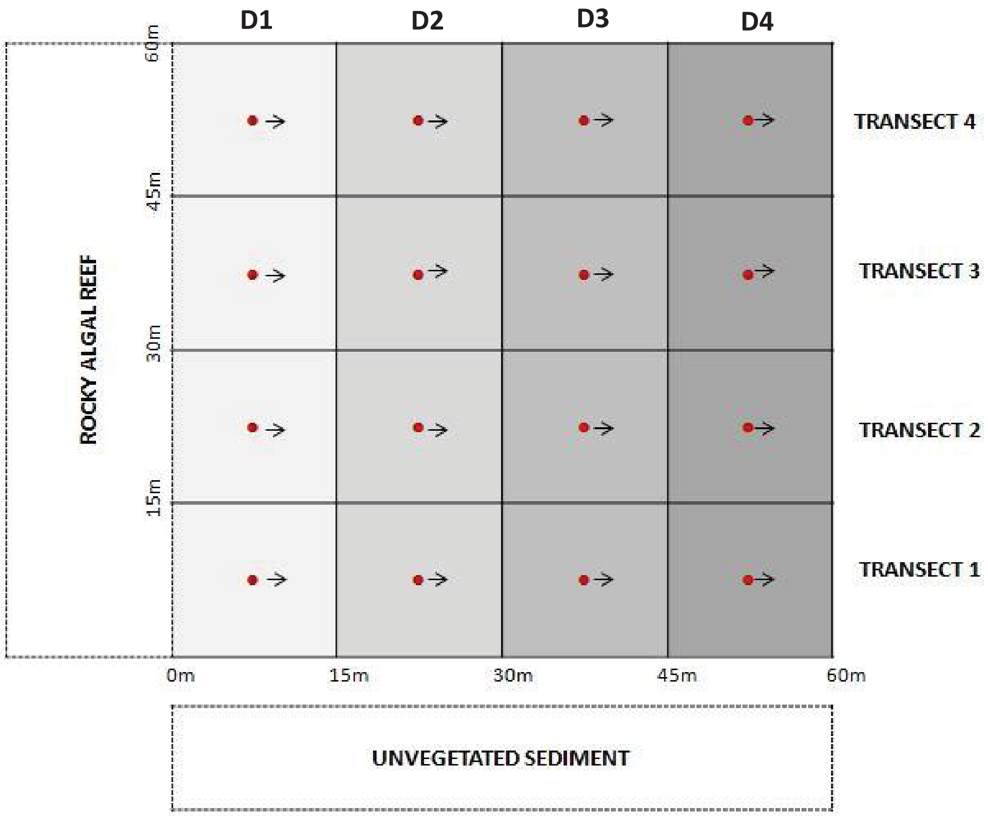


Fig 3.1 Placement of GoPro video cameras in each quadrant (filled circle) with the arrow indicating lens direction.

Analysis of GoPro Footage

August-September 2013

The first ten minutes of each video for each quadrant was analysed and the following parameters measured:

1. Number of species/taxa observed
2. *Average Max N (AvrMaxN)* (Smith et al. 2011): This was calculated as the average number of fish individuals of each species/taxa counted over the five 30-sec slots containing the most fish over the ten minute period. Zero values were also included in the average if there were less than five non-zero counts for each species/taxa, for each ten minute footage. Steps taken to minimize recounting of fish followed that employed by Smith et al. (2011). In the case of schooling fish moving through the field of view, 2 – 5 counts were taken where possible of the number of fish in each frame over each 30s slot and highest number obtained used to represent the number of fish for that 30s slot. Values are presented as AvrMaxN per ten-minute slot and are applied to (i) individual fish species/taxa, (ii) total fish encountered in each quadrant on each occasion and (iii) individual fish functional guilds in the two classification schemes as outlined in Chapter 1 i.e. the FMFG (Feeding Mode Functional Grouping) and EUFG (Estuarine Use Functional Grouping).

January-February 2014

The summer sampling session involved a more detailed analysis of the fish assemblage as it supported higher abundances of fish. This is in contrast to the winter season where sparser fish assemblages were observed. As such application of this more detailed analysis, involving replication per week, inclusion of the %TiV measure (percent time in view) for total fish assemblage, for each taxon and functional group and analysis of behavioural and fish position in the seagrass habitat was deemed more fruitful and valid for the summer session.

The first ten minutes of each video for each quadrant was analysed and the following parameters measured:

1. Number of species/taxa observed

2. *Average Max N (AvrMaxN)*: as described above

3. %TiV (Time in view): The full ten-minute video footage was analysed in 30-second slots and the number of 30 second slots containing each taxa tallied and divided by twenty (i.e. the maximum number of 30-second slots in ten minutes). This proportion was then multiplied by 100 to give a percentage of time spent in view. The actual number of fish of each species/taxa within each 30-second slot is not taken into account with this measure but instead each species' general presence. This value thereby more closely represents the species' frequency of occurrence. As with the AvrMaxN measure, these values are also applied to (i) individual fish species/taxa, (ii) total fish encountered in each quadrant on each occasion and (iii) individual fish functional guilds in the FMFG and EUFG classification schemes.

The following measures were assessed on analysis of the ten-minute video footage for each quadrant for each sampling occasion (n=96):

Foraging events

The number of feeding events on epiphytes and slow meandering through seagrass blades (collectively termed "foraging") observed regardless of fish species/taxa were counted with each fish feeding on epiphytic material and slowly meandering through the canopy (mutually exclusive events) coded as a single foraging event. While each solitary individual or group of less than eight fish within the same frame was coded as individual foraging events, each school was coded as a single foraging event.

Relative swim speed

Swim speed was placed in two categories – "slow" and "fast". The relative swim speed of each fish regardless of species/taxa was recorded and tallied in the two swim speed categories. While each solitary individual or group of less than eight fish within the same frame was coded as separate individual swim events, each school was coded as a single swim event.

Position in habitat

The number of times fish were viewed in following three categories – (1) within the "seagrass canopy", (2) "midwater column" and (3) spanning a combination of the two i.e. canopy into midwater column were recorded. Single individuals and groups less than eight were coded as single events each while a school was considered a unit and coded as a single point when observed.

The following rules were applied when coding videos for behavioural and habitat position metrics:

- For continuous schooling a new event was deemed after 30 seconds had elapsed.
- Behaviour was not coded if the fish was peering towards and investigating the camera or if the observed behaviour was deemed to be affected by the camera placement.
- "Slow" – includes hovering, stopping and starting and dipping movements while "fast" indicates swimming through quickly.
- Each fish or school of fish in each frame was coded only once for each behaviour and habitat position category.
- If it was evident that it was the same fish individual/ school within the frame as in the subsequent 30 second slot, it was not recounted, for instance if the individual/ school entered the frame in the opposite direction from which it left the subsequent time period within 10 seconds.

Statistical analysis

Section 1: GoPro data only

Multivariate PERMANOVA was performed on (i) fish total occurrence, (ii) species/taxa richness, (iii) community composition of individual taxa and (iv) community composition as classed according to feeding mode and estuarine use functional groupings (FMFG and EUFG respectively). Each dominant individual species and functional group was also similarly analysed via univariate PERMANOVA using two separate orthogonal designs:

Design 1. "distance from reef" – Di (fixed), "distance from bare sediment" – Tr (fixed), "site" – Si (random) and "season" – Se (fixed) along with their interactions *and*

Design 2. "distance from general edge" – Ed (fixed), "site" – Si (random) and "season" – Se (fixed) along with their interactions.

The factor "week" – wk (fixed) was also included when analysing the summer season separately as in this season, as outlined in the Methods above, video footage was collected once per week for three weeks in all positions at both sites. PCO analyses of the fish community structure at both sites at the three weekly video footage collections illustrate that the identical community composition was not being repeatedly sampled on each occasion at either site. Relevant PCO plots assessing faunal communities sampled weekly are displayed in (Appendix III).

"Week" as stated above was treated as a fixed factor based on the sampling design and deemed proper interpretation of results. Each site and all positions within were sampled within the same given one week period for each of the three weekly sampling occasions. As such the observations obtained may be specific to that particular "week" period in the year and could not be validly treated as a random sampling event. Had any three sampling occasions been chosen randomly for each site within the summer season, then another factor such as "sampling event" or "occasion" would have been employed, which would in that instance be considered a random factor.

"General edge" or edge *per se* was determined as outlined in Chapter 2. Where there was a high non-significance ($p \geq 0.2$) for any one factor it was removed from the design and the statistical test rerun. If removal of the highly non-significant factor did not change the p values of the remaining ones the factor was retained in the design. The factors kept in the model for each significant trend observed is noted in summary statistical tables throughout the Results section. All data was log transformed to achieve homogeneity of variances around each factor. Where homogeneity was not achieved even after log transformation the significance level was set at $p \leq 0.01$ (Underwood 1981). Taxa richness in most cases already displayed homogeneity of variances in its natural state. Where this was not the case, square-root transformation was sufficient to meet this requirement and is indicated in the relevant Results sections. All significant differences illustrated in graphical representation of results represent analysis performed on log-transformed data with the exception of species/taxa richness as outlined above.

Principle Coordinates (PCO) analysis was performed on the log-transformed community data converted into Bray-Curtis resemblance matrices to visually evaluate community composition trends with distance from both adjacent habitats and general edge. This was done for the community of individual fish taxa and community of functional groups and included where appropriate. SIMPER analysis was also performed on each significant community trend to ascertain the groups with the greatest contributions to the observed trends. All analysis was done in PRIMER 6 version 6.1.13 and PERMANOVA+.

Section 2: Complete picture: combination of GoPro and seine net data

Multivariate PERMANOVA was performed on a combined dataset of GoPro and seine net data (presented in Chapter 2) across both sites and seasons assessing (i) taxa richness, (ii) community composition of individual taxa and (iii) community composition as classed according to FMFG and EUFG classifications. The community data in each case was converted to a presence/absence matrix before application of an appropriate similarity matrix in PERMANOVA. Each dominant individual fish species/taxa and functional group was also individually converted into presence/absence matrices. All data was then analysed using two separate orthogonal designs:

Design 1. “distance from reef” – Di (fixed), “distance from bare sediment” – Tr (fixed), “site” - Si (random), “season” – Se (fixed) and “method” – Me (fixed) along with their interactions *and*

Design 2. “distance from general edge” – Ed (fixed), “site” – Si (random), “season” – Se (fixed) and “method” – Me (fixed) along with their interactions.

The combined taxa richness data was analysed in its natural form without transformation, having already exhibited homogeneity of variances. As with the data in *Section 1* above, there was a stepwise removal of highly non-significant ($p \geq 0.2$) factors if there was a resultant change in p-values of the remaining factors, with factors retained presented in relevant tables in the Results section. Principle Coordinates (PCO) and SIMPER analysis were also similarly performed on the combined dataset with all analysis done in PRIMER 6 version 6.1.13 and PERMANOVA+. To gain an overall understanding graphically of the relative abundance of individuals within the functional guilds across both methods, sites and seasons the original combined data was converted to a semi-quantitative dataset where abundances were converted to one of five ordered ranks ranging from 0 to 5 (Elliott & Dewailly 1995). As in Elliott & Dewailly (1995) “0” denotes absent, “1” – rare, “2” – occasional, “3” – common, “4” – frequent and “5” – very abundant.

3.3 Results

Section 1: GoPro data only

3.3.1 Overall analysis

Fourteen taxonomic groups, as outlined in Table 3.1, were observed over the two seasons in all seagrass positions (quadrants) at the two sites, with the summer season having just over double (13) the number of taxa compared to winter (5). Mugilidae, Sparidae and Atherinidae were grouped due to the difficulty in distinguishing between species from the video footage. Taxa were ranked with regard to overall occurrence (Table 3.1) based mean AvrMaxN (over all sampling positions) for the winter season while for the summer, rankings were done based on both mean %TiV (average %TiV over all sampling positions) and mean AvrMaxN (over all positions) separately. The most abundant and frequently observed taxa over both seasons included *Ambassis jacksoniensis*, the Atherinidae, Mugilidae, *Girella tricuspidata*, Sparidae and the leatherjacket, *Acanthaluteres spilomelanurus* in that order with “1” denoting the highest abundance (Table 3.1).

While results are subsequently described for distribution patterns incorporating both seasons as indicated, the greater number of taxa, different overall fish community with inherently different interspecific interactions, and higher fish occurrences in the summer warranted the seasons to also be analysed separately to avoid drawing conclusions across both seasons, possibly highly biased by fish distribution patterns in one particular season, likely the summer. As such results are described incorporating both seasons first, for specific indicated distribution variables, and then described by season. Fish functional group analysis is presented only from data obtained in the extended summer sampling session where greater species richness and fish occurrences justify assignment in appropriate functional guilds.

3.3.2 Fish taxa distribution

3.3.2.1 Both seasons

Due to the greater number of taxa encountered in the summer and the increased sampling effort in this season (video footage taken once a week for three weeks) PERMANOVA analysis of the fish community was not performed over both seasons but for the summer season only. Total abundance (AvrMaxN), species richness and abundance of specific taxa common to both seasons were however analysed over both seasons. Due to the high significance of “site” for total abundance and species richness considering both seasons ($p<0.001$), analysis was also done and presented for both sites separately (Table 3.2). The common taxa, however, *Ambassis jacksoniensis,* not only displayed similar trends across both sites but its distribution was highly non-significant for the factor "site" ($0.4233<p<0.5489$). As such, this taxa's abundances were pooled across sites.

Total abundance

There was no significant difference in total abundance with distance in any plane i.e. from the reef, bare sediment or general edge (Table 3.2). Although there was a general trend of greater occurrences within 30m of the reef (for both sites) (Fig 3.2 a,b) and within 30m of the general edge (for Greenpoint only) (Fig 3.2f) this may be highly driven by the presence of the schooling *A. jacksoniensis* and Atherinidae especially in the summer sampling session which is addressed in Section 3.3.2.3 (Summer season). For both sites there was also a general trend of increasing abundance away from the bare sediment with a decline at the furthest distance (Fig 3.2c,d).

Species richness

Taxa richness increased significantly with "distance from reef" (*pseudo-F* = 9.303, $p=0.0429$) pooling both sites with significantly higher number of taxa encountered at the 45-60m distance compared to the first two distance categories i.e. 0-15m and 15-30m ($p=0.0227$ and $p=0.0182$ respectively: pairwise comparisons) (Table 3.2a; Fig 3.3a). There was no significant effect of "distance from bare sediment" (*pseudo-F* = 2.7895; $p=0.2447$) or "distance from general edge" (*pseudo-F* = 15.668; $p=0.1998$) in this regard (Table 3.2b,c).

As there was a significant effect of "site" (*pseudo-F* =12.926; $p = 0.0074$), due to consistently higher numbers of taxa at Greenpoint (GP) compared to Callala Bay (CB), each site was analysed separately over both seasons for this variable. At both sites the effect of "season" was highly non-significant ($p>0.75$). There was a significant effect of "distance from bare sediment" (*pseudo-F* = 4.1147; $p=0.0117$) and "general edge" (*pseudo-F* = 4.0124; $p=0.0211$) at GP (Table 3.2b,c), with significantly more taxa encountered at distances further away from the bare sediment and general edge (Fig 3.3d,f). There was also a general trend of increased numbers of taxa with increasing "distance from reef" at this site; this, however, was not significant. Although similar trends, especially with "distance from bare sediment" and "general edge", were observed at CB across both seasons (Fig 3.3d,f) these were not statistically significant.

Individual taxa – common to both seasons

Ambassis jacksoniensis, *Girella tricuspidata*, the Mugilidae and Sparidae were common at both seasons with last three taxa found predominantly at GP throughout both seasons. *Ambassis jacksoniensis* even though persistent through both seasons was not encountered at GP in winter. As such this species was analysed separately for the summer season in Section 3.3.2.3. *Girella tricuspidata*, the Mugilidae and Sparidae at GP all varied significantly with increasing distance from the adjacent habitat edges and/or general edge over both seasons (Table 3.2; Fig 3.4).

Girella tricuspidata

Girella tricuspidata varied with distance in all planes ($p<0.01$) (Table 3.2) with occurrences being significantly highly at 45-60m from the reef compared to the first two distances ($p = 0.0035$ with 0-15m, $p = 0.0109$ with 15-30m: pairwise comparisons) (Table 3.2a; Fig 3.4a). T4 (45-60m+ from the bare sediment) also had significantly higher occurrences of this species than the first two distances i.e. 0-15m+ and 15-30m+ ($p = 0.0067$, 0.0114 respectively: pairwise comparisons) with occurrences at T3 (30-34m+) also being significantly greater than at T1 (0-15m+) ($p=0.0109$: pairwise comparison) (Table 3.2b; Fig 3.4b). With regards to the significant effect of "general edge" (*pseudo-F* = 11.687; $p=0.0002$) (Table 3.2c), observed occurrences at the furthest general edge distance (E30-60m) were significantly greater than the inner two general edge positions ($p = 0.0002$ with E0-15m, $p = 0.0032$ with E15-30m: pairwise comparisons) (Table 3.2c; Fig 3.4c).

Mugilidae

The Mugilidae displayed a trend of increasing occurrences away from the reef with a sharp significant increase at the 15-30m distance over the immediate seagrass-reef edge (0-15m) ($p=0.0011$: pairwise comparison) (Table 3.2a; Fig 3.4a) and remained consistently high at subsequent distances from the reef (Fig 3.4a). A non-significant trend of decreasing occurrences away from the bare sediment and general edge was also displayed by this taxon (Fig 3.4b,c).

Sparidae

A significant effect of “distance from bare sediment” (pseudo-F = 4.7296; p=0.0017) was displayed for this taxa with the only non-significant pairwise comparisons being between the T1 (0-15m+) and T2 (15-30m+) and between T3 (30-45m+) and T4 (45-60m+) distance categories (Table 3.2b). All other combinations of “distance from bare sediment” positions displayed significantly different occurrences of this taxa (p <0.01: pairwise comparisons) (Table 3.4b) with individuals only encountered at T3 and T4 over both seasons. There were no meaningful trends with distance from the reef or general edge, however, the taxa comprising *Rhabdosargus sarba* and *Acanthopagrus australis*, was generally absent from the E0-15m position (Fig 3.4c).

3.3.2.2 Winter season

As aforementioned PERMANOVA analysis on the fish community data is presented from the summer season only. Trends in total abundance and species richness are however presented for the winter season.

Total abundance

There was a significant effect of “distance from reef” (*pseudo-F* = 3.5587; p=0.0236) and “distance from general edge” for total AvrMaxN (*pseudo*-F = 4.0027; p=0.0251) (Table 3.2a,c) with consistently lower occurrences at the immediate seagrass-reef and general edge positions (Fig 3.5a,c). Pairwise comparisons revealed significantly lower occurrences at the 0-15m “distance from reef” position compared to that at 15-30m and 30-45m positions (p=0.0055 and 0.0226 respectively), while occurrences at E0-15m were significantly lower than at E15-30m (p=0.0019) (Table 3.2b,c; Fig 3.5a,c). The fish community at CB was dominated by the schooling *A. jacksoniensis* in this season while *G. tricuspidata*, Mugilidae and Sparidae were the dominant taxa at GP during winter.

Species richness

A significant effect of “distance from general edge” was found for the number of fish taxa observed at both sites (*pseudo-F* = 3.7023; p=0.05 – GP and *pseudo-F* = 4.1993; p=0.0351 – CB) (Table 3.2c). Pairwise comparisons show a significant increase in taxa richness at E3 compared to E1 (GP; p=0.0193) and at E2 compared to E1 (CB; p=0.0213) (Table 3.2c; Fig 3.5c). Contrary to observed trends at GP, taxa richness increased to the second general edge position (E15-30) and declined thereafter in the most interior position at CB in this season (Fig 3.4f). At GP, however, there was a steady increase in taxa richness towards the seagrass interior away from the immediate general edge position (Fig 3.4f). There was also a consistent, however non-significant trend of increasing taxa richness at GP away from the 0-15m "distance from reef" position and from the 0-15m+ and 15-30m+ distances from bare sediment (Fig 3.5d,e). While less taxa were observed at the immediate seagrass-reef position compared the two subsequent positions (Fig 3.4d) and none at the first "distance from bare sediment" position closest to the edge at CB (Fig 3.4e), the increase in taxa richness was not a steady one as at GP. Taxa richness peaked at the 15-30m distance from the reef and declined thereafter with no taxa observed at the furthest position (45-60m) (Fig 3.4d), while being relatively similar for all other "distance from bare sediment" distance categories (Fig 3.4e).

3.3.2.3 Summer season

Fish community composition

PERMANOVA analysis on the complete fish community revealed a significant effect of "distance from reef" (*pseudo-F* = 2.8825; p=0.0296) for the AvrMaxN measure but not with %TiV. Due to higher fish occurrences at GP and the high significance of "site" for all statistical models assessing community composition (p=0.0001 in all cases), PERMANOVA analysis was also performed on the fish community distribution and other metrics such as total abundance and taxa richness on each site separately. Additionally, as the fish community composition at CB showed no significant variation with either the AvrMaxN or %TiV measure with increasing distance in any plane (0.2402<p<0.7382) (Table 3.2), likely an artefact of the low fish occurrences found at this site, some fish distribution metrics are described for GP only which will be indicated in the text.

Greenpoint

PERMANOVA analysis showed significant variation in the fish community with either AvrMaxN and/or %TiV measures for distances in all planes (0.0014<p<0.0461) (Table 3.2). Significant pairwise comparisons for each measure of each variable i.e. "distance from reef", "distance from bare sediment" and "distance from general edge" may also be viewed in Table 3.2. The furthest distance in all planes (45-60m from reef, 45-60m+ from bare sediment and E30-60m) hosted a significantly different fish community relative to the seagrass bordering the adjacent habitats and general edge (0-15m from reef, 0-15m+ from bare sediment, E0-15m) (0.0043<p<0.0225) with the %TiV measure (Table 3.2).

SIMPER analysis of the fish community between the significantly varying seagrass positions, noted above in each plane, showed *G. tricuspidata*, Atherinidae, Mugilidae, *A. jacksoniensis*, *R. sarba* (Sparidae) and *S. obtusata* as having the greatest contribution to the statistically significant trend observed (Table 3.3). These taxa were also among the most commonly occurring (Table 3.1). *G. tricuspidata* and the Atherinidae consistently accounted for at least 50% of the variation in fish community trends with both the AvrMaxN and %TiV measures with their contributions being more evenly distributed for the %TiV measure.

Individual taxa

Ambassis jacksoniensis and the Atherinidae were commonly abundant at both sites while *G. tricuspidata*, *S. obtusata,* the Mugilidae and Sparidae (*R. sarba*) were particularly abundant at GP and hence were considered for that site only.

Ambassis jacksoniensis

Considering the weeks for both sites in summer where the gregarious species was observed (Week 3 for CB; Week 2 for GP), there was a high non-significance for the effect "site" for both measures of abundance i.e. AvrMaxN and %TiV (p>0.35) which was then removed from the model. Trends displayed by this species was similar at both sites and with the occurrence data for this species at both sites pooled there was a significant effect with "distance from reef" for both occurrence measures (0.0098<p<0.0113) (Table 3.2) but none with "distance from bare sediment" or "distance from general edge". Nonetheless, the species was noticeably absent from the furthest edge position (E30-60m) and increased steadily in occurrence away from bare sediment (Fig 3.6c-f). With respect to the reef habitat, pairwise comparisons show a significant difference between this species' occurrences between the 15-30m and 30-45m distances from the reef for AvrMaxN (p = 0.0041) and between the 15-30m and 45-60m reef distances for both measures (p = 0.0025 AvrMaxN; p = 0.0077 %TiV) (Table 3.2a). Occurrences were observed to peak at the 15-30m "distance from reef" category (Fig 3.6a-b).

Atherinidae – *Atherinosoma microstomata* and *Atherinomorus vaigiensis*

The atherinids showed no consistent trend with distance in any plane for either abundance measure across sites (Appendix IV). The taxa displayed opposing trends at both sites with occurrences being greater towards the reef and general edge for GP and towards the furthest reef and general edge distances at CB. There were noticeable fewer overall occurrences of this taxa at CB compared to GP.

Girella tricuspidata

Occurrences of this species in the summer season increased in a stepwise and significant fashion for both measures with increased distance from both adjacent habitats and general edge ($0.0002<p< 0.0081$) (Fig 3.7; Table 3.2). Pairwise comparisons showed significantly higher occurrences at the furthest distance category in all planes (45-60m; reef, 45-60m+; bare sediment and E30-60m: general edge) compared to those within 30m of the habitat edges and general edge with AvrMaxN ($0.0013<p<0.044$) within the 45m of the reef and bare sediment for %TiV ($0.0038<p<0.0209$) (Table 3.2; Fig 3.7).

Sphyraena obtusata

This species, which was only observed in the summer sampling session, displayed a significant increase in occurrences with “distance from reef” for AvrMaxN (*pseudo-F* = 5.6037; $p=0.0077$) (Table 3.2a; Fig 3.7a,b). It was also significantly more frequently observed at E3 compared to E1 for AvrMaxN ($p=0.0085$: pairwise comparison) and %TiV ($p=0.012$: pairwise comparison), marginally so in the latter case with the significance level set at 0.01 due to non-homogeneity of variances in this instance (Table 3.2c; Fig 3.7e,f). There was no significant effect of “distance from bare sediment” for either measure but there was a trend of decreasing occurrences away from 15-30m+ position, with the species not being observed at 0-15m+ (Fig 3.7c,d).

Mugilidae

There was no significant effect with either abundance measure for this taxon with increasing distance in any plane when analyzed separately for the summer season. There were, however, the trends of increasing numbers away from the reef and increasing numbers towards the bare sediment and general edge (Fig 3.7).

Sparidae – *Rhabdosargus sarba* and *Acanthopagrus australis*

The sparids (*R. sarba* at Greenpoint) displayed a significant effect with “distance from bare sediment” only, for %TiV (*pseudo-F* = 5.0081; $p=00016$) (Table 3.2b) being noticeably absent in the first two distance categories in this plane (Fig 3.7c,d). Pairwise comparison indicates significant differences in occurrences between the 30-45m+ positions and both the 0-15m+ and 15-30m+ distances ($p = 0.004$ and 0.0049 respectively) (Table 3.2b). There was a non-significant trend of decreasing occurrence of this taxon with distance away from the reef (Fig 3.7a,b) while being evenly spread over all general edge positions (Fig 3.7e,f).

Total abundance

There was a significant effect of “distance from bare sediment” in total AvrMaxN i.e. including all taxa (*pseudo-F* = 14.852; p = 0.0412) with the 30-45m+ position having significantly greater occurrences compared to 0-15m+ and 45-60m+ (p = 0.0111 and 0.0076 respectively: pairwise comparisons) (Table 3.2b; Fig 3.8c). There was no significant variation with %TiV, with the fall in occurrences at the furthest distance with AvrMaxN not being consistently reflected in %TiV values (Fig 3.8d). There was no consistent trend with distance from the reef or general edge for either measure of total abundance but a noticeable trend of greater total occurrences for both measures at the first two “distance from reef” categories at GP (Fig 3.8a,b) and for AvrMaxN only at the first two “general edge” positions also at that site (Fig 3.8a). Total occurrences at CB, however, displayed a general increase with increasing distances towards the seagrass interior in these two planes with the exception of “distance from reef” for AvrMaxN (Fig 3.8).

Species richness

A general trend of increasing taxa richness was observed with distance in all planes being more pronounced with distance from the bare sediment i.e. increasing transect number, and general edge (Fig 3.9). These trends were, however, not statistically significant.

3.3.3 Functional group distribution

Fish functional group analysis is presented on the extended summer sampling session where species richness and number were greater to justify group assignments.

3.3.3.1 Feeding Mode Functional Groups (FMFG)

FMFG community distribution

Due to the high significance with the FMFG community with “site” for all models (p = 0.0001), most likely due to the overall higher occurrences at GP, PERMANOVA was applied to the community separately for both sites. With both sites considered together, however, there was a significant effect of “distance from reef” for AvrMaxN only (*pseudo-F* = 4.1073; p = 0.0209) with no significant pairwise comparisons (Table 3.4a) and no statistical significance in guild community distribution with distance in any other plane (Table 3.4b,c). More meaningful trends in FMFG community and individual guild distribution were found at Greenpoint, having greater fish occurrences and representative number of taxa within each guild. Hence, unless otherwise stated observed trends at Greenpoint will be the focus of the community distribution analysis.

Greenpoint

The FMFG community varied significantly with “distance from reef” (*pseudo-F* = 2.863; p = 0.0145) and “distance from bare sediment” (*pseudo-F* = 3.1761; p = 0.0102) for %TiV only (Table 3.4a,b). The FMFG guild distribution at the 45-60m reef distance was significantly different from that at all other distance categories ($p < 0.05$: pairwise comparisons) in this plane (Table 3.4a). Similarly, guild distribution at 45-60m+ from the bare sediment differed significantly from the 30-45m+ position ($p < 0.05$) (Table 3.4b). There was no significant effect with “distance from general edge”.

SIMPER analysis of the FMFG community between seagrass positions with significant pairwise comparisons in both planes showed the CNP and HV feeding guilds to contribute most to the significance observed. Both guilds contributed to between 58 – 70% cumulatively with the % TiV measure and between 60 – 78% for the AvrMaxN measure across the same distance categories (included for comparison) even though for the latter measure there was no significant variation. The percent contribution of these two groups was more evenly distributed with the % TiV measure with the ranking of the two groups changing positions in different instances (Table 3.5).

The ZP group, largely dominated by the gregarious *A. jacksoniensis* at GP (Table 3.6a), from SIMPER analysis contributed to between 10 and 16.5% of the significance in the FMFG community distribution at the significant pairings in the “distance from reef” and “distance from bare sediment” planes for % TiV (14 – 23 % for AvrMaxN) while the OV guild contribution range fell between 24 and 30% for %TiV (16 – 26% for AvrMaxN) (Table 3.5).

Individual FMFG guilds

Zooplanktivores (ZP)

The ZP FMFG guild with all sampling weeks and both sites included in the models were highly non-significant for both “site” ($0.2721<p< 0.5594$) and “week” ($0.8661<p<0.9026$) and hence were pooled across sites and the weeks containing no ZP individuals removed from the dataset before reanalysing. The observed occurrence of this guild showed a significant variation with “distance from reef” ($0.0023<p< 0.0048$) for both measures (Table 3.4a). Pairwise comparisons showed occurrences at the 15-30m distance to be significantly greater compared to the furthest two positions i.e. 30-45m and 45-60m with AvrMaxN ($0.0041<p<0.0067$) and to the 45-60m only ($p=0.0036$) with %TiV (Table 3.4a) with both sites pooled. Individuals of this guild were not observed at 45-60m from the reef at either site (Fig 3.10, 3.11).

As all other FMFG guilds varied significantly with “site” for both measures with all models ($0.0001<p< 0.0145$) univariate analysis was also performed for each site separately. While the OV guild showed no significant trend for either measure with distance in any plane and is not described in further detail in this section, the occurrence of CNP (including and excluding Atherinidae) and HV FMFG guilds varied significantly for either or both occurrence measures with distance from the reef, bare sediment and/or general edge.

Non-Piscivorous Carnivores (CNP)

With the inclusion of the Atherinidae across both sites, there was a significant effect of “distance from general edge” with the CNP guild for the %TiV measure (*pseudo-F* = 489.41; $p=0.0026$) (Table 3.4c) with occurrences at E0-15m being significantly higher than at the two more distance general edge positions ($p<0.05$: pairwise comparisons) (Table 3.4c; Fig 3.11e,f). The occurrences at E15-30m and E30-60m were also significantly different, albeit with a weaker relationship ($p = 0.0416$: pairwise comparison) (Table 3.4c). At Greenpoint this guild varied significantly with “distance from bare sediment” (%TiV) (*pseudo-F* = 3.3697; $p=0.0261$) with the 15-30m+ and 30-45m+ positions having significantly higher occurrences than the furthest distance category, 45-60m+ ($p<0.05$: pairwise comparison) (Table 3.4b; Fig 3.11c).

With exclusion of the gregarious Atherinidae, the CNP guild occurrences at Greenpoint displayed a significant relationship with "distance from reef" for both measures (*pseudo-F* = 5.3317; p = 0.0094, AvrMaxN; *pseudo-F =* 4.6237; p=0.0147, %TiV) (Table 3.4a) and with "distance from general edge" for %TiV only (*pseudo-F =* 3.687; p=0.039) (Table 3.4c). For both occurrence measures there were significantly higher occurrences at the 45-60m distance from reef position compared to the immediate seagrass-reef position (0.0174<p<0.0342: pairwise comparisons), while for the %TiV measures occurrences at this distance (45-60m) was also significantly greater than at the 15-30m and 30-45m distance categories (p=0.0134 and 0.0135 respectively: pairwise comparisons) (Table 3.4a; Fig 3.12a,d). For both measures the furthest "general edge" position hosted significantly higher occurrences of this guild (excluding the Atherinidae) compared to the E0-15m position (0.0039<p<0.0085) (Table 3.4c; Fig 3.12c,f). There was no consistent or significant trend in CNP occurrence disregarding Atherinidae at Callala Bay.

Herbivores (HV)

The herbivore guild dominated by *G. tricuspidata* at GP for the % TiV measure (Table 3.6a) followed the trend of this species varying significantly (0.0005<p<0.001) for this measure with distances in all planes at GP. The occurrence at the 45-60m distance from reef position was significantly higher than at all other distance categories (p<0.01 with 15-30m; p<0.05 with 0-15m and 30-45m: pairwise comparisons) (Table 3.4a; Fig 3.10a,3.11a). Similarly, there were significantly higher occurrences at the 45-60m+ distance from bare sediment position compared to all other positions (p<0.01 with 0-15m+; p<0.05 with 15-30m+ and 30-45m+: pairwise comparison) (Table 3.4b; Fig 3.10c,3.11c) and at the furthest general edge position (E30-60m) compared to the first two (p<0.01 with E0-15m; p<0.05 with E15-30m: pairwise comparisons) (Table 3.4c; Fig 3.10e,3.11e). Although this guild displayed similar trends at CB with greater occurrences at the furthest two general edge positions and only being encountered at the furthest distance from bare sediment position, low occurrences at this site may not have made statistical analysis valid.

3.3.3.2 Estuarine Use Functional Groups (EUFG)

The four EUFG guilds were collapsed into the two major groupings – Estuarine Species (ES) and Marine Species (MSp) to allow for valid comparison between the various distance categories in all planes. Univariate PERMANOVA was performed on the ES and MSp guilds separately. Even though the trends observed at both sites for both EUFG guilds were very similar and in many instances identical between both sites, the disparity in numbers between the two sites rendered the effect of “site” statistically significant ($p < 0.001$) and as such the guilds were analysed separately for each site.

Estuarine species (ES)

There was a significant effect of “distance from reef” for the ES guild at GP for both measures (*pseudo-F* = 7.5466; p=0.0074 for AvrMaxN; *pseudo-F* = 4.5618; p=0.0138 for % TiV) with pairwise comparisons showing the first two distance categories having significantly higher occurrences than the latter two ($p<0.05$) for both measures (Table 3.4a; Fig 3.13a,d). The trend of decreasing occurrences of this guild away from the reef was also observed at CB but was not statistically significant. A trend of decreasing occurrences of the ES guild away from the first two general edge positions was also observed at GP for both measures and at CB for % TiV. These latter trends were however not statistically significant. No consistent trend with distance from the bare sediment was observed for this guild at either site.

Marine species (MSp)

The MSp guild was generally lower in occurrence compared to the ES guild at both sites (Table 3.6b) and displayed a trend directly opposite to that of the ES increasing in occurrence with increasing distance in all planes for both measures at both sites (Figs 3.13). This trend was statistically significant at GP with “distance from reef” for both measures ($0.0134<p<0.0305$) and “distance from bare sediment” for % TiV only (p=0.0122) (Table 3.4b). Significantly greater occurrences of this guild was observed at the 45-60m “distance from reef” category compared to that at 0-15m for both measures (p=0.0192 for AvrMaxN; p=0.0029 for % TiV: pairwise comparison) (Table 3.4a; Fig 3.13a,d). Occurrences were also significantly greater at the 30-45m+ “distance from bare sediment” category at GP compared to the first two distance positions in this plane for % TiV ($0.0183<p< 0.0252$) and at the 45-60m+ position compared to 15-30m+ (p= 0.0094) also at this site (Table 3.4b; Fig 3.13e).

3.3.4 Behaviour metrics and physical position in habitat

For analysis of the number of foraging events and relative positions frequented in the seagrass ecosystem with distance in all planes, the first two and furthest two distances from the reef and bare sediment were grouped to form two distance categories in both directions i.e. 0-30m and 30-60m for “distance from reef” and 0-30m+ and 30-60m+ for “distance from bare sediment”. This was done due to the similarity in occurrences with the two distance categories within each of the newly formed larger group and provided more meaningful trends. The original three “distance from general edge” categories were retained. Only GP data was analysed and here presented due to the low occurrences at CB. Swim speed did not display consistent meaningful trends and were therefore not presented.

Foraging events

Pairwise comparison indicated a significantly higher number of all foraging events at the 30-60m distance from reef category compared to that at the 0-30m ($p<0.05$) (Table 3.7; Fig 3.14) with an overall effect of “distance from reef” being (*pseudo-F* = 3.9157; p=0.05; Permdisp p=0.092) (Table 3.7). There was no significant effect with distance from bare sediment (*pseudo-F* = 0.24375; p=0.6371) or general edge (*pseudo-F* = 0.81638; p=0.4709).

Position in seagrass ecosystem

There was a consistent increase in seagrass canopy occupancy with increasing distance away from the edges in all planes (Fig 3.15) being just significant for distance from the bare sediment (*pseudo-F* = 4.2616; p = 0.0468; Permdisp p=0.232) with pairwise comparison between these two distance from bare sediment positions being significantly different (p=0.04) (Table 3.7). Midwater column usage followed the opposing trend of increasing towards the seagrass edges but was more pronounced with respect to the bare sediment and general edge (Fig 3.7). These trends were, however, non-significant. Use of a combination of the two habitat positions i.e. the seagrass canopy and midwater column was rare and homogeneously observed across distance categories in all planes (Fig 3.15).

Section 2: Complete picture: combination of GoPro and seine net data

3.3.5 Combined sampling methods

3.3.5.1 Taxa richness

Taxa richness data from both seine net (n=64 across all positions, both sites and seasons) (Chapter 2) and GoPro data (n=128) were placed in one data set (n=192) as described in the Methods, with “method” as an additional factor in the PERMANOVA design. Justification for combining the datasets lie in the very narrow margin of overlapping taxa sampled collectively over both seasons by the two techniques (see Appendix V). Put alternately, as the taxa sampled were generally different between sampling methods combining the number of taxa observed in each position for both methods would offer an additive overall view of the number of taxa observed in each position and not have a repetitive effect. Seine netting overall sampled significantly more taxonomical groups ($p<0.01$) (Table 3.7; Fig 3.16) but showed the same general trend of increasing number of groups with increasing distance from the habitat edges in all planes as did the GoPro data (Fig 3.16). This disparity in number of taxa sampled with sampling method still persists despite the grouping of Mugilidae and Sparidae in GoPro video analysis.

With PERMANOVA analysis applied to the single data set across both sites, seasons and sampling methods, there was a significant effect of "distance from reef" (*pseudo-F* = 8.5965; p=0.0412; Permdisp p=0.150) with no significant effect of "distance from bare sediment" (*pseudo-F* = 2.5102; p=0.2573) or "distance from general edge" (*pseudo-F* = 34.574; p=0.0904) on combined taxa richness. There were no detected significant pairwise comparisons of distance from reef categories for taxa richness. While both sites displayed the same trend in variation in taxa richness with distance from both adjacent habitats and general edge, to better detect significant changes in this variable with particular distance categories, PERMANOVA analysis was performed on the dataset from each site separately.
Both sites showed a significant effect with "distance from reef" (*pseudo-F* = 6.1555; p=0.0005 for CB; *pseudo-F* = 3.484; p=0.0436 for GP) and "distance from general edge" (*pseudo-F* = 11.078; p=0.0002 for CB; *pseudo-F* = 4.405; p=0.0136 for GP) (Table 3.8) with combined methods taxa richness over both seasons with no significant effect of "distance from bare sediment". While the Greenpoint data displayed homogeneity of variances, that at Callala Bay did not and hence the significance level is set at ($p<0.01$) for the latter site. Pairwise comparison of the "method × season" interaction, which was highly significant at Greenpoint for both "distance from reef" and "distance from edge" ($0.0074<p<0.008$) (Table 3.8), showed that this was due to the more substantial effect of "method" in the summer data ($p<0.001$). At Callala Bay, the significant difference in taxa richness between the immediate edge and most interior "distance from reef" and "distance from general edge" positions for the seine net data only ($p<0.01$ and $p<0.001$ respectively) resulted in the highly significant "method × distance from reef" and "method × distance from general edge" interactions ($p<0.001$) noted for this site (Table 3.8).

Pairwise comparison of "distance from reef" categories at both sites showed significantly greater number of taxa at the furthest distance i.e. 45-60m compared to all others at Greenpoint ($p<0.05$ with 0-15m and 30-45m; $p<0.01$ with 15-30m: pairwise comparisons) and at Callala Bay significantly higher numbers of taxa again at the furthest distance compared to the first two distance categories ($p<0.001$ with 0-15m and $p<0.01$ with 15-30m: pairwise comparisons) (Table 3.8a; Fig 3.16a). There were also significantly more taxa sampled at the 30-45m category compared to the immediate seagrass-reef position ($p< 0.01$: pairwise comparison) at CB (Table 3.8a; Fig 3.16a).

With regards to "distance from general edge" both sites showed increasing more taxa sampled at the furthest "general edge" position i.e. E30-60m compared to the first two categories ($0.01<p<0.0138$ for GP; $0.0001<p<0.01$ for CB: pairwise comparisons) (Table 3.8b; Fig 3.16e). There was no significant effect found with "distance from bare sediment" but a general increase in taxa richness was observed with distance towards the interior in this plane, being more pronounced at Greenpoint (Fig 3.16c).

3.3.5.2 Community composition of individual taxa

With the community of individual fish taxa data from both sites, seasons and sampling methods converted to a "presence/absence" matrix, to standardize for different units of measure, there was a high non-significance of the effect of "season" ($0.4944<p<0.4956$) and "method" ($p=0.4912$) with no significant interaction between site and distance in any of the three planes ($0.0576<p<0.3937$). There was, however, a highly significant effect of "site" for both statistical designs ($p=0.0001$) which was retained in all statistical models. Community data analysis revealed a significant effect for "distance from reef" (*pseudo-F* = 2.4965; $p=0.0451$; Permdisp $p=0.154$) (Table 3.9) with no significant effect for "distance from bare sediment" (*pseudo-F* = 1.434; $p = 0.2538$) or "distance from general edge" (pseudo-F = 2.7635; $p=0.1395$) (Table 3.9). Pairwise comparison of the "distance from reef" categories showed a significant variation in the communities at the 0-15m and 45-60m distances from reef ($p = 0.0256$; pairwise comparison) with a weaker significant effect between the 0-15m and 30-45m distances ($p = 0.0476$: pairwise comparison) (Table 3.9). SIMPER analysis revealed the taxa contributing cumulatively to just under 50% of the significance between the 0-15m and 45-60m "distance from reef" categories to be the Atherinidae (16.75%), Mugilidae (11.19%), *Girella tricuspidata* (10.25%) and *Stigmatopora argus* (8.89%), with the Sparidae (5.12%), *Brachaluteres jacksonianus* (5.05%) and *Ambassis jacksoniensis* (4.88%) completing the top

60% contribution to the significant difference in community composition found between these extremes of distances.

3.3.5.3 Community of functional guilds

Feeding Mode Functional Group (FMFG) community distribution

With the fish community assigned to FMFG guilds and converted to a “presence/absence” matrix, there was a high non-significance of the effect of “season” ($0.4913<p<0.5003$), “method” ($0.3305<p<0.3395$) and interaction of site with distances in all three planes ($0.3661<p<0.8285$). There was, however a high significance of “site” ($p=0.0001$) for both statistical models. FMFG community analysis revealed a significant effect of “distance from reef” (*pseudo-F* = 3.1372; $p=0.0237$; PERMDISP $p=0.068$) and “distance from general edge” (*pseudo-F* = 11.79; $p=0.0037$; PERMDISP $p=0.043$) on the distribution of these guilds (Table 3.9). The CP (piscivorous carnivores) functional group was not included in the combined dataset due to lack of its representation in GoPro data. The significance level for the effect of “distance from general edge” was taken at $p<0.01$ as homogeneity of variances was not achieved. Pairwise comparisons of the FMFG community distribution showed a significant difference in the distribution of guilds between the 0-15m and 45-60m ($p=0.0418$) and 15-30m and 45-60m ($p=0.029$) distances from the reef (Table 3.9). SIMPER analysis illustrated that at these significant pairwise comparisons the CNP guild contributed to approximately 30% of the significance in community distribution while the contributions of the other three guilds were approximately similar to each other ranging from 20 – 25% (Table 3.10).

Further analysis of individual FMFG guilds showed a significant effect of “distance from general edge” for CNP (*pseudo-F* = 17.677; $p=0.0423$) with a significant difference found between the first two “general edge” positions ($p= 0.0001$: pairwise comparison) (Table 3.9). Additionally, the ZP guild showed a significant difference in its distribution at the 45-60m “distance from reef” position compared to both the 15-30m and 30-45m positions ($p=0.0078$ and $p=0.0376$ respectively: pairwise comparisons) (Table 3.9). There was no significant effect with “distance from bare sediment” for these two FMFG guilds and no significant effect with increasing distance in any plane for the OV and HV guilds. In statistical analysis of the distribution of both these individual guilds there was a highly non-significant effect of “season” ($0.3302<p<0.5072$), “method” ($0.3280<p<0.3349$), “site” ($0.7215<p<0.9901$) and interaction of site with distance in all three planes ($0.6444<p<0.879$) with the exception of “site × distance from reef” interaction for ZP (p=0.0511) and the effect of “method” for CNP in the “general edge” statistical design i.e. Design 2 (p=0.0001).

Application of the semi-quantitative ranking of the combined dataset, graphically presented in Appendix VI, showed a steady increase in abundance of the CNP guild with distance away from the reef and general edge with no meaningful trend with respect to the bare sediment. The ZP guild individuals peaked in abundance at the 15-30m distance from reef position and declined thereafter. This guild was also less represented at the furthest distance from bare sediment and general edge positions. A sharp increase in HV abundance was noted at the furthest distance from reef and general edge positions, with a steady increase away from the bare sediment. Lastly, the OV guild was more homogeneously distributed among all positions compared with the other guilds but still displayed a slight increase in distance away from the seagrass edge habitats in all planes.

Estuarine Use Functional Group (EUFG) community distribution

Statistical analysis of community as classified in four original EUFG guilds i.e. the two groups of Estuarine species (ES): Estuarine Residents – ES, Estuarine Migrants – EM and the two groups of Marine species (MSp): Marine Migrants – MM and Marine Stragglers – MS, converted into a “presence/absence” matrix again showed a highly non-significant effect of “season” ($0.4881<p<0.4968$), “method” ($0.4981<p<0.5047$), site interactions with distance in all three planes ($0.8244<p<0.9533$) with a high significance of “site” (p=0.0001). A significant variation again was found with “distance from reef” (*pseudo-F* = 3.1798; p=0.0404; Permdisp p=0.344) and “distance from general edge” (*pseudo-F* = 7.0666; p=0.0093; Permdisp p=0.21) with no significant effect with “distance from bare sediment” (Table 3.9). Pairwise comparison showed significant differences between the immediate seagrass-reef edge (0-15m) and furthest (45-60m) “distance from reef” positions (p = 0.04) and between the most edge-ward (E0-15m) “general edge” and most interior positions (E30-60) (p = 0.01) (Table 3.9). The three main groups contributing to this significance from SIMPER analysis at these extremes of positions for both distance from reef and general edge were the EM (33.46%, “reef”; 32.37%, “general edge”), MM (30.19%, “reef”; 32.15%, “general edge”) and ER (29.42%, “reef”; 31.01%, “general edge”) guilds whose contribution was fairly evenly distributed (Table 3.10).

Further analysis of the four individual EUFG guilds showed a significant effect for the MM guild only. This guild almost completely dominated the Marine species group due to the very low representation of MS (Marine stragglers). The MM guild displayed a significant effect of “distance from reef” only (*pseudo-F* = 12.636; p=0.0317) (Table 3.9) with no significant pairwise comparisons between seagrass positions from the reef. A high non-significance of the factors "season" ($0.6752<p<0.8307$), "method" ($0.6625<p<0.6651$) and site interactions with distance in all three planes ($0.7842<p<0.9795$) was found along with a highly significant effect of the factor "site" ($p=0.0001$) in this instance. Semi-quantitative measures applied to the dataset (see Appendix VI) revealed a consistent increase in occurrence of Marine species dominated by the MM guild with increasing distance from both adjacent habitat types and consequently with general edge. The Estuarine species, conversely, from semi-quantitative application was generally more frequently occurring at seagrass positions closer to the reef edge but displayed no meaningful trend with respect to the bare sediment or general edge.

3.4 Discussion

Section 1 – Fish distribution (GoPro data)

Total abundance and species richness

Even though there was no consistent pattern in total fish occurrences with distance from the adjacent habitats and general edge, the persistent low occurrences towards the habitat edges in the winter season, together with the decrease in species richness at the immediate edges in both seasons suggests a less desirable, likely more harsh environmental conditions at the adjacent habitat edges (Moore & Hovel 2010; Barros, Underwood & Lindegarth 2001; Pattiaratchi et al. 1995; Sorokin 1993; Van Elven, Lavery & Kendrick 2004). Decreased fish species richness and abundances at seagrass habitat edges have also been reported in literature (Jelbart, Ross & Connolly 2006; Moore & Hovel 2010; Smith, Jenkins & Hutchinson 2012). As discussed in the previous chapter higher fish abundances have also been recorded closer to seagrass edges where these edges were bordered by rocky reef only (Tuya et al. 2010; Valentine & Duffy 2007; Vanderklift et al. 2007). These studies, however, unlike those recording higher numbers and species diversity in the interior were sampling more pelagic taxa as opposed to cryptic ones (see Discussion in section 2.4). A brilliant study by Dorenbosch et al (2005) reported the opposing trend in fish density and species richness between larger more pelagic coral reef fish and seagrass residents at coral reef-seagrass edges. While coral reef fish density and species richness were seen to decline significantly away from the reef edge into the seagrass beds up to within tens of meters, the density of seagrass residents increased significantly at and beyond 30 m from the edge. This undoubtedly reflects the varying nutritional needs and predation evasion strategies required and employed by these two classes of fish. As resident seagrass fish are often small bodied these individual may avoid the edges where predation risk is increased (Bologna & Hack 1999; Connolly & Hindell 2006; Fagan, Cantrell & Cosner 1999; Moore & Hovel 2010) and seek refuge within the seagrass bed interior.

Additionally, the particular orientation of the reef relative to the seagrass bed, which may affect microclimate patterns at the seagrass-reef edge (Ries et al. 2004), likely induces increased, continuous water movement at this interface as waves are directed towards the reef surface (Sorokin 1993; Van Elven, Lavery & Kendrick 2004). This undoubtedly leads to a less stable environment and potentially to the physical removal of potential food sources including zooplankton, reef associated algae and smaller molluscs (all important food sources for the sampled community) carried on the waves to further distances which the fish follow (Ries et al. 2004). This unique interaction or transition in relative degree of water turbulence with increasing distance from the reef may account for the more pronounced effect of reef-ward distance in species richness compared to that with respect to the bare sediment.

Community and individual taxa distribution

There was not however, a sweeping increase in all individual species/taxa with increasing distance away from both habitat edge types. It is worth noting that due to intrinsic characteristics of individual taxa including total body length, vulnerability to predation and mobility, edge effects may be species-dependent with some being more sensitive to these effects than others (Ries et al. 2004; Tuya et al. 2010). Additionally, the particular habitat forming the edge with seagrass is of great importance as different species may be differentially affected by the presence of the different habitats depending on their specific requirements i.e. dietary or predator evading and/or foraging strategies.

Lack of significant effects at Callala Bay likely resulted from the lower fish occurrences at this site compared to Greenpoint, with the latter in many cases having significantly higher fish occurrences. With data from both sites considered, however, the community composition varied significantly only with distance from the reef ($p<0.05$) during the summer. The fish community structure at Greenpoint in particular during this season varied significantly with increasing distance from both adjacent habitats ($p<0.05$) and consequently general edge ($p<0.05$) indicative of a more important effect of edge *per se* on the community than the identity of the adjacent habitat itself. This, however, may only be said for the community considered as a unit and not the individual taxa within. Considering both adjacent habitat edges, the fish community structure at the immediate edge positions was significantly different from that at the furthest positions. This was especially evident for the community beyond 30m of the general edge compared to that found at the immediate general edge (p=0.004), with the more mobile often larger marine species more frequently observed beyond 30m from the immediate general edge.

The disparity in community structure found at the extreme of distances relative to the adjacent habitats and general edge may be due to a number of factors influencing individual taxa including (i) the type of prey most available at the habitat edges compared to the inner positions, (ii) the greater shelter requirements of the smaller pelagic fish that may want to align themselves closer to the reef for occasionally retreating in its crevices and/or (iii) the mode of feeding employed where the proximity to the edge, particularly the reef edge, provide an area of increased water flow facilitating filter feeding (Bustamante & Branch 1996).

As *G. tricuspidata* are primarily herbivorous and may not be as dependent on the reef for shelter (having body sizes too large for the reef crevices to accommodate – pers. obs.) they may be more suited for the inner beds for both food and shelter among the blades. Depth was not considered as a possible factor with the entire sampling area being a maximum of 1.5m at both sites during sampling periods (two hours within peak low tide on all occasions). This species consistently displayed significantly higher occurrences away from both adjacent habitats and consequently general edge across both seasons. *G. tricuspidata* was also noticeably absent from the immediate edge position of both adjacent habitats. Interestingly, even though another larger, highly mobile taxon, the Mugilidae, shared a similar trend in increasing occurrences away from the reef, having significantly lower occurrences at the seagrass-reef position, the two taxa appeared to avoid each other along the plane of the shoreward bare sediment and general edge (Fig 3.4 and Appendix IV). As the Mugilidae are "opportunists" (classed in this study as omnivorous), it is likely a case of this more generalist taxon adjusting its position to the presence of the herbivorous seagrass and algae consuming *G. tricuspidata*.

A similar spatial partitioning was encountered between the two gregarious taxa (*Ambassis jacksoniensis* and the Atherinidae – *Atherinosoma microstomata* and *Atherinomorus vaigiensis*) which avoided each other along all directional planes at both sites (although less obvious with distance away from bare sediment at Callala Bay) in the summer sampling period (Appendix IV). Due to the considerable volumes of water each school can occupy it is likely that this spatial division is due to physical space sharing or partitioning to allow for efficient ecosystem resource use.

Functional group distribution

Feeding Mode Functional Groups (FMFG)

With generally few taxa comprising each FMFG, interpretation of results solely from GoPro data should be received with caution. Although it may be indicative of trends by taxa of similar feeding mode this cannot be ascertained as trends observed may be specific-taxa driven. Comparison and combination of data with that collected by seine net sampling (Chapter 2) from the same positions at the same sites will prove more useful in this venture which is done in the subsequent section.

FMFG community analysis revealed a significant variation in guild composition with increasing distance from the reef only ($p<0.05$) with both sites considered. While there was no significant FMFG guild community variation with seagrass position at Callala Bay, the guild community varied significantly with distance from both habitat edge types at Greenpoint ($p=0.01$) but not with edge *per se*. The guild community at this site at the most interior distance from reef seagrass position was significantly different from all other seagrass positions ($p<0.05$) with SIMPER analysis indicating the CNP and HV guilds as the highest contributors to this significance (cumulative 59 – 70%). With respect to distance from the bare sediment, the most distant seagrass position hosted a significantly different guild composition than the position immediately before i.e. 30-45m+ with SIMPER analysis revealing the CNP, HV and OV to be the top contributors (cumulative approximately 87%) slightly edged by the CNP group.

On average the CNP along with the ZP guild had the highest percent representation among the fish taxa at both sites in the summer season for both the AvrMaxN and %TiV measures with the CNP having the most representative number of taxa (6). This is not surprising due to the rich mollusc population found within the seagrass beds (Chapter 4) likely due to the adjacent rocky reef habitat source. The number of species of this guild found in seine net catches at the same sites and same positions was also relatively high (10) (Chapter 2) with an overlap between sampling methods of only one taxa – the Atherinidae.

CNP guild

With the inclusion of the schooling Atherinidae, the CNP guild showed no meaningful distributional trend with distance from the habitat edges. Removing these schooling individuals from the analysis however, resulted in a significant increase in occurrences in this guild away from the reef ($p=0.01$) and general edge ($p=0.04$) at Greenpoint – a distributional pattern mirrored by the members of this guild in seine net catches (Chapter 2) (Fig 3.17a-d).

With the taxa of this guild sampled by video footage being the larger more mobile species while those sampled by the seine being smaller bodied cryptic individuals, it is likely that both these individuals, regardless of size, mobility and their vertical position in the habitat, are mapping on to the availability of benthic invertebrates, primarily molluscs present in this ecosystem (Chapter 4).

ZP guild

The ZP guild, dominated by the schooling *A. jacksoniensis*, exhibited the same general trend at both sites displaying no significant effect with distance from the shoreward bare sediment but a significant one with respect to the reef. Occurrences were generally low at the immediate seagrass-reef position but increased sharply at the 15-30m position and fell significantly again thereafter, being completely absent at the furthest distance from the reef and the furthest edge position – a trend also captured by seine net catches (Fig 3.17e,f). Although this trend is highly driven by a single species, a similar trend of fall in the abundance of non-schooling more cryptic zooplanktivore species was also observed from seine net data (Chapter 2). Due to the small size and low trophic level of these taxa forming the ZP guild from both sampling methods, it is likely that their distribution is a compromise between the availability of zooplankton in the environment (Chapter 4) and being close enough to the reef crevices for additional protection from predation. A combination of their small size and greater water movement or turbulence at the immediate edge, particularly the seagrass-reef edge may also render this position undesirable due to its lack of stability as well as physically removing these smaller individuals by the force. Smith, Jenkins & Hutchinson (2012) also attributed the reduced occurrences of fish at the immediate edge to reduced water currents closer to the seagrass interior allowing for greater ease of swimming and feeding. While no significant effect was displayed with distance from the bare sediment, this guild displayed a general increase in abundance with distance towards the seagrass interior along this plane. This goes contrary to the findings of increased zooplankton feeders at the seagrass-sand edge mapping on to higher abundances of trapped zooplankton prey in this region reported in literature (*Stigmatopora argus* – Macreadie et al. 2010) and from the pilot study done in conjunction with this research (Appendix I). Results from this pilot study conducted in seagrass beds adjacent to sand, in the absence of a reef structure, showed planktivorous fish comprising both *Ambassis jacksoniensis* and *Atherinosoma microstomata* to display consistently higher abundances over two seasons at the immediate seagrass-sand edge compared to the seagrass interior between 30-40m away from the sand edge (Appendix I). This disparity in results is likely due to the lack of the reef structure in the latter case, not creating a hydrodynamic effect at the edge and thereby allowing any accumulation of zooplankton at seagrass-sand edges to now have a contributing effect on zooplanktivore distribution.

HV guild

The HV guild was highly driven by the presence of *G. tricuspidata* in GoPro video analysis and as such the guild distribution may be as suggested earlier a factor of the species itself and not it's feeding mode functional status. It is worth noting, however, that the herbivorous leatherjackets in seine net catches although constituting only a small percent of the population (on average 1.28% and 7.61% with and without Atherinidae inclusion respectively) showed a general non-significant increase away from the general edge. Regardless of feeding mode, the occurrences of foraging within the seagrass canopy, primarily by the larger more mobile *G. tricuspidata*, the non-atherinid CNP taxa and Mugilidae from video analysis were significantly greater 30m away from the reef habitat. This is possibly due to a more prey-rich environment, including plant epiphytic material, beyond 30m with material, including algae, taken from the reef structure and deposited beyond that distance by wave action after breaking on the reef's physical structure. This may coincide with the preference of uninterrupted (homogeneous) seagrass habitat for the larger foraging individuals (Cheminée et al 2013). A review of literature by Ries et al. (2004) showed that species preferring edges also tend to be found in seagrass beds of smaller sizes. The reverse may also apply where larger individuals desiring larger habitat ranges and sizes may avoid edge positions as is the case with *G. tricuspidata* which may restrict their movement especially when feeding (Cheminée et al 2013). This noted increase in herbivorous fish abundance with distance from the edge corresponded to increased herbivory reported in *Posidonia australis* transplants with increasing distance from a sand edge up to 10 m from the edge (Statton et al. 2015). The study, however, did report a decrease in herbivory thereafter, at distances beyond 30m up to 100m. Disparity in results may be due to the lack of a reef structure forming the seagrass edge in the above study assessing the sand-seagrass interface. The presence of the reef alters the microclimatic conditions at the edge (Pattiaratchi et al. 1995; Sorokin 1993; Van Elven, Lavery & Kendrick 2004) which may have an impact on the availability of epiphytes on seagrass blades with respect to the edge (Van Elven, Lavery & Kendrick 2004) to which the herbivores respond. The impact of the reef on epiphyte load in addressed in detail in Chapters 4 and 6.

OV guild

The omnivores, heavily dominated by the Mugilidae family, showed no statistically significant trend with distance from the adjacent habitats and general edge. This is likely due to a combination of two factors: (i) the less strict dietary requirements of the OV taxa and hence not being restricted to or influenced greatly by the distribution of any one particular prey type and (i) the relative high mobility of the Sparidae and Mugilidae comprising this guild in GoPro analysis. Their mobility would facilitate ready use of all potential prey types regardless of the prey's relative distribution with habitat edges leading to the more homogeneous distribution observed for this guild. This apparent insensitivity to the edge may be due to the more generalist nature of the omnivorous guild (Murphy et al. 2010) being able to capitalize on a wider range of prey resources in combination with its higher mobility. The latter is noted as a key feature in determining an organism's degree of sensitivity to edge (Connolly & Hindell 2006; Ries & Sisk 2004).

Estuarine Use Functional Groups – EUFG

This effect of taxa mobility and body size on the differential distribution with respect to the adjacent habitat edges (Ries & Sisk 2004) is highlighted more efficiently in the division of the observed taxa into EUFG guilds. Although body size was not directly measured in GoPro video footage, relative individual size could be roughly determined by using the seagrass blades in the footage as reference markers and from prior knowledge of the relevant taxa gained from snorkelling the sampled sites. The Marine species (MSp) guild, dominated by the larger more mobile Sparidae (*Rhabdosargus sarba* and *Acanthopagrus australis*), Mugilidae and *G. tricuspidata* had consistently higher observed occurrences away from both adjacent habitats and the general edge for both measures of occurrence being statistically significant for both measures with distance from reef and for % TiV only with distance from bare sediment. The Estuarine species (ES), however, displayed the opposing trend with significantly lower occurrences beyond 30m of the reef. Although there was a general trend of lower occurrences beyond 30m of the general edge this was not statistically significant and there was no meaningful distributional trend with distance from bare sediment for this group. The disparity in distribution between these two collated EUFG groupings is likely due to intrinsic characteristics of the individual taxa constituting these guilds including body size, mobility, diet and vulnerability to predation. With the ES taxa being smaller-bodied and in this study of lower trophic status and hence more susceptible to predation the habitat edges may be more suitable to gain access in particular to the reef crevices. The larger marine species on the other hand would, as earlier mentioned for *G. tricuspidata* find greater protection, if required, amongst the seagrass canopy with the reef crevices not being suited to their larger sizes (pers. observ.). They may also be less susceptible to predation due to their larger body sizes and hence focus more time and energy foraging for food where available. The division in use of the precise vertical position in the seagrass habitat sampled was also highlighted by the increase in use of the seagrass canopy beyond 30m of both habitat edges and hence edge *per se* primarily by the larger bodied foraging Marine guild taxa. The opposite trend was observed for the more pelagic schooling individuals primarily of the ES guild occupying the midwater column more frequently within 30m of the general edge.

Section 2 – Complete picture (both sampling methods – combined and compared)

Species richness

Combination of the number of taxa sampled by the separate methods yielded a consistent stepwise statistically significant increase in taxa richness with distance from the reef and general edge with no significant variation with distance from the bare sediment. This corresponds with trends in species richness observed with both sampling methods as described in *Section 1* above and in Chapter 2. The significant interaction observed with "method" is likely due to the consistently higher number of taxa sampled with the seine net (Fig 3.16) which may depict clearer trends of increase with distance away from the edges. This again points to increase in taxa richness in the inner seagrass positions but also suggests that the edge effect observed may be driven more by the effect of the identity of the edge type particularly the rocky reef when both adjacent habitats are present.

Community distribution

Converting the community data from both sampling methods to a "presence/ absence" matrix and performing PERMANOVA analysis proved a useful tool in combining the very different combination of taxa sampled by each method as shown by the distinct clustering in the PCO plot of overall community based on method (Fig 3.18a) to get a bigger picture of trends in the fish community over all seagrass positions. The "presence/absence" matrix also ensures valid comparison between the different units of measure and sampling efforts (seine net hauls vs 10-min video footage analysis) employed by the different methods. While overall community composition of individual taxa showed a weak overall relationship with distance from the reef ($p<0.05$) and no relationship with distance from bare sediment or general edge, the community of both functional guilds varied significantly with distance from the reef ($p<0.05$) and distance from the general edge ($p<0.01$) again with no relationship with distance from the bare sediment. The complete dataset also again highlighted the difference in community composition (at the individual taxa and functional guild levels) between the immediate edge position and the most interior seagrass positions with respect to the rocky reef and general edge. The presence of a significant relationship with distance from reef and not bare sediment for the community of individual taxa and functional groups again points to the importance of the rocky reef adjacent habitat in driving the general edge effect.

While the community of individual taxa and EUFG guilds at the immediate seagrass-reef edge was significantly different from that at 30-45m away (taxa) and 45-60m away (EUFG guilds) from the reef, the FMFG community at the second distance category (15-30m) was significantly different from that at 45-60m away from the reef habitat. These pairwise comparisons point to a shift in the community structure beyond the 30m distance away from the reef hosting a different combination of individual taxa and functional groups, likely a group better adapted to the more stable conditions at and beyond 30m from the reef.

With the presence of the reef being a physically more imposing feature compared to bare sediment and creating a barrier to wave energy and water, flow both influencing faunal distribution (Barros, Underwood & Lindegarth 2001; McLachlan & Hesp 1984; McQuaid & Branch 1984) and transport of prey, it may be playing a greater role in distribution of the fish taxa with respect to this edge interface compared to bare sediment when both habitats are present as the fish follows their prey. Such a conclusion, however, should not be drawn without first looking at the distribution of possible prey items with distance from both adjacent habitats which is addressed in Chapter 4.

Importance of using more than one sampling technique

While information may be lost in terms of sheer abundance with a combination of both sampling techniques due to the differing nature of taxa sampled by each, it becomes imperative to incorporate both to achieve a complete picture of distributional trends. Video footage proved more appropriate, for instance, for sampling and describing trends with EUFG whereas seine netting may be better at sampling FMFG more efficiently. Video footage more efficiently sampled the larger more mobile species that are typically of the Marine species guild, as well as Estuarine schooling species, but was not very efficient at sampling cryptic species. As such seine net catch data would be needed for supplementation.

As seine net catch data allows for the handling of individual fish, a better indication of species size, and hence life stage can be obtained. This fact allows for their FMFG status to be more accurately assessed using this sampling method as this status often depends on the size and life stage of the individual. Video data may not always allow for identification to species level and determination of size class and life stage may prove more difficult, leaving room for error.

The lower number of taxa that were able to be assigned FMFG guilds from the video data compared to seine net catches in this study (see Appendix V), which sampled more taxa overall, is further evidence that the seine net is a more reliable technique for FMFG assessment. Hence if both sampling methods cannot, for some reason, be used in assessing functional groups of estuarine seagrass fish taxa, results from this dataset suggest that seine net sampling may be appropriate for assessing trends with the FMFG while video footage analysis may prove more useful with EUFG trend evaluations. To assess the complete community of individual species a combination of both techniques is essential.

Importance of functional group analysis

Functional group analysis is an important tool in assessing the importance of ecosystems (Elliott et al. 2007). It not only allows for comparability of studies across different seasons and sites (present study) and different geographical locations (Elliott et al. 2007) but it also aids in the standardization the fish community across different sampling methods (present study). This is illustrated by the disappearance of the distinct clustering of the fish community with different sampling methods once functional guild assignment is performed (Fig 3.20b,c).

Inherent variability of fish data

Of all the seagrass faunal groups assessed in the current research, the fish community, while displaying meaningful and significant trends, displayed the highest level of variability. This was especially the case before assignment of functional group status. This variability is likely a function of the intrinsic higher mobility noted with fish along with the patchy schooling distribution of some of the fish taxa encountered over the two seasons. This accompanied with the generally low numbers of fish noted for Jervis Bay compared to other estuaries (Ferrell et al. 1993) likely add to this phenomenon. The chosen Jervis Bay sites, however, after site evaluation along the NSW coast, possessed the most ideal sampling area with extensive continuous beds of the protected *Posidonia australis* adjacent to both habitat types and with uniform depth. This depth uniformity allowed for the elimination of this factor and for seine netting to be possible at low tide. In order to get a better understanding of trends occurring over a wider section of ecosystem that may be driving the fish's distribution, the prey community (zooplankton and benthic invertebrate communities and epiphyte load measures) was also sampled at the chosen sites. This was accompanied with fish gut content analysis. In order to complete all the above-named levels of the ecosystem, fish data was collected over two seasons in the time frame afforded for the research. The study seeks to begin a trend of assessing ecosystems with multiple edges which has been understandably avoided in literature due to its complex nature.

Conclusion

Results of this study validate the rejection of all null hypotheses set at the beginning of this chapter with the exception of 4b as it regards swim speed differences in relation to edge which was not eventually addressed, as outlined in the Results section (Section 3.3.4). In conclusion, variation in fish occurrences is evident within the *P. australis* seagrass beds with respect to the different habitat edges. There was, in particular, the overriding importance of the presence of the rocky reef at the seagrass edge in structuring seagrass fish assemblages vs the presence of bare sediment. This was also evident after considering the complete dataset from both fish sampling methods. Differences in fish distribution were also seen to be taxa-specific (Smith, Jenkins & Hutchinson 2012), functional guild-specific (Cheminée 2012) and the strength of these differences to some degree site-specific (Ries & Sisk 2004). This underscores the need to avoid making sweeping overgeneralizations of community variation in ecology especially with respect to edges.

Additionally, while body size was not explicitly measured in GoPro footage and not the focus of the seine net study, this factor should be included in the design of further research. Body size has been noted in research to influence habitat choice and predatory evasion behaviour (Chivers et al. 2001; Gotceitas & Brown 1993; Helfman 1989; Wahle 1992). Smaller bodies organisms in these studies were more likely to utilize sheltered, more structured habitats compared to larger organisms (Chivers et al. 2001; Cuadros 2015; Gotceitas & Brown 1993; Wahle 1992). Interestingly, in this Jervis Bay study the characteristically smaller-bodied estuarine species functional group was associated more strongly to the edge, in particular the seagrass-reef edge. This was also illustrated in recently published research where addition of boulders to seagrass beds was associated to increased juvenile fish density and species richness (Cuadros 2015). Their relatively larger-bodied marine species counterparts were, however, found in this Jervis Bay study to be associated with the seagrass interior.

While it is possible that these smaller species prefer the additional crevices of the rocky reef along with seagrass at this edge opposed to seagrass only for protection (Cuadros 2015), the preferential position may also be a function of their diet. Additionally, as the larger marine species have likely outgrown the crevice sizes of the rocky reef, preference may be given to the canopy. Again the acquired position of this group may also be a function of their differential diet whose response to edge they follow (Ries & Sisk 2004) along with lower intensity predator evasion strategies employed given their larger sizes (Chivers et al. 2001). Additionally larger, more mobile species may require a more open unrestricted range especially when feeding (Cheminée et al. 2013) and hence their preference for the interior. Experimental designs that carefully separate these factors would yield very valuable information.

While there was consistency between the two sampling methods in the distribution of at least two FMFGs – zooplanktivores and non-piscivorous carnivores, there was a differential efficiency of capture of different individual taxa and functional groups between them. Related to the differential fish distribution observed with distance from the habitat edges, was the differential use of vertical positions of the seagrass ecosystem at different distance positions.

Fish responses to edges are largely driven by the responses of their potential prey to these same edges (Ries & Sisk 2004). As such, the fish species and feeding functional group distribution in relation to the edge cannot be validly commented on without first investigating the edge response of the main potential prey. This is addressed in the following chapter (Chapter 4) and a comparative discussion of the fish and potential prey responses to edge presented in the Chapter 6 (General Discussion). Predation risk is also reported to influence an organism's edge response (Ries & Sisk 2004) and impact fish behaviour and habitat choice (Creel et al. 2005; Dill, Heithaus & Walters 2003; Grabowski et al. 2005; Ljungberg et al. 2013; Madin, Madin & Booth 2011; Ripple & Beschta 2004; Schmitz, Krivan & Ovadia 2004). The very sparse presence of piscivorous carnivores, however, represented only by the small bodied (on average 5 cm) *Siphaemia cephalotes* in this field study dominated by zooplanktivores and non-piscivorous carnivores (benthic invertebrate feeders) does not allow this issue to be addressed at depth at this stage. The dominance of these lower trophic level functional groups in the seagrass ecosystem (Franco et al. 2011) and estuaries in general (Elliot & Dewailly 1995) is also noted in literature. The influence of predation, however, is investigated in manipulative experiments (Chapter 5) and will be discussed in Chapters 5 and 6 (General Discussion).

Table 3.1 Rank of importance of fish taxa sampled with GoPro video cameras using mean AvrMaxN only (winter) and both mean AvrMaxN and mean %TiV (summer) values for each taxon. *Numbers in brackets represent ranking based on % TiV values.*

		Rank	
Species/Taxa		**Winter**	**Summer**
Acanthaluteres spilomelanurus	Bridled leatherjacket		4 (4)
Acanthaluteres vittiger	Toothbrush leatherjacket		10 (10)
Ambassis jacksoniensis	Glassfish	1	2 (2)
Atherinosoma microstomata and *Atherinomorus vaigiensis*	Small-mouthed and Ogilby's Hardyheads (Atherinidae)		1 (1)
Atypichthys strigatus	Mado		8 (8)
Cheilodactylus spectabilis	Banded morwong		10
Girella tricuspidata	Luderick	4	5 (5)
Mugilidae		3	3 (3)
Pseudocaranx wrighti	Skipjack Trevally		9 (9)
Sillago ciliata	Sand whiting	2	
Sparidae*		5	6 (6)
Sphyraena obtusata	Striped barracuda		7 (7)
Tetractenos glaber	Smooth toadfish		10 (10)
Trygonorrhina fasciata	Fiddler ray		10 (10)

* *Rhabdosargus sarba* (tarwhine) and *Acanthopagrus australis* (bream)

Table 3.2 (a) Summary of PERMANOVA results of the effect of “Distance from reef” on indicated community and individual taxa distribution across both and separate seasons (Se), across both sites (Si), except where indicated. *GP (Greenpoint only), CB (Callala Bay only); “Di” – “Distance from reef”, “Tr” – distance from bare sediment / transect; D1=0-15m, D2=15-30m, D3=30-45m, D4=45-60m; “Wk” – sampling week; significant permdisp (in bold) indicate non-homogeneity of variances; permdisp values of significant relationships only reported.*

		Distance from Reef				**Factors Included in Model**					**Pairwise Comparisons**						
	Measure	**Df**	**MS**	**pseudo-F**	**p**	**Di**	**Tr**	**Si**	**Se**	**Wk**	**D1-D2**	**D1-D3**	**D1-D4**	**D2-D3**	**D2-D4**	**D3-D4**	**Permdisp**
BOTH SEASONS																	
Total Abundance	AvrMaxN	3	2.0508	2.5067	0.2501	*	*	*	*								
Species/ Taxa Richness		3	12.792	9.303	**0.0429**	*	*	*					**0.023**		**0.018**		0.752
[GP only] sqrt		3	0.17008	0.64224	0.589	*	*										
[CB only] sqrt		3	0.36229	0.96612	0.4245	*	*		*								
Individual Species/ Taxa:																	
Ambassis jacksoniensis	AvrMaxN	3	4.2991	3.0703	0.0266	*									**0.012**		**0.001**
Girella tricuspidata [GP]	AvrMaxN	3	0.38277	4.3929	**0.0085**	*	*						**0.003**		**0.011**		0.055
Mugilidae [GP]	AvrMaxN	3	0.58383	2.4689	0.0738						**0.001**						**0.018**
Sparidae [GP]	AvrMaxN	3	$7.901E^{-2}$	1.4782	0.2659	*	*		*								
WINTER SEASON																	
Total Abundance	AvrMaxN	3	2.7354	3.5587	**0.0236**	*					**0.005**	**0.023**			**0.031**		0.06
Species Richness		3	1.7813	3.3529	0.1933	*	*	*									
[GP only]		3	1.5833	1.3902	0.3077	*	*										
[CB only]		3	0.72917	2.561	0.1241	*	*										
SUMMER SEASON																	
Community (All taxa)	AvrMaxN	3	1814.4	2.8825	**0.0296**	*	*	*		*							0.52
	%TiV	3	2115	1.4069	0.2981	*		*									
[GP only]	AvrMaxN	3	2015.5	2.4385	**0.0146**	*	*			*							**0.033**
	%TiV	3	2974	2.5078	**0.0129**	*	*			*			**0.014**		**0.018**	**0.036**	0.127
[CB only]	AvrMaxN	3	428.34	0.63168	0.7382	*	*			*							
	%TiV	3	644.36	0.77729	0.6739	*	*			*							

Table 3.2 (a) cont'd Summary of PERMANOVA results of the effect of "Distance from reef" on indicated community and individual taxa distribution across both and separate seasons (Se), across both sites (Si), except where indicated. *GP (Greenpoint only), CB (Callala Bay only); "Di" – "Distance from reef", "Tr" – distance from bare sediment / transect; D1=0-15m, D2=15-30m, D3=30-45m, D4=45-60m; "Wk" – sampling week; significant permdisp (in bold) indicate non-homogeneity of variances; permdisp values of significant relationships only reported.*

	Distance from Reef					**Factors in Model**				**Pairwise Comparisons**						
	Measure	**df**	**MS**	**pseudo-F**	**p**	**Di**	**Tr**	**Si**	**Wk**	**D1-D2**	**D1-D3**	**D1-D4**	**D2-D3**	**D2-D4**	**D3-D4**	**Permdisp**
Total Abundance	AvrMaxN	3	3.8036	4.2479	0.1397	*	*	*	*							
	%TiV	3	0.51411	2.1632	0.2911	*	*	*	*							
[GP only]	AvrMaxN	3	4.1699	4.4288	0.0183	*	*				0.039	0.018		0.046		**0.006**
	%TiV	3	0.64648	0.60442	0.6201	*	*		*							
[CB only]	AvrMaxN	3	0.52908	0.24984	0.8585	*	*		*							
	%TiV	3	0.10528	7.3579E^{-2}	0.9729	*	*		*							
Species / Taxa Richness		3	0.56944	4.5556	0.1529	*	*	*	*							
[GP only]		3	0.52778	2.7423	0.7732	*	*		*							
[CB only]		3	0.16667	0.25352	0.8602	*	*		*							
Individual Species / Taxa:																
Ambassis jacksoniensis	AvrMaxN	3	16.457	5.5928	**0.0098**	*	*						**0.004**	**0.002**		**0.001**
	%TiV	3	6.6227	4.4875	**0.0113**	*								**0.008**		**0.001**
Atherinidae	AvrMaxN	3	3.0733	1.4511	0.364	*	*	*	*							
	%TiV	3	1.4682	1.5063	0.3242	*	*	*	*							
Atherinidae [GP]	AvrMaxN	3	4.9255	1.7117	0.2365	*	*		*							
	%TiV	3	2.0751	1.0078	0.4252	*	*		*							
Atherinidae [CB]	AvrMaxN	3	0.26571	0.15629	0.9234	*	*		*							
	%TiV	3	0.36786	0.67347	0.5901	*	*		*							
Girella tricuspidata [GP]	AvrMaxN	3	0.2978	5.2314	**0.0081**	*	*		*			**0.027**		**0.008**		0.094
	%TiV	3	5.1875	10.686	**0.0003**	*	*		*			**0.009**		**0.006**	**0.021**	0.105
Sphyraena obtusata [GP]	AvrMaxN	3	0.18822	5.6037	**0.0077**	*	*		*			0.030			0.029	**0.001**
	%TiV	3	1.4628	3.5056	0.0215	*			*			0.037		0.040	0.038	**0.016**
Sparidae [GP]	AvrMaxN	3	3.883E^{-2}	1.2945E^{-2}	0.8143	*	*		*							
	%TiV	3	0.16547	0.22049	0.8783	*	*		*							
Mugilidae [GP]	AvrMaxN	3	0.42337	1.9068	0.2016	*	*		*							
	%TiV	3	1.3435	0.98351	0.4397	*	*		*							

Interaction terms not presented in table for logistics purposes. As described in General Discussion (6.6.1) interaction terms were evaluated to determine statistical approach and/ or cited in the text and subsequently discussed where highly significant terms may influence valid interpretation of data.

Table 3.2 (b) Summary of PERMANOVA results of the effect of “Distance from bare sediment” on indicated community and individual taxa distribution across both and separate seasons (Se), across both sites (Si), except where indicated. *GP (Greenpoint only), CB (Callala Bay only); “Di” – “Distance from reef”, “Tr” – distance from bare sediment / transect; T1=0-15m+, T2=15-30m+, T3=30-45m+, T4=45-60m+; “Wk” – sampling week; significant permdisp (in bold) indicate non-homogeneity of variances; permdisp values of significant relationships only reported.*

	Distance from Bare Sediment					**Factors Included in Model**					**Pairwise Comparisons**						
	Measure	**df**	**MS**	**pseudo-F**	**p**	**Di**	**Tr**	**Si**	**Se**	**Wk**	**T1-T2**	**T1-T3**	**T1-T4**	**T2-T3**	**T2-T4**	**T3-T4**	**Permdisp**
BOTH SEASONS																	
Total Abundance	AvrMaxN	3	2.3749	2.5942	0.2335	*	*	*	*								
Species/ Taxa Richness		3	2.2083	2.7895	0.2447	*	*	*	*								
[GP only] sqrt		3	1.0897	4.1147	**0.0117**	*	*					**0.004**	**0.044**	**0.008**			0.835
[CB only] sqrt		3	0.20179	0.5381	0.6542	*	*		*								
Individual Species/Taxa:																	
Ambassis jacksoniensis	AvrMaxN	3	0.98143	0.66536	0.5863	*	*	*	*								
Girella tricuspidata [GP]	AvrMaxN	3	0.49609	5.6934	**0.0014**	*	*					**0.011**	**0.007**		**0.011**		**0.01**
Mugilidae [GP]	AvrMaxN	3	0.18367	0.76484	0.5089	*	*		*								
Sparidae [GP]	AvrMaxN	3	0.30752	4.7296	**0.0017**		*					**0.008**	**0.007**	**0.007**	**0.008**		**0.001**
WINTER SEASON																	
Total Abundance	AvrMaxN	3	0.68634	0.68062	0.5976	*	*										
Species Richness		3	1.5313	1.3738	0.4243	*	*	*									
[GP only]		3	2.25	1.9756	0.1887	*	*										
[CB only]		3	0.39583	1.3902	0.3124	*	*										
SUMMER SEASON																	
Community (All taxa)	AvrMaxN	3	850.9	0.84711	0.6227	*	*	*		*							
	%TiV	3	2263	0.87032	0.6542	*	*	*									
[GP only]	AvrMaxN	3	1180.8	1.4285	0.1948	*	*			*							
	%TiV	3	3976.8	3.3535	**0.0014**	*	*			*		**0.037**	**0.022**		**0.046**		0.871
[CB only]	AvrMaxN	3	674.6	0.99484	0.4358	*	*			*							
	%TiV	3	886.39	1.0692	0.3891	*	*			*							

Table 3.2 (b) cont'd Summary of PERMANOVA results of the effect of "Distance from bare sediment" on indicated community and individual taxa distribution across both and separate seasons (Se), across both sites (Si), except where indicated. *GP (Greenpoint only), CB (Callala Bay only); "Di" – "Distance from reef", "Tr" – distance from bare sediment / transect; T1=0-15m+, T2=15-30m+, T3=30-45m+, T4=45-60m+; "Wk" – sampling week; significant permdisp (in bold) indicate non-homogeneity of variances; permdisp values of significant relationships only reported.*

	Distance from Bare Sediment					Factors in Model				Pairwise Comparisons						
	Measure	**df**	**MS**	**pseudo-F**	**p**	**Di**	**Tr**	**Si**	**Wk**	**T1-T2**	**T1-T3**	**T1-T4**	**T2-T3**	**T2-T4**	**T3-T4**	**Permdisp**
Total Abundance	AvrMaxN	3	2.9764	14.852	**0.0412**	*	*	*	*		**0.011**				**0.008**	0.385
	%TiV	3	0.90731	1.2444	0.4816	*	*	*	*							
[GP only]	AvrMaxN	3	1.5485	1.6446	0.2118	*	*									
	%TiV	3	1.5974	1.4935	0.2525	*	*		*							
[CB only]	AvrMaxN	3	1.6284	0.76897	0.5247	*	*		*							
	%TiV	3	3.903E^{-2}	2.1183E^{-2}	0.9928	*	*		*							
Species / Taxa Richness		3	2.0694	1.0276	0.5211	*	*	*	*							
[GP only]		3	3.9167	2.5636	0.0627		*		*							
[CB only]		3	0.16667	0.25352	0.8656	*	*		*							
Individual Species/Taxa:																
Ambassis jacksoniensis	AvrMaxN	3	1.8915	0.6428	0.5974	*	*									
	%TiV	3	0.29527	0.17493	0.9134	*	*									
Atherinidae	AvrMaxN	3	2.0793	0.76866	0.5698	*	*	*	*							
	%TiV	3	1.8799	1.1185	0.5249	*	*	*	*							
Atherinidae [GP]	AvrMaxN	3	3.9453	1.3711	0.3098	*	*		*							
	%TiV	3	3.1928	1.5505	0.2684	*	*		*							
Atherinidae [CB]	AvrMaxN	3	0.83913	0.49356	0.6948	*	*		*							
	%TiV	3	0.36786	0.67347	0.5834	*	*		*							
Girella tricuspidata [GP]	AvrMaxN	3	0.25766	4.5262	**0.013**	*	*		*			**0.041**		**0.044**		0.171
	%TiV	3	3.7986	7.825	**0.0016**	*	*		*			**0.004**		**0.023**	**0.007**	0.089
Sphyraena obtusata [GP]	AvrMaxN	3	6.131E^{-2}	1.8254	0.1748	*	*		*							
	%TiV	3	0.66594	1.7197	0.2049	*	*		*							
Sparidae [GP]	AvrMaxN	3	0.10444	2.197	0.0665		*									
	%TiV	3	3.2989	5.0081	**0.0016**		*				**0.004**		**0.005**			**0.001**
Mugilidae [GP]	AvrMaxN	3	0.21131	0.95169	0.4528	*	*		*							
	%TiV	3	1.5797	1.1564	0.3707	*	*		*							

Interaction terms not presented in table for logistics purposes. As described in General Discussion (6.6.1) interaction terms were evaluated to determine statistical approach and/ or cited in the text and subsequently discussed where highly significant terms may influence valid interpretation of data.

Table 3.2 (c) Summary of PERMANOVA results of the effect of “Distance from general edge” on indicated community and individual taxa distribution across both and separate seasons (Se), across both sites (Si), except where indicated. *GP (Greenpoint only), CB (Callala Bay only); “Ed” denotes “Distance from general edge”; E1=E0-15m, E2=E15-30m, E3=30-60m; Wk” – sampling week; significant permdisp (in bold) indicate non-homogeneity of variances; permdisp values of significant relationships only reported.*

	Distance from General Edge					Factors Included in Model				Pairwise Comparisons			
	Measure	**df**	**MS**	**pseudo-F**	**P**	**Ed**	**Si**	**Se**	**Wk**	**E1-E2**	**E1-E3**	**E2-E3**	**Permdisp**
BOTH SEASONS													
Total Abundance	AvrMaxN	2	2.2218	2.1633	0.3656	*	*	*					
Species/ Taxa Richness		2	16.717	15.668	0.1998	*	*	*					
[GP only] sqrt		2	1.0828	4.0124	**0.0211**	*		*			**0.012**		0.76
[CB only] sqrt		2	0.559	1.8373	0.1724	*		*					
Individual Species/Taxa:													
Ambassis jacksoniensis	AvrMaxN	2	1.0359	2.2057	0.3028	*	*	*					
Girella tricuspidata [GP]	AvrMaxN	2	1.0841	11.687	**0.0002**	*					**0.0002**	**0.0032**	**0.001**
Mugilidae [GP]	AvrMaxN	2	0.37699	1.4778	0.2377	*		*					
Sparidae [GP]	AvrMaxN	2	0.10389	1.3481	0.2524	*		*					
WINTER SEASON													
Total Abundance	AvrMaxN	2	3.2157	4.0027	**0.0251**	*				**0.002**			0.091
Species Richness		2	3.5469	2.2668	0.3866	*	*						
[GP only]		2	3.9464	3.7023	**0.0503**	*					**0.0192**		0.477
[CB only]		2	1.1652	4.1993	**0.0351**	*				**0.021**			0.816
SUMMER SEASON													
Community (All taxa)	AvrMaxN	2	1493.9	1.3382	0.3107	*	*		*				
	%TiV	2	2095.5	1.0209	0.5103	*	*						
[GP only]	AvrMaxN	2	1814.8	1.8088	0.0819	*			*				
	%TiV	2	3101.4	2.0805	**0.0461**	*			*		**0.0042**		0.157
[CB only]	AvrMaxN	2	795.36	1.2892	0.2652	*			*				
	%TiV	2	1046.9	1.2695	0.2402	*			*				

Table 3.2 (c) cont'd Summary of PERMANOVA results of the effect of "Distance from general edge" on indicated community and individual taxa distribution across both and separate seasons (Se), across both sites (Si), except where indicated. *GP (Greenpoint only), CB (Callala Bay only); "Ed" denotes "Distance from general edge"; E1=E0-15m, E2=E15-30m, E3=30-60m; Wk" – sampling week; significant permdisp (in bold) indicate non-homogeneity of variances; permdisp values of significant relationships only reported.*

	Distance from General Edge					**Factors in Model**			**Pairwise Comparisons**			
	Measure	**df**	**MS**	**pseudo-F**	**P**	**Ed**	**Si**	**Wk**	**E1-E2**	**E1-E3**	**E2-E3**	**Permdisp**
Total Abundance	AvrMaxN	2	0.26068	0.10897	0.9853	*	*	*				
	%TiV	2	$2.6413E^{-2}$	0.43794	0.6712	*	*	*				
[GP only]	AvrMaxN	2	2.095	1.1582	0.3171	*		*				
	%TiV	2	$6.2584E^{-2}$	$5.5382E^{-2}$	0.9468	*		*				
[CB only]	AvrMaxN	2	0.55795	0.3145	0.7342	*		*				
	%TiV	2	$4.8282E^{-2}$	$2.1183E^{-2}$	0.9783	*		*				
Species / Taxa Richness		2	1.1833	4.2479	0.2428	*	*	*				
[GP only]		2	1.2143	0.70449	0.5083	*		*				
[CB only]		2	0.24762	0.47706	0.6346	*		*				
Individual Species/Taxa:												
Ambassis jacksoniensis	AvrMaxN	2	12.768	3.6298	0.0374	*					0.035	**0.001**
	%TiV	2	5.6396	3.2767	0.0518	*					0.036	**0.001**
Atherinidae	AvrMaxN	2	2.7997	1.2445	0.4484	*	*	*				
	%TiV	2	1.2723	3.2281	0.2514	*	*	*				
Atherinidae [GP]	AvrMaxN	2	2.4862	0.94292	0.3976	*		*				
	%TiV	2	1.3267	0.62898	0.5408	*		*				
Atherinidae [CB]	AvrMaxN	2	2.5631	2.4044	0.1041	*		*				
	%TiV	2	0.33967	0.59068	0.5532	*		*				
Girella tricuspidata [GP]	AvrMaxN	2	0.65932	9.4829	**0.0002**	*		*		**0.001**	**0.003**	**0.001**
	%TiV	2	6.7642	6.7182	**0.0036**	*		*		**0.003**	**0.019**	0.056
Sphyraena obtusata [GP]	AvrMaxN	2	0.13662	3.0652	0.0549	*		*	0.037	**0.008**		**0.01**
	%TiV	2	1.269	2.8297	0.0741	*		*		**0.012**		**0.015**
Sparidae [GP]	AvrMaxN	2	$9.041E^{-3}$	$8.1701E^{-2}$	0.9607	*						
	%TiV	2	0.76151	0.91731	0.4004	*						
Mugilidae [GP]	AvrMaxN	2	0.16316	0.54656	0.5926	*		*				
	%TiV	2	0.50873	0.35728	0.7068	*		*				

Interaction terms not presented in table for logistics purposes. As described in General Discussion (6.6.1) interaction terms were evaluated to determine statistical approach and/ or cited in the text and subsequently discussed where highly significant terms may influence valid interpretation of data.

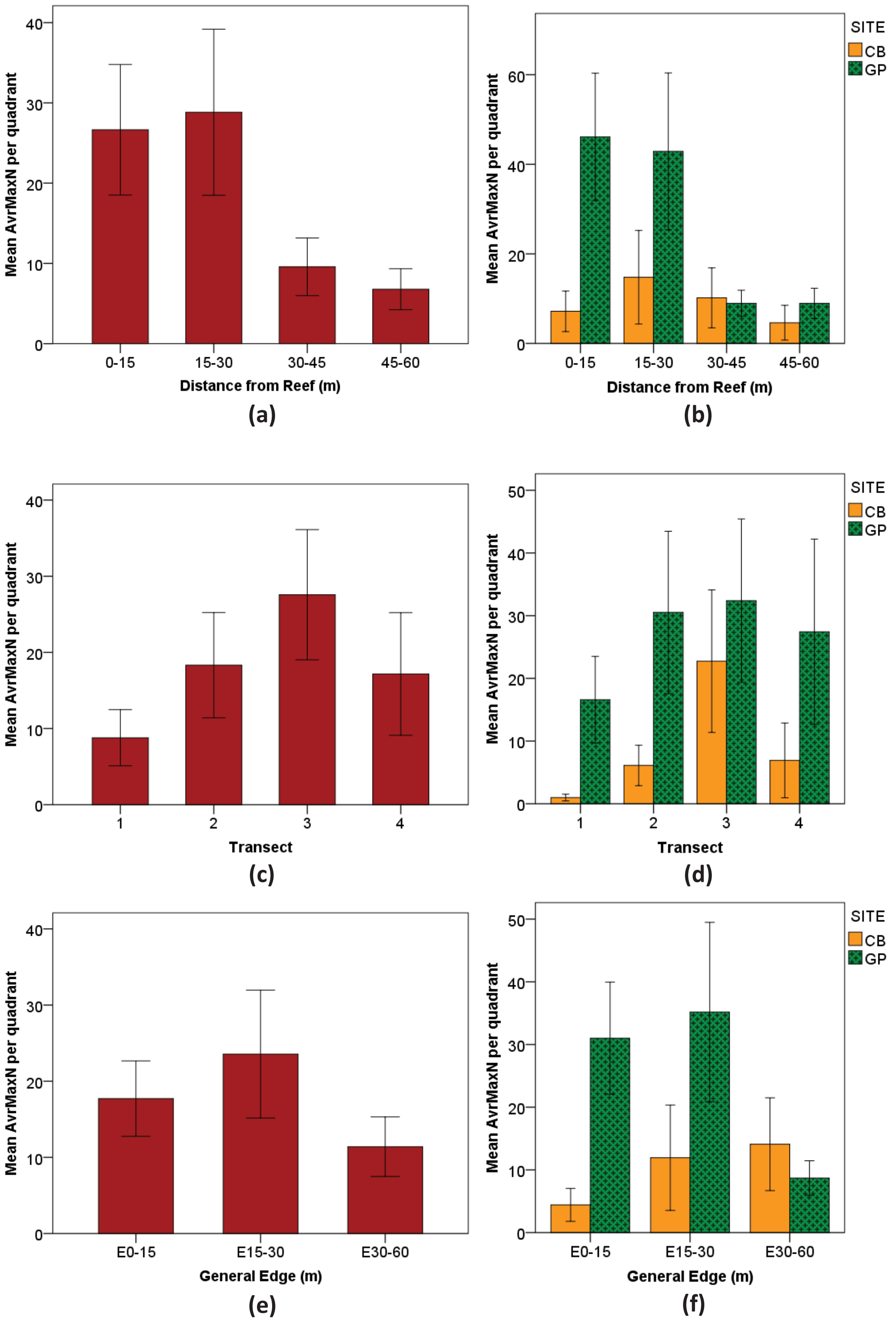
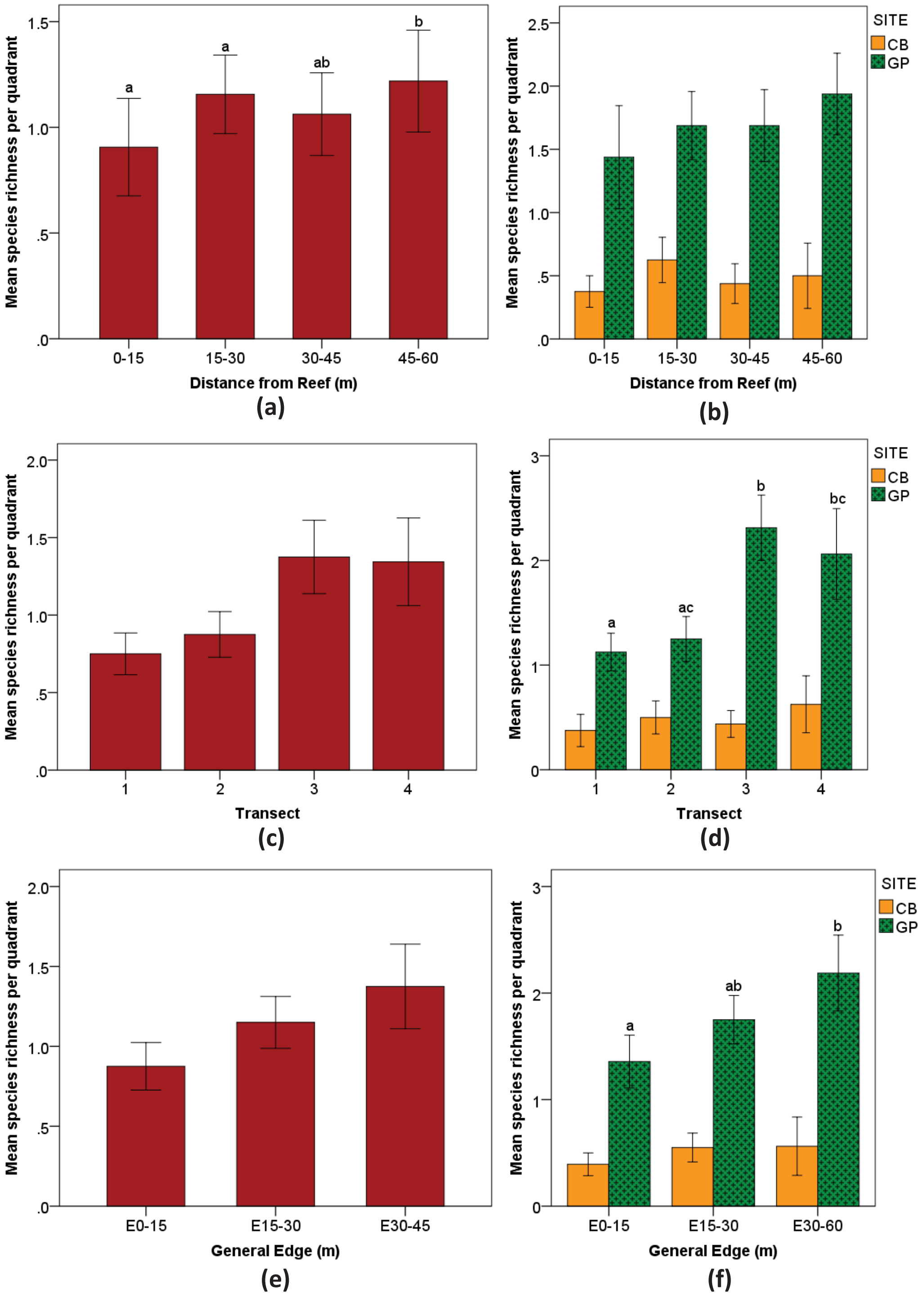


Fig 3.2 Total AvrMaxN with increasing distance from (a,b) rocky reef, (c,d) bare sediment (increasing transect number) and (e,f) general edge at both sites (means across both sites in left panel) across both seasons. *CB=Callala Bay, GP=Greenpoint.*

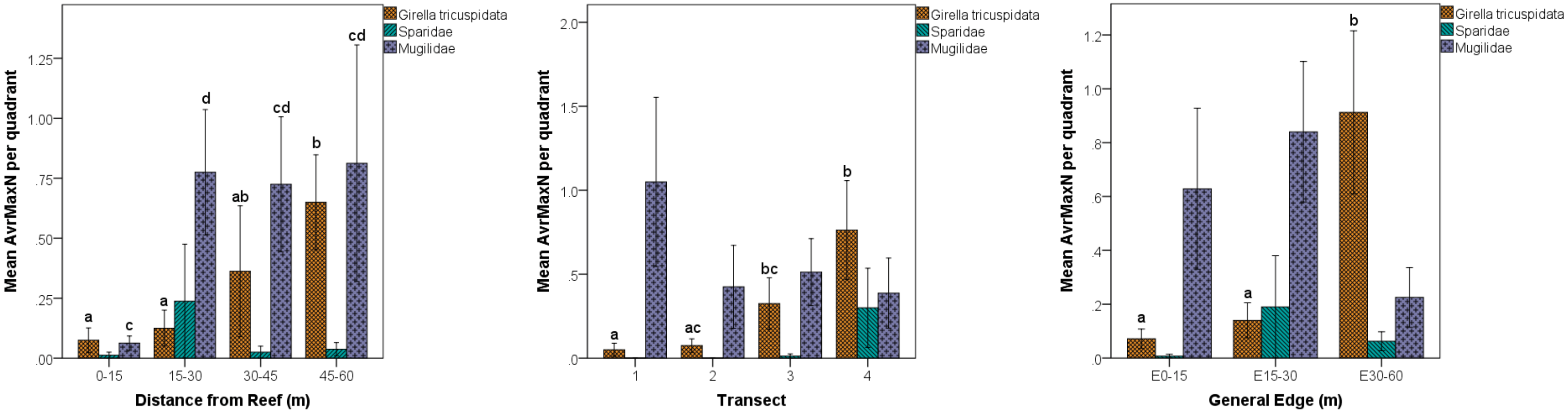


(a) (b)

(c) (d)

(e) (f)

Fig 3.3 Species richness with increasing distance from (a,b) rocky reef, (c,d) bare sediment (increasing transect number) and (e,f) general edge at both sites (means across both sites in left panel) across both seasons. *Letters above bars represent the results of pairwise comparisons with distance categories lacking similar letters being significantly different from each other; CB=Callala Bay, GP=Greenpoint.*



(a) **(b)** **(c)**

Fig 3.4 Distribution of the dominant Greenpoint fish species/taxa with increasing distance from (a) rocky reef, (b) bare sediment (increasing transect number) and (c) general edge across both seasons. *Letters above bars represent the results of pairwise comparisons of log-transformed data with distance categories lacking similar letters being significantly different from each other; the bar lettering of each subsequent bar category begin with the letter following alphabetically the highest lettering of the bar category immediately before.*

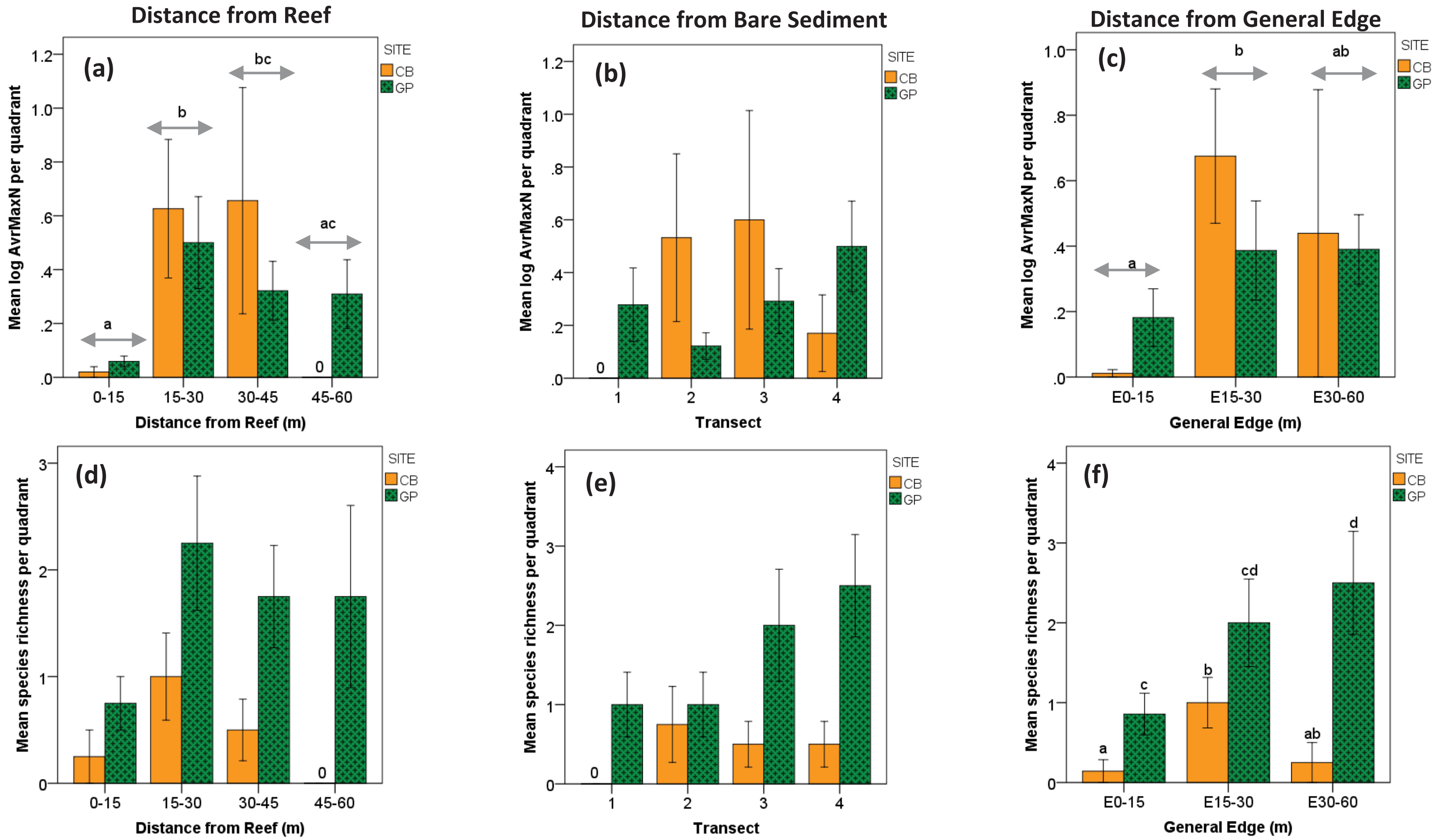
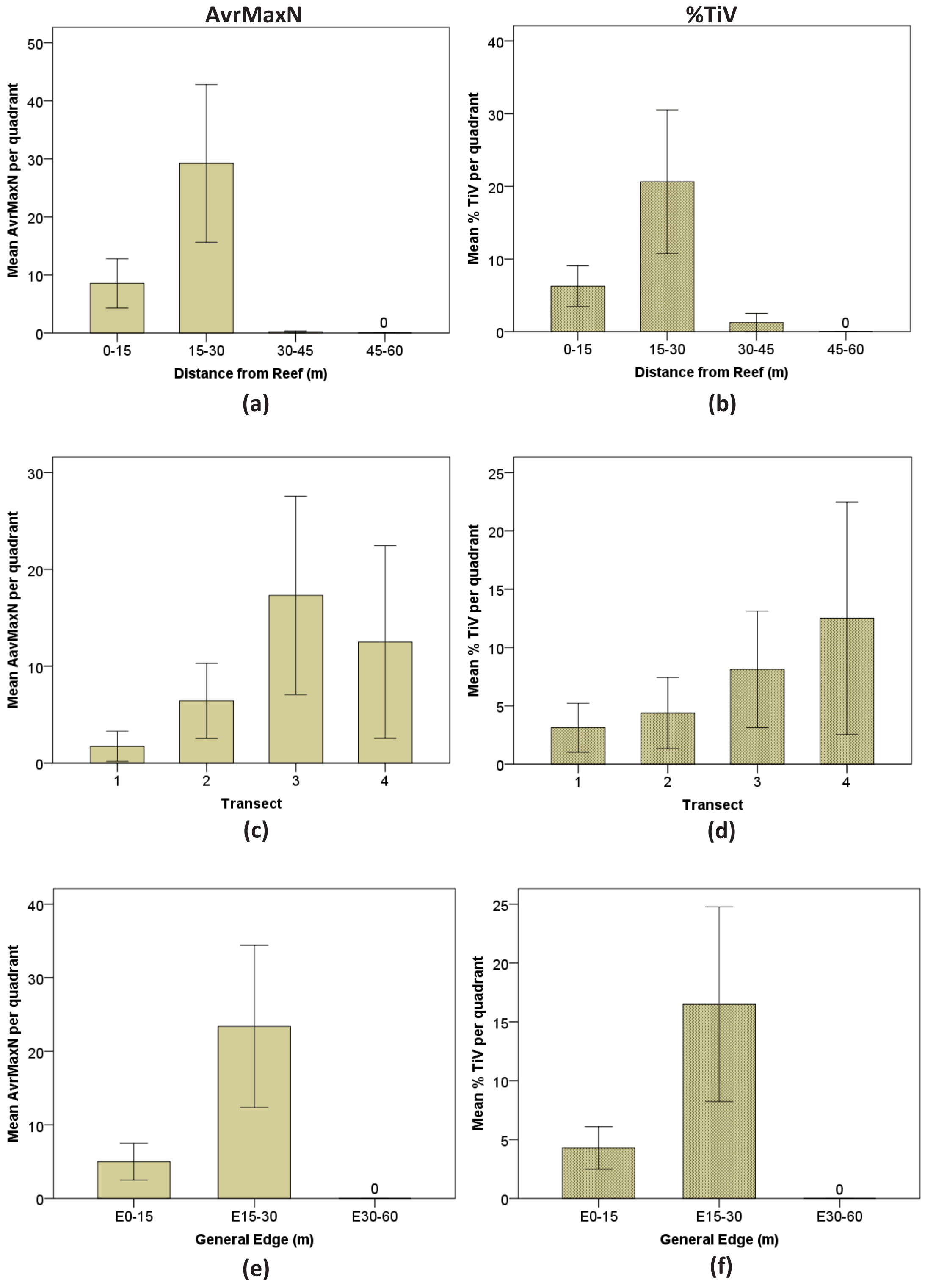


Fig 3.5 Total AvrMaxN (a-c) and species richness (d-f) with increasing distance from rocky reef, bare sediment (increasing transect number) and general edge at both sites for the winter sampling session only. *Letters above bars represent the results of pairwise comparisons with distance categories lacking similar letters being significantly different from each other; the bar lettering of each subsequent bar category begin with the letter following alphabetically the highest lettering of the bar category immediately before; double sided arrows show significant pairwise comparison results with sites pooled.*

Table 3.3 Percent contribution by fish taxa to significant community variations in “Distance from reef”, “Distance from bare sediment” and “Distance from general edge” for both AvrMaxN and %TiV values from SIMPER analysis (cut off point set at cumulative contribution 90%) at Greenpoint, Jervis Bay (summer season).

Species/Taxa:	**AvrMaxN**	**Species/Taxa:**	**%TiV**
Distance from Reef [D1-D4]			
Atherinidae	**45.74**	**Atherinidae**	**26.99**
G. tricuspidata	**14.55**	***G. tricuspidata***	**25.62**
Mugilidae	13.51	Mugilidae	16.56
A. jacksoniensis	13.49	*S. obtusata*	11.5
S. obtusata	6.54	*A. jacksoniensis*	8.44
		R. sarba	8.35
Distance from Bare Sediment [T1-T4]			
Atherinidae	**32.54**	***G. tricuspidata***	**29.48**
G. tricuspidata	**21.53**	**Atherinidae**	**21.25**
A. jacksoniensis	18.07	Mugilidae	19.35
Mugilidae	17.39	*A. jacksoniensis*	13.13
R. sarba	3.73	*R. sarba*	7.72
Distance from General Edge [E1-E3]			
Atherinidae	**43.85**	***G. tricuspidata***	**27.60**
G. tricuspidata	**20.71**	**Atherinidae**	**25.59**
Mugilidae	13.67	Mugilidae	16.23
A. jacksoniensis	7.82	*R. sarba*	12.21
R. sarba	4.92	*S. obtusata*	8.25
		A. jacksoniensis	4.94



(a) (b)

(c) (d)

(e) (f)

Fig 3.6 Distribution of *Ambassis jacksoniensis* (AvrMaxN and %TiV) with increasing distance from (a,b) rocky reef, (c,d) bare sediment (increasing transect number) and (e,f) general edge pooling both sites (Callala Bay and Greenpoint) for the summer season only.

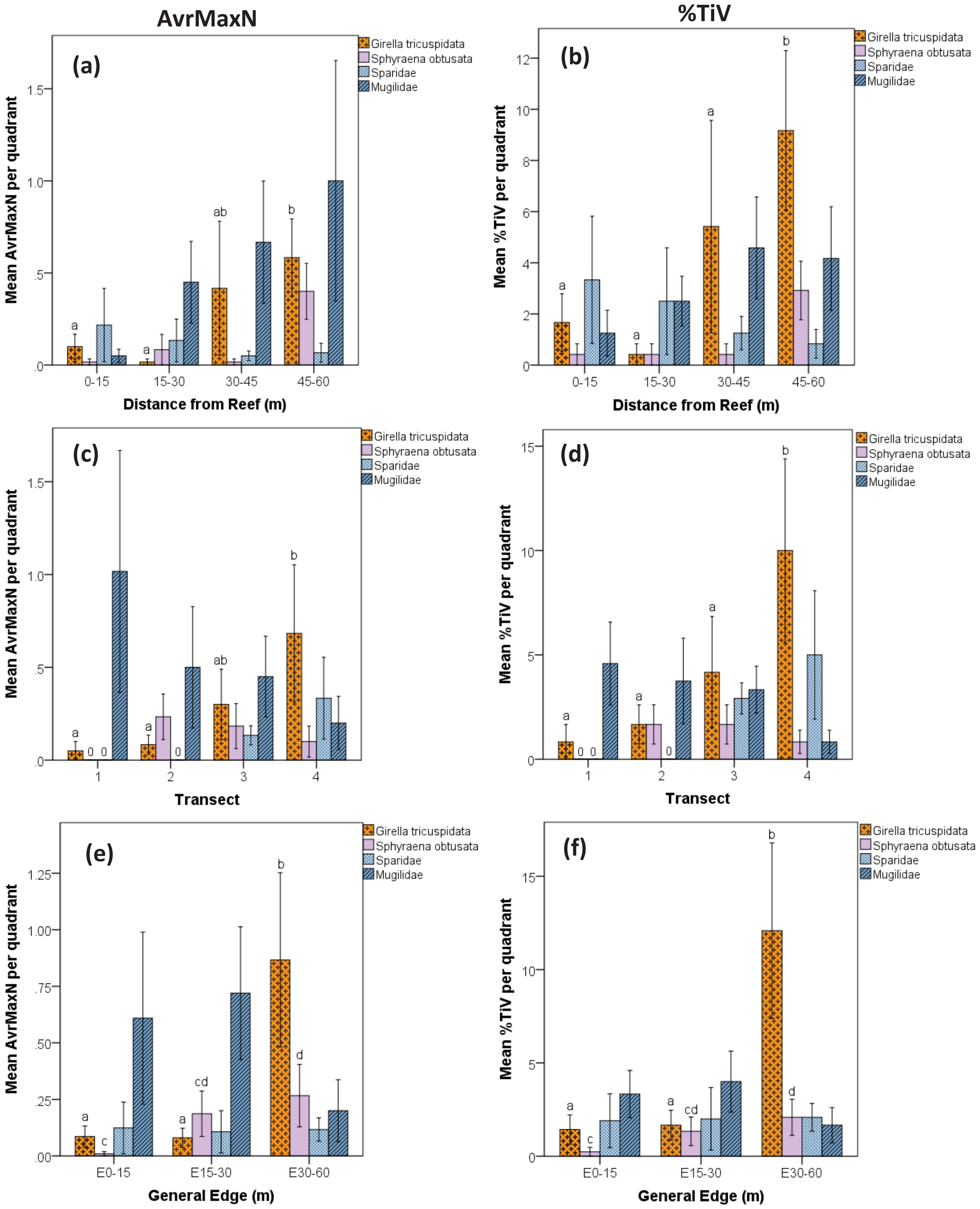


Fig 3.7 Distribution of dominant species/taxa with increasing distance from (a,b) rocky reef, (c,d) bare sediment (increasing transect number) and (e,f) general edge at Greenpoint for the summer sampling session only. *Letters above bars represent the results of pairwise comparisons of log-transformed data with distance categories lacking similar letters being significantly different; the bar lettering of each subsequent bar category begin with the letter following alphabetically the highest lettering of the bar category immediately before.*

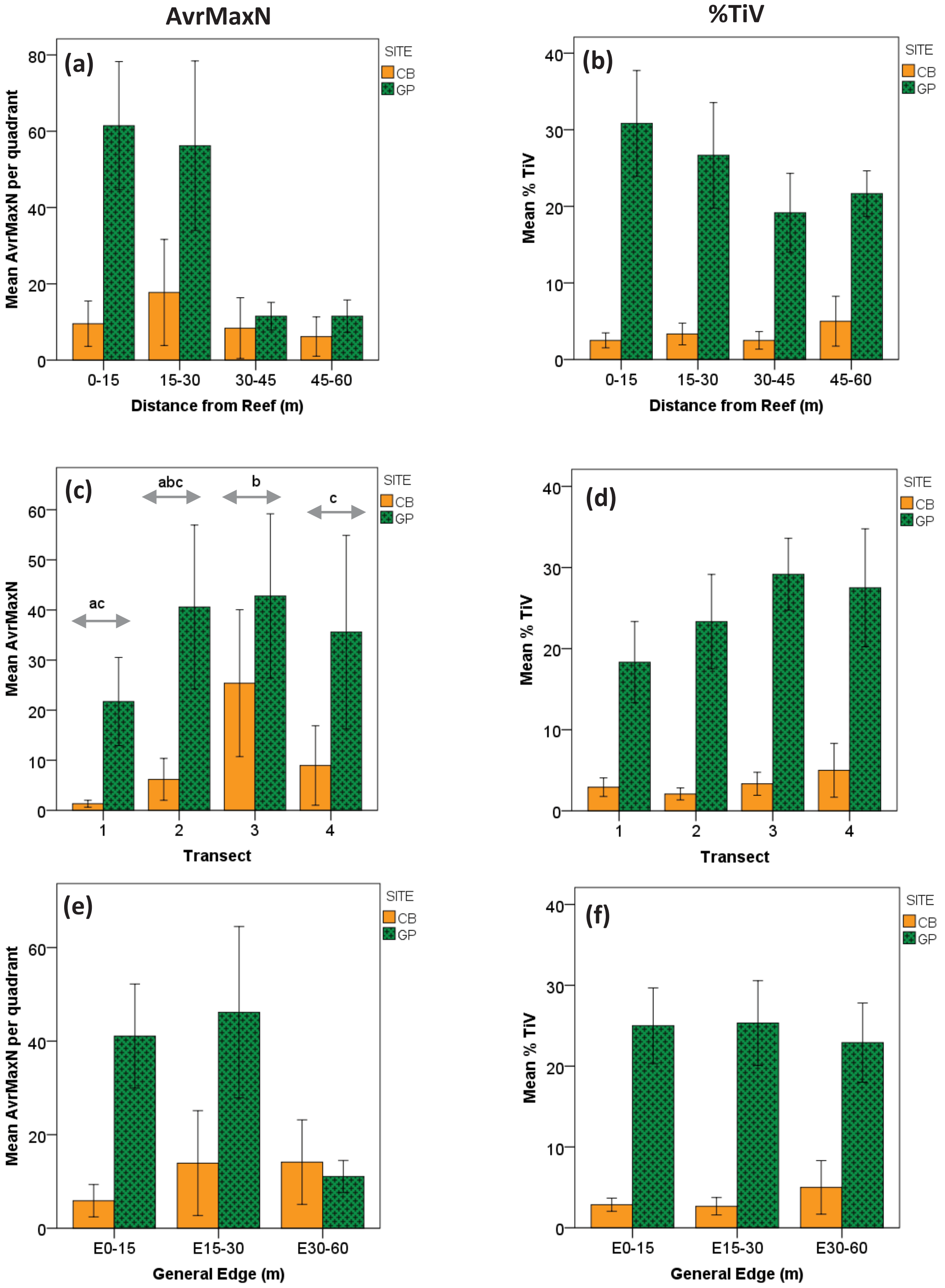


Fig 3.8 Total AvrMaxN and %TiV with increasing distance from (a,b) rocky reef, (c,d) bare sediment (increasing transect number) and (e,f) general edge at both sites for summer season only. *Double sided arrows show significant pairwise comparison results of log-transformed data with sites pooled.*

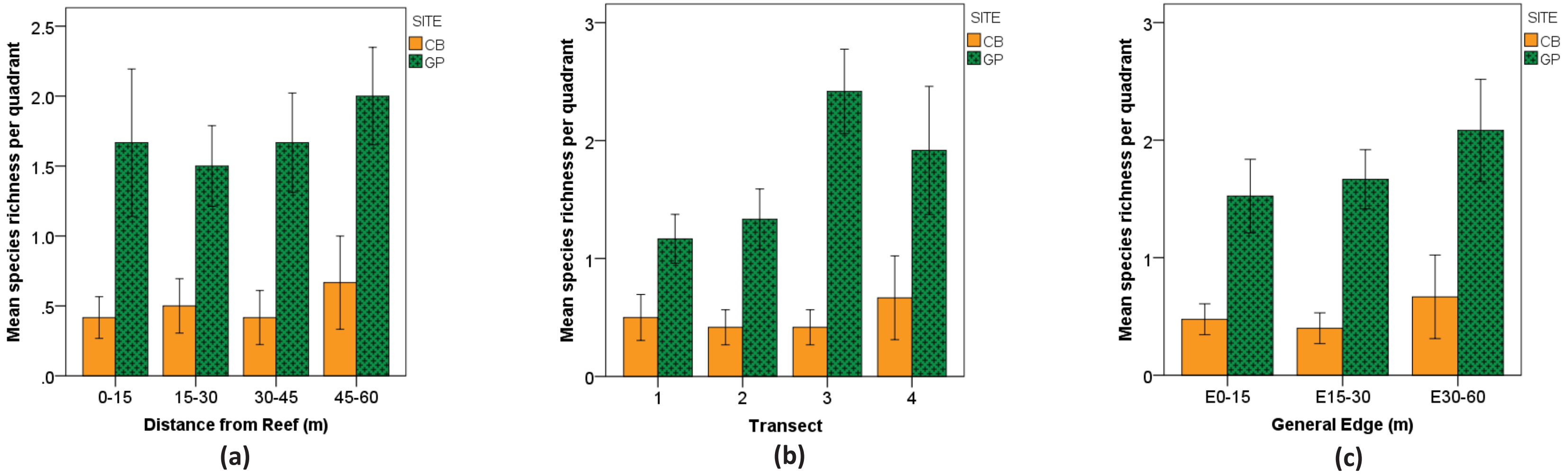


Fig 3.9 Species richness with increasing distance from (a) rocky reef, (b) bare sediment (increasing transect number) and (c) general edge at both sites for the summer sampling session only.

Table 3.4 (a) Summary of PERMANOVA results of the effect of “Distance from reef” on indicated functional group community and individual guild distribution across both sites, except where indicated, over the summer sampling session. *“Di” denotes “Distance from reef”, “Tr” – distance from bare sediment / transect; D1=0-15m, D2=15-30m, D3=30-45m, D4=45-60m; significant permdisp (in bold) indicate non-homogeneity of variances; permdisp values of significant relationships only reported.*

	Distance from Reef					**Factors Included**				**Pairwise Comparisons**						
	Measure	**df**	**MS**	**pseudo-F**	**p**	**Di**	**Tr**	**Si**	**Wk**	**D1-D2**	**D1-D3**	**D1-D4**	**D2-D3**	**D2-D4**	**D3-D4**	**Permdisp**
Feeding Mode Functional Groups (FMFG)																
Community (As guilds)	AvrMaxN	3	1809.4	4.1073	**0.0209**	*	*	*	*							0.351
	%TiV	3	2057.9	2.1516	0.1278	*	*	*	*							
[GP only]	AvrMaxN	3	1817.5	2.3658	0.0301	*	*		*							**0.01**
	%TiV	3	2510.7	2.863	**0.0145**	*	*		*			**0.027**		**0.023**	**0.030**	0.15
[CB only]	AvrMaxN	3	432.35	0.63387	0.7309	*	*		*							
	%TiV	3	503.59	0.60799	0.7603	*	*		*							
Individual Guilds:																
Zooplanktivores	AvrMaxN	3	12.368	5.9069	**0.0023**	*			*			0.027	**0.007**	**0.004**		**0.001**
	%TiV	3	6.1046	5.3029	**0.0048**	*			*			0.030	0.016	**0.004**		**0.001**
CNP	AvrMaxN	3	1.815	1.3899	0.3935	*	*	*								
	%TiV	3	0.80874	1.2519	0.4375	*	*	*	*							
[GP only]	AvrMaxN	3	4.3873	1.6791	0.2312	*	*		*							
	%TiV	3	1.2095	1.216	0.3295	*	*		*							
[CB only]	AvrMaxN	3	0.19599	0.1768	0.9143	*	*		*							
	%TiV	3	0.24524	0.47826	0.6987	*	*		*							
CNP (No Atherinidae)	AvrMaxN	3	0.11264	2.2235	0.1903	*	*	*	*							
	%TiV	3	1.3212	6.9742	0.0777	*	*	*	*							
[GP only]	AvrMaxN	3	0.2356	5.3317	**0.0094**	*	*					**0.017**				0.112
	%TiV	3	1.8647	4.6237	**0.0147**	*	*					**0.034**		**0.013**	**0.013**	0.44
Omnivores	AvrMaxN	3	0.1848	5.6862	0.0767	*	*	*	*							
	%TiV	3	0.508	2.3162	0.2854	*	*	*	*							
[GP only]	AvrMaxN	3	0.16268	0.92473	0.4449	*	*		*							
	%TiV	3	0.3033	0.28302	0.8353	*	*		*							
Herbivores	AvrMaxN	3	0.15311	0.95537	0.563	*	*	*	*							
	%TiV	3	2.7492	1.1651	0.5062	*	*	*	*							
[GP only]	AvrMaxN	3	0.31245	1.0051	0.4219	*	*		*							
	%TiV	3	5.0197	9.1808	**0.0005**	*	*		*			**0.019**		**0.005**	**0.024**	0.16

Table 3.4 (a) cont'd Summary of PERMANOVA results of the effect of "Distance from reef" on indicated functional group community and individual guild distribution across both sites, except where indicated, over the summer sampling session. *"Di" denotes "Distance from reef", "Tr" – distance from bare sediment / transect; D1=0-15m, D2=15-30m, D3=30-45m, D4=45-60m; significant permdisp (in bold) indicate non-homogeneity of variances; permdisp values of significant relationships only reported.*

	Distance from Reef					**Factors Included**				**Pairwise Comparisons**						
	Measure	**df**	**MS**	**pseudo-F**	**p**	**Di**	**Tr**	**Si**	**Wk**	**D1-D2**	**D1-D3**	**D1-D4**	**D2-D3**	**D2-D4**	**D3-D4**	**Permdisp**
Estuarine Use Functional Groups (EUFG):																
Estuarine Species	AvrMaxN	3	7.0092	4.2686	0.1367	*	*	*								
	%TiV	3	1.9618	1.343	0.4483	*	*	*	*							
[GP only]	AvrMaxN	3	11.463	7.5466	**0.0074**	*	*		*		**0.046**	**0.030**	**0.039**	**0.032**		0.06
	%TiV	3	3.2873	4.5618	**0.0138**	*	*		*		**0.042**	**0.048**	**0.031**	**0.017**		0.605
[CB only]	AvrMaxN	3	1.009	0.48832	0.6957	*	*		*							
	%TiV	3	0.13519	0.16062	0.9191	*	*		*							
Marine Species	AvrMaxN	3	0.54872	3.8306	0.1069	*	*	*								
	%TiV	3	3.4958	4.3451	0.1269	*	*	*	*							
[GP only]	AvrMaxN	3	0.62337	3.7778	**0.0305**	*	*		*			**0.019**		**0.049**		0.448
	%TiV	3	3.5531	4.8679	**0.0134**	*	*		*			**0.003**				0.692
[CB only]	AvrMaxN	3	$6.8599E^{-2}$	0.81121	0.5146	*	*		*							
	%TiV	3	0.74728	1.2469	0.3241	*	*		*							

Table 3.4 (b) Summary of PERMANOVA results of the effect of “Distance from bare sediment” on indicated functional group community and individual guild distribution across both sites, except where indicated, over the summer sampling session. *“Di” denotes “Distance from reef”, “Tr” – distance from bare sediment / transect; T1=0-15m+, T2=15-30m+, T3=30-45m+, T4=45-60m+; significant permdisp (in bold) indicate non-homogeneity of variances; permdisp values of significant relationships only reported.*

	Distance from Bare Sediment					**Factors Included**				**Pairwise Comparisons**						
	Measure	**df**	**MS**	**pseudo-F**	**p**	**Di**	**Tr**	**Si**	**Wk**	**T1-T2**	**T1-T3**	**T1-T4**	**T2-T3**	**T2-T4**	**T3-T4**	**Permdisp**
Feeding Mode Functional Groups (FMFG):																
Community (As guilds)	AvrMaxN	3	800.15	0.94152	0.535	*	*	*	*							
	%TiV	3	2107.2	1.3469	0.2793	*	*	*	*							
[GP only]	AvrMaxN	3	1010.8	1.3157	0.2658	*	*		*							
	%TiV	3	2785.2	3.1761	**0.0102**	*	*		*						**0.024**	0.188
[CB only]	AvrMaxN	3	639.25	0.93719	0.4893	*	*		*							
	%TiV	3	886.47	1.0702	0.4025	*	*		*							
Individual Guilds:																
Zooplanktivores	AvrMaxN	3	0.83653	0.35483	0.793	*	*		*							
	%TiV	3	$6.6338E^{-2}$	$4.0946E^{-2}$	0.9875	*	*		*							
CNP	AvrMaxN	3	1.564	0.75275	0.5618	*	*	*								
	%TiV	3	1.8919	1.0618	0.4925	*	*	*	*							
[GP only]	AvrMaxN	3	4.662	1.7842	0.2224	*	*		*							
	%TiV	3	3.2502	3.3697	**0.0261**		*		*					**0.037**	**0.037**	0.213
[CB only]	AvrMaxN	3	0.53365	0.48139	0.689	*	*		*							
	%TiV	3	0.42359	0.82609	0.5015	*	*		*							
CNP (No Atherinidae)	AvrMaxN	3	$3.6128E^{-2}$	0.81016	0.6257	*	*	*	*							
	%TiV	3	0.3576	0.5457	0.6879	*	*	*	*							
[GP only]	AvrMaxN	3	0.12004	2.7166	0.0759	*	*									
	%TiV	3	1.3856	3.4356	0.0432	*	*									**0.001**
Omnivores	AvrMaxN	3	$8.3932E^{-2}$	0.8452	0.4879	*	*	*	*							
	%TiV	3	1.2969	0.96104	0.473	*	*	*	*							
[GP only]	AvrMaxN	3	$4.805E^{-2}$	0.27314	0.8464	*	*		*							
	%TiV	3	1.8805	1.7548	0.191	*	*		*							
Herbivores	AvrMaxN	3	0.46437	1.2519	0.4428	*	*	*	*							
	%TiV	3	3.2792	2.6089	0.1851	*	*	*	*							
[GP only]	AvrMaxN	3	0.83252	2.6855	0.0341		*		*							**0.008**
	%TiV	3	4.2687	7.8072	**0.001**	*	*		*			**0.006**		**0.021**	**0.011**	0.068

Table 3.4 (b) cont'd Summary of PERMANOVA results of the effect of "Distance from bare sediment" on indicated functional group community and individual guild distribution across both sites, except where indicated, over the summer sampling session. *"Di" denotes "Distance from reef", "Tr" – distance from bare sediment / transect; T1=0-15m+, T2=15-30m+, T3=30-45m+, T4=45-60m+; significant permdisp (in bold) indicate non-homogeneity of variances; permdisp values of significant relationships only reported.*

	Distance from Bare Sediment					Factors Included				Pairwise Comparisons						
	Measure	**df**	**MS**	**pseudo-F**	**p**	**Di**	**Tr**	**Si**	**Wk**	**T1-T2**	**T1-T3**	**T1-T4**	**T2-T3**	**T2-T4**	**T3-T4**	**Permdisp**
Estuarine Use Functional Groups (EUFG):																
Estuarine Species	AvrMaxN	3	3.6282	9.4846	**0.0457**	*	*	*			**0.004**					0.306
	%TiV	3	1.6067	1.8908	0.2882	*	*	*	*							
[GP only]	AvrMaxN	3	2.7793	1.8297	0.2135	*	*		*							
	%TiV	3	1.5348	2.1298	0.1335	*	*		*							
[CB only]	AvrMaxN	3	2.1579	1.0443	0.4003	*	*		*							
	%TiV	3	0.9216	1.0949	0.3773	*	*		*							
Marine Species	AvrMaxN	3	0.29413	3.8836	0.1737	*	*	*								
	%TiV	3	3.2873	2.0946	0.3406	*	*	*	*							
[GP only]	AvrMaxN	3	0.21145	1.2815	0.311	*	*		*							
	%TiV	3	3.5893	4.9175	**0.0122**	*	*		*		**0.025**		**0.018**	**0.009**		0.396
[CB only]	AvrMaxN	3	0.15841	1.8733	0.1664	*	*		*							
	%TiV	3	1.2675	2.5624	0.0629		*		*							

Table 3.4 (c) Summary of PERMANOVA results of the effect of “Distance from general edge” on indicated functional group community and individual guild distribution across both sites, except where indicated, over the summer sampling session. *“Ed” denotes “Distance from general edge”; E1=E0-15m, E2=E15-30m, E3=E30-60m; significant permdisp (in bold) indicate non-homogeneity of variances; permdisp values of significant relationships only reported.*

	Distance from General Edge					Factors Included			Pairwise Comparisons			
	Measure	**df**	**MS**	**pseudo-F**	**p**	**Ed**	**Si**	**Wk**	**E1-E2**	**E1-E3**	**E2-E3**	**Permdisp**
Feeding Mode Functional Groups (FMFG)												
Community (As guilds)	AvrMaxN	2	1355	1.7348	0.2403	*	*	*				
	%TiV	2	1686.5	1.729	0.273	*	*	*				
[GP only]	AvrMaxN	2	1426.4	1.5367	0.1682	*		*				
	%TiV	2	1974.6	1.5514	0.1857	*		*				
[CB only]	AvrMaxN	2	709.7	1.1834	0.3185	*		*				
	%TiV	2	687.4	0.88236	0.5193	*		*				
Individual Guilds:												
Zooplanktivores	AvrMaxN	2	8.489	3.2882	0.0489	*		*			0.020	**0.001**
	%TiV	2	3.885	2.8487	0.0759	*		*				
CNP	AvrMaxN	2	1.7443	1.3881	0.4065	*	*					
	%TiV	2	0.36235	489.41	**0.0026**	*	*	*	**0.028**	**0.026**	**0.041**	0.678
[GP only]	AvrMaxN	2	1.9127	0.74145	0.4944	*		*				
	%TiV	2	0.19779	0.14046	0.8747	*		*				
[CB only]	AvrMaxN	2	1.7257	2.5132	0.0907	*		*				
	%TiV	2	0.1653	0.34966	0.7055	*		*				
CNP (No Atherinidae)	AvrMaxN	2	$9.9868E^{-2}$	1.127	0.5026	*	*	*				
	%TiV	2	0.70823	0.62741	0.6133	*	*	*				
[GP only]	AvrMaxN	2	0.28247	4.352	0.018	*				**0.004**		**0.001**
	%TiV	2	2.681	3.687	**0.039**	*				**0.008**		0.054
Omnivores	AvrMaxN	2	$4.5746E^{-2}$	0.13494	0.9308	*	*	*				
	%TiV	2	0.29	0.31008	0.856	*	*	*				
[GP only]	AvrMaxN	2	0.18428	0.69461	0.5211	*		*				
	%TiV	2	0.16053	$9.6562E^{-2}$	0.9054	*		*				
Herbivores	AvrMaxN	2	0.2532	1.0521	0.5835	*	*	*				
	%TiV	2	3.8819	1.4511	0.3767	*	*	*				
[GP only]	AvrMaxN	2	0.49275	1.5807	0.2128	*		*				
	%TiV	2	6.4501	5.8709	**0.0056**	*		*		**0.005**	**0.018**	0.133

Table 3.4 (c) cont'd. Summary of PERMANOVA results of the effect of "Distance from general edge" on indicated functional group community and individual guild distribution across both sites, except where indicated, over the summer sampling session. *"Ed" denotes "Distance from general edge"; E1=E0-15m, E2=E15-30m, E3=E30-60m; significant permdisp (in bold) indicate non-homogeneity of variances; permdisp values of significant relationships only reported.*

	Distance from General Edge					Factors Included			Pairwise Comparisons			
	Measure	**df**	**MS**	**pseudo-F**	**p**	**Ed**	**Si**	**Wk**	**E1-E2**	**E1-E3**	**E2-E3**	**Permdisp**
Estuarine Use Functional Groups (EUFG):												
Estuarine Species	AvrMaxN	2	1.2301	0.75496	0.5689	*	*					
	%TiV	2	1.2238	2.9423	0.2693	*	*	*				
[GP only]	AvrMaxN	2	4.167	1.6053	0.2213	*		*				
	%TiV	2	1.2709	1.0737	0.3468	*		*				
[CB only]	AvrMaxN	2	$8.1557E^{-2}$	$4.4429E^{-2}$	0.9588	*		*				
	%TiV	2	0.36887	0.45537	0.6287	*		*				
Marine Species	AvrMaxN	2	0.36549	10.691	0.1209	*	*					
	%TiV	2	3.4843	14.906	0.0692	*	*	*				
[GP only]	AvrMaxN	2	0.20395	0.68155	0.5076	*		*				
	%TiV	2	2.7615	1.7246	0.1978	*		*				
[CB only]	AvrMaxN	2	0.19572	2.8524	0.0386	*		*				**0.001**
	%TiV	2	0.95658	2.1706	0.1233	*		*				

Interaction terms not presented in table for logistics purposes. As described in General Discussion (6.6.1) interaction terms were evaluated to determine statistical approach and/ or cited in the text and subsequently discussed where highly significant terms may influence valid interpretation of data.

Table 3.5 Percent contribution of each FMFG guild for significant pairwise comparisons of FMFG community distribution (%TiV) from SIMPER analysis, all at Greenpoint only (cut off point set at cumulative contribution of 90%). *AvrMaxN contributions across the same distance categories included for comparison of measures only.*

Individual guild:	**AvrMaxN**	**Individual guild:**	**%TiV**
Distance from Reef [D1-D4]			
CNP	51.46	CNP	35.13
HV	18.10	HV	30.80
OV	16.06	OV	24.01
ZP	14.38	ZP	10.06
[D2-D4]			
CNP	40.30	HV	30.11
ZP	22.80	CNP	28.46
OV	19.92	OV	24.96
HV	16.98	ZP	16.47
[D3-D4]			
CNP	51.73	HV	35.56
OV	26.05	CNP	34.08
HV	22.21	OV	30.37
Distance from Bare Sediment [T3-T4]			
CNP	45.31	CNP	29.72
HV	19.83	HV	28.56
ZP	19.05	OV	28.45
OV	15.81	ZP	13.27

Table 3.6 (a) Feeding Mode Functional Groups: Overall percentage contribution per functional group and percent contribution by individual species/taxa to each group in the summer season only. *Values in parenthesis represent percentage contribution in functional groups disregarding all Atherinidae in that group. Values in grey boxes represent percentages calculated from %TiV; unshaded boxes represent values calculated from AvrMaxN.*

CALLALA BAY		**CNP**		**ZP**		**OV**		**HV**	
	Overall Percentage:	**35.59**	**30**	**62.76**	**30**	**1.57**	**33.33**	**0.08**	**6.67**
Atherinosoma microstomata and *Atherinomorus vaigiensis*	**Hardyheads**: small-mouthed and Ogilby's	99.77	77.78						
Cheilodactylus spectabilis	Banded morwong	0.11 (50)	11.11 (50)						
Tetractenos glaber	Smooth toadfish	0.11 (50)	11.11 (50)						
Ambassis jacksoniensis	Glassfish			100	100				
Trygonorrhina fasciata	Fiddler ray					2.56	10		
	Mugilidae					87.18	70		
Acanthopagrus australis and *Rhabdosargus sarba*	**Sparidae** – bream and tarwhine					10.26	20		
Acanthaluteres vittiger	Toothbrush leatherjacket							50	50
Girella tricuspidata	Luderick							50	50

Table 3.6 (a) cont'd Feeding Mode Functional Groups: Overall percentage contribution per functional group and percent contribution by individual species/taxa to each group in the summer season only. *Values in parenthesis represent percentage contribution in functional groups disregarding all Atherinidae in that group. Values in grey boxes represent percentages calculated from %TiV; unshaded boxes represent values calculated from AvrMaxN.*

GREENPOINT		**CNP**		**ZP**		**OV**		**HV**	
	Overall Percentage:	**59.77**	**45.23**	**35.83**	**16.60**	**1.88**	**20.33**	**2.52**	**17.84**
Atherinosoma microstomata and *Atherinomorus vaigiensis*	**Hardyheads**: small-mouthed and Ogilby's	99.29	88.99						
Pseudocaranx wrighti	Skipjack trevally	0.1 (13.89)	1.83 (16.67)						
Sphyraena obtusata	Striped barracuda (juv)	0.6 (86.11)	9.17 (83.33)						
Ambassis jacksoniensis	Glassfish			99.21	90				
Atypichthys strigatus	Mado			0.79	10				
	Mugilidae					82.28	61.22		
Acanthopagrus australis and *Rhabdosargus sarba*	**Sparidae** – bream and tarwhine					17.72	38.78		
Acanthaluteres spilomelanurus	Bridled leatherjacket							68.4	6.98
Girella tricuspidata	Luderick							31.6	93.02

Table 3.6 (b) Estuarine Use Functional Groups: Overall percentage contribution per functional group and percent contribution by species/taxa to each group. *Values in parenthesis represent percentage contribution in functional groups disregarding Ambassis jacksonianus only in that group. Values in grey boxes represent percentages calculated from %TiV; unshaded boxes represent values calculated from AvrMaxN; ES=Estuarine Species – combination of EM (Estuarine Migrants) and ER (Estuarine Residents); M=Marine Species – ^{1}Marine Straggler (MS) and ^{2}Marine Migrant (MM).*

<u>CALLALA BAY</u>		**EM**		**ER**		**ES**		**M**	
	Overall Percentage:	**62.88**	**40**	**35.51**	**23.33**	**98.39**	**63.33**	**1.61**	**36.67**
Ambassis jacksoniensis	Glassfish	99.81	75			63.79			
Acanthaluteres vittiger	Toothbrush leatherjacket	0.06 (33.33)	8.33 (33.33)			0.04			
Tetractenos glaber	Smooth toadfish	0.06 (33.33)	8.33 (33.33)			0.04			
Trygonorrhina fasciata	Fiddler ray	0.06 (33.33)	8.33 (33.33)			0.04			
Atherinosoma microstomata and *Atherinomorus vaigiensis*	**Hardyheads** – small-mouthed and Ogilby's			100	100	36.09			
Cheilodactylus spectabilis	^{1}Banded morwong							2.5	9.09
Girella tricuspidata	^{2}Luderick							2.5	9.09
Acanthopagrus australis and *Rhabdosargus sarba*	^{2}**Sparidae** – bream and tarwhine							10	18.18
	^{2}**Mugilidae**							85	63.63

Table 3.6 (b) cont'd. Estuarine Use Functional Groups: Overall percentage contribution per functional group and percent contribution by species/taxa to each group. *Values in parenthesis represent percentage contribution in functional groups disregarding Ambassis jacksonianus only in that group. Values in grey boxes represent percentages calculated from %TiV; unshaded boxes represent values calculated from AvrMaxN; ES=Estuarine Species – combination of EM (Estuarine Migrants) and ER (Estuarine Residents); M=Marine Species –* ^{1}*Marine Straggler (MS) and* ^{2}*Marine Migrant (MM).*

GREENPOINT		**EM**		**ER**		**ES**		**M**	
	Overall Percentage:	**37.98**	**22.82**	**59.35**	**40.25**	**97.34**	**63.07**	**2.67**	**36.93**
Ambassis jacksoniensis	Glassfish	93.59	65.45			36.52	23.68		
Atypichthys strigatus	Mado	0.75 (11.71)	7.27 (21.05)			0.29	2.63		
Pseudocaranx wrighti	Skipjack trevally	0.16 (2.44)	3.64 (10.53)			0.06	1.31		
Sphyraena obtusata	Striped barracuda (juv)	0.97 (15.12)	18.18 (52.63)			0.38	6.58		
Acanthaluteres spilomelanurus	Bridled leatherjacket	4.53 (70.73)	5.45 (15.79)			17.68	1.97		
Atherinosoma microstomata and *Atherinomorus vaigiensis*	**Hardyheads** – small-mouthed and Ogilby's			100	100	60.98	63.82		
Girella tricuspidata	^{2}Luderick							29.78	44.94
Acanthopagrus australis and *Rhabdosargus sarba*	^{2}**Sparidae** – bream and tarwhine							12.44	21.35
	^{2}**Mugilidae**							57.78	33.71

*%TiV averages done across all positions for each species/taxa allowing the frequency of occurrence of species/taxa to be considered in the final figure while AvrMaxN values represent overall totals across all positions.

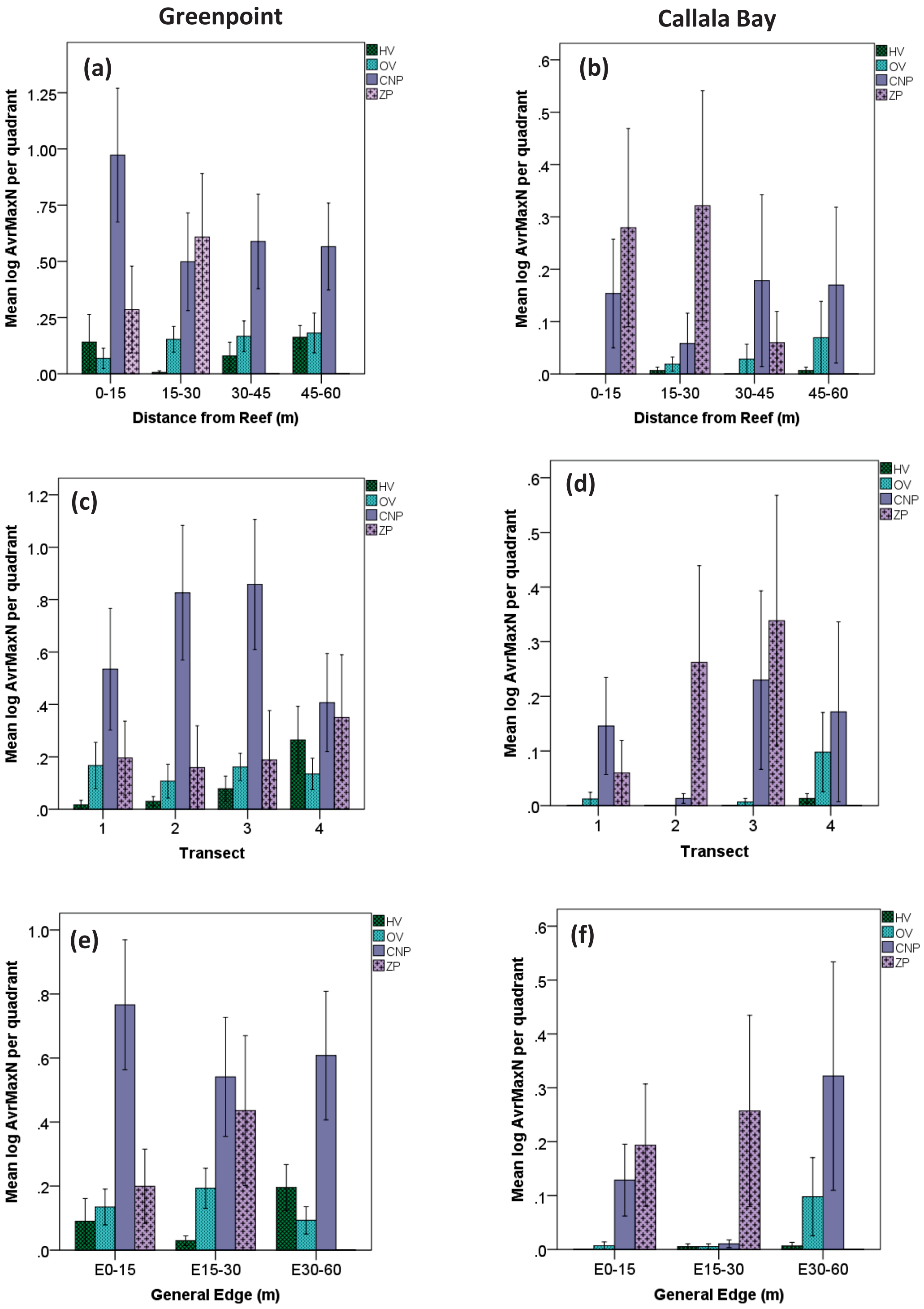


Fig 3.10 Distribution of FMFG guilds (AvrMaxN) with increasing distance from (a,b) rocky reef, (c,d) bare sediment (increasing transect number) and (e,f) general edge at both sites for the summer sampling session only. *Letters above bars represent the results of pairwise comparisons of log-transformed data with distance categories lacking similar letters being significantly different from each other*.

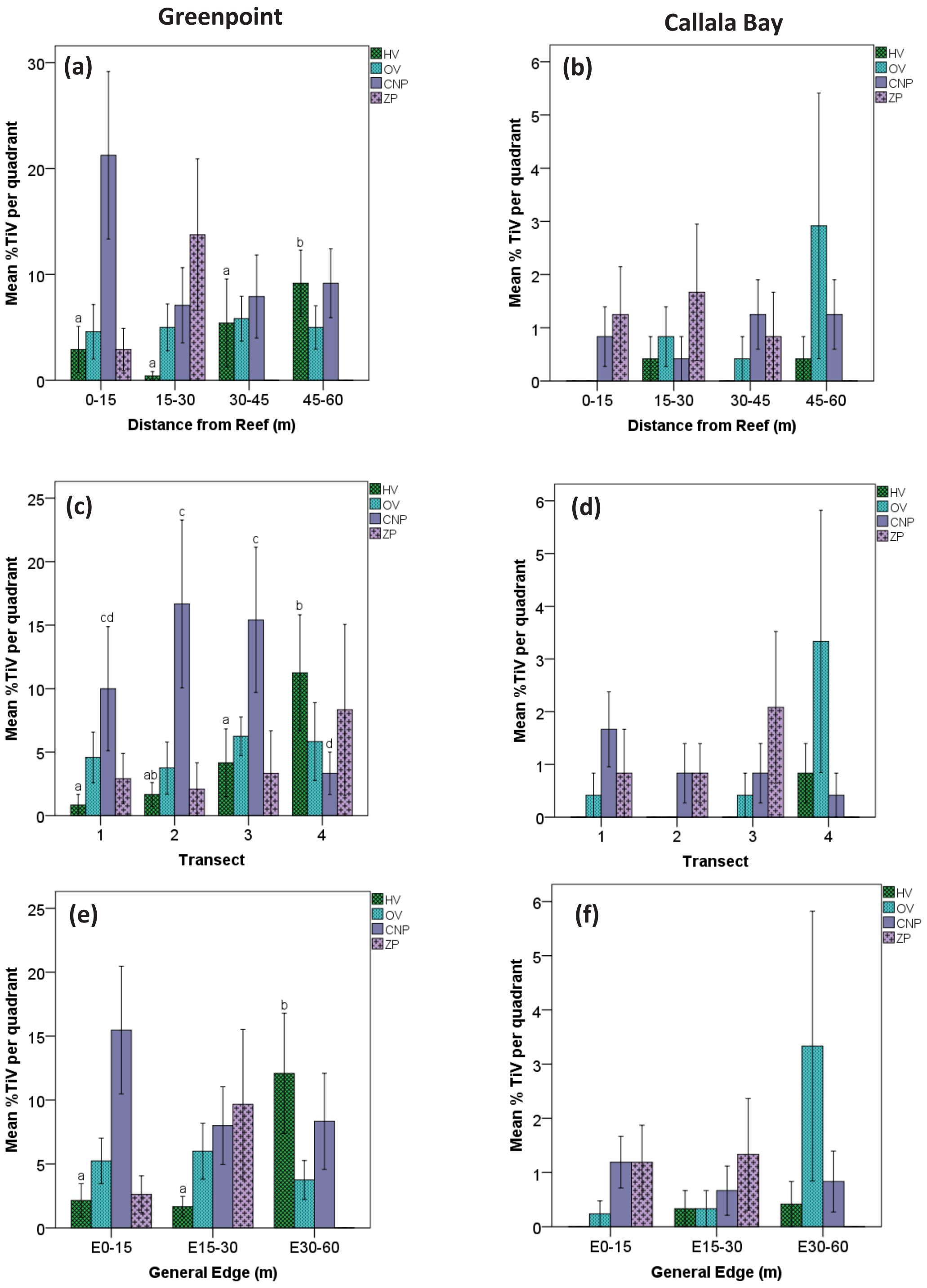


Fig 3.11 Distribution of FMFG guilds (%TiV) with increasing distance from (a,b) rocky reef, (c,d) bare sediment (increasing transect number) and (e,f) general edge at both sites for the summer sampling session only. *Letters above bars represent the results of pairwise comparisons of log-transformed data with distance categories lacking similar letters being significantly different from each other.*

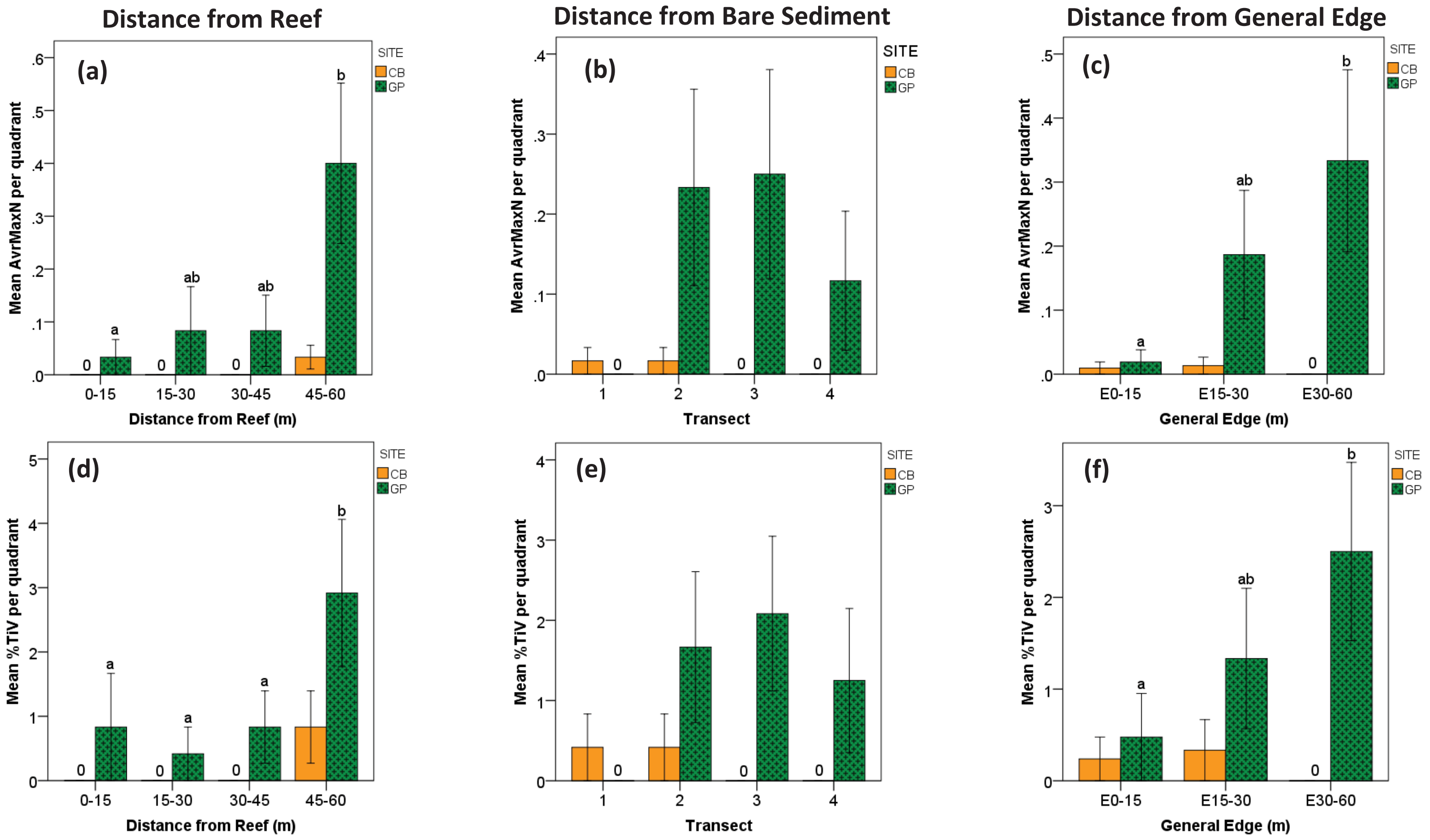


Fig 3.12 Distribution of CNP (excluding Atherinidae) using AvrMaxN (a-c) and %TiV (d-f) measures with increasing distance from rocky reef, bare sediment (increasing transect number) and general edge at both sites for the summer sampling session only. *Letters above bars represent the results of pairwise comparisons of log-transformed data with distance categories lacking similar letters being significantly different from each other; CB – Callala Bay, GP – Greenpoint.*

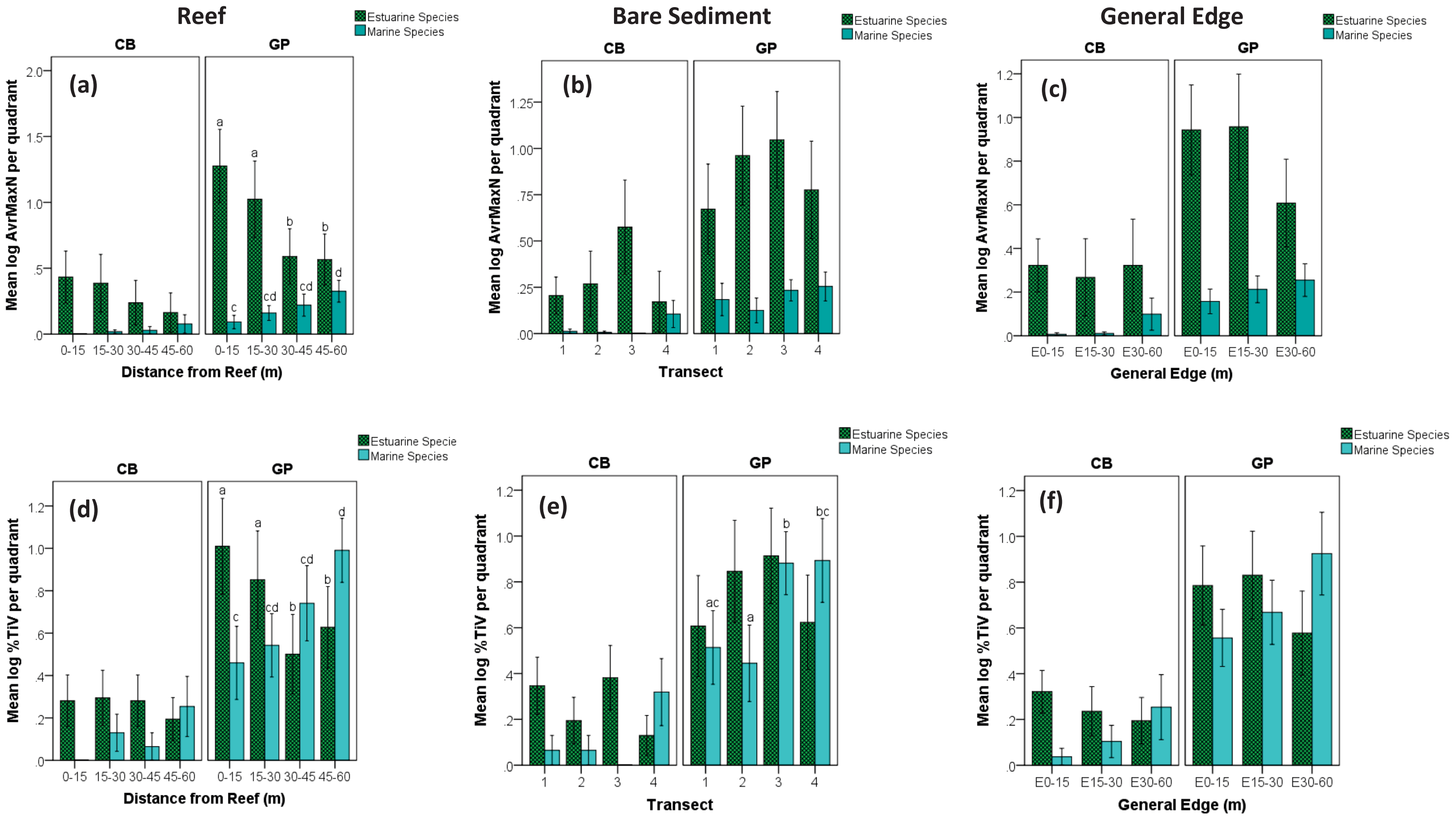


Fig 3.13 Distribution of collated EUFG guilds – Estuarine and Marine Species, using AvrMaxN (a-c) and %TiV (d-f) measures with increasing distance from rocky reef, bare sediment (increasing transect number) and general edge at both sites for the summer session only. *Letters above bars represent the results of pairwise comparisons with distance categories lacking similar letters being significantly different; bar lettering of each subsequent bar category begin with the letter following alphabetically the highest lettering of the bar category immediately before; CB – Callala Bay, GP – Greenpoint.*

Table 3.7 Summary statistics of PERMANOVA analysis of number of foraging events and physical habitat position occupied by sampled fish taxa with distance in all three planes: "Reef", "Bare Sediment" and "General Edge" at Greenpoint in the summer sampling session. *"Distance from Reef" and "Distance from Bare Sediment" categories collapsed to form two categories each: 0-30m and 30-60m, 0-30m+ and 30-60m+ respectively*.

	df	**MS**	***pseudo-F***	**p**	**Pairwise comparison (p)**
Foraging Events					
"Reef"	1	1.027	3.9157	0.05	**0.0473** (0-30m vs 30-60m)
"Bare Sediment"	1	7.0575E^{-2}	0.24375	0.6371	
"General Edge"	2	0.27207	0.81638	0.4709	
Physical Position:					
Seagrass Canopy					
"Reef"	1	1.4691	2.5738	0.1157	
"Bare Sediment"	1	2.4324	4.2616	**0.0468**	**0.0442** (0-30m+ vs 30-60m+)
"General Edge"	2	0.75877	1.1318	0.3289	
Midwater Column					
"Reef"	1	0.351	0.54999	0.4606	
"Bare Sediment"	1	0.20296	0.31802	0.5697	
"General Edge"	2	1.0263	1.4121	0.2502	

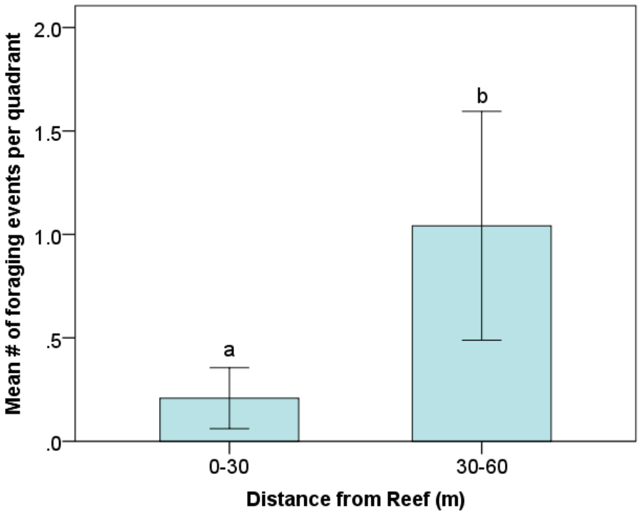


Fig 3.14 Number of viewed foraging events at two distance categories from the rocky reef at Greenpoint only in the summer sampling session. *Letters above bars represent the results of pairwise comparisons of log-transformed data with distance categories lacking similar letters being significantly different from each other.*

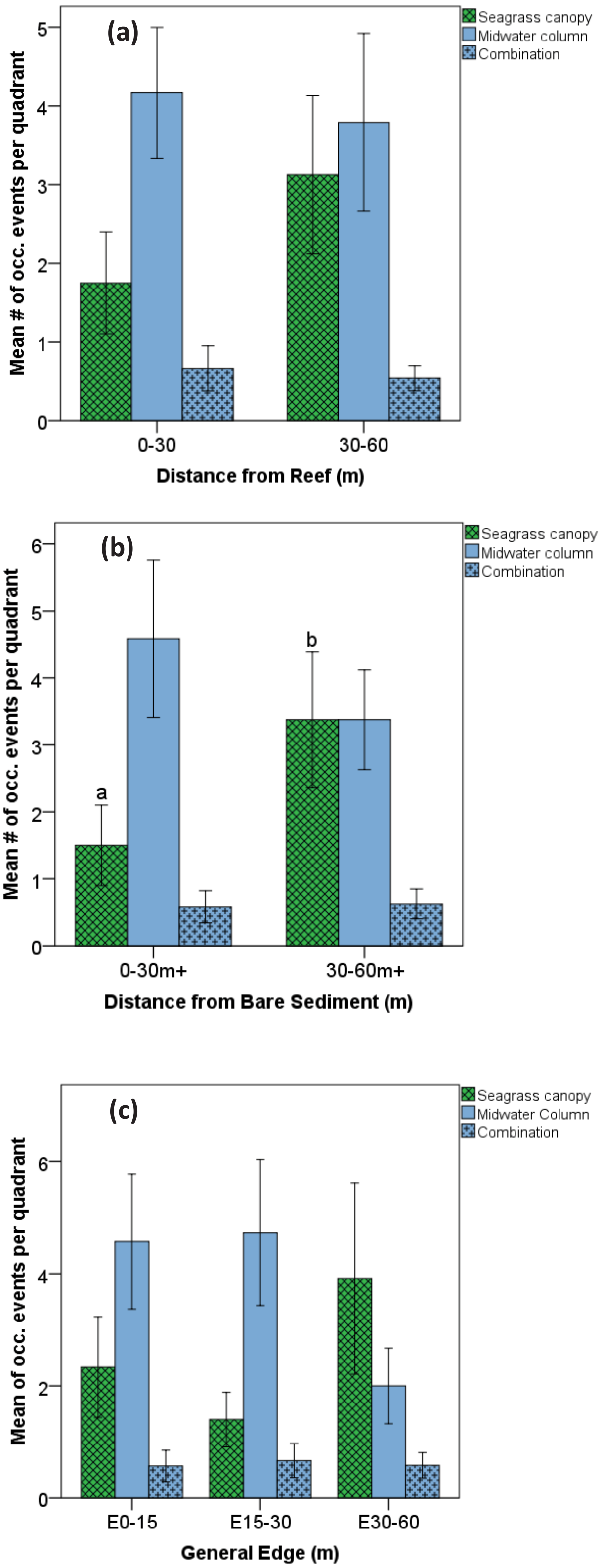


Fig 3.15 Number of occurrence events in different seagrass habitat vertical positions with increasing distance from the (a) reef, (b) bare sediment and (c) general edge at Greenpoint only in the summer. *Letters above bars represent the results of pairwise comparisons of log-transformed data with distance categories lacking similar letters being significantly different.*

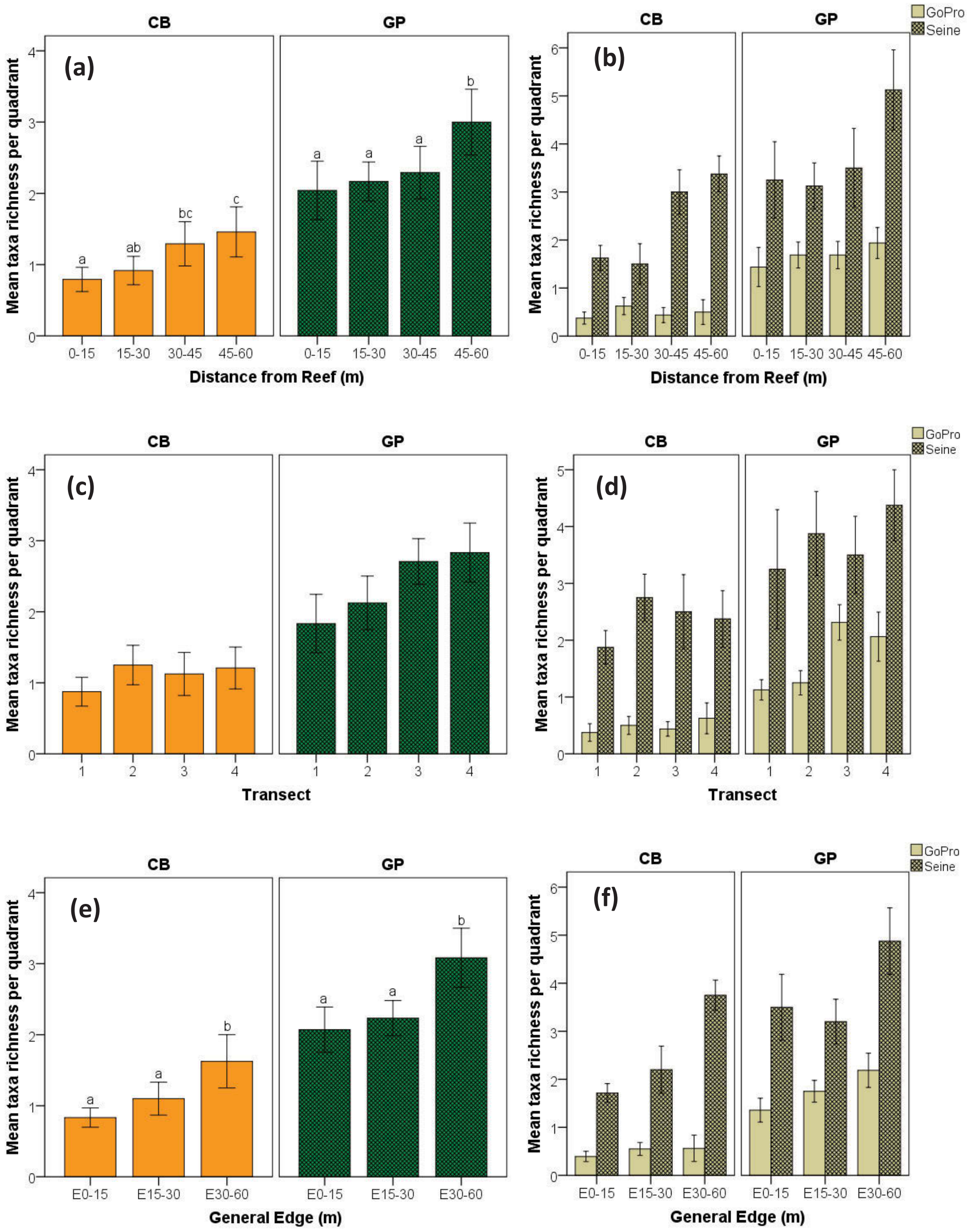


Fig 3.16 Combined methods: taxa richness with increasing distance from (a,b) rocky reef, (c,d) bare sediment (increasing transect number) and (e,f) general edge at both sites across both seasons. *Letters above bars represent the results of pairwise comparisons with distance categories lacking similar letters being significantly different from each other; left panel graphs (a,c,e) represent mean values incorporating both sampling methods.*

Table 3.8 Combined methods: PERMANOVA summary statistics including significant factor interactions and pairwise comparisons for taxa richness with distance in all planes: (a) “reef” and “bare sediment” and (b) “general edge” incorporating both sampling methods and seasons at each site. *“D1 – D4” denotes “Distance from reef” categories while “E1 – E3” denotes “Distance from general edge” categories; significant interaction terms here presented.*

(a)	**df**		**MS**		**Pseudo-F**		**P**	
	CB	**GP**	**CB**	**GP**	**CB**	**GP**	**CB**	**GP**
Method (Me)	1	1	76.255	84.122	99.877	48.989	**0.0001**	**0.0001**
Season (Se)	1	1	0.16875	18.583	0.25312	10.822	0.623	**0.0046**
“Reef” (Di)	3	3	4.6997	5.9825	6.1555	3.484	**0.0005**	**0.0436**
“Bare Sediment” (Tr)	3	3	1.2521	4.5007	1.8781	2.621	0.1841	0.097
Me×Se		3		15.554		9.058		**0.0074**
Me×Di	3		5.0885		6.6648		**0.0004**	
Me×Se×Tr		3		6.2751		3.6543		**0.0334**

(a)	**D1**		**D2**		**D3**		**D4**	
	CB	**GP**	**CB**	**GP**	**CB**	**GP**	**CB**	**GP**
D1 (0-15m)			n.s	n.s	**0.0029**	n.s	**0.0005**	**0.0218**
D2 (15-30m)	n.s	n.s			n.s	n.s	**0.0049**	**0.0051**
D3 (30-45m)	n.s	n.s	n.s	n.s			n.s	**0.0273**
D4 (45-60m)	n.s	n.s	n.s	n.s	n.s	n.s		

(b)	**df**		**MS**		**Pseudo-F**		**P**	
	CB	**GP**	**CB**	**GP**	**CB**	**GP**	**CB**	**GP**
Method (Me)	1	1	85.31	79.428	113.71	35.635	**0.0001**	**0.0001**
Season (Se)	1	1	0.2739	15.313	0.36881	6.87	0.5446	**0.0123**
“General Edge” (Ed)	2	2	8.3114	9.8184	11.078	4.405	**0.0002**	**0.0151**
Me×Se		1		16.267		7.2981		**0.008**
Me×Ed	2		6.19		8.2504		**0.0002**	

(b)	**E1**		**E2**		**E3**	
	CB	**GP**	**CB**	**GP**	**CB**	**GP**
E1 (0-15m)			n.s.	n.s	**0.0001**	**0.0101**
E2 (15-30m)	n.s	n.s			**0.0102**	**0.0138**
E3 (30-60m)	n.s.	n.s	n.s.	n.s		

Table 3.9 Combined methods: PERMANOVA summary statistics and pairwise comparisons of community distribution (as individual taxa and functional group classification) and select functional guilds displaying significant trends from the generated "presence/absence" matrix with distance from "reef", "bare sediment" and "general edge". *Both sites, seasons and sampling methods incorporated; "Me" denotes fish sampling method*.

Distance from Reef | Factors Included in Model | Pairwise Comparisons

Community Data:	df	MS	pseudo-F	p	Di	Tr	Si	Se	Me	D1-D2	D1-D3	D1-D4	D2-D3	D2-D4	D3-D4	Permdisp
Individual Taxa	3	2342.2	2.4965	**0.0451**	*		*		*		**0.0476**	**0.0256**				0.154
FMFG	3	2.4618	3.1372	**0.0237**	*		*		*			**0.0418**		**0.029**		0.068
CNP	3	0.75694	4.037	0.1675	*		*		*							
ZP	3	0.31493	2.4431	0.0668	*	*		*	*					**0.0078**	**0.0376**	0.05
EUFG	3	0.98264	3.1798	**0.0404**	*	*	*		*	**0.0028**		**0.0438**				0.344
MM	3	0.24132	12.636	**0.0317**	*		*									0.191

Distance from Bare Sediment | Factors Included in Model | Pairwise Comparisons

Community Data:	df	MS	pseudo-F	p	Di	Tr	Si	Se	Me	T1-T2	T1-T3	T1-T4	T2-T3	T2-T4	T3-T4	Permdisp
Individual Taxa	3	2108.9	1.434	0.2538	*	*	*	*	*							
FMFG	3	0.61354	0.77534	0.6634	*	*	*	*	*							
CNP	3	0.13194	0.7073	0.6065	*	*	*		*							
ZP	3	0.24271	1.8828	0.1403	*	*		*	*							
EUFG	3	0.55903	2.2676	0.11	*	*	*		*							
MM	3	0.15799	2.1163	0.3483	*	*	*									

Distance from General Edge | Factors in Model | Pairwise Comparisons

Community Data:	df	MS	pseudo-F	p	Ed	Si	Se	Me	E1-E2	E1-E3	E2-E3	Permdisp
Individual Taxa	2	4074.6	2.7635	0.1395	*	*	*	*				
FMFG	2	1.993	11.79	**0.0037**	*	*		*	0.0233	0.0185		**0.043**
CNP	2	0.51295	17.677	**0.0423**	*	*		*	**0.0001**			0.192
ZP	2	0.124	7.3548	0.163	*	*	*	*				
EUFG	2	1.5784	7.0666	**0.0093**	*	*		*		**0.0101**		0.21
MM	2	$6.775E^{-2}$	2.303	0.3519	*	*	*	*				

Interaction terms not presented in table for logistics purposes. As described in General Discussion (6.6.1) interaction terms were evaluated to determine statistical approach and/ or cited in the text and subsequently discussed where highly significant terms may influence valid interpretation of data.

Table 3.10 Combined methods: Percent contribution by individual guilds in SIMPER analysis at distance categories having significant ($p<0.05$) pairwise comparisons for functional group community distribution with “Distance from reef” (unshaded boxes) and “Distance from general edge” (shaded boxes). *“D1, D2 and D4” denote “Distance from reef” categories while “E1 and E3” denote “Distance from general edge” categories*.

Feeding Mode Functional Groups

Individual guilds:	**D1-D4**	**D2-D4**	**E1-E3**
CNP	32.08	29.89	30.51
OV	24.99	24.31	24.50
ZP	22.25	23.28	23.64
HV	20.67	22.52	21.35

Estuarine Use Functional Groups

Individual guilds:	**D1-D2**	**D1-D4**	**E1-E3**
EM	40.43	33.46	32.37
MM	27.73	30.19	32.15
ER	26.37	29.42	31.01

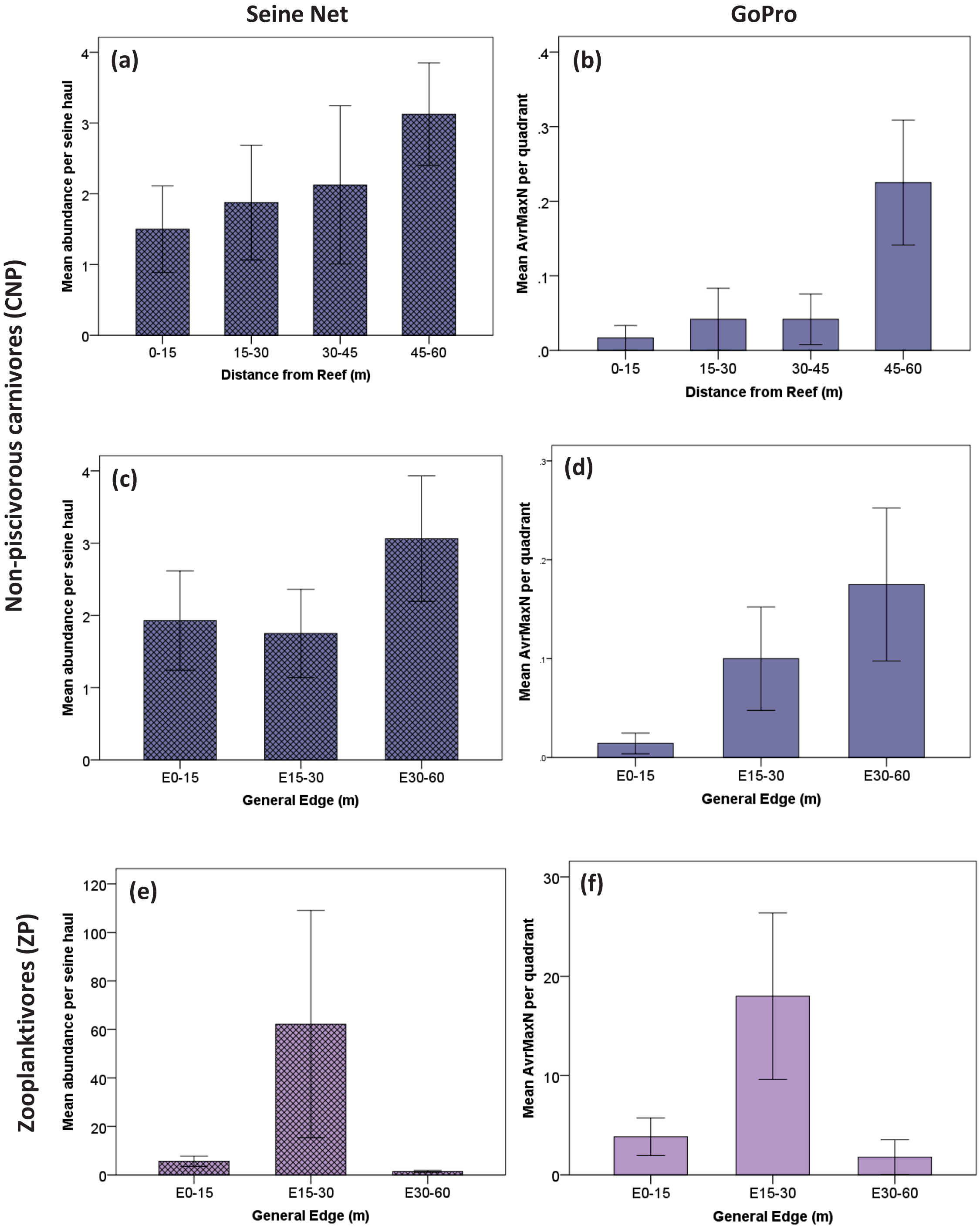
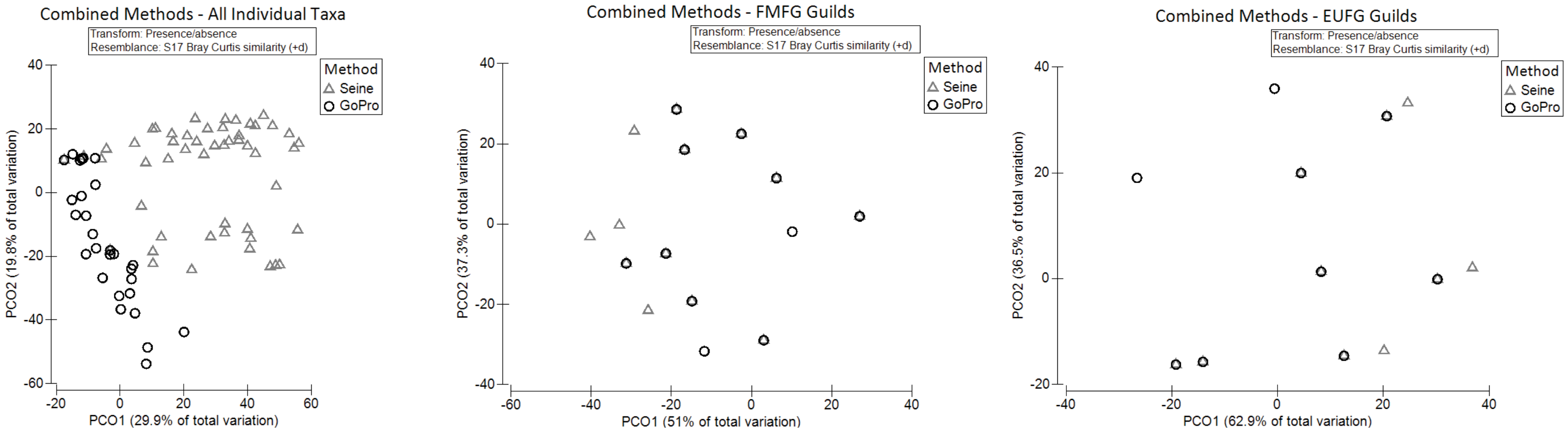


Fig 3.17 Consistency in distribution of total CNP (excluding atherinidae) (a-d) and ZP (e,f) across both sites and seasons between sampling methods with increasing distance from rocky reef and general edge.



(a) **(b)** **(c)**

Fig 3.18 PCO plots of community data converted into a "presence/absence" matrix with community represented as (a) individual species/taxa, (b) FMFG guilds and (c) EUFG guilds.

Chapter 4: ***Distribution of Prey Community (Zooplankton and Benthic Invertebrates) and Epiphyte Load Measures within P. australis with Respect to the Different Habitat Edge Types***

4.1 Introduction

Fish individuals will tend to choose positions in their habitat best suited to their survival (Anderson et al. 2009; Bell & Westoby 1986b; Cheminée 2012; Cocheret de la Morinière et al. 2004; Legendre, Galzin & Harmelin-Vivien 1997; Levin et al. 2000; Pérez-Matus & Shima 2010). These decisions are often driven by the availability of adequate food supplies (Jenkins & Hamer 2001) and shelter from predation (Gullström et al. 2011; Nagelkerken et al. 2000; Smith et al. 2011) or from other undesirably environmental conditions that threaten their growth rate and survival.

Understanding the factors influencing seagrass fish community structure, species richness and the distribution of individual fish taxa and functional groups with distance from a particular adjacent habitat or edge *per se* is an essential aspect of adjacent habitat and “edge” studies (Ries et al. 2004) as it forms the underlying basis for the observed response to the seagrass habitat’s edge. Ries & Sisk (2004) put forward a predictive model describing how organisms’ distribution will vary with edge based solely on resource availability, with “resource” including food availability along with, nest sites, service-providers or favourable abiotic features such as light (Ries & Sisk 2004).

This model put forward by Ries & Sisk (2004) described the response as “positive” (increasing towards the edge), “negative” (increasing away from the edge) or “neutral” (no trend with edge) hinging primarily on whether the adjacent possesses complementary (different and favourable) or supplementary (similar to that within resident habitat) resources. In essence, the model confers that if the adjacent habitat is of equally good quality and possesses complementary resources then there will be a positive response by the organism. If, however, it offers a supplementary resource, then there would be no benefit to the organism of approaching the adjacent habitat, hence a neutral response. A positive response is also predicted to occur if the adjacent habitat is of poorer quality but possesses complementary resources, as the organism may more conveniently access both in this position i.e. closer to the resident habitat’s edge and not within the adjacent habitat itself. The authors however concede that this model is based on a simple landscape of two habitats adjacent to each other and noted that the strength or existence of a trend with edge may be influenced by a host of factors including (i) the type of edge (Fagan, Cantrell & Cosner 1999; Ries et al. 2004), (ii) edge orientation (Tanner 2003) and (iii) edge contrast (Ries et al. 2004); (iv) the species in consideration (Fagan, Cantrell & Cosner 1999) – it's size, range of mobility and perception of edge (Burel & Baudry 2003); (v) local environmental factors affecting resource distribution at the edge and (vi) any predicted change in resource use by the species across space and time (Ries & Sisk 2004).

Mapping on of fish to its prey

A key principle stemming from Ries & Sisk (2004) is the "resource mapping" (Ries et al. 2004) of organisms in their distribution to that of their prey i.e. the *sensitivity* or strength of response of an organism to a particular adjacent habitat edge and the *direction* of this sensitivity/response (positive or negative) may depend heavily on the sensitivity and direction of sensitivity of its prey. Sampling of the seagrass fish community at the two locations in Jervis Bay (Chapters 2 and 3) indicated the dominance of non-piscivorous carnivores (benthic invertebrate feeders), zooplanktivores, and grazing on epiphytic material, the latter by at least one dominant marine migrant species utilizing the seagrass, *Girella tricuspidata*. Understanding how the prey items of these fish functional guilds i.e. benthic invertebrates, zooplankton and seagrass epiphytic material are distributed with respect to the two adjacent habitat edges is essential in explaining the fish's own distribution and sensitivity to these habitat edges (Ries et al. 2004; Ries & Sisk 2004). This is especially important as aforementioned, prey availability will influence the abundance of its predators (Bologna & Heck 2000; Jenkins & Hamer 2001; Macreadie et al. 2010; Moore & Hovel 2010) and hence determine the predator's distribution (Ries et al. 2004; Ries & Sisk 2004). Macreadie et al. (2010) for instance found higher zooplanktivorous pipefish abunadances closer to the seagrass-sand edges where zooplankton abundances were also at its peak. Moore & Hovel (2010) additionally found higher fish prey abundances in the seagrass interior which corresponded to higher cryptic fish abundances in the same area. Higher bivalve densities in yet another study was also linked to the presence of its epiphyte prey (Bologna & Heck 2000). These and several other studies highlight the importance of prey distribution in influencing the abundance and by extension distribution of their predators.

It is important also to note that these prey communities themselves respond to varying local environmental conditions (Boström & Bonsdorff 2000; Bustamante & Branch 1996; Helmuth et al. 2006; McQuaid & Branch 1984; Posey & Ambrose Jr 1994; Tuya et al. 2010) that may change with distance from edge habitats (Murcia 1995). Food intake by key fish species at varying positions from a particular edge type may also give additional insight into what prey items are more important in these habitat positions. As seagrass blade length, width and area may influence epiphyte load, investigating these blade metrics may also give further insight into the interactions and cascading effects on fish distribution within the seagrass bed with distance from the adjacent habitats, in an attempt to elucidate the mechanisms structuring the fish community. As such the main aim of this chapter is to evaluate the distribution of the prey items of main the fish functional guilds mentioned above, sampled in the same locations (Chapters 2 and 3) in order to elucidate relationships between the prey and fish distributions. Reference is also made to the results of gut content analysis (Appendix IIA) of select fish taxa collected along the identical seagrass positions in order to determine any differential utilization of prey at different positions from the edge habitats.

Specific questions being addressed by this chapter

1. Is there a difference in community structure, total abundance and taxa-specific abundance of zooplankton in the sampled seagrass beds with distance from the rocky reef, bare sediment or edge *per se*?

2. Is there a difference in community structure, total abundance, taxa-specific abundance and size-class specific abundance of benthic invertebrates in the sampled seagrass beds with distance from the rocky reef, bare sediment or edge *per se*?

The distribution of the benthic invertebrate community at one of the two sites, Callala Bay, with respect to the reef and bare sediment is described in published literature (Ollivier et al. 2015) done in association with this dissertation and has been placed as the final Appendix in this thesis. The benthic invertebrate community at Greenpoint and size class distribution at both sites, as this was not addressed in the above published work is here presented. Reference, however, is made to results from Callala Bay in the Discussion.

3. Is there a difference in seagrass epiphyte load measures with distance from the rocky reef, bare sediment or edge *per se*?

4. Can any trend in seagrass epiphyte load with distance in any direction be explained by seagrass leaf morphology?

Null hypotheses tested:

1. There is no difference in a. community structure, b. total abundance and c. taxa-specific abundance of zooplankton in the sampled seagrass beds with distance from the rocky reef, bare sediment or edge *per se*.
2. There is no difference in a. community structure, b. total abundance, c. taxa-specific abundance and c. size-class specific abundance of benthic invertebrates in the sampled seagrass beds with distance from the rocky reef, bare sediment or edge *per*.
3. There is no difference in seagrass epiphyte load metrics with distance from the rocky reef, bare sediment or edge *per se*.
4. There is no correlation between seagrass epiphyte load metrics and blade metrics.
5. There is no difference in edge response with respect to the unique habitat edge types for a. the zooplankton community, b. the benthic invertebrate community and c. epiphyte load metrics.

Rationale:

Answers to the research questions stated above provide useful insight into the reason behind seagrass fish responses to differing adjacent habitat edge types at the community, taxa and functional group levels on the mesoscale (tens of meters) spatial scale. Information gained will be useful in developing a predictive framework outlining factors influencing and mechanisms determining the strength and direction of sensitivity of fish taxa and functional groups utilizing these prey communities to the relevant habitat edge types.

4.2 Methods

4.2.1 Zooplankton

Zooplankton collection

Zooplankton samples were collected from within the same sixteen 15m × 15m sampling units/quadrants (as described in Chapters 2 and 3) within *Posidonia australis* at each of two sites in Jervis Bay – Callala Bay and Greenpoint. The collection positions i.e. the quadrants at each site for this and all other prey communities and blade morphological characteristics were identical to the positions from which fish were collected. Zooplankton collection was done once weekly for three weeks between January and February 2014 (austral summer) in each position (n=96). Collection was done with an 85 µm mesh, approximately 50cm long plankton net with the opening ring diameter being 15 cm at the smaller and approximately 22.8 cm at the larger of the two rings (Fig 4.1). The net was held in a horizontal manner as illustrated in Fig 4.1 and while holding opposite ends as illustrated, was dragged through the water column just above and including the top surface of the seagrass canopy at a consistent pace in an S-shaped manner as shown in Fig 4.2 within each quadrant. The path covered approximately 55m within each quadrant with the filtrate being collected in a 120 ml collection bottle fixed to the end of the net. At the end of each tow the sides of the net were washed with seawater to dislodge any plankton on the sides into the collection bottle. The filtrate was then transferred into opaque previously labelled wide mouthed plastic bottles, covered and placed on ice.

All collections were done in daytime hours between 7:30 am and 6:00 pm within one hour before and after peak low tide. All weekly collections from the sixteen locations for each site was collected on the same day and completed within an hour.

Zooplankton Collection Times:

Callala Bay

Week 1: January 15, 2014 (2:15 – 3:15pm)

Week 2: January 26, 2015 (10:30 – 11:30am)

Week 3: February 20, 2014 (5:00 – 6:00pm)

Greenpoint

Week 1: January 14, 2014 (2:45 – 3:45pm)

Week 2: January 27, 2015 (11:30am – 12:30pm)

Week 3: February 22, 2014 (7:30 – 8:30am)

Fig 4.1 Zooplankton net, with collection sample bottle attached for zooplankton collection

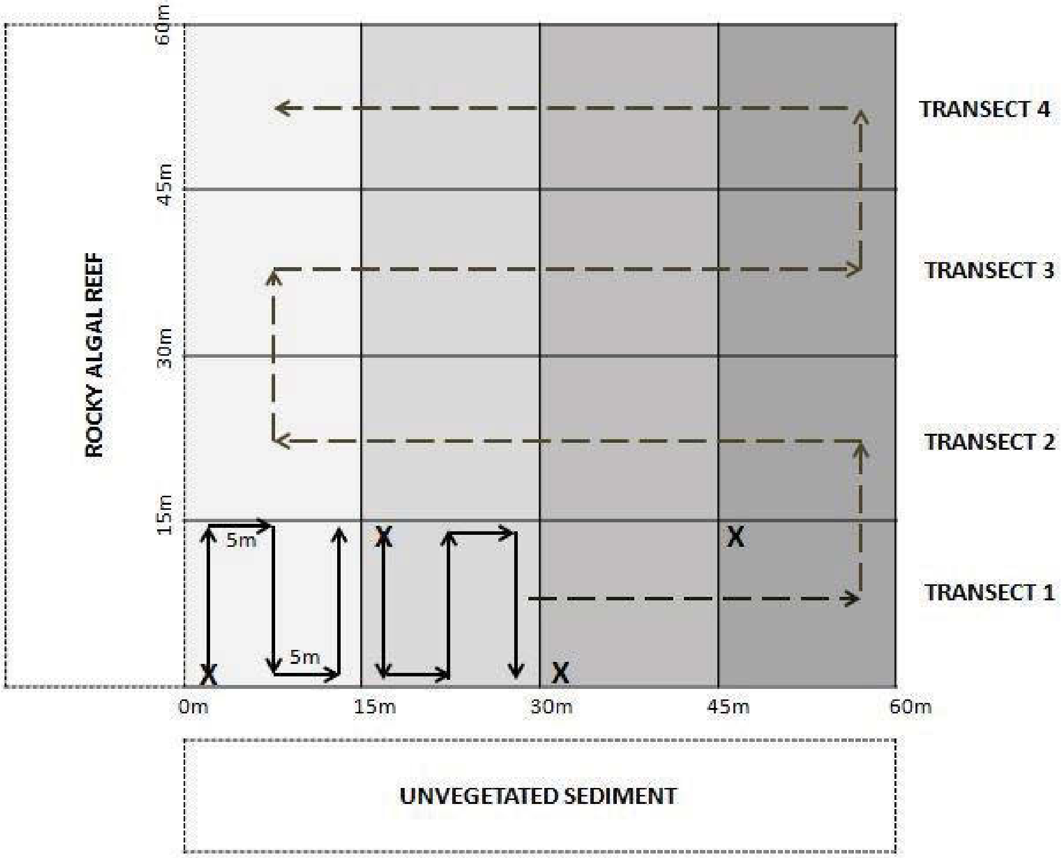


Fig 4.2 Zooplankton sampling S-path method applied to each sampling unit (15×15m quadrant). ***X** denotes the starting position of the S-path within each quadrant; broken arrows indicate the direction of zooplankton collection on each sampling occasion at each site*.

Zooplankton processing

Within one to two hours of collection the filtrate was taken from the ice and filtered through ash-free filter paper to remove the seawater. The zooplankton residue was fixed while on the filter paper with 95% alcohol for 15 seconds (Black & Dodson 2003). It was then transferred to 200 ml of 70% ethanol for storage (Black & Dodson 2003) which was later diluted to 400 ml with 70% alcohol in the lab before counting due to the high zooplankton density within samples.

Three 20 ml aliquots were removed from each sample bottle containing the 400 ml with a syringe while the bottle was constantly agitated. The aliquots were transferred to a modified counting S-tray with 1cm wide, 0.5 cm deep convoluted grooves. Counts were made under a Leica compound microscope of each individual encountered in each aliquot, each of which was identified to the lowest discernible taxonomic group. The counts from the three aliquots from each quadrant were then averaged to give a final value for each taxonomic group for each seagrass position, sampling session and site (n=96) which was used in data analysis.

4.2.2 Benthic invertebrates

Benthic invertebrates were collected from within each 15m × 15m quadrant (described in Chapters 2 and 3) within the *Posidonia australis* seagrass beds from six haphazardly, blindly chosen positions within each quadrant. Samples were taken with a benthic corer of approximately 9cm internal diameter inserted up to 10 cm within the sediment. The sediment and invertebrate samples within collected were then transferred to already labelled bags and 90-95% ethanol added within each bag on site to preserve the organisms.

Once at the laboratory, the sediment was sieved with a 1mm diameter sieve and the invertebrates from each core picked out and stored in 90% ethanol. The invertebrates from four of the six cores from each quadrant were then identified to species level (Greenpoint) and tallied. Numbers of individuals per replicate core per seagrass position was used in data analysis. The other two cores were initially used to provide a species list of invertebrates found within the core samples and were not included in the data analysis. Benthic invertebrate collection was done in the summer sampling session only following sampling of other parts of the ecosystem as described in this research to avoid disruption of the habitat. Although minor, such disruption may have otherwise affected the distribution of other organisms.

4.2.3 Shoot density, blade metrics and epiphyte load

Seagrass shoot density

Three 50cm × 50cm quadrats were haphazardly thrown within each 15m × 15m quadrant sampling unit within the *Posidonia australis* bed at each site. All shoots within each of the three 0.25 cm^2 quadrats were counted and the values converted to $\#/m^2$. Each shoot consisted of between three to four blades. This was done on one occasion in the January 2014 coinciding with the austral summer sampling session.

Seagrass blade metrics and epiphyte load measures

Fifteen shoots were haphazardly chosen and removed from within each 15m × 15m sampling unit at each site in January 2014. The shoots were put on ice at the collection site and transferred to a minus 20° C freezer on reaching the laboratory. The lengths and widths of the blades from these fifteen shoots collected from within each sampling unit were recorded and then placed in a holding tray with tap water just covering the extended blades. The blades were here scraped with a razor of all epiphytic growth, which comprised primarily of attached macroalgae and to a lesser extent encrusting algal forms, into the water forming an epiphyte slurry. The blades were then removed and the slurry poured through a 63µm sieve. The resulting residue was wet weighed on a Sartorius CP224S Analytical Balance as were the scraped seagrass blades. The dry weight and ash-free dry weight of the both the scraped seagrass and the epiphytes were obtained for each sampling unit. The dry weight was obtained by drying at 80°C for 72 hrs (Gullström et al. 2011) while ash-free dry weight was obtained by combustion within a muffle furnace at 550°C for 4 h (Lee, Fong & Wu 2001). The following measures of epiphyte load were calculated:

$$\text{Epiphyte load index} = \frac{\text{weight (AFDW) of epiphyte}}{\text{mean LL} + \text{mean LW} + \#\text{ of blades}}$$

(Jackson et al. 2006)

$$\text{Epiphyte biomass load per seagrass (gram per gram)} = \frac{\text{AFDW of epiphyte (g)}}{\text{AFDW of seagrass (g)}}$$

(Myers & Virnstein 2000)

where AFDW = ash-free dry weight; LL = leaf length and LW = leaf width

Statistical analysis

Zooplankton distribution

Multivariate PERMANOVA was performed on the zooplankton community data with the averages of the three aliquot subsamples counted from each position taken as individual data points for each taxa for each site on each of the three weekly sampling occasions (n=96). Community composition and distribution of individual taxa were analysed using two separate orthogonal designs:

Design 1: "distance from reef" – Di (fixed), "distance from bare sediment" – Tr (fixed), "site" – Si (random), "week" – wk (fixed) and their interactions *and*

Design 2: "distance from general edge" – Ed (fixed), "site" – (Si) random, "week" – wk (fixed) and their interactions

The justification for treatment of "week" as a fixed factor is as described in Section 3.2 (*Statistical Analyses*). PCO analyses of the zooplankton community structure at both sites at the three weekly collections illustrate that an identical community composition was not being removed from the water column on each occasion at each site, effectively ruling out pseudo replication. This difference is not surprising considering the dynamic nature of this group of organisms. Relevant PCO plots are displayed in the final Appendix of this thesis (Appendix III).

Benthic invertebrate distribution

Multivariate PERMANOVA was performed on the benthic invertebrate community data as total abundance, community composition, community composition with size class labels and for each individual major family (Greenpoint only) using two separate orthogonal designs:

Design 1: "distance from reef" – "Di" (fixed), "distance from bare sediment" – "Tr" (fixed) along with their interaction and

Design 2: "distance from general edge" – "Ed" (fixed).

Size class distribution, i.e. both the trend in the size class combination and individual size classes within seagrass positions with respect to both edge habitat types and general edge at both sites were similarly analysed as above but included the effect of site as follows:

Design 1: “distance from reef” – “Di” (fixed), “distance from bare sediment” – “Tr” (fixed) and “site” – Si (random) along with their interactions *and*

Design 2: “distance from general edge” – “Ed” (fixed) and “site” – Si (random) along with their interaction

Principle Coordinates (PCO) analysis was performed on the community data of both benthic invertebrates and zooplankton to view the change in distribution with distance in all planes i.e. with respect to reef, bare sediment and general edge and included where appropriate. SIMPER analysis was also done on each significant community trend to ascertain the groups with the greatest contributions to the observed trends. All analysis was done in PRIMER 6 version 6.1.13 and PERMANOVA + version 1.0.3.

Seagrass blade metrics and epiphyte load measures

Variation in seagrass shoot density, blade length, width and area, and both measures of epiphyte load index based on AFDW values i.e. epiphyte/seagrass (g/g) and the calculated epiphyte load index were analysed with respect to distance from each habitat edge type and general edge using the following orthogonal designs in PRIMER 6 version 6.1.13 and PERMANOVA + version 1.0.3:

Design 1: “distance from reef” – “Di” (fixed), “distance from bare sediment” – “Tr” (fixed) and “site” – (Si) random along with their interaction *and*

Design 2: “distance from general edge” – “Ed” (fixed) and “site” – (Si) random along with their interaction

Pearson Correlation, in SPSS Statistics 22, was also performed between the averages of the seagrass morphological metrics i.e. blade length, width and area within each quadrant and the associated epiphyte/seagrass (g/g) epiphyte load measure. Each variable was assessed for its normal distribution using the Shapiro-Wilk test also in SPSS. As the calculated epiphyte load index has already incorporated blade length and width in its calculation, correlation between seagrass blade metrics and this measure of epiphyte load was not performed.

Other general statistical applications

Unless otherwise stated all data were log transformed to achieve to achieve homogeneity of variances around each factor. Where homogeneity was not achieved even after log transformation the significance level was set at $p \leq 0.01$ (Underwood 1981). Whether homogeneity of variances was achieved or not is indicated throughout the subsequent Results section with homogeneity of multivariate dispersions “permdisp” p-value calculated in PRIMER 6 version 6.1.13 and PERMANOVA + version 1.0.3 reported for each instance of statistical significance. Permdisp p values greater than 0.05 indicate homogeneity of variances. Pairwise comparison of each instance of significance was also performed in this statistical package and indicated in relevant statistics summary tables in the subsequent section. All graphical representation illustrating significant variation represents analysis performed on log-transformed data.

For PERMANOVAs including more than two factors, factors displaying a highly non-significant effect ($p \geq 0.2$) were removed from the analysis and the statistical test rerun as described in Chapters 2 and 3. Where removal of the highly significant factor did not affect the p-value of the remaining factors, the highly significant factor was retained. The factors retained in the statistical model for each significant trend observed are noted in the summary statistics table where applicable throughout the Results section.

4.3 Results

4.3.1 Zooplankton distribution

4.3.1.1 Overall analysis

A total of 62,366 individuals from 47 different identifiable taxonomic groups were counted across both sites and all aliquots with approximately 46% of this originating from Callala Bay (28,726 individuals; 47 taxonomic groups) and the remaining 54% (33,640 individuals; 43 taxonomic groups) from Greenpoint. These taxonomic groupings representing the lowest level of identification of each individual (Appendix VII), were combined to form 24 taxonomic groups common to both sites which formed the basis of the zooplankton community analysis. A list of these groups and the number of individuals sampled in each is presented in Tables 4.1 and 4.2.

4.3.1.2 Total abundance

A general increase in total zooplankton abundance was observed at both sites with distance from reef and general edge (Fig 4.3). Callala Bay additionally exhibited a statistically significant increase in distance from the bare sediment (pseudo-*F* = 4.4349; p = 0.0163) (Table 4.3b; Fig 4.3c). Pairwise comparisons at this site in this plane showed a significantly higher abundance of zooplankton at the 45-60m+ position compared to that at the 0-15m+ and 15-30m+ distances (p=0.0072 and p=0.027 respectively) and between the 15-30m+ and 30-45m+ “distance from bare sediment” positions (p=0.0208) (Table 4.3b; Fig 4.3c). The increase in total zooplankton abundance at Callala Bay with distance from general edge was also significant (pseudo-*F* = 7.4639; p=0.002) with the furthest general edge position (E30-60m) hosting significantly higher abundances compared to the E0-15m and E15-30m positions (0.0016<p<0.0056; pairwise comparisons) (Table 4.3c; Fig 4.3e).

4.3.1.3 Zooplankton community composition

The zooplankton community with both sites included varied significantly with “distance from general edge” (pseudo-*F* = 6.0481; p=0.0053) with the community at the immediate general edge position (E0-15m) being significantly different from the two more interior positions, i.e. E15-30m and E30-60m (p<0.05; pairwise comparison) (Table 4.3c). Due to the high significance of the factor “site” in PERMANOVA community analysis in all statistical models with both sites included (p<0.001), the community distribution at both sites was analysed separately.

Greenpoint

The zooplankton community at Greenpoint varied significantly with “distance from reef” (pseudo-*F* = 2.0764; p=0.0189), “distance from bare sediment” (pseudo-*F* = 2.1098; p=0.0241) and “distance from general edge” (pseudo-*F* = 2.0134; p=0.0369) (Table 4.3a-c). For both “distance from reef” and “distance from bare sediment” the zooplankton community at the positions closest to both adjacent habitats (0-15m and 0-15m+ respectively) differed significantly from the community at the furthest distance in its respective plane (p<0.01 – reef, p<0.05 – bare sediment: pairwise comparisons) (Table 4.3a,b). With regards to community variation with general edge, the community at E0-15m differed significantly from that at E15-30m (p<0.05; pairwise comparison) (Table 4.3c).

Callala Bay

The zooplankton community at Callala Bay varied significantly with distance from the bare sediment (pseudo-*F* = 4.6773; p=0.0001) and general edge (pseudo-*F* = 3.9152; p=0.0004) with no significant variation with distance from reef (pseudo-*F* = 1.827; p = 0.0502) (Table 4.3). Pairwise comparison, however, showed a significant difference in community between the closest (0-15m) and furthest (45-60m) “distance from reef” positions (p<0.05). The most significant pairwise comparisons in distance from bare sediment positions lay between the 45-60m+ position and the first two distance categories, 0-15m+ and 15-50m+ (p<0.01) (Table 4.3b). With regards to “distance from general edge” the community at the furthest general edge position differed significantly from the more edge-ward two (p<0.001 with E0-15m; p<0.01 with E15-30m: pairwise comparisons) (Table 4.3c).

4.3.1.4 Major zooplankton taxa

The major zooplankton groups contributing to the significance in community variation in distance along all planes from SIMPER analysis include the cyclopoid and calanoid copepods, ostracods, bivalve larvae, crustacean nauplii and unidentified eggs at Callala Bay, while at Greenpoint harpacticoid and cyclopoid copepods, ostracods, gastropod larvae, crustacean nauplii and unidentified eggs were the more highly contributing taxa (Table 4.4). From SIMPER analysis at statistically significant pairwise comparisons, crustacean nauplii and Ostracoda consistently contributed to greater than 10% to the level of significance for Greenpoint while the Cyclopoida (in all cases) and Bivalvia larvae (5 of 7 cases) contributed to at least 10% to the level of significance at Callala Bay. The above named taxa were also among the most commonly occurring (Table 4.2). PERMANOVA results of the variation in these major groups along with significant pairwise comparisons are presented in Table 4.3 and graphs depicted their general distribution with distance in all planes in Figs 4.4-4.7. Additional graphs depicting abundances with increasing distance from each habitat edge and general edge of each zooplankton taxa, including those outside of these top eight taxa, may be viewed in Appendix VIII.

Groups increasing in abundance with distance from adjacent habitat and general edge

Gastropoda larvae, crustacean nauplii, calanoid and cyclopoid copepods displayed a general increase with distance in at least one plane at either or both sites (Figs 4.4-4.6). The increase in gastropoda larvae was statistically significant with “distance from bare sediment” at both sites (*pseudo-F* = 3.8898; p=0.0176 – GP; *pseudo-F* = 6.0419; p=0.0047 – CB) (Table 4.3b) and with general edge at Callala Bay (*pseudo-F* = 5.4534; p=0.006) (Table 4.3c). The increase in crustacean nauplii was significant with distance from the reef and general edge at Greenpoint (*pseudo-F* = 5.6704; p=0.0026 – reef and *pseudo-F* = 5.3168; p=0.0093 – general edge) (Table 4.3a,c) and from the bare sediment only at Callala Bay (*pseudo-F* = 4.0298; p=0.0125) (Table 4.3b). The calanoid copepods demonstrated a significant increase with distance in all planes at Callala Bay only (*pseudo-F* = 4.4004; p=0.0171 – reef; *pseudo-F* = 18.392; p=0.0001 – bare sediment and *pseudo-F* = 13.093; p=0.0003 – general edge) (Table 4.3a-c). Lastly, cyclopoid copepods increased in abundance with distance in all planes at Callala Bay, significantly so with respect to the bare sediment (*pseudo-F* = 10.819; p=0.0006) (Table 4.3b) and general edge (*pseudo-F* = 8.3699; p=0.0008) (Table 4.3c). This taxa also increased with “distance from reef” at Greenpoint (*pseudo-F* = 3.1808; p=0.051) but displayed a non-significant decrease away from bare sediment (Table 4.3b; Fig 4.5b) with no meaningful trend with distance from general edge (Fig 4.6b). Harpacticoida displayed a general non-significant increase with distance from the reef and general edge at Greenpoint only (Fig 4.7) but decreased in abundance at Callala Bay with distance along these planes (Fig 4.4, 4.6).

It should be noted that the general increase in gastropod larvae (Greenpoint) and Calanoida (both sites) with “distance from bare sediment” occur up to the 30-45m+ position with a decline at the final distance (45-60m+) (Fig 4.5). Pairwise comparisons of abundances of the main zooplankton taxa at varying seagrass positions with distance along all three planes are presented in Table 4.3a-c.

Groups decreasing in abundance with distance from adjacent habitat and general edge

Ostracoda and “unidentified eggs” displayed a general decrease with distance in all planes at both sites (Figs 4.4-4.6). This decrease in ostracoda was statistically significant with “distance from reef” only at Greenpoint (*pseudo-F* = 4.2182; p=0.0216) (Table 4.3a) and with bare sediment (*pseudo-F* = 9.813; p=0.0003) (Table 4.3b) and general edge (*pseudo-F* = 6.5821; p=0.0033) (Table 4.3c) at Callala Bay. The decrease in the unidentified eggs was significant with “distance from reef” at Greenpoint only (*pseudo-F =* 6.3556; p=0.0044) (Table 4.3a). The harpacticoid copepods also decreased significantly with “distance from bare sediment” at Greenpoint only (*pseudo-F =* 3.0421; p=0341) (Table 4.3b; Fig 4.7b).

Bivalve larvae showed no consistent meaningful trend in abundance, apart from a general non-significant increase with “distance from general edge” at Greenpoint (Fig 4.6b) and a statistically significant effect at Callala Bay with distance from the reef (*pseudo-F* = 3.3604; p=0.0401) (Table 4.3a) and general edge (pseudo-F = 3.6861; p=0.0317) (Table 4.3c). Significant pairwise comparisons of the main taxonomic groups at varying seagrass distance positions are presented in Table 4.3a-c.

Larger taxonomic groupings

The three larger taxonomic groupings of “All mollusc larvae”, “All copepods” and “All crustaceans” (including copepods) increased with “distance from reef” at both sites, being statistically significant for the mollusc larvae at Callala Bay only (*pseudo-F* = 3.4304; p=0.0381) (Table 4.3a; Fig 4.8). Mollusc larvae increased significantly at Greenpoint with “distance from bare sediment” (*pseudo-F* = 3.3634; p=0.0317) while total copepod and total crustacean abundances decreased significantly at this site with distance in this plane (*pseudo*-F = 3.0581; p=0.039 and *pseudo-F* = 2.9594; p=0.0452 respectively) (Table 4.3b; Fig 4.8e). Conversely, at Callala Bay total mollusc larvae, copepods and crustaceans increased with “distance from bare sediment” (Fig 4.8b), significantly so for the latter two groups (*pseudo-F* = 11.0009; p= 0.0001 – “all copepods”; *pseudo-F* = 8.0229; p=0.0013 – “all crustaceans”) (Table 4.3b). All three groups increased with “distance from general edge” at both sites (Fig 4.3c,f) with the exception of total crustacean abundance at Greenpoint which displayed no meaningful trend (Fig 4.3f). This increase in abundance with general edge was significant for all three groups at Callala Bay (*pseudo-F* = 5.515; p=0.0083 – “all mollusc larvae”, *pseudo-F* = 11.159; p=0.0002 – “all copepods” and *pseudo-F* = 10.401; p=0.0003 – “all crustaceans”) (Table 4.3c). Significant pairwise comparisons of the abundances of these larger taxonomic groups at varying seagrass distance positions are presented in Table 4.3a-c.

4.3.2 Benthic invertebrate distribution

4.3.2.1 Overall analysis

The distribution of the benthic invertebrate community at Callala Bay with respect to the reef and bare sediment is described in published literature (Ollivier et al. 2015) done in association with this dissertation and has been placed in the final Appendix. The community distribution at this site consequently is not described in this section except for the distribution of the varying size classes which was not covered in that publication. The distribution of the benthic invertebrate community at Greenpoint only will therefore be discussed in this section.

A total of 9,689 individuals forming 24 different taxonomic groups were sampled in benthic cores from the *Posidonia australis* at Greenpoint (Table 4.5). As the vast majority of the individuals consisted of molluscs (Phylum Mollusca – 99.9%; 99.7% Class Gastropoda, < 0.2% Class Bivalvia) the emphasis is placed on mollusc distribution with distances in all planes in lieu of all benthic invertebrates. Even though the mollusc distribution is by far driven by the 19 gastropod families at Greenpoint, for the sake of comparison of size class distribution with that at Callala Bay where bivalves had a relatively more prominent albeit erratic distribution with adjacent habitats (Ollivier et al. 2015), the whole mollusc community was considered.

4.3.2.2 Total abundance (Greenpoint)

Total mollusc abundance displayed a significant stepwise increase away from the reef (pseudo-*F* = 32.037; p=0.0001) (Table 4.6a; Fig 4.9a) and decrease away from bare sediment (pseudo-*F* = 8.1234; p=0.0003) (Table 4.6b; Fig 4.9b) with no significant or meaningful trend observed with distance from the general edge (Fig 4.6c). With the exception of the pairwise comparison between the first two (0-15m and 15-30m; p=0.01) and furthest two (30-45m and 45-60m; p=0.0172) "distance from reef" categories, all other pairwise comparisons of "distance from reef" positions were significant at the p<0.001 significance level (Table 4.6a). With "distance from bare sediment", however, the decrease in abundance occurred at the 30-45m+ position (T3) (Fig 4.9b) with the abundances at the "distance from bare sediment" categories within 30m of the bare sediment being significantly higher than that at the categories beyond 30m in this plane (0.0006<p<0.041: pairwise comparisons) (Table 4.6b).

4.3.2.3 Mollusc community composition (Greenpoint)

The mollusc community varied significantly with distance from the reef (pseudo-*F* = 5.984; p=0.0001) (Table 4.6a) and bare sediment (pseudo-*F* = 3.3736; p=0.0001) (Table 4.6b) but had no significant variation with distance from the general edge (Table 4.6c). With the exception of the pairwise comparison between 30-45m and 45-60m distance from reef categories, all other comparisons displayed a significant difference in the mollusc community (0.0001<p<0.0089) with distance from the reef (Table 4.6a). Conversely, with "distance from bare sediment", significant difference in community composition was displayed between the furthest (45-60m+) and the first two positions i.e. 0-15m+ and 15-30m+ (0.001<p<0.0022: pairwise comparisons), with the community at the 15-30m+ position also being significantly different from that at 30-45m+ (p = 0.0141: pairwise comparison) (Table 4.6b).

PCO plots of mollusc community composition with increasing distance in each plane illustrated a clustering of data points at the "distance from reef" categories beyond 30m (Fig 4.10a), with no similarly tight clustering found with distance from bare sediment (Fig 4.10b) or general edge (Fig 4.10c). The furthest "distance from general edge" position (E3; E30-60m), however, showed a tighter clustering of data points compared to the other more edge-ward two "general edge" positions (Fig 4.10c). Additionally, the distance categories in all planes within 30m displayed relatively larger dispersion of data points (Fig 4.10a-c).

4.3.2.4 Major mollusc taxa (Greenpoint)

SIMPER analysis at significant pairwise comparisons of the mollusc community with distance from the reef and bare sediment illustrated the top contributing mollusc (gastropod) families to be Potamididae, Litiopidae, Littorinidae, Trochidae, Columbellidae and to a lesser extent Cerithiopsidae (Table 4.7). These taxa were also among the most commonly occurring (Table 4.5). With the exception of Trochidae, which showed a general non-significant decline away from the reef (Fig 4.11a), the remaining major families increased significantly away from the reef (0.0001<p<0.0335) (Table 4.6a; Fig 4.11a). Trochidae abundance increased significantly away from the bare sediment (*pseudo-F* = 7.395; p=0.0005) while Potamididae (*pseudo-F* = 11.563; p=0.0001) and Litiopidae (*pseudo-F* = 5.9508; p=0.0018) decreased (Table 4.6b; Fig 4.11b). The remaining major gastropod families showed no meaningful trend with distance from bare sediment (Fig 4.11b). Only Columbellidae individuals displayed a significant trend with "distance from general edge" (*pseudo-F* = 7.4475; p=0.0014) (Table 4.6c), that of an increase (Fig 4.11c). While Cerithiopsidae and Littorinidae displayed a general trend of increase away from the general edge (Fig 4.11c), this was not statistically significant (Table 4.6c).

4.3.2.5 Mollusc size class distribution

Due to the overwhelming abundance of the two smallest mollusc size classes, i.e.0-3 and 3-6mm at Callala Bay (95.61% of all molluscs) compared to Greenpoint where the majority of molluscs fell in the 3-6 and 6-9mm size classes (76.47%) (Table 4.8), there was a significant effect of "site" with regards to size class distributions ($0.0001<p<0.0039$). As such statistical analyses of the size class combinations (community of individual size classes) and abundance of individual size classes with increasing distance in all planes were rerun separately for each site.

Size class community composition

Whereas the community composition of the seven mollusc size classes (Table 4.8) differed significantly with distance from both adjacent habitats (*pseudo-F* = 11.318; p=0.0001 – reef, *pseudo-F* = 4.1345; p=0.0001 – bare sediment) and with general edge (*pseudo-F* = 3.0021; p=0.0066) at Greenpoint (Table 4.9a-c), the composition at Callala Bay varied significantly with "distance from bare sediment" only (*pseudo-F* = 3.1885; p=0.0015) (Table 4.9b) with the composition at 0-15m+ being significantly different from that at 15-30m+ and at 30-45m+ ($0.0015<p< 0.0034$: pairwise comparisons) (Table 4.9b). At Greenpoint, with the exception the pairwise comparison between the furthest two "distance from bare sediment" (30-45m+ and 45-60m+) and "distance from reef" (30-45m and 45-60m) positions, all other comparisons showed significant difference in size class community composition ($p<0.001$ – reef; $0.0011<p<0.0172$ – bare sediment). There were no significant pairwise comparisons for general edge positions at this site (Table 4.9c).

PCO plots of mollusc size class composition with increasing distance from the habitat edges and general edge at Greenpoint showed at tight clustering of the 30-45m and 45-60m "distance from reef" category data points forming a close knit grouping (Fig 4.12a). As with community distribution, the points representing the size class composition at the first edge positions (0-15m – reef; 0-15m+ – bare sediment; E0-15m – general edge) were the most highly dispersed. The level of dispersion of points declined for the 15-30m data points and formed more distinct clusters at distance categories beyond 30m for size class composition with distance from the reef and general edge only (Fig 4.12a,c). A looser clustering of points was observed with distance from bare sediment (Fig 4.12b). No meaningful clustering of data points was observed with the size class composition distribution at Callala Bay with increasing distance in any plane.

SIMPER analysis of the mollusc size class composition at both sites (Table 4.10) at significant pairwise positions in all planes illustrated consistent high contributions to the significance observed by the smaller size classes (3-6 and 6-9mm at Greenpoint; 0-3 and 3-6mm at Callala Bay).

Individual size classes

While at Greenpoint all size classes, with the exception of >18mm, increased significantly with distance away from the reef ($0.0001<p<0.0013$) (Table 4.9a; Fig 4.13a), at Callala Bay there was no observed trend with “distance from reef” with most size classes homogeneously distributed along this plane (Table 4.9a; Fig 4.14a). With respect to “distance from bare sediment” at Greenpoint, only the >18mm group increased significantly with distance away from this adjacent habitat (*pseudo-F* = 7.4611; p=0.0004) (Table 4.9b; Fig 4.13b), while two other size classes at the site (3-6mm and 6-9mm) decreased significantly with distance in this plane ($p<0.001$) (Table 4.9b; Fig 4.13b). No consistent trend was observed with the other size classes at this site. At Callala Bay, three size classes (0-3mm, 3-6mm and 9-12mm) decreased significantly with “distance from bare sediment” ($0.0003<p<0.0163$) (Table 4.9b; Fig 4.14b) with the other size classes displaying no meaningful trend. With respect to the general edge, all but the 0-3mm category displayed an increasing trend with distance in this plane at Greenpoint (Fig 4.13c) being statistically significant for the four size classes between 6 – 18mm ($0.0002<p<0.0205$) (Table 4.9c). Conversely, two size classes (6-9mm and 9-12mm) displayed a decreasing trend with distance from the general edge at Callala Bay (Fig 4.14c) being statistically significant for the 9-12mm size class (*pseudo-F* = 5.7861; p=0.008) (Table 4.9c). Pairwise comparisons of size class abundances in the varying seagrass positions with distance away from both adjacent habitats and general edge are presented in Table 4.9a-c.

4.3.3 Shoot density, blade metrics and epiphyte load measures

4.3.3.1 Shoot density

Shoot density displayed a high non-significance for the effect “site” ($0.2284<p<0.2362$) along with a high non-significance with distance in all planes at both sites ($0.1855<p<0.881$) and with sites pooled ($0.1666<p<0.6596$) (Table 4.11a-c). No variation was observed in shoot density with increasing distance from either adjacent habitat or general edge (Fig 4.15). An average of approximately 145 shoots m^{-2} (n=96 quadrats) was measured across all seagrass positions at both sites.

As there was a high significance of the factor “site” for all blade metrics and both measures of epiphyte load ($p=0.0001$ for all designs) and at least one instance of a significant interaction of “site” with distance from reef, bare sediment and/or general edge for each variable ($0.0001<p<0.0324$), statistical analysis was rerun for each site separately for these variables as described below.

4.3.3.2 Blade length, width and area

Greenpoint

Blade length, width and area increased significantly with “distance from reef” ($p<0.001$) (Table 4.11a; Fig4.16a,b) with the increase in blade width occurring after the 15-30m distance category (Fig 4.16b). A significant increase in all blade metrics at this site was also observed with “distance from bare sediment” ($0.0006<p<0.0075$) (Table 4.11b; Fig 4.16c,d) but was less pronounced compared to the increase with “distance from reef” especially so for blade length and area (Fig 4.16a,c). A significant increase in blade length and area was also observed with increasing distance from general edge ($p<0.001$) (Table 4.11c; Fig 4.16e) with the general increase in blade width displayed along this plane (Fig 4.16f) not statistically significant (*pseudo-F* = 4.2579; $p=0.0133$; significance level set at $p<0.01$ for non-homogeneity of variances) (Table 4.11c). Pairwise comparisons between individual distance categories in all planes are presented in Table 4.11a-c.

Callala Bay

Blade length, width and area at this site varied significantly with distance in all planes ($p<0.0001$) (Table 4.11a-c) increasing consistently with “distance from bare sediment” (Fig 4.16c,d) and “distance from general edge” (Fig 4.16e,f), with the increase along the bare sediment plane being particularly pronounced (Fig 4.16c,d). Blade length, width and area declined significantly away from the 0-15m distance from reef position followed by a statistically significant increase after the 30-45m position in all cases ($0.0001<p<0.0099$: pairwise comparisons) (Table 4.11a; Fig 4.11a,b). All other pairwise comparisons between individual distance categories in all planes are presented in Table 4.11a-c.

4.3.3.3 Epiphyte load measures

Greenpoint

Both measures of epiphyte load i.e. epiphyte/seagrass (g/g) and the calculated epiphyte load index, increased significantly with “distance from reef” only (*pseudo-F* = 5.8817; p=0.0199 and *pseudo-F* = 4.5053; p=0.0361 respectively) (Table 4.11a-c; Fig 4.17a,b). While there was a general trend of decreasing epiphyte load values away from the bare sediment (Fig 4.17c,d) this was not significant. There was no meaningful trend observed with “distance from general edge” apart from a very marginal general increase towards the seagrass interior (Fig 4.17e,f).

Callala Bay

Both epiphyte load measures increased significantly with “distance from bare sediment” ($p<0.01$) and “distance from general edge” ($p<0.05$) (Table 4.11b,c; Fig 4.17c-f). The observed increase with “distance from bare sediment” occurred at and beyond the 30m distance (Fig 4.17c,d) while that with general edge was a more gradual increase (Fig 4.17e,f). Although there was a marginal general increase in epiphyte load measures with increasing distance from the reef at this site (Fig 4.17a,b), no statistically significant variation was displayed.

Some concern has been expressed regarding the application of the published calculated epiphyte load index of Jackson et al. (2006). This concern stems around the difference in the contribution of the denominator terms (leaf length, leaf width and # of blades) to the overall index value should different units of leaf length and width be used. Whereas this is a valid concern, it is highly likely that given the dimensions of *Posidonia australis* seagrass blades, only two units could ever be reasonably applied i.e. cm and mm. Additionally, if the units are held constant throughout the research and held at the most reasonable unit for assessing seagrass blades (cm) this concern will be alleviated. Two measures of epiphyte load were nonetheless used in this research, the above-mentioned calculated index (Jackson et al. 2006) and the calculation of epiphyte (g) / seagrass (g) (Myers & Virnstein 2000). Both yielded almost identical trends (Fig 4.17).

4.3.3.4 Correlations between epiphyte load [epiphyte/seagrass (g/g)] and seagrass blade metrics

Epiphyte load with both sites pooled was highly correlated to all measured seagrass blade metrics ($r = 0.881$, blade length; $r = 0.611$, blade width; $r = 0.858$, blade area; all $n=32$; $p<0.0001$) using Pearson Correlation (Table 4.12; Fig 4.18a-c) with blade length. To decipher any site-specific relationships, Pearson Correlations were performed between the same variables at each site. This revealed stronger associations of epiphyte load (g/g) with blade metrics at Callala Bay ($r = 0.819$; $n = 16$; $p<0.0001$ for blade length; $r = 0.761$; $n = 16$; $p=0.001$ for blade width; $r = 0.816$; $n = 16$; $p<0.0001$ for blade area) (Table 4.12; Fig 4.18d-f). No significant correlation was displayed between epiphyte load and blade width at Greenpoint ($r = 0.189$; $n = 16$; $p=0.483$) (Table 4.12; Fig 4.18h), with blade length and area displaying significant but weaker correlations with epiphyte load ($r = 0.632$; $n = 16$; $p=0.009$ for blade length; $r = 0.587$; $n = 16$; $p=0.017$ for blade area) (Table 4.12; Fig 4.18g,i).

4.4 Discussion

Distribution of prey taxa with distance from habitat edges

Zooplankton

Total zooplankton abundances displayed a more consistent meaningful trend of an increase with distance from the reef habitat and general edge than from the bare sediment across both sites. Three major groups of zooplankton taxa, namely the collated mollusc larvae and copepod groupings as well as all crustacean nauplii increased with distance away from the reef and general edge. This distribution of zooplankton away from the edge, especially that of the reef edge-habitat may be explained by the physical structure of the reef regarding water movement, as waves break on its structure, creating a microenvironment of greater turbulence (Barros, Underwood & Lindegarth 2001; Bustamante & Branch 1996; Pattiaratchi et al. 1995; Sorokin 1993; Van Elven, Lavery & Kendrick 2004) at the immediate edge compared to further distances. Retreating water depositing zooplankton at further distances or their active movement (Hicks 1986; Thorson 1950) indicating a possible preference for a less dynamic environment, may help to explain the increased zooplankton abundances away from the reef edge. Similarly, it has been noted in literature where the dispersal of planktonic larvae of rocky shore invertebrates are partially controlled by wave action (Pechenik 1999) and hydrodynamics (Boström & Bonsdorff 1997; Eckman 1983; Eckman 1987) even more so than predation (Boström & Bonsdorff 1997; Eckman 1983; Eckman 1987).

The opposing trend of higher abundances of zooplanktonic eggs (most likely egg stages of the rocky reef invertebrates) in closer proximity to both adjacent habitat and general edge at both sites may be due to them adhering to seagrass surfaces (Thorson 1950) and held at the edge, withstanding water movement and thus reducing their deposition at further distances from both the reef and bare sediment. Ostracods displayed a similar distribution pattern being found in greater abundances towards the edge regardless of habitat type, possibly in part due to the relatively higher ability of this taxa to withstand harsher conditions (Boström & Bonsdorff 2000) encountered at the seagrass-reef edge (Pattiaratchi et al. 1995; Sorokin 1993; Van Elven, Lavery & Kendrick 2004).

While total zooplankton abundance displayed a more consistent trend with distance from the reef and general edge there was some level of site-specific response to different habitat edge types (Ries & Sisk 2004) for individual taxa. While five of the eight predominant taxa, namely gastropod larvae, ostracods, crustacean nauplii, calanoid copepods and the zooplanktonic larval eggs displayed the same general trend with both habitat edge types across both sites, the bivalve larvae, cyclopoid and harpacticoid copepods did not. While the bivalve larvae displayed a neutral response with both habitat edge types and edge *per se* at Callala Bay there was a general increase in their abundance with distance from the bare sediment and general edge at Greenpoint. Cyclopoids displayed an opposing trend with respect to the bare sediment and general edge, declining away from the bare sediment and showing a neutral trend with general edge at Callala Bay while showing an increase in both these planes, significantly so for bare sediment, at Greenpoint. Lastly, harpacticoids while decreasing in abundance away from the rocky reef at Callala Bay had the opposing general trend at Greenpoint. Additionally while this taxa showed no distributional trend with bare sediment at Callala Bay, it displayed a significant decline in abundance in this plane at Greenpoint. These results are not surprising as different locations i.e. Callala Bay and Greenpoint may host ecological interactions which range from being slightly different to completely unique between these sites. A change in ecological interactions with site is likely to impact resource distribution relative to edges (Ries & Sisk 2004) thus leading to a differing response to habitat edges. Greenpoint being more frequently exposed to higher wave energy on sampling occasions in comparison to the consistently lower energy more sheltered waters of Callala Bay (pers. observ.) may play a role in site-specific resource distribution relative to edges likely to be influencing this differential distribution of certain zooplankton taxa. Warry et al. (2009) investigating edge effects of seagrass meiofauna relative to sand also reported numerical dominance of their samples by harpacticoid and calanoid copepods along with crustacean nauplii and ostracods. This study reported a decline in total meiofauna, total harpacticoids, and several harpacticoid families and crustacean nauplii with distance away from the seagrass-sand edge i.e. towards the seagrass interior. It should be noted, however, that this study was performed on the scale of tens of centimetres while the current study is applied over tens of meters. The authors noted a differential response in meiofaunal groups to edges which they attributed to the specific characteristics of the species involved (Fagan, Cantrell & Cosner 1999; Ries & Sisk 2004). Similar taxa specific edge responses in seagrass zooplanktonic groups were reported in (Murphy et al. (2010). While harpacticoids and tanaids were more abundant at the seagrass-sand edge relative to the interior, the opposite was true for isopods (Murphy et al. 2010). Additionally, greater copepod abundances were observed at the seagrass-sand edge relative to the seagrass interior in artificial seagrass studies (Macreadie et al. 2010). It should be kept in mind that comparison with these studies should be done with caution as the seagrass sampling sites of the current study are bordered by two distinct adjacent habitat types forming two distinct edge structures.

As such the edge effects noted in the dyad system may not apply when more than one adjacent habitat types are present (Fletcher 2005). This is so as the presence of an additional edge type may intensify edge effects (Fletcher 2005). This dual edge structure has not to date been encountered in publications in the marine system with the exception of the benthic invertebrate study done in conjunction with this PhD research (Ollivier et al. 2015).

Benthic invertebrates (Molluscs)

Total mollusc abundance displayed a different overall pattern with respect to adjacent habitat between sites (see Ollivier et al. (2015) for Callala Bay mollusc community distribution). While total molluscs exhibited a higher affinity to seagrass within 30m of the shoreward bare sediment at both sites (see (Ollivier et al. 2015) for comparison), at Greenpoint there was a significant, incremental increase in mollusc abundance away from the reef not observed at Callala Bay (Ollivier et al. 2015). In fact at Callala Bay significantly higher abundances of major groups were associated at the seagrass-reef edge there (Ollivier et al. 2015). This difference alludes to differing local conditions at the habitat edge types between sites. All but one of the major gastropod families, namely Trochidae, increased in abundance with increasing distance from the reef at Greenpoint while the five major families sampled at Callala Bay all displayed a significant decline in abundance with increasing distance in this plane, two consistently so (Ollivier et al. 2015). It should be noted that these five major Callala Bay mollusc families were also sampled at Greenpoint indicating a site-specific edge response for these groups. Only Trochidae, also sampled at Callala Bay, *Calthalotia fragum* (Ollivier et al. 2015), displayed the same trend across both sites. This disparity in response is likely due to site-specific resource distribution and site-specific local microclimatic conditions cited in literature as the probable cause of differential edge responses of the same species across space and time (Ries & Sisk 2004; Warry et al. 2009; van Houte-Howes, Turner & Pilditch 2004). As physicochemical parameters at each site were not the focus of this study, those features making each site unique cannot be validly commented on. However, as stated above while Greenpoint was characterised by higher energy waters on sampling occasions, Callala Bay was a more sheltered site (pers. observ). Helmuth et al. (2006) also emphasized the importance of small scale localized conditions in determining population trends compared to larger scale factors such as climate change. As such the authors postulate that the same species may respond differently at different sites based on the unique localized characteristics at each site.

The Callala Bay study ruled out any influence of seagrass biomass on determining edge responses at that site (Ollivier et al. 2015). It should additionally be noted, however, that while there was a difference in the direction of the edge response with respect to the reef edge for both sites, a greater influence of the presence of the reef in structuring the mollusc assemblage, albeit with less number of taxa, was reported in the Callala Bay study. While Multivariate PERMANOVA assigned a p-value of 0.001 for the effect of "distance from reef" at Callala Bay, that with "distance from bare sediment/sand" was 0.745 (Ollivier et al. 2015). Community analyses are further addressed in subsequent sections.

With respect to size class distribution, all but one size class, i.e. the largest (>18mm), increased in abundance away from the reef at Greenpoint. Conversely, all size classes of molluscs were homogeneous distributed with distance from the reef at Callala Bay as presented in this chapter. The disparity may be partially explained by hydrodynamics. A stronger hydrodynamic gradient from seagrass-reef edge to seagrass interior compared to that from the seagrass-bare sediment edge to the interior is likely due to the structure of the reef itself. The reef forms a raised physical barrier to water movement resulting in greater turbulence at that habitat edge as it encounters wave action (Barros, Underwood & Lindegarth 2001; Pattiaratchi et al. 1995; Sorokin 1993; Van Elven, Lavery & Kendrick 2004) compared to the seagrass interior. Additionally, with the higher wave energy and water movement at the Greenpoint seagrass-reef edge (pers. observ.) on sampling occasions along with the more vertical, solid structure of the reef at this site compared to Callala Bay, this seagrass-reef edge to interior hydrodynamic gradient is likely to be more pronounced at Greenpoint. As such while greater water movement at the Greenpoint seagrass-reef edge may strip molluscs from the seagrass benthos, especially those below 18mm, and deposit them at further distances from that adjacent habitat, lack of this similar hydrodynamic gradient in this plane at Callala Bay would lead to the more homogeneous distribution in mollusc size classes found there. Similarly, a gentler hydrodynamic gradient in the seagrass-bare sediment plane at Greenpoint would explain the lack of a similar consistent distributional trend towards the interior along this plane. The importance of hydrodynamics in structuring macroinvertebrate assemblages has also been reported in literature (Boström & Bonsdorff 1997, 2000; Bustamante & Branch 1996; Turner et al. 1999). Turner et al. (1999) interestingly attributed 62.5% of the variation in the benthic seagrass community to landscape and wave exposure metrics. This highlights the importance of the edge structure itself with the particular habitat constitution of one edge type (seagrass-reef) influencing faunal abundances (Fagan, Cantrell & Cosner 1999; Ries & Sisk 2004; Warry et al. 2009).

Considering the Greenpoint mollusc community only, the increase in total and individual taxa abundance and that of all size classes below 18 mm with distance away from the reef edge may also in part be linked to hydrodynamics (Bustamante & Branch 1996; McQuaid & Branch 1984) affecting sediment stability (McQuaid & Branch 1984) and sediment composition with coarser sediments associated with regions closer to the reef (Barros, Underwood & Lindegarth 2001). Higher sediment instability at the immediate edges, particularly the seagrass-reef edge, renders that section of the benthos more uninhabitable and would hence lead to lower invertebrate species richness (McQuaid & Branch 1984) and less of these benthic individuals choosing to settle there (Bertness et al. 1999; Helmuth et al. 2006; Thorson 1966).

Coarser sediments at the immediate seagrass-reef edge at both study sites (pers. observ.) with relatively large rocks protruding from the nearby reef within the seagrass benthos is indicative of erosion at this position (Sorokin 1993). This phenomenon has been noted in other benthic habitats immediately adjacent to reefs in literature (Barros, Underwood & Lindegarth 2001). This “spillover” (Ries et al. 2004) of the reef habitat into the seagrass bed is likely to render this region less stable and inhabitable, particularly for the smaller more vulnerable size classes, and may favour settlement by larger, more sturdy gastropods (> 18mm in this study), such as those of the Trochidae family (90% of all molluscs >18 mm) found in highest abundances at the seagrass-reef edge.

Similar studies on benthic macrofauna abundance with increasing reef edge distance have yielded comparable results without however attributing differences to hydrodynamics, erosion, or sediment stability but to predation. Posey & Ambrose Jr (1994) found total benthic macrofauna within a sand habitat to be most abundant at 75m away from a North Carolina reef crop compared to the other closer reef distances (1, 10 and 25m) but attributed this more to the reef structure holding more benthic predators, keeping the benthic invertebrate abundances low closer to the reef. This stance was held by another study (Tuya et al. 2010) showing similar distributional trends with certain gastropod groups in *Posidonia spp* and *Amphibolis spp* seagrass with distance away from reef. The authors attributed the instances of higher benthic invertebrate abundances closer to the reef as a strategy to replenish the population in light of the higher predation rates measured at this seagrass-reef edge (Tuya et al. 2010). Other studies investigating the edge effects of seagrass macroinvertebrates relative to sand have yielded conflicting results. While some studies report an increase in macroinvertebrates at the seagrass-sand edge (Bologna & Heck 2000; Moore & Hovel 2010;

Tanner 2005) associated with higher larval encounter rates at the exposed seagrass-sand edge (Bologna & Heck 2000; Connolly & Hindell 2006) a review by Connolly & Hindell (2006) illustrated differential responses. Of the twenty-five studies reviewed within, approximately half reported increased invertebrate abundances at the seagrass-sand edges and the other half the opposing trend (Connolly & Hindell 2006). This again illustrates that variation in edge responses is likely among different species and different sampling occasions and sites (Ries & Sisk 2004). It again should be kept in mind that these studies investigate a dyad system and do not incorporate the effect of two distinct adjacent habitats which would likely lead to differing edge effects (Fletcher 2005).

The distribution of mollusc taxa at Greenpoint showed the clearest example of a distinct difference in response to one edge habitat type compared to the other (Ries & Sisk 2004) at the same location. Whereas there was a significant incremental increase in total abundance with distance from the reef at Greenpoint there was a clear preference for the seagrass positions closer to the bare sediment edge at the same site with significantly more individuals being found within 30 m of the bare sediment. This again may be due to the quite different structures of the seagrass-reef and seagrass-bare sediment edge habitats differentially influencing distributional trends (Fagan, Cantrell & Cosner 1999; Ries & Sisk 2004; Warry et al. 2009). The differing edge constitutions likely facilitate unique local hydrodynamic and ecological interactions (Tuya et al. 2010) and resources available at each which in itself may help influence the distribution of potential predators relative to the different edge types.

Seagrass blade metrics and epiphyte load

The significant increase in seagrass blade metrics observed with increasing distance from both adjacent habitats and general edge has also been noted in literature. While Smith et al. (2008) found longer *Heterozostera nigricaulis* blades at the seagrass bed interior compared to the shoreward seagrass edge in Port Phillip Bay, Victoria, Moore & Hovel (2010) reported greater shoot length and biomass in interior positions of *Zostera marina* beds of San Diego, California compared to the seagrass-sand interface. Increased *P. australis* blade metrics in this current study may be at least partially explained by the previously mentioned change in microclimatic conditions from the habitat edges towards the less hydrodynamic, more stable seagrass interior where leaf growth is favoured. Boström & Bonsdorff (1997), for instance, attributed increased *Zostera* seagrass blades at 5m vs 3m depths to the reduced effects of wave exposure and hence less physical environmental disturbance at the relatively deeper positions, while

Jenkins & Hamer (2001) found longer *Heterozostera tasmanica* leaves in sheltered muddy habitats compared to more exposed ones. Similarly, Bonsdorff & Nelson (1996) found the brown alga, *Fucus vesiculosus* to display lower and more variable apical tip growth at an exposed site compared to a more sheltered one. Interestingly there was site-specific, adjacent habitat-specific degree of increase in blade metrics. While blade length, width and area increased more sharply and incrementally with distance from the reef compared to the bare sediment at Greenpoint, at Callala Bay the reverse was true.

This site-specific response of blade metrics with adjacent habitat was associated with a sharper increase in epiphyte load measures with distance from bare sediment at Callala Bay compared to the reef. On the other hand epiphyte load measures increased significantly with distance from the reef with no increase from the bare sediment at Greenpoint. Pearson correlation analysis correspondingly illustrated a significant positive relationship between blade length and area at both sites being more pronounced at Callala Bay ($r=0.8196-0.819$, $p<0.0001$ for Callala Bay; $r=0.587-0.632$, $0.017<p<0.009$ for Greenpoint).

It should be noted, however, that while this relationship between blade metrics and epiphyte load exists, the increase in leaf length, width and area at Greenpoint with respect to the bare sediment did not translate to an increase in epiphyte load along this plane as at Callala Bay, but in fact a decrease. This indicates that some other factor apart from blade metrics may be contributing to the epiphyte load distribution at Greenpoint.

Seagrass epiphytic algae and detached macroalgae have been associated with macroalgae from adjacent reef habitats (Van Elven, Lavery & Kendrick 2004; Wernberg et al. 2006). Water movement at the seagrass-reef edge is likely to influence epiphyte distribution (Van Elven, Lavery & Kendrick 2004) by transporting macroalgal material from the reef and depositing it at some distance away from the reef, enabling it to accumulate in this region of reduced wave energy (Bustamante & Branch 1996). In this study the area of reduced wave energy appears to be beyond 30m for both sites where epiphyte load was seen to increase sharply over the two more edge-ward positions. Additionally, as mentioned earlier, blades may be attaining greater lengths in more stable conditions (Bonsdorff & Nelson 1996; Boström & Bonsdorff 1997) in the seagrass interior, influencing greater epiphytic growth there.

The likely steeper hydrodynamic gradient at the seagrass-reef to interior plane compared to the seagrass-bare sediment plane at Greenpoint helps to explain the more pronounced increase in both leaf metrics and epiphyte load along this plane at this site. With the impact of high energy waves against the reef structure not an overriding factor at Callala Bay epiphytic material brought into the bay or originating from the nearby reef structure may be held by the longer blades (Boström & Bonsdorff 2000) especially so beyond 30m from the bare sediment.

Community level distribution with habitat edges

Importance of the 30m boundary

For both the zooplankton and mollusc communities, there was a clear disparity in the community composition between the closest (0-15m) and furthest seagrass (45-60m) positions from pairwise analysis in PERMANOVA from at least one adjacent habitat which did not in all cases translate to a difference in community with general edge. The zooplankton community, for instance, at the seagrass-reef edge and at the most interior position (45-60 m) relative to the reef was significantly different from each other at both sites. While there was a weak but significant difference in community composition at distance extremes from bare sediment at Greenpoint, the communities at the extremes of distances in this plane were again significantly different at Callala Bay, with the community at the 15-30m+ position also being significantly different from that the furthest distance (45-60m+). There was, however, no significant variation in community composition between the two seagrass positions within 30m of the reef or bare sediment and between the two positions beyond 30m from both adjacent habitats for either site. The community distribution with respect to both habitat edges described above translated to a significantly different zooplankton community at the first general edge position (E0-15m) compared to at least one of the more interior seagrass positions in this plane at both sites with a stronger relationship found at Callala Bay ($0.0002<p<0.0041$: pairwise comparisons).

The mollusc community at Greenpoint showed a similar trend with the community composition at the seagrass-reef and seagrass-bare sediment edges being significantly different from that at the furthest distances but displayed no effect of general edge. Additionally the communities beyond the 30m distance in both planes, particularly with distance from reef were more similar to each other than to any other distance, illustrated by the tight clustering of the mollusc community data points along this reef plane with the 30-45m and 45-60m positions. Interestingly this was accompanied by a similar trend displayed by the in-gut “prey community” data of at least one taxa, the benthic invertebrate feeding (CNP in this study) weed whiting at Greenpoint (refer to Appendix II(A), Fig J). The in-gut “prey community" for this taxa displayed a distinct separation of data points between the gut content from fish caught within 30m of the reef from those sampled beyond 30m in PCO analysis (refer to Appendix II(A), Fig J). This is further supported by the 30-45m and 45-60m distance from reef pair being the only case of statistical non-significance (p=0.3587) from pairwise comparisons of the mollusc community at all possible combinations of distance categories in this plane while all other comparisons yielded p values ranging between 0.0001 to 0.0097.

This apparent shift in community composition within the seagrass beyond 30m from the seagrass edge, particularly with the reef habitat is also highlighted in epiphyte load measures. Although more pronounced at Greenpoint, at both sites epiphyte per seagrass measures increased sharply at the 30-45m distance from reef and remained similarly high at the subsequent 45-60m distance from reef. While this trend was also observed with distance from bare sediment at Callala Bay, it was not at Greenpoint. These results indicate an apparent shift in the nature of the seagrass ecosystem beyond a "30m threshold" distance from the edge after which conditions favour a shift in the zooplankton and mollusc community and enhances seagrass epiphytic load, particularly with respect to the reef habitat.

Along with the significant difference in prey community between the most edge-ward and interior positions relative to both adjacent habitats, greater community variation was displayed closer to the seagrass edges, with this variability gradually decreasing towards the interior for the mollusc community (Greenpoint). PCO plots indicate an apparent stabilizing of the community beyond 30m from the adjacent habitats with less widely separated point at the furthest distance categories. This increased community variability towards the seagrass edge was more noticeable however with respect to the reef habitat and has also been demonstrated in other benthic communities in literature (Barros, Underwood & Lindegarth 2001; Van Elven, Lavery & Kendrick 2004) with one author (Van Elven, Lavery & Kendrick 2004) citing increased water motion at the vicinity of the reef (Pattiaratchi et al. 1995; Sorokin 1993) as the primary reason. The mollusc community at this site also showed increasingly higher levels of variability towards the immediate general edge position from PCO analysis. The greater water movement associated with the general edge particularly at the reef edge may render this area (within 30m) a less stable, harsher environment that the many organisms may avoid and that may limit seagrass epiphyte establishment.

Conclusion

Results from this study validate the rejection of all set null hypotheses presented at the beginning of this chapter. Distinct distributional trends were observed with all sampled prey types (zooplankton, molluscs and epiphyte load) with distance from at least one adjacent habitat edge which were dependent in some instances on individual taxa and/or site and the type of edge habitat in question, i.e. rocky reef or bare sediment. Results also indicate a significantly different community composition of both the zooplankton and mollusc prey communities between the most edge-ward and interior seagrass positions, with greater community variation towards the edges in particular the reef edge (mollusc – Greenpoint) compared to the seagrass interior. Both these differences are likely a response to the harsher more dynamic conditions at the edge, especially at the reef, bound to influence the distribution of higher trophic status taxa utilizing these groups for prey (Ries & Sisk 2004). Significant correlations were also observed between seagrass epiphyte metrics and seagrass morphology which displayed a site-specific differential response to the adjacent habitat types.

A comparison of the distribution of the prey communities assessed in this chapter with that of the fish sampled from the same locations (Chapters 2 and 3) is made in the final discussion chapter (Chapter 6). Additionally, the relative sensitivities or degree of response to the two adjacent habitat types of each prey type and fish are assessed and compared in Chapter 6.

While this chapter assessed the distribution of potential fish prey communities in order to help understand the fish’s own distribution with respect to habitat edge, food acquisition is not the only factor that may affect the fish’s position from and/or sensitivity to a particular edge habitat type. With the more mobile mid to higher trophic level fish, for instance, there is always the dual quest to eat and not be eaten. With each edge community comprising two unique habitats it is important to test whether the structure of the different habitat combinations provided by the edge or the homogeneous habitats towards the interior is more highly favoured and if this preference is altered when faced with predation. This is addressed in manipulative experiments in the following chapter (Chapter 5).

Table 4.1 Zooplankton community collected just above seagrass canopy at both sites (Greenpoint and Callala Bay). *Classification levels in bold represent the taxonomic groups included in PERMANOVA community analysis*

Phylum	Subphylum	Class	Subclass	Infraclass	Superorder	Order	Suborder	Family
Cnidaria		**Hydrozoa**						
Mollusca		**Bivalvia**						
		Gastropoda						
Arthropoda	Crustacea	**Ostracoda**						
		Malacostraca			**Eucarida**			
					Pericarida			
		Maxillopoda	Copepoda			**Calanoida**		
						Cyclopoida		
						Poecilostomatoida		
						Harpacticoida		
			Copepoda (juv)					
			Copepoda (unidentified)					
			Thecostraca	**Cirrepedia**				
		Branchiopoda	Phyllopoda			Diplostraca	**Cladocera**	
	Crustacean nauplii							
Annelida		**Polychaeta**						
Phoronida								**Phoronidae**
Chaetognatha								
Urochordata								
Echinodermata								
Dinoflagellata		Noctiluciphyceae				**Noctilucales**		
(Unid. eggs)								
(Unid. larvae)								
(Unknown)								

Table 4.2 Total number of individuals of main zooplankton taxonomic groups included in community analysis sampled over both sites (Callala Bay – CB and Greenpoint – GP), Jervis Bay.

Zooplankton Taxonomic Group	**TOTAL #**	**CB**	**GP**
Harpacticoida	19089	1658	17431
Ostracoda	8229	3051	5178
Bivalvia larvae	7994	6999	995
Gastropoda larvae	7758	4427	3331
Calanoida	7448	7107	341
Crustacean nauplii	4163	1503	2660
Cyclopoida	3765	2372	1393
Unidentified planktonic eggs	1155	453	702
Polychaeta (larvae)	713	201	512
Pericarida	607	441	166
Copepoda (juvenile)	603	18	585
Poecilostomatoida	266	96	170
Urochordata	132	118	14
Hydroida	89	73	16
Noctilucales	71	26	45
Cirrepedia (Barnacle nauplii)	70	54	16
Eucarida	67	34	33
Cladocera	55	42	13
Chaetognatha	20	18	2
Phoronidae	19	15	4
Unidentified planktonic larvae	13	3	10
Unidentified Crustacea*	9	1	8
Unidentified Copepoda	3	1	2
Echinodermata	2	1	1
Unknown	26	14	12
Total	**62366**	**28726**	**33640**

*excluding Copepoda

Table 4.3 (a) Summary of PERMANOVA results of the effect of "Distance from reef" on community and individual taxonomic group distribution during the summer season across both sites, except where indicated i.e. Greenpoint only (GP) or Callala Bay (CB) only. *"Di" denotes "Distance from reef", "Tr" – distance from bare sediment i.e. increasing transect #, "Wk" – sampling week; D1=0-15m, D2=15-30m, D3=30-45m, D4=45-60m; significant permdisp (in bold) indicate non-homogeneity of variances; permdisp values of significant relationships only reported.*

	Distance from Reef				Factors Included in Model				Pairwise Comparisons						
	df	**MS**	**pseudo-F**	**p**	**Di**	**Tr**	**Site**	**Wk**	**D1-D2**	**D1-D3**	**D1-D4**	**D2-D3**	**D2-D4**	**D3-D4**	**Permdisp**
Total Abundance	3	0.10902	0.46064	0.6915	*	*	*	*							
Greenpoint	3	8.8675E^{-2}	0.40709	0.7404	*	*		*							
Callala Bay	3	0.25703	1.9957	0.1539	*	*		*							
Community Distribution	3	400.61	2.0158	0.1412	*	*	*								
Greenpoint	3	350.88	2.0764	**0.0189**	*	*		*			**0.0089**				0.781
Callala Bay	3	248.47	1.827	0.0502	*	*		*			**0.0381**				0.283
Major Groups:															
Hydrozoa	3	6.1754E^{-2}	0.68315	0.6461	*	*	*	*							
Greenpoint	3	3.3484E^{-3}	0.16647	0.9129	*	*		*							
Callala Bay	3	0.1488	2.2588	0.1158	*	*		*							
Bivalve Larvae	3	0.26148	1.0993	0.4554	*	*	*	*							
Greenpoint	3	0.15333	0.63645	0.606	*	*		*							
Callala Bay	3	0.346	3.3604	**0.0401**	*	*		*	**0.0152**	0.0505		**0.0339**			0.74
Gastropod Larvae	3	0.18334	0.2921	0.8766	*	*	*	*							
Greenpoint	3	0.27476	1.0154	0.4068	*	*		*							
Size Class A Gastropod Larvae[1] [GP]	3	0.43816	1.6268	0.2222	*	*		*							
Size Class B Gastropod Larvae[2] [GP]	3	0.23306	0.76415	0.5252	*	*		*							
Callala Bay	3	0.53622	2.6949	0.0724	*	*		*							
Ostracods	3	1.4924	4.7673	0.0875	*	*	*	*							
Greenpoint	3	1.5326	4.2182	**0.0216**	*	*		*		**0.0413**	**0.0135**				0.571
Callala Bay	3	0.27281	1.4623	0.256	*	*		*							

[1] <0.9mm (87.25% of total GP gastropod larvae); [2] >0.9mm (12.75% of total GP gastropod larvae); no size distinction for CB gastropod larvae noted for CB

Table 4.3 (a) cont'd Summary of PERMANOVA results of the effect of "Distance from reef" on community and individual taxonomic group distribution during the summer season across both sites, except where indicated i.e. Greenpoint only (GP) or Callala Bay (CB) only. *"Di" denotes "Distance from reef", "Tr" – distance from bare sediment / transect, "Wk" – sampling week; D1=0-15m, D2=15-30m, D3=30-45m, D4=45-60m.*

	Distance from Reef				Factors Included in Model				Pairwise Comparisons						
	df	**MS**	**pseudo-F**	**p**	**Di**	**Tr**	**Site**	**Wk**	**D1-D2**	**D1-D3**	**D1-D4**	**D2-D3**	**D2-D4**	**D3-D4**	**Permdisp**
Eucarida	3	3.9196E^{-2}	0.49393	0.6892	*	*	*	*							
Pericarida	3	4.6305E^{-2}	0.18772	0.8966	*	*	*	*							
Greenpoint	3	8.9716E^{-2}	0.59637	0.627	*	*		*							
Callala Bay	3	0.20326	1.0075	0.4184	*	*		*							
Crustacean nauplii	3	0.89995	0.9059	0.5073	*	*	*	*							
Greenpoint	3	1.4072	5.6704	**0.0026**	*			*	**0.0088**	**0.0029**	**0.0031**				0.608
Callala Bay	3	0.48617	1.0244	0.3955	*	*		*							
Calanoida	3	0.83708	2.3828	0.2734	*	*	*	*							
Greenpoint	3	0.27519	1.542	0.2382	*	*		*							
Callala Bay	3	0.91319	4.4004	**0.0171**	*	*		*			**0.0186**		**0.0195**	**0.0195**	0.798
Cyclopoida	3	1.0136	7.9795	0.0795	*	*	*	*							
Greenpoint	3	0.6998	3.1808	0.051	*	*		*			**0.0115**				0.932
Callala Bay	3	0.44088	2.8424	0.0705	*	*		*							
Poecilostomatoida	3	0.50753	3.0361	0.1762	*	*	*	*							
Greenpoint	3	0.53167	4.9331	**0.0102**	*	*		*	**0.0228**		**0.0096**				0.262
Callala Bay	3	0.14303	1.2291	0.3303	*	*		*							
Harpacticoida	3	7.0916E^{-2}	0.11531	0.9292	*	*	*	*							
Greenpoint	3	0.33044	1.3797	0.2845	*	*		*							
Callala Bay	3	0.35547	1.6864	0.2092	*	*		*							
Cirrepedia (Barnacle larvae)	3	0.16761	4.2491	0.1224	*	*	*	*							
Greenpoint	3	3.418E^{-2}	0.83247	0.4903	*	*		*							
Callala Bay	3	0.17288	2.7152	0.0519	*			*		**0.0367**	**0.0075**				0.31

Table 4.3 (a) cont'd Summary of PERMANOVA results of the effect of "Distance from reef" on community and individual taxonomic group distribution during the summer season across both sites, except where indicated i.e. Greenpoint only (GP) or Callala Bay (CB) only. *"Di" denotes "Distance from reef", "Tr" – distance from bare sediment / transect, "Wk" – sampling week; D1=0-15m, D2=15-30m, D3=30-45m, D4=45-60m.*

	Distance from Reef				Factor Included in Model				Pairwise Comparisons						
	df	MS	pseudo-F	p	Di	Tr	Site	Wk	D1-D2	D1-D3	D1-D4	D2-D3	D2-D4	D3-D4	Permdisp
Cladocera	3	0.1074	0.65137	0.6428	*	*	*	*							
Greenpoint	3	$5.697E^{-2}$	3.4609	0.0414	*	*		*	**0.0107**						**0.001**
Callala Bay	3	0.21532	7.3253	**0.0022**	*	*		*			**0.0181**		**0.0329**	**0.0416**	0.259
Polychaeta (Larvae)	3	0.47329	2.0157	0.3055	*	*	*	*							
Greenpoint	3	0.56251	2.915	0.0565	*	*		*	**0.0411**						0.542
Callala Bay	3	0.14558	1.1713	0.3465	*	*		*							
Total Unidentified Eggs	3	1.5005	11.748	**0.0345**	*	*	*	*							0.063
Greenpoint	3	1.2473	6.3556	**0.0044**	*	*		*			**0.0021**				**0.025**
Callala Bay	3	0.38088	1.6973	0.2014	*	*		*							
Larger Groupings:															
All Mollusca Larvae	3	0.13955	0.29443	0.8185	*	*	*	*							
Greenpoint	3	0.19898	0.68836	0.5715	*	*		*							
Callala Bay	3	0.41453	3.4304	**0.0381**	*	*		*	**0.031**				0.0487		0.329
All Copepods	3	0.41868	1.164	0.4404	*	*	*	*							
Greenpoint	3	0.32565	1.4491	0.2695	*	*		*							
Callala Bay	3	0.45271	2.0741	0.1382	*	*		*							
All Crustaceans	3	0.1643	0.64646	0.6344	*	*	*	*							
Greenpoint	3	0.11774	0.52848	0.6618	*	*		*							
Callala Bay	3	0.3007	1.9072	0.1642	*	*		*							

Interaction terms not presented in table for logistics purposes. As described in General Discussion (6.6.1) interaction terms were evaluated to determine statistical approach and/ or cited in the text and subsequently discussed where highly significant terms may influence valid interpretation of data.

Table 4.3 (b) Summary of PERMANOVA results of the effect of "Distance from bare sediment" on community and individual taxonomic group distribution during the summer season across both sites, except where indicated i.e. Greenpoint only (GP) or Callala Bay (CB) only. *"Di" denotes "Distance from reef", "Tr" – distance from bare sediment / transect, "Wk" – sampling week; T1=0- 15m+, T2=15-30m+, T3=30-45m+, T4=45-60m+.*

	Distance from Bare Sediment				Factors Included in Model				Pairwise Comparisons						
	df	MS	pseudo-F	p	Di	Tr	Site	Wk	T1-T2	T1-T3	T1-T4	T2-T3	T2-T4	T3-T4	Permdisp
Total Abundance	3	0.39048	0.58734	0.6416	*	*	*	*							
Greenpoint	3	0.48414	2.2226	0.1274	*	*		*							
Callala Bay	3	0.57117	4.4349	**0.0163**	*	*		*			**0.0072**	**0.0208**	**0.027**		0.811
Community Distribution	3	616.89	1.642	0.2853	*	*	*								
Greenpoint	3	356.52	2.1098	**0.0241**	*	*		*		**0.0474**	**0.0426**				0.992
Callala Bay	3	636.08	4.6773	**0.0001**	*	*		*		**0.0253**	**0.0035**	**0.0304**	**0.0043**		0.849
Major Groups:															
Hydrozoa	3	0.45871	3.762	0.1522	*	*	*	*							
Greenpoint	3	6.4124E^{-2}	3.188	0.0458	*	*		*					0.0166		**0.015**
Callala Bay	3	0.51652	7.8407	**0.0012**	*	*		*		0.0176	0.0225	0.0294	**0.0084**		**0.001**
Bivalve Larvae	3	0.57931	1.7086	0.3275	*	*	*	*							
Greenpoint	3	0.48502	2.0132	0.1519	*	*		*							
Callala Bay	3	0.43335	4.2087	**0.0212**	*	*		*			**0.0064**		**0.0043**		0.066
Gastropod Larvae	3	0.84413	0.72742	0.567	*	*	*	*							
Greenpoint	3	0.80237	3.8898	**0.0176**		*		*		**0.0013**				**0.0148**	0.797
Size Class A Gastropod Larvae^1 [GP]	3	1.1106	5.073	**0.0054**		*		*	0.0486	**0.0004**				**0.0168**	0.885
Size Class B Gastropod Larvae^2 [GP]	3	0.57799	1.8951	0.1708	*	*		*							
Callala Bay	3	1.2022	6.0419	**0.0047**	*	*		*			**0.0147**		**0.0099**		0.176
Ostracods	3	2.8256	19.096	**0.0159**	*	*	*	*							0.261
Greenpoint	3	1.1428	3.1453	0.0562	*	*		*			**0.0162**				0.567
Callala Bay	3	1.8308	9.813	**0.0003**	*	*		*	0.0149		**0.0024**		**0.0013**		**0.037**

Table 4.3 (b) cont'd Summary of PERMANOVA results of the effect of “Distance from bare sediment” on community and individual taxonomic group distribution during the summer season across both sites, except where indicated i.e. Greenpoint only (GP) or Callala Bay (CB) only. *“Di” denotes “Distance from reef”, “Tr” – distance from bare sediment / transect, “Wk” – sampling week; T1=0- 15m+, T2=15-30m+, T3=30-45m+, T4=45-60m+.*

	Distance from Bare Sediment				Factor Included in Model				Pairwise Comparisons						
	df	**MS**	**pseudo-F**	**p**	**Di**	**Tr**	**Site**	**Wk**	**T1-T2**	**T1-T3**	**T1-T4**	**T2-T3**	**T2-T4**	**T3-T4**	**Permdisp**
Eucarida	3	$7.21E^{-2}$	1.0317	0.4629	*	*	*	*							
Pericarida	3	0.53043	1.446	0.4085	*	*	*	*							
Greenpoint	3	0.19169	1.2743	0.3144	*	*		*							
Callala Bay	3	0.70558	3.3461	**0.0268**		*		*					0.0479	**0.0167**	0.13
Crustacean nauplii	3	1.386	2.0767	0.3302	*	*	*	*							
Greenpoint	3	0.34107	1.3417	0.2899	*	*		*							
Callala Bay	3	1.7123	4.0298	**0.0125**		*		*		**0.0254**	**0.0081**		**0.0238**		0.72
Calanoida	3	3.1318	3.11	0.1958	*	*	*	*							
Greenpoint	3	0.32195	1.8039	0.1864	*	*		*							
Callala Bay	3	3.8169	18.392	**0.0001**	*	*		*		**0.0043**	**0.0038**	**0.0016**	**0.012**		0.078
Cyclopoida	3	0.32822	0.16257	0.9055	*	*	*	*							
Greenpoint	3	0.66908	3.0412	0.0576	*	*		*							0.5
Callala Bay	3	1.6782	10.819	**0.0006**	*	*		*			**0.0006**	**0.0428**	**0.0003**		0.073
Poecilostomatoida	3	0.5415	4.1498	0.1422	*	*	*	*							
Greenpoint	3	0.44751	4.1523	**0.0214**	*	*		*		**0.0079**	**0.0114**				0.784
Callala Bay	3	0.22448	1.929	0.1592	*	*		*							
Harpacticoida	3	0.68756	3.4872	0.1621	*	*	*	*							
Greenpoint	3	0.68218	3.0421	**0.0341**		*		*			**0.0132**			**0.025**	0.934
Callala Bay	3	0.20255	0.96095	0.4311	*	*		*							
Cirrepedia (Barnacle larvae)	3	$8.13E^{-3}$	0.62344	0.6604	*	*	*	*							
Greenpoint	3	$1.5518E^{-3}$	$3.7795E^{-2}$	0.9905	*	*		*							
Callala Bay	3	$1.9619E^{-2}$	0.27772	0.8426	*	*		*							

Table 4.3 (b) cont'd Summary of PERMANOVA results of the effect of “Distance from bare sediment” on community and individual taxonomic group distribution during the summer season across both sites, except where indicated i.e. Greenpoint only (GP) or Callala Bay (CB) only. *“Di” denotes “Distance from reef”, “Tr” – distance from bare sediment / transect, “Wk” – sampling week; T1=0-15m+, T2=15-30m+, T3=30-45m+, T4=45-60m+.*

	Distance from Bare Sediment				Factors Included in Model				Pairwise Comparisons						
	df	**MS**	**pseudo-F**	**p**	**Di**	**Tr**	**Site**	**Wk**	**T1-T2**	**T1-T3**	**T1-T4**	**T2-T3**	**T2-T4**	**T3-T4**	**Permdisp**
Cladocera	3	0.205	1.0705	0.4521	*	*	*	*							
Greenpoint	3	1.9387E^{-2}	1.1778	0.3436	*	*		*							
Callala Bay	3	0.37711	12.83	**0.0001**	*	*		*			**0.009**		**0.0023**	**0.0038**	0.376
Polychaeta (Larvae)	3	0.49285	1.4354	0.3823	*	*	*	*							
Greenpoint	3	0.67041	3.4743	0.0415	*	*		*							**0.015**
Callala Bay	3	0.16579	1.334	0.3002	*	*		*							
Total Unidentified Eggs	3	0.92264	10.014	0.0571	*	*	*	*							0.088
Greenpoint	3	0.3612	1.8404	0.1786	*	*		*							
Callala Bay	3	0.65358	2.9125	0.0618	*	*		*							
Larger Groupings:															
All Mollusca Larvae	3	0.51513	0.88241	0.516	*	*	*	*							
Greenpoint	3	0.72938	3.3634	**0.0317**		*		*		**0.0014**				**0.0176**	0.855
Callala Bay	3	0.36953	3.0581	0.0582	*	*		*							
All Copepods	3	1.1399	0.59507	0.6469	*	*	*	*							
Greenpoint	3	0.65261	3.0968	**0.039**		*		*			**0.0175**			**0.0244**	0.964
Callala Bay	3	2.4029	11.009	**0.0001**	*	*		*		**0.0111**	**0.008**	**0.0024**	**0.017**		0.792
All Crustaceans	3	0.70143	0.59813	0.6584	*	*	*	*							
Greenpoint	3	0.6092	2.9594	**0.0452**		*		*			**0.0132**			**0.0226**	0.885
Callala Bay	3	1.2649	8.0229	**0.0013**	*	*		*		**0.0301**	**0.0098**	**0.0061**	**0.0124**		0.907

Interaction terms not presented in table for logistics purposes. As described in General Discussion (6.6.1) interaction terms were evaluated to determine statistical approach and/ or cited in the text and subsequently discussed where highly significant terms may influence valid interpretation of data.

Table 4.3 (c) Summary of PERMANOVA results of the effect of "Distance from general edge" on community and individual taxonomic group distribution during the summer season across both sites, except where indicated i.e. Greenpoint only (GP) or Callala Bay (CB) only. *"Ed" denotes "Distance from general edge", "Wk" – sampling week; E1=E0-15m, E2=E15-30m, E3=30-60m.*

	Distance from General Edge				Factor Included			Pairwise Comparisons			
	df	**MS**	**pseudo-F**	**p**	**Ed**	**Site**	**Wk**	**E1-E2**	**E1-E3**	**E2-E3**	**Permdisp**
Total Abundance	2	0.85962	1.5496	0.398	*	*	*				
Greenpoint	2	$2.2999E^{-2}$	$9.7578E^{-2}$	0.9077	*		*				
Callala Bay	2	1.3914	7.4639	**0.002**	*		*		**0.0056**	**0.0016**	0.677
Community Distribution	2	989.2	6.0481	**0.0053**	*	*		**0.0227**	**0.019**		0.583
Greenpoint	2	443.58	2.0134	**0.0369**	*		*	**0.0401**			0.971
Callala Bay	2	709.17	3.9152	**0.0004**	*		*		**0.0002**	**0.0041**	0.691
Major Groups:											
Hydrozoa	2	0.32122	1.5113	0.3715	*	*	*				
Greenpoint	2	$8.3427E^{-3}$	0.23851	0.8087	*		*				
Callala Bay	2	0.52543	4.5124	**0.0151**	*		*		**0.0335**	**0.0051**	0.257
Bivalve Larvae	2	0.74087	1.9792	0.3894	*	*	*				
Greenpoint	2	0.16223	0.56446	0.5764	*		*				
Callala Bay	2	0.95297	3.6861	**0.0317**	*		*			**0.0062**	0.175
Gastropod Larvae	2	1.5892	1.6716	0.421	*	*	*				
Greenpoint	2	0.77774	3.0392	0.0561	*		*		**0.0212**		0.693
Size Class A Gastropod Larvae[1] [GP]	2	1.3556	5.4681	**0.0084**	*		*	**0.0166**	**0.0028**		0.412
Size Class B Gastropod Larvae[2] [GP]	2	$2.7391E^{-2}$	$5.7984E^{-2}$	0.9444	*		*				
Callala Bay	2	1.7621	5.4534	**0.006**	*		*			**0.0065**	**0.011**
Ostracods	2	3.7589	47.972	**0.0194**	*	*	*				0.499
Greenpoint	2	1.9258	3.0462	0.0541	*		*	**0.045**			0.902
Callala Bay	2	1.9114	6.5821	**0.0033**	*		*	**0.0131**	**0.0012**		0.278

Table 4.3 (c) cont'd Summary of PERMANOVA results of the effect of "Distance from general edge" on community and individual taxonomic group distribution during the summer season across both sites, except where indicated i.e. Greenpoint only (GP) or Callala Bay (CB) only. *"Ed" denotes "Distance from general edge", "Wk" – sampling week; E1=E0-15m, E2=E15-30m, E3=30-60m.*

	Distance from General Edge				Factors Included			Pairwise Comparisons			
	df	MS	pseudo-F	p	Ed	Site	Wk	E1-E2	E1-E3	E2-E3	Permdisp
Eucarida	2	$1.0565E^{-2}$	$7.0384E^{-2}$	0.8779	*	*	*				
Pericarida	2	$8.5632E^{-2}$	1.011	0.6007	*	*	*				
Greenpoint	2	0.16954	1.2992	0.2778	*		*				
Callala Bay	2	$7.9297E^{-4}$	$3.4954E^{-3}$	0.9954	*		*				
Crustacean nauplii	2	2.327	5.847	0.1319	*	*	*				
Greenpoint	2	1.3482	5.3168	**0.0093**	*		*	**0.0062**	**0.014**		0.734
Callala Bay	2	1.3769	2.6561	0.0806	*		*				
Calanoida	2	4.4809	3.8162	0.166	*	*	*				
Greenpoint	2	0.55482	3.1749	0.0588	*		*		**0.0191**		0.85
Callala Bay	2	5.1003	13.093	**0.0003**	*		*		**0.0001**	**0.0019**	0.536
Cyclopoida	2	1.8161	1.9371	0.3428	*	*	*				
Greenpoint	2	$8.5735E^{-2}$	0.28895	0.7485	*		*				
Callala Bay	2	2.6679	8.3699	**0.0008**	*		*		**0.0002**	**0.0041**	0.267
Poecilostomatoida	2	1.2867	4.7604	0.2243	*	*	*				
Greenpoint	2	1.3671	9.0476	**0.001**	*		*	**0.0007**	**0.0073**		0.065
Callala Bay	2	0.18984	1.9968	0.1528	*		*				
Harpacticoida	2	0.13528	0.55972	0.6114	*	*	*				
Greenpoint	2	$1.5192E^{-2}$	$5.5329E^{-2}$	0.9451	*		*				
Callala Bay	2	0.36177	2.0158	0.1502	*		*				
Cirrepedia (Barnacle larvae)	2	$7.5981E^{-2}$	12.485	0.0765	*	*	*				
Greenpoint	2	$3.342E^{-2}$	1.0111	0.3769	*		*				
Callala Bay	2	$4.8647E^{-2}$	0.63146	0.5402	*		*				

Table 4.3 (c) cont'd Summary of PERMANOVA results of the effect of "Distance from general edge" on community and individual taxonomic group distribution during the summer season across both sites, except where indicated i.e. Greenpoint only (GP) or Callala Bay (CB) only. *"Ed" denotes "Distance from general edge", "Wk" – sampling week; E1=E0-15m, E2=E15-30m, E3=30-60m.*

	Distance from General Edge				Factors Included			Pairwise Comparisons			
	df	MS	pseudo-F	p	Ed	Site	Wk	E1-E2	E1-E3	E2-E3	Permdisp
Cladocera	2	0.46812	1.4951	0.3642	*	*	*				
Greenpoint	2	3.606E-2	1.8779	0.1654	*		*				
Callala Bay	2	0.74516	13.269	**0.0002**	*		*		**0.0001**	**0.0047**	0.173
Polychaeta (Larvae)	2	0.86949	0.92812	0.5173	*	*	*				
Greenpoint	2	1.6034	7.2999	**0.0022**	*		*	**0.0002**	**0.0088**		**0.019**
Callala Bay	2	0.20293	1.3441	0.2693	*		*				
Total Unidentified Eggs	2	2.2446	51.581	0.1338	*	*	*				
Greenpoint	2	1.3203	2.5107	0.0944	*		*				
Callala Bay	2	0.96783	2.7163	0.0759	*		*				
Larger Groupings:											
All Mollusca Larvae	2	0.94183	1.3821	0.4292	*	*	*				
Greenpoint	2	0.52873	1.908	0.1588	*		*				
Callala Bay	2	1.0945	5.5513	**0.0083**	*		*	**0.0333**		**0.0034**	0.751
All Copepods	2	1.9908	1.4207	0.3884	*	*	*				
Greenpoint	2	$2.5942E^{-2}$	$9.9329E^{-2}$	0.9056	*		*				
Callala Bay	2	3.3662	11.159	**0.0002**	*		*		**0.0004**	**0.0023**	0.793
All Crustaceans	2	1.2123	1.1439	0.4741	*	*	*				
Greenpoint	2	$3.3463E^{-2}$	0.13205	0.8768	*		*				
Callala Bay	2	2.2386	10.401	**0.0003**	*		*		**0.0001**	**0.0008**	0.724

Interaction terms not presented in table for logistics purposes. As described in General Discussion (6.6.1) interaction terms were evaluated to determine statistical approach and/ or cited in the text and subsequently discussed where highly significant terms may influence valid interpretation of data.

Table 4.4 Percent contribution of individual zooplankton taxa (cut off point set at top cumulative contribution of 50 – 60%) in SIMPER analysis at significant pairwise comparisons of distance categories in all planes for zooplankton community data. *D1-D4: "Distance from reef"; T1-T4: "Distance from bare sediment"; E1-E3: "Distance from general edge"; n.s. – no significant difference.*

Callala Bay		**Greenpoint**	
D1-D4			
Cyclopoida	11.31	Crustacean nauplii	12.25
Bivalvia larvae	10.92	Ostracoda	10.94
Crustacean nauplii	9.62	Cyclopoida	9.02
Calanoida	9.39	Unidentified eggs	8.95
Ostracoda	7.67	Harpacticoida	7.54
Unidentified eggs	6.42	Gastropoda larvae	7.34
T1-T3			
Calanoida	12.54	n.s.	n.s.
Bivalvia larvae	10.92	n.s.	n.s.
Cyclopoida	10.78	n.s.	n.s.
Crustacean nauplii	8.65	n.s.	n.s.
Ostracoda	8.61	n.s.	n.s.
T1-T4			
Cyclopoida	10.92	Crustacean nauplii	12.53
Ostracoda	9.95	Ostracoda	10.40
Bivalvia larvae	9.84	Cyclopoida	10.09
Calanoida	9.70	Harpacticoida	7.99
Crustacean nauplii	8.90	Unidentified eggs	7.71
T2-T3			
Bivalvia larvae	12.28	n.s.	n.s.
Cyclopoida	11.84	n.s.	n.s.
Calanoida	11.10	n.s.	n.s.
Crustacean nauplii	8.61	n.s.	n.s.
Ostracoda	7.46	n.s.	n.s.
T2-T4			
Cyclopoida	12.04	n.s.	n.s.
Bivalvia larvae	11.21	n.s.	n.s.
Ostracoda	9.01	n.s.	n.s.
Crustacean nauplii	8.93	n.s.	n.s.
Calanoida	8.34	n.s.	n.s.
E1-E2			
n.s.	n.s.	Crustacean nauplii	12.57
n.s.	n.s.	Ostracoda	10.13
n.s.	n.s.	Cyclopoida	9.19
n.s.	n.s.	Unidentified eggs	7.62
n.s.	n.s.	Gastropoda larvae	7.58
n.s.	n.s.	Annelida larvae	7.56

Table 4.4 cont'd Percent contribution of individual zooplankton taxa (cut off point set at top cumulative contribution of 50 – 60%) in SIMPER analysis at significant pairwise comparisons of distance categories in all planes for zooplankton community data. *D1-D4: "Distance from reef"; T1-T4: "Distance from bare sediment"; E1-E3: "Distance from general edge"*; *n.s. – no significant difference.*

Callala Bay		**Greenpoint**	
E1-E3			
Cyclopoida	11.63	n.s.	n.s.
Calanoida	9.94	n.s.	n.s.
Bivalvia larvae	9.20	n.s.	n.s.
Crustacean nauplii	9.13	n.s.	n.s.
Ostracoda	8.87	n.s.	n.s.
E2-E3			
Cyclopoida	12.22	n.s.	n.s.
Bivalvia larvae	10.00	n.s.	n.s.
Calanoida	9.32	n.s.	n.s.
Crustacean nauplii	8.49	n.s.	n.s.
Ostracoda	8.45	n.s.	n.s.

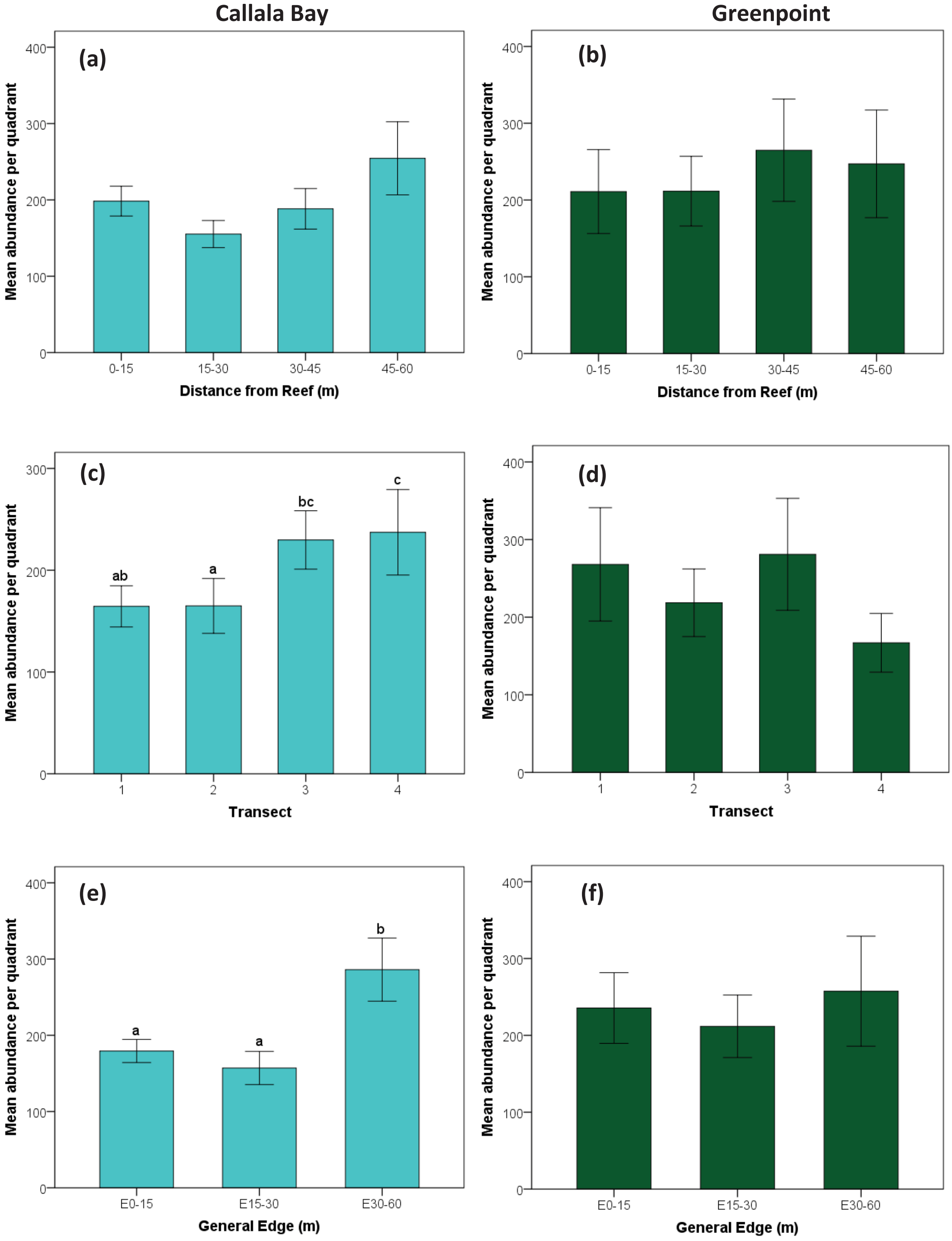


Fig 4.3 Total zooplankton abundance sampled within the *P. australis* habitat with distance from reef (a,b), bare sediment – increasing transect number (c,d) and general edge (d,e) at Callala Bay and Greenpoint during the summer sampling session. *Letters above bars represent the results of pairwise comparisons of log-transformed data with distance categories lacking similar letters being significantly different from each other.*

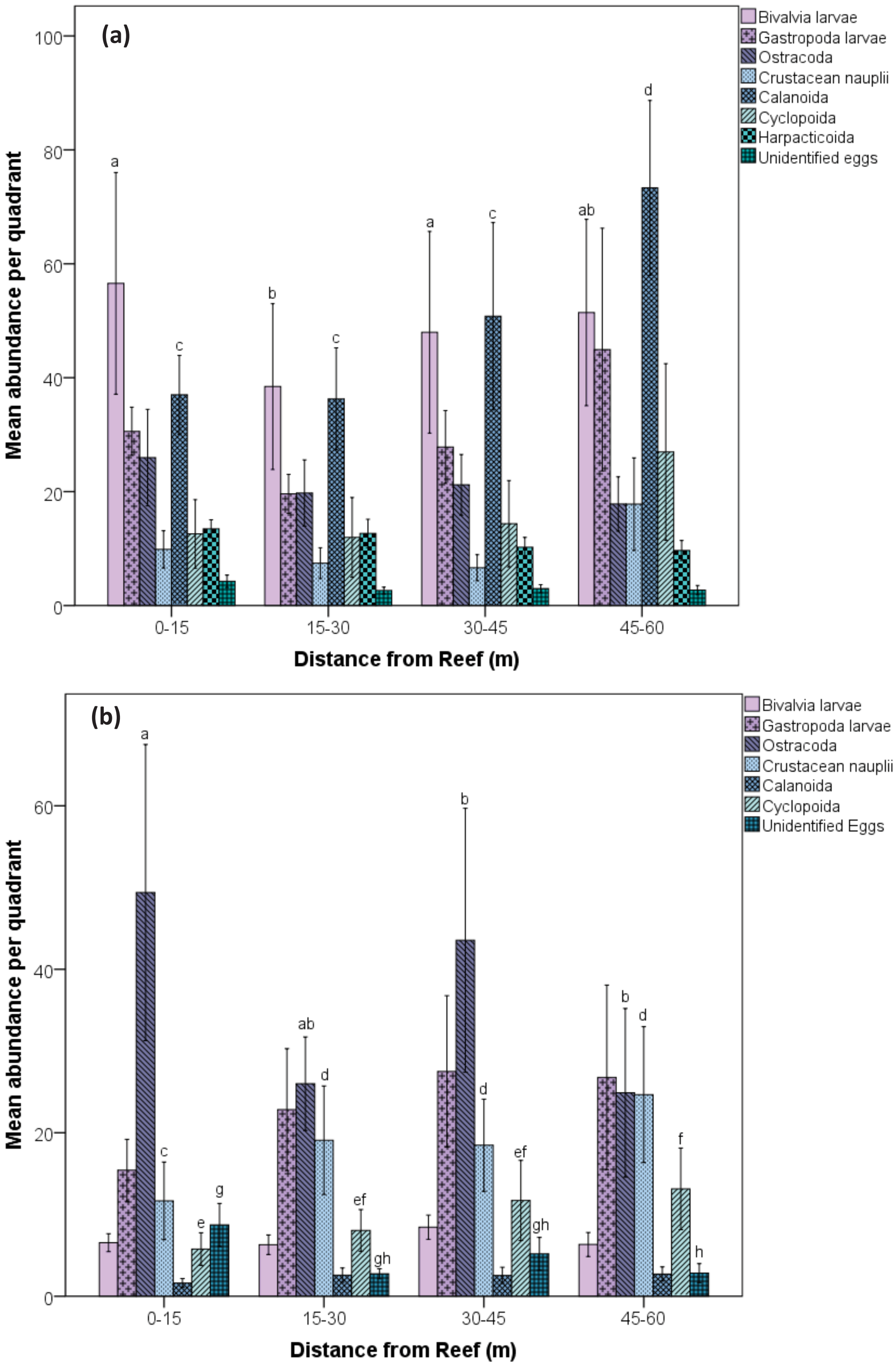


Fig 4.4 Abundance of major zooplankton taxa with "distance from reef" at (a) Callala Bay and (b) Greenpoint (excluding harpacticoid copepods). *Letters above bars represent the results of pairwise comparisons of log-transformed data with distance categories lacking similar letters being significantly different; the bar lettering of each subsequent bar category begin with the letter following alphabetically the highest lettering of the bar category immediately before.*

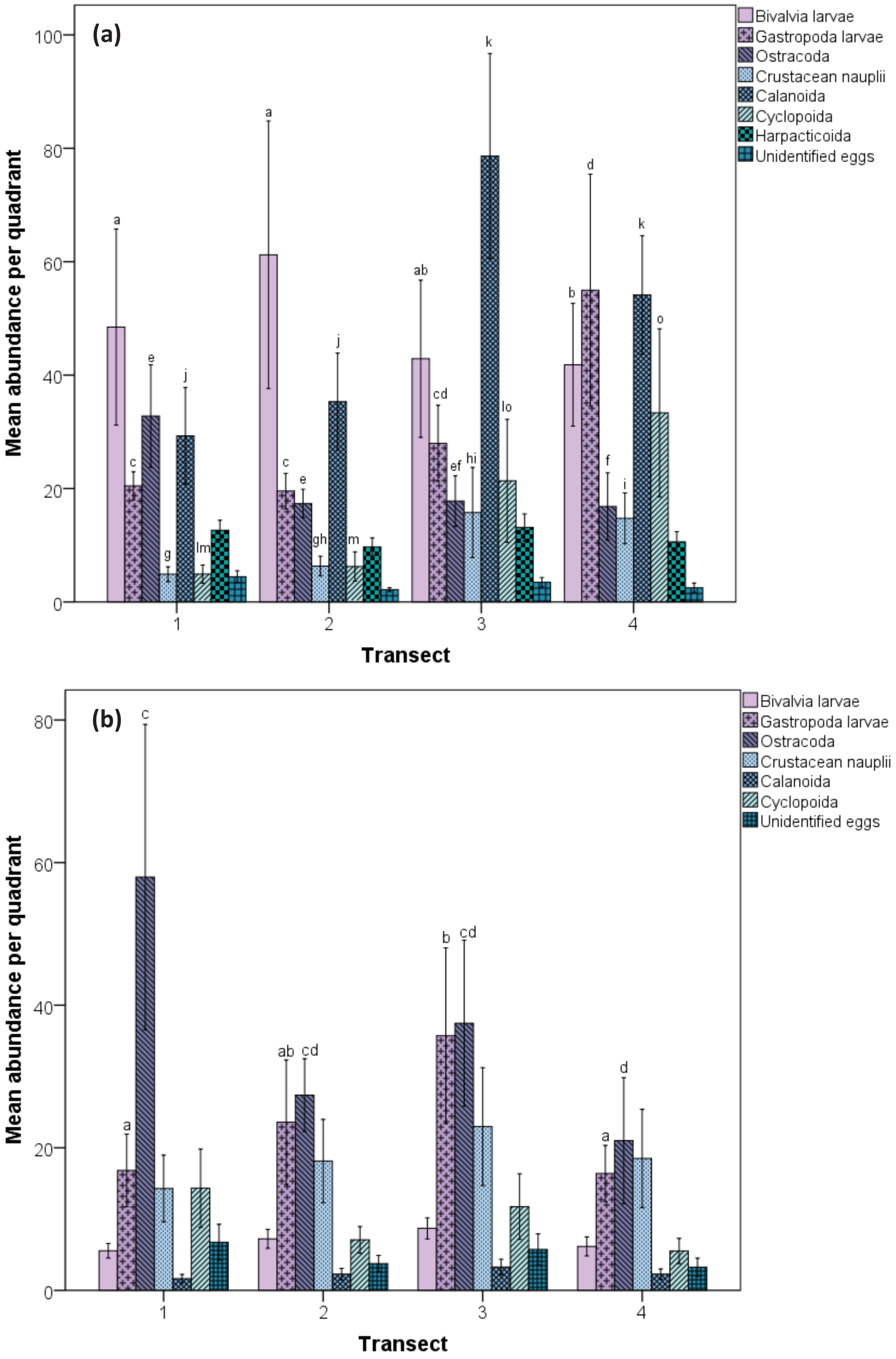


Fig 4.5 Abundance of major zooplankton taxa with “distance from bare sediment” – increasing transect number at (a) Callala Bay and (b) Greenpoint (excluding harpacticoid copepods). *Letters above bars represent the results of pairwise comparisons of log-transformed data with distance categories lacking similar letters being significantly different; the bar lettering of each subsequent bar category begin with the letter following alphabetically the highest lettering of the bar category immediately before.*

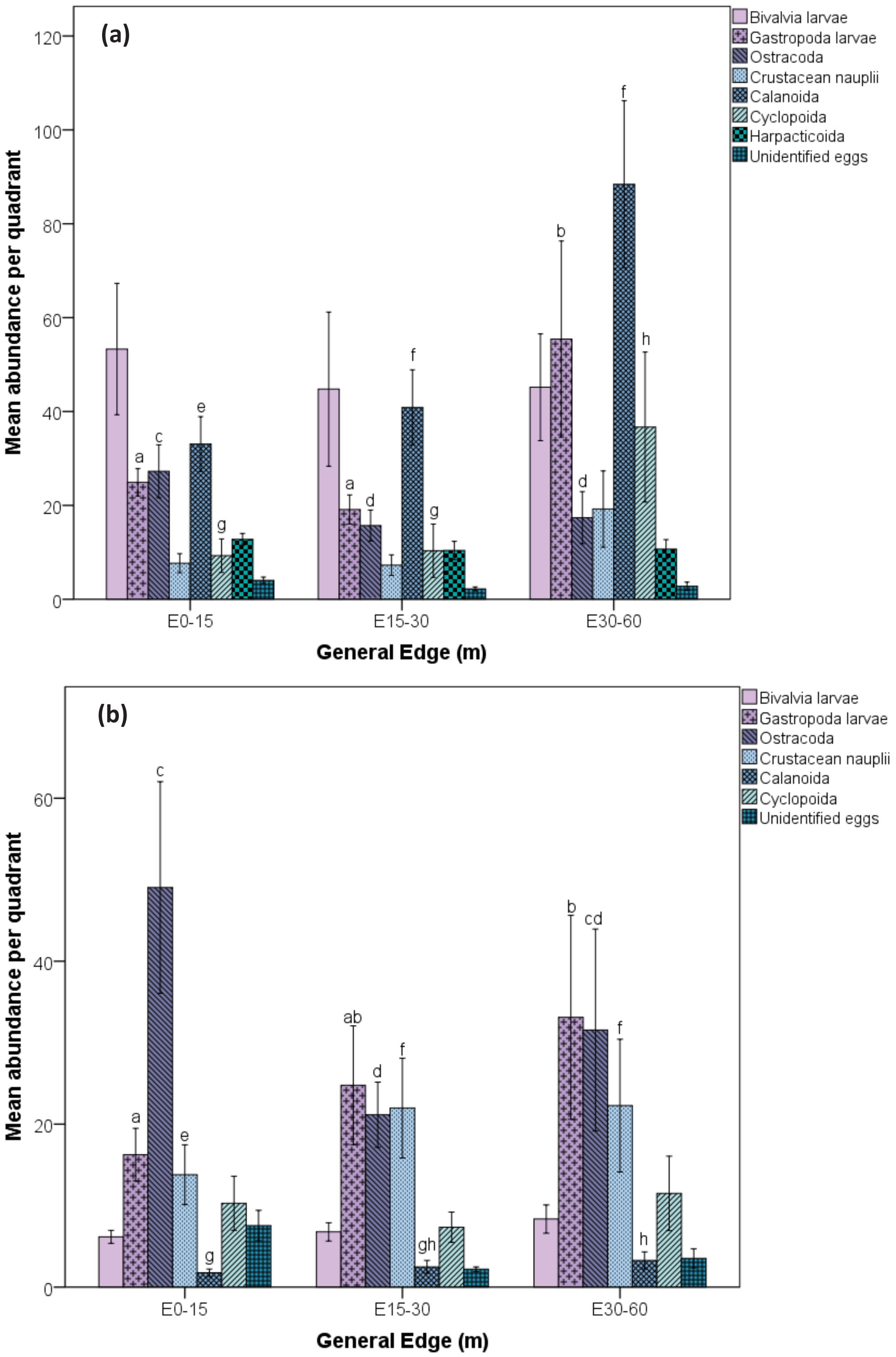
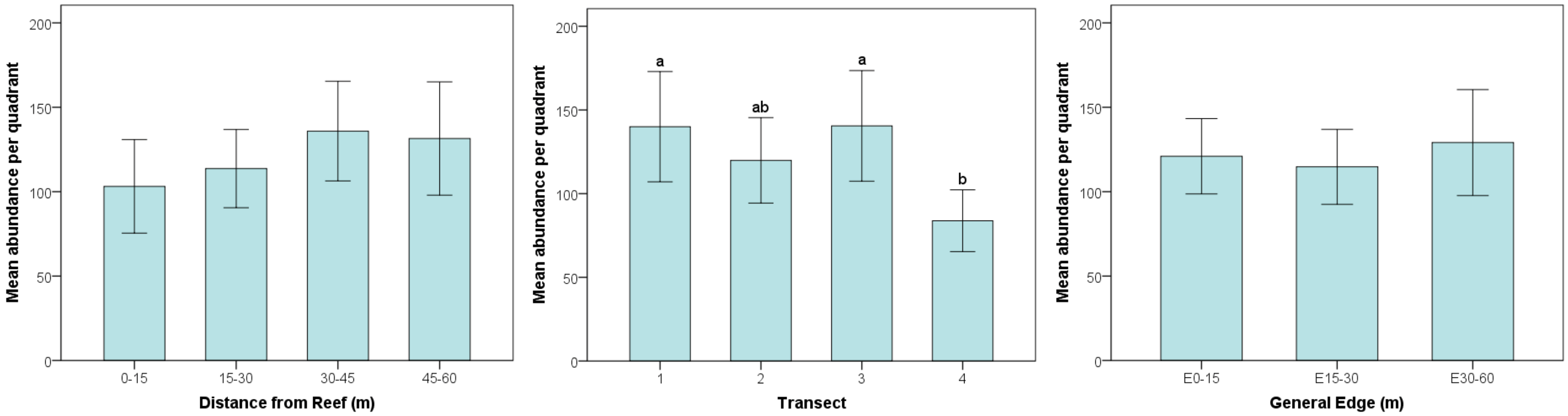


Fig 4.6 Abundance of major zooplankton taxa with "distance from general edge" at (a) Callala Bay and (b) Greenpoint (excluding harpacticoid copepods). *Letters above bars represent the results of pairwise comparisons of log-transformed data with distance categories lacking similar letters being significantly different; the bar lettering of each subsequent bar category begin with the letter following alphabetically the highest lettering of the bar category immediately before.*



(a) **(b)** **(c)**

Fig 4.7 Harpacticoid copepod abundance at Greenpoint with distance from (a) reef, (b) bare sediment (increasing transect number) and (c) general edge. *Letters above bars represent the results of pairwise comparisons of log-transformed data with distance categories lacking similar letters being significantly different from each other*.

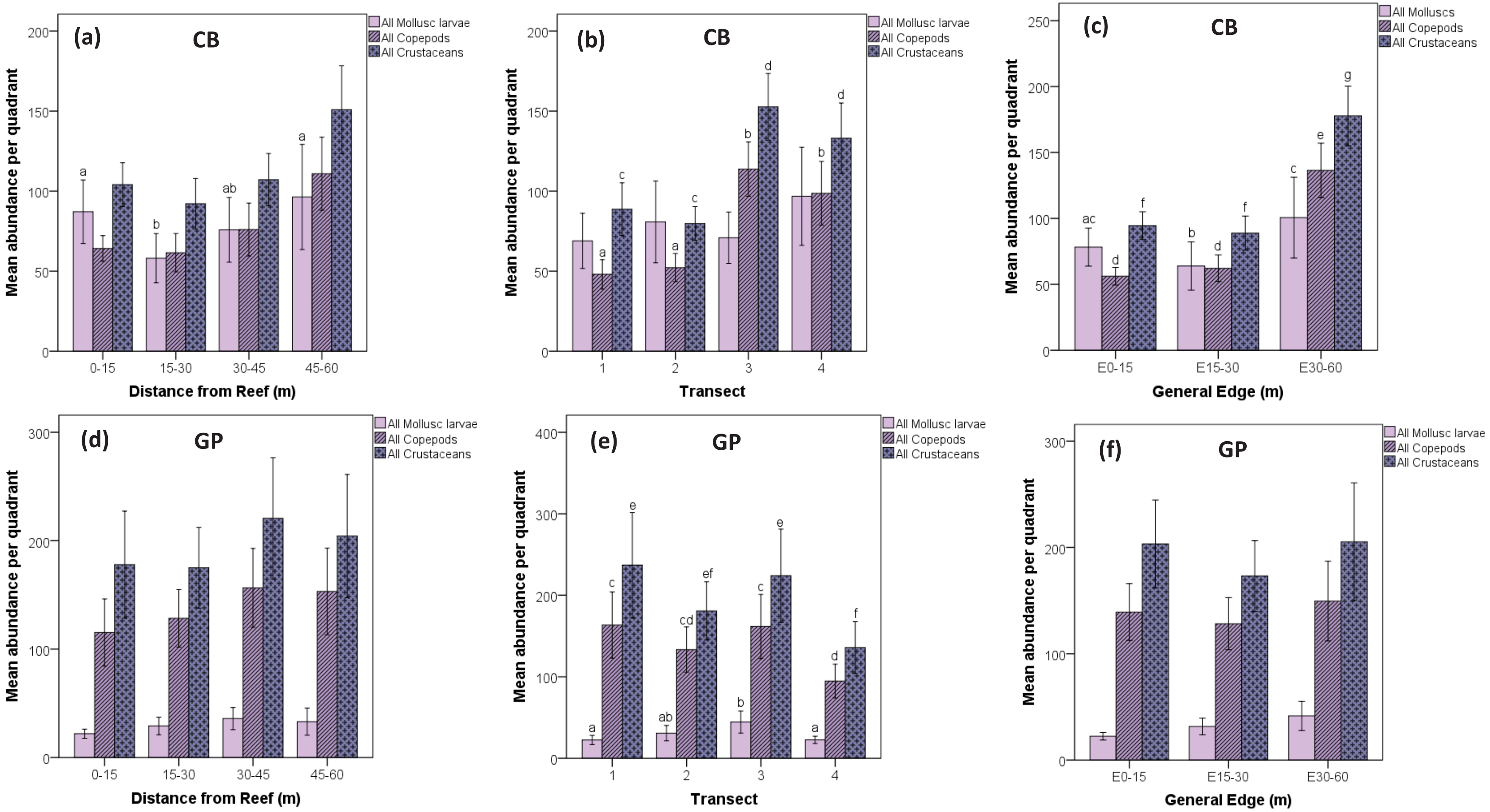


Fig 4.8 Total abundance of major zooplanktonic groups (mollusc larvae, crustaceans and copepods only) with distance from (a,d) reef, (b,e) bare sediment (increasing transect number) and (c,f) general edge at Callala Bay (CB) and Greenpoint (GP), Jervis Bay. *Letters above bars represent the results of pairwise comparisons of log-transformed data with distance categories lacking similar letters being significantly different; the bar lettering of each subsequent bar category begin with the letter following alphabetically the highest lettering of the bar category immediately before.*

Table 4.5 Benthic invertebrate taxonomic groups (predominantly gastropods) sampled with sediment cores within *Posidonia australis* bed of Greenpoint, Jervis Bay.

Benthic Invertebrate Taxa	**# of individuals sampled**
Gastropod Families:	
Potamididae	7441
Columbellidae	1105
Litiopidae	244
Littorinidae	241
Trochidae	233
Cerithiopsidae	117
Buccinidae	58
Pyramidellidae	56
Rissoidae	48
Muricidae	37
Dialidae	21
Marginellidae	18
Turridae	17
Tornidae	7
Unidentified Gastropoda	6
Ellobiidae	4
Epitoniidae	4
Nassiidae	1
Naticidae	1
Class Bivalvia	17
Other groups:	
Class Polychaeta	8
Class Malacostraca	2
Class Ostracoda	2
Phylum Chordata (Fish) larvae	1
Total Number of Individuals	**9689**

Table 4.6 (a) Summary of PERMANOVA results of the effect of “Distance from reef” on indicated benthic invertebrate community composition and individual taxa abundance during the summer at Greenpoint only, except where indicated. *“Di” denotes “Distance from reef”, “Tr” – distance from bare sediment / transect; D1=0-15m, D2=15-30m, D3=30-45m, D4=45-60m; significant permdisp (in bold) indicate non-homogeneity of variances; permdisp values of significant relationships only reported.*

	Distance from Reef				**Factors Included**		**Pairwise Comparisons**						
	df	**MS**	**pseudo-F**	**p**	**Di**	**Tr**	**D1-D2**	**D1-D3**	**D1-D4**	**D2-D3**	**D2-D4**	**D3-D4**	**Permdisp**
Greenpoint only:													
Total Abundance (All individuals)	3	10.27	32.063	**0.0001**	*	*	**0.0104**	**0.0001**	**0.0001**	**0.0013**	**0.0001**	**0.0159**	0.351
Total Abundance (All Molluscs)	3	10.347	32.037	**0.0001**	*	*	**0.0103**	**0.0001**	**0.0001**	**0.0009**	**0.0001**	**0.0172**	0.35
Overall Community	3	3076.2	5.769	**0.0001**	*	*	**0.0007**	**0.0003**	**0.0001**	**0.0097**	**0.0001**		**0.001**
Mollusc Community	3	3073.7	5.984	**0.0001**	*	*	**0.0007**	**0.0001**	**0.0001**	**0.0089**	**0.0002**		**0.001**
Mollusc Community (Taxa per size class)	3	5548.1	5.9509	**0.0001**	*	*	**0.0001**	**0.0001**	**0.0001**	**0.0039**	**0.0001**		**0.001**
Major Families (Gastropods):													
Potamididae	3	20.525	40.292	**0.0001**	*	*	**0.0004**	**0.0001**	**0.0001**	**0.0013**	**0.0001**	**0.0189**	0.535
Columbellidae	3	5.8025	16.41	**0.0001**	*	*	**0.0061**	**0.0001**	**0.0001**		**0.0012**	**0.0269**	0.866
Litiopidae	3	3.9531	7.9753	**0.0002**	*	*		**0.0057**	**0.0006**	0.0138	**0.0013**		**0.042**
Trochidae	3	0.52752	1.3697	0.2587	*	*							
Cerithiopsidae	3	3.7533	7.3496	**0.0008**	*	*		**0.0012**	**0.0017**	**0.0072**	**0.0047**		**0.001**
Littorinidae	3	1.4901	3.1112	**0.0335**	*	*			**0.0193**		**0.01**		0.34
Both Sites (CB,GP) Pooled:													
[1]Trochidae	3	6.7162	5.0852	**0.0027**	*	*		0.0168	**0.0011**				**0.002**

[1] Abundances for this gastropod family was pooled across both sites using abundance data from Callala Bay previously presented in (Ollivier et al. 2015) along with Greenpoint data. Pooling was justified due to the high significance of the factor “site” when included in both statistical designs (0.4257<p<0.7482).

Table 4.6 (b) Summary of PERMANOVA results of the effect of “Distance from bare sediment” on indicated benthic invertebrate community composition and individual taxa abundance during the summer at Greenpoint only, except where indicated. *“Di” denotes “Distance from reef”, “Tr” – distance from bare sediment / transect; T1=0-15m+, T2=15-30m+, T3=30-45m+, T4=45-60m+; significant permdisp (in bold) indicate non-homogeneity of variances; permdisp values of significant relationships only reported.*

	Distance from Bare Sediment				Factors Included		Pairwise Comparisons						
	df	**MS**	**pseudo-F**	**p**	**Di**	**Tr**	**T1-T2**	**T1-T3**	**T1-T4**	**T2-T3**	**T2-T4**	**T3-T4**	**Permdisp**
Greenpoint only:													
Total Abundance (All individuals)	3	2.6316	8.2158	**0.0005**	*	*		**0.0401**	**0.0205**	**0.0005**	**0.0001**		0.715
Total Abundance (All Molluscs)	3	2.6238	8.1234	**0.0003**	*	*		**0.041**	**0.0229**	**0.0006**	**0.0004**		0.75
Overall Community	3	1781.4	3.3407	**0.0001**	*	*	**0.0433**		**0.0001**	**0.0132**	**0.0013**	0.0454	0.589
Mollusc Community	3	1732.9	3.3736	**0.0001**	*	*			**0.0001**	**0.0141**	**0.0022**	0.0453	0.551
Mollusc Community (Individuals per size class)	3	2439.9	2.6171	**0.0001**	*	*	**0.0418**	**0.0101**	**0.0001**	**0.0058**	**0.0048**		0.237
Major Families (Gastropods):													
Potamididae	3	5.8902	11.563	**0.0001**	*	*		**0.0011**	**0.001**	**0.0002**	**0.0001**		**0.013**
Columbellidae	3	0.62889	1.7786	0.1641	*	*							
Litiopidae	3	2.9497	5.9508	**0.0018**	*	*			**0.0042**		**0.0006**		**0.04**
Trochidae	3	2.8481	7.395	**0.0005**	*	*	**0.0029**	**0.0088**	**0.0002**				0.83
Cerithiopsidae	3	1.0049	1.9678	0.136	*	*							
Littorinidae	3	1.3466	2.8115	0.049	*	*			**0.0089**				0.466
Both Sites (CB,GP) Pooled:													
[1]Trochidae	3	1.1715	0.88703	0.4432	*	*							

Interaction terms not presented in table for logistics purposes. As described in General Discussion (6.6.1) interaction terms were evaluated to determine statistical approach and/ or cited in the text and subsequently discussed where highly significant terms may influence valid interpretation of data.

Table 4.6 (c) Summary of PERMANOVA results of the effect of “Distance from general edge” on indicated benthic invertebrate community composition and individual taxa abundance during the summer at Greenpoint only, except where indicated. *E1=E0-15m, E2=E15-30m, E3=30-60m; significant permdisp (in bold) indicate non-homogeneity of variances; permdisp values of significant relationships only reported.*

	Distance from General Edge				Pairwise Comparisons			
	df	**MS**	**pseudo-F**	**p**	**E1-E2**	**E1-E3**	**E2-E3**	**Permdisp**
Greenpoint only:								
Total Abundance (All individuals)	2	3.3587	3.9625	0.0266				**0.024**
Total Abundance (All Molluscs)	2	3.3861	3.9756	0.0219				**0.027**
Overall Community	2	1092.9	1.4358	0.1542				
Mollusc Community	2	1094.3	1.4813	0.1295				
Mollusc Community (Individuals per size class)	2	2828.8	2.2657	**0.0043**		**0.0054**		**0.001**
Major Families (Gastropods):								
Potamididae	2	7.3394	4.6027	0.0142				**0.002**
Columbellidae	2	3.9116	7.4475	**0.0014**	**0.0018**	**0.0109**		0.068
Litiopidae	2	0.80508	1.07	0.3464				
Trochidae	2	0.29242	0.43792	0.6528				
Cerithiopsidae	2	0.69895	1.0408	0.3646				
Littorinidae	2	0.28431	0.41014	0.6672				
Both Sites (CB,GP) Pooled:								
[1]Trochidae	2	1.375	0.97654	0.386				

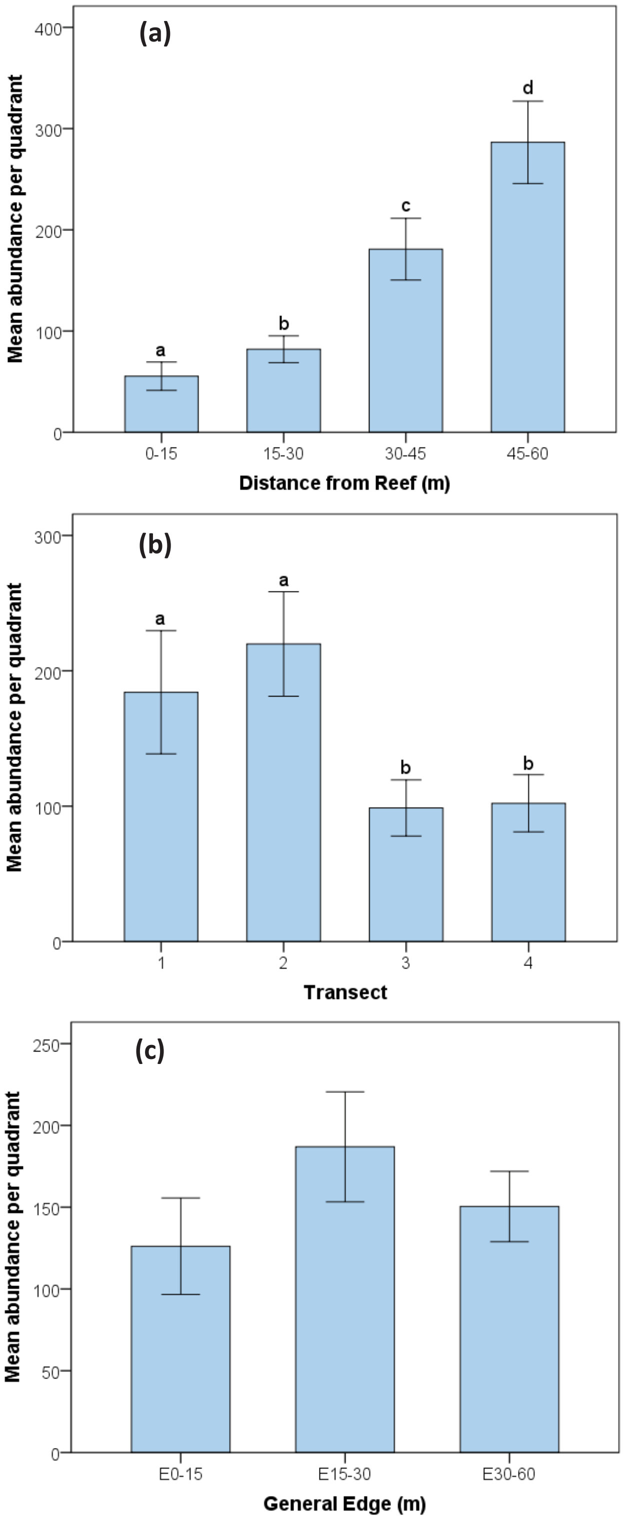


Fig 4.9 Total Mollusca abundance sampled by sediment cores within *P. australis* at Greenpoint, Jervis Bay with distance from (a) reef, (b) bare sediment (increasing transect number), and (c) general edge. *Letters above bars represent the results of pairwise comparisons of log-transformed data with distance categories lacking similar letters being significantly different from each other.*

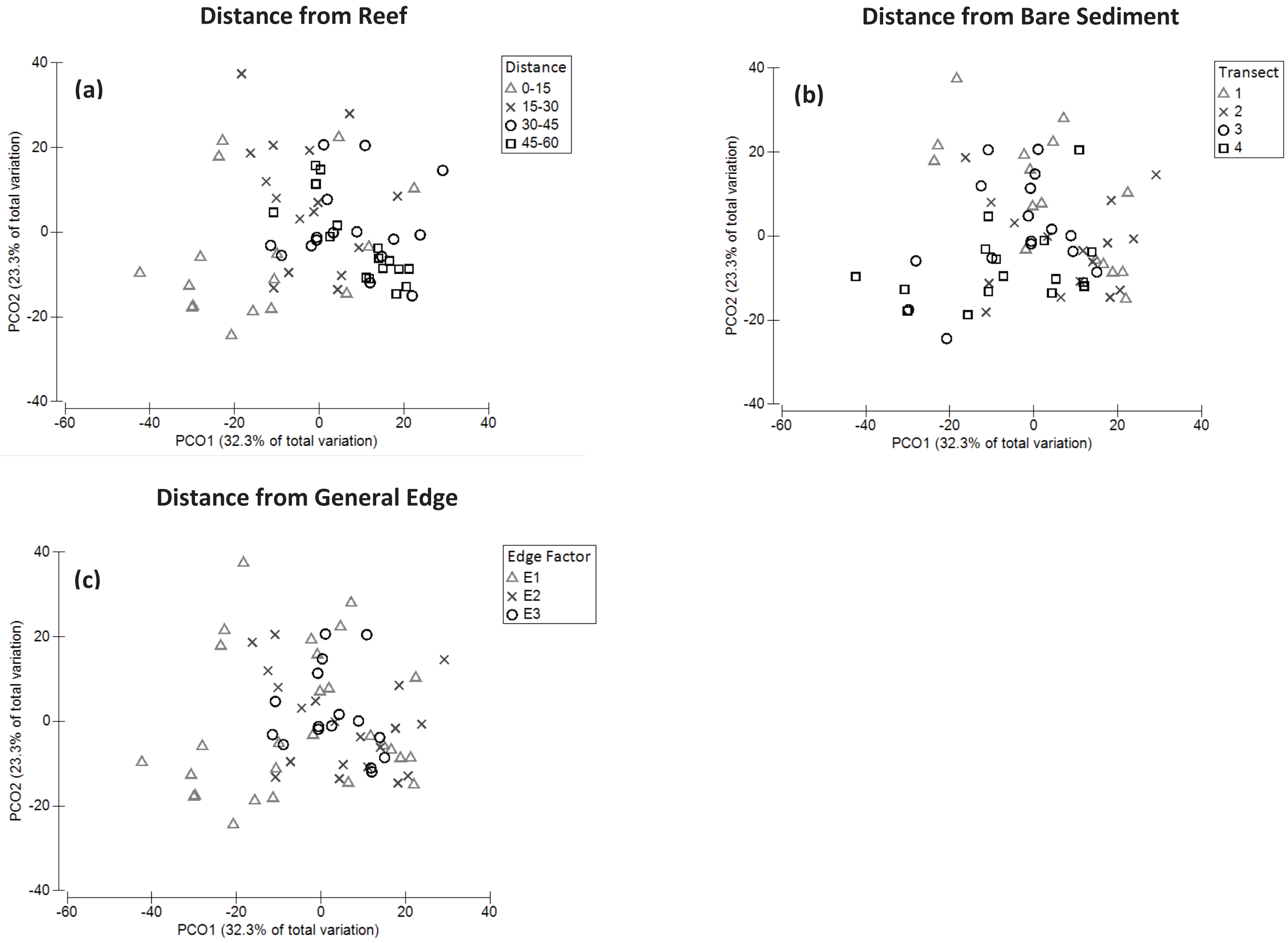


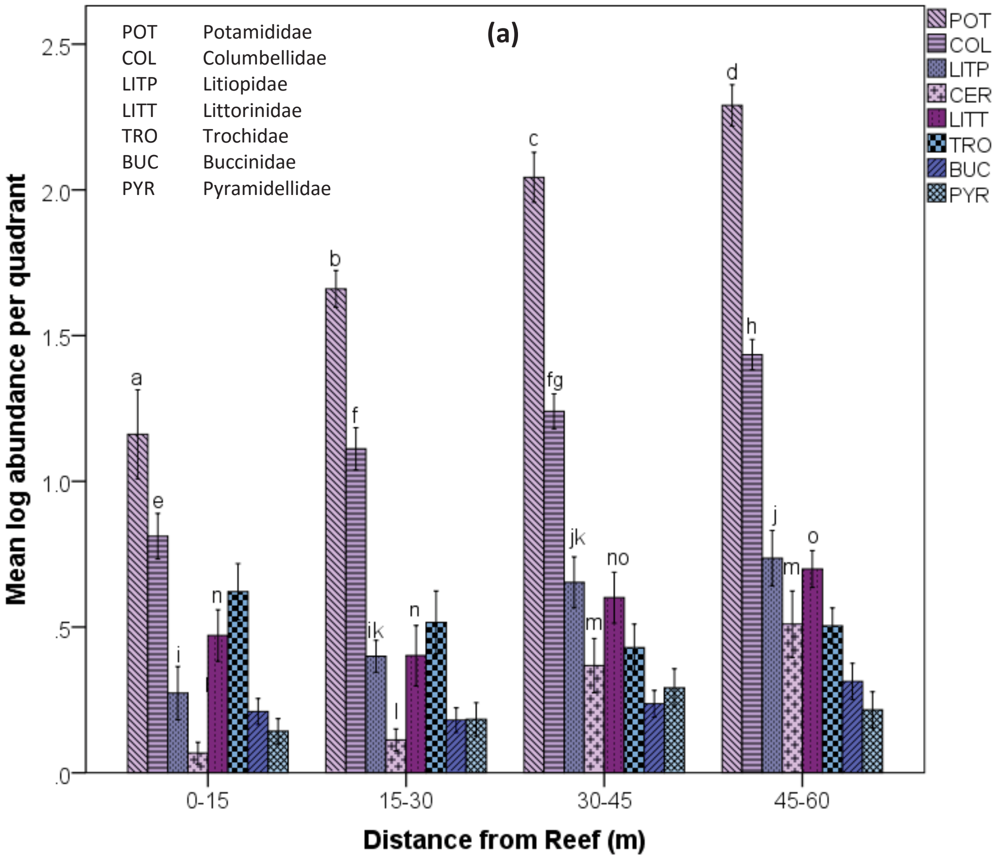
Fig 4.10 PCO plots illustrating Greenpoint mollusc community distribution with distance from (a) reef, (b) bare sediment i.e. increasing transect number – 1(0-15m+), 2(15-30m+), 3(30-45m+) and 4(45-60m+) and (c) general edge – E1(E0-15m), E2(E15-30m) and E3 (E30-60m).

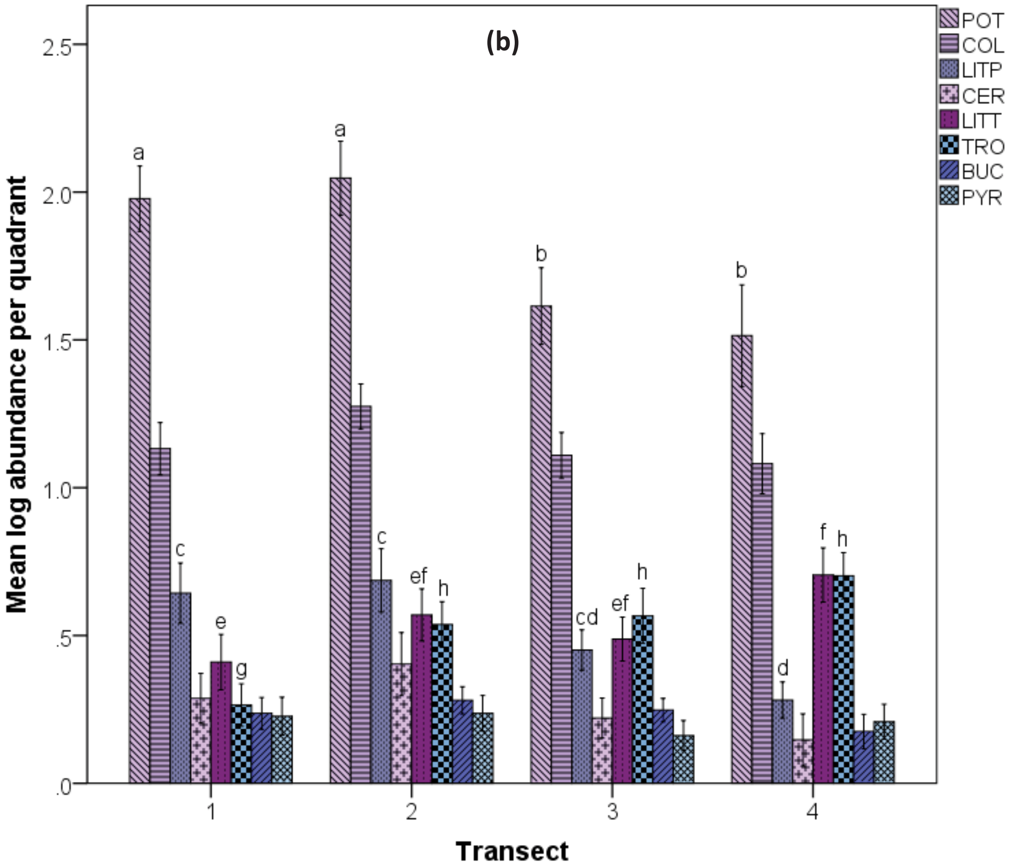
Table 4.7 Percent contribution of individual taxa (cut off set at cumulative 50 – 60% top contribution) and taxa by size class (contributing ≥ 5% only) in SIMPER analysis at significant pairwise comparisons of Greenpoint mollusc community data. *POT- Potamididae, COL-Columbellidae and LITT-Littorinidae*.

Greenpoint Mollusc Community		**Mollusc Community by Size Class (mm)**	
D1-D2			
Potamididae	17.74	POT 3>6	9.31
Trochidae	11.69	POT 6>9	8.26
Columbellidae	10.75	COL 9>12	5.51
Littorinidae	10.74	POT 12>15	5.46
Litiopidae	8.98	LITT 0>3	5.13
D1-D3			
Potamididae	21.22	POT 3>6	10.16
Litiopidae	10.93	POT 6>9	9.36
Columbellidae	10.58	POT 12>15	6.09
Littorinidae	8.86	COL 9>12	5.17
Trochidae	8.68		
D1-D4			
Potamididae	23.61	POT 3>6	10.20
Columbellidae	12.82	POT 6>9	10.11
Litiopidae	11.11	POT 12>15	6.42
Cerithiopsidae	8.79	POT 15>18	6.18
		COL 9>12	5.69
D2-D3			
Littorinidae	12.49	POT 3>6	6.25
Potamididae	11.98	POT 6>9	6.10
Trochidae	10.90	LITT 0>3	5.61
Litiopidae	9.36	POT 0>3	5.45
Cerithiopsidae	8.40		
D2-D4			
Potamididae	15.06	POT 6>9	7.35
Littorinidae	11.41	POT 3>6	6.84
Cerithiopsidae	10.17	POT 15>18	5.21
Trochidae	9.73		
Litiopidae	9.58		
T1-T2			
Potamididae	12.71	POT 3>6	6.49
Litiopidae	11.15	POT 6>9	6.27
Littorinidae	10.34	POT 12>15	5.14
Trochidae	9.77	POT 15<18	5.00
Columbellidae	9.44		
T1-T3			
Potamididae	15.80	POT 3>6	8.72
Trochidae	11.72	POT 6>9	6.73
Littorinidae	10.71	POT 12>15	5.16
Litiopidae	10.50		
Columbellidae	10.26		

Table 4.7 cont'd Percent contribution of individual taxa (cut off set at cumulative 50 – 60% top contribution) and taxa by size class (contributing ≥ 5% only) in SIMPER analysis at significant pairwise comparisons of Greenpoint mollusc community data. *POT- Potamididae, COL-Columbellidae and LITT-Littorinidae*.

Greenpoint Mollusc Community		**Mollusc Community by Size Class (mm)**	
T1-T4			
Potamididae	17.46	POT 3>6	8.63
Trochidae	11.57	POT 6>9	8.41
Littorinidae	11.35	LITT 0>3	5.39
Litiopidae	9.95	COL 9>12	5.11
Columbellidae	9.84		
T2-T3			
Potamididae	16.21	POT 3>6	8.55
Litiopidae	10.87	POT 6>9	6.90
Littorinidae	9.20	POT 12>15	5.11
Columbellidae	9.11		
Trochidae	9.05		
T2-T4			
Potamididae	17.80	POT 3>6	8.43
Litiopidae	10.94	POT 6>9	8.18
Columbellidae	9.31		
Littorinidae	8.95		
Cerithiopsidae	8.69		
E1-E3			
n.s.	n.s.	POT 3>6	8.39
n.s.	n.s.	POT 6>9	8.14
n.s.	n.s.	POT 12>15	5.65
n.s.	n.s.	COL 9>12	5.59
n.s.	n.s.	POT 15>18	5.49


(a)
POT Potamididae
COL Columbellidae
LITP Litiopidae
LITT Littorinidae
TRO Trochidae
BUC Buccinidae
PYR Pyramidellidae
POT
COL
LITP
CER
LITT
TRO
BUC
PYR
Mean log abundance per quadrant
2.5
2.0
1.5
1.0
.5
.0
a
e
i
n
b
f
ik
l
n
c
fg
jk
m
no
d
h
j
m
o
0-15
15-30
30-45
45-60
Distance from Reef (m)


(b)
POT
COL
LITP
CER
LITT
TRO
BUC
PYR
Mean log abundance per quadrant
2.5
2.0
1.5
1.0
.5
.0
a
c
e
g
a
c
ef
h
b
cd
ef
h
b
d
f
h
1
2
3
4
Transect

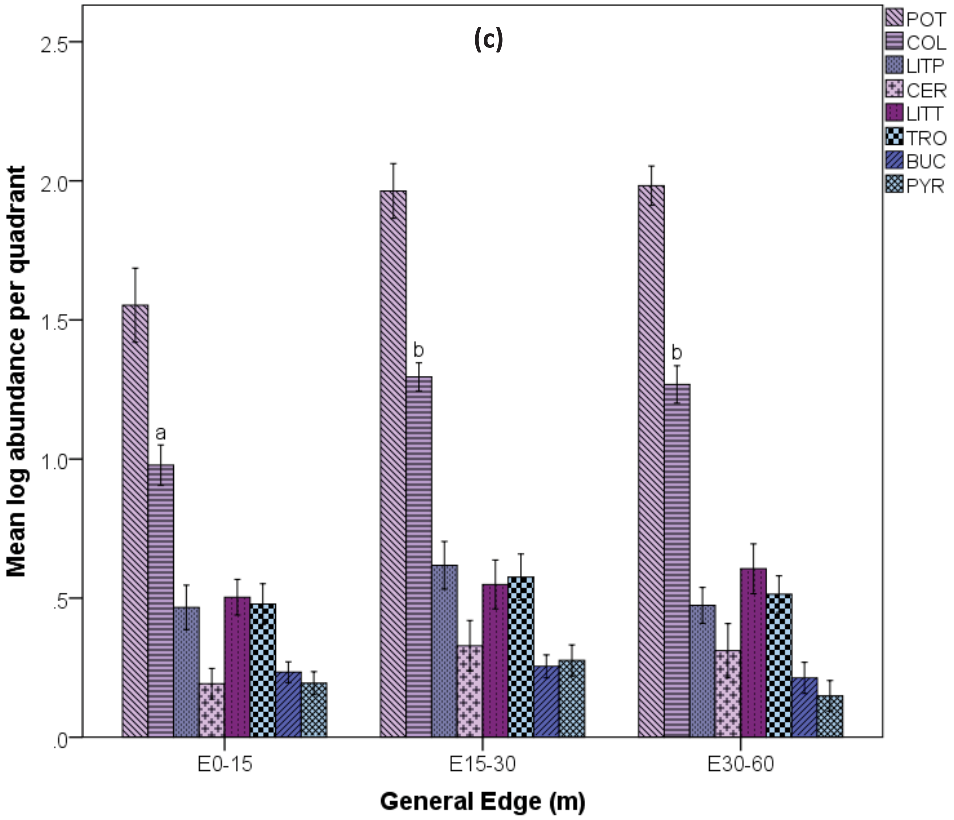


Fig 4.11 Abundance of main gastropod families sampled within *P. australis* at Greenpoint, Jervis Bay with distance from (a) reef, (b) bare sediment (increasing transect number) and (c) general edge. *Letters above bars represent the results of pairwise comparisons of log-transformed data with distance categories lacking similar letters being significantly different; the bar lettering of each subsequent bar category begin with the letter following alphabetically the highest lettering of the bar category immediately before.*

Table 4.8 Total number of molluscs within and % composition of each of seven size classes from benthic cores within *Posidonia australis* beds at Greenpoint, Jervis Bay. *Percentages in brackets represent corresponding size class composition at Callala Bay*.

Mollusc Size Class (mm)	**#s per size class**	**Percentage (%)**
0-3	565	5.84 (63.27)
3-6	5050	52.19 (32.34)
6-9	2349	24.28 (1.79)
9-12	963	9.95 (1.74)
12-15	351	3.63 (0.30)
15-18	255	2.64 (0.42)
>18	143	1.48 (0.13)
TOTAL	**9676**	

Table 4.9 (a) Summary of PERMANOVA results of the effect of “Distance from reef” on the mollusc community as grouped in size classes and on abundances within individual size classes during the summer across both sites, except where indicated. *“Di” denotes “Distance from reef”, “Tr” – distance from bare sediment / transect; D1=0-15m, D2=15-30m, D3=30-45m, D4=45-60m; significant permdisp (in bold) indicate non-homogeneity of variances; permdisp values of significant relationships only reported.*

	Distance from Reef				Factors Included			Pairwise Comparisons						
	df	**MS**	**pseudo-F**	**p**	**Di**	**Tr**	**Site**	**D1-D2**	**D1-D3**	**D1-D4**	**D2-D3**	**D2-D4**	**D3-D4**	**Permdisp**
Size Class Composition Distribution	3	1762.2	1.0401	0.5278	*	*	*							
Greenpoint	3	3247.8	11.318	**0.0001**	*	*		**0.0001**	**0.0001**	**0.0001**	**0.0005**	**0.0001**		**0.001**
Callala Bay	3	294.58	1.2802	0.2399	*	*								
Individual Size Classes:														
0 > 3 mm	3	1.378	0.85595	0.5396	*	*	*							
Greenpoint	3	3.0183	6.4789	**0.0013**	*	*			**0.0117**		**0.0005**	**0.0043**		0.292
Callala Bay	3	$1.015E^{-2}$	$2.8422E^{-2}$	0.9931	*	*								
3 > 6 mm	3	8.7668	1.0166	0.5237	*	*	*							
Greenpoint	3	17.991	22.269	**0.0001**	*	*		**0.007**	**0.0003**	**0.0001**	**0.0072**	**0.0002**		**0.006**
Callala Bay	3	$3.3299E^{-2}$	$7.4775E^{-2}$	0.9717	*	*								
6 > 9 mm	3	6.7094	0.80044	0.6295	*	*	*							
Greenpoint	3	15.588	31.686	**0.0001**	*	*		**0.0033**	**0.0001**	**0.0001**	**0.0068**	**0.0001**	**0.012**	0.155
Callala Bay	3	0.174	0.43485	0.7221	*	*								
9 > 12 mm	3	2.2241	0.48605	0.8292	*	*	*							
Greenpoint	3	6.7228	17.623	**0.0001**	*	*		**0.0013**	**0.0004**	**0.0001**		**0.004**	**0.0144**	0.826
Callala Bay	3	0.34781	1.2759	0.2942	*	*								
12 > 15 mm	3	3.037	0.69057	0.7295	*	*	*							
Greenpoint	3	7.5921	15.196	**0.0001**	*	*		**0.0054**	**0.0003**	**0.0001**		**0.0018**	**0.0477**	0.53
Callala Bay	3	0.14765	1.1478	0.3371	*	*								
15 > 18 mm	3	1.1048	0.33523	0.8585	*	*	*							
Greenpoint	3	4.3541	7.9976	**0.0006**	*	*			**0.0447**	**0.0001**		**0.0034**	**0.007**	0.93
Callala Bay	3	0.33201	2.1193	0.1089	*	*								
≥ 18 mm	3	0.10343	0.36718	0.748	*	*	*							
Greenpoint	3	0.31575	0.9851	0.4075	*	*								
Callala Bay	3	$7.1656E^{-2}$	1.3016	0.2855	*	*								

Table 4.9 (b) Summary of PERMANOVA results of the effect of “Distance from bare sediment” on the mollusc community as grouped in size classes and on abundances within individual size classes during the summer across both sites, except where indicated. *“Di” denotes “Distance from reef”, “Tr” – distance from bare sediment / transect; T1=0-15m+, T2=15-30m+, T3=30-45m+, T4=45-60m+; significant permdisp (in bold) indicate non-homogeneity of variances; permdisp values of significant relationships only reported.*

	Distance from Bare Sediment				Factors Included			Pairwise Comparisons						
	df	MS	pseudo-F	p	Di	Tr	Site	T1-T2	T1-T3	T1-T4	T2-T3	T2-T4	T3-T4	Permdisp
Size Class Composition Distribution	3	1003.4	1.1046	0.4448	*	*	*							
Greenpoint	3	1186.4	4.1345	**0.0001**	*	*		**0.0039**	**0.0016**	**0.0001**	**0.0172**	**0.0011**		0.323
Callala Bay	3	733.67	3.1885	**0.0015**	*	*		**0.0034**	**0.0015**					**0.04**
Individual Size Classes:														
0 > 3 mm	3	0.98126	0.31186	0.7877	*	*	*							
Greenpoint	3	1.4517	3.1162	**0.0296**	*	*		**0.0401**			**0.0248**		**0.0362**	0.08
Callala Bay	3	2.6094	7.3067	**0.0003**	*	*		**0.0007**	**0.0335**	**0.0136**		**0.0094**		0.099
3 > 6 mm	3	6.1087	2.5503	0.2805	*	*	*							
Greenpoint	3	6.8956	8.5352	**0.0003**	*	*			**0.002**	**0.001**	**0.0039**	**0.0011**		0.8
Callala Bay	3	1.6589	3.7251	**0.0163**	*	*		**0.023**	**0.0025**	**0.0384**				0.455
6 > 9 mm	3	2.5808	1.2124	0.4715	*	*	*							
Greenpoint	3	4.0189	8.1692	**0.0002**	*	*			**0.0243**	**0.0041**	**0.002**	**0.0011**		0.247
Callala Bay	3	0.68649	1.7156	0.1744	*	*								
9 > 12 mm	3	0.64506	0.47793	0.7146	*	*	*							
Greenpoint	3	0.67655	1.7735	0.1614	*	*								
Callala Bay	3	1.2974	4.7593	**0.0046**	*	*			**0.0018**		**0.0202**			0.892
12 > 15 mm	3	0.57638	0.68967	0.6087	*	*	*							
Greenpoint	3	1.2571	2.5162	0.0683	*	*								
Callala Bay	3	0.1533	1.1918	0.3211	*	*								
15 > 18 mm	3	0.5616	0.99451	0.5081	*	*	*							
Greenpoint	3	1.1339	2.0827	0.114	*	*								
Callala Bay	3	$2.6097E^{-2}$	0.16658	0.9199	*	*								
≥ 18 mm	3	1.2651	1.2145	0.4743	*	*	*							
Greenpoint	3	2.3915	7.4611	**0.0004**	*	*		**0.0097**	**0.0228**	**0.0001**		**0.0342**		0.385
Callala Bay	3	$1.8536E^{-2}$	0.3367	0.8105	*	*								

Table 4.9 (c) Summary of PERMANOVA results of the effect of "Distance from general edge" on the mollusc community as grouped in size classes and on abundances within individual size classes during the summer across both sites, except where indicated. *E1=E0-15m, E2=E15-30m, E3=30-60m; significant permdisp (in bold) indicate non-homogeneity of variances; permdisp values of significant relationships only reported.*

	Distance from General Edge				Factors Included		Pairwise Comparisons			
	df	**MS**	**pseudo-F**	**p**	**Ed**	**Site**	**E1-E2**	**E1-E3**	**E2-E3**	**Permdisp**
Size Class Composition Distribution	2	716.59	0.59908	0.6556	*	*				
Greenpoint	2	1405.6	3.0021	**0.0066**	*		0.0119			**0.001**
Callala Bay	2	507.2	1.901	0.0835	*					
Individual Size Classes:										
0 > 3 mm	2	$4.4696E^{-2}$	$5.0602E^{-2}$	0.974	*	*				
Greenpoint	2	0.40524	0.48992	0.6034	*					
Callala Bay	2	0.52274	0.99172	0.3817	*					
3 < 6 mm	2	1.4007	0.32521	0.7097	*	*				
Greenpoint	2	5.1242	2.8351	0.0664	*					
Callala Bay	2	0.58365	1.0579	0.3556	*					
6 > 9 mm	2	1.1167	0.22181	0.7785	*	*				
Greenpoint	2	5.2366	4.0834	**0.0183**	*		**0.0331**	**0.0228**		0.051
Callala Bay	2	0.91477	2.4715	0.0899	*					
9 > 12 mm	2	0.94224	0.13945	0.7497	*	*				
Greenpoint	2	6.0045	11.817	**0.0002**	*		**0.0002**	**0.0008**		0.273
Callala Bay	2	1.6944	5.7861	**0.008**	*			**0.001**		0.484
12 > 15 mm	2	1.3585	0.4441	0.6615	*	*				
Greenpoint	2	4.2414	5.4729	**0.0081**	*		**0.0066**	**0.0211**		0.164
Callala Bay	2	0.17611	1.3391	0.2849	*					
15 > 18 mm	2	1.0258	0.54118	0.6133	*	*				
Greenpoint	2	2.8214	4.1768	**0.0205**	*		**0.0189**	**0.0329**		0.598
Callala Bay	2	0.10002	0.54708	0.5856	*					
≥ 18 mm	2	0.40374	3.7931	0.2131	*	*				
Greenpoint	2	0.4008	0.79872	0.4536	*					
Callala Bay	2	0.10939	2.1221	0.1472	*					

Interaction terms not presented in table for logistics purposes. As described in General Discussion (6.6.1) interaction terms were evaluated to determine statistical approach and/ or cited in the text and subsequently discussed where highly significant terms may influence valid interpretation of data.

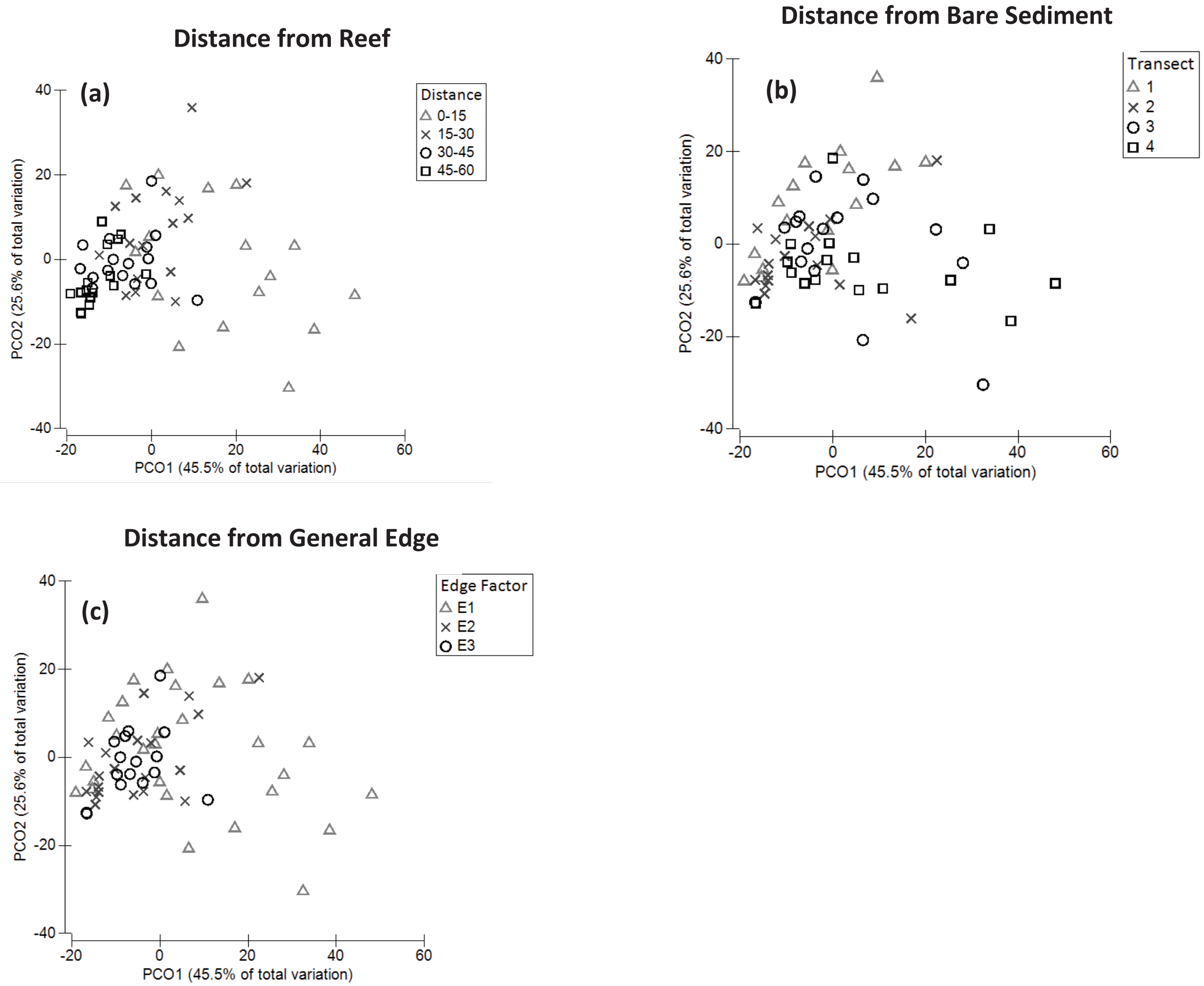


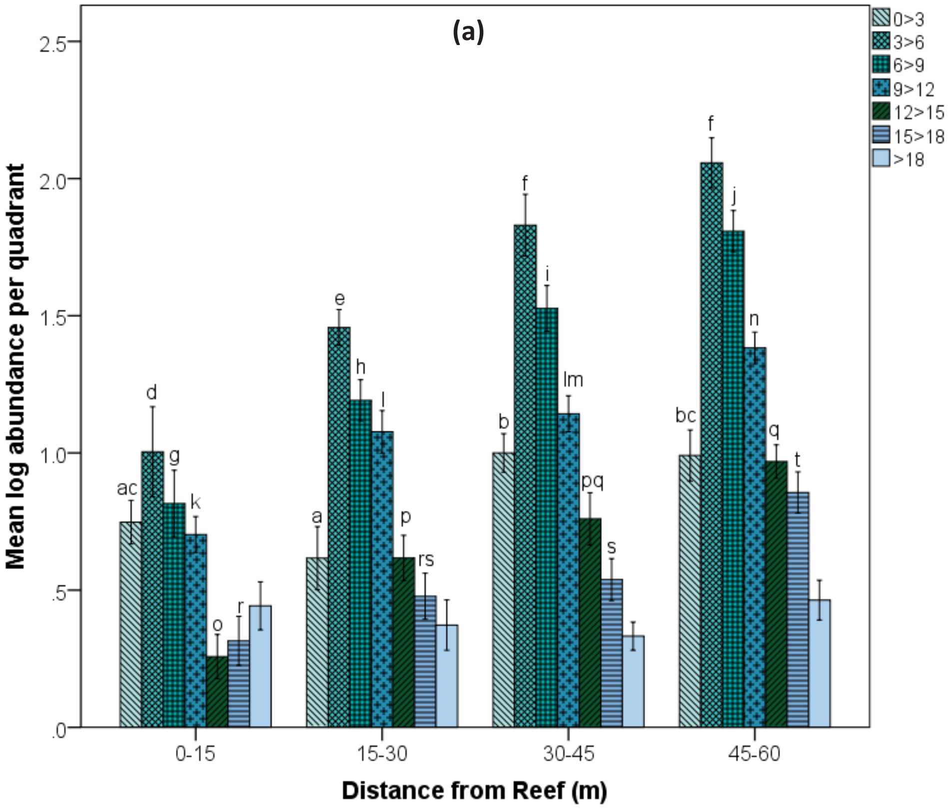
Fig 4.12 PCO plots illustrating Greenpoint mollusc size class composition with distance from (a) reef, (b) bare sediment i.e. increasing transect number – 1(0-15m+), 2(15-30m+), 3(30-45m+) and 4(45-60m+) and (c) general edge – E1(E0-15m), E2(E15-30m) and E3 (E30-60m).

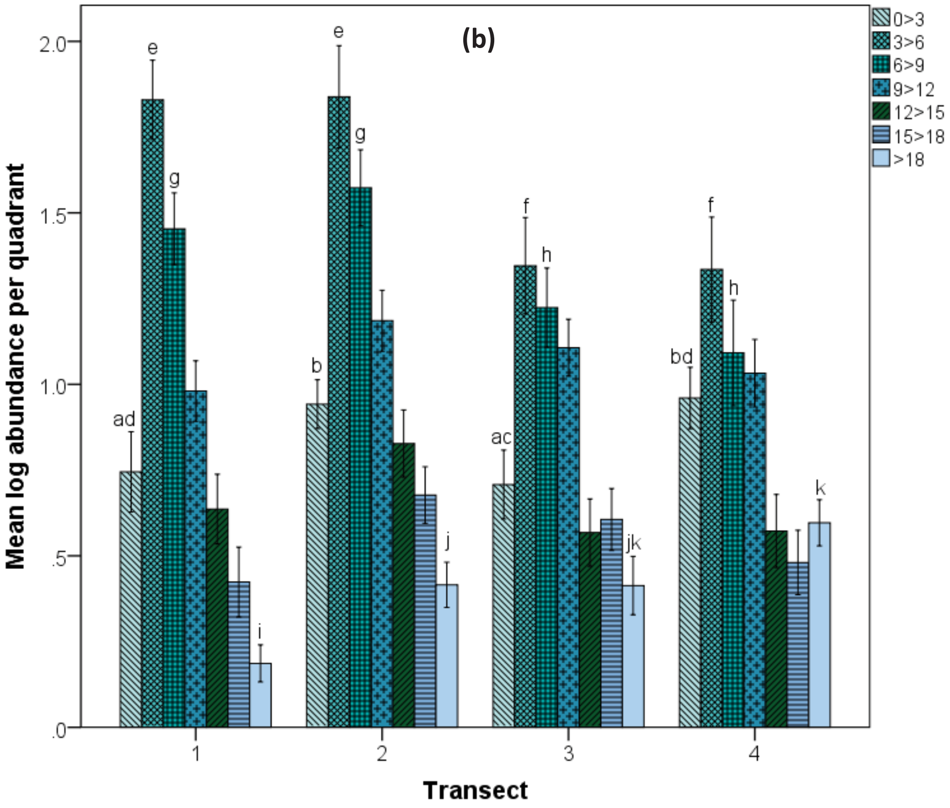
Table 4.10 Percent contribution of individual mollusc size classes (top 90% cumulative contribution) in SIMPER analysis at significant pairwise comparisons of size class community composition at both sites. *D1-D4: "Distance from reef"; T1-T4: "Distance from bare sediment"; n.s. – no significant difference.*

Callala Bay		**Greenpoint**	
D1-D2			
n.s.	n.s.	3>6 mm	20.58
n.s.	n.s.	6>9 mm	16.53
n.s.	n.s.	12>15 mm	13.73
n.s.	n.s.	0>3 mm	13.39
n.s.	n.s.	9>12 mm	12.97
n.s.	n.s.	> 18 mm	11.43
n.s.	n.s.	15>18 mm	11.36
D1-D3			
n.s.	n.s.	3>6 mm	24.22
n.s.	n.s.	6>9 mm	20.29
n.s.	n.s.	12>15 mm	14.74
n.s.	n.s.	9>12 mm	12.17
n.s.	n.s.	15>18 mm	10.48
n.s.	n.s.	0>3 mm	10.05
D1-D4			
n.s.	n.s.	3>6 mm	22.51
n.s.	n.s.	6>9 mm	20.72
n.s.	n.s.	12>15 mm	14.70
n.s.	n.s.	9>12 mm	13.75
n.s.	n.s.	15>18 mm	12.11
n.s.	n.s.	0>3 mm	9.00
D2-D3			
n.s.	n.s.	0>3 mm	19.05
n.s.	n.s.	3>6 mm	17.36
n.s.	n.s.	6>9 mm	15.52
n.s.	n.s.	12>15 mm	13.99
n.s.	n.s.	15>18 mm	12.34
n.s.	n.s.	> 18 mm	11.00
n.s.	n.s.	9>12 mm	10.74
D2-D4			
n.s.	n.s.	6>9 mm	17.99
n.s.	n.s.	3>6 mm	17.94
n.s.	n.s.	0>3 mm	16.71
n.s.	n.s.	15>18 mm	13.48
n.s.	n.s.	12>15 mm	12.11
n.s.	n.s.	9>12 mm	11.19
n.s.	n.s.	> 18 mm	10.58

Table 4.10 cont'd Percent contribution of individual mollusc size classes (top 90% cumulative contribution) in SIMPER analysis at significant pairwise comparisons of size class community composition at both sites. *D1-D4: "Distance from reef"; T1-T4: "Distance from bare sediment"; n.s. – no significant difference.*

Callala Bay		**Greenpoint**	
T1-T2			
0>3 mm	27.93	3>6 mm	17.95
3>6 mm	22.15	6>9 mm	15.13
6>9 mm	18.34	0>3 mm	14.94
9>12 mm	15.27	12>15 mm	14.61
15>18 mm	7.02	15>18 mm	14.09
		9>12 mm	13.29
T1-T3			
3>6 mm	25.58	3>6 mm	20.27
9>12 mm	22.25	6>9 mm	15.40
0>3 mm	18.68	0>3 mm	14.87
6>9 mm	16.26	12>15 mm	13.46
15>18 mm	8.26	15>18 mm	13.39
		9>12 mm	11.77
		> 18 mm	10.84
T1-T4			
n.s.	n.s.	3>6 mm	20.39
n.s.	n.s.	6>9 mm	18.72
n.s.	n.s.	0>3 mm	13.83
n.s.	n.s.	12>15 mm	12.47
n.s.	n.s.	> 18 mm	12.09
n.s.	n.s.	9>12 mm	11.36
n.s.	n.s.	15>18 mm	11.14
T2-T3			
n.s.	n.s.	3>6 mm	22.53
n.s.	n.s.	6>9 mm	17.19
n.s.	n.s.	12>15 mm	14.42
n.s.	n.s.	0>3 mm	12.36
n.s.	n.s.	15>18 mm	11.79
n.s.	n.s.	9>12 mm	11.73
T2-T4			
n.s.	n.s.	3>6 mm	22.53
n.s.	n.s.	6>9 mm	20.40
n.s.	n.s.	12>15 mm	14.11
n.s.	n.s.	9>12 mm	11.96
n.s.	n.s.	15>18 mm	11.95
n.s.	n.s.	0>3 mm	10.22


(a)
Mean log abundance per quadrant
2.5
2.0
1.5
1.0
.5
.0
0>3
3>6
6>9
9>12
12>15
15>18
>18
ac
d
g
k
o
r
a
e
h
l
p
rs
b
f
i
lm
pq
s
bc
f
j
n
q
t
0-15
15-30
30-45
45-60
Distance from Reef (m)


(b)
Mean log abundance per quadrant
2.0
1.5
1.0
.5
.0
0>3
3>6
6>9
9>12
12>15
15>18
>18
ad
e
g
i
b
e
g
j
ac
f
h
jk
bd
f
h
k
1
2
3
4
Transect

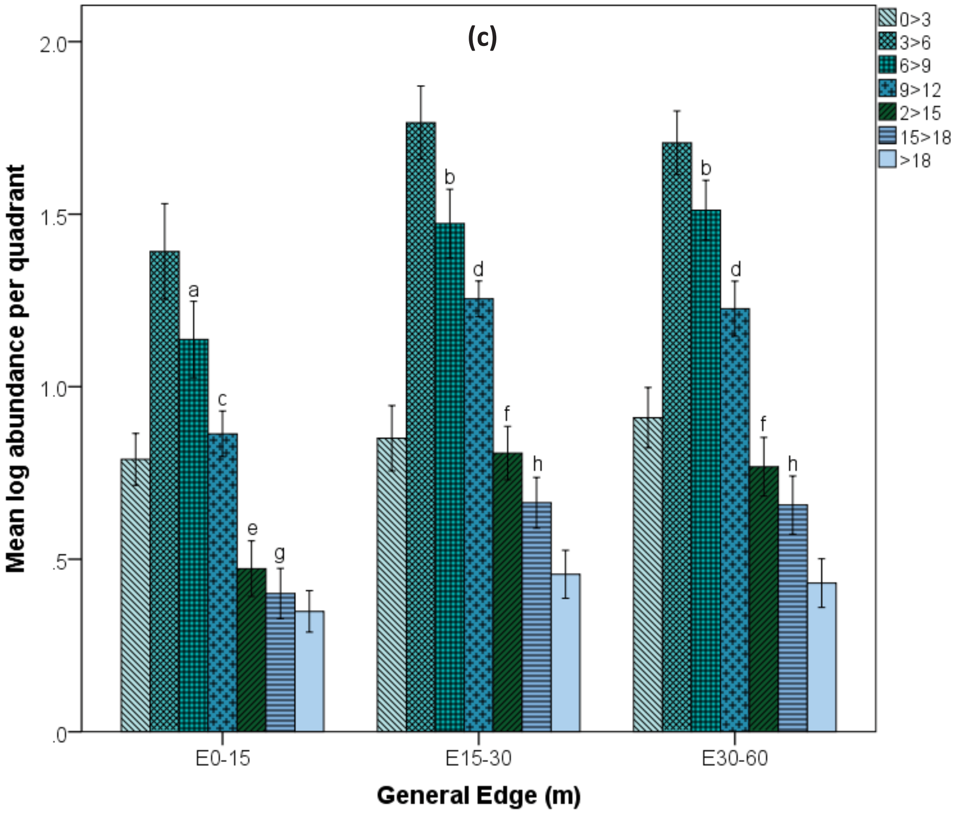
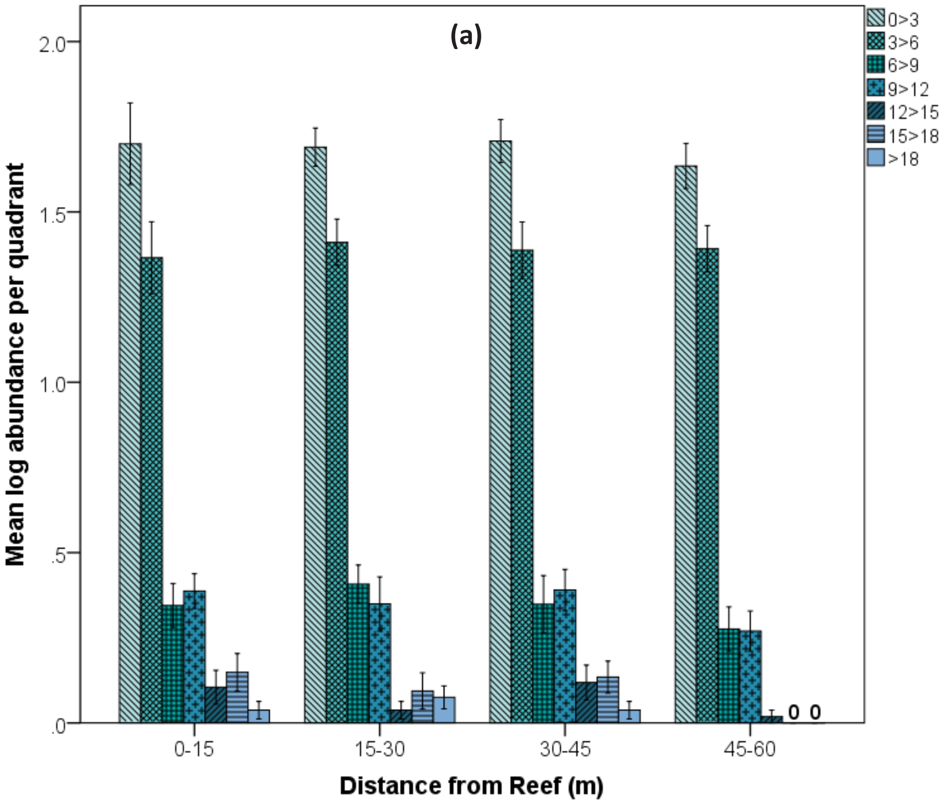
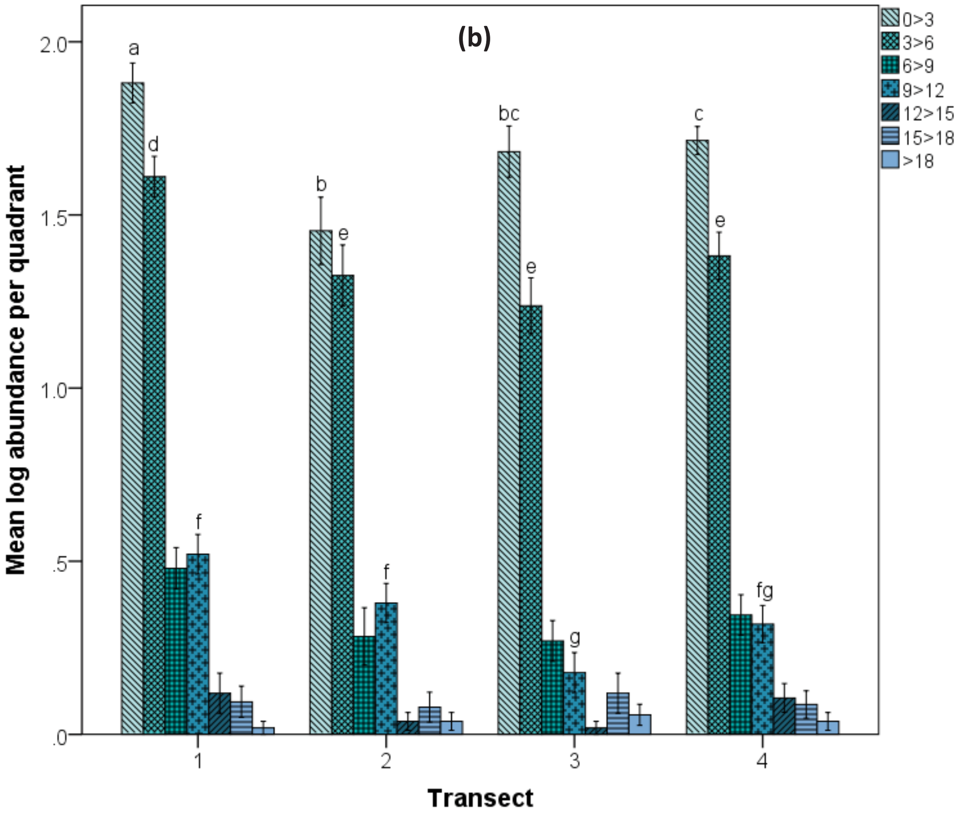


Fig 4.13 Abundances within mollusc size classes (mm) at Greenpoint, Jervis Bay with distance from (a) reef, (b) bare sediment (increasing transect number) and (c) general edge. *Letters above bars represent the results of pairwise comparisons of log-transformed data with distance categories lacking similar letters being significantly different; the bar lettering of each subsequent bar category begin with the letter following alphabetically the highest lettering of the bar category immediately before.*


(a)
Mean log abundance per quadrant
2.0
1.5
1.0
.5
.0
0>3
3>6
6>9
9>12
12>15
15>18
>18
0-15
15-30
30-45
45-60
0
0
Distance from Reef (m)


(b)
Mean log abundance per quadrant
2.0
1.5
1.0
.5
.0
0>3
3>6
6>9
9>12
12>15
15>18
>18
a
d
f
b
e
f
bc
e
g
c
e
fg
1
2
3
4
Transect

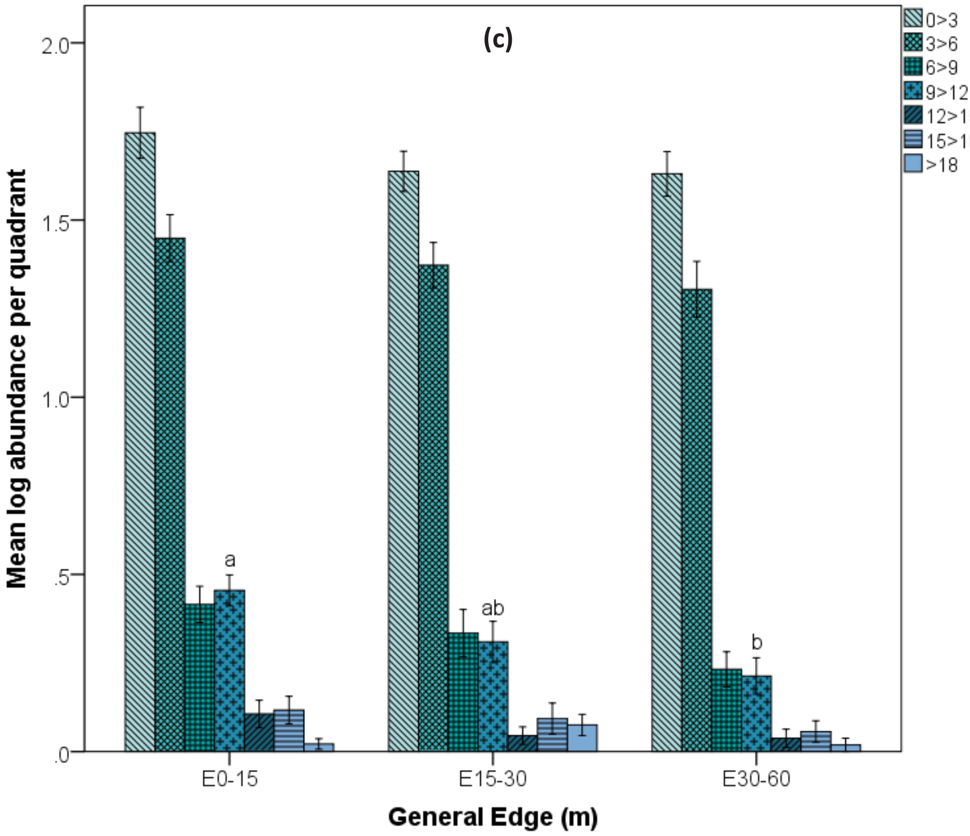


Fig 4.14 Abundances within mollusc size classes (mm) at Callala Bay, Jervis Bay with distance from (a) reef, (b) bare sediment (increasing transect number) and (c) general edge. *Letters above bars represent the results of pairwise comparisons of log-transformed data with distance categories lacking similar letters being significantly different; the bar lettering of each subsequent bar category begin with the letter following alphabetically the highest lettering of the bar category immediately before.*

Table 4.11 (a) Summary of PERMANOVA results of the effect of “Distance from reef” on shoot density, seagrass blade metrics and epiphyte load measures during summer across both and at individual sites as indicated. *Di” denotes “Distance from reef”, “Tr” – distance from bare sediment / increasing transect #; D1=0-15m, D2=15-30m, D3=30-45m, D4=45-60m; significant permdisp (in bold) indicate non-homogeneity of variances; permdisp values of significant relationships only reported.*

	Distance from Reef				Factors Included			Pairwise Comparisons						
	df	**MS**	**pseudo-F**	**p**	**Di**	**Tr**	**Site**	**D1-D2**	**D1-D3**	**D1-D4**	**D2-D3**	**D2-D4**	**D3-D4**	**Permdisp**
Shoot Density	3	$8.5861E^{-3}$	0.54944	0.6596	*	*	*							
Greenpoint	3	$1.4416E^{-2}$	0.24113	0.881	*	*								
Callala Bay	3	$9.7977E^{-3}$	0.23797	0.8749	*	*								
Blade Length	3	0.40197	1.0603	0.4128	*	*	*							
Greenpoint	3	0.43913	27.676	**0.0001**	*	*		**0.0001**	**0.0001**	**0.0001**				0.787
Callala Bay	3	0.34194	11.535	**0.0001**	*	*		**0.0003**			**0.0028**	**0.0001**	**0.0099**	**0.006**
Blade Width	3	$2.5863E^{-2}$	5.8122	0.1291	*	*	*							
Greenpoint	3	$1.534E^{-2}$	7.5426	**0.0001**	*	*				**0.0056**	**0.0098**	**0.0001**		**0.001**
Callala Bay	3	$1.4973E^{-2}$	6.8687	**0.0003**	*	*			**0.0183**			**0.0005**	**0.0001**	0.074
Blade Area	3	0.7526	1.6968	0.3384	*	*	*							
Greenpoint	3	0.60699	22.293	**0.0001**	*	*		**0.0002**	**0.0001**	**0.0001**		**0.0006**		0.724
Callala Bay	3	0.58915	15.511	**0.0001**	*	*		**0.0001**		**0.0097**		**0.0001**	**0.0004**	**0.043**
Epiphyte/Seagrass (g/g) (AFDW)	3	$5.953E^{-3}$	7.2168	0.1074	*	*	*							
Greenpoint	3	$5.4188E^{-3}$	5.8817	**0.0199**	*	*			**0.0263**	**0.0257**				0.878
Callala Bay	3	$1.359E^{-3}$	2.7884	0.1042	*	*								
Epiphyte Load Index (AFDW)	3	$6.4898E^{-5}$	2.49	0.2702	*	*	*							
Greenpoint	3	$8.341E^{-5}$	4.5053	**0.0361**	*	*			**0.024**	**0.0113**				0.604
Callala Bay	3	$7.5514E^{-6}$	1.2736	0.3414	*	*								

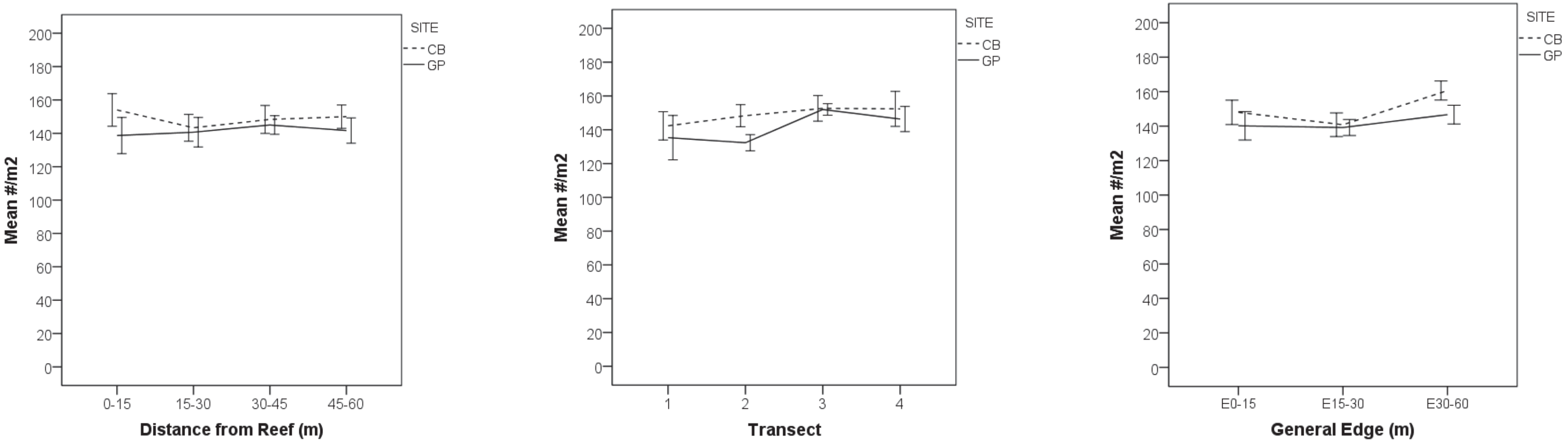
Table 4.11 (b) Summary of PERMANOVA results of the effect of “Distance from bare sediment” on shoot density, seagrass blade metrics and epiphyte load measures during summer across both and at individual sites as indicated. *Di” denotes “Distance from reef”, “Tr” – distance from bare sediment / increasing transect #; T1=0-15m+, T2=15-30m+, T3=30-45m+, T4=45-60m+; significant permdisp (in bold) indicate non-homogeneity of variances; permdisp values of significant relationships only reported.*

	Distance from Bare Sediment				Factors Included			Pairwise Comparisons						
	df	**MS**	**pseudo-F**	**p**	**Di**	**Tr**	**Site**	**T1-T2**	**T1-T3**	**T1-T4**	**T2-T3**	**T2-T4**	**T3-T4**	**Permdisp**
Shoot Density	3	$7.4317E^{-2}$	3.7859	0.1666	*	*	*							
Greenpoint	3	$8.1833E^{-2}$	1.3688	0.2741	*	*								
Callala Bay	3	$1.2114E^{-2}$	0.29423	0.8373	*	*								
Blade Length	3	2.0798	1.272	0.4284	*	*	*							
Greenpoint	3	$6.3749E^{-2}$	4.0178	**0.0075**	*	*		**0.0027**		**0.0123**				0.594
Callala Bay	3	3.6512	123.16	**0.0001**	*	*		**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**		**0.001**
Blade Width	3	$7.7362E^{-2}$	4.4943	0.1371	*	*	*							
Greenpoint	3	$1.3124E^{-2}$	6.4533	**0.0006**	*	*				**0.0001**		**0.0022**	**0.0136**	0.204
Callala Bay	3	$8.1451E^{-2}$	37.365	**0.0001**	*	*		**0.0342**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0196**	0.724
Blade Area	3	1.5862	1.5862	0.3777	*	*	*							
Greenpoint	3	0.14866	5.4597	**0.0007**	*	*		**0.0057**		**0.0001**				**0.004**
Callala Bay	3	5.8368	153.67	**0.0001**	*	*		**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**		**0.001**
Epiphyte/Seagrass (g/g) (AFDW)	3	$2.11E^{-4}$	$2.8685E^{-2}$	0.8821	*	*	*							
Greenpoint	3	$3.0076E^{-3}$	3.2645	0.0735	*	*								
Callala Bay	3	$4.5592E^{-3}$	9.3546	**0.0041**	*	*				**0.0031**	**0.026**			0.962
Epiphyte Load Index (AFDW)	3	$1.4774E^{-5}$	0.20174	0.8386	*	*	*							
Greenpoint	3	$2.3795E^{-5}$	1.2852	0.3362	*	*								
Callala Bay	3	$6.4208E^{-5}$	10.829	**0.0026**	*	*				**0.0034**	**0.0294**	**0.012**		0.536

Table 4.11 (c) Summary of PERMANOVA results of the effect of “Distance from general edge” on shoot density, seagrass blade metrics and epiphyte load measures during summer across both and at individual sites as indicated. *E1=E0-15m, E2=E15-30m, E3=30-60m; significant permdisp (in bold) indicate non-homogeneity of variances; permdisp values of significant relationships only reported.*

	Distance from General Edge				Factors Included		Pairwise Comparisons			
	df	**MS**	**pseudo-F**	**p**	**Ed**	**Site**	**E1-E2**	**E1-E3**	**E2-E3**	**Permdisp**
Shoot Density	2	$7.8613E^{-2}$	4.727	0.255	*	*				
Greenpoint	2	$2.5435E^{-2}$	0.43218	0.6854	*					
Callala Bay	2	$6.9808E^{-2}$	1.7626	0.1855	*					
Blade Length	2	2.0719	3.1	0.2261	*	*				
Greenpoint	2	0.45818	24.588	**0.0001**	*		**0.0001**	**0.0001**		0.816
Callala Bay	2	2.2821	41.876	**0.0001**	*		**0.0025**	**0.0001**	**0.0001**	**0.001**
Blade Width	2	$5.3106E^{-2}$	5.4618	0.2201	*	*				
Greenpoint	2	$1.1721E^{-2}$	4.2579	0.0133	*			0.0139	**0.0034**	**0.019**
Callala Bay	2	$5.1108E^{-2}$	17.751	**0.0001**	*		**0.0408**	**0.0001**	**0.0002**	0.088
Blade Area	2	3.3327	3.6852	0.1834	*	*				
Greenpoint	2	0.56853	16.233	**0.0001**	*		**0.0001**	**0.0001**		0.469
Callala Bay	2	3.6685	47.135	**0.0001**	*		**0.0019**	**0.0001**	**0.0001**	**0.001**
Epiphyte/Seagrass (g/g) (AFDW)	2	$3.3765E^{-3}$	1.6437	0.3399	*	*				
Greenpoint	2	$8.2455E^{-5}$	$3.2087E^{-2}$	0.9619	*					
Callala Bay	2	$5.3483E^{-3}$	6.0751	**0.0169**	*			**0.0036**		0.182
Epiphyte Load Index (AFDW)	2	$6.3936E^{-5}$	6.8599	0.1536	*	*				
Greenpoint	2	$1.7857E^{-5}$	0.51298	0.6128	*					
Callala Bay	2	$5.5399E^{-5}$	4.5627	**0.0353**	*			**0.0043**		0.427

Interaction terms not presented in table for logistics purposes. As described in General Discussion (6.6.1) interaction terms were evaluated to determine statistical approach and/ or cited in the text and subsequently discussed where highly significant terms may influence valid interpretation of data.



(a) **(b)** **(c)**

Fig 4.15 *P. australis* shoot density (#/m^2) with distance from the (a) reef, (b) bare sediment (increasing transect number) and (c) general edge at both sites during the summer sampling session. *CB = Callala Bay, GP = Greenpoint*.

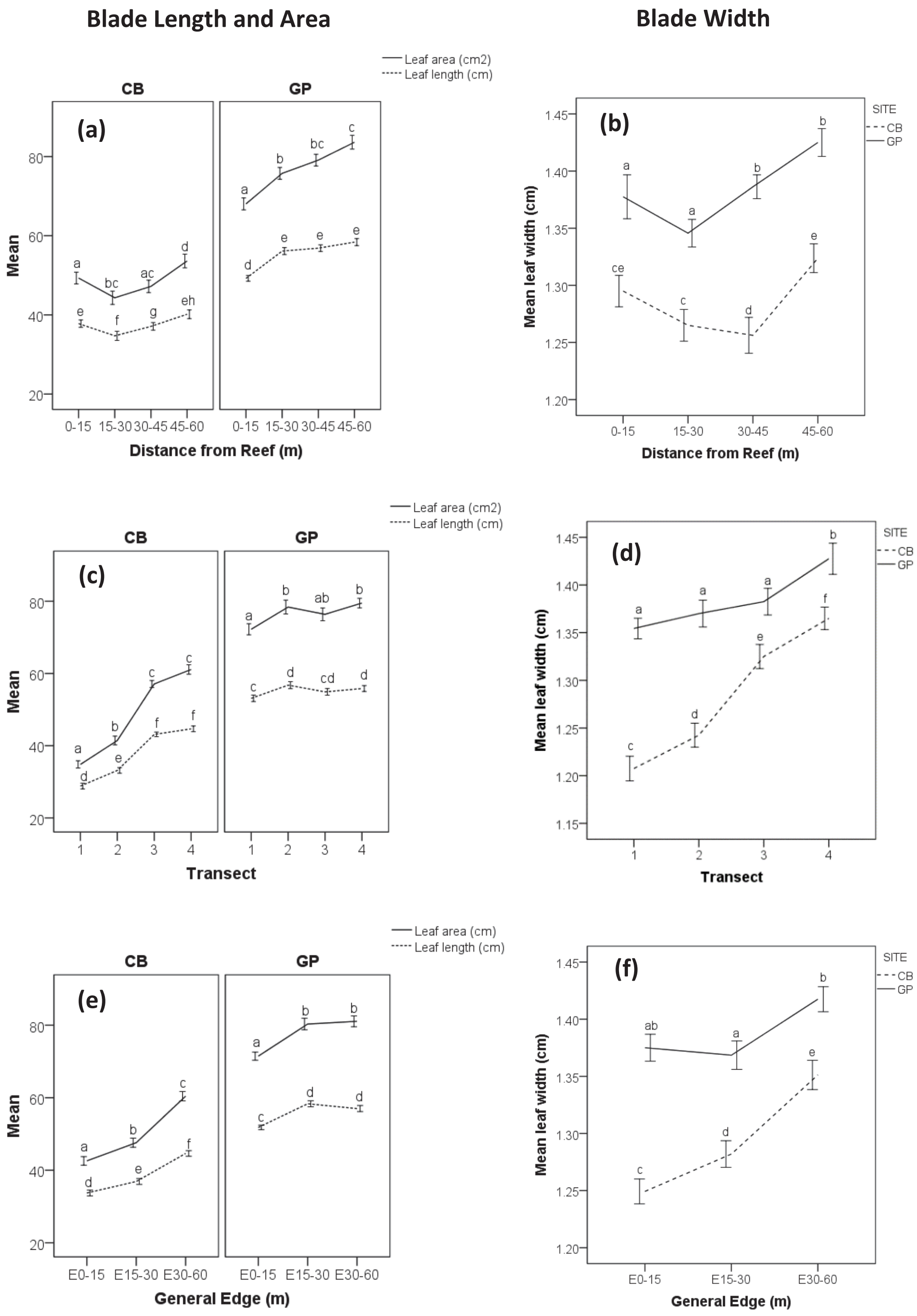
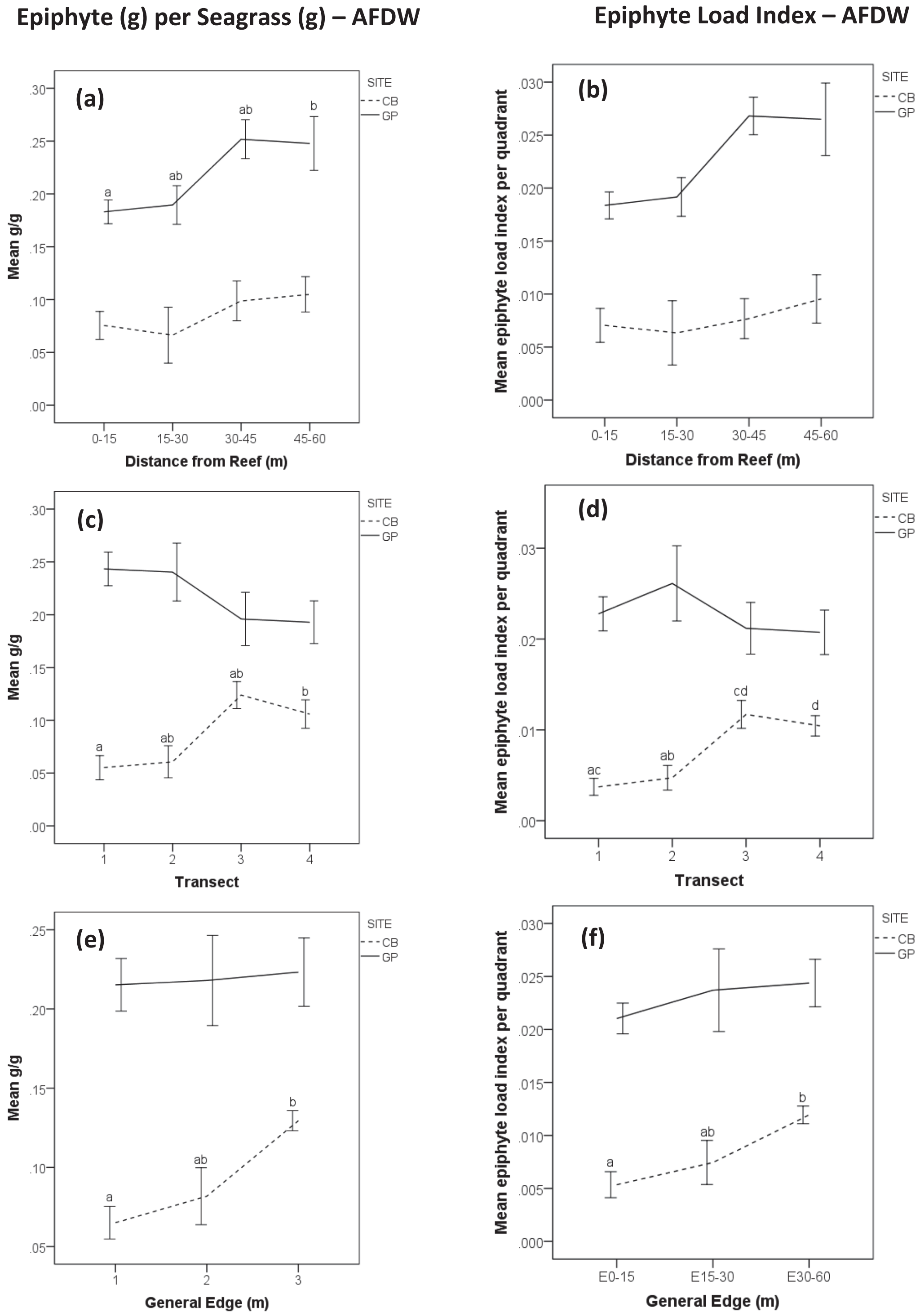


Fig 4.16 Seagrass blade metrics (blade length, width and area) with distance from (a,b) reef, (c,d) bare sediment (increasing transect number) and (e,f) general edge at both sites, measured during the summer sampling session. *CB = Callala Bay, GP = Greenpoint; letters above points represent the results of pairwise comparisons of log-transformed data with distance categories lacking similar letters being significantly different from each other.*



Epiphyte (g) per Seagrass (g) – AFDW

Epiphyte Load Index – AFDW

Fig 4.17 Epiphyte per seagrass (g/g) and epiphyte load index with distance from (a,b) reef, (c,d) bare sediment (increasing transect number) and (e,f) general edge at both sites, measured during the summer sampling session. *CB = Callala Bay, GP = Greenpoint; letters above points represent the results of pairwise comparisons of log-transformed data with distance categories lacking similar letters being significantly different.*

Table 4.12 Summary of Pearson correlation between seagrass blade metrics and epiphyte load as AFDW epiphyte/seagrass (g/g) measured from *P. australis* beds at both sites during the summer sampling session.

		Epiphyte/Seagrass (g/g)		
		Sites Pooled	**Greenpoint**	**Callala Bay**
Leaf Length (cm)	Pearson Correlation	.881	0.632	0.819
	P value	**<0.0001**	**0.009**	**0.0001**
	N	32	16	16
Leaf Width (cm)	Pearson Correlation	.611	0.189	0.761
	P value	**0.0002**	0.483	**0.001**
	N	32	16	16
Leaf Area (cm^2)	Pearson Correlation	.858	0.587	0.816
	P value	**<0.0001**	**0.017**	**0.0001**
	N	32	16	16

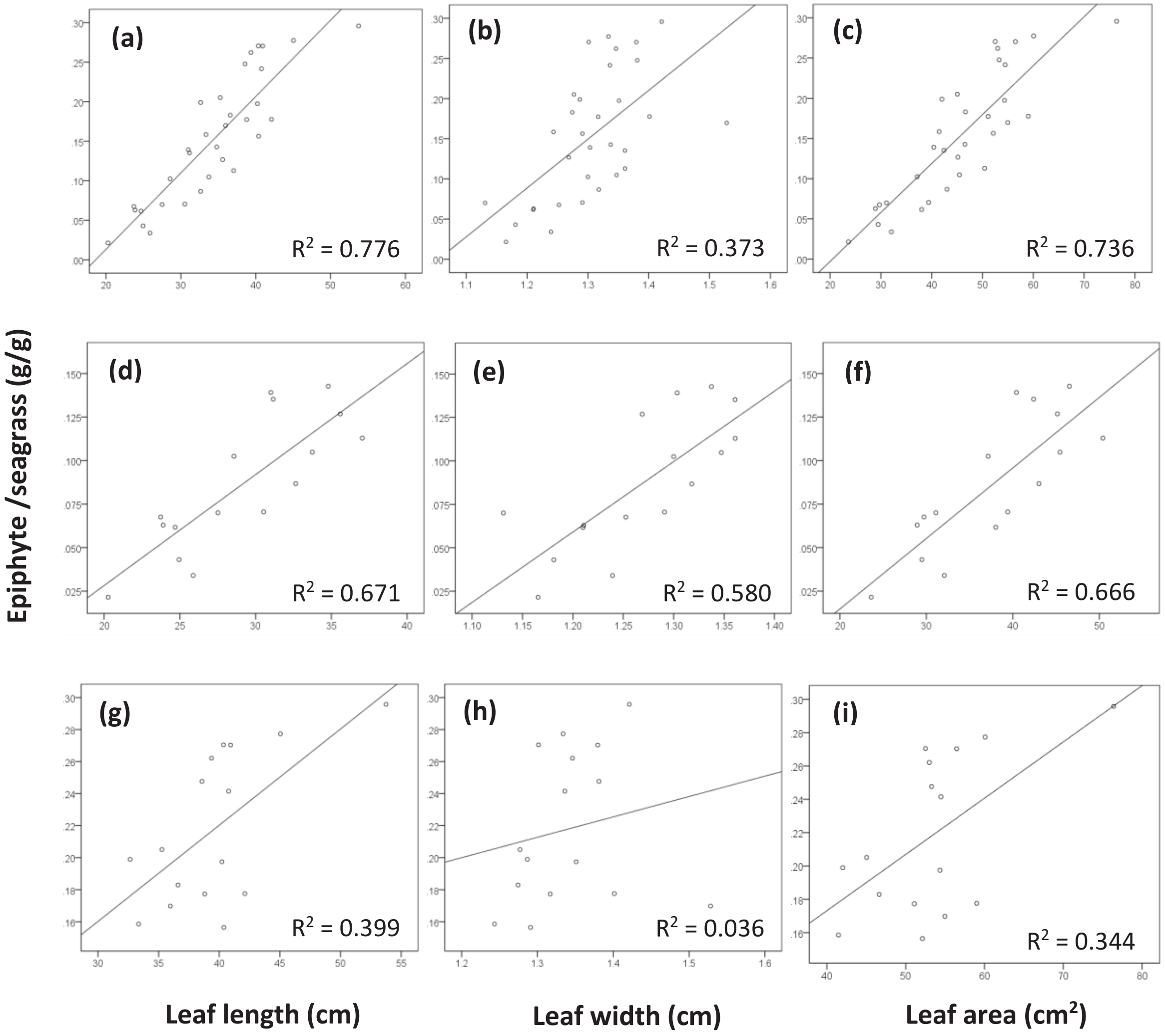


Fig 4.18 Scatterplots showing relationship between seagrass blade metrics and epiphyte load as AFDW Epiphyte/Seagrass (g/g) for (a-c) sites pooled, (d-f) Callala Bay only and (g-i) Greenpoint only.

Chapter 5: *Effect of Predatory Threat on Habitat Position Assumed by Select Seagrass Fish Species*

5.1 Introduction

Habitat shifts in face of predation and Predator-risk trade off

Although an organism's distribution and abundance is closely associated with that of its prey and other local environmental factors, whether an organism remains in a habitat or a particular position within it, regardless of other inherent benefits, may depend greatly on its perceived level of predation (Cheminée 2012; Grol et al. 2011; Sih 1980). This trade-off, often between foraging efficiency and/or growth rate and minimizing predation risk, also suggests that organisms may choose habitats, or positions within it, of inferior nutritional quality for the sake of avoiding predation (Gullström et al. 2011; Schmitz, Krivan & Ovadia 2004). While some organisms may deem the trade-off too detrimental to their own survival and risk foraging in predator rich environments (Schmitz, Krivan & Ovadia 2004), several studies have noted habitat shifts, strategy adjustments and shifts from rudimentary activities such as feeding and territory defence with added predator risk (Creel et al. 2005; Gotceitas & Brown 1993; Helfman 1989; Lima & Dill 1990; Scheibling & Hamm 1991; Schmitz, Krivan & Ovadia 2004; Sih 1980; Wahle 1992).

Schmitz, Krivan & Ovadia (2004) put forward a somewhat prey-centric synthesis of four possible responses of prey under varying breadths of habitat use of both predator and prey as follows:

1. If both prey and predator have a similarly narrow domain within the same portion of the entire habitat the prey will respond with immediate, strong predator evading behaviour.

2. When prey, displaying a narrow habitat domain, encounters a widely roaming predator it reduces any conspicuous behaviour when the predator encroaches on its space.

3. Prey having a broad domain and capable of utilizing multiple habitats will shift its habitat use when faced with a predator displaying a narrow range.

4. No habitat shifts or change in activity will be displayed by the prey if both prey and predator exhibit wide domains.

The above synthesis and other literature (cited above) clearly illustrate the change in not only the mode of activity but sections of the habitat used with the added influence of the predator.

This influence is noted to even extend beyond the level of the individual and influence distributions at the population (Madin, Madin & Booth 2011; Schmitz, Krivan & Ovadia 2004), community (Schmitz, Krivan & Ovadia 2004) and ecosystem level (Hammill, Atwood & Srivastava 2015; Ripple & Beschta 2004) over time and space as these responses to predator-threat are learnt with experience (Gotceitas & Brown 1993; Hossain, Tanaka & Masuda 2002). This shift in strategy, activity involvement and habitat use instigates an interesting phenomenon of a division in habitat position use or distribution depending on the degree of predatory stress being encountered. An individual or population therefore may use a certain seagrass position, or position relative to a particular habitat edge for essential activities such as feeding and use another position when faced with the threat of predation. This new position may contain inferior quality prey or be devoid of prey, which may be non-essential if the shift is temporary as predator avoidance and not feeding would now be the major objective.

Importance of habitat complexity and habitat heterogeneity

Seagrasses add structure to the otherwise bare substratum enhancing the complexity of the habitat. Complexity has in many cases been linked to the number or available spaces, holes, cracks or crevices available (Hackradt, Félix-Hackradt & García-Charton 2011) for appropriately sized fauna to shelter within, especially when faced with the threat of predation. Increasing numbers of these spaces are akin to increased structural complexity in these and many other studies spanning ecosystems and are associated with elevated species richness and abundance (Berg 2002; Chapman & Reich 2007; Cocheret de la Morinière et al. 2004; Cranfield et al. 2004; Hackradt, Félix-Hackradt & García-Charton 2011; Nagelkerken et al. 2000; Söderström & Pärt 2000). The size of the spaces has also been reported as having a predator-excluding effect (Gotceitas & Brown 1993; Johnson, Beaumier & Lynch Jr 1988; Scheibling & Hamm 1991). Some authors go as far as to suggest that the number of spaces and hence habitat complexity is a limiting factor to the growth and survival of species (Scheibling & Hamm 1991). This effect is mediated by the available number of spaces being indicative of the number of individuals being able to shelter within (Gotceitas & Brown 1993), and therefore survive to reproduce.

It seems therefore likely that individuals will, in the face of predator stress, shelter within sections of their habitat offering the greatest concealment, regardless of prey quality and abundance contained within. In many cases, with the exception of those finding greatest concealment by burying within unvegetated sediment, more highly complex regions will provide greater protection (Gotceitas & Brown 1992). This last point, however, illustrates the species-specific response to habitat complexity (Cheminée 2012) that should not be overlooked. While some taxa may find complexity beneficial, others may require a less complex habitat or position within (Cheminée 2012). This has been clearly illustrated for fish assemblages where preference for complex (containing structural cover such as macroalgae, seagrass or rocks) or simple (bare sediment) habitats differs among differing species (Anderson et al. 2009; Connolly 1994; Ferrell & Bell 1991; Franco et al. 2006; Franco et al. 2011; Gray, McElligott & Chick 1996; Jenkins & Wheatley 1998). These interspecific differences in habitat complexity preferences often depend on body morphology, size and/or feeding mode characteristics (Bell & Westoby 1986a; Connolly 1994; Franco et al. 2006; Franco et al. 2011; Jenkins & Wheatley 1998; Valesini, Potter & Clarke 2004).

“Habitat heterogeneity” refers to a break in habitat continuity and the incorporation of more than one habitat patch in a given region. Habitat heterogeneity has also been increasingly linked to heightened structural complexity, offering a greater range of resources and microclimate conditions for exploitation by more species (Collinge 1996) than a homogenous one. Once again a varying species-specific response to habitat heterogeneity is reported across ecosystems (Berg 2002; Cheminée 2012; Collinge 1996; Jackson et al. 2006). These conflicting responses to habitat heterogeneity and complexity by varying species depend largely on the niche of the taxa and how the fine structure i.e. the structural make-up of the heterogeneous and homogeneous habitats (Beck 2000; Becker, Cowley & Whitfield 2010) themselves may benefit or be deleterious to it.

Adjacent habitats

Whether the habitat’s heterogeneity is beneficial or otherwise will depend largely on the habitat types forming the mosaic, again underscoring the importance of the type of adjacent habitat bordering a focal one. Within each heterogeneous landscape there will be at least two different habitat types bordering each other with one habitat prone to have an impact on faunal distribution in the other (Anderson et al. 2009; Ferrel & Bell 1991; Nagelkerken et al. 2008; Whitlow & Grabowski 2012). In the scope of this study the focal habitat is the *Posidonia australis* seagrass bed and the adjacent ones being rocky reef and sand. In this manipulative experiment a suite of habitat combination choices (six in total) are offered in aquarium experiments to four seagrass fish species namely the spotted pipefish, *Stigmatopora argus*, bridled leatherjacket, *Acanthaluteres spilomelanurus*, eastern striped trumpeter, *Pelates sexlineatus* and the small-mouthed hardyhead, *Atherinosoma microstomata*. The habitat combination choices include the seagrass-sand and seagrass-rock combinations along with a "seagrass only" section to observe any preferences for seagrass with differing or no adjacent habitats under differing degrees of threat (i.e. in the absence and presence of a predator). It should be noted that the seagrass-rock and seagrass-sand sections (along with the other combinations) in this experiment are intended to give some indication of the use of seagrass adjacent to rocky reef and sand respectively by the tested species in the wild. Likewise, the "seagrass-only" section within the experimental tank is meant to represent the section of the seagrass away from both adjacent habitat types i.e. the seagrass interior.

Specific questions being addressed by this chapter

The study seeks to answer the following research questions:

1. Is there a habitat combination preference based on (a) time spent in each section and (b) first section selected by tested fish species?

2. Does the habitat combination preference observed vary with species tested?

3. Does the habitat combination preference exhibited by each tested species vary with the inclusion of a predator model in its domain?

With the six habitat combination choices assigned to increasing heterogeneity-complexity levels of which there are four (described in Methods):

4. Is there a heterogeneity-complexity level preference exhibited by tested fish species?

5. Does the heterogeneity-complexity preference vary with species?

6. Does the heterogeneity-complexity preference observed by each tested species vary with the inclusion of a predator model in its domain?

Null hypotheses tested:

1. There is no notable habitat combination preference in the absence of the predator model for a. *Atherinosoma microstomata*, b. *Acanthaluteres spilomelanurus*, c. *Stigmatopora argus* and c. *Pelates sexlineatus*.

2. There is no notable heterogeneity-complexity level preference exhibited in the absence of the predator model for a. *Atherinosoma microstomata*, b. *Acanthaluteres spilomelanurus*, c. *Stigmatopora argus* and c. *Pelates sexlineatus*.
3. There is no species-specific a. habitat combination or b. heterogeneity-complexity preference in the absence of the predator model.
4. There is no notable change in habitat combination preferences with the inclusion of the predator model for a. *Atherinosoma microstomata*, b. *Acanthaluteres spilomelanurus*, c. *Stigmatopora argus* and c. *Pelates sexlineatus*.
5. There is no notable change in heterogeneity-complexity preferences with the inclusion of the predator model for a. *Atherinosoma microstomata*, b. *Acanthaluteres spilomelanurus*, c. *Stigmatopora argus* and c. *Pelates sexlineatus*.
6. There is no species-specific shift in a. habitat combination or b. heterogeneity-complexity preference with the inclusion if the predator model.
7. There is no overall a. habitat combination or b. heterogeneity-complexity preference in the absence of the predator model.
8. There is no overall shift in a. habitat combination or b. heterogeneity-complexity preference with the inclusion of the predator model.
9. There is no notable difference in species preference between “seagrass only”, “seagrass-sand” and “seagrass-rock” sections for a. *Atherinosoma microstomata*, b. *Acanthaluteres spilomelanurus*, c. *Stigmatopora argus* and c. *Pelates sexlineatus* in the absence of the predator model.

Rationale:

This manipulative experiment will help to cement habitat position preferences observed in the field (Chapters 2 and 3) especially by comparing relative preferences of the “seagrass only”, seagrass-rock and seagrass-sand sections by the tested species. Understanding any habitat shifts by the tested species with the predator model inclusion will also provide knowledge on the range of habitats utilized by certain fish taxa not necessarily linked to the habitat’s or specific habitat position’s prey content. Additionally, the differential preference by and hence importance of varying habitat combinations within the NSW seascape to different seagrass species under low and high predator risk will be determined.

5.2 Methods

Fish collection

Approximately 159 fish were collected from within seagrass beds in two estuaries along the New South Wales coastline – thirty-five (35) from Careel Bay, Pittwater (33°36'47.88"S 151°19'15.79"E) and the majority – one hundred and twenty four (124) from Kurnell in Botany Bay (34° 0'20.31"S 151°12'50.60"E). The fish were collected with a seine net and transported in containers of fresh seawater fitted with aerators. On reaching the laboratory the fish were immediately placed in holding tanks that had been set up two days prior to their arrival. The species collected include: *Atherinosoma microstomata* (68), *Pelates sexlineatus* (46), *Stigmatopora argus* (28), *Acanthaluteres spilomelanurus* (11) and low numbers of a few other species: *Siphaemia cephalotes* (1), *Meuschenia freycineti* (1) and Blenniidae (3). These incidentals were not included in data analysis. The 124 individuals from Kurnell were collected on February 11, 2015 from within *Posidonia australis* while the 35 from Careel Bay were collected on March 9, 2015 from a mixed *Posidonia australis* and *Zostera spp.* seagrass bed.

Experimental tank

The experimental tank apparatus consisted of a round 250L water trough with an external diameter of 1m. Internal diameter at the base was approximately 90 cm. The three habitats (collected *Posidonia australis* blades, rocks and sand) were arranged in a circular continuous fashion of equal area in the outer most section of the tank, with each habitat having contact with the next (Fig 5.1). The habitats extended from the inner walls of the trough and extended approximately a uniform 15 cm into the centre of the tank (Fig 5.1).

The seagrass blades were cleaned of epiphytes by scraping with a blade, the rocks washed and scrubbed and the sand washed through before being used in the experiment. Individual seagrass blades were threaded through a dark plastic mesh at the base of the tank in the seagrass section. The blades were attached to the mesh with cable ties in four rows to best

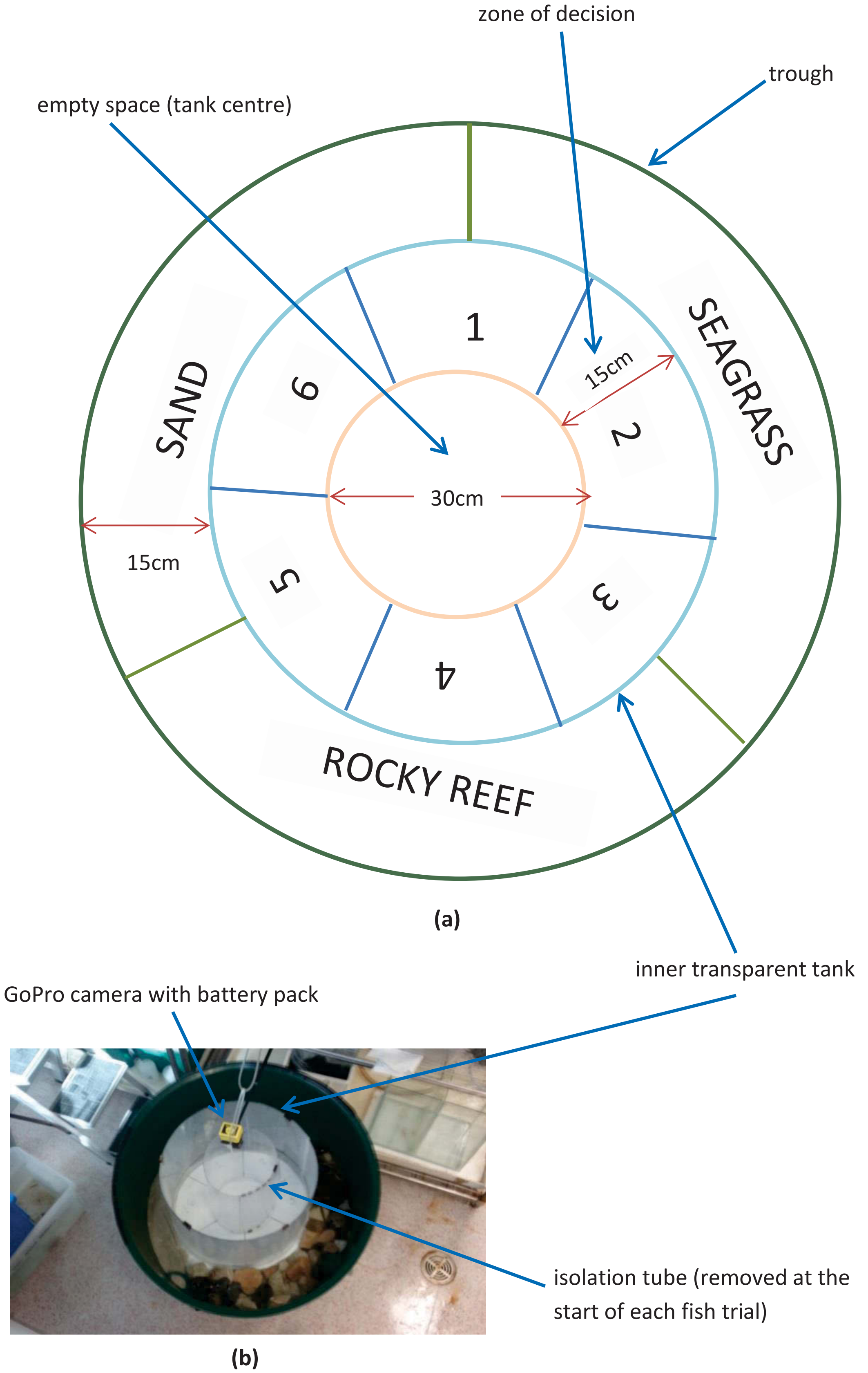


Fig 5.1 Design of experimental tank showing (a) dimensions and habitat combination sections and (b) experimental set up with camera and isolation tube

represent the shoot density typical of the *Posidonia australis* seagrass bed based on results in Chapter 4. The rocks, as illustrated in Fig 5.1b, were arranged in a fashion to represent the rocky reef environment encountered within the NSW seascape and Jervis Bay. Each rock measured between 8 to 10 cm, at the widest point, and were all arranged to provide obvious crevices for retreat. Sand was at the base of the three habitat types with the "sand" sector having sand only and devoid of any structure. A 60-cm diameter transparent tank was placed in the centre of the larger tank 15 cm away from the inner walls of the tank and fitted with a white base with the outer walls of the transparent tank making contact with the habitats. On the white base a 15-cm wide circular section was marked off spanning from the inner walls of the transparent tank protruding into the tank centre, leaving a 30-cm centre corresponding with the centre of the entire test aquarium. The 15 cm wide inner circular section was divided into 6 equal parts corresponding to the habitats immediately facing it.

Each of the three habitats was spatially divided into four equal parts with the outer most parts of each being considered as constituting the "edge" with its neighbouring habitat, and the inner two quarters as the "interior". This resulted in 6 habitat combination sections as illustrated in Fig 5.1:

1 – seagrass-sand (*representing "seagrass-sand edge"*)

2 – seagrass only (*representing "seagrass interior"*)

3 – seagrass-rock (*representing "seagrass-rocky reef edge"*)

4 – rock only (*representing "rocky reef interior"*)

5 – rocky-sand (*representing rocky reef-sand edge"*)

6 – sand only (*representing sand only habitat*)

Each individual test fish was deemed and recorded to have made a choice once it entered these sections i.e. within 15 cm of the transparent inner tank and relevant habitat combination section. This application of a "zone of decision" is similarly applied in rectangular tank experiments of Igulu et al. (2011) where test fish were recorded as making a choice when swimming within 20 cm of two displayed microhabitats at opposite ends of the tank. The 30-cm diameter centre of the circular tank in the current study was bare and devoid of any sand or other structure. The test tank was filled with seawater of depth between 20cm to 25cm with water temperatures maintained as closely as possible to that of their natural environment during the austral summer-spring, corresponding to their time of collection. These temperatures, on average between 21 and 22°C, were also maintained within the fish holding tanks. A GoPro camera was fixed directly above the centre of the test tank without having contact with the tank itself (Fig 5.1).

Habitat choice experiments

Experiment A – "No predator" trials [NP]

Fish were placed individually in the centre of the test tank within the inner transparent tank. They were held in a transparent isolation tube of approximately 25 cm diameter for 2 – 3 minutes to settle and view the habitat choices. After the acclimatization period the camera was switched on and the inner isolation tube removed. The fish were each videoed for 15 minutes with the GoPro during which time I left the aquarium room to avoid an impact on fish habitat choice.

Experiment B – "Predator" trials [P]

Immediately after the first 15-min period the test fish was removed from the inner tank and placed within the central isolation tube and allowed to settle again for 1 – 2 minutes. A predator model consisting of a completely intact carcass of a fish market-purchased yellowfin bream (*Acanthopagrus australis*) was placed upright in a clear plastic bag filled with seawater and sealed to prevent mixing with water within the tank. The predator model was approximately 26.6cm TL while that of the test fish were on average 5.24 ± 0.52cm (mean ± SD) TL (*A. microstomata*), 7.22 ± 0.92cm TL (*A. spilomelanurus*), 13.02 ± 3.49cm TL (*S. argus*) and 4.7 ± 2.49cm TL (*P. sexlineatus*). This predator model was submerged in the tank and manoeuvred in a circular path around the isolation tube containing the fish for 4 – 5 revolutions simulating active hunting mode. The isolation tube was then removed and the model left hanging in the centre of the inner tank immersed in the water on a horizontal pole, assuming a "sit-and-wait" hunting mode (Schmitz, Krivan & Ovadia 2004). The model was placed high enough to avoid direct contact with the fish or prevent the test fish's movement to any part of the tank. The fish was then recorded for another 15 minutes. This was repeated for each fish with the water being changed after each fish and the side of the inner tank washed.

The tank was turned between 90 to 120 degrees clockwise after every 3 – 4 fish. Fish were only used once and were returned to their natural habitat within each estuary at the end of the experiment. Fish were not fed within 12 hours of the trials and all experiments were conducted within daylight hours (9:30 to 19:30). The windows of the aquarium room were covered to avoid differential illumination of the habitat combination sections within the tank with time of day, with light coming from artificial sources from the ceiling above the tank.

Control experiments

Although predator models have been used in literature to provide predator stress (Chivers et al. 2001), control experiments were performed to ensure the model used in this study generated an adequate enough scare factor to at least one species of the test fish. Twenty four (24) of the collected small-mouthed hardyhead, *A. microstomata* (average 6.50 ± 0.44 cm TL), not previously or subsequently used in the above experiments, were used in these control experiments. Each fish was videoed for two 15-minute trials, one with the model of the predator being introduced as described above and the other with an empty seawater-filled bag lacking the predator. Between each 15-minute session the test fish was collected from the inner transparent tank and placed within the transparent isolation tube for 2 minutes as before. The order in which the models were introduced was changed for approximately half of the fish used, with 13 fish having the “predator in the bag” model introduced before the “empty bag” model and the other 11 having the reverse. As before, the water was changed after each test fish trial and the sides of the inner tank washed. The bag containing the predator model was sealed and checked for leakage before each trial. The level of agitation (low, medium or high) displayed by each fish during the manoeuvring of both model types (“predator in bag” and “empty bag”) was recorded.

Video analysis

Each 15-minute video was viewed in its entirety and the position of each test fish noted at first release of the fish from the isolation tube and every 5 seconds after for a total of 181 recorded positions points per trial. The percentage of the total time spent in each section i.e. 1 – 6 as well as the tank centre, for each fish was then calculated by dividing the number of times a fish was observed in each section by 181. Percentages were then recalculated removing the time spent in the centre position as (i) the relative time spent in each habitat combination section by each species did not change with this removal, (ii) assessment of relative time spent in each habitat combination section is the main aim of the experiment and (iii) average time spent in the centre of the tank between both “no predator” and “predator” trials was inconsequential for all four species (5.1% - *A. microstomata*, 1.19% - *A. spilomelanurus*, 5.36% - *S. argus*, 6.22% - *P. sexlineatus*). Both the percentage of time spent in each habitat combination section by each species and the percent of fish (of each species) selecting each section as their first choice upon removal of the isolation tube was assessed to determine habitat combination preference.

Statistical analysis

Each habitat combination section was then assigned a homogeneity-complexity level encompassing both its level of homogeneity and level of complexity. While sand or any combination containing sand was assigned a complexity level of "1", those habitat sections containing some form of structure (and no sand) were assigned a complexity level of "2". For the homogeneity component, single component sections were termed "homogeneous" while those containing two termed "heterogeneous". This created four heterogeneity-complexity levels – "homogeneous 1" (sand section), "homogeneous 2" (seagrass section and rock section), "heterogeneous 1" (seagrass-sand and rock-sand sections) and "heterogeneous 2" (seagrass-rock section).

For statistical comparison of time spent in each habitat combination section and in each assigned homogeneity-complexity level for each species, PERMANOVA analysis was performed separately for "no predator" and "predator" trials in each case in PRIMER 6 version 6.1.13 and PERMANOVA + version 1.0.3. The fixed independent factor was "Habitat combination structure" in the first instance having 6 levels – seagrass, seagrass-sand, seagrass-rock, rock, rock-sand and sand and "Homogeneity-complexity level" in the second instance having 4 levels – homogeneous 1 (homogen-1), homogeneous 2 (homogen-2), heterogeneous 1 (heterogen-1), heterogeneous 2 (heterogen-2). All data was log-transformed to achieve homogeneity of variances around each factor. Where homogeneity was not achieved even after log transformation the significance level was set at $p \leq 0.01$ (Underwood 1981). All significant differences illustrated in graphical representation of results represent analysis performed on log-transformed data.

Pairwise comparisons of each possible pair of habitat combinations and homogeneity-complexity levels were performed also in PRIMER 6 version 6.1.13 and PERMANOVA + version 1.0.3. The Bonferroni correction was applied to pairwise comparisons at the habitat combination level as there were fifteen possible pairwise comparisons resulting in an adjusted alpha value of $p<0.0033$. All percentage time data were log-transformed and homogeneity of variances was tested using the PERMDISP (Homogeneity of Dispersion) function in PRIMER 6 version 6.1.13 and PERMANOVA + version 1.0.3. These PERMDISP values are quoted or referred to throughout the Results section for all significant effects.

Paired samples t-tests were performed for each habitat combination section and assigned homogeneity-complexity level to test for a significant difference in time spent between "no predator" and "predator" trials. This statistical analysis allowed for the test of significant difference in a "before" and "after" scenario for each species for each habitat combination and homogeneity-complexity level. Each pair consisted of the same individual tracing its choice in both trial conditions. The Shapiro-Wilk test was used to ascertain an approximate normal distribution in the differences between the paired groups. This was done separately for each species on untransformed data. The McNemar's Chi-square test for binary matched pairs (Agresti & Kateri 2011) was used to test for a significant difference in the first habitat and associated homogeneity-complexity level selected upon release in "no predator" vs "predator" trials by tracing the choices of each individual test fish. This again was done separately for each test species. The paired samples t-tests, Shapiro-Wilk and McNemar's Chi-square tests were all performed in SPSS Statistics 22.

<u>5.3 Results</u>

5.3.1 Experiment A – "No predator" trials

Habitat combination structure

Three of the four test species, *A. spilomelanurus*, *S. argus* and *A. microstomata*, displayed a significant effect of habitat combination structure. The first two named species, however, displayed a stronger attachment to particular habitat combination sections (pseudo-*F* = 20.873, 13.113 respectively; $p=0.0001$ for both) compared to the hardyhead, *A. microstomata* (pseudo-*F* = 2.5054; $p=0.0293$) (Table 5.1). The trumpeter, *P. sexlineatus*, displayed no significant effect with habitat combination structure (pseudo-*F* = 1.0822; $p=0.3774$) (Table 5.1) and showed no other apparent trend in time spent in each section apart from generally lower % time spent in the rock and seagrass-rock sections (Fig 5.2).

Acanthaluteres spilomelanurus spent significantly more time in the seagrass only section compared to all other sections except for seagrass-rock and seagrass-sand ($0.0001<p<0.0005$:pairwise comparisons) (Table 5.2; Fig 5.2). Individuals of this species also spent significantly less time in the rock section compared to all other sections ($0.0001<p<0.0002$: pairwise comparisons) but that of sand and rock-sand (Table 5.2; Fig 5.2). This corresponds with "first choice data" values for this species i.e. data indicating the percentage of test fish of each species selecting each habitat combination section as their first choice after the lifting of the isolation tube. This first choice data indicated that 54.55% of these leatherjackets made the seagrass section their first choice while no individual initially chose rock-sand (Table 5.3). Additionally no individuals initially chose sand after release (Table 5.3).

Significantly more time was spent in the seagrass-sand and sand sections by *S. argus* than in any other section apart from the seagrass section ($0.0001<p<0.0006$: pairwise comparisons) (Table 5.2; Fig 5.2). Rock and seagrass-rock sections were the two most infrequently occupied sections by this species followed by rock-sand (Table 5.2; Fig 5.2). The time spent in the seagrass only section was intermediate to these two extremes, but this section was the most popular first choice upon release for these pipefish (35.71% of individuals) followed by seagrass-sand (21.43%) (Table 5.3).

The hardyheads, *A. microstomata*, displayed a less pronounced but still statistically significant effect of habitat combination sections with seagrass-rock being the most infrequently occupied section (Table 5.1; Fig 5.2). Pairwise comparison of time spent in seagrass-rock with the most frequently occupied (rock-sand) section was almost significant after Bonferroni correction ($p = 0.0038$: pairwise comparison) (Table 5.2; Fig 5.2). Rock-sand was the first habitat section choice for 27.03% of these individuals, the highest compared to all other habitat combinations, with the seagrass-sand section being the least popular first choice (8.11%) (Table 5.3).

This trend was similar to that of the trumpeters, *P. sexlineatus*, with the seagrass-sand along with seagrass-rock being the least popular first habitat choice (both 10.64%) (Table 5.3). Conversely, rock-sand, seagrass and rock were the more popular first choice habitat combinations (23.4%, 21.28% and 19.15% respectively) (Table 5.3). There was, however, no overwhelming habitat combination favourite with respect to its first choice upon release or with regards to percentage time spent in each section for this species.

Homogeneity-complexity levels

With the habitat combination sections grouped in homogeneity-complexity levels *A. spilomelanurus* spent comparable more time more complex habitats regardless of homogeneity although there was no significant effect (Table 5.1). This species occupied the homogen-2 and heterogen-2 sections more and equally frequently compared to homogen-1 and heterogen-1 sections (Fig 5.3a). The opposite was true for *A. microstomata* and *S. argus* (Fig 5.3c,e). Both these species displayed a significant effect with homogeneity-complexity levels (*pseudo-F* = 3.952; p=0.01, *A. microstomata*; *pseudo-F* = 12.3; p=0.0001, *S. argus*) (Table 5.1) and spent more time in lower complexity sections regardless of homogeneity levels i.e. homogen-1 and heterogen-1 compared to homogen-2 and heterogen-2 (Fig 5.3c,e).

This trend was more pronounced in the pipefish with individuals spending significantly more time in both homogen-1 and heterogen-1 section compared to the other two levels (0.0001<p<0.0013: pairwise comparisons) (Table 5.4; Fig 5.3e). For the hardyhead species, however, only the percent time spent in homogen-1 was significantly greater than homogen-2 and heterogen-2 (0.032<p<0.0048: pairwise comparisons) (Table 5.4; Fig 5.3c). The hardyheads also spent significantly less percentage time in heterogen-2 compared to heterogen-1 sections (p=0.0084: pairwise comparison) (Table 5.4; Fig 5.3c).

There was no meaningful or significant trend in percent time spent in homogeneity-complexity levels with the trumpeters, *P. sexlineatus*, apart from the heterogen-2 level (seagrass-rock only) being the least frequently occupied (Table 5.4; Fig 5.3g). With the exception of the pipefish, the above-described trends corresponded with first choice percent of fish values albeit generally less pronounced (Fig 5.3 – right panel). The comparatively higher percentage of pipefish individuals initially choosing homogen-2 (Fig 5.3f) was highly driven by the popularity of the seagrass section as a first choice for this species.

5.3.2 Experiment B – "Predator" (inclusion) trials

Control experiments

Control experiments proved the predator model efficient at producing a sufficient enough scare factor, at least for the species tested, *A. microstomata*. Approximately 91.7% (22 of 24) of the individuals displayed either medium or high level agitation with the "predator in bag" trials compared to 27.3% (6 of 22) with the "empty bag" trials. The loss of data for two individuals accounted for the lower number of individual data points in "empty bag" trials.

"Predator" trials

A combination of both % time spent in each section and first choice data was used to evaluate habitat combination preference with predator inclusion and for comparison with "no predator" trials. Focus was placed on those cases where both measures correspond. Solely assessing % time spent in each section with predator inclusion may be misleading, especially if no clear choices were made by the test fish with predator inclusion in their agitated state.

Without comparison with Experiment A results, *A. spilomelanurus* and *A. microstomata* displayed a more pronounced habitat structure preference with predator inclusion, being statistically significant for the latter (pseudo-F = 2.6702; p=0.0201) (Table 5.1) compared to the other two species. The leatherjacket individuals spent relatively more time in the seagrass-rock section, but this was not statistically significant, or was the difference particularly pronounced especially compared to the seagrass section. First choice percent individual data provided a more pronounced distinction, however, with half of all individuals choosing seagrass-rock initially upon release with the predator present, and none choosing seagrass initially (Fig 5.4b).

The hardyheads spent significantly more percent time in rock-sand compared to seagrass (p=0.0027: pairwise comparison) considering the Bonferroni correction for multiple comparisons. Without this consideration percent time spent in sand was also greater compared to seagrass and seagrass-rock (p=0.0155 and 0.0147 respectively: pairwise comparisons) (Table 5.2; Fig 5.4c). First choice data, however, pointed to a relatively similar preference for all sections but one as a first choice upon release, slightly edged out by all sections containing seagrass. The sand-only section stood out as the least initially selected, being chosen first by only 5.41% of individuals (n=37) (Table 5.3; Fig 5.4d).

While *S. argus* and *P. sexlineatus* made less pronounced habitat combination choices with respect to % time spent in each section, possibly due to its heightened agitated state above that of the other species with predator inclusion, trends were observed with this measure as well as with first choice data especially for the pipefish, *S. argus*. This species spent relatively more time in sand and seagrass-sand and least in seagrass-rock and rock-sand with predator inclusion (Fig 5.4e) with first choice data indicating a greater percentage of pipefish initially choosing seagrass-sand (33.33%) and seagrass (29.63%) (n=27) upon release (Table 5.3).

The trumpeter, *P. sexlineatus*, displayed the least pronounced habitat combination choices reflected in both % time spent and fish first choice data with predator inclusion as it did in Experiment A. They, however, spent relatively more time in seagrass-rock and seagrass-sand than any other section and least time in the rock only section (Fig. 5.4g). Apart from rock also being one of the habitat combination sections least chosen by this species in first choice data (13.64%) (n=44) (Table 5.3; Fig. 5.4h) there was no other consistency between percentage time spent in each section and first choice data. No overwhelming first choice preference was displayed for this species with predator inclusion.

Comparison with Experiment A: Habitat combination sections

While significant paired samples t-tests were registered for two species for two different habitat combination sections (described below), no significant relationship was found for the McNemar Chi-square tests and are such are not discussed in the subsequent section. Noteworthy trends observed by tracing the selection of each individual test fish between both trials are however described. Initial habitat combination section and assigned homogeneity-complexity level chosen by each individual fish upon release in “no predator” and “predator” trials is available in Appendix IX.

Acanthaluteres spilomelanurus spent significantly less time in the seagrass only section upon predator inclusion compared to “no predator” trials (paired t-tests: p = 0.016) (Table 5.5; Fig 5.4a). Generally less time was spent in the seagrass-sand section and a pronounced but non-significant increase in time spent in the rock and rock-sand sections. First choice values illustrate a pronounced difference in sectional preference with predator inclusion with a sharp increase in percent of individuals choosing seagrass-rock (18.18% - NP vs 50% - P) and rock-sand (0% - NP vs 30% - P) upon release (Table 5.3; Fig 5.4b). Additionally, whereas just over 50% of individuals initially chose the seagrass section upon release in “no predator” trials, with predator inclusion, no individual of this species made seagrass their first habitat combination choice (Table 5.3; Fig 5.4b).

As the experimental design allowed each fish to be monitored following its habitat combination choice without predator inclusion (done first) and with predator inclusion, the change in first choice with this additional environmental stress i.e. the predator, could be monitored per fish. This data for this species revealed that of the five individuals that chose seagrass initially in “no predator” trials, four chose seagrass-rock with “predator” trials and the fifth rock-sand (Appendix IX). Additionally the two individuals choosing seagrass-rock initially in “no predator” trials chose rock and rock-sand on predator inclusion (Appendix IX).

Atherinosoma microstomata generally spent more time in rock-sand and seagrass-rock in “predator” trials and less time in the seagrass and sand sections compared to “no predator” trials (Fig 5.4c). First choice data was consistent for two of these habitat combination sections, with a sharp decline in the percent of fish individuals initially choosing sand (18.92% - NP vs 5.41% - P) and an increase in the percent initially choosing seagrass-rock (13.51% - NP vs 21.62% - P) (Table 5.3: Fig 5.4d). First choice data also revealed a sharp increase in preference of the seagrass-sand section with predator inclusion (8.11% - NP vs 21.62% - P) (Table 5.3; Fig 5.4d).

Tracing individual fish first choices as outlined in Appendix IX, none of the six hardyheads initially choosing sand in “no predator” trials maintained that first choice upon release with predator inclusion, with two subsequently choosing rock, two seagrass, two seagrass-sand and one rock-sand. Of the six individuals first selecting seagrass in “no predator” trials, three maintained this first choice while the other three chose seagrass-rock, rock and rock-sand in “predator” trials. Additionally, of the three individuals choosing seagrass-sand initially in “no predator” trials, two chose rock-sand and one seagrass in “predator” trials.

Stigmatopora argus individuals followed a similar pattern as in “no predator” trials with regards to relative percent time spent in each habitat section with predator inclusion. This species, however, displayed a decline in the time spent in seagrass and seagrass-sand sections (paired t-test, *seagrass-sand*: $p = 0.05$) (Table 5.5; Fig 5.4e) and more in seagrass-rock and rock sections, the latter when compared with “no predator” trials being statistically significant (paired t-test, *rock*: $p = 0.038$) (Table 5.5; Fig 5.4e). This did not entirely correspond with first choice data, however, which illustrated a decline in percent fish first choice of seagrass-rock upon predator inclusion (14.29% - NP; 7.41% - P). This species also displayed a pronounced increase in initial selection of seagrass-sand (21.43% - NP; 33.33% - P) and to a lesser extent rock-sand (7.14% - NP; 11.11% - P) and a decline in preference of seagrass (35.71% - NP; 29.63% - P) in “predator” over “no predator” trials (Table 5.3; Fig 5.4e). There was, however, a consistent decline in the percent time spent in sand and the percent of individuals initially selecting sand with predator inclusion (Table 5.3; Fig 5.4e,f).

Comparing first choices for individual pipefish individuals (Appendix IX), of the six test fish initially choosing seagrass-sand in “no predator” trials, two maintained that initial selection, while one chose rock-sand, another seagrass, and the other two, seagrass-rock and rock with predator inclusion. Additionally, of the ten pipefish individuals initially selecting seagrass in "no predator" trials, four maintained this first choice, three switched to seagrass-sand, one to seagrass-rock, and the other two to rock and sand respectively with predator inclusion.

Higher variation existed in *P. sexlineatus* data compared to the other three species but there was a noticeable general decline in percent time spent in the seagrass and rock-sand sections compared to "no predator" trials as well as an increase in time spent in seagrass-rock with predator inclusion (Fig 5.4g). This was consistent with first choice percent fish data, albeit less pronounced with regard to the seagrass section, (Table 5.3; Fig 5.4h) and was accompanied by an approximately 5% increase in the number of fish initially selecting seagrass-sand with predator inclusion (Table 5.3).

Notably from tracing individual trumpeter first choices (Appendix IX), none of the six fish initially choosing sand in "no predator" trials maintained that first choice with predator inclusion with two choosing seagrass-sand, two rock and the remaining two seagrass and rock-sand respectively. Additionally, of the five initially selecting seagrass-sand in "no predator" trials, again none maintained this selection. Two individuals switched to seagrass, two others to seagrass-rock and rock-sand and the last to sand with predator inclusion.

Comparison with Experiment A: Homogeneity-complexity levels

Clearer consistent trends were observed for *A. spilomelanurus* and *A. microstomata* when comparing test fish trends with homogeneity-complexity levels for both % time spent in each level and their first choice between "no predator" and "predator" trials. These comparisons, however, did not yield significant paired t-test relationships. With respect to the leatherjackets, correspondence between percent time spent and first choice data was observed for three of the four levels namely, homogen-2, heterogen-1 and heterogen-2. While there was increased percent time spent in and first selection of heterogen-1 and heterogen-2 in "predator" compared to "no predator" trials, the increase in heterogen-1 preference being more pronounced in first choice data, there was a decline for homogen-2 preference with predator inclusion, being again more pronounced in first choice data (Fig 5.3a,b).

The hardyheads displayed a consistent decline in percent time spent in and first selection of homogen-1 and an increase in both heterogen-1 and heterogen-2 with predator inclusion (Fig 5.3c,d). Conversely, *S. argus* and *P. sexlineatus* did not display meaningful consistent trends when considering percent time spent in and first choice of the homogeneity-complexity levels in “no predator” versus “predator” trials. A decline, however, in both measures in homogen-2 and increase in heterogen-2 for the trumpeter with predator inclusion (Fig 5.3g,h) was observed. The decline in both measures in homogen-1 for the pipefish with predator addition is already described above as this level consists of the sand section only.

Pooling all individuals: change in habitat combination and homogeneity-complexity levels with predator inclusion

When considering the mean percent of individuals of all species initially selecting the varying habitat combinations and homogeneity-complexity levels, seagrass was the most popular first choice in “no predator” trials (31.94%) with the remaining sections being of relatively similar popularity (11.13-14.59%) (Table 5.6; Fig 5.5a). This translated to more fish initially choosing homogen-2 levels (22.87%) compared to the other three homogeneity-complexity levels (11.13-14.49%) in “no predator” trials (Table 5.6; Fig 5.5b).

Interestingly in “predator” trials, seagrass-rock, seagrass-sand and rock-sand were most frequently chosen first upon release followed by seagrass, rock and sand in that order (Table 5.6; Fig 5.5b). This translated to a higher percentage of fish initially choosing both heterogen-1 and heterogen-2 levels (19.55% and 23.17% respectively) and less fish initially choosing homogen-1 and homogen-2 levels (7.75% and 15.00% respectively) with predator inclusion, with homogen-1 being the least initially chosen (Table 5.6; Fig 5.5b).

Comparing first choice values for each habitat structure combination and homogeneity-complexity levels between trials, there was a decrease in initial selection of all homogeneous sections i.e. seagrass, rock and sand, being most pronounced with seagrass (Table 5.6; Fig 5.5a). This coincided with an increase in initial selection of all heterogeneous sections i.e. seagrass-rock, seagrass-sand and rock-sand with predator inclusion being more pronounced with seagrass-rock (Table 5.6; Fig 5.5a). This translated to a decrease in initial selection of homogen-1 and homogen-2 and an increase in heterogen-1 and heterogen-2 levels with predator inclusion versus “no predator” trials (Table 5.6; Fig 5.5b).

5.4 Discussion

Habitat combination structure and homogeneity-complexity preference without predator stress

Results of this experiment highlighted the differing habitat combinations and homogeneity-complexity preferences of different species as illustrated in literature (Cheminée 2012). This is not surprising considering the unique features of the tested species with differential preferences possibly driven by inherent characteristics, including but not limited to body morphology, diet and style of locomotion. The primarily herbivorous leatherjackets, for instance, showed a clear statistically significant preference for the seagrass habitat ($p<0.001$) and were generally more present in areas of higher habitat complexity regardless of homogeneity. Similar results were also reported in field studies of Smith, Jenkins & Hutchinson (2012) where this species was more abundant in the seagrass interior and less so and absent at the seagrass-sand edge and sand respectively. Conversely, the zooplanktivorous pipefish preferred the seagrass-sand (Jelbart, Ross & Connolly 2006; Macreadie et al. 2010; Smith et al. 2008) and sand habitat sections ($p<0.001$) and the less complex habitats ($p<0.001$) regardless of homogeneity. The pipefish's affinity for the sand edge has in other published research been attributed to the heightened zooplankton abundance trapped at the interface of the seagrass and sand which these fish map on to (Macreadie et al. 2010).

The schooling pelagic hardyheads displayed their affinity to the water column by staying relatively close to the water surface in tank trials compared to the more benthic disposition of the other species, a feature similarly reported in literature (Connolly 1994). This species also displayed a greater affinity for sand and rock-sand habitats and were least common in seagrass-rock. The affinity to these habitat combinations is likely linked to their body morphology, being silvery to olive green above and pale yellowish below (Thompson & Bray 2011) similar in colour to that of the rock and sand. Being pelagic and schooling this may be the best defence mechanism against pelagic predators instead of through seagrass, against which they would be more obvious prey. Hence a lowered habitat complexity i.e. the presence of sand, based on the parameters set by this study, appeared more preferred by this species. The trumpeters did not display a particular affinity to a particular habitat combination possibly linked to its tendency to dart, hide and stay still in a particular section of the tank regardless of the habitat structure until the end of the trials. No apparent choice was being made by this species from observation of video trials apart from generally spending less time in the rock and seagrass-rock sections and more time in sections containing sand. Similar observations were made for this species in the published field studies in Pittwater, New South Wales where no significant variation in occurrences was observed with distance from a seagrass-sand edge (Jelbart, Ross & Connolly 2006).

Change in habitat structure and homogeneity-complexity preference with predator stress

Although greater variability in the data ensued with addition of the predator model, an expected phenomenon due to the increased level of agitation with the added stimuli, interesting trends were noted in change of habitat structure and associated homogeneity-complexity level with each species and with all species taken together. With regards to habitat structure, the bridled leatherjacket displayed a significant decrease in percent time spent in the seagrass habitat (paired t-test: p = 0.016) with no individual initially choosing this habitat section with predator model inclusion (compared to 54.55% before predator inclusion). This coincided with an increased time spent in all habitats consisting of rock, with seagrass-rock being the most popular fish individual first choice with predator inclusion.

An increase in the mean percent time spent in seagrass-rock was actually common for all four species and a decrease in mean percent time in seagrass for two other species (*A. microstomata* and *P. sexlineatus*). Similarly, pipefish individuals spent significantly more time in rock (paired t-test: p=0.038) with predator inclusion and less time in the seagrass and seagrass-sand positions. The seagrass-rock combination before predator inclusion was among the least commonly visited section for all species and for *S. argus* and *A. microstomata* was still among the least frequented with predator inclusion compared to other habitat combinations. This mirrored results from the seine net and GoPro data from the Jervis Bay field study described in Chapters 2 and 3, especially for cryptic canopy dwelling fish species that increased in abundance towards the seagrass interior away from the seagrass-rocky reef edge. While this is the case, with predator inclusion there was a clear increase in occupancy of this section by all species with four of the eleven individual leatherjackets that initially chose seagrass on release in predator absence, choosing seagrass-rock first upon release in predator presence. First choice data also revealed that for all species except *S. argus* the percentage of individuals choosing seagrass-rock first increased with predator inclusion especially so for the leatherjackets (3% increase – *P. sexlineatus*; 8.11% increase – *A. microstomata*; 31.82% increase – *A. spilomelanurus*).

The increase in preference for the seagrass-rock section in this study may partially be due to the combination of two unique habitats offering differing forms of protection, likely supplementing each other and superceding that offered by the individual habitats themselves (Anderson et al. 2009) which become especially important with increased risk of predation.

While the seagrass offers inter-shoot spaces, below-canopy shelter and camouflage for similarly coloured individuals (e.g. *S. argus* and *A. spilomelanurus* from this study), the rocky substrate offers crevice of varying sizes into which prey may achieve complete exclusion from the surrounding threat (Gotceitas & Brown 1993), as well as camouflage opportunity for light sandy to dark brown coloured individuals (e.g. *A. microstomata* and *P. sexlineatus* from this study). The pronounced switch by the leatherjackets from seagrass to seagrass-rock with predator inclusion may partially be due to their body colour being a combination of that of seagrass and the rocky substrate of varying shades (Bray 2011) increasing its chances of being hidden when faced with predation risk compared to being in seagrass only. This may also become increasing relevant in the actual marine environment where rocks are often covered with algae of varying shades of green and brown (algae was scrubbed from rocks and *Posidonia australis* blades in this study to remove the compounding factor of food availability).

In general, taking all species together, there was an obvious shift in the individual's first habitat choice from the homogeneous habitats i.e. seagrass, rock and sand, to the heterogeneous ones i.e. seagrass-rock, seagrass-sand and rock-sand being edged out by the seagrass-rock habitat structure. There was also a general increase in the first selection of habitats of increasing complexity with predator inclusion, with homogen-1 associated with the least complexity followed by homogen-2, heterogen-1 and heterogen-2 in that order of increasing complexity. The seagrass-rock section, which in this study design was tagged "heterogeneous-2", and at the highest scale of complexity, being both heterogeneous and containing two structural habitats, displayed a general increase in fish preference in the presence of the predator. Similar studies have highlighted a shift in behaviour of individuals with the added risk of predation (Dugatkin & Alfieri 1991; Scheibling & Hamm 1991) coined as the "threat sensitive predator avoidance hypothesis" (Helfman 1989) with individuals now forsaking other mundane activities such as feeding and territorial defence to escape predation (Chivers et al. 2001; Helfman 1989; Lima & Dill 1990). Hence individuals may likely avoid these mundane activities performed in other habitat positions and assume new positions of greater complexity to facilitate predator evasion. Habitat complexity, often associated with greater availability of interstices for hiding (Hackradt, Félix-Hackradt & García-Charton 2011) and exclusion of the generally larger predators (Gotceitas & Brown 1993; Johnson, Beaumier & Lynch Jr 1988) is noted to be more highly preferred with this added predation risk (Gotceitas & Brown 1993; Johnson, Beaumier & Lynch Jr 1988; Lima & Dill 1990; Scheibling & Hamm 1991). Additionally, Kaiser (1983) in microscale experiments using mite prey, reported lower incidences of predation associated with higher degrees of habitat spatial heterogeneity.

The increased agitation of the test individuals with predator inclusion was reflected in the greater data variability per species in predator trials. This should be taken into account when regarding the relative time spent in each habitat section with predator presence and when making comparisons with “no predator: trials as differences observed may partially be an artefact of the experimental design. Although test individuals were clearly choosing and associating with sections, as individuals become faced with the threat of predation and may now prefer direct contact with the habitat for hiding, not being able to physically access the habitat directly may influence percentage time data in each section per species. This is especially so for *S. argus* and *P. sexlineatus*, as these species did not seem to make clear preferences with regards to percentage time as did the other two species with predator inclusion. As such first choice data were considered along with percent time spent in each section, particularly with predator inclusion, to have a better understanding of preferences. With the test individuals being allowed to visually assess the positions of all sections before release in “predator” trials and having spent at least fifteen minutes prior in the experimental tank in “no-predator” trials, this first choice measure was deemed an accurate indication of the individual’s preferences immediately upon release, with the majority of individuals making a decision within seconds of removal of their transparent holding tube. Hence the combination of % time, first choice data and tracing the choices of each individual between both trials proved useful and sufficient in determining habitat preferences and changes in strategy with predator inclusion.

Importance of habitat edge type

Results from this experiment show that for at least two species (*S. argus* and *A. microstomata*) a clear distinction is made between seagrass next to sand and seagrass bordered by rocky substrate, both spending less time in seagrass bordered by rock with this difference being significant for the pipefish (p=0.0001). This highlights the importance of the adjacent habitat type at a seagrass edge over the generality of the existence of an edge *per se*. This also highlights the differing responses to edge by different species as the two remaining species showed no such distinction in their preferences.

Edge vs interior (Seagrass)

Results from this study may be also extrapolated to suggest that a fish's position in a seagrass bed relative to an adjacent habitat may not only be based on food availability and local hydrodynamics, as described in Chapter 3, but may vary with predator stress for some fish species (Chivers et al. 2001). If the seagrass-rock and seagrass-sand sections were to represent the seagrass-reef and seagrass-sand habitat edges it can be seen, particularly for the pipefish, where introduction of the predator led to a decline in the time spent in the previously preferred seagrass-sand and an increase in that spent in the seagrass-rock section. This may translate in the natural habitat to this species being more sensitive to the seagrass-reef edge and being positioned more closely in relation to the reef when perceiving a greater threat and less so to the seagrass-sand edge. It may then return to its "preferred" position at the seagrass-sand edge (Jelbart, Ross & Connolly 2006; Macreadie et al. 2010) in the absence or reduction of this threat. A similar shift in habitat position with removal of predator stress was observed in experiments performed on juvenile Atlantic cod, *Gadus morhua*, moving progressively back to the water column from their hiding within interstices of cobbles on predator withdrawal (Gotceitas & Brown 1993). Additionally, if the seagrass-only section represents the seagrass interior, results suggests that the bridled leatherjacket may move away from the seagrass interior and towards the seagrass-rock edge (and not seagrass-sand) if available when faced with predator presence. This species was in fact primarily associated with more complex habitats both before and increasingly so during predator exposure. The preference for structure by this species has been noted in published descriptions (Gomon, Glover & Kuiter 1994), being associated with seagrass beds and rocky reefs. This sheds light on an interesting phenomenon where an individual's response to habitat edges of particular configuration is not only dependent on prey availability but also on perceived predatory threat which can change with time.

Conclusion

Results of this study validate the rejection of all null hypotheses set at the beginning of this chapter with the exception of 1d, 2a, 2c, 5d and 9d. The non-rejection of these hypotheses largely reflect the lack of edge responses observed by the species, *Pelates sexlineatus* in the presence and absence of the predator model.

The following summarizes the main points drawn from this experiment:

1. The different species tested displayed differential habitat combination and habitat homogeneity-complexity level preferences under “no-predator” conditions *A. spilomelanurus* generally preferred more complex habitats and habitat combinations, while *S. argus* and *A. microstomata* favoured less complex conditions, being more often associated with sand and/or habitat combinations including sand. *P. sexlineatus* did not display distinct preferences.

2. With predator presence there was an increased percent time spent in the seagrass-rock section compared to “no-predator trials” which was also reflected in higher percentage of fish initially selecting this section in “predator” trials for all species except *S. argus*.

3. With all species considered there was a decrease in first choice selection of homogeneous sections and those of lower complexity coinciding with an increase in all heterogeneous sections and those of higher structural complexity with predator inclusion.

4. For at least two species (*S. argus* and *A. microstomata*) a clear distinction was made between seagrass bordered by rocky substrate and seagrass next to sand, with both preferring the latter. This highlights the importance of adjacent habitat type constituting an edge when considering species’ edge responses.

5. Under “no-predator” conditions the seagrass-rock section was among the least visited sections for all species coinciding with seine net data of cryptic seagrass fish distribution with relation to the seagrass-reef edge (Chapter 2).

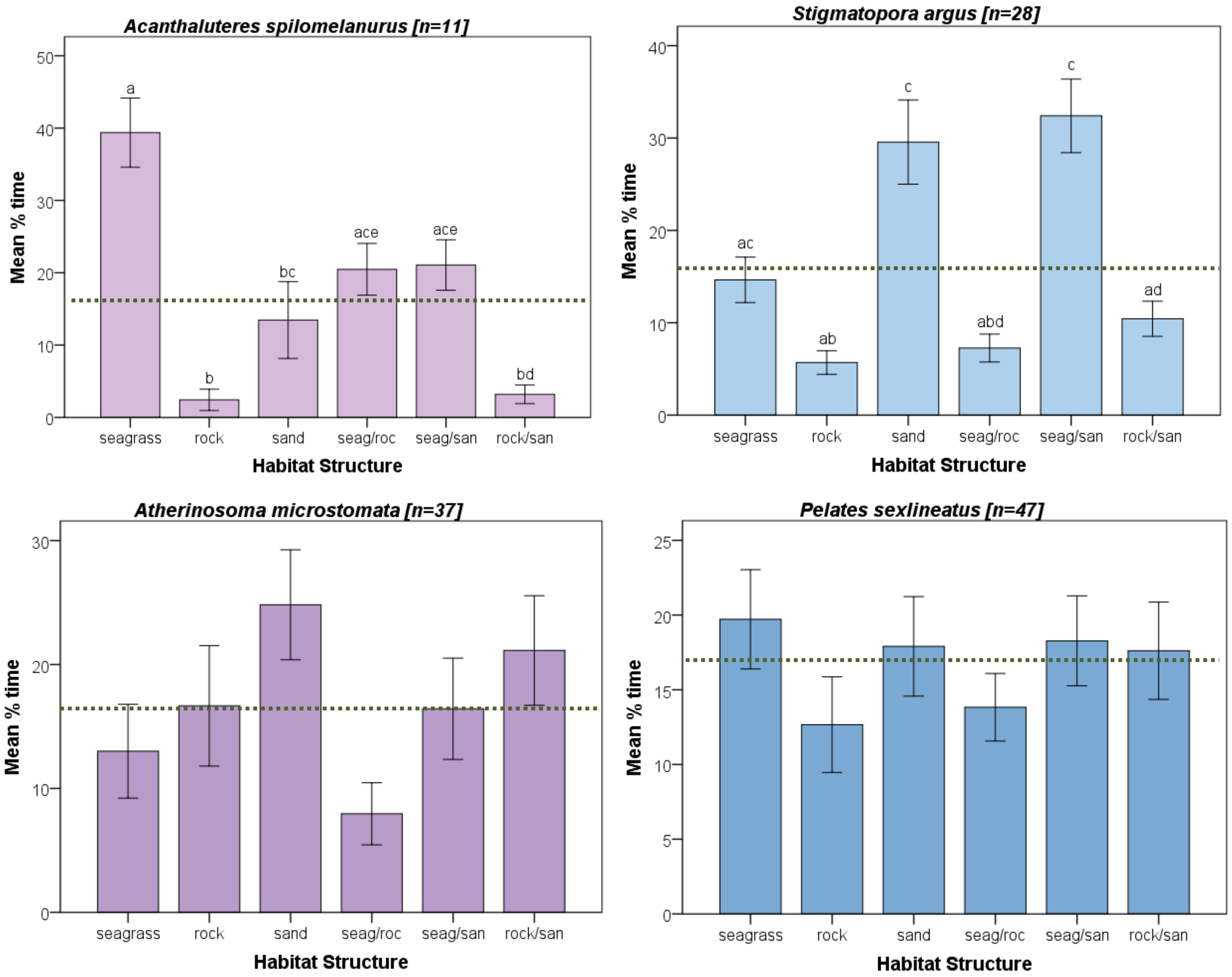
6. Overarching conclusion: Fish distributional patterns are not homogeneous throughout all positions within a habitat especially in relation to another adjacent unique habitat, with this being species-specific and differing with level of predation risk. This is so as each habitat position, whether homogeneous (interior) or heterogeneous (edge) in nature provide varying levels of potential for shelter which is differentially exploited by different species depending on several intrinsic characteristics including colour. Other intrinsic characteristics that may prove important, however not tested in this experiment, include fish size (Chivers et al. 2001; Scheibling & Hamm 1991; Wahle 1992).

Table 5.1 Summary of PERMANOVA results comparing percentage of time spent in each habitat combination section (Hab.Com.) and its assigned homogeneity-complexity (Hm-C) level for indicated species in Experiment A [“no predator” trials – NP] and Experiment B [“predator” trials – P]. *Number in brackets represents homogeneity of multidispersions permdisp p-value; [n=Experiment A, Experiment B]; *Disparity in numbers between trials due to loss of data for four individuals in “predator” trials.*

Test Species		**df**		**MS**		**pseudo-*F***		**p value**	
		Hab. Com.	Hm-C. Level	Hab. Com.	Hm-C. Level	Hab. Com.	Hm-C. Level	Hab. Com.	Hm-C. Level
Acanthaluteres spilomelanurus [n=11;10]*	**NP**	5	3	14.71	1.8039	20.873	1.0128	**0.0001** (0.196)	0.3952
	P	5	3	1.322	0.67839	0.71943	0.366	0.6067	0.7742
Atherinosoma microstomata [n=37;37]	**NP**	5	3	6.1654	9.6697	2.5054	3.9523	**0.0293** (0.298)	**0.01** (0.132)
	P	5	3	6.8211	7.1743	2.6702	2.7713	**0.0201** (0.077)	0.046 (0.018)
Stigmatopora argus [n=28;27]*	**NP**	5	3	14.925	15.921	13.113	12.36	**0.0001** (0.495)	**0.0001** (0.135)
	P	5	3	2.3567	1.6691	1.0033	0.7066	0.4186	0.5472
Pelates sexlineatus [n=47;45]*	**NP**	5	3	2.0261	1.1893	1.0822	0.6318	0.3774	0.5873
	P	5	3	1.5956	1.2003	0.59802	0.4505	0.6871	0.7281

Table 5.2 Pairwise comparisons of all possible combinations of habitat structure sections. *Numbers in brackets represents p-values for "predator" trials (Experiment B); bold p-values represent significant pairwise comparisons after Bonferroni correction (alpha value set at p<0.0033) for multiple comparisons; n.s. – no significant difference.*

Pairwise Comparisons		*Acanthaluteres spilomelanurus*	*Atherinosoma microstomata*	*Stigmatopora argus*	*Pelates sexlineatus*
seagrass-sand	Seagrass	n.s.	n.s.	0.0052	n.s.
	seagrass-rock	n.s.	n.s.	**0.0001**	n.s.
	Rock	n.s.	n.s.	**0.0001**	n.s.
	rock-sand	n.s.	n.s.	**0.0006**	n.s.
	Sand	n.s.	n.s.	n.s.	n.s.
seagrass	seagrass-rock	n.s.	n.s.	0.0268	n.s.
	Rock	n.s.	n.s.	0.0075	n.s.
	rock-sand	(**0.0027**)	(**0.0027**)	n.s.	n.s.
	Sand	0.0472 (0.0155)	0.0472 (0.0155)	0.006	n.s.
seagrass-rock	Rock	n.s.	n.s.	n.s.	n.s.
	rock-sand	0.0075	0.0075	n.s.	n.s.
	Sand	0.0038 (0.0147)	0.0038 (0.0147)	**0.0001**	n.s.
rock	rock-sand	n.s.	n.s.	0.0285	n.s.
	Sand	n.s.	n.s.	**0.0001**	n.s.
rock-sand	Sand	n.s.	n.s.	**0.0004**	n.s.



Acanthaluteres spilomelanurus [n=11]

Stigmatopora argus [n=28]

Atherinosoma microstomata [n=37]

Pelates sexlineatus [n=47]

Fig 5.2 Mean percent time spent in each of six habitat combination sections by test fish individuals (tested singly) for four different species (Experiment A). *Broken lines denote level of expected observations (i.e. 100%/6 = 16.6667% for each section); letters above bars represent the results of pairwise comparisons of log-transformed data with habitat combinations sections lacking similar letters being significantly different.*

Table 5.3 Percentage of total number of individuals of each species making indicated habitat combination section its first choice after release in "no predator" (NP) and "predator" (P) trials.

Habitat Combinations	***A. spilomelanurus***		***A. microstomata***		***S. argus***		***P. sexlineatus***	
	NP (n=11)	**P (n=10)**	**NP (n=37)**	**P (n=37)**	**NP (n=28)**	**P (n=27)**	**NP (n=47)**	**P (n=44)**
Seagrass	54.55	0	16.22	18.92	35.71	29.63	21.28	20.45
Rock	9.09	10	16.22	16.22	10.71	11.11	19.15	13.64
Sand	0.00	0	18.92	5.41	10.71	7.41	14.89	18.18
Seagrass-rock	18.18	50	13.51	21.62	14.29	7.41	10.64	13.64
Seagrass-sand	18.18	10	8.11	21.62	21.43	33.33	10.64	15.91
Rock-sand	0.00	30	27.03	16.22	7.14	11.11	23.40	18.18

Table 5.4 Pairwise comparisons of all possible combinations of the four assigned homogeneity-complexity levels. *Numbers in brackets represents p-values for "predator" trials (Experiment B); values with asterisks represent non-homogeneity of variances for relevant variable and thus significance levels taken at p≤0.01.*

Pairwise Comparisons		*Acanthaluteres spilomelanurus*	*Stigmatopora argus*	*Atherinosoma microstomata*	*Pelates sexlineatus*
heterog-1	homogen-2	n.s.	**0.0013**	(0.028*)	n.s.
	heterog-2	n.s.	**0.0004**	**0.0084**	n.s.
	homogen-1	n.s.	n.s.	n.s.	n.s.
homogen-2	heterog-2	n.s.	n.s.	n.s.	n.s.
	homogen-1	n.s.	**0.0001**	**0.032** (0.0414*)	n.s.
heterog-2	homogen-1	n.s.	**0.0001**	**0.0048**	n.s.

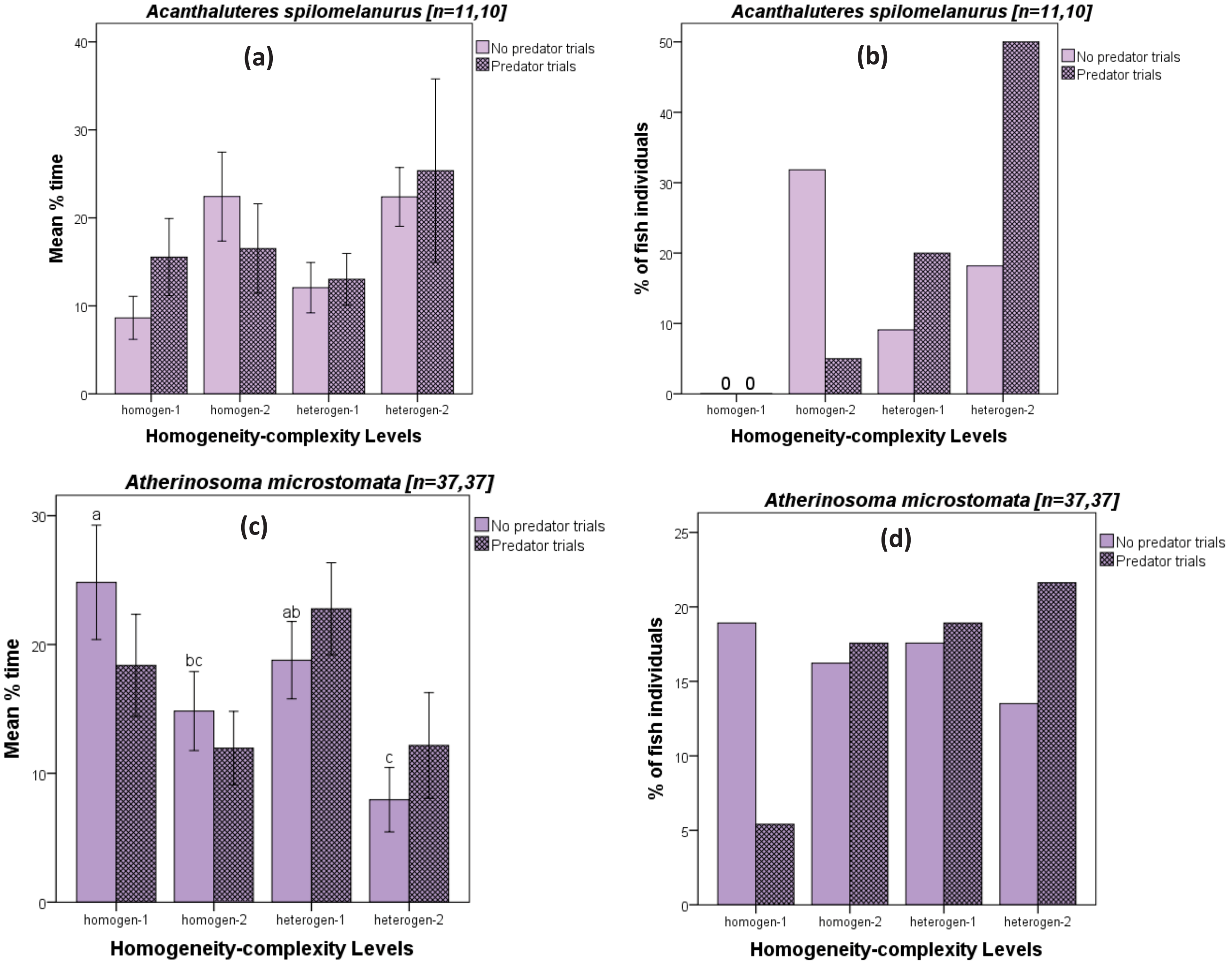


Fig 5.3 Mean percent time spent in (a,c) and percentage of test fish initially choosing (b,d) assigned homogeneity-complexity levels for each tested species in "no predator" vs "predator" trials. *[n=Experiment A, Experiment B]; letters above bars represent the results of pairwise comparisons of log-transformed data with levels lacking similar letters being significantly different.*

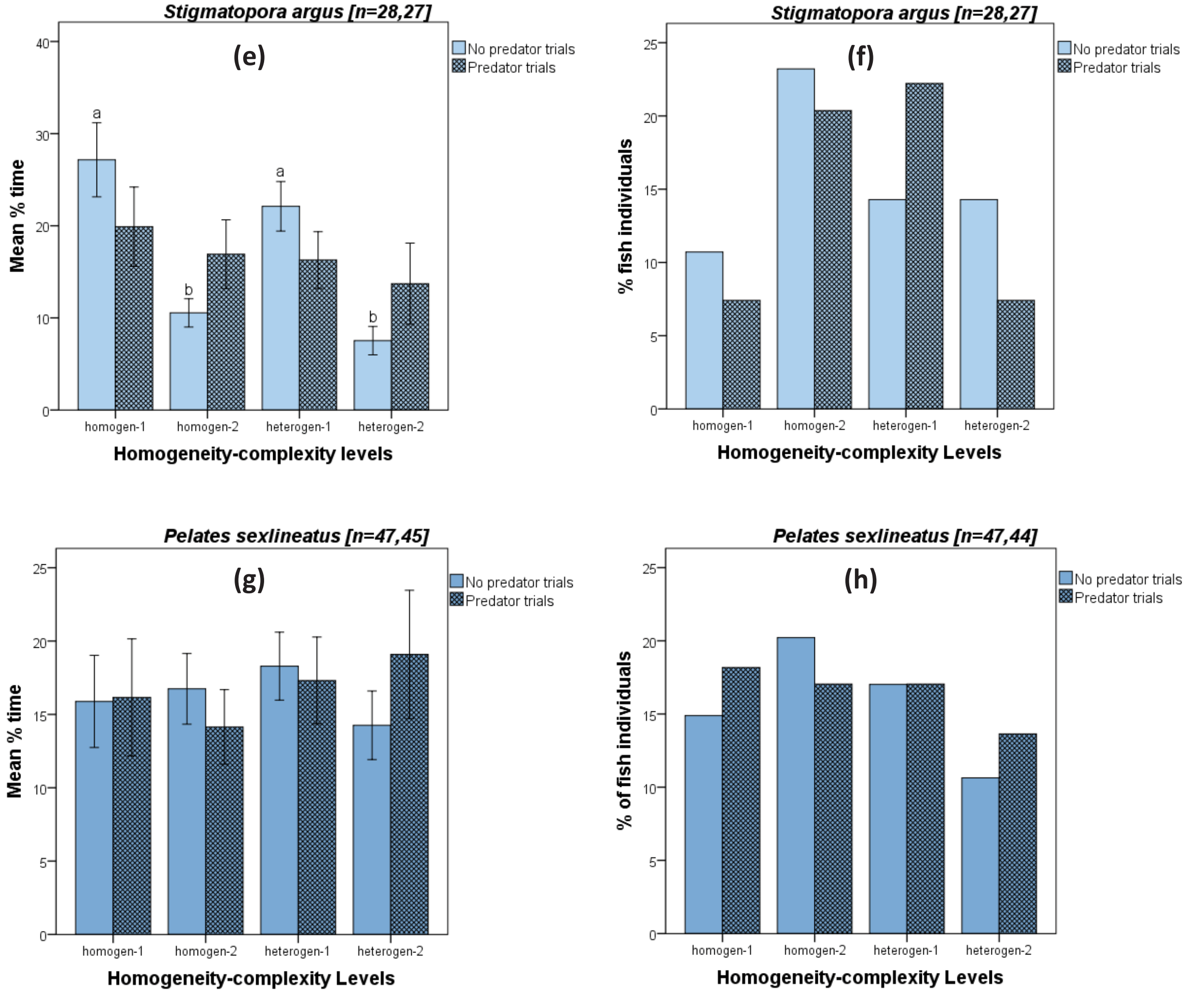


Fig 5.3 (cont'd) Mean percent time spent in (e,g) and percentage of test fish initially choosing (f,h) assigned homogeneity-complexity levels for each tested species in "no predator" vs "predator" trials. *[n=Experiment A, Experiment B]; letters above bars represent the results of pairwise comparisons of log-transformed data with levels lacking similar letters being significantly different.*

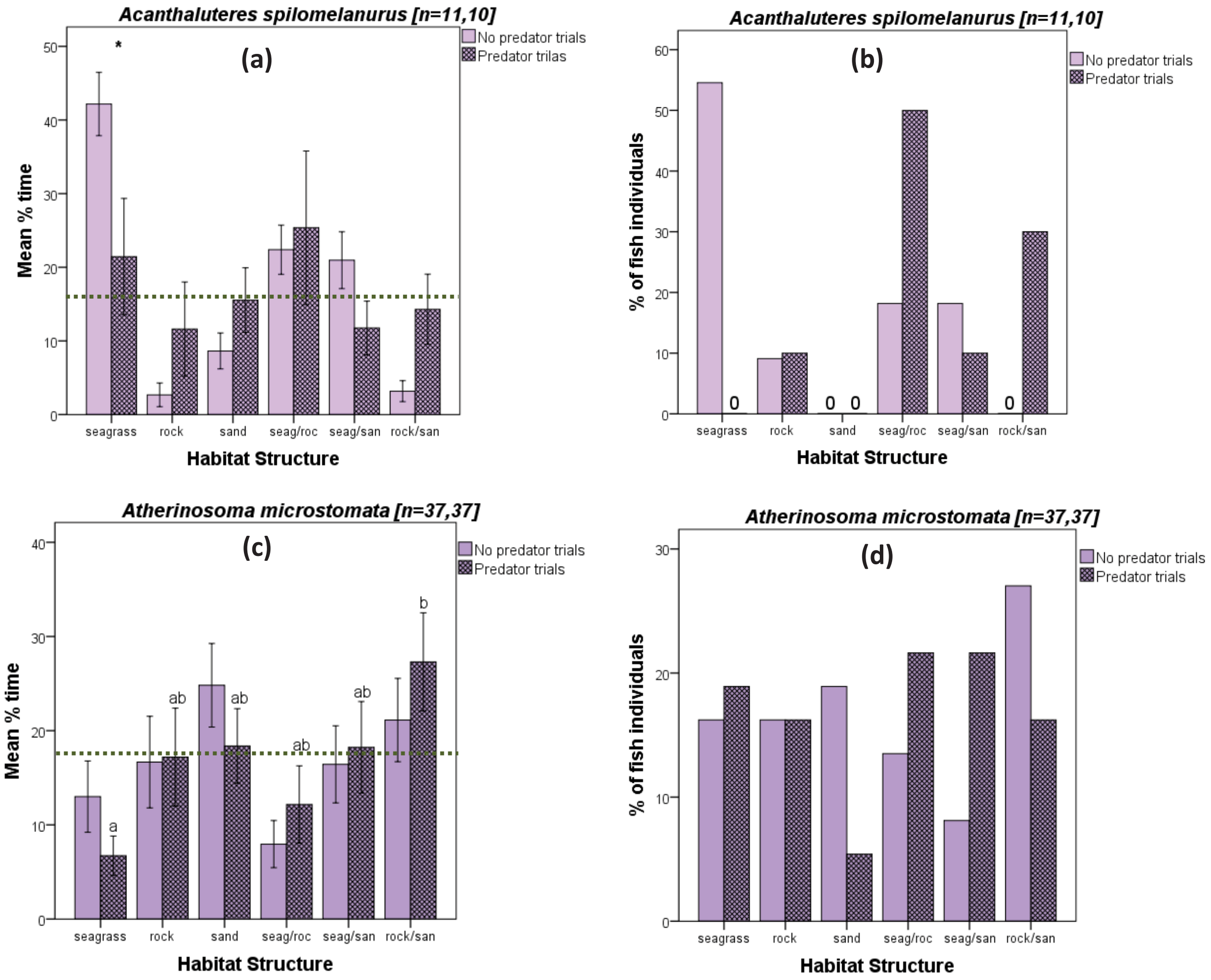


Fig 5.4 Mean percent time spent in (a,c) and percentage of fish of tested species initially choosing (b,d) habitat combination sections; *[n=Expt A, Expt B]; broken lines denote level of expected observations (i.e. 100%/6 = 16.6667% for each section); letters above bars represent the results of pairwise comparisons of log-transformed data with sections lacking similar letters being significantly different;* - significant paired t-test result.*

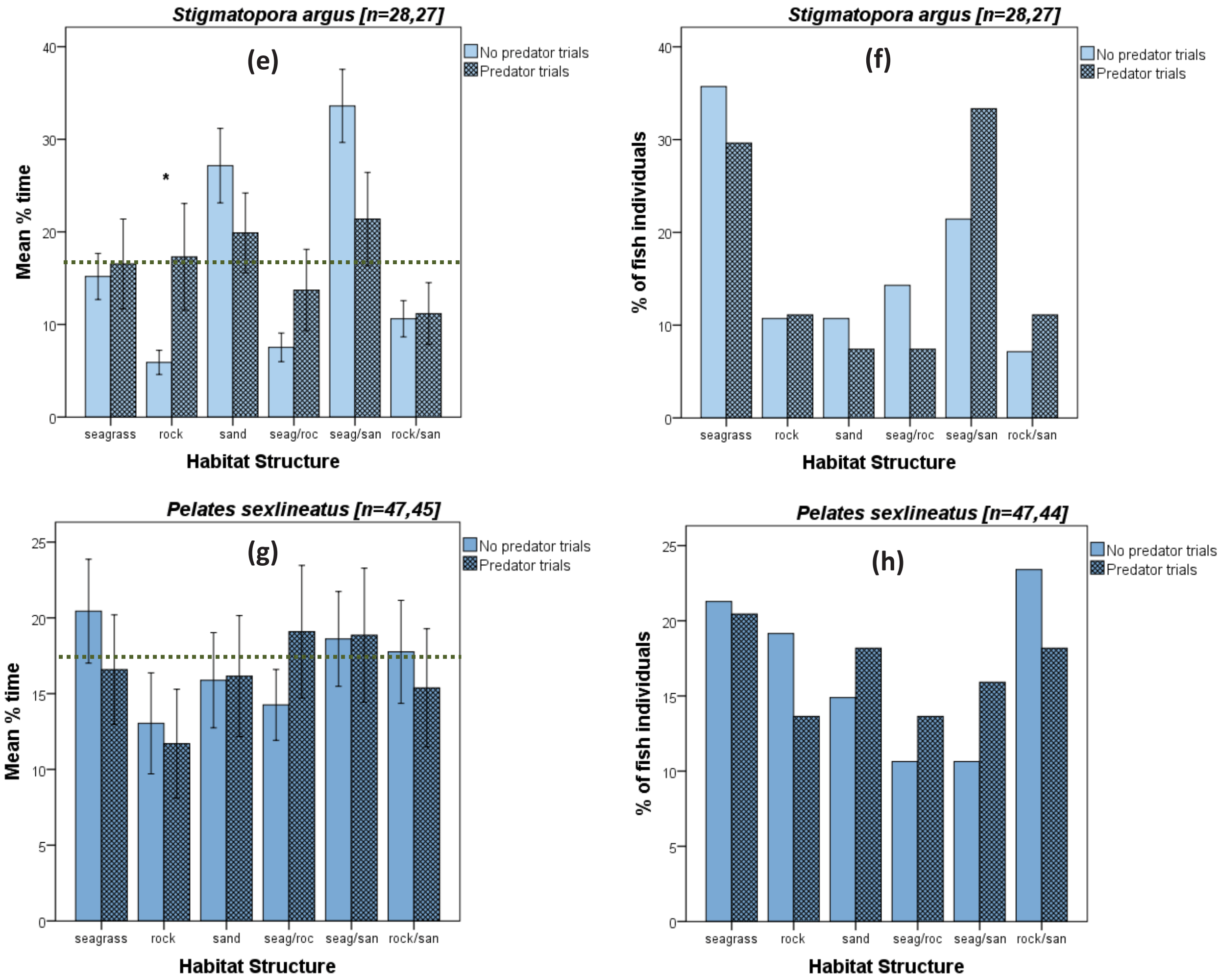


Fig 5.4 (cont'd) Mean percent time spent in (e,g) and percentage of fish of tested species initially choosing (f,h) habitat combination sections; *[n=Expt A, Expt B]; broken lines denote level of expected observations (i.e. 100%/6 = 16.6667% for each section); letters above bars represent the results of pairwise comparisons of log-transformed data with sections lacking similar letters being significantly different;* - significant paired t-test result.*

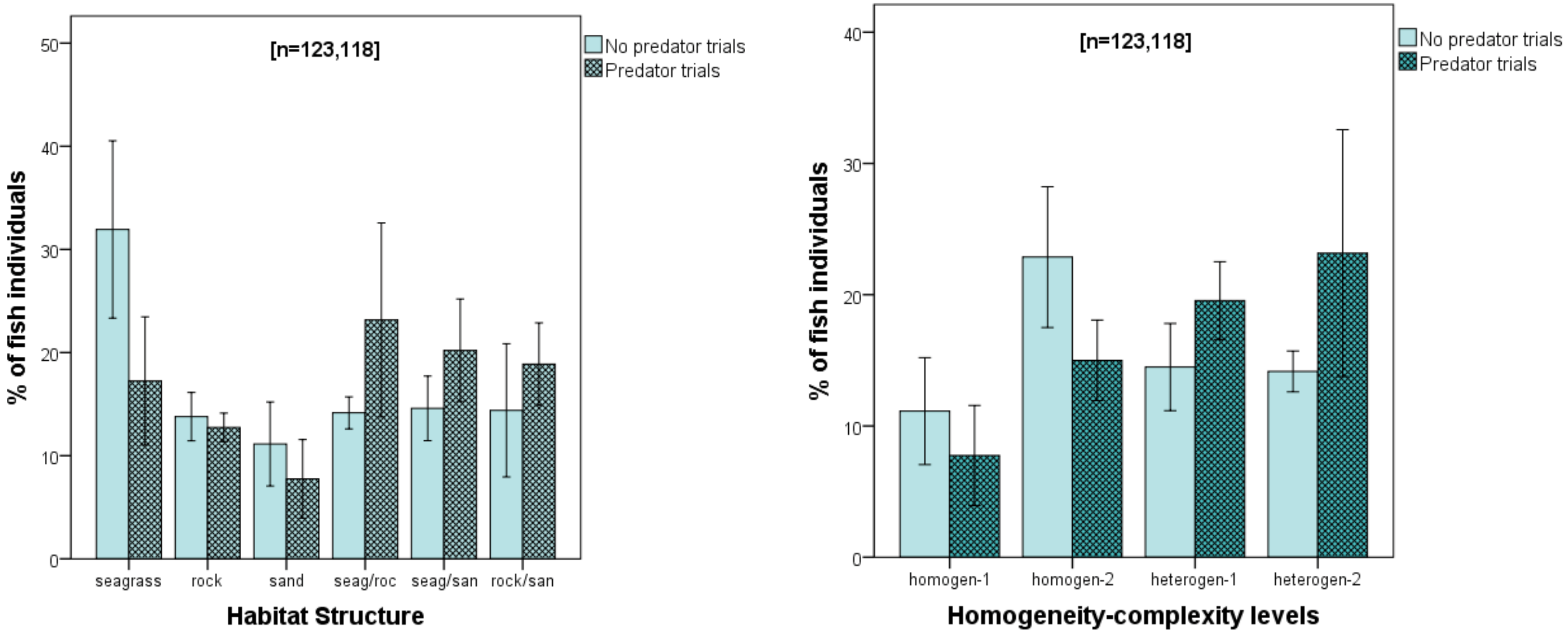
Table 5.5 Summary of paired samples t-tests in SPSS between percent time spent in "no predator" and "predator" trials for individual habitat combinations for each tested species.

Habitat Combination	*Acanthaluteres spilomelanurus*			*Atherinosoma microstomata*			*Stigmatopora argus*			*Pelates sexlineatus*		
	p value	**t**	**df**	**p value**	**t**	**df**	**p value**	**t**	**df**	**p value**	**t**	**df**
seagrass	**0.016**	2.964	9	0.155	1.452	36	0.787	-0.273	26	0.438	0.782	44
Rock	0.185	-1.436	9	0.943	-0.073	36	**0.038***	-2.182	26	0.653	0.453	44
Sand	0.114	-1.753	9	0.263	1.137	36	0.132	1.556	26	0.953	-0.060	44
seagrass-rock	0.777	-0.291	9	0.413	-0.829	36	0.229	-1.231	26	0.277	-1.101	44
seagrass-sand	0.078	1.989	9	0.752	-0.319	36	**0.05**	2.055	26	0.954	-0.059	44
rock-sand	0.058	-2.167	9	0.410	-0.083	36	0.880	-0.153	26	0.647	0.461	44

**It should be noted that in this instance i.e. difference in % time for S. argus in "rock" only, the assumption of normal distribution was not met and the appropriate parallel non-parametric Wilcoxon signed rank test did not a yield a significant difference between the two trials in this habitat section.*

Table 5.6 Descriptive statistics for percentage of fish initially selecting indicated habitat combination and assigned homogeneity-complexity levels pooling all individuals [n=123, 118] of all four tested species in "no predator" (NP) and "predator" (P) trials.

		% fish initial choice [NP; n=123]			**% fish initial choice [P; n=118]**		
		Mean	N	S.D. (S.E.)	Mean	N	S.D. (S.E.)
Habitat Combination							
	seagrass	31.94	4	17.19(8.59)	17.25	4	12.43(6.22)
	rock	13.79	4	4.70(2.35)	12.74	4	2.77(1.39)
	sand	11.13	4	8.14(4.07)	7.75	4	7.63(3.81)
	seag-rock	14.16	4	3.11(1.55)	23.17	4	18.81(9.41)
	seag-sand	14.59	4	6.25(3.13)	20.22	4	9.95(4.97)
	rock-sand	14.39	4	12.92(6.46)	18.88	4	7.99(4.00)
Homogeneity-complexity							
	homogen-1	11.13	4	8.14(4.07)	7.75	4	7.63(3.81)
	homogen-2	22.87	8	15.17(5.36)	15.00	8	8.68(3.07)
	heterogen-1	14.49	8	9.40(3.32)	19.55	8	8.38(2.96)
	heterogen-2	14.16	4	3.11(1.55)	23.17	4	18.81(9.41)



(a) (b)

Fig 5.5 Mean percentage of total number of individuals, pooling all four test species, making indicated (a) habitat structure combination section and (b) its assigned homogeneity-complexity level their first choice after release in both “no predator” (Experiment A) and “predator” (Experiment B) trials. *N values [n=Expt A, Expt B].*

Chapter 6 – General Discussion:

The distribution of several seagrass fish and prey taxa with respect to the two adjacent habitat edge types was examined in the first three data chapters of this thesis at varying levels i.e. at the community, taxa-specific and guild-specific levels. Results illustrated distinctive distributional patterns with respect to the differing edge types. This highlights the importance of the identity of the adjacent habitat in driving edge effects within the seagrass bed. This finding is in line with published edge-effect determining mechanisms (Fagan, Cantrell & Cosner 1999; Ries & Sisk 2004). Here the authors attribute the type of edge i.e. edge structure as a determining factor to species distribution with respect to the edge. The comparative distributions of fish and prey fauna at the varying levels, incorporating findings of the manipulative aquarium experiment are subsequently discussed. As the fish distributions are being compared with that of their primary prey communities, more emphasis is here placed on the FMFG guild distributions over the EUFG. It should be noted, however, that the trends observed in the EUFG guilds are likely a function of not only their inherent size and mobility but their diet. Additionally the "sensitivity to edge" (Ries et al. 2004), in this study defined as the degree or strength of the observed effect, as opposed to merely the directional response with respect to the specific edge type, of all seagrass faunal groups is assessed and compared. Possible mechanisms explaining observed trends after a synthesis of the distributional trends of all faunal groups is also offered.

Consistent with the incorporation and synthesis of the results of all previous chapter the following null hypotheses were tested with regards to potential prey (zooplankton, benthic invertebrate and epiphyte load – Chapter 4) and fish (Chapters 2 and 3) edge responses:

1. There is no similarity in edge responses between the zooplankton prey and zooplanktivorous (ZP) fish functional group.

2. There is no similarity in edge responses between the benthic invertebrate (mollusc) prey and the non-piscivorous carnivores (CNP) fish functional group.

3. There is no similarity in edge responses between the epiphyte load metrics and dominant herbivorous (HV) fish individuals.

Along with the above stated hypotheses is the apriori prediction that:

The edge sensitivities measured (as outlined in subsequent sections of this chapter) of the fish functional groups will be similar to that of their potential prey.

6.1 Faunal distribution in relation to habitat edges: direction of response

Comparative distribution of fish and prey fauna

Fish taxa, especially those sampled by the seine net were primarily cryptic seagrass canopy dwellers. These individuals increased in total abundance with distance from the reef and “general edge” with no apparent trend with bare sediment for both sites illustrating again the importance of edge type in determining edge responses (Fagan, Cantrell & Cosner 1999; Ries & Sisk 2004). While there was also an increase in fish taxa richness with both sampling methods i.e. seine net and GoPro video footage, combined in all planes, this was more pronounced and statistically significant with distance from reef and from edge (irrespective of adjacent habitat type). With respect to the main feeding mode functional groups, the canopy dwelling non-piscivorous carnivores (Atherinidae excluded) feeding primarily on benthic invertebrates, increased significantly with distance away from the reef. This functional guild was likely following the distribution of its mollusc prey (Ries et al. 2004) which also increased in abundance with distance from the reef in this study. The main herbivore encountered, *Girella tricuspidata*, often captured in video footage feeding within the canopy on epiphytic growth, also mapped onto seagrass positions associated with the greatest epiphytic load measures, i.e. the furthest distance from both adjacent habitat types. These grazers are also more likely to choose less hydrodynamic regions within the seagrass in which to feed (Bustamante & Branch 1996; Van Elven, Lavery & Kendrick 2004) and in general more feeding events primarily within the seagrass canopy were encountered beyond 30 m in this study at Greenpoint where they were more frequently observed.

The zooplanktivores displayed a more consistent trend with distance from reef and general edge compared to distance from the bare sediment. This trend was consistent with both fish sampling methods representing a combination of mid-water column positioned schooling individuals and cryptic seagrass canopy species, with the former being more abundant. While this functional group declined in abundance at the most interior general edge position and avoided the immediate seagrass edge they were notably more abundant at the second general edge position in this plane (E15-30m) for both sampling methods pooling both seasons and sites. This trend was identical to that displayed in the summer season (GoPro data) during which time the zooplanktivores were also less abundant at the immediate seagrass-reef edge position pooling both sites and relatively homogenously distributed with distance from bare sediment. The absence of these generally small-bodied individuals at the furthest distances even though these positions corresponded with the greatest zooplankton abundances may be due to the significantly greater occurrences of the larger more mobile marine species functional guild found at the furthest distances in this study (Chapter 3) while concurrently being less abundant at the immediate seagrass-reef edge due to the wave action repelling them (Sorokin 1993) or causing them to retreat vertically within the seagrass to escape the hydrodynamic conditions (Menge & Sutherland 1987). As such these individuals appear to choose a position away from both extremes of distance from the reef edge and general edge which in this study is 15-30m from the reef edge and also 15-30m from the general edge as an optimum environment. With the zooplankton total abundances though not strikingly different with distance from the reef and general edge, the greater abundance of their prey at the furthest distances may not generate sufficient benefit for them to warrant risking predation at these distances (Grabowski et al. 2005; Schmitz, Krivan & Ovadia 2004). Additionally, while this functional group appears to be avoiding the immediate edge they were found in relatively high abundances within 30m of the reef, close enough for the water movement relative to the reef to assist their filter feeding activities (Bustamante & Branch 1996).

Influence of predatory threat on seagrass fish distribution with edge

As illustrated in the aquarium experiments, these mid-trophic level estuarine seagrass fish may choose their position in the habitat based on whether there is an imminent threat of predation and not solely guided by the distribution of their prey and/or local hydrodynamic conditions. While it cannot be determined whether this threat was present at the time of fish sampling, it is reasonable to extrapolate that positions relative to the edge for at least some species including *Stigmatopora argus*, *Acanthaluteres spilomelanurus*, *Atherinosoma microstomata* and to a lesser extent *Pelates sexlineatus* may differ depending on perceived threat of predation. This threat is likely to draw these individuals towards sections of the habitat of greater habitat complexity to avoid mortality (Johns & Mann 1987) in this case the seagrass-rock habitat combination reflective of the seagrass-rocky reef edge in nature. Hence, this generally avoided immediate seagrass-reef edge position may become more inhabited in response to predatory threat. Although reef habitats have been associated with greater occurrence of predatory fish in literature (Tuya et al. 2010; Vanderklift et al. 2007), video footage of the reef habitats themselves at the studied sites revealed no dominant piscivorous predators at the time of the summer fish sampling session (Appendix X) that would deter these mid-level cryptic and schooling species monitored. It is also highly likely that an intermediate position is acquired with respect to the habitat edges by some taxa where individuals will have quick access to both food supply where it may be in its greatest abundance towards the seagrass interior and the seagrass-reef edge where they may gain added protection from predation (Cheminée 2012).

Influence of unique edge construction and microclimatic conditions

Although variation existed in the directional response with respect to the differing habitat edge types there was an overall more consistent increase in prey abundance (total zooplankton, molluscs and epiphyte load measures) as well as that of cryptic seagrass fish species (seine net sampled) and fish species richness with increasing distance away from the seagrass-reef edge. The seagrass-reef edge likely presents harsher conditions with greater water movement against the reef surface (Barros, Underwood & Lindegarth 2001; Sorokin 1993; Van Elven, Lavery & Kendrick 2004) along with coarser sediments (Barros, Underwood & Lindegarth 2001) and hence greater sediment instability noted for this region. The water motion itself may be physically removing zooplankton and small fish or repelling them due to the energy that would be required to maintain their position in this region. This increased water movement may also be removing reef based algal material and carrying it to further distances, notably beyond 30m, helping to establish a more prolific community there.

The benthic mollusc community may itself be responding to this increased epiphyte load (Bologna & Heck 2000) away from the reef as well as avoiding the more unstable sediments (McQuaid & Branch 1984) at the immediate seagrass-reef edge to settle within more stable sediments at the furthest distances. Sediment loss at the immediate reef edge due to wave action (Barros, Underwood & Lindegarth 2001; Sorokin 1993) may also account for the reduction in benthic molluscs, as they are carried away within the translocated sediment (Boström & Bonsdorff 2000). As in previous studies noting an “infaunal halo” at the reef edge (Posey & Ambrose Jr 1994), also referred to as a “browse zone” for organisms sheltering within the reef (Fagan, Cantrell & Cosner 1999), mollusc abundance at Greenpoint may be kept low at the seagrass-reef edge due to predation by reef-dwelling benthic invertebrate feeding taxa. This is, however, beyond the scope of this study as only qualitative observations were made of reef fish taxa as assessing the seagrass habitat was the primary aim. These qualitative measures did, however, illustrate a greater number of non-piscivorous carnivore fish taxa than any other feeding mode functional guild (Appendix X). This may to some degree help to explain a lack of this trend of decreasing mollusc abundance observed towards the reef habitat at the bare sediment edge, towards which the molluscs increased, which would not be hosting similar reef-based predators.

Evidence of "edge" vs "interior" seagrass faunal communities

Community analysis showed a significant difference in fish community composition between the immediate seagrass-reef position and the most interior seagrass position between 45-60m away from the reef (and only in this plane). This was accompanied by a significant community composition difference in the zooplankton and molluscs (Greenpoint) communities at these extremes of distances in this plane. Even though the sensitivities to edge of the above named seagrass fauna varied (described in Section 6.2 below), with the prey communities displaying greater sensitivities to the different edge types compared to the fish, nonetheless this consistency in community variation in immediate seagrass-reef and seagrass interior was present. This is suggestive of two separate communities within the seagrass bed separated by a distance of at least 30m with the seagrass-reef edge community likely composed of individuals able to tolerate and thrive under edge conditions, i.e. more pioneer taxa (Ranney, Bruner & Levenson 1981), while the individuals towards the interior prefer more stable, homogeneous conditions. These more "interior" species may include those requiring more open spaces away from habitat edges to facilitate feeding (Cheminée et al. 2013).

6.2 Sensitivities of faunal groups to different habitat edges

Sensitivity of prey community to edge habitats

While previous chapters described the direction of any observed response of differing fauna to the different habitat edge types, here the "sensitivities" to the habitat edges i.e. the relative strength of the observed response are assessed and compared. The study attempted to label taxonomic groups, at varying levels (total numbers, numbers of individual taxa and community composition) based on statistical analysis of their distribution and general trends exhibited, as being either sensitive to a particular habitat edge type over the other (i.e. rocky reef or bare sediment), to both habitat types differently or similarly, to general edge *per se* (i.e. sensitivity to edge regardless of edge habitat type) or exhibiting no sensitivity to edge. The strength of the significant effect i.e. the calculated p-value along with the consistency of distributional patterns along the plane of each edge type was used as the measure of sensitivity. The following criteria were applied:

1. If an effect was noted with one habitat and was homogeneously distributed or having no meaningful trend with distance from the other, the taxa was labelled as being more sensitive to the former.

2. If the taxa showed an equally strong effect with both habitat types in the same direction along with an incremental distribution with general edge, it was labelled as being sensitive to edge *per se* and not dependent on the habitat type at the edge.

3. If the taxa showed an equally strong or weak effect with both habitat types in the same direction and were evenly distributed with respect to general edge, it was labelled as being sensitive to both habitat types (similarly with regards to direction) and not to edge *per se*.

4. If the taxa exhibited opposing trends of similar strength (strong or weak) with respect to both habitat edges, it was labelled as being sensitive to both habitat edges (differently with regards to direction), regardless of its trend with general edge.

5. If the taxa was seen to have a particularly strong effect with either habitat and a weak or no relationship with the other and displayed an effect with "general edge", this "general edge" effect was determined to be driven by the presence of the habitat with which the taxa had the more pronounced effect.

6. If there was no meaningful trend observed for the taxa with either habitat but one noted for "general edge", the taxa was labelled as being sensitive to edge *per se* and not a particular habitat edge.

7. Lastly, if the taxa showed no meaningful trend with distance from either habitat edge or with "general edge" it was deemed to not display edge sensitivity.

Individual taxa level sensitivity

Total zooplankton numbers displayed a higher sensitivity to the bare sediment (sand) edge habitat at Callala Bay, while the rocky reef at Greenpoint had the greater influence on this group of organisms (Table 6.1). While eight of the fifteen major zooplankton groups displayed a greater effect with distance from the bare sediment at Callala Bay, three with the reef and four with general edge (one displaying no edge effect – bivalve larvae), six groups at Greenpoint were more greatly influenced by the reef, five by bare sediment and four by edge *per se*. Gastropod larvae, ostracods, cirrepedia and calanoid and harpacticoid copepods shared the same edge-habitat sensitivity in the same direction at both sites.

The individual mollusc families at Greenpoint and individual size classes at both sites displayed a more pronounced sensitivity to one edge habitat over the other compared to the individual zooplankton taxa. Seven of the nine major gastropod families showed high sensitivity to the reef edge (Greenpoint), with four of these also displaying sensitivity to the bare sediment in the opposing direction (Greenpoint). Only one family, Trochidae, was more sensitive to the bare sediment compared to the reef. This is likely due to the predominantly larger sizes of this family sampled and its shape having a wider, flatter aperture for greater hold, likely rendering it less affected by the sediment stability gradient away from the seagrass-reef edge (Sorokin 1993) and the varying hydrodynamics (Barros, Underwood & Lindegarth 2001; Pattiaratchi et al. 1995; Sorokin 1993; Van Elven, Lavery & Kendrick 2004) along this plane. This would, however, be more likely to affect the other families with narrow tighter coils and smaller apertures, hence their higher sensitivity to the reef edge.

All individual mollusc size classes at Callala Bay had a greater sensitivity to either bare sediment or general edge with none being more sensitive to the neighbouring reef, while at Greenpoint only the largest size class (>18 mm) had a higher sensitivity to bare sediment with the remaining six being sensitive to reef structure and four of this six exclusively so. The molluscs, mostly gastropods, at Greenpoint greater than 18 mm are again likely being more resilient to the local hydrodynamic changes often occurring at reef-edges. The absence of a more solid, less vertical reef face at Callala Bay and generally calmer waters at this site is likely to have reduced the effect of the reef being a barrier to water movement and the creation of a less pronounced overall reef-effect with regards to water movement at its physical structure at this site compared to Greenpoint. This may render the effect of the reef-edge habitat at Callala Bay being less pronounced for these relatively less mobile organisms (Fagan, Cantrell & Cosner 1999; Ries & Sisk 2004).

The pronounced difference in sensitivity to both edge habitats between sites was also highlighted in the blade morphology metrics and epiphyte load measures with all these variables being more greatly affected by distance from bare sediment at Callala Bay and with distance from reef at Greenpoint.

Community level sensitivity

While the importance of evaluating community data in monitoring ecosystem health cannot be denied, it should be kept in mind that the trends of individual taxa even at the level of family or order may actually differ from that of the community and thus community data should be interpreted and used with caution and based on research needs. For instance, while the zooplankton and mollusc size class community distribution held its greater sensitivity to bare sediment at Callala Bay as many of the individual taxa did for this site, these community distributions at Greenpoint were seen to be more sensitive to general edge as opposed to the reef to which most of the individual taxa and groups at this site were sensitive (Table 6.2).

Additionally, while the mollusc community at Greenpoint did not lose its high sensitivity to reef it was seen to be equally highly sensitive to both edge habitat types with no general edge sensitivity which does not take into account the exclusive sensitivity to reef of a third of the gastropod families at this site.

Sensitivity of fish community to edge habitats

Individual taxa level sensitivity

When the same measures to determine edge-habitat sensitivity was applied to the fish taxonomic and functional groups described in Chapters 2 and 3, while the smaller-bodied cryptic seagrass canopy dwelling *Siphaemia cephalotes* and the weed whitings (*Neoodax balteatus* and *Haletta semifasciata*) displayed a high sensitivity to the reef edge, the more mobile *Girella tricuspidata* displayed a strong general edge effect i.e. to edge *per se* (Table 6.3). The direction of this effect was one of increasing towards the interior of the bed, indicating its preference for continuous seagrass, a feature that may be more common among larger, more mobile fish species. This herbivorous species (Anderson 1991) whose diet consists primarily of seagrass, filamentous green *Entermorpha* spp and *Ulva* spp and red algae *Gracilaria* spp (Gray et al. 2010) may also be more attracted to the seagrass away from the general edge (especially from the seagrass-reef edge at Greenpoint) due to the greater epiphyte load in more distant seagrass positions. The omnivorous Sparidae and Mugilidae had weaker but present sensitivity to both edge-habitats in different directions with each of these two taxa displaying opposing trends in their direction of increase from both edge habitat types. The more general omnivorous nature of the sparids (primarily bream, *Acanthopagrus australis* and tarwhine, *Rhabdosargus sarba*) and mullets likely renders their sensitivity to edge habitat types somewhat weaker (Murphy et al. 2010), with these taxa more likely to shift positions in the seagrass beds to avoid potential competitors in acquiring their resources.

Functional groups/guilds level sensitivity

The omnivorous functional group in fact showed no sensitivity with either habitat type or general edge with either seine net or GoPro samples or from the presence/absence data which combined both sampling methods, sites and seasons. The non-piscivorous carnivores (CNP) and zooplanktivore (ZP) groups, however, displayed a higher sensitivity to the reef for two of the three analysis types i.e. seine net, GoPro and presence/absence analyses, with the third illustrating sensitivity to general edge for both guilds. The reef edge habitat sensitivity was greater for the CNP functional group compared to the ZP likely related to the generally stronger sensitivity to reef for the mollusc community and individual gastropod families and the weaker comparative sensitivity to reef by the zooplankton prey at both sites.

With the primary herbivorous species over both sites and seasons being the more highly occurring *G. tricuspidata* and the less encountered leatherjackets, *Acanthaluteres spilomelanurus* and *Acanthaluteres vittiger* this was not deemed enough to infer the edge habitat type sensitivity of that functional group as it would have been highly driven by a single species.

With regards to estuarine use functional groups, both the collated Estuarine Species and Marine Species groups from GoPro data analysis displayed a greater and strong sensitivity to reef habitat edge and no sensitivity to general edge and additionally in the case of Estuarine species no sensitivity to bare sediment. This was also reflected in the presence/absence analysis combining both fish sampling methods, sites and seasons with the more highly occurring marine species category – Marine Migrants, also showing a greater sensitivity to the reef habitat edge. The direction of sensitivity in GoPro analysis was opposite for both functional groups with the estuarine species primarily smaller bodied schooling species displaying a preference to the seagrass-reef edge, while the generally larger, more mobile marine species displayed greater preference to the bed interior positions.

Fish community level sensitivity

Fish community data (as individual taxa) showed an overall higher sensitivity to reef compared to bare sediment and general edge. The fish community from seine net and presence/absence analysis, capturing both sites and seasons, as well as GoPro analysis in the summer sampling period at Greenpoint only all showed a higher sensitivity to the reef habitat edge, with the GoPro analysis producing the highest strength of reef sensitivity. The fish community as feeding mode functional groups also displayed a greater reef-habitat edge sensitivity for the seine and presence/absence analysis, with the GoPro analysis showing an equal sensitivity to both edge types and no sensitivity to general edge. Lastly, presence/absence analysis of the community of estuarine use functional groups also showed a higher sensitivity to reef habitat.

Comparative sensitivities all sampled seagrass fauna

If the edge habitat sensitivities of each group of marine seagrass organisms sampled at the community level were compared, the fish community showed consistently higher sensitivity to the reef-edge; the mollusc community was highly sensitive to both habitat edge types at

Greenpoint and the reef at Callala Bay (Ollivier et al. 2015) while the zooplankton community was less sensitive to the reef-habitat edge and more sensitive to bare sediment at Callala Bay and at Greenpoint to edge *per se*. A generally higher degree of sensitivity to at least one adjacent habitat of the molluscs at the community and individual taxa level over the zooplankton and fish community was observed. This likely results from the more sessile nature of the molluscs, more likely to be site-attached and to respond more strongly to changes in their local environment. Consequently they are more prone to being influenced by varying local interactions at the edge and hence more edge sensitive over the more mobile fish and zooplankton (Hicks 1986) which tend to be more dynamic in their distributions. This differential sensitivity corresponds with the predictive models of Ries et al. (2004) naming taxa mobility along with body size and vulnerability to predation as likely factors influencing edge sensitivity. It should be noted, however, that the more obvious trends and hence strength of edge effects observed with the molluscs may be a function of the ease with which they can be captured and assessed due to their sessile nature compared to the other two communities whose inherent increased mobility renders their distributional patterns harder to detect (Connolly & Hindell 2006). Although this may be the case to some degree, it is interesting to note the similarity in edge sensitivities between select FMFG guilds and their prey (Ries & Sisk 2004). While zooplanktivores shared the same generally lower degree of sensitivity to habitat edges as its zooplankton prey, the non-piscivorous carnivores (CNP) exhibited a generally higher degree of edge sensitivity as did one of its primary prey items i.e. the molluscs. Hence, it seems more appropriate when comparing the sensitivities of these fauna to not solely provide comparisons of large groups such as “all fish” with that of other interacting communities, but to illustrate comparisons between sub-sections or functional guilds of the fish fauna with that of the community it is known to utilize. In some instances grouping organisms and being too general in focus may lead to conflicting, misleading and even erroneous conclusions and seemingly unanswered questions.

Sensitivities to the different edge habitat types and the organism’s preferred position in relation to it is likely at least partially driven by resource distribution and the immediate physical environment created or facilitated by the presence of particular adjacent habitats along with particular requirements of the taxa (Fagan, Cantrell & Cosner 1999; Ries & Sisk 2004). From the current research with regards to fish edge habitat sensitivity, apart from nutritional requirements, a fish’s life stage may also determine its position from and sensitivity to the edge habitat through changing diet (Grol et al. 2011) for at least one taxa – the Ogilby’s hardyhead, *Atherinomorus vaigiensis* at Callala Bay. While copepods and zooplanktonic bivalves formed a main part of the diet the smallest individuals (≤ 50 mm TL; *juv 1*), there is an apparent switch to a gastropod-dominated diet with significantly less bivalves and practically no copepods in collected individuals between 55 – 75 mm TL (*juv 2*) (Appendix IIA). Interestingly, these two juvenile classes were more abundant at the furthest distance from reef positions (*juv 1*: n=0 individuals at 0-15m; 83 at 15-30m; 518 at 30-45m; 989 at 45-60m and *juv 2*: n=0 at 0-15 and 15-30m; 52 at 30-45m and 31 at 45-60m). The omnivorous adult Ogilby's hardyheads on the other hand, with its diet completely devoid of copepods and bivalves, but rich in gastropods and plant material including algae (Appendix IIA), were exclusively found in this study at the immediate seagrass-reef edge (n=25). These adults were likely foraging for gastropods and macroalgae associated with the reef and possibly attempting to avoid the larger school of the juvenile stages occupying the further distances.

6.3 Interaction between local seagrass characteristics and faunal position from edge

Blade area and length displayed a significant increase towards the seagrass interior. The degree of increase, however, was seen to be adjacent habitat-specific and site-specific, having a more marked increase with distance away from the reef at Greenpoint and away from the bare sediment at Callala Bay. This more marked increase along a particular plane with each site in itself is likely partially a response to the different hydrodynamic conditions at both sites with lower energy conditions in literature associated with greater macrophyte growth and leaf lengths (Bonsdorff & Nelson 1996; Boström & Bonsdorff 1997). The higher energy Greenpoint site is likely to display a greater hydrodynamic gradient along its seagrass-reef plane compared to that along the seagrass-bare sediment plane in comparison to the more sheltered Callala Bay site which would help to explain the edge type-specific blade response with site. Additionally, while there was no consistent corresponding increase in epiphyte load towards the interior along both planes, it is likely that the generally longer blades encountered at the seagrass interior, irrespective of adjacent habitat type, is providing larger surface area for the attachment of algae stripped from the reef by increased hydrodynamic conditions at the seagrass-reef edge for herbivorous and omnivorous fish taxa. The longer epiphyte-laden blades may also provide a greater buffering action to water motion resulting in a more stable environment within the interior seagrass canopy noted to facilitate herbivory (Bustamante & Branch 1996; McQuaid & Branch 1984) compared to the harsher more dynamic conditions noted at habitat edges (Ries & Sisk, 2004). The seagrass interior's more stable environment is also likely to foster a more diverse (Bustamante & Branch 1996; McQuaid & Branch 1984) and stable benthic invertebrate community on which the invertebrate consumers (CNP) can feed explaining their greater preference at interior positions away from the reef edge. Although earlier research has given conflicting accounts of the effect of longer seagrass blades on invertebrate abundances (Bell & Westoby 1986a; Bell & Westoby 1986b), increased seagrass canopy height has been positively correlated to increased seagrass invertebrate densities (Jackson, Atrill & Jones 2006a). As such, longer blades are likely to be providing, both directly and indirectly, a prey rich environment towards the bed interior to which the seagrass fish can map onto explaining the higher fish taxa diversity associated with the seagrass interior in this study.

The general “openness” of interior seagrass positions regardless of adjacent edge type may also be a more preferred, even required, condition for some taxa to facilitate feeding (Cheminée et al. 2013). Additionally the presence of an edge comprised of a physical barrier, such as the seagrass-reef edge, may restrict “open” species’ mobility and foraging activities (Fagan, Cantrell & Cosner 1999) and hence deter them from that position. Likewise a break in the continuous seagrass habitat, whether by a physical barrier or not, may also deter some taxa rendering them sensitive to edge *per se* but not to any particular edge construction, which is likely the case for *Girella tricuspidata* in the current research.

6.4 Further Research

While this study seeks to elucidate the mechanisms helping to structure fish assemblages with respect to different adjacent edge habitats by (1) investigating the distribution of potential prey and (2) investigating habitat shifts in predator stress situations it likely does not represent a complete explanation of the fish distributional trends observed. Due to the multitude of interactions taking place at the ecosystem level, there undoubtedly will be several levels of interaction, direct and indirect, between different aspects of the community at varying spatial scales not captured in this study that will influence an organism’s response to habitat edges. These factors may be additionally interacting with small-scale local environmental conditions including hydrodynamics to impact the structure of both the fish and their prey communities. Water depth, for instance, is one such factor. Water depth was not expected to influence prey community distribution or that of the fish with distance from the habitat edges with a 0.44m – 1.46m depth range for all positions incorporating both sites. Two other studies investigating effects of depth on fish distribution, for instance, grouped all sites less than 1.5m (Smith, Jenkins & Hutchinson 2012 – edge study) and between 1 – 2m (Gray, Rotherham & Johnson

2011 – habitat structure study) as “shallow”. The latter study also considered sites of mean depth < 2m as “shallow”. There may, however, be a minimal effect of water depth on blade metrics (Bonsdorff & Nelson 1996; Boström & Bonsdorff 1997), which may have implications for epiphyte distribution and by extension all users of the epiphyte community. The above named publications noted greater blade length (Boström & Bonsdorff 1997) and apical tip growth (Bonsdorff & Nelson 1996) in a number of macrophytes including seagrasses with increased depth some over a depth difference of 2m (Boström & Bonsdorff 1997) attributing this trend to reduced wave exposure (Boström & Bonsdorff 1997) and surface light irradiance (Boström & Bonsdorff 1997; Dennison & Alberte 1985) with depth. Assessment of the depth profile at sampling locations across both sites presented in Appendix XI showed a more significant trend of depth increase with distance from shoreward bare sediment than from reef for both sites and showed no consistent relationship between depth, blade metrics and epiphyte load. Significant positive relationships between water depth and blade metrics and with epiphyte load measures were found at Callala Bay only (Appendix XI). The “water depth-blade metrics-epiphyte load-grazers relationship” with particular seagrass edge types is however worthy of investigation and should be incorporated into experimental designs of further studies having larger depth ranges. Additionally teasing out any potential influence of water depth and edge orientation (Ries et al. 2004; Tanner 2003) on habitat-type specific edge effects should be a feature of further studies.

Also worthy of further study is the comparison of edge effects on fauna associated with these two edge types i.e. the seagrass-reef and seagrass-bare sediment edge, when only one is present, with environments comprised of both edge types as done in this study. It is likely that the presence of one habitat edge type may alter, intensify or diminish the effect of the other (Fletcher 2005; Ries et al. 2004) when both are present. Indeed, Fletcher (2005) noted an intensification of the edge effect on bird population when a dual edge model was applied to a terrestrial ecosystem. Such studies would provide additional understanding of the influence of multiple edged habitats in structuring marine faunal assemblages within a focal one and the interaction of these influences when several adjacent habitats are present.

Systematic increase in replication across seagrass sites, estuaries, including varying positions from estuary mouths, geographical locations, seasons, tidal ranges and different seagrass species where both single and multiple edge construction types are present in carefully designed monitoring schemes will increase the breadth of knowledge in this field. This increase in replication will also increase statistical power, likely increasing the degree to which an edge effect may be detected (Ries & Sisk 2004).

Understanding the edge sensitivities and responses to habitat edges of different construction of different fish life stages and/or size classes is yet another area that requires exploration. With each life stage and/or size classes having unique requirements, nutritional and otherwise, and differing vulnerabilities to predation, they are likely to display varying responses and sensitivity to habitat edges translating to differing distributions in the ecosystem.

6.5 Conclusion

Following the above synthesis of the potential prey and fish edge responses and deduced sensitivity to edge, null hypotheses 2 and 3 set at the beginning of this chapter can be validly rejected. Hypothesis 1, however, cannot be rejected based on the findings of this study as the zooplanktivore edge response did not follow the edge response of their zooplankton prey. As discussed in the discourse above this is likely due to two factors – 1. the fact that the small schooling nature of these fish being low on the food chain are likely attaining a position relative to the adjacent habitats in particularly the reef that is a compromise between food availability (further from reef) and ideal shelter from predation (at the reef-seagrass interface) and 2. the differential response of varying zooplankton groups to the habitat edges despite the overall increase away from the edges, may influence the response of zooplanktivores differently depending on their precise diet. As it concerns comparative faunal edge sensitivities, the apriori prediction of fish functional groups sharing the edge sensitivities of their prey was realized. As illustrated in this study different species are differentially distributed with respect to the seagrass edge. Differing degrees of effect or sensitivities is taxa-specific, feeding functional mode and estuarine use mode-specific, edge construction type-specific as well as site-specific according to the local scale environmental interactions occurring within. While Greenpoint and Callala Bay differed in marine protected status, with the protected Greenpoint site generally having greater fish occurrences, the site-specific differences in edge sensitivities for the sampled seagrass fauna appear more a function of the different local hydrodynamic conditions at each site and not its protected status. Fish taxa may also be differentially distributed with regards to habitat combination, extrapolated to habitat edge construction, depending on the level of predation risk being experienced. The generally harsher conditions associated with edges, particularly the seagrass-reef edge noted in literature, likely account for the consistently significantly different community compositions of three different seagrass faunal groups (zooplankton, benthic molluscs and fish) at the immediate seagrass-reef edge compared to the seagrass interior 45-60m away from the reef.

This difference points to a more “edge hardy” community within 15m of the reef compared to those suited to the interior seagrass conditions 45-60m away. Although there was some sensitivity to the bare sediment edge for select fauna there seemed to be an overall stronger, more consistent influence of the effect of the reef on seagrass faunal assemblage likely due to the imposing physical structure it provides at the boundary with the seagrass. This undoubtedly creates a unique microclimatic situation at the seagrass-reef edge not present at the seagrass-bare sediment edge due to the lack of a physical boundary in the latter instance. A concept diagram summarizing possible unique mechanisms occurring at the seagrass-reef edge is displayed in Fig 6.1.

Fish taxa were also seen in most cases to share the distributional pattern and edge sensitivity of their prey. The differential distributional trends observed with edge and the differing edge sensitivities with respect to the two different adjacent habitat types again demonstrates the importance of edge construction itself. Edge construction refers to the type of adjacent habitat forming the edge with the focal one and needs to be considered in ecological surveys to inform management and planning initiatives. Assessing edge sensitivities as outlined in this synthesis also provides a useful, innovative tool in deciphering differential edge effects that may be applied in other multiple edge studies across differing faunal communities and sampling techniques.

This research represents the first of its kind in the marine ecosystem to demonstrate the importance of edge structure in structuring a cross section of seagrass faunal communities. One other study done on conjunction with this thesis and placed in my Appendices (Appendix XII: Ollivier et al. 2015) is the only other noted to achieve this for the benthic invertebrate community. These studies point to the importance of the identity of the adjacent habitat, and not just the fact that there is an edge, in structuring faunal communities within a focal habitat. This effect was seen to transcend throughout the entire seagrass community sampled. The importance of the adjacent habitat has been demonstrated in terrestrial studies with one author making the bold assertion that structure of the adjacent habitat is a greater determining factor of faunal distribution than the structure of the habitat in which the fauna resides (Berg 2002). Marine ecologists should, therefore, follow suit and incorporate the role of adjacent habitat identity edge study design and data interpretation. Additionally, specifically measuring the unique microclimatic conditions such as water flow, at different edge types should be incorporated in marine edge studies.

6.6 Statistical Notes

6.6.1 Treatment of interaction terms

Due to the sheer number of possible interaction terms (upward of ten terms) for each measured variable, the p-values associated for these terms were not presented unless otherwise stated. This was done to avoid over-complication of the research outcome and to keep the focus on the main effects throughout this research which involves numerous dependent variables and factors. The p-value of interaction terms were, however, considered in both determining the factors to be retained in each model and the applied statistical approach in Chapters 2 to 4 which contained multiple factors. For instance, if there were a high significance of the effect “site” accompanied by highly significant p-values for all interaction terms containing “site”, statistical analysis was not only applied across both sites but at each site separately to address the significant interaction.

Where significant interaction terms were not sufficiently addressed by an additional statistical approach and they were deemed to greatly impact the interpretation of results, they are highlighted and discussed throughout the text (see Section 3.3.5.1). Non-significant interaction terms were also highlighted in Section 3.3.5.3 with the sole aim to demonstrate the value of applying the “presence/absence” matrix. This matrix was shown to standardize the dataset across sampling methods, sites and seasons before testing for the main effects (“distance from reef”, “distance from bare sediment” and “distance from general edge”). This was illustrated by the non-significant effects obtained for “method”, “site” and “season” along with interaction terms including these factors, unless otherwise stated, as noted in Section 3.3.5.3.

6.6.2 Use of the Bray-Curtis Similarity Matrix

Similarity matrices are widely used in published literature to compare the compositional and differential abundance variations between faunal assemblages across space and time. A particularly common similarity matrix used in ecology is the Bray Curtis similarity matrix (Clarke & Warwick 1994) after Bray and Curtis (1957) which allows for the comparison of multiple assemblages. This matrix is calculated by assessing the average of pairwise comparisons of a particular assemblage from a calculated centroid (Jost, Chao & Chazdon 2011; Clarke & Warwick 1994). The prevalence of this matrix in published ecological research in multivariate analysis of assemblage data along with its relatively sound biological application even among its critics (Clarke, Somerfield & Chapman 2006; Jost, Chao & Chazdon, 2011) were grounds for its application in this research.

While Clarke, Somerfield & Chapman (2006) suggest an adjustment to the Bray Curtis coefficient to improve its practical application, Jost, Chao & Chazdon (2011) offer the use of other similarity matrices the authors deem more appropriate. Jost, Chao & Chazdon (2011) discuss three key components a similarity matrix must possess to adequately reflect compositional similarity. These include what the authors deem the core concept of similarity in the form of "monotonicity", along with "density invariance" and "replication invariance". While the Bray Curtis similarity matrix was by these authors noted to meet the "monotonicity" and "replication invariance" components it did not meet that of "density invariance". The latter was decided as this matrix is not solely sensitive to relative abundances but is also sensitive to raw species abundances within the assemblage. The authors, however, did assert that lacking this property was not void of allowing other valid interpretations (Jost, Chao & Chazdon 2011). The Horn and Morisita-Horn indices were suggested as alternatives to abundance based compositional comparison studies having been noted to meet all three criteria of similarity matrices (Jost, Chao & Chazdon 2011). Additionally, at least one source has reported the limitation of similarity matrices that are computed from pairwise comparisons such as the Bray Curtis matrix (Chao et al. 2008). The authors suggest that use of pairwise comparisons does not completely represent multiple community similarity as the similarity shared between three communities is ignored.

Although these arguments are noted, the Bray Curtis similarity matrix is still widely applied in ecological studies. Even though it may possess some limitations it was deemed necessary to use statistical methods accepted within this field of study which are still deemed applicable, even though not perfect, among its critics.

6.6.3 Treatment of "site" as a random factor

The factor "site" applied in the field component of this thesis (Chapters 2 – 4) was treated as a random factor. While there are only two sites, although some comparison on site-specific local conditions is made in the discussions within, the effect of "site" was not intended to be the main focus of this study. The differential influence of distance from each structurally unique adjacent habitat edge and "general edge" on all communities and seagrass characteristics is the main focus of this study. While other factors such as "season" are treated as fixed, due to the inherent characteristics of each season expected to influence measured parameters differently, the interpretation of results is intended to be focused on the influence of distance from edge, regardless of the site of collection. That being said, where the factor "site" was seen to display a significant p-value for the measured variables, as well as displaying significant effect within interaction terms, data analysis was done for each community and variable at each site separately as in Chapters 3 and 4. This also allowed for the results to be displayed in tables and graphs considering both sites and at each site separately.

Table 6.1 Comparative strength of effect of and inferred overall sensitivity to presence of reef, bare sediment or general edge position for key variables measured within *Posidonia australis* seagrass beds during the summer sampling period at Callala Bay and Greenpoint, Jervis Bay. *Sensitivities coded as RF – greater sensitivity to reef edge; BS – greater sensitivity to bare sediment; RF, BS (d) – equal sensitivity to both edge habitats in different directions; ED – sensitivity to general edge; 0 – no sensitivity. Sign indicates direction of increase of variable (+ increasing away from; - decreasing away from edge; x – no trend). Single sign indicates present but weaker, primarily non-significant trends; double signs indicate significant (p<0.05) and consistent distributional trend in that direction; "Sens." – sensitivity.*

	Callala Bay				**Greenpoint**			
	Strength of effect			**Sens.**	**Strength of effect**			**Sens.**
Zooplankton Distribution	**Reef**	**BS**	**Edge**		**Reef**	**BS**	**Edge**	
All zooplankton Individuals	+	++	++	BS	+	×	+	RF
Dominant taxa:								
Bivalve larvae	×	×	×	0	×	+	+	BS
Gastropod larvae	+	++	++	BS	+	++	++	BS
Ostracoda	-	--	--	BS	-	--	--	BS
Crustacean nauplii	+	++	+	BS	++	+	++	RF
Calanoida	++	++	++	ED	+	+	++	ED
Cyclopoida	+	++	+	BS	++	-	×	RF
Harpacticoida	-	×	-	RF	+	--	-	BS
Unidentified Eggs	-	-	-	ED	--	-	-	RF
Other taxa:								
Hydrozoa	×	++	++	BS	×	+	+	BS
Eucarida	-	×	×	RF	×	×	+	ED
Pericarida	+	++	+	BS	+	×	+	RF
Poecilostomatoida	×	-	-	BS	--	--	--	ED
Cirrepedia	--	×	-	RF	-	×	-	RF
Cladocera	++	++	++	ED	--	+	×	RF
Polychaete larvae	+	+	+	ED	++	++	++	ED
Mollusc Distribution								
Total Molluscs					++	--	×	RF,BS (d)
Potamididae					++	--	×	RF,BS (d)
Columbellidae					++	×	++	RF
Litiopidae					++	--	×	RF,BS (d)
Cerithiopsidae					++	×	+	RF
Littorinidae					++	++	+	ED
Trochidae					-	++	×	BS
Buccinidae					+	-	×	RF,BS (d)
Pyramidellidae					+	×	×	RF

Table 6.1 cont'd Comparative strength of effect of and inferred overall sensitivity to presence of reef, bare sediment or general edge position for key variables measured within *Posidonia australis* seagrass beds during the summer sampling period at Callala Bay and Greenpoint, Jervis Bay. *Sensitivities coded as RF – greater sensitivity to reef edge; BS – greater sensitivity to bare sediment; RF, BS (d) – equal sensitivity to both edge habitats in different directions; ED – sensitivity to general edge; 0 – no sensitivity. Sign indicates direction of increase of variable (+ increasing away from; - decreasing away from edge; x – no trend). Single sign indicates present but weaker, primarily non-significant trends; double signs indicate significant (p<0.05) and consistent distributional trend in that direction; "Sens." – sensitivity.*

Mollusc Size Classes (cm)	**Callala Bay**				**Greenpoint**			
	Strength of effect			**Sens.**	**Strength of effect**			**Sens.**
	Reef	**BS**	**Edge**		**Reef**	**BS**	**Edge**	
0-3	×	--	×	BS	+	×	×	RF
3-6	×	--	×	BS	++	--	+	RF,BS (d)
6-9	×	×	-	ED	++	--	++	RF,BS (d)
9-12	×	--	--	BS	++	×	++	RF
12-15	×	×	-	ED	++	×	++	RF
15-18	×	×	-	ED	++	×	++	RF
>18	×	+	×	BS	×	++	+	BS
Blade Morphology								
Blade length	×	++	++	BS	++	+	++	RF
Blade width	×	++	++	BS	++	+	++	RF
Blade area	+	++	++	BS	++	+	+	RF
Epiphyte Load								
Epiphyte / Seagrass (g/g)	+	++	++	BS	++	-	×	RF
Epiphyte Load Index	+	++	++	BS	++	-	+	RF

Table 6.2 Comparative strength of effect of and inferred overall sensitivity to presence of reef, bare sediment or general edge position for community distributions of the seagrass fauna and fish functional groups sampled within *Posidonia australis* seagrass beds over the indicated seasons, sites and methods of collection. *Sensitivities coded as RF – greater sensitivity to reef edge; BS – greater sensitivity to bare sediment; ED – sensitivity to general edge; 0 – no sensitivity. Single asterisks represent significance at the p<0.05 level and double, the p<0.01 level; "Seas." – season, "SM" – summer sampling session only.*

Community Distribution			**Strength of Effect**			
	Site	**Seas.**	**Reef**	**BS**	**Edge**	**Sens.**
Zooplankton Community	CB	SM	×	**	**	BS
Zooplankton Community	GP	SM	*	*	*	ED
Mollusc Community	GP	SM	**	**	×	RF,BS
Mollusc Size Class Composition	CB	SM	×	**	**	BS
Mollusc Size Class Composition	GP	SM	**	**	**	ED
Fish Distribution:						
Community (individual Taxa): seine	both	both	*	×	×	RF
Community (individual Taxa): GoPro	GP	SM	**	*	×	RF
Community (individual Taxa): P/A	both	both	*	×	×	RF
Community (FMFG): seine	both	both	**	×	**	RF
Community (FMFG): GoPro	GP	SM	*	*	×	RF,BS
Community (FMFG): P/A	both	both	*	×	**	RF
Community (EUFG): P/A	both	both	*	×	**	RF

Table 6.3 Comparative strength of effect of and inferred overall sensitivity to presence of reef, bare sediment or general edge position for fish taxonomic and functional groups sampled within *Posidonia australis* seagrass beds over the indicated seasons, sites and methods of collection. *Sensitivities coded as RF – greater sensitivity to reef edge; BS – greater sensitivity to bare sediment; RF, BS (d) – equal sensitivity to both edge habitats in different directions; ED – sensitivity to general edge; 0 – no sensitivity. Sign indicates direction of increase of variable (+ increasing away from; - decreasing away from edge; × - no trend). Single sign indicates present but weaker, primarily non-significant trends. Double signs indicate significant (p<0.05) consistent distributional trend in that direction. For GoPro data single signs indicate significance with one measure (either AvrMaxN or %TiV) while double signs indicate significance for both. For P/A data the ^ represents the strength of significance (^ – p<0.05; ^^ – p <0.01); "Meth" – fish sampling method.*

Fish Taxa and Functional Group Distribution				**Strength of effect**			
	Meth	**Site**	**Seas**	**Reef**	**BS**	**Edge**	**Sens.**
Total Abundance[1]	seine	both	both	+	×	+[2]	RF
Species Richness	both	both	both	++	+	++	RF
Individual Fish Taxa							
Siphaemia cephalotes	seine	both	both	++	+	+	RF
Weed whitings: *Neoodax balteatus* and *Haletta semifasciata*	seine	GP	both	+	×	+	RF
Girella tricuspidata	GoPro	GP	both	++	++	++	ED
Sparidae	GoPro	GP	both	-	+	×	RF,BS (d)
Mugilidae	GoPro	GP	both	+	-	-	RF,BS (d)
Feeding Mode Functional Groups (FMFG)							
Non-Piscivorous Carnivores (CNP)[1]	seine	both	both	++	×	++	RF
Non-Piscivorous Carnivores (CNP)[1]	GoPro	GP	SM	++	×	++	RF
Non-Piscivorous Carnivores (CNP)	P/A	both	both	×	×	^^	ED
Zooplanktivores (ZP)[1]	seine	both	both	×	×	-	ED
Zooplanktivores (ZP)	GoPro	both	SM	--	+	-	RF
Zooplanktivores (ZP)	P/A	both	both	^	×	×	RF
Omnivores (OV)	seine	both	both	×	×	×	0
Omnivores (OV)	GoPro	GP	SM	×	×	×	0
Omnivores (OV)	P/A	both	both	×	×	×	0
Estuarine Use Functional Groups (EUFG)							
All Estuarine Species (ES)	GoPro	both	SM	--[3]	×	×	RF
All Marine Species (M)	GoPro	both	SM	++	+	×	RF
Marine Migrants (MM)	P/A	both	both	^	×	×	RF

[1]disregarding gregarious schooling taxa; [2]observed trend at CB only; [3]significant only at GP although trend similar at CB

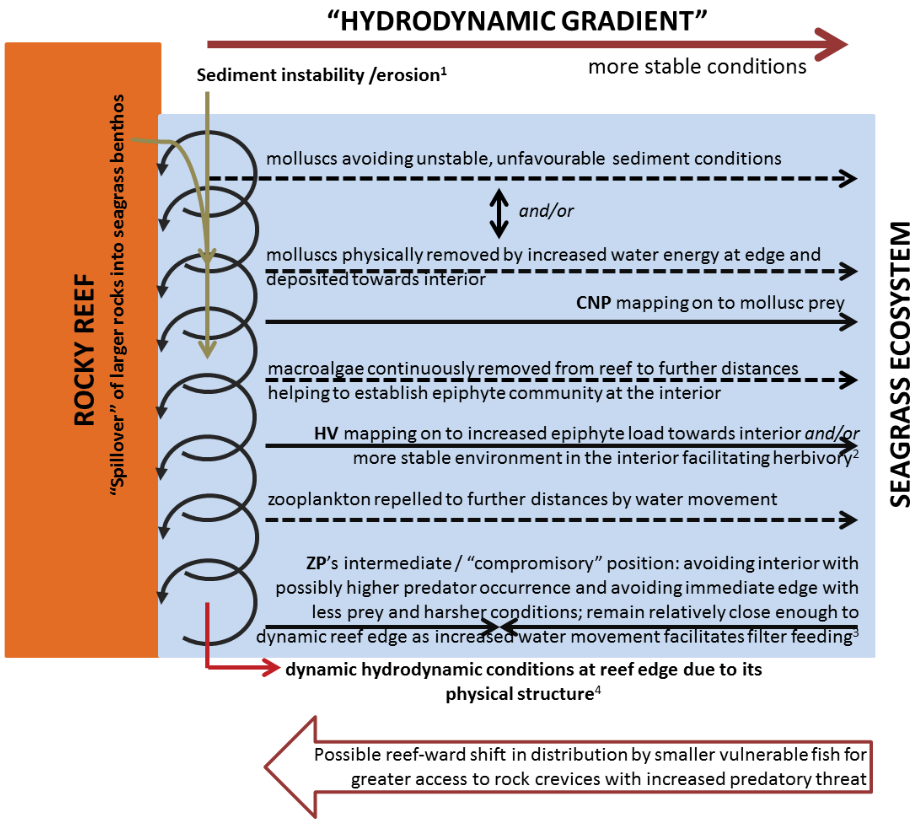


Fig 6.1 Concept diagram illustrating possible mechanisms driving the unique reef-edge effect within the seagrass ecosystem. *Broken lines denote prey trends, solid lines fish FM FG trends;* [1](Sorokin 1993); [2](Bustamante & Branch 1996; McQuaid & Branch 1984); [3](Bustamante & Branch 1996); [4](Barros, Underwood & Lindegarth 2001; Sorokin 1993; Van Elven, Lavery & Kendrick 2004).

References

Agresti, A. & Kateri, M. 2011, *Categorical data analysis*, Springer.

Anderson, M.J., Gorley, R.N. & Clarke, K.R. 2008, 'PERMANOVA+ for PRIMER: Guide to Software and Statistical Methods.', PRIMER-E, Plymouth.

Anderson, T. 1991, 'Mechanisms of digestion in the marine herbivore, the luderick, Girella tricuspidata (Quoy and Gaimard)', *Journal of fish biology*, vol. 39, no. 4, pp. 535-47.

Anderson, T.J., Syms, C., Roberts, D.A. & Howard, D.F. 2009, 'Multi-scale fish–habitat associations and the use of habitat surrogates to predict the organisation and abundance of deep-water fish assemblages', *Journal of Experimental Marine Biology and Ecology*, vol. 379, no. 1–2, pp. 34-42.

Banks, S.A. & Skilleter, G.A. 2007, 'The importance of incorporating fine-scale habitat data into the design of an intertidal marine reserve system', *Biological Conservation*, vol. 138, no. 1–2, pp. 13-29.

Barros, F., Underwood, A.J. & Lindegarth, M. 2001, 'The Influence of Rocky Reefs on Structure of Benthic Macrofauna in Nearby Soft-sediments', *Estuarine, Coastal and Shelf Science*, vol. 52, no. 2, pp. 191-9.

Bartholomew, A., Diaz, R.J. & Cicchetti, G. 2000, 'New dimensionless indices of structural habitat complexity: predicted and actual effects on a predator’s foraging success', *Marine Ecology Progress Series*, vol. 206, pp. 45-58.

Beck, M.W. 2000, 'Separating the elements of habitat structure: independent effects of habitat complexity and structural components on rocky intertidal gastropods', *Journal of Experimental Marine Biology and Ecology*, vol. 249, no. 1, pp. 29-49.

Becker, A., Cowley, P.D. & Whitfield, A.K. 2010, 'Use of remote underwater video to record littoral habitat use by fish within a temporarily closed South African estuary', *Journal of Experimental Marine Biology and Ecology*, vol. 391, no. 1–2, pp. 161-8.

Bell, J.D. & Westoby, M. 1986b, 'Variation in seagrass height and density over a wide spatial scale: Effects on common fish and decapods', *Journal of Experimental Marine Biology and Ecology*, vol. 104, no. 1–3, pp. 275-95.

Bell, J.D., Steffe, A.S. & Westoby, M. 1988, 'Location of seagrass beds in estuaries: effects on associated fish and decapods', *Journal of Experimental Marine Biology and Ecology*, vol. 122, no. 2, pp. 127-46.

Bell, J.D. & Westoby, M. 1986a, 'Importance of local changes in leaf height and density to fish and decapods associated with seagrasses', *Journal of Experimental Marine Biology and Ecology*, vol. 104, no. 1–3, pp. 249-74.

Berg, Å. 2002, 'Breeding birds in short-rotation coppices on farmland in central Sweden—the importance of Salix height and adjacent habitats', *Agriculture, Ecosystems & Environment*, vol. 90, no. 3, pp. 265-76.

Bertness, M.D., Leonard, G.H., Levine, J.M. & Bruno, J.F. 1999, 'Climate-driven interactions among rocky intertidal organisms caught between a rock and a hot place', *Oecologia*, vol. 120, no. 3, pp. 446-50.

Black, A.R. & Dodson, S.I. 2003, 'Ethanol: a better preservation technique for Daphnia', *Limnology and Oceanography-Methods*, vol. 1, p. 45.

Bologna, P.A. & Heck, K.L. 2000, 'Impacts of seagrass habitat architecture on bivalve settlement', *Estuaries*, vol. 23, no. 4, pp. 449-57.

Bonsdorff, E. & Nelson, W. 1996, 'Apical growth-measurements of Fucus vesiculosus L.: Limited value in monitoring', *Botanica marina*, vol. 39, no. 1-6, pp. 129-32.

Boström, C. & Bonsdorff, E. 1997, 'Community structure and spatial variation of benthic invertebrates associated with Zostera marina (L.) beds in the northern Baltic Sea', *Journal of Sea Research*, vol. 37, no. 1, pp. 153-66.

Boström, C. & Bonsdorff, E. 2000, 'Zoobenthic community establishment and habitat complexity-the importance of seagrass shoot-density, morphology and physical disturbance for faunal recruitment', *Marine Ecology Progress Series*, vol. 205, pp. 123-38.

Bray, D.J. 2011, *Blue Weed-whiting, Haletta semifasciata, in Fishes of Australia*, viewed 3 May 2016, <http://www.fishesofaustralia.net.au/home/species/298>.

Bray, J.R. & Curtis, J.T. 1957, 'An ordination of the upland forest communities of southern Wisconsin', *Ecological Monographs*, vol. 27, no. 4, pp. 325-49.

Bryant, E.A., Young, R.W., Price, D.M., Wheeler, D.J. & Pease, M.I. 1997, 'The impact of tsunami on the coastline of Jervis Bay, southeastern Australia', *Physical Geography*, vol. 18, no. 5, pp. 440-59.

Burel, F. & Baudry, J. 2003, *Landscape ecology: concepts, methods, and applications*, Science Publishers.

Bustamante, R. & Branch, G. 1996, 'Large scale patterns and trophic structure of southern African rocky shores: the roles of geographic variation and wave exposure', *Journal of Biogeography*, vol. 23, no. 3, pp. 339-51.

Chao, A., Jost, L., Chiang, S., Jiang, Y.H. & Chazdon, R.L. 2008, 'A Two-Stage Probabilistic Approach to Multiple-Community Similarity Indices', *Biometrics*, vol. 64, no. 4, pp. 1178-86.

Castel, J., Labourg, P.-J., Escaravage, V., Auby, I. & Garcia, M.E. 1989, 'Influence of seagrass beds and oyster parks on the abundance and biomass patterns of meio-and macrobenthos in tidal flats', *Estuarine, coastal and shelf science*, vol. 28, no. 1, pp. 71-85.

Chapman, K.A. & Reich, P.B. 2007, 'Land use and habitat gradients determine bird community diversity and abundance in suburban, rural and reserve landscapes of Minnesota, USA', *Biological Conservation*, vol. 135, no. 4, pp. 527-41.

Cheminée, A. 2012, 'Ecological functions, transformations and management of infralittoral rocky habitats from the Northwestern Mediterranean: the case of fish (Teleostei) nursery habitats', Université Nice Sophia Antipolis.

Cheminée, A., Sala, E., Pastor, J., Bodilis, P., Thiriet, P., Mangialajo, L., Cottalorda, J.-M. & Francour, P. 2013, 'Nursery value of Cystoseira forests for Mediterranean rocky reef fishes', *Journal of experimental marine biology and ecology*, vol. 442, pp. 70-9.

Chivers, D.P., Mirza, R.S., Bryer, P.J. & Kiesecker, J.M. 2001, 'Threat-sensitive predator avoidance by slimy sculpins: understanding the importance of visual versus chemical information', *Canadian Journal of Zoology*, vol. 79, no. 5, pp. 867-73.

Cho, G. 1998, 'Conservation and management in Jervis Bay, Australia', *Aquatic Conservation: Marine and Freshwater Ecosystems*, vol. 8, no. 5, pp. 701-17.

Clarke, KR (1993). 'Non-parametric multivariate analyses of changes in community structure', *Australian Journal of Ecology* 18: 117-143

Clarke, K. & Gorley, R. 2006, 'User manual/tutorial', *Primer-E Ltd., Plymouth*, p. 93.

Clarke, K.R., Somerfield, P.J. & Chapman, M.G. 2006, 'On resemblance measures for ecological studies, including taxonomic dissimilarities and a zero-adjusted Bray–Curtis coefficient for denuded assemblages', *Journal of Experimental Marine Biology and Ecology*, vol. 330, no. 1, pp. 55-80.

Clarke, K. & Warwick, R. 1994, 'An approach to statistical analysis and interpretation', *Change in Marine Communities*, vol. 2.

Cocheret de la Morinière, E., Nagelkerken, I., van der Meij, H. & van der Velde, G. 2004, 'What attracts juvenile coral reef fish to mangroves: habitat complexity or shade?', *Marine Biology*, vol. 144, no. 1, pp. 139-45.

Collinge, S.K. 1996, 'Ecological consequences of habitat fragmentation: implications for landscape architecture and planning', *Landscape and Urban Planning*, vol. 36, no. 1, pp. 59-77.

Connell, J.H. 1985, 'Variation and persistence of rocky shore populations ', in P.G. Moore & R. Seed (eds), *The Ecology of Rocky Coasts*, Hodder and Stoughton, London, pp. 57-69.

Connolly, R. 1994, 'A comparison of fish assemblages from seagrass and unvegetated areas of a southern Australian estuary', *Marine and Freshwater Research*, vol. 45, no. 6, pp. 1033-44.

Connolly, R.M. & Hindell, J.S. 2006, 'Review of nekton patterns and ecological processes in seagrass landscapes', *Estuarine, Coastal and Shelf Science*, vol. 68, no. 3, pp. 433-44.

Cranfield, H.J., Rowden, A.A., Smith, D.J., Gordon, D.P. & Michael, K.P. 2004, 'Macrofaunal assemblages of benthic habitat of different complexity and the proposition of a model of biogenic reef habitat regeneration in Foveaux Strait, New Zealand', *Journal of Sea Research*, vol. 52, no. 2, pp. 109-25.

Creel, S., Winnie, J., Maxwell, B., Hamlin, K. & Creel, M. 2005, 'Elk alter habitat selection as an antipredator response to wolves', *Ecology*, vol. 86, no. 12, pp. 3387-97.

Cuadros, A. 2015, 'Settlement and post-settlement processes of Mediterranean littoral fishes: influence of seascape attributes and environmental conditions at different spatial scales', Universitat de les Illes Balears.

Dennison, W.C. & Alberte, W.C. 1985, 'Role of daily light period in the depth distribution of Zostera marina (eelgrass)', *Mar. Ecol. Prog. Ser.*, vol. 25, pp. 51-61.

Dugatkin, L.A. & Alfieri, M. 1991, 'Guppies and the TIT FOR TAT strategy: preference based on past interaction', *Behavioral Ecology and Sociobiology*, vol. 28, no. 4, pp. 243-6.

Eckman, J. 1983, 'Hydrodynamic processes affecting benthic recruitment', *Limnol. Oceanogr*, vol. 28, no. 2, pp. 241-57.

Eckman, J.E. 1987, 'The role of hydrodynamics in recruitment, growth, and survival of Argopecten irradians (L.) and Anomia simplex (D'Orbigny) within eelgrass meadows', *Journal of Experimental Marine Biology and Ecology*, vol. 106, no. 2, pp. 165-91.

Elliott, M. & Dewailly, F. 1995, 'The structure and components of European estuarine fish assemblages', *Netherland Journal of Aquatic Ecology*, vol. 29, no. 3-4, pp. 397-417.

Elliott, M., Whitfield, A.K., Potter, I.C., Blaber, S.J.M., Cyrus, D.P., Nordlie, F.G. & Harrison, T.D. 2007, 'The guild approach to categorizing estuarine fish assemblages: a global review', *Fish and Fisheries*, vol. 8, no. 3, pp. 241-68.

Fagan, W.F., Cantrell, R.S. & Cosner, C. 1999, 'How habitat edges change species interactions', *The American Naturalist*, vol. 153, no. 2, pp. 165-82.

Ferrell, D., McNeill, S., Worthington, D. & Bell, J. 1993, 'Temporal and spatial variation in the abundance of fish associated with the seagrass *Posidonia australis* in South-eastern Australia', *Marine and Freshwater Research*, vol. 44, no. 6, pp. 881-99.

Ferrell, D.J. & Bell, J.D. 1991, 'Differences among assemblages of fish associated with *Zostera capricorni* and bare sand over a large spatial scale', *Marine Ecology Progress Series*, vol. 72, pp. 15 - 24.

Fishelson, L., Gon, O., Goren, M., Ben-Davis-Zaslow, R. 2005, 'The oral cavity and bioluminescent organs of the cardinal fish species *Siphamia permutata* and *S. cephalotes* (Perciformes, Apogonidae)', *Marine Biology,* vol. 147, pp. 603-9.

Fletcher, R.J. 2005, ' Multiple edge effects and their implications in fragmented landscapes', *Journal of Animal Ecology*, vol. 74, no. 2, pp. 342-52.

Fonseca, M.S. & Fisher, J.S. 1986, 'A comparison of canopy friction and sediment movement between four species of seagrass with reference to their ecology and restoration', *Marine Ecology Progress Series*, vol. 29, no. 1.

Fonseca, M.S., Zieman, J.C., Thayer, G.W. & Fisher, J.S. 1983, 'The role of current velocity in structuring eelgrass (Zostera marina L.) meadows', *Estuarine, Coastal and Shelf Science*, vol. 17, no. 4, pp. 367-80.

Franco, A., Elliott, M., Franzoi, P. & Torricelli, P. 2008, 'Life strategies of fishes in European estuaries: the functional guild approach', *Marine Ecology Progress Series*, vol. 354, pp. 219-28.

Franco, A., Franzoi, P., Malavasi, S., Riccato, F. & Torricelli, P. 2006, 'Fish Assemblages in Different Shallow Water Habitats of the Venice Lagoon', *Hydrobiologia*, vol. 555, no. 1, pp. 159-74.

Franco, A., Pérez-Ruzafa, A., Drouineau, H., Franzoi, P., Koutrakis, E.T., Lepage, M., Verdiell-Cubedo, D., Bouchoucha, M., López-Capel, A., Riccato, F., Sapounidis, A., Marcos, C., Oliva-Paterna, F.J., Torralva-Forero, M. & Torricelli, P. 2011, 'Assessment of fish assemblages in coastal lagoon habitats: Effect of sampling method', *Estuarine, Coastal and Shelf Science*, pp. 1-10.

Gomon, M.F., Glover, J.C. & Kuiter, R.H. 1994, 'Fishes of Australia's south coast'.

Google Earth 2014, viewed 2014.

Gotceitas, V. & Brown, J.A. 1993, 'Substrate selection by juvenile Atlantic cod (Gadus morhua): effects of predation risk', *Oecologia*, vol. 93, no. 1, pp. 31-7.

Grabowski, J.H., Hughes, A.R., Kimbro, D.L. & Dolan, M.A. 2005, 'How habitat setting influences restored oyster reef communities', *Ecology*, vol. 86, no. 7, pp. 1926-35.

Gray, C., McElligott, D. & Chick, R. 1996, 'Intra- and inter-estuary differences in assemblages of fishes associated with shallow seagrass and bare sand', *Marine and Freshwater Research*, vol. 47, no. 5, pp. 723-35.

Gray, C.A., Ives, M.C., Macbeth, W.G. & Kendall, B.W. 2010, 'Variation in growth, mortality, length and age compositions of harvested populations of the herbivorous fish Girella tricuspidata', *Journal of Fish Biology*, vol. 76, no. 4, pp. 880-99.

Gray, C.A., Rotherham, D. & Johnson, D.D. 2011, 'Consistency of temporal and habitat-related differences among assemblages of fish in coastal lagoons', *Estuarine, Coastal and Shelf Science*, vol. 95, no. 4, pp. 401-14.

Grol, M.G.G., Nagelkerken, I., Rypel, A.L. & Layman, C.A. 2011, 'Simple ecological trade-offs give rise to emergent cross-ecosystem distributions of a coral reef fish', *Oecologia*, vol. 165, no. 1, pp. 79-88.

Guidetti, P. 2000, 'Differences Among Fish Assemblages Associated with Nearshore Posidonia oceanica Seagrass Beds, Rocky–algal Reefs and Unvegetated Sand Habitats in the Adriatic Sea', *Estuarine, Coastal and Shelf Science*, vol. 50, no. 4, pp. 515-29.

Gullström, M., Berkström, C., Öhman, M., Bodin, M. & Dahlberg, M. 2011, 'Scale-dependent patterns of variability of a grazing parrotfish *Leptoscarus vaigiensis* in a tropical seagrass-dominated seascape', *Marine Biology*, vol. 158, no. 7, pp. 1483-95.

Hackradt, C.W., Félix-Hackradt, F.C. & García-Charton, J.A. 2011, 'Influence of habitat structure on fish assemblage of an artificial reef in southern Brazil', *Marine Environmental Research*, vol. 72, no. 5, pp. 235-47.

Hammill, E., Atwood, T.B. & Srivastava, D.S. 2015, 'Predation threat alters composition and functioning of bromeliad ecosystems', *Ecosystems*, vol. 18, no. 5, pp. 857-66.

Harvey, E.S., Cappo, M., Kendrick, G.A. & McLean, D.L. 2013, 'Coastal fish assemblages reflect geological and oceanographic gradients within an Australian zootone', *PLoS ONE*, vol. 8, no. 11, p. e80955.

Helfman, G. 1989, 'Threat-sensitive predator avoidance in damselfish-trumpetfish interactions', *Behavioral Ecology and Sociobiology*, vol. 24, no. 1, pp. 47-58.

Helmuth, B., Mieszkowska, N., Moore, P. & Hawkins, S.J. 2006, 'Living on the edge of two changing worlds: forecasting the responses of rocky intertidal ecosystems to climate change', *Annual Review of Ecology, Evolution, and Systematics*, pp. 373-404.

Hicks, G.R. 1986, 'Distribution and behaviour of meiofaunal copepods inside and outside seagrass beds', *Mar. Ecol. Prog. Ser*, vol. 31, pp. 159-70.

Hossain, M.A., Tanaka, M. & Masuda, R. 2002, 'Predator–prey interaction between hatchery-reared Japanese flounder juvenile, Paralichthysolivaceus, and sandy shore crab, Matutalunaris: daily rhythms, anti-predator conditioning and starvation', *Journal of Experimental Marine Biology and Ecology*, vol. 267, no. 1, pp. 1-14.

Howard, R. & Koehn, J. 1985, 'Population dynamics and feeding ecology of pipefish (Syngnathidae) associated with eelgrass beds of Western Port, Victoria', *Marine and Freshwater Research*, vol. 36, no. 3, pp. 361-70.

Hyslop, E. 1980, 'Stomach contents analysis—a review of methods and their application', *Journal of fish biology*, vol. 17, no. 4, pp. 411-29.

Igulu, M.M., Nagelkerken, I., Fraaije, R., van Hintum, R., Ligtenberg, H. & Mgaya, Y.D. 2011, 'The potential role of visual cues for microhabitat selection during the early life phase of a coral reef fish (Lutjanus fulviflamma)', *Journal of Experimental Marine Biology and Ecology*, vol. 401, no. 1–2, pp. 118-25.

Jackson, E.L., Attrill, M.J., Rowden, A.A. & Jones, M.B. 2006, 'Seagrass complexity hierarchies: Influence on fish groups around the coast of Jersey (English Channel)', *Journal of Experimental Marine Biology and Ecology*, vol. 330, no. 1, pp. 38-54.

Jackson, E.L., Attrill, M.J. & Jones, M.B. 2006a, 'Habitat characteristics and spatial arrangement affecting the diversity of fish and decapod assemblages of seagrass (Zostera marina) beds around the coast of Jersey (English Channel)', *Estuarine, Coastal and Shelf Science*, vol. 68, no. 3, pp. 421-32.

Jelbart, J.E., Ross, P.M. & Connolly, R.M. 2006, 'Edge effects and patch size in seagrass landscapes: an experimental test using fish', *Marine Ecology Progress Series*, vol. 319, p. 93.

Jenkins, G. & Hamer, P. 2001, 'Spatial variation in the use of seagrass and un-vegetated habitats by post-settlement King George whiting (Percoidei: Sillaginidae) in relation to meiofaunal distribution and macrophyte structure', *Marine Ecology Progress Series*, vol. 224, pp. 219-29.

Jenkins, G.P., Keough, M.J. & Hamer, P.A. 1998, 'The contributions of habitat structure and larval supply to broad-scale recruitment variability in a temperate zone, seagrass-associated fish', *Journal of Experimental Marine Biology and Ecology*, vol. 226, no. 2, pp. 259-78.

Jenkins, G.P. & Sutherland, C.R. 1997, 'The influence of habitat structure on nearshore fish assemblages in a southern Australian embayment: colonisation and turnover rate of fishes associated with artificial macrophyte beds of varying physical structure', *Journal of Experimental Marine Biology and Ecology*, vol. 218, no. 1, pp. 103-25.

Jenkins, G.P. & Wheatley, M.J. 1998, 'The influence of habitat structure on nearshore fish assemblages in a southern Australian embayment: Comparison of shallow seagrass, reef-algal and unvegetated sand habitats, with emphasis on their importance to recruitment', *Journal of Experimental Marine Biology and Ecology*, vol. 221, no. 2, pp. 147-72.

Johns, P. & Mann, K. 1987, 'An experimental investigation of juvenile lobster habitat preference and mortality among habitats of varying structural complexity', *Journal of Experimental Marine Biology and Ecology*, vol. 109, no. 3, pp. 275-85.

Johnson, D.L., Beaumier, R.A. & Lynch Jr, W.E. 1988, 'Selection of habitat structure interstice size by bluegills and largemouth bass in ponds', *Transactions of the American Fisheries Society*, vol. 117, no. 2, pp. 171-9.

Jost, L., Chao, A. & Chazdon, R.L. 2011, 'Compositional similarity and β (beta) diversity', *Biological diversity: frontiers in measurement and assessment, A. Magurran y BJ McGill (eds.). Oxford University Press, New York*, pp. 66-87.

Kirkman, H. 1997, 'Seagrasses of Australia', *Australia: State of the Environment Technical Paper Series (Estuaries and the Sea)*, Department of the Environment, Canberra.

Kohn, A.J. & Leviten, P.J. 1976, 'Effect of habitat complexity on population density and species richness in tropical intertidal predatory gastropod assemblages', *Oecologia*, vol. 25, no. 3, pp. 199-210.

Lee, S.Y., Fong, C. & Wu, R. 2001, 'The effects of seagrass (Zostera japonica) canopy structure on associated fauna: a study using artificial seagrass units and sampling of natural beds', *Journal of Experimental Marine Biology and Ecology*, vol. 259, no. 1, pp. 23-50.

Legendre, P., Galzin, R. & Harmelin-Vivien, M.L. 1997, 'Relating Behavior to Habitat: Solutions to the Fourth-corner Problem', *Ecology*, vol. 78, no. 2, pp. 547-62.

Levin, P.S., Tolimieri, N., Nicklin, M. & Sale, P.F. 2000, 'Integrating individual behavior and population ecology: the potential for habitat-dependent population regulation in a reef fish', *Behavioral Ecology*, vol. 11, no. 5, pp. 565-71.

Lima, S.L. & Dill, L.M. 1990, 'Behavioral decisions made under the risk of predation: a review and prospectus', *Canadian Journal of Zoology*, vol. 68, no. 4, pp. 619-40.

Livingston, R. 1987, 'Field sampling in estuaries: The relationship of scale to variability', *Estuaries and Coasts*, vol. 10, no. 3, pp. 194-207.

Ljungberg, P., Hasper, T.B., Nilsson, P.A. & Persson, A. 2013, 'Effects of small-scale habitat fragmentation on predator–prey interactions in a temperate sea grass system', *Marine biology*, vol. 160, no. 3, pp. 667-75.

Macreadie, P., Hindell, J.S., Keough, M.J., Jenkins, G.P. & Connolly, R.M. 2010, 'Resource distribution influences positive edge effects in a seagrass fish', *Ecology*, vol. 91, no. 7, pp. 2013-21.

Macreadie, P.I., Hindell, J.S., Jenkins, G.P., Connolly, R.M. & Keough, M.J. 2009, 'Fish Responses to Experimental Fragmentation of Seagrass Habitat', *Conservation Biology*, vol. 23, no. 3, pp. 644-52.

Madin, E.M., Madin, J.S. & Booth, D.J. 2011, 'Landscape of fear visible from space', *Scientific reports*, vol. 1.

McGlathery, K.J. 1995, 'Nutrient and grazing influences on a subtropical seagrass community', *Marine ecology progress series. Oldendorf*, vol. 122, no. 1, pp. 239-52.

McLachlan, A. & Hesp, P. 1984, 'Faunal response to morphology and water circulation of a sandy beach with cusps', *Marine ecology progress series. Oldendorf*, vol. 19, no. 1, pp. 133-44.

McQuaid, C. & Branch, G. 1984, 'Influence of sea temperature, substratum and wave exposure on rocky intertidal communities: An analysis of faunal and floral biomass', *Marine ecology progress series. Oldendorf*, vol. 19, no. 1, pp. 145-51.

McRoy, C.P. & Helfferich, C. 1980, 'Applied aspects of seagrasses', *Handbook of seagrass biology: an ecosystem perspective*, pp. 297-343.

Menge, B.A. & Sutherland, J.P. 1987, 'Community regulation: variation in disturbance, competition, and predation in relation to environmental stress and recruitment', *American Naturalist*, pp. 730-57.

Middleton, M.J., Bell, J.D., Burchmore, J.J., Pollard, D.A. & Pease, B.C. 1984, 'Structural differences in the fish communities of Zostera capricorni and Posidonia australis seagrass meadows in Botany Bay, New South Wales', *Aquatic Botany*, vol. 18, no. 1–2, pp. 89-109.

Moore, E.C. & Hovel, K.A. 2010, 'Relative influence of habitat complexity and proximity to patch edges on seagrass epifaunal communities', *Oikos*, vol. 119, no. 8, pp. 1299-311.

Murcia, C. 1995, 'Edge effects in fragmented forests: implications for conservation', *Trends in ecology & evolution*, vol. 10, no. 2, pp. 58-62.

Murphy, H.M., Jenkins, G.P., Hindell, J.S. & Connolly, R.M. 2010, 'Response of fauna in seagrass to habitat edges, patch attributes and hydrodynamics', *Austral Ecology*, vol. 35, no. 5, pp. 535-43.

Myers, R. & Virnstein, R. 2000, 'Development and use of an epiphyte photo-index for assessing epiphyte loadings on seagrass Halodule wrightii', Proceedings of the subtropical and tropical seagrass ecology: Responses to environmental stress workshop. CRC Press.

Nagelkerken, I., Bothwell, J., Nemeth, R.S., Pitt, J.M. & van der Velde, G. 2008, 'Interlinkage between Caribbean coral reefs and seagrass beds through feeding migrations by grunts (Haemulidae) depends on habitat accessibility', *Marine Ecology Progress Series*, vol. 368, pp. 155-64.

Nagelkerken, I., Dorenbosch, M., Verberk, W.C.E.P., Morinière, E.C.d.l. & Velde, G.v.d. 2000, 'Importance of shallow-water biotopes of a Caribbean bay for juvenile coral reef fishes: patterns in biotope association, community structure and spatial distribution', *Marine Ecology Progress Series*, vol. 202, pp. 175-92.

Neckles, H.A., Wetzel, R.L. & Orth, R.J. 1993, 'Relative effects of nutrient enrichment and grazing on epiphyte-macrophyte (Zostera marina L.) dynamics', *Oecologia*, vol. 93, no. 2, pp. 285-95.

NSW Department of Primary Industries (Fisheries).

Olds, A.D., Connolly, R.M., Pitt, K.A. & Maxwell, P.S. 2012, 'Habitat connectivity improves reserve performance', *Conservation Letters*, vol. 5, no. 1, pp. 56-63.

Ollivier, Q.R., Bramwell, N.A., Hammill, E., Foster-Thorpe, C. & Booth, D.J. 2015, 'Are the effects of adjacent habitat type on seagrass gastropod communities being masked by previous focus on habitat dyads?', *Australian Journal of Zoology*, vol. 63, no. 5, pp. 357-63.

Orth, R.J. 1977, 'The importance of sediment stability in seagrass communities', *Ecology of marine benthos*, vol. 6, pp. 281-300.

Pattiaratchi, C., Imberger, J., Zaker, N. & Svenson, T. 1995, 'Perth coastal waters study, Project P2: physical measurements', *Cent. Water Res. Rep. WP 958 CP*.

Payne, M., Rippingale, R. & Longmore, R. 1998, 'Growth and survival of juvenile pipefish (Stigmatopora argus) fed live copepods with high and low HUFA content', *Aquaculture*, vol. 167, no. 3, pp. 237-45.

Pechenik, J.A. 1999, 'On the advantages and disadvantages of larval stages in benthic marine invertebrate life cycles', *Marine Ecology Progress Series*, vol. 177, no. 1, pp. 269-97.

Pérez-Matus, A. & Shima, J.S. 2010, 'Disentangling the effects of macroalgae on the abundance of temperate reef fishes', *Journal of Experimental Marine Biology and Ecology*, vol. 388, no. 1–2, pp. 1-10.

Peterson, C.H., Luettich, R.A., Micheli, F. & Skilleter, G.A. 2004, 'Attenuation of water flow inside seagrass canopies of differing structure', *Marine Ecology Progress Series*, vol. 268, no. 8, pp. 81-92.

Pinkas, L. & Iverson, I. 1971, 'Food habits of albacore, bluefin tuna and bonito in Californian waters', *California Department of Fish and Game: Fish Bulletin*, vol. 152, pp. 1-105.

Pollard, D.A. 1984, 'A review of ecological studies on seagrass—fish communities, with particular reference to recent studies in Australia', *Aquatic Botany*, vol. 18, no. 1–2, pp. 3-42.

Posey, M. & Ambrose Jr, W. 1994, 'Effects of proximity to an offshore hard-bottom reef on infaunal abundances', *Marine Biology*, vol. 118, no. 4, pp. 745-53.

Ranney, J., Bruner, M. & Levenson, J.B. 1981, 'Importance of edge in the structure and dynamics of forest islands', *Ecological studies; analysis and synthesis*.

Ries, L., Fletcher Jr, R.J., Battin, J. & Sisk, T.D. 2004, 'Ecological responses to habitat edges: mechanisms, models, and variability explained', *Annual Review of Ecology, Evolution, and Systematics*, pp. 491-522.

Ries, L. & Sisk, T.D. 2004, 'A predictive model of edge effects', *Ecology*, vol. 85, no. 11, pp. 2917-26.

Ripple, W.J. & Beschta, R.L. 2004, 'Wolves and the Ecology of Fear: Can Predation Risk Structure Ecosystems?', *BioScience*, vol. 54, no. 8, pp. 755-66.

Robertson, C. & White, R. 1986, 'Feeding patterns of Nesogobius sp., Gymnapistes marmoratus, Neoodax balteatus and Acanthaluteres spilomelanurus from a Tasmanian seagrass meadow', *Marine and Freshwater Research*, vol. 37, no. 4, pp. 481-9.

Roy, P.S., Williams, R.J., Jones, A.R., Yassini, I., Gibbs, P.J., Coates, B., West, R.J., Scanes, P.R., Hudson, J.P., Nichol, S. 2001. 'Structure and Function of South-east Australian Estuaries', *Estuarine, Coastal and Shelf Science*, vol. 53, no.3, pp. 351-84

Santana-Garcon, J., Newman, S.J. & Harvey, E.S. 2014, 'Development and validation of a mid-water baited stereo-video technique for investigating pelagic fish assemblages', *Journal of Experimental Marine Biology and Ecology*, vol. 452, pp. 82-90.

Scheibling, R. & Hamm, J. 1991, 'Interactions between sea urchins (Strongylocentrotus droebachiensis) and their predators in field and laboratory experiments', *Marine Biology*, vol. 110, no. 1, pp. 105-16.

Schmitz, O.J., Grabowski, J.H., Peckarsky, B.L., Preisser, E.L., Trussell, G.C. & Vonesh, J.R. 2008, 'From individuals to ecosystem function: Toward an integration of evolutionary and ecosystem ecology', *Ecology*, vol. 89, no. 9, pp. 2436-45.

Schmitz, O.J., Krivan, V. & Ovadia, O. 2004, 'REVIEW Trophic cascades: the primacy of trait-mediated indirect interactions', *Ecology Letters*, vol. 7, no. 2, pp. 153-63.

Sheppard, J.N., James, N.C., Whitfield, A.K. & Cowley, P.D. 2011, 'What role do beds of submerged macrophytes play in structuring estuarine fish assemblages? Lessons from a warm-temperate South African estuary', *Estuarine, Coastal and Shelf Science*, vol. 95, no. 1, pp. 145-55.

Sih, A. 1980, 'Optimal behavior: can foragers balance two conflicting demands', *Science*, vol. 210, no. 4473, pp. 1041-3.

Sisk, T.D. & Battin, J. 2002, 'Habitat edges and avian ecology: geographic patterns and insights for western landscapes', *Studies in Avian Biology*, vol. 25, pp. 30-48.

Smith, T.M., Hindell, J.S., Jenkins, G.P. & Connolly, R.M. 2008, 'Edge effects on fish associated with seagrass and sand patches', *Marine Ecology Progress Series*, vol. 359, pp. 203 - 13.

Smith, T.M., Hindell, J.S., Jenkins, G.P., Connolly, R.M. & Keough, M.J. 2011, 'Edge effects in patchy seagrass landscapes: The role of predation in determining fish distribution', *Journal of Experimental Marine Biology and Ecology*, vol. 399, no. 1, pp. 8-16.

Smith, T.M., Jenkins, G.P. & Hutchinson, N. 2012, 'Seagrass edge effects on fish assemblages in deep and shallow habitats', *Estuarine, Coastal and Shelf Science*, vol. 115, pp. 291-9.

Söderström, B. & Pärt, T. 2000, 'Influence of Landscape Scale on Farmland Birds Breeding in Semi-Natural Pastures', *Conservation Biology*, vol. 14, no. 2, pp. 522-33.

Sorokin, Y.I. 1993, *Coral reef ecology*, vol. 102, Springer Science & Business Media.

Statton, J., Gustin-Craig, S., Dixon, K.W. & Kendrick, G.A. 2015, 'Edge Effects along a Seagrass Margin Result in an Increased Grazing Risk on Posidonia australis Transplants', *PLoS One*, vol. 10, no. 10.

Summerson, H. & Peterson, C. 1984, 'Role of predation in organizing benthic communities of a temperate-zone seagrass bed', *Marine ecology. Progress series*, vol. 15, no. 1-2, pp. 63-77.

Tanner, J.E. 2003, 'Patch shape and orientation influences on seagrass epifauna are mediated by dispersal abilities', *Oikos*, vol. 100, no. 3, pp. 517-24.

Thompson, V. & Bray, D. 2011, *Smallmouth Hardyhead, Atherinosoma microstoma, in Fishes of Australia*, viewed 16 Feb 2016 2016, <http://www.fishesofaustralia.net.au/home/species/4633>.

Thorson, G. 1950, 'Reproductive and larval ecology of marine bottom invertebrates', *Biological reviews*, vol. 25, no. 1, pp. 1-45.

Thorson, G. 1966, 'Some factors influencing the recruitment and establishment of marine benthic communities', *Netherlands Journal of Sea Research*, vol. 3, no. 2, pp. 267-93.

Turner, S., Hewitt, J., Wilkinson, M., Morrisey, D., Thrush, S., Cummings, V. & Funnell, G. 1999, 'Seagrass patches and landscapes: the influence of wind-wave dynamics and hierarchical arrangements of spatial structure on macrofaunal seagrass communities', *Estuaries*, vol. 22, no. 4, pp. 1016-32.

Tuya, F., Vanderklift, G.A.H., Hyndes, G.A., Wernberg, T., Thomsen, M.S. & Hanson, C. 2010, 'Proximity to rocky reefs alters the balance between positive and negative effects on seagrass fauna', *Marine Ecology Progress Series*, vol. 405, pp. 175 - 86.

Underwood, A. 1981, 'Techniques of analysis of variance in experimental marine biology and ecology', *Oceanography and marine biology: an annual review*.

Valentine, J.F. & Duffy, J.E. 2007, 'The central role of grazing in seagrass ecology', *Seagrasses: Biology, Ecology and Conservation*, Springer, pp. 463-501.

Valentine J.F., Heck K.L. Jr, Blackmon D., Goecker M.E., Christian J., Kroutil, R.M., Kirsch, K.D., Peterson, B.J., Beck, M & Vanderklift, M.A. 2007, 'Food web interactions along seagrass–coral reef boundaries: effects of piscivore reductions on cross habitat energy exchange.' *Marine Ecology Progress Series*, vol. 333, pp. 37–50

Valesini, F.J., Potter, I.C. & Clarke, K.R. 2004, 'To what extent are the fish compositions at nearshore sites along a heterogeneous coast related to habitat type?', *Estuarine, Coastal and Shelf Science*, vol. 60, no. 4, pp. 737-54.

Van Elven, B., Lavery, P. & Kendrick, G. 2004, 'Reefs as contributors to diversity of epiphytic macroalgae assemblages in seagrass meadows', *Marine Ecology Progress Series*, vol. 276, pp. 71-83.

van Houte-Howes, K., Turner, S. & Pilditch, C. 2004, 'Spatial differences in macroinvertebrate communities in intertidal seagrass habitats and unvegetated sediment in three New Zealand estuaries', *Estuaries*, vol. 27, no. 6, pp. 945-57.

van Montfrans, J., Wetzel, R.L. & Orth, R.J. 1984, 'Epiphyte-grazer relationships in seagrass meadows: consequences for seagrass growth and production', *Estuaries*, vol. 7, no. 4, pp. 289-309.

Vanderklift, G.A.H., How, J., Wernberg, T., MacAurthur, L.D., Heck Jr, K.L. & Valentine, J.F. 2007, 'Proximity to reef influences density of small predatory fishes, while type of seagrass influences intensity of their predation on crabs', *Marine Ecology Progress Series*, vol. 340, pp. 235-43.

Wahle, R.A. 1992, 'Body-size dependent anti-predator mechanisms of the American lobster', *Oikos*, pp. 52-60.

Warry, F.Y., Hindell, J.S., Macreadie, P.I., Jenkins, G.P. & Connolly, R.M. 2009, 'Integrating edge effects into studies of habitat fragmentation: a test using meiofauna in seagrass', *Oecologia*, vol. 159, no. 4, pp. 883-92.

Wernberg, T., Vanderklift, M.A., How, J. & Lavery, P.S. 2006, 'Export of detached macroalgae from reefs to adjacent seagrass beds', *Oecologia*, vol. 147, no. 4, pp. 692-701.

Werner, E.E. & Hall, D.J. 1988, 'Ontogenetic habitat shifts in Bluegill: The foraging rate-predation risk trade-off', *Ecology*, vol. 69, no. 5, pp. 1352-66.

Whitlow, W.L. & Grabowski, J.H. 2012, 'Examining how landscapes influence benthic community assemblages in seagrass and mudflat habitats in southern Maine', *Journal of Experimental Marine Biology and Ecology*, vol. 411, no. 0, pp. 1-6.

Zacharia, P., Abdurahiman, K. & Mohamed, K. 2004, 'Methods of stomach content analysis of fishes', *Winter School on Towards Ecosystem Based Management of Marine Fisheries—Building Mass Balance Trophic and Simulation Models*, pp. 148-58.

Appendix I Pilot Study: Fish species richness and abundances in *Posidonia australis* seagrass beds at the sand-edge (0-15m) vs more interior positions (30-50m from sand-edge)

Method:

The fish community within *Posidonia australis* seagrass beds within three estuaries along the New South Wales Coast (Port Stephens - 32°41’22.81”S 152°04’01.24”E, Lake Macquarie - 33°05’34.11”S 151°35’21.47”E and Gunnamatta Bay - 34°3'56.31"S 151° 8'40.88"E in Port Hacking) was assessed at two positions from adjacent sand patches. Fish was collected within the seagrass bed using a seine net from the immediate seagrass edge i.e. within 15m of the edge and towards the interior of the bed approximately 30-50m from any sand patch. The breadth of each position was largely driven by the dimensions of the seine net, being 18.7m in length, 1.6m high, with a 2.3m length of cod end and 5mm unstretched mesh size. Individuals caught were identified to species and measured. Two replicate positions were sampled in each bed i.e. two “0-15m” positions and two “30-50m” positions all within a single extensive seagrass bed within each estuary. Fish assessment was performed in November-December 2012 corresponding with austral summer for Port Stephens and Lake Macquarie and for Gunnamatta Bay, Port Hacking on two occasions, August 2012 (austral winter) and November-December 2012. Comparison of fish populations with edge was also performed at Vincentia - 35° 4'6.62"S 150°40'41.64"E in Jervis Bay and Batemans Bay - *35°42’30.17”S 150°10’39.41”E,* but these comparing fish assemblages in *P. australis* at the immediate rocky reef edge and seagrass interior. These results are not here presented due to the low fish occurrences encountered. Individual fish taxa were grouped in Feeding Mode Functional Guilds (FMFG) as outlined in Chapter 1 of this dissertation.

Univariate PERMANOVA, in the PRIMER 6 version 6.1.13 and PERMANOVA+ version 1.0.3 statistical package, was performed to assess any significant variation in total abundance, species richness, taxa specific and FMFG specific abundances and total fish body lengths with seagrass position. A similarity matrix was created with data in each case using Euclidean distances in the statistical package. With the exception of species richness, all other data was log-transformed to achieve homogeneity of variances. Data was analysed including all sites (estuaries) sampled in the summer only, with the fixed factors included in the model being “seagrass position” having two levels and “site” having three levels. Data was reanalysed for each site separately with the fixed factor “seagrass position” applied in the case of Port Stephens and Lake Macquarie, and for Gunnamatta Bay “seagrass position” (fixed) and “season” (fixed) having two levels in an orthogonal design. Pairwise comparison between seagrass positions of each tested variable was also performed in the above-mentioned PRIMER 6 and PERMANOVA+ statistical package.

A compilation of figures summarizing some of the more noteworthy results of the pilot study along with a list of all species encountered is presented below.

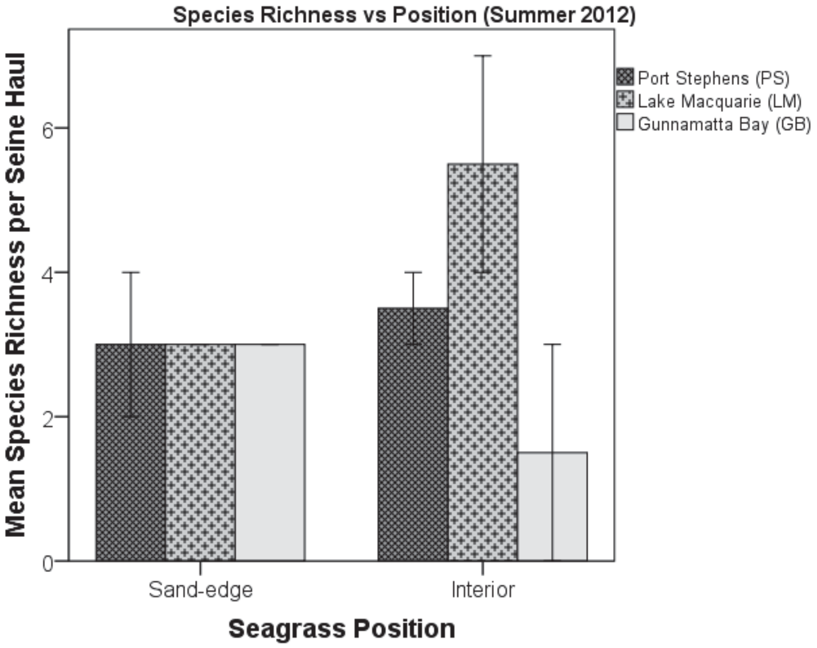
List of Species:

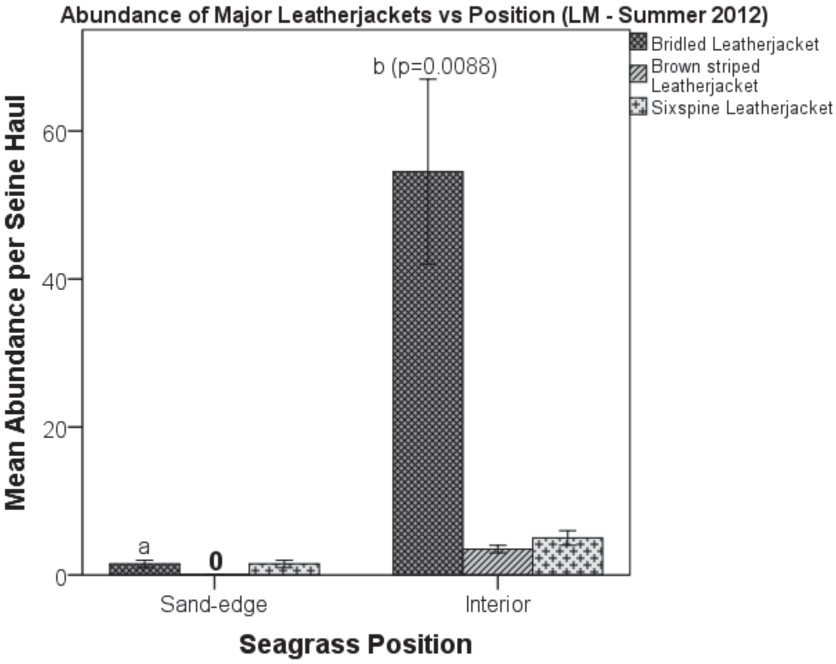
Table A. List of species within sampled seagrass beds; *GB – Gunnamatta Bay, LM – Lake Macquarie and PS – Port Stephens*

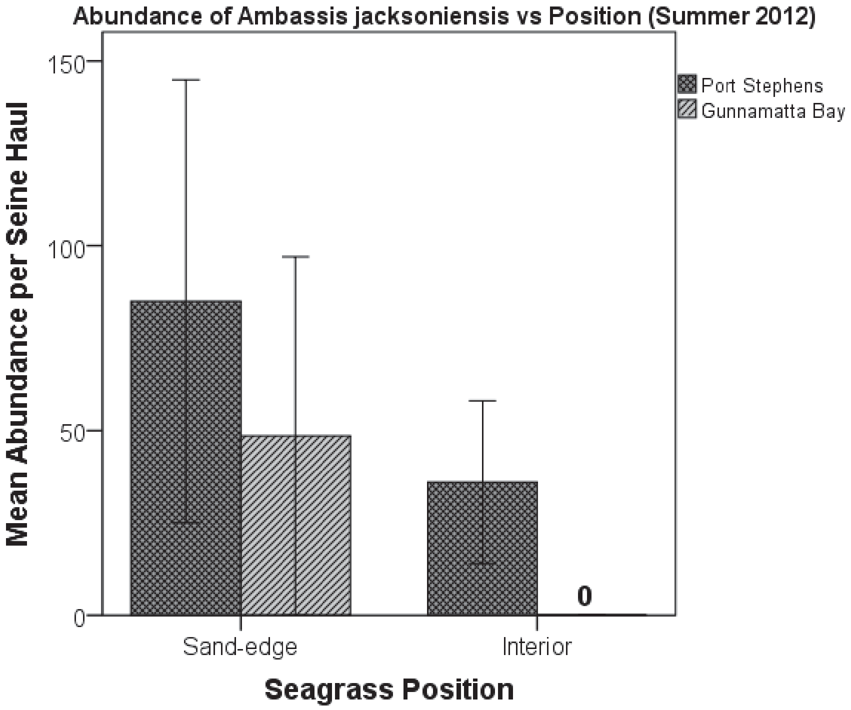
Species name	Common name	Winter	Summer
Acanthaluteres spilomelanurus	bridled leatherjacket	GB	LM
Ambassis jacksoniensis	Port Jackson glassfish		GB,PS
Arenigobius frenatus	half bridled goby		GB
Atherinosoma microstomata	small-mouthed hardyhead	GB	PS
Atypichthys strigatus	Australian mado		PS
Bathygobius krefftii	Krefft's frillgoby		PS
Brachaluteres jacksonianus	pygmy leatherjacket	GB	
Diodon nicthemerus	globefish	GB	
Engraulis australis	Australian anchovy		GB
Enoplosus armatus	old wife		GB
Hyperlophus vittatus	sandy sprat		LM
Hyporhamphus regularis	river garfish		PS
Meuschenia australis	brown striped leatherjacket		LM
Meuschenia freycineti	sixspine leatherjacket		GB,LM,PS
Microcanthus strigatus	stripey		LM
Monocanthus chinensis	fanbelly leatherjacket	GB	
Notolabrus fucicola	purple wrasse		LM
Pelates sexlineatus	Eastern striped trumpeter		LM, PS
Rhabdosargus sarba	tarwhine		LM
Scorpis lineolata	silver sweep		PS
Spratelloides robustus	blue sprat	GB	
Stigmatopora argus	spotted pipefish	GB	LM
Synchiropus ocellatus	marbled dragonet		GB
Tetractenos glaber	smooth toadfish		LM
Tetractenos hamiltoni	common toadfish	GB	GB
Upeneicthys lineatus	blue striped goatfish		PS

Summary of Results (In Figures):

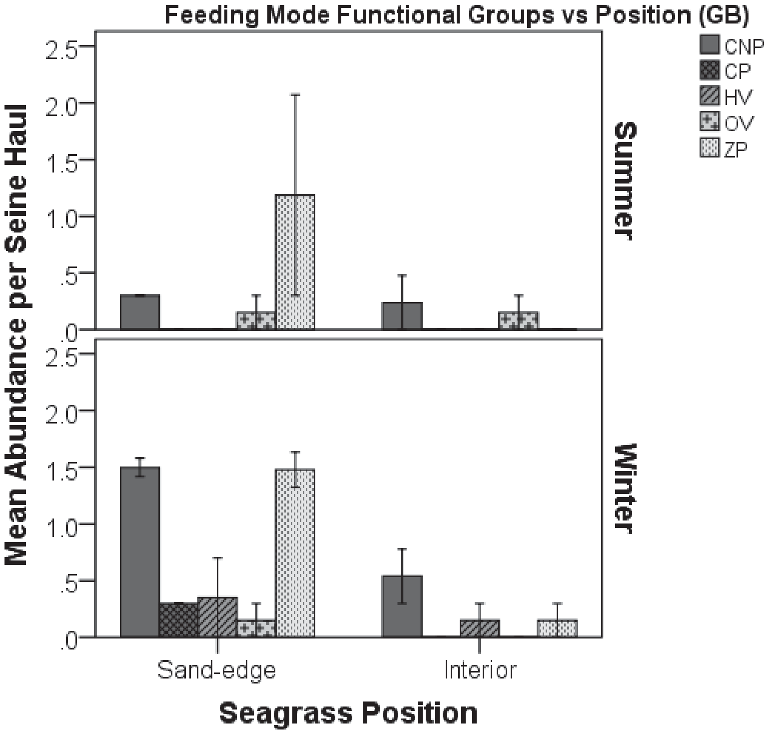
Letters above bars represent the results of pairwise comparisons; bars lacking similar letters represent a significant difference; the bar lettering of each subsequent bar category begin with the letter following alphabetically the highest lettering of the bar category immediately before. P-values in brackets are the results of the respective pairwise comparison on log-transformed data (with the exception of species richness).

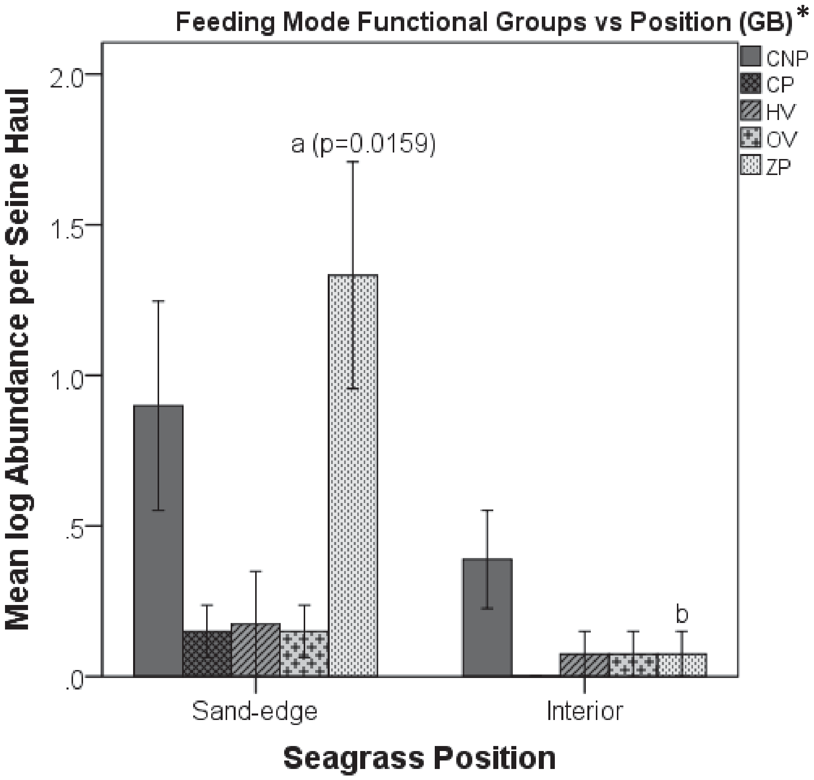




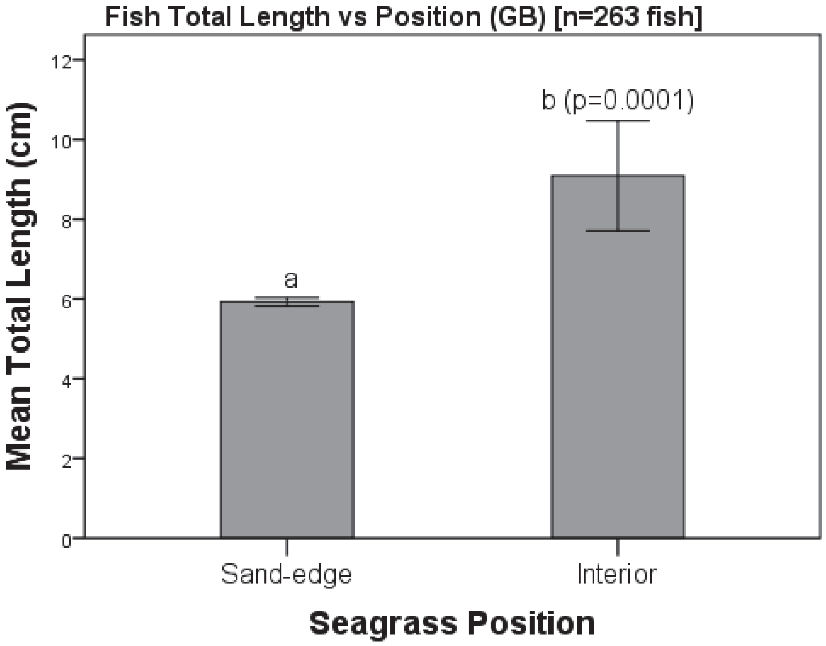

Abundance of Ambassis jacksoniensis vs Position (Summer 2012)
Mean Abundance per Seine Haul
150
100
50
0
0
Sand-edge
Interior
Seagrass Position
Port Stephens
Gunnamatta Bay

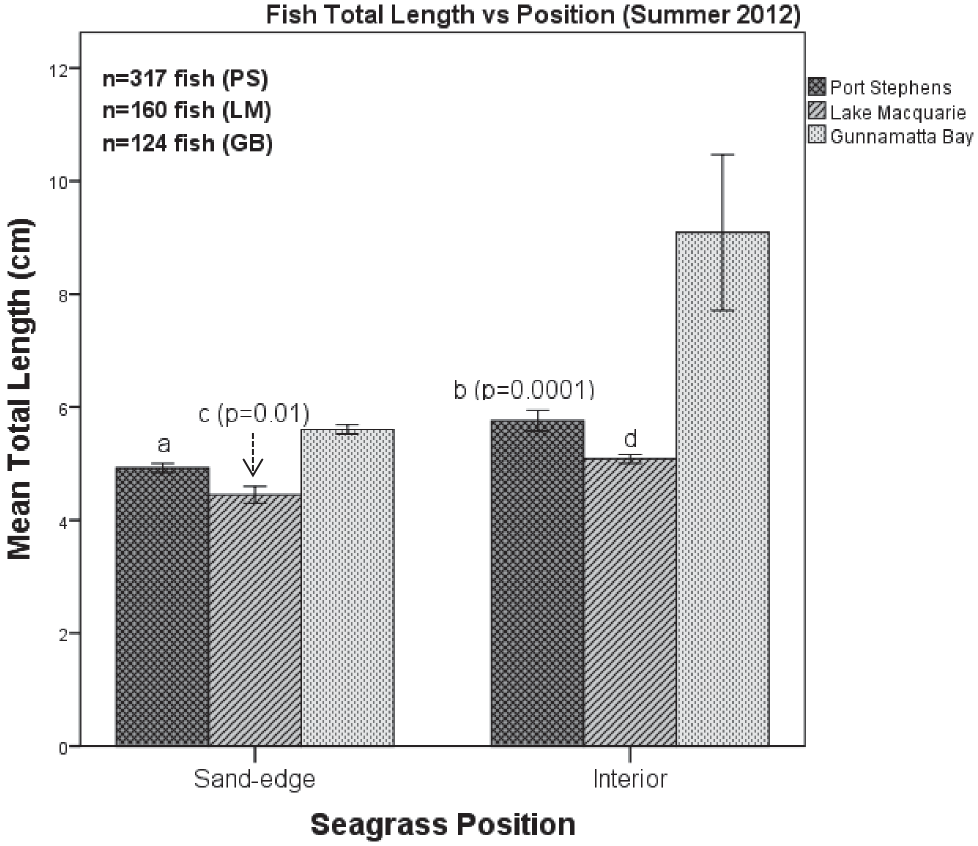

Abundance of Atherinosoma microstomata (GB) vs Position
Mean Abundance per Seine Haul
40
30
20
10
0
0
0
sand-edge
interior
Seagrass Position
Summer
Winter





* incorporating both seasons


Fish Total Length vs Position (GB) [n=263 fish]
Mean Total Length (cm)
0
2
4
6
8
10
12
a
b (p=0.0001)
Sand-edge
Interior
Seagrass Position


Fish Total Length vs Position (Summer 2012)
n=317 fish (PS)
n=160 fish (LM)
n=124 fish (GB)
Port Stephens
Lake Macquarie
Gunnamatta Bay
Mean Total Length (cm)
0
2
4
6
8
10
12
a
c (p=0.01)
b (p=0.0001)
d
Sand-edge
Interior
Seagrass Position

Appendix II(A) Gut Content Analysis (Description of Results)

Rationale

Gut content analyses of target taxa were primarily undertaken to determine if prey utilization within the sampled seagrass beds of the current study varied with distance from either adjacent habitat or general edge. This knowledge may give an indication of the relative importance of certain prey items at different seagrass positions and be useful in explaining to some degree the fish taxa's distribution relative to the habitat edges. Additionally, gut content analysis was used to support Feeding Mode Functional Group (FMFG) classification for the two taxa involved – Ogilby's hardyhead (*Atherinomorus vaigiensis*) and the weed whitings (*Neoodax balteatus* and *Haletta semifasciata*). One of the two taxa, *A. vaigiensis*, as will be discussed in this Appendix while not represented in all seagrass positions with distance from the adjacent habitats were present in three distinct life stages. This presented me with the opportunity to examine possible diet changes with life stage for this taxon, which may in turn impact the seagrass position chosen at least in the context of this site. Fish were collected from within the same sampling units (quadrants) at the same sites i.e. Callala Bay and Greenpoint, both on the Jervis Bay northern shores (see site description in Chapter 1) of the current study. Reference is made to results of the gut content analysis throughout discussion chapters of this thesis.

Method

Fish were collected using a seine net (18.7m long, 2.3m high, 5mm mesh and attached 1.6m long cod end) within *Posidonia australis* beds within two locations in Jervis Bay namely, Callala Bay (34°59'53.47"S 150°43'37.89"E) and Greenpoint (35°00'34.37"S 150°46'04.24"E). Fish were collected from Callala Bay on February 21, 2015 in 0.4 – 1m depth while the fish from Greenpoint were collected from 0.85 – 1.5m depth on January 29 and January 30, 2015. Fish collection was done in conjunction with the summer fish seine net surveys (Chapter 2) with those individuals kept for stomach analysis a subset of those tallied in the surveys. As such all sampling conditions described in the Methods section of Chapter 2 apply. Individuals of two target taxa, one chosen based on its high abundance, and therefore assumed importance to the ecosystem, and the other based on its uniform distribution among the sixteen 15m × 15m quadrants, was collected, one taxon from each site. The fish were put on ice at the capture site and taken to the laboratory where they were stored in a minus 20°C freezer until processed.

Prior to processing, fish were individually measured, weighed and placed in separate plastic bags, noting the transect number (representing distance from bare sediment) and distance from reef from which it was taken. Fish were removed from the freezer individually and allowed to thaw before each dissection.

Atherinomorus vaigiensis

Fish from Callala Bay were solely the abundant Ogilby's hardyheads, *Atherinomorus vaigiensis*, which included 11 adults and 66 juveniles based on size of the individual specimen in relation to its maximum attainable size as in Gullström et al. (2011). These 66 juveniles were for the purposes of the study further divided into two groups, namely juvenile *class 1* (29-50.7mm TL; 41 individuals) and juvenile *class 2* (55.9-72.79mm TL; 25 individuals) based on their body sizes and the distinctly different diet found between the two size classes. The adults were all between 132-157mm TL.

The entire gut was removed by teasing away flesh at the ventral surface of the body and locating the anterior and posterior-most part of the alimentary canal which was then cut out and extended within a petridsh all under the dissecting microscope. The stomach was separated from the intestines for each fish and considered separately. The dimensions of the stomach and intestines were measured using an ocular micrometre and a visual index of fullness (Hyslop 1980) ranging from 0 (empty) – 10 (full) was assigned to each stomach and intestine. The stomach and intestines were separately cut open with dissecting scissors and the contents removed into the petri dish by gently scraping the walls of the alimentary canal. As the nature of the prey material shifted with hardyhead fish life stage, the prey quantification method differed slightly by life stage to ensure the most appropriate method for each prey type. At the same time there was at least one common measure to allow comparability.

Juveniles – Class 1 and 2

The stomach and intestine content of each fish was spread out on a petri dish to which was attached a 1mm× 1mm grid to allow for the counting of prey items by moving the tray in an S-shape under the dissecting microscope to avoid recounting of items. Each individual prey item was identified to class and counted for % contribution by number (%N) (Hyslop 1980; Zacharia, Abdurahiman & Mohamed 2004). The dimensions (length and width) of a representative subset of each prey item were measured using an ocular micrometre and an average obtained for each item for each fish in most instances. The average was comprised of dimensions representing the varying prey sizes in the sample observed. This average was multiplied by the number of individuals of each prey type to acquire the prey item volume for each fish. The breadth for these primarily zooplankton prey in these fish life stages was considered consistent and negligible and hence this area calculated i.e. length × width, was used to represent volume. This measure was used to calculate % contribution by volume (%V) for each prey item for each replicate fish (Hyslop 1980; Zacharia, Abdurahiman & Mohamed 2004)**.**

Adults

The entire gut was removed as described above and the stomach/foregut cut away from the intestines/hindgut. Both sections were cut open with a dissecting scissors under the dissecting microscope and the contents removed onto a petri dish fitted with the 1mm × 1mm counting grid by gently scraping the walls of the gut. Due to the level of mastication of the food items and the type of food material found, individual prey items could not be counted. Similar food items were grouped together in the petri dish under the dissecting microscope and each group was spread evenly to equal thickness ensuring consistent breadth. The area occupied by each prey group was measured using the ocular micrometre and taken as the volume (Hyslop 1980). This volume was used to calculate % contribution by volume (%V) for each prey item.

Percent frequency of occurrence (%O) (Hyslop 1980; Zacharia, Abdurahiman & Mohamed 2004) and index of relative importance (IRI) (Pinkas & Iverson 1971) were calculated for each prey item for all fish samples. A full description and equations for all measures used in gut content analysis is found in Appendix IIB.

Fish with ruptured alimentary canals were discarded.

Weed whitings – *Neoodax balteatus* and *Haletta semifasciata*

Fish collected from Greenpoint were weed whitings. These were chosen due to their generally good spread within the seagrass bed in most quadrants albeit more numerous towards the seagrass interior away from the rocky reef edge. Two species of weed whitings were collected namely, the little weed whiting, *Neoodax balteatus* (n = 46) and the blue weed whiting, *Haletta semifasciata* (n = 10). Both species possess a similar niche, especially regarding nutrition within the seagrass bed, based both on published literature (Bray 2011; Robertson & White 1986) and the results of this study, and hence were regarded together as a single group.

The entire gut was removed from the fish by making a longitudinal cut through the ventral region of the body and locating the anterior and posterior-most part of the gut. Cuts were made at both ends to remove the gut which was then stretched out onto the petri dish. The distinction between fore and hind gut for the weed whitings was less clear but the hind gut was consistently taken as the section just after the more bulbous anterior section. The gut of each fish was cut into the anterior region (foregut) and the posterior region (hindgut) and the dimensions (length and width) and weight of each taken. A visual index of fullness (between 0 and 10) was also assigned to each section of the gut for each fish as described above.

The foregut and hindgut were separately cut open with dissecting scissors under the microscope and the contents removed by gently scraping the walls of the gut onto a petri dish. The contents were separated into different prey groups each of which were spread evenly on the petri dish to even thickness ensuring consistent breadth. The dimensions of each group (length and width) were measured using an ocular micrometre to obtain the area of each group which was taken as the volume from which % contribution by volume (%V) was calculated (see Appendix IIB). The weight of each prey group for each fish was also measured to 4 d.p. with a Sartorius CP224S Analytical Balance from which was calculated the % contribution by weight (%W) for each prey group (see Appendix IIB).

Percent frequency of occurrence (%O) (Hyslop 1980; Zacharia, Abdurahiman & Mohamed 2004) and index of relative importance (IRI) (Pinkas & Iverson 1971) were calculated for each prey group for all fish samples as with the Ogilby’s hardyhead. All weed whitings individuals were between 46 – 102mm TL and were subdivided into four size classes to test if any difference in prey content may be attributed body size. The size classes were as follows: 45-55mm (n=14), 55-56mm (n=17), 65-75mm (n=10) and 75-100mm (n=9), chosen to represent the most appropriate spread of individuals among a suitable number of size classes, set at four (classes) in this instance.

Statistical Analysis

Gut Content Analysis

The variation in “prey community” and individual prey items within the alimentary canal of the Ogilby’s hardyhead (collected from Callala Bay) within the three collected fish life stages was analysed as percent by number (%N), percent by volume (%V) and index of relative importance

(IRI) using multivariate and univariate analysis in PRIMER 6 version 6.1.13 and PERMANOVA + version 1.0.3 with the single factor “life stage” being fixed.

Multivariate and univariate analysis were also applied to the “prey community” and individual prey items occurring within weed whiting alimentary canals (collected from Greenpoint) as percent by volume (%V), percent by weight (%W) and IRI with respect to distance from both habitat edge types, general edge and size class also in PRIMER 6 version 6.1.13 and PERMANOVA + version 1.0.3. The orthogonal statistical models applied in this instance were as follows:

Design 1: “Distance from reef” – “Di” (fixed) and “Distance from bare sediment” – “Tr” (fixed) along with their interaction *and*

Design 2: “Distance from general edge” – “Ed” (fixed).

Design 3: “Size class” (fixed)

Principle Coordinates (PCO) analysis was performed on the “prey community” composition within the alimentary canal of each taxon to visually evaluate any separation of points and distinctive differences in occurrence of prey items with fish life stage (hardyheads) or distance from habitat edges (weed whitings). Further, SIMPER analysis was applied to ascertain the prey types contributing most significantly to observed significant trends in in-gut “prey community”.

Fullness indices for each taxon was analysed with respect to distance from each habitat edge and general edge position using univariate analysis in PRIMER 6 version 6.1.13 and PERMANOVA + version 1.0.3 using the following orthogonal designs:

Design 1: “Distance from reef” – “Di” (fixed) and “Distance from bare sediment” – “Tr” (fixed) along with their interaction *and*

Design 2: “Distance from general edge” – “Ed” (fixed).

Results

Fullness indices

Ogilby's Hardyhead – *Atherinomorus vaigiensis* (Callala Bay)

The fullness index (visual measure) of Ogilby's hardyhead stomachs increased significantly with distance from bare sediment (pseudo-*F* = 5.865; p=0.0206) and general edge (pseudo-*F* = 7.8179; p=0.0067) (Table A(ii),(iii); Fig A(ii),(iii)). There was also a significant variation in stomach fullness with distance from reef (pseudo-*F* = 20.046; p=0.0002) (Table A(i); Fig A(i)) with a sharp increase from the 0-15m to the 30-45m positions and a sharp decline thereafter (Fig A(i)). There was no representation of Ogilby's hardyhead samples from the 15-30m distance from reef, 0-15m+ distance from bare sediment or the E15-30m general edge categories for gut analysis.

Intestine fullness increased with both distance from reef and general edge being significant in the latter case (pseudo-*F* = 67.891; p=0.0001) (Table A(i),(iii); Fig A(i),(iii)). A sharp increase in intestine fullness was observed with distance from bare sediment from the 15-30m+ to the 30-45m+ position but decreased thereafter (Fig A(ii)). This was, however, not statistically significant.

Weed whitings – *Neoodax balteatus* and *Haletta semifasciata*

Stomach fullness, using the visual measure, decreased significantly (pseudo-*F* = 3.9953; p=0.0221) with distance from general edge (Table A(iii); Fig B (iii)) with no other meaningful trend with stomach or intestine fullness with distance in any other plane for this measure (visual fullness index) observed apart from a general, non-significant decline in intestine fullness with distance from reef (Fig B(i)).

The calculated whole gut fullness index displayed a trend reflective of an average of the visual fullness index of the stomach and intestines (Fig B) and showed a general decrease with distance away from the reef and general edge (Fig B(iv),(vi)) with the former being statistically significant (pseudo-*F* = 14.8; p=0.0001) (Table A(i)). No consistent meaningful trend was observed with distance from bare sediment apart from a sharp significant decrease in

Table A Summary of PERMANOVA results of Fullness Indices ("visual" – both fish taxa; calculated fullness index – Weed whitings only) of indicated alimentary canal section of two fish taxa (*Atherinomorus vaigiensis* – Callala Bay and weed whitings [82.14% *Neoodax balteatus* and 17.86% *Haletta semifasciata*] – Greenpoint) sampled from *Posidonia australis* seagrass beds in Jervis Bay with (i) distance from reef, (ii) distance from bare sediment and (iii) distance from general edge. *Number in square brackets denotes number of fish (stomachs, intestines, or whole gut) used for each analysis; Significant permdisp (in bold) indicate non-homogeneity of variances. Permdisp values of significant relationships only reported. D1=0-15m, D2=15-30m, D3=30-45m, D4=45-60m; T1=0- 15m+, T2=15-30m+, T3=30-45m+, T4=45-60m+; E1=E0-15m, E2=E15-30m, E3=30-60m; interaction terms not here presented.*

	Distance from Reef				Factors Included		Pairwise Comparisons						
	df	**MS**	**pseudo-F**	**p**	**Di**	**Tr**	**D1-D2**	**D1-D3**	**D1-D4**	**D2-D3**	**D2-D4**	**D3-D4**	**Permdisp**
Fullness Index (Visual): **Stomach:**													
Weed whitings (GP) [56]	3	1.4643	2.8751	0.0522	*	*							**0.001**
Hardyheads (CB) [76]	1	10.356	20.046	**0.0002**	*	*						**0.0002**	0.665
Intestines:													
Weed whitings (GP) [56]	3	12.697	1.8501	0.1362	*	*							
Hardyheads (CB) [51]	1	$1.7988E^{-2}$	$3.3659E^{-2}$	0.8582	*	*							
Fullness Index [Calculated]: Whole gut													
Weed whitings (GP) [56]	3	78420	14.8	**0.0001**	*	*			**0.0004**	**0.0095**	**0.0342**	**0.0001**	0.227

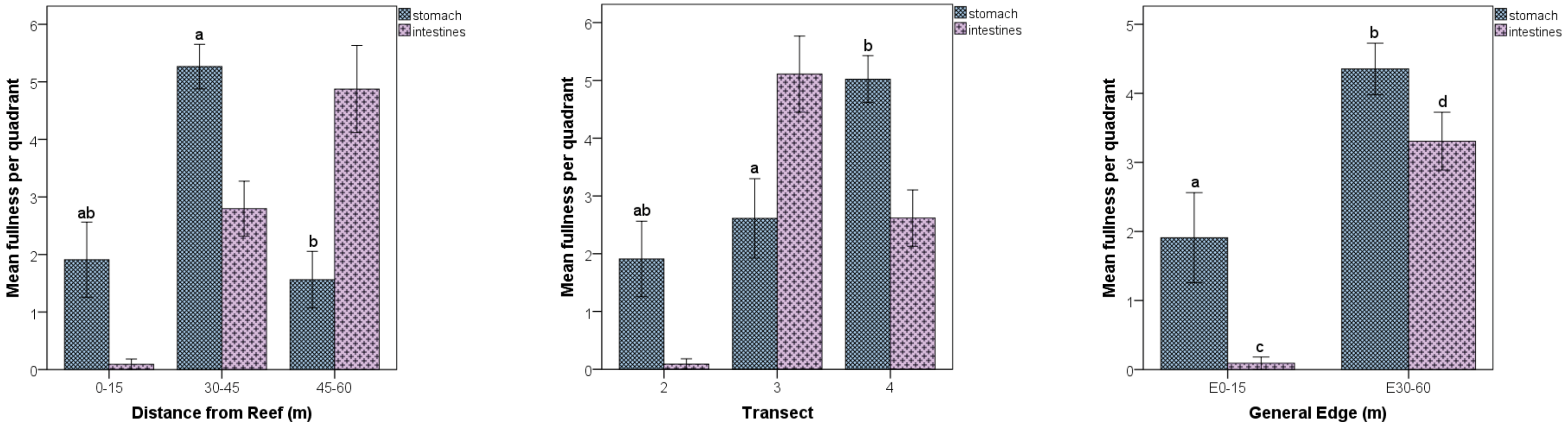
(i)

	Distance from Bare Sediment				Factors Included		Pairwise Comparisons						
	df	**MS**	**pseudo-F**	**p**	**Di**	**Tr**	**T1-T2**	**T1-T3**	**T1-T4**	**T2-T3**	**T2-T4**	**T3-T4**	**Permdisp**
Fullness Index (Visual): **Stomach:**													
Weed whitings (GP) [56]	3	0.89621	1.7596	0.158	*	*							
Hardyheads (CB) [76]	1	3.0299	5.865	**0.0206**	*	*						**0.0153**	0.139
Intestines:													
Weed whitings (GP) [56]	3	12.717	1.853	0.1477	*	*							
Hardyheads (CB) [51]	1	$2.1674E^{-3}$	$4.0556E^{-3}$	0.9514	*	*							
Fullness Index [Calculated]: Whole gut													
Weed whitings (GP) [56]	3	18093	3.4148	**0.0279**	*	*	**0.0158**	**0.0204**			**0.0324**		0.147

(ii)

	Distance from General Edge				Pairwise Comparisons			
	df	**MS**	**pseudo-F**	**p**	**E1-E2**	**E1-E3**	**E2-E3**	**Permdisp**
Fullness Index (Visual): **Stomach:**								
Weed whitings (GP) [56]	2	3.3308	3.9953	**0.0221**		**0.0185**		0.109
Hardyheads (CB) [76]	1	5.9749	7.8179	**0.0067**		**0.0076**		0.757
Intestines:								
Weed whitings (GP) [56]	2	35.946	4.7314	**0.0162**	**0.0142**		**0.0162**	0.263
Hardyheads (CB) [51]	1	37.408	67.891	**0.0001**		**0.0001**		**0.019**
Fullness Index [Calculated]: Whole gut								
Weed whitings (GP) [56]	2	26585	2.4119	0.0931				

(iii)



(i) **(ii)** **(iii)**

Fig A Fullness Index (visual) of indicated alimentary canal section of *Atherinomorus vaigiensis* (Ogilby's hardyhead) sampled from *Posidonia australis* seagrass bed in Callala Bay, Jervis Bay with distance from (i) reef, (ii) bare sediment and (iii) general edge.

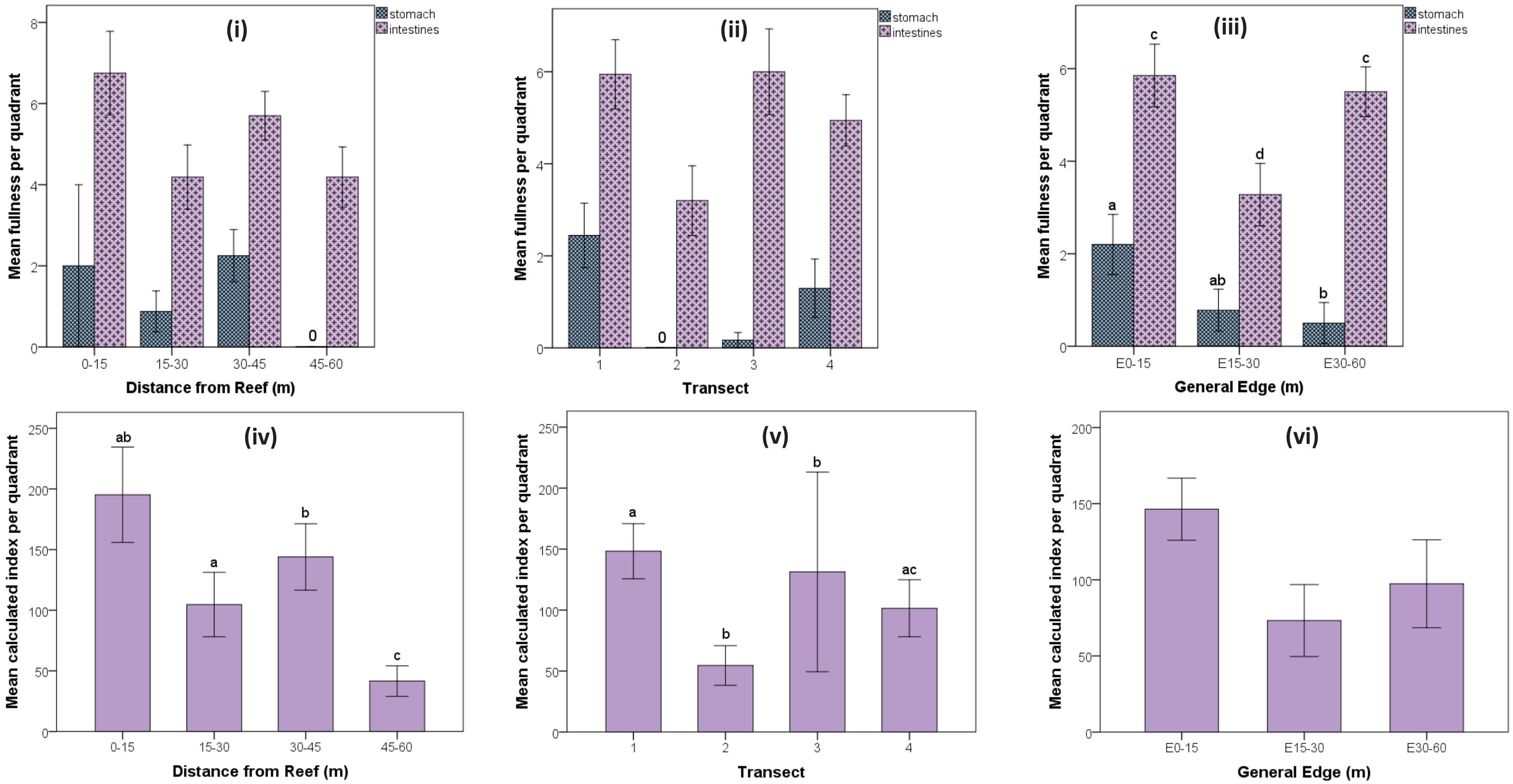


Fig B Fullness Index (visual) (i – iii) and whole gut calculated fullness index (iv – vi) of indicated alimentary canal section of weed whitings (82.14% *Neoodax balteatus* and 17.86% *Haletta semifasciata*) sampled from *P.australis* in Greenpoint, Jervis Bay with distance from (i,iv) reef, (ii,v) bare sediment and (iii,vi) general edge. *Letters above bars represent the results of pairwise comparisons, with distance categories lacking similar letters being significantly different from each other; the bar lettering of each subsequent bar category begin with the letter following alphabetically the highest lettering of the bar category immediately before.*

calculated fullness from the 0-15m+ to 15-30m+ distance categories (p = 0.0158: pairwise comparison) (Table A(ii); Fig B(v)).

In-gut prey items

Ogilby's hardyhead (*Atherinomorus vaigiensis*) – Callala Bay

% Frequency of occurrence of prey items

The main prey items found in the alimentary canal of the three life stages of Ogilby's hardyhead analysed are presented in Table B. While % frequency of occurrence (%O) of bivalves fell sharply from a high of 87.8 – 96% for the juveniles i.e. *juv1* and *juv 2* to a low of 12.5% for the adults, there was in increase in %O of gastropoda prey in the second juvenile stage, *juv 2* (96%) and in adults (75%) over the smallest hardyhead individuals, *juv 1* (44.68%) (Table B; Fig C). While copepods, particularly harpacticoids, were almost exclusively found in the first juvenile stage, *juv 1*, (95.12%), plant material comprising of seagrass and filamentous algae were almost exclusively found in adult guts (**Table B; Fig C**).

% by Number, % by Volume and Index of Relative Importance

The combination of main prey items found in Ogilby's hardyhead guts measured as %N, %V and assigned calculated IRI values all varied significantly between life stage (p=0.0001) (Table C) with PCO plots showing tight groupings of data points for each measure forming three distinct groups – one for each life stage (Fig. D). The prey items included in the community analysis may be found in Table B, with the exception of the "All Copepoda" category. "Seagrass" and "Algae" were only included in the %V measure.

There was a significant difference in all three measures i.e. %N, %V and IRI for the bivalve, gastropod, ostracod, all copepods combined and *Evadne* prey items (p<0.001) and with respect to % V for plant material prey (seagrass and filamentous algae combined; p=0.0001) with fish life stage (Table C). While bivalves (for all measures) were significantly more prevalent in both juvenile stages compared to the adults (p=0.0001; pairwise comparisons) (Table C; Fig E), gastropods were significantly lower in *juv 1* compared to the other two life stages (%N and IRI; p = 0.0001; pairwise comparisons) (Table C; Fig E). Copepods and *Evadne* were significantly more prevalent in *juv 1* compared to the other two life stages (all measures – p<0.001), while

Table B % Frequency of occurrence of prey items in Ogilby's hardyhead, *Atherinomorus vaigiensis*, alimentary canal in the sampled three life stages (n = 74 fish with food present in alimentary canal) collected from *P. australis* at Callala Bay.

	Life Stages		
Prey Items	**Juv 1 (n=41)**	**Juv 2 (n=25)**	**Adult (n = 8)**
Bivalvia	87.8	96	12.5
Gastropoda	44.68	96	75
Ostracoda	36.59	92	12.5
Harpacticoida (Copepoda)	90.24	0	0
Corycaeidae (Copepoda)	60.98	0	0
Calanoida (Copepoda)	14.63	0	0
Cyclopoida (Copepoda)	4.88	0	0
Unidentified Copepoda	39.02	8	0
All Copepoda	95.12	8	0
Evadne	53.66	4	0
Macrocrustacean	24.39	24	0
Unidentified Mollusca	0	4	12.5
Phoronidae	2.44	0	0
Insecta	0	16	0
Seagrass	2.44	0	37.5
Algae	0	0	50
Polychaeta	0	4	0

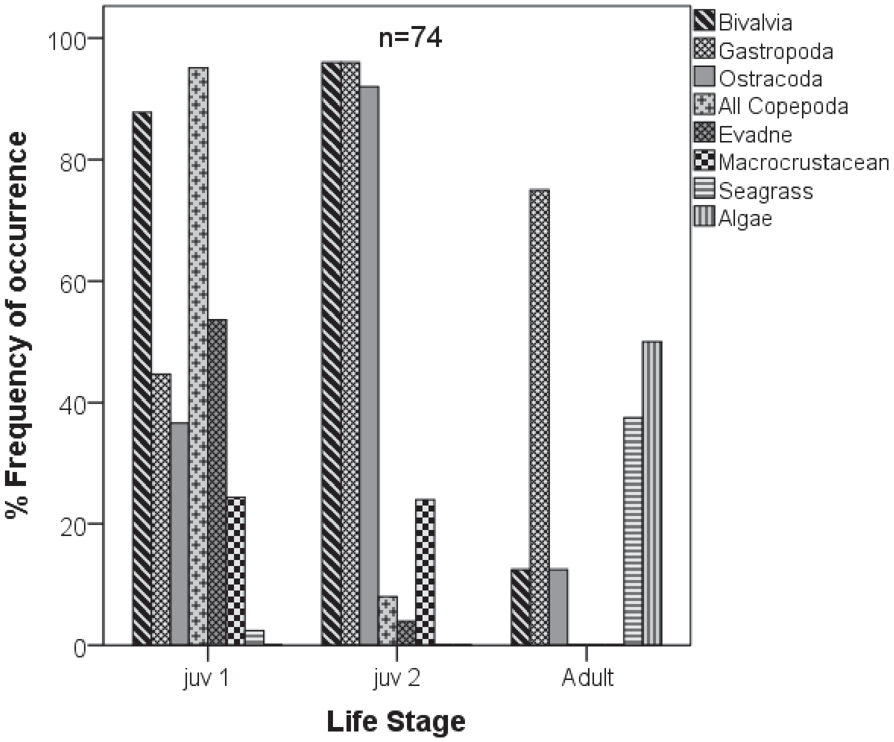
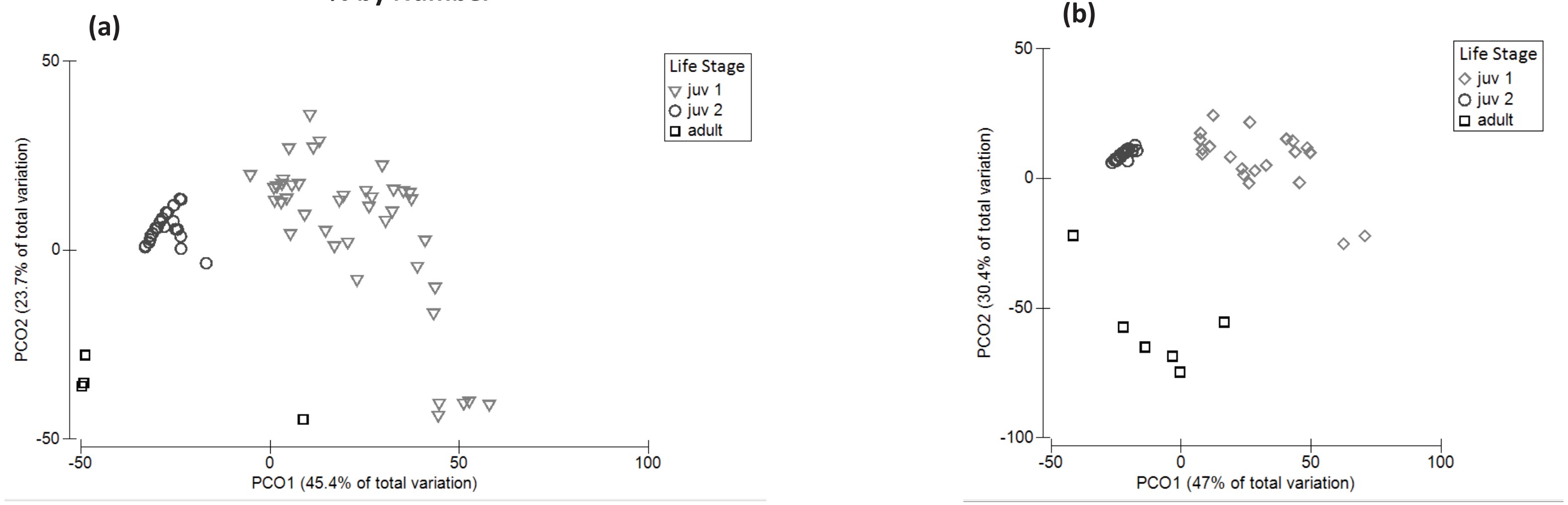


Fig C % Frequency of occurrence of prey items in Ogilby's hardyhead, *Atherinomorus vaigiensis*, alimentary canal in the three sampled life stages (n = 74 fish with food present in alimentary canal) collected from *P. australis* at Callala Bay.

Table C Summary of PERMANOVA results of distribution of prey community and individual prey items in alimentary canals of three life stages of Ogilby's hardyhead, *Atherinomorus vaigiensis*, collected from *P. australis* at Callala Bay, calculated as % by N (n=75), % by V (n=55) and IRI (n=51); *Permdisp values with asterisks indicate non-homogeneity of variances.*

					Pairwise Comparisons			
	df	**MS**	**pseudo-F**	**p**	**Juv1-Juv2**	**Juv1-Adult**	**Juv2-Adult**	**Permdisp**
Gut prey community								
%N	2	31264	26.93	**0.0001**	**0.0001**	**0.0001**	**0.0001**	0.001*
%V	2	28686	25.692	**0.0001**	**0.0001**	**0.0001**	**0.0001**	0.001*
IRI (By Life Stage)	2	23547	61.693	**0.0001**	**0.0001**	**0.0002**	**0.0001**	0.001*
Bivalves								
%N	2	55.879	43.425	**0.0001**		**0.0001**	**0.0001**	0.015*
%V	2	46.421	53.34	**0.0001**		**0.0001**	**0.0001**	0.006*
IRI (By Life Stage)	2	188.69	53.773	**0.0001**		**0.0001**	**0.0001**	0.014*
Gastropods								
%N	2	79.658	67.834	**0.0001**	**0.0001**	**0.0006**	**0.0046**	0.001*
%V	2	59.955	54.024	**0.0001**	**0.0001**		**0.0001**	0.001*
IRI (By Life Stage)	2	239.38	56.338	**0.0001**	**0.0001**	**0.0001**		0.001*
Ostracods								
%N	2	12.074	16.744	**0.0001**	**0.0001**		**0.0008**	0.987
%V	2	19.991	22.312	**0.0001**	**0.0001**		**0.0001**	0.002*
IRI (By Life Stage)	2	151.51	26.158	**0.0001**	**0.0001**		**0.0001**	0.001*
All Copepods								
%N	2	56.144	59.714	**0.0001**	**0.0001**	**0.0001**		0.001*
%V	2	39.516	72.822	**0.0001**	**0.0001**	**0.0001**		0.001*
IRI (By Life Stage)	2	317.16	137.39	**0.0001**	**0.0001**	**0.0001**		0.133
Evadne								
%N	2	9.1704	11.298	**0.0005**	**0.0003**	**0.0108**		0.001*
%V	2	18.521	19.161	**0.0001**	**0.0001**	**0.002**		0.001*
IRI (By Life Stage)	2	117.84	23.687	**0.0001**	**0.0001**	**0.009**		0.001*
Plant Material: Seagrass + Filamentous Algae								
%V	2	20.015	15.991	**0.0001**		**0.002**	**0.0009**	0.001*



% by Number

% by Volume

Index of Relative Importance (IRI)

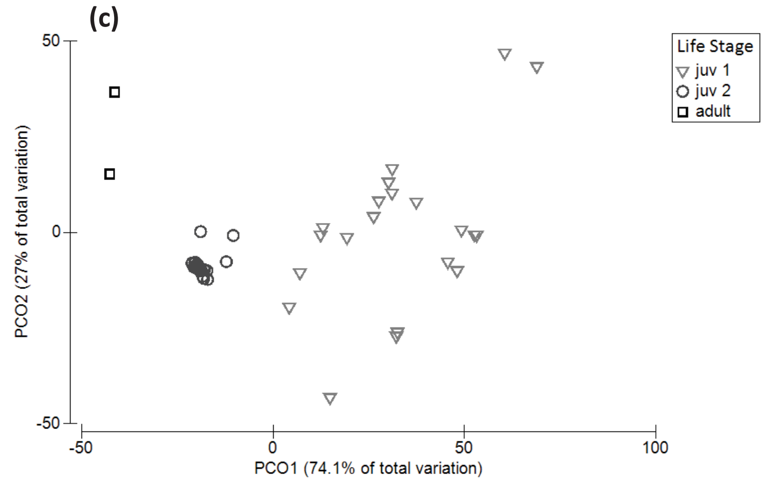
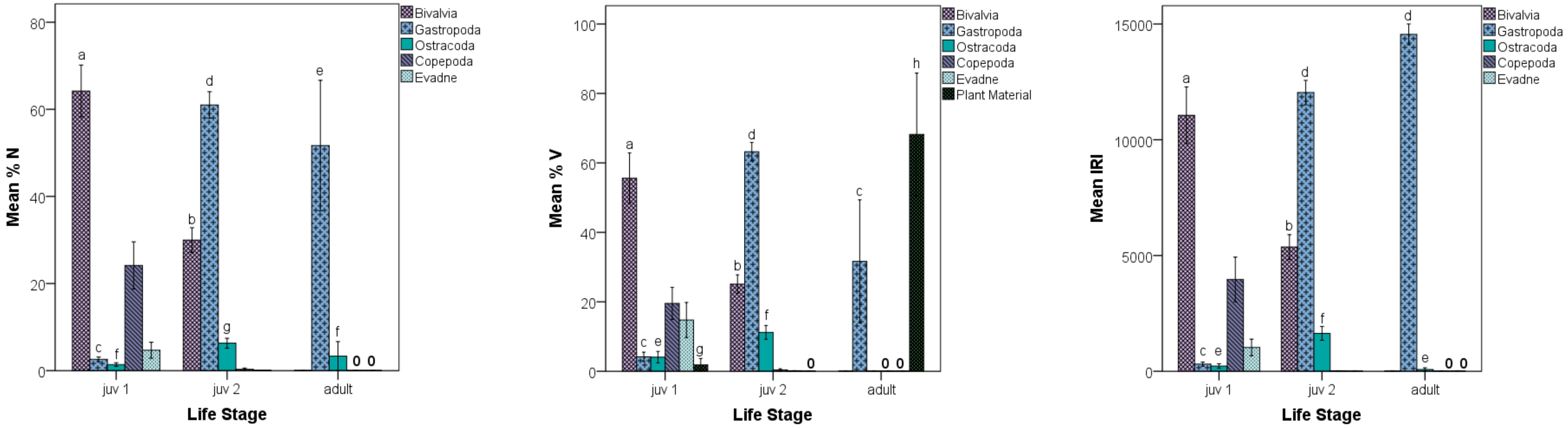


Fig D PCO plots of distribution of in-gut prey composition as (a) %N, (b) %V and (c) IRI among the three Ogilby's hardyhead, *Atherinomorus vaigiensis*, life stages sampled in Callala Bay, Jervis Bay.



(i) **(ii)** **(iii)**

Fig E Relative abundance of individual prey items measured as (i) %N and (ii) %V, and (iii) prey IRI (Index of Relative Importance) of the three sampled life stages of Ogilby's Hardyhead, *Atherinomorus vaigiensis*, caught in *P. australis* at Callala Bay, Jervis Bay. *Letters above bars represent the results of pairwise comparisons with distance categories lacking similar letters being significantly different from each other; the bar lettering of each subsequent bar category begin with the letter following alphabetically the highest lettering of the bar category immediately before.*

Table D Percent contribution by individual prey items from SIMPER analysis of Ogilby's Hardyhead, *Atherinomorus vaigiensis*, alimentary canal prey community at significant pairwise comparisons of the three sampled life stages (set to at least 90% cumulative distribution) in PERMANOVA analysis.

% N		**% V**		**IRI [LIFE STAGE]**	
Juvenile 1 – Juvenile 2					
Average dissimilarity: 58.10%		*Average dissimilarity: 59.18%*		*Average dissimilarity: 55.30%*	
Gastropoda	27.72	Gastropoda	26.27	Gastropoda	20.90
Harpacticoida (Copepod)	15.96	Harpacticoida (Copepod)	14.44	Harpacticoida (Copepod)	19.99
Ostracoda	11.79	Ostracoda	14.30	Ostracoda	15.84
Bivalvia	11.13	Evadne	13.69	Corycaeidae (Copepod)	13.78
Corycaeidae (Copepod)	9.15	Bivalvia	10.85	Evadne	13.64
Evadne	7.93	Corycaeidae (Copepod)	10.69	Unidentified Copepod	6.91
Unidentified Crustacean	5.79				
Unidentified Copepod	5.68				
Juvenile 1 – Adult					
Average dissimilarity: 92.85%		*Average dissimilarity: 92.04%*		*Average dissimilarity: 84.97%*	
Bivalvia	31.88	Bivalvia	22.85	Bivalvia	23.86
Gastropoda	18.78	Algae	15.32	Gastropoda	19.67
Harpacticoida (Copepod)	15.79	Gastropoda	12.45	Harpacticoida (Copepod)	17.51
Corycaeidae (Copepod)	8.65	Harpacticoida (Copepod)	11.12	Evadne	12.01
Evadne	7.44	Evadne	10.57	Corycaeidae (Copepod)	11.85
Ostracoda	5.59	Seagrass	8.43	Ostracoda	6.95
Unidentified Copepod	4.99	Corycaeidae (Copepod)	8.14		
		Ostracoda	4.71		
Juvenile 2 – Adult					
Average dissimilarity: 64.94%		*Average dissimilarity: 71.94%*		*Average dissimilarity: 42.39%*	
Bivalvia	42.24	Bivalvia	28.45	Bivalvia	56.53
Gastropoda	28.73	Algae	21.60	Ostracoda	39.44
Ostracoda	21.12	Gastropoda	19.40		
		Ostracoda	19.14		
		Seagrass	11.40		

plant material was significantly more prevalent in the adult hardyhead guts compared to that of both *juv 1* and *juv 2* (%V – 0.002<p<0.0009; pairwise comparisons) (Table C; Fig E). Additionally, the second juvenile stage contained significantly more ostracod prey compared to the other two life stages (all measures – p<0.001: pairwise comparisons) (Table C; Fig E).

SIPMER analysis of the alimentary canal prey community at significant pairwise comparisons between life stages showed the highest average dissimilarity being between *juv 1* and adults for all measures (average of 89.953%) followed by *juv 2* and adults (average of 59.757%) and between the two juvenile stages (57.527%) (Table D).The main prey items contributing to the statistical significance at significant pairwise life stage comparisons included the gastropod and harpacticoid copepod prey (between *juv 1* and *2*); bivalve, gastropod and algae (between *juv 1* and adults) and the bivalve, gastropod, ostracod and algae prey (between *juv 2* and adults) (Table D).

<u>Weed whitings (*Neoodax balteatus* and *Haletta semifasciata*) – Greenpoint</u>

% Frequency of Occurrence (%O) of Prey Items

Gastropod prey was highly prevalent (100% frequency of occurrence) within the guts of the sampled weed whitings with food in the alimentary canal (n=50) (Table E; Fig F). A voluminous fleshy macroalgae (referred to as Plant Material 1 in this study) and filamentous macroalgae, often found associated with pieces of seagrass, (referred to as Plant Material 2) were also observed in fish guts (40% and 42% respectively) followed by macrocrustaceans (26%) and incidental copepods (10%) and ostracods (2%) (Table E; Fig F).

Plant material 2 and macrocrustacean prey were more frequently found in fish collected within the first 30 m of the reef (n=17 fish) (Table F; Fig G), particularly at the seagrass-reef edge where percent frequency of occurrences were the highest for these prey items (Table F; Fig G(i)) with the fleshy macroalgae found in 100% of fish guts at this position. Copepod prey was most frequently found (23.08%) in fish collected from the 15-30m distance from reef category (Table F; Table G(i)).

There was a more homogeneous spread of %O in prey items with distance from the bare sediment with the exception of an increase in the %O of copepods in fish collected from beyond 30 m of the bare sediment (Table G; Fig H).

Table E % Frequency of occurrence of prey items in weed whiting (*Neoodax balteatus* and *Haletta semifasciata*) alimentary canal in all fish (with food in the gut; N=50) collected from *P. australis* at Greenpoint.

Prey Items	**% Frequency of Occurrence (n = 50)**
Gastropoda	100
Plant Material 1: Seagrass + Filamentous algae	42
Plant Material 2: Fleshy Macroalgae	40
Macrocrustacean Material	26
Other	14
All Copepoda	10
Unidentified Copepoda	8
Calanoida	2
Ostracoda	2

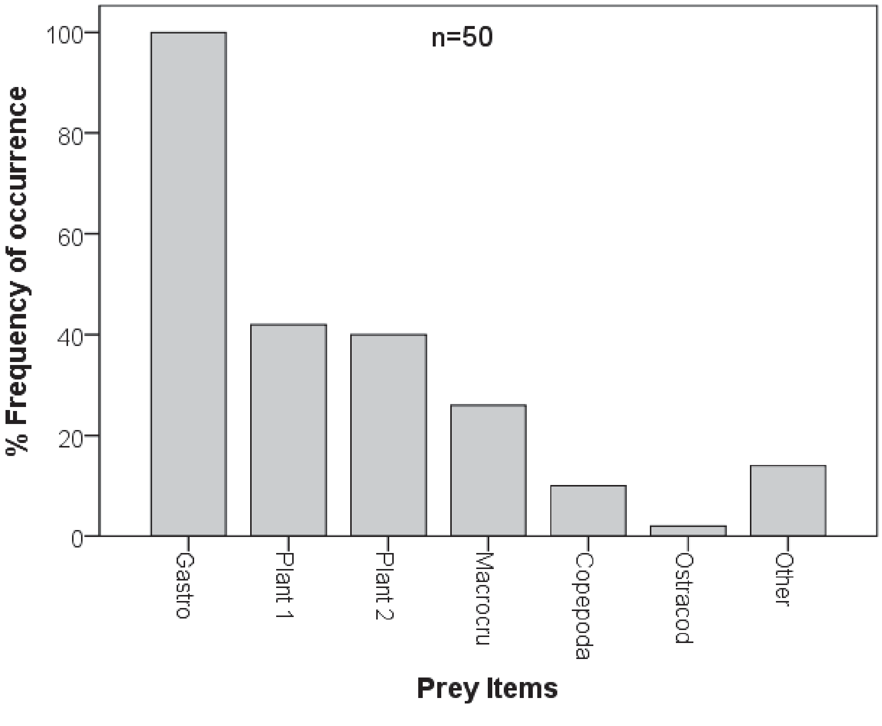
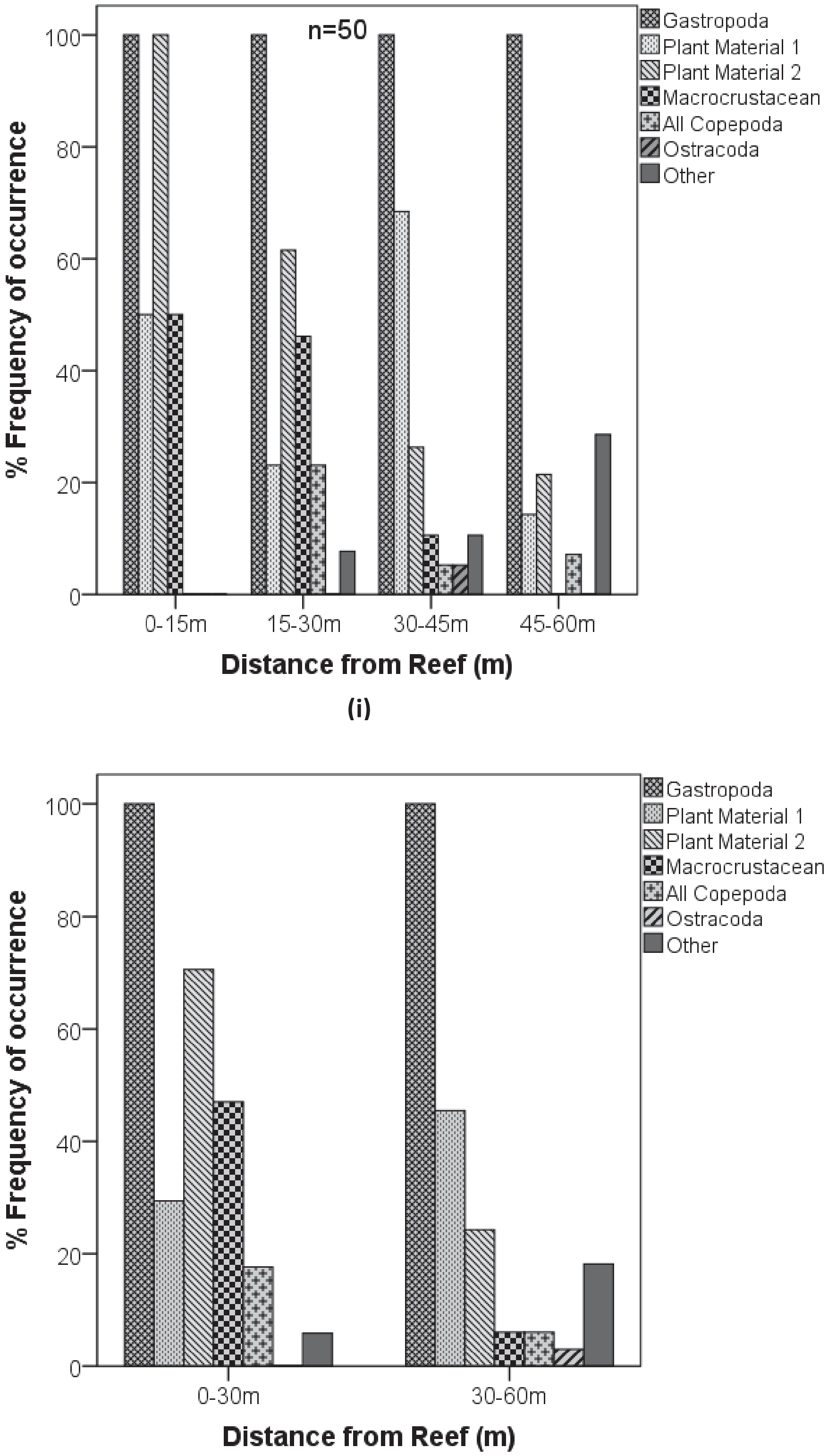


Fig F % Frequency of occurrence of prey items in weed whiting (*Neoodax balteatus* and *Haletta semifasciata*) alimentary canal in all fish (with food in the gut) caught within *P. australis* at Greenpoint, Jervis Bay.

Table F % Frequency of occurrence of prey items in weed whiting alimentary canal, *Neoodax balteatus* and *Haletta semifasciata* collected from *P. australis* at Greenpoint, in all fish with food in the gut at varying “distance from reef categories” (m).

	Distance from reef categories (m)					
Prey Items	**0-15m (n=4)**	**15-30m (n=13)**	**30-45m (n=19)**	**45-60m (n=14)**	**0-30m (n=17)**	**30-60m (n=33)**
Gastropoda	100	100	100	100	100	100
Plant Material 1: Seagrass + Filamentous algae	50	23.07	68.42	14.28	29.41	45.45
Plant Material 2: Fleshy Macroalgae	100	61.54	26.32	21.43	70.59	24.24
Macrocrustacean material	50	46.15	10.53	0	47.06	6.06
Other	0	7.69	10.53	28.57	5.88	18.18
All Copepoda	0	23.08	5.26	7.14	17.65	6.06
Unidentified Copepoda	0	23.08	0	7.14	17.65	3.03
Ostracoda	0	0	5.26	0	0	3.03
Calanoida	0	0	5.26	0	0	3.03



(i)

(ii)

Fig G % Frequency of occurrence of prey items in weed whiting (*Neoodax balteatus* and *Haletta semifasciata*) alimentary canal (n=50) caught within *P. australis* at Greenpoint, Jervis Bay at varying "distance from reef" categories (m). *(i) original four distance categories, (ii) collated distance categories.*

Table G % Frequency of occurrence of prey items in weed whiting alimentary canal, *Neoodax balteatus* and *Haletta semifasciata* collected from *P. australis* at Greenpoint, in all fish caught with food in the gut at varying distance from bare sediment (m)

	Distance from bare sediment categories (m+)					
Prey Items	**0-15m+ (n=17)**	**15-30m+ (n=11)**	**30-45m+ (n=6)**	**45-60m+ (n=16)**	**0-30m+ (n=28)**	**30-60m+ (n=22)**
Gastropoda	100	100	100	100	100	100
Plant Material 1: Seagrass + Filamentous algae	64.68	18.18	0	43.75	46.42	36.36
Plant Material 2: Fleshy Macroalgae	35.29	36.36	33.33	50	35.71	45.45
Macrocrustacean material	29.41	27.27	0	25	28.27	18.18
Other	11.76	0	33.33	18.75	7.14	22.72
All Copepoda	0	9.09	0	25.00	3.57	18.19
Unidentified Copepoda	0	9.09	0	18.75	3.57	13.64
Ostracoda	5.88	0	0	0	3.57	0
Calanoida	0	0	0	6.25	0	4.55

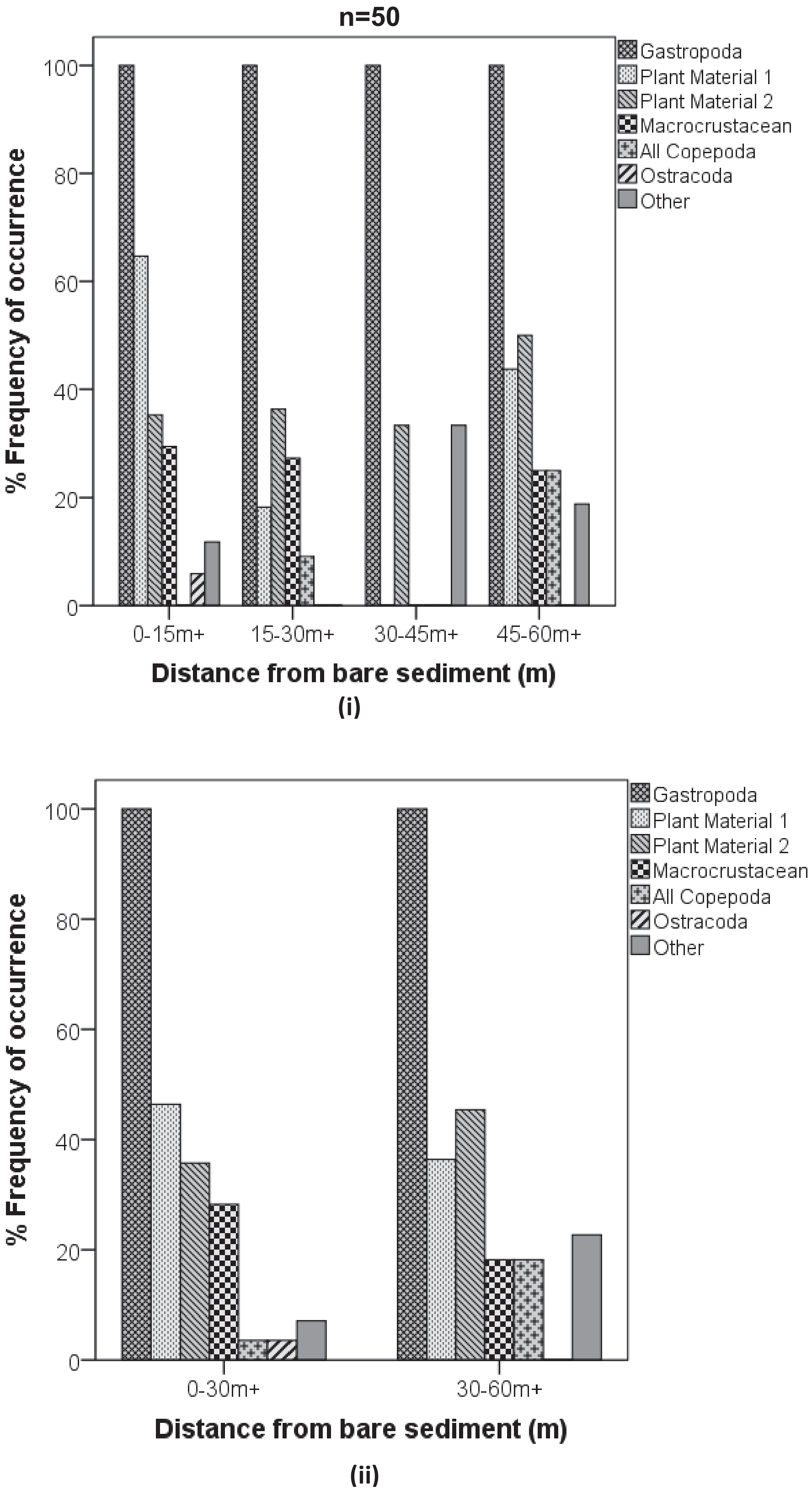


Fig H % Frequency of occurrence of prey items in weed whiting (*Neoodax balteatus* and *Haletta semifasciata*) alimentary canal (n=50) caught within *P. australis* at Greenpoint, Jervis Bay at varying "distance from bare sediment" categories (m). *(i) original four distance categories, (ii) collated distance categories.*

Table H % Frequency of occurrence of prey items in Greenpoint *P. australis* weed whiting alimentary canal in all fish caught with food in the gut for varying size classes (TL); n=a,b; a = # of *Neoodax balteatus* and b = # of *Haletta semifasciata*)

	Size Class (mm)			
Prey Items	**45>55mm (n=13,1)**	**55>65mm (n=12,5)**	**65>75mm (n=8,2)**	**75>100mm (n=7,2)**
Gastropoda	100	100	100	100
Plant Material 1: Seagrass + Filamentous algae	35.71	29.41	50	66.66
Plant Material 2: Fleshy Macroalgae	28.57	47.06	30	55.56
Macrocrustacean material	28.57	17.65	30	22.22
Other	21.43	11.76	0	22.22
All Copepoda	14.29	17.65	0	0
Unidentified Copepoda	7.14	17.65	0	0
Ostracoda	7.14	0	0	0
Calanoida	7.14	0	0	0

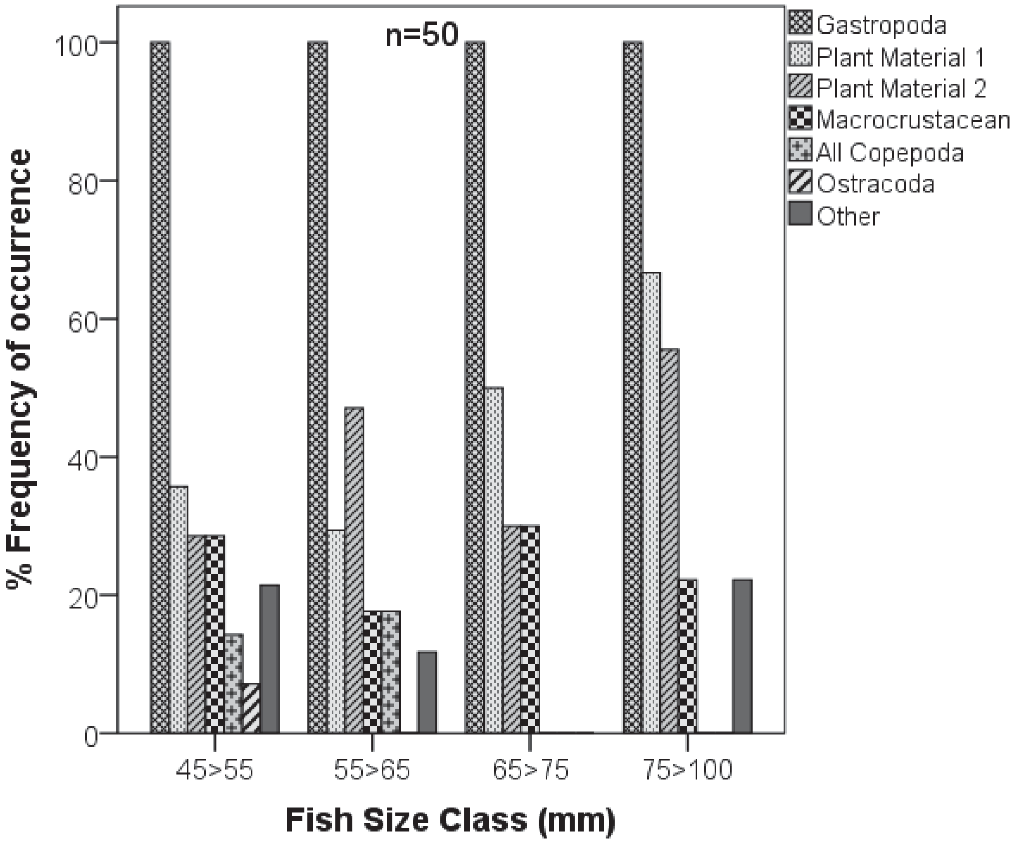


Fig I % Frequency of occurrence of prey items in the different size class (mm) weed whitings' (*Neoodax balteatus* and *Haletta semifasciata*) alimentary canal (n=50) caught within *P. australis* at Greenpoint, Jervis Bay.

Apart from an increase in % O of seagrass and filamentous algae in weed whitings above 65mm and an absence of copepod prey in this same size category (Table H; Fig I), there were no other meaningful variation in % O of prey items across fish of different sizes.

% by Volume, % by Weight and Index of Relative Importance of Prey Items

There was a high level of statistical non-significance for the effect of fish "size class" for the entire prey community and major individual prey items for all measures ($0.1715<p<0.9426$) and so is not considered for the remaining discourse.

The combination of all prey items varied significantly only with respect to IRI values with distance from the reef (pseudo-F = 4.5575; $p=0.0012$) (Table I(i)) with the PCO plot of these values showing a separation of the data points representing the fish guts analysed in distance categories beyond 30m (30-45m and 45-60m) from those closer to the reef (0-15m and 15-30m) (Fig J).

SIMPER analysis at significant pairwise "distance from reef" position comparisons showed the two plant material categories to be consistently highly contributing items to the levels of significance (14.55% - 53.57%) (Table J). Fleshy macroalgae (Plant Material 2) displayed higher values for all measures closer to the reef (Fig K(i),(iv)) and displayed a significant effect with "distance from reef" for both % V (pseudo-F = 3.8961; $p=0.014$) and IRI values (pseudo-F = 6.0613; $p=0.0018$) (Table I(i)). No significant or noteworthy trend was observed with distance in any other plane for this prey item.

Significantly higher % V and IRI values for seagrass and filamentous algae (Plant Material 1) was found in fish at the 30-45m distance from reef compared to the 15-30m and 45-60m distance categories ($p<0.01$: pairwise comparisons) (Table I(i); Fig K(i), L(i)) with a similar but non-significant trend for this prey item found for % W (Fig K(iv))**.** Additionally this prey item displayed a significant decline in IRI values with distance from the general edge (pseudo-F = 5.4528; $p=0.0083$) (Table I(iii); Fig L(iii)). No meaningful trend was displayed with distance from bare sediment.

Macrocrustacean prey had a trend of decreasing values within fish collected at increasing distance from the reef and general edge (Figs K,L) with this being significant for % W values with "distance from reef" (pseudo-F = 6.6874; $p=0.0006$) (Table I(i)). No trend was observed with "distance from bare sediment".

Gastropod prey items had consistently high values for all measures with increasing distance in all planes (Figs K, L). Ostracod and copepod prey items were too low in occurrence for meaningful statistical analysis to be performed on their individual abundance values.

Table I Summary of PERMANOVA results of distribution of in-gut prey community and individual prey items in alimentary canals of weed whitings – *Neoodax balteatus* and *Haletta semifasciata* (collected from *P. australis* at Greenpoint) calculated as %W (n=56), %V (n= 56) and IRI (n = 50) with varying distance from (i) reef, (ii) bare sediment and (iii) general edge; *where D1=0-15m, D2=15-30m, D3=30-45m, D4=45-60m; T1=0-15m+, T2=15-30m+, T3=30-45m+, T4=45-60m+; E1=E0-15m, E2=E15-30m, E3=30-60m. Significant permdisp (in bold) indicate non-homogeneity of variances. Permdisp values of significant relationships only reported; interaction terms not here presented.*

	Distance from Reef				Factors Included		Pairwise Comparisons						
	df	**MS**	**pseudo-F**	**p**	**Di**	**Tr**	**D1-D2**	**D1-D3**	**D1-D4**	**D2-D3**	**D2-D4**	**D3-D4**	**Permdisp**
Prey Community													
%V	3	1038.3	1.8329	0.1365	*	*							
%W	3	1535.5	2.4055	0.0613	*	*							
IRI (BY DISTANCE)	3	2278.9	4.5575	**0.0012**	*			**0.0032**	**0.011**	**0.0088**		**0.0159**	0.513
Gastropods													
%V	3	1.9427	0.80143	0.4759	*	*							
%W	3	2.5425	0.99464	0.3922	*	*							
IRI (BY DISTANCE)	3	1.9266	1.6702	0.1345	*								
Macrocrustacean Material													
%V	3	0.34081	0.43955	0.6648	*	*							
%W	3	14.007	6.6874	**0.0006**	*	*	**0.0169**	**0.0118**	**0.0019**	**0.0354**	**0.0263**		0.627
IRI (BY DISTANCE)	3	20.6	3.6425	0.0203	*			0.0352		0.0187	0.0384		**0.002**
Plant Material 1: SG + Filamentous Algae													
%V	3	3.4785	6.4045	**0.0031**	*					**0.0055**		**0.0015**	**0.001**
%W	3	3.0663	3.4462	0.0267	*					0.0171		0.0207	**0.028**
IRI (BY DISTANCE)	3	34.608	6.2987	**0.001**	*					**0.0069**		**0.0017**	**0.002**
Plant Material 2: Fleshy Macroalgae													
%V	3	8.3357	3.8961	**0.014**	*	*	**0.0158**	**0.0252**	**0.0036**				0.791
%W	3	1.3537	1.3845	0.2499	*	*							
IRI (BY DISTANCE)	3	65.991	6.0613	**0.0018**	*			**0.0005**	**0.0009**		**0.0366**		0.137

(i)

	Distance from Bare Sediment				**Factors Included**		**Pairwise Comparisons**						
	df	**MS**	**pseudo-F**	**p**	**Di**	**Tr**	**T1-T2**	**T1-T3**	**T1-T4**	**T2-T3**	**T2-T4**	**T3-T4**	**Permdisp**
Prey Community													
%V	3	991.83	1.7508	0.1543	*	*							
%W	3	1135.5	1.7789	0.1323	*	*							
IRI (BY TRANSECT)	3	1221.2	2.1826	0.0592		*							
Gastropods													
%V	3	0.7897	0.32578	0.8109	*	*							
%W	3	1.0934	0.42773	0.74	*	*							
IRI (BY TRANSECT)	3	1.0131	0.83518	0.4915	*								
Macrocrustacean Material													
%V	3	0.25315	0.32649	0.7732	*	*							
%W	3	6.1251	2.9242	**0.0453**	*	*							0.604
IRI (BY TRANSECT)	3	3.9663	0.67372	0.5996	*								
Plant Material 1: SG + Filamentous Algae													
%V	3	0.27938	0.46372	0.6921	*	*							
%W	3	1.011	1.1194	0.3454	*	*							
IRI (BY TRANSECT)	3	31.951	5.6688	**0.0034**	*		**0.0052**	**0.005**					**0.001**
Plant Material 2: Fleshy Macroalgae													
%V	3	4.7812	2.2347	0.0955	*	*							
%W	3	0.50744	0.51899	0.6644	*	*							
IRI (BY TRANSECT)	3	6.0943	0.42774	0.7423	*								

(ii)

	Distance from General Edge				Pairwise Comparisons			
	df	**MS**	**pseudo-F**	**p**	**E1-E2**	**E1-E3**	**E2-E3**	**Permdisp**
Prey Community								
%V	2	723.84	1.2234	0.3118				
%W	2	1013	1.4797	0.237				
IRI (OVERALL)	2	1234.2	2.2187	0.0878				
Gastropods								
%V	2	3.0465	1.3488	0.2694				
%W	2	5.0106	2.1044	0.1346				
IRI (OVERALL)	2	2.4034	2.0905	0.0723				
Macrocrustacean Material								
%V	2	1.3939	1.3939	0.2609				
%W	2	0.12521	$4.8459E^{-2}$	0.9539				
IRI (OVERALL)	2	12.58	2.4413	0.0953				
Plant Material 1: SG + Filamentous Algae								
%V	2	2.0275	3.1036	0.0512	**0.0054**			0.07
%W	2	4.1364	4.6454	**0.0103**	**0.0056**			0.087
IRI (OVERALL)	2	30.623	5.4528	**0.0083**	**0.0046**	**0.0341**		0.112
Plant Material 2: Fleshy Macroalgae								
%V	2	1.0717	0.45555	0.6369				
%W	2	2.058	1.9902	0.1495				
IRI (OVERALL)	2	0.43369	$3.0448E^{-2}$	0.9818				

(iii)

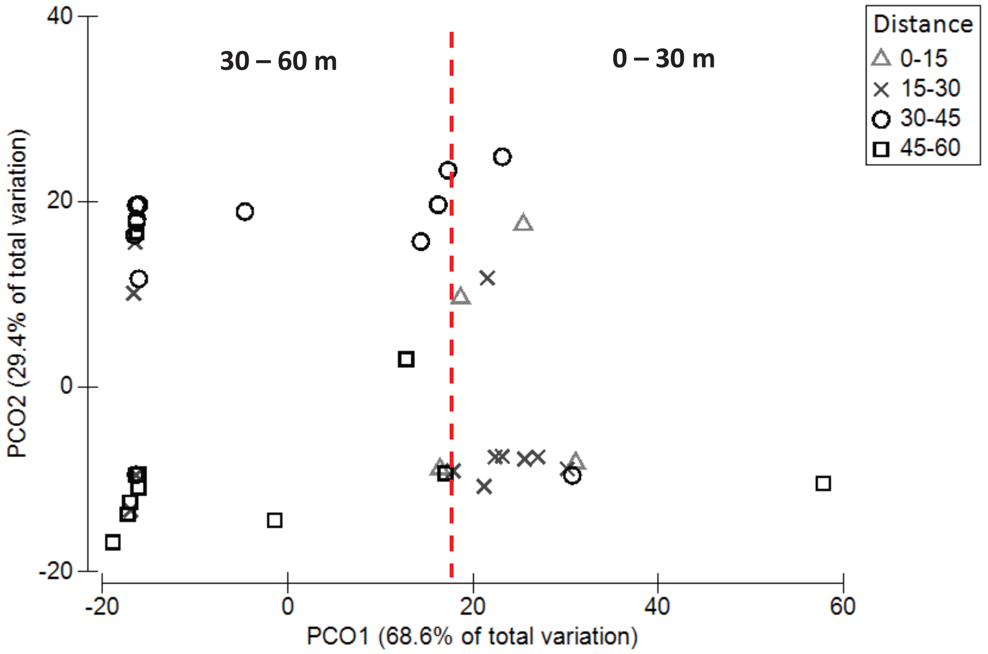


Fig J PCO plot of the distribution of main weed whiting in-gut prey composition (as IRI) within fish collected at varying distances from the reef. *Dotted line illustrates formation of two main groupings with values (0-30m and 30-60m from reef).*

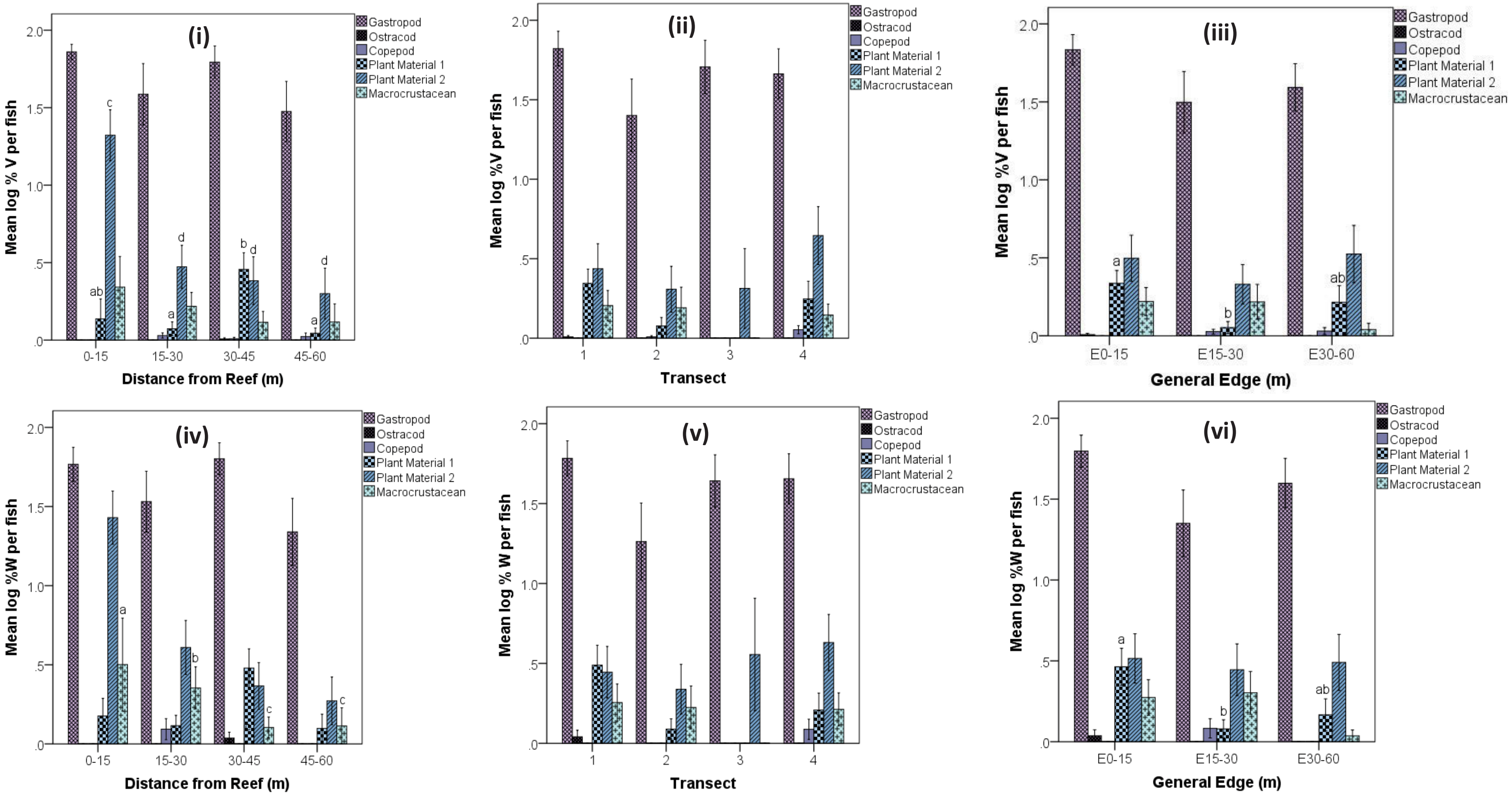
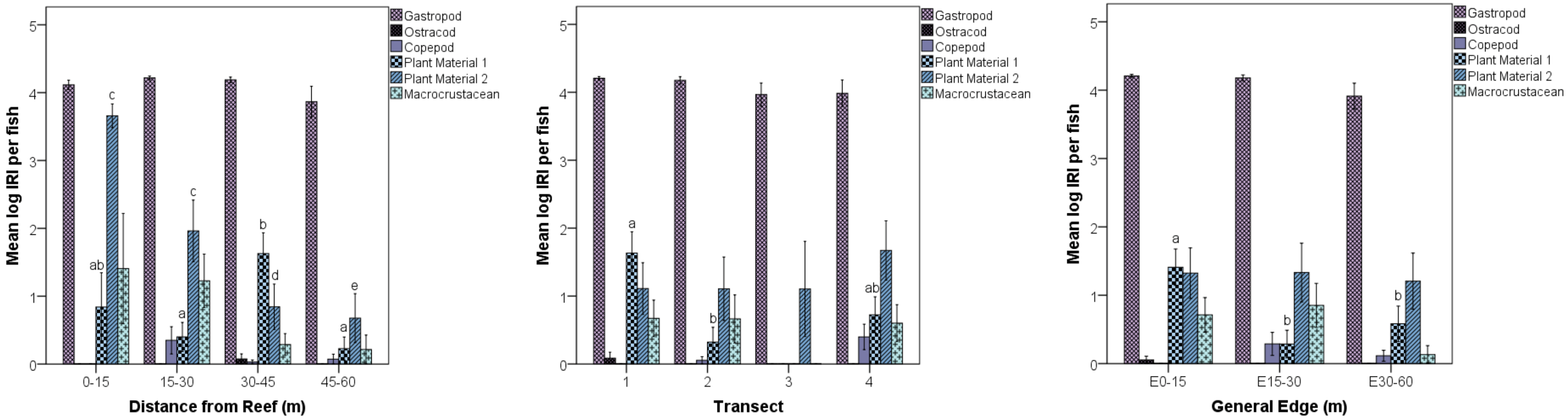


Fig K Abundance of main prey items in weed whiting (caught within *P. australis* at Greenpoint) alimentary canal calculated as %V and %W at varying distances from the (i,iv) reef, (ii,v) bare sediment – increasing transect number and (iii,vi) general edge. *Letters above bars represent the results of pairwise comparisons with distance categories lacking similar letters being significantly different from each other; the bar lettering of each subsequent bar category begin with the letter following alphabetically the highest lettering of the bar category immediately before.*



(i) (ii) (iii)

Fig L Index of Relative Importance (IRI) of main prey items in weed whiting (caught within *P. australis* at Greenpoint) alimentary canal at varying distances from the (i) reef, (ii) bare sediment – increasing transect number and (iii) general edge. *Letters above bars represent the results of pairwise comparisons with distance categories lacking similar letters being significantly different from each other; the bar lettering of each subsequent bar category begin with the letter following alphabetically the highest lettering of the bar category immediately before.*

Table J Percent contribution of individual prey items (as IRI) from SIMPER analysis of Greenpoint *P. australis* weed whiting's[1] in-gut prey community at significant pairwise comparisons of "distance from reef" categories (set at 90% cumulative contribution) from PERMANOVA analysis; where *D1=0-15m, D2=15-30m, D3=30-45m, D4=45-60m.*

Distance from Reef	**% Contribution**
D1-D3	
Plant Material 2: Fleshy Macroalgae	50.45
Plant Material 1: Seagrass + filamentous algae	23.22
Macrocrustacean material	21.97
D1-D4	
Plant Material 2: Fleshy Macroalgae	53.57
Crustacean material	22.64
Plant Material 1: Seagrass + filamentous algae	14.55
D2-D3	
Plant Material 2: Fleshy Macroalgae	36.03
Plant Material 1: Seagrass + filamentous algae	30.25
Macrocrustacean material	22.88
All Copepods	7.26
D3-D4	
Plant Material 1: Seagrass + filamentous algae	41.50
Plant Material 2: Fleshy Macroalgae	29.58
Gastropods	13.49
Macrocrustacean material	11.18

[1] *Neoodax balteatus* and *Haletta semifasciata*

Appendix II(B) Measurements used in gut content analysis

Quantitative Measurements

Number Method (Zacharia, Abdurahiman & Mohamed 2004): A count was made of all prey items encountered within each fish. The percent composition by number of the total number of prey items for each prey for each fish was then calculated.

%N (prey type A) = (Number of prey type A / Total number of prey in fish) * 100

This was done for juv 1 and juv 2 Ogilby's hardyhead collected in Callala Bay as these fish had diets consisting mainly of whole zooplankton.

Volume Method Type 1 (Hyslop 1980): The length and width of the prey items grouped and spread thinly and evenly (consistent relatively negligible breadth) on the petri dish was calculated for each prey type and taken as the volume. The percent volume of the total volume of all other prey items found within that fish was then calculated.

%V (prey type A) = volume of prey type A / total volume of all prey in fish) * 100

This was done for adult Ogilby's hardyhead from Callala Bay and all weed whitings from Greenpoint as the diet consisted of masticated prey and some plant material and not whole organisms that could be counted.

Volume Method Type 2 (Hyslop 1980) *along with study-specific modifications*: Dimensions of representative, mostly zooplanktonic organisms, (length and width only; assuming negligible breadth) were taken and the average of this multiplied by the number of prey individuals of each type within each fish to achieve the volume for each prey type for each fish. The percent volume of each prey type of the total volume of all prey found within that fish was then calculated.

Calculated Volume (Prey type A) = Avr Prey A volume * number of Prey A individuals within fish

%V (Prey type A) = (Calculated Volume of Prey class A / total calculated volume of all prey types within fish) * 100 (Hyslop 1980).

This was done for juv 1 and juv 2 Ogilby's hardyhead collected in Callala Bay as these fish had diets consisting mainly of whole zooplankton that could be individually counted and measured.

Weight Method (Hyslop 1980; Zacharia, Abdurahiman & Mohamed 2004): The wet weight (g) of each prey item was obtained on a Sartorius CP224S Analytical Balance within each fish after separation. The percent weight of each prey type of the total weight of all prey items found within each fish was then calculated.

%W (Prey type A) = (weight (g) of prey type A / total weight of all prey within fish) * 100

This was done for all weed whitings collected from Greenpoint.

Indices calculated for gut content analysis

Fullness Index (Zacharia, Abdurahiman & Mohamed 2004): This is the ratio of the weight of the total gut content of each fish to its own body weight, expressed as parts per 10,000 or parts per decimile.

Fullness Index = (weight of gut contents / weight of fish) * 10,000

This was done for all weed whitings collected from Greenpoint as prey item weights were measured from these fish. Food items from the Ogilby's hardyhead juv 1 and juv 2 individuals would be too miniscule to be weighed and hence weights were not taken. The adult hardyhead prey items were also not weighed as there would be no weights from the other life stages with which to compare it from the same site.

Frequency of Occurrence (Hyslop 1980; Zacharia, Abdurahiman & Mohamed 2004): This is the ratio of the number of guts containing a particular prey item to the total number of guts containing food. This may be expressed as a percentage.

%O = (number of guts containing prey type A / total number of stomach containing food) * 100

%O of each prey type was calculated for different circumstances as follows:

1. Overall for all fish at each site regardless of seagrass position, life stage or size class
2. Per transect (indicative of distance from bare sediment) (Weed whitings – *Neoodax balteatus* and *Haletta semifasciata*)
3. Per distance category from rocky reef (Weed whitings – *Neoodax balteatus* and *Haletta semifasciata*)
4. Per life stage (Ogilby's hardyhead, *Atherinomorus vaigiensis*)
5. Per size class (Weed whitings – *Neoodax balteatus* and *Haletta semifasciata*)

Index of Relative Importance (Pinkas & Iverson 1971): This index encompasses both the number and bulk of the food items within each fish along with their frequency of occurrence to have a better estimate of its importance.

IRI = (%N + %V) * %O

As the incorporated %O was calculated for the different circumstances listed above, so were IRI values.

This calculation of IRI was done for all fish. A modification was done, however, with the weed whitings where food items were not counted, by replacing "%N" with "%W" in the above equation. IRI was only calculated for fish and prey items where all three measures for the prey item were done. As such for plant material of the Ogilby's hardyhead where only % V and %O were calculated, there were no associated IRI measures.

Additional Intricacies of Method

% occurrence and IRI were calculated for fish with food in the alimentary canal only while prey percentage contributions (%N, %V and %W) were calculated with all fish with intact alimentary canals. There were 56 weed whitings in total (46 *Neoodax balteatus* and 10 *Haletta semifasciata*) with 50 of these having food in the alimentary canal (40 *N. balteatus* and 10 *H. semifasciata*) collected from *Posidonia australis* at Greenpoint. All 77 hardyhead samples (*Atherinomorus vaigiensis*) collected from Callala Bay contained food in the stomachs.

Ogilby's hardyhead (Atherinomorus vaigiensis)

All but one of the 77 hardyheads was used for stomach visual fullness estimations due to the stomach of that one fish being ruptured. The intestines of approximately half the *juv 1* samples (n=21 of 41) were not assessed for prey content as at that initial stage of analysis only the stomachs were deemed important and hence only stomach content analysis was done. In order for there to be comparability between this life stage, however, and the other two – *juv 2* and adults, whose alimentary canal was assessed in its entirety, due to the larger and more obvious intestine in these larger fish, intestinal analysis was performed for the other 20 *juv 1* individuals. As such there were less individuals assessed for intestinal fullness and content compared to that within the stomachs.

% Number calculations

% N was consistently done for all prey items (with the exception of plant material found in the guts of *juv 2* and adult hardyheads) in all but two of the hardyhead (n=75). Additionally after analysing the guts of the 41 juveniles the stomach were seen to contain a majority of the prey content and no new prey types were seen in the much thinner intestinal lumen. As such the %N of prey items found in the stomach only (n=21 fish) was used in the analysis along with the other 20 *juv 1* and all adults where the full gut content was enumerated.

% Volume Calculation

% V was not considered for the 21 of the 41 *juv 1* fish samples as length and width measurements of prey were not done at the early stages of analysis with these 21 fish representing the first samples assessed for prey content in the study. As such, less fish were used in the %V measurements (n=55).

Whereas all prey individuals were included in %N prey calculations, only major prey items (%O>25%) were included in %V analysis. % V measurements were used for these major prey items for the *juv 2*, adults and approximately half the total number of *juv 1* (n=55 fish)

IRI was only calculated for fish with prey having both %N and %V calculated (n = 51 fish), as such fish having plant prey items in their intestines were excluded from these measures as this prey item lacked the %N component.

Due to the varying nature of the fish prey items there was some difficulty in finding one method that would appropriately represent and compare each prey item across life stages. The measure closest to doing this was %V which was able to capture and compare both plant and non-plant prey items. %N and IRI excluded the plant material found in the later stage fish. %W was not found to be efficient in measuring the minuscule mass carried in the zooplankton prey predominant in the smallest juveniles, *juv 1*.

Greenpoint – Weed whitings (Neoodax balteatus and Haletta semifasciata)

All 56 fish were used for %W and %V estimations for all prey items. All 50 fish with food in the alimentary canal were used for %O and IRI calculations. All prey types were included in statistical analysis as the fish were mostly within the same life stage (53 juveniles and 3 sub-adults). These were, however, placed in four size classes: 45-55mm, 55- 65 mm, 65- 75 mm and 75-100 mm. These measures (%N, %W, %O and IRI) were able to appropriately represent the suite of prey items found in the gut of these fish.

References

Bray, D.J. 2011, *Blue Weed-whiting, Haletta semifasciata, in Fishes of Australia*, viewed 3 May 2016, <http://www.fishesofaustralia.net.au/home/species/298>.

Gullström, M., Berkström, C., Öhman, M., Bodin, M. & Dahlberg, M. 2011, 'Scale-dependent patterns of variability of a grazing parrotfish *Leptoscarus vaigiensis* in a tropical seagrass-dominated seascape', *Marine Biology*, vol. 158, no. 7, pp. 1483-95.

Hyslop, E. 1980, 'Stomach contents analysis—a review of methods and their application', *Journal of fish biology*, vol. 17, no. 4, pp. 411-29.

Pinkas, L. & Iverson, I. 1971, 'Food habits of albacore, bluefin tuna and bonito in Californian waters', *California Department of Fish and Game: Fish Bulletin*, vol. 152, pp. 1-105.

Robertson, C. & White, R. 1986, 'Feeding patterns of Nesogobius sp., Gymnapistes marmoratus, Neoodax balteatus and Acanthaluteres spilomelanurus from a Tasmanian seagrass meadow', *Marine and Freshwater Research*, vol. 37, no. 4, pp. 481-9.

Zacharia, P., Abdurahiman, K. & Mohamed, K. 2004, 'Methods of stomach content analysis of fishes', *Winter School on Towards Ecosystem Based Management of Marine Fisheries—Building Mass Balance Trophic and Simulation Models*, pp. 148-58.

Appendix III PCO plots visualizing fish and zooplankton community composition with sampling week "wk" at both sites (Greenpoint and Callala Bay, Jervis Bay) during the summer sampling session

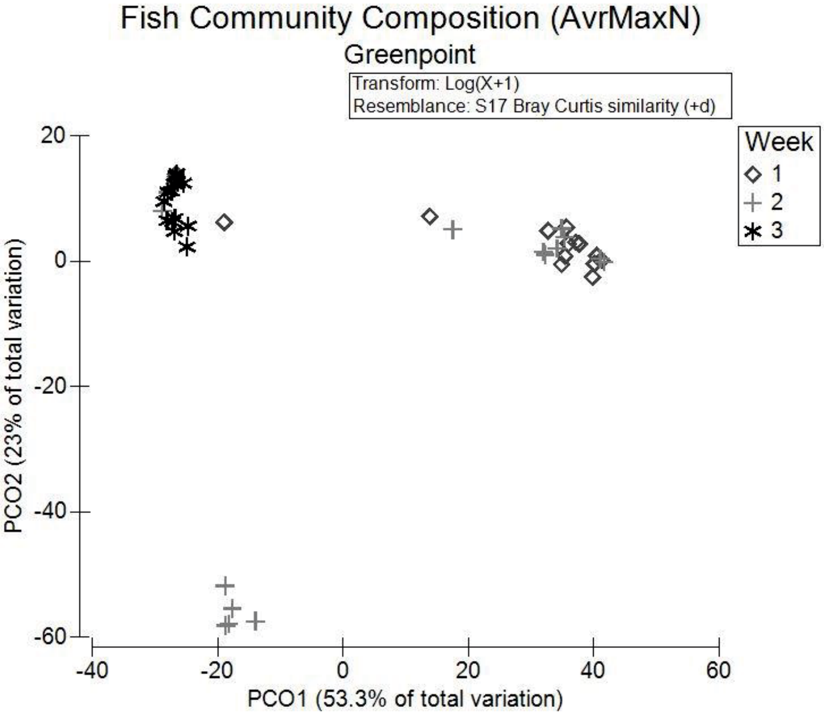


Fig A PCO plot illustrating variation in fish community composition (AvrMaxN) at Greenpoint with sampling occasion (week) over the summer sampling session

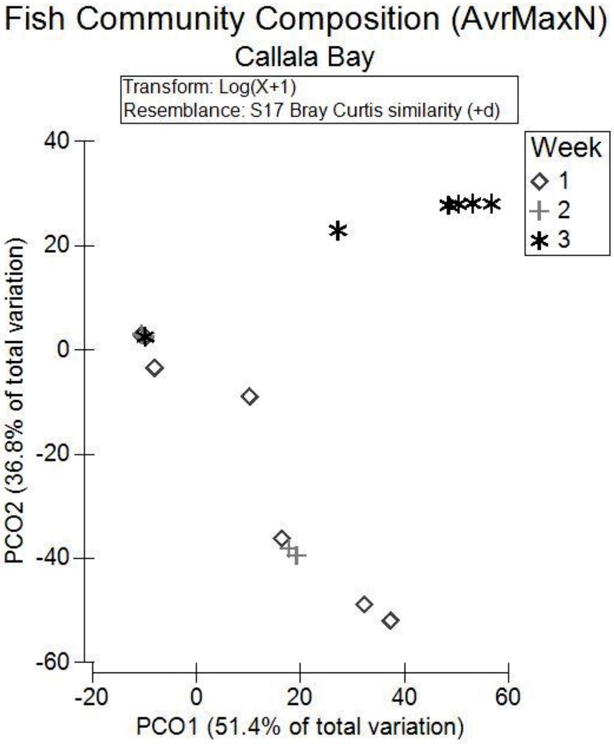


Fig B PCO plot illustrating variation in fish community composition (AvrMaxN) at Callala Bay with sampling occasion (week) over the summer sampling session

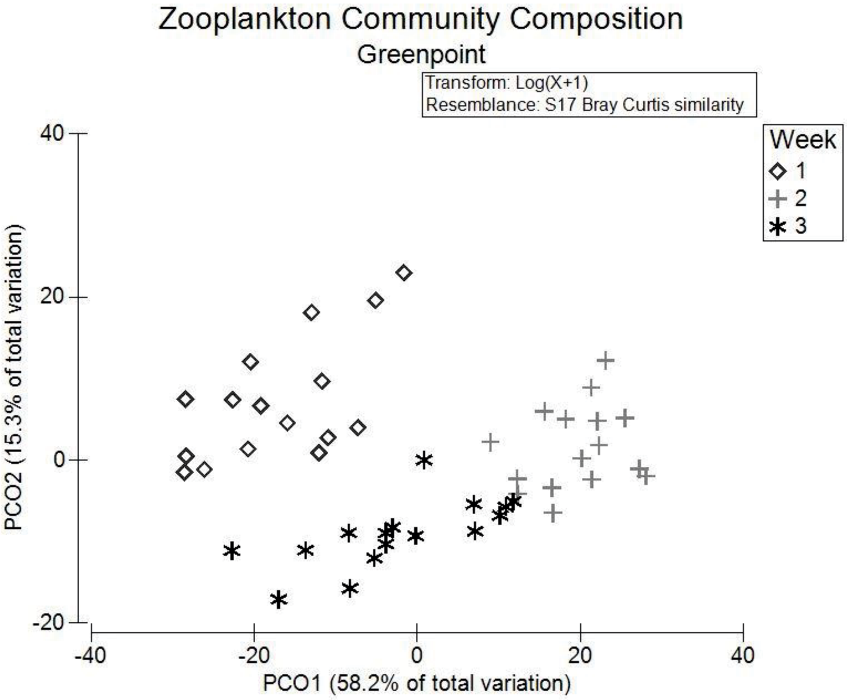


Fig C PCO plot illustrating variation in zooplankton community composition at Greenpoint with sampling occasion (week) over the summer sampling session

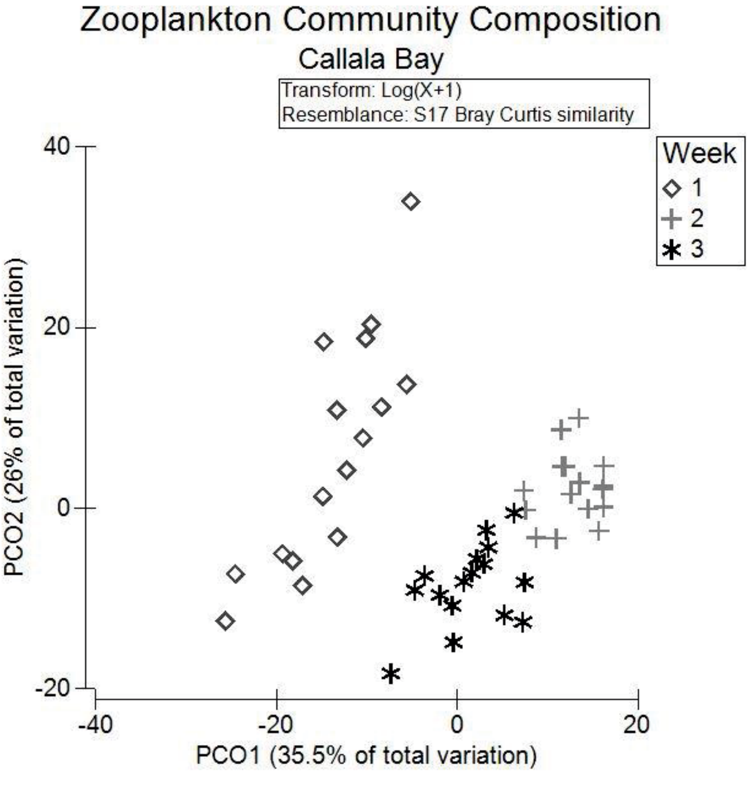


Fig D PCO plot illustrating variation in zooplankton community composition at Callala Bay with sampling occasion (week) over the summer sampling session

Appendix IV Graphical presentation of distribution of select taxa in seagrass positions with increasing distance from both adjacent habitats and general edge for indicated seasons and sites from GoPro video analysis.

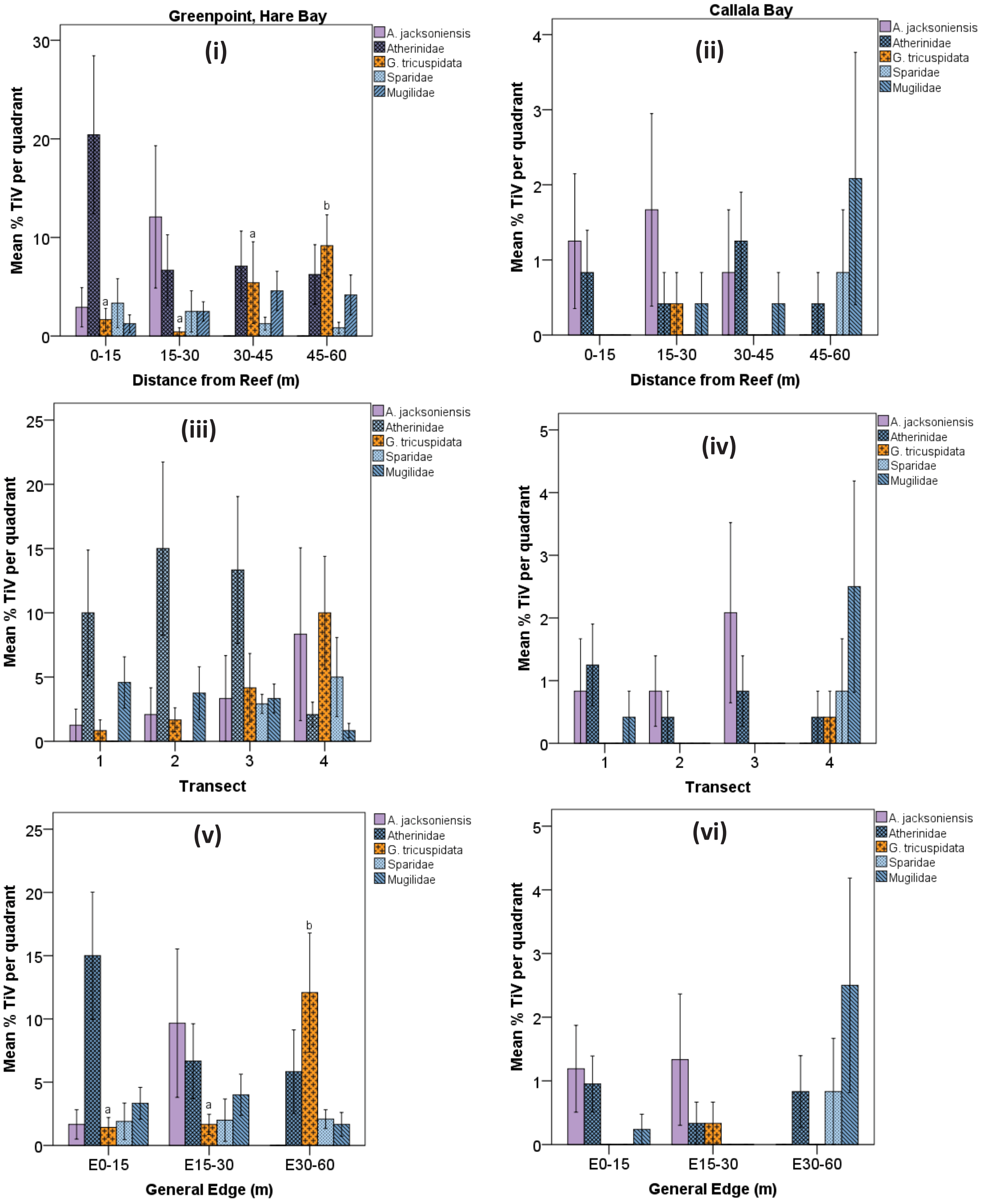


Fig A Distribution (%TiV) of common taxa between both sites (Callala Bay, CB and Greenpoint, GP) with increasing distance from (i,ii) rocky reef, (iii,iv) bare sediment (increasing transect number) and (v,vi) general edge for the summer sampling session only. *Letters above bars represent the results of pairwise comparisons with distance categories lacking similar letters being significantly different.*

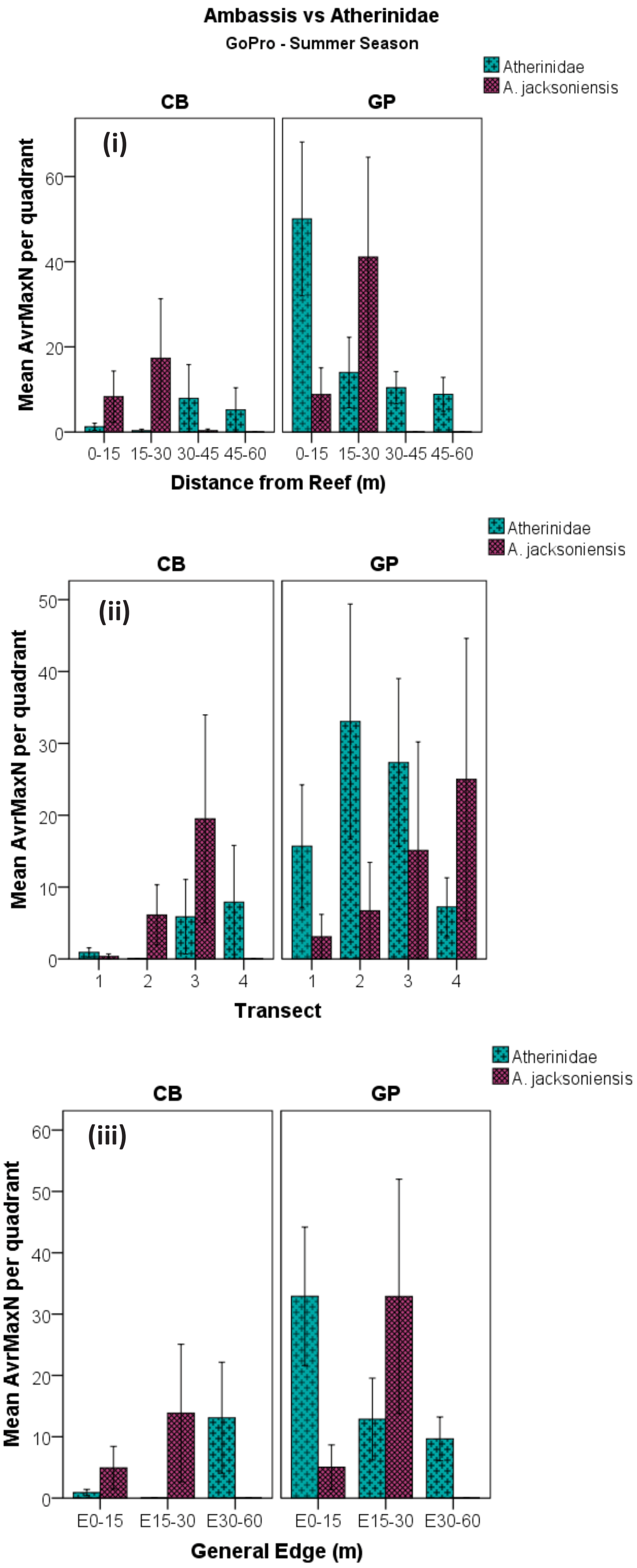


Fig B Comparative distribution of *Ambassis jacksoniensis* and the Atherinidae at both sites during the summer sampling season with increasing distance from (i) rocky reef, (ii) bare sediment (increasing transect number) and (iii) general edge.

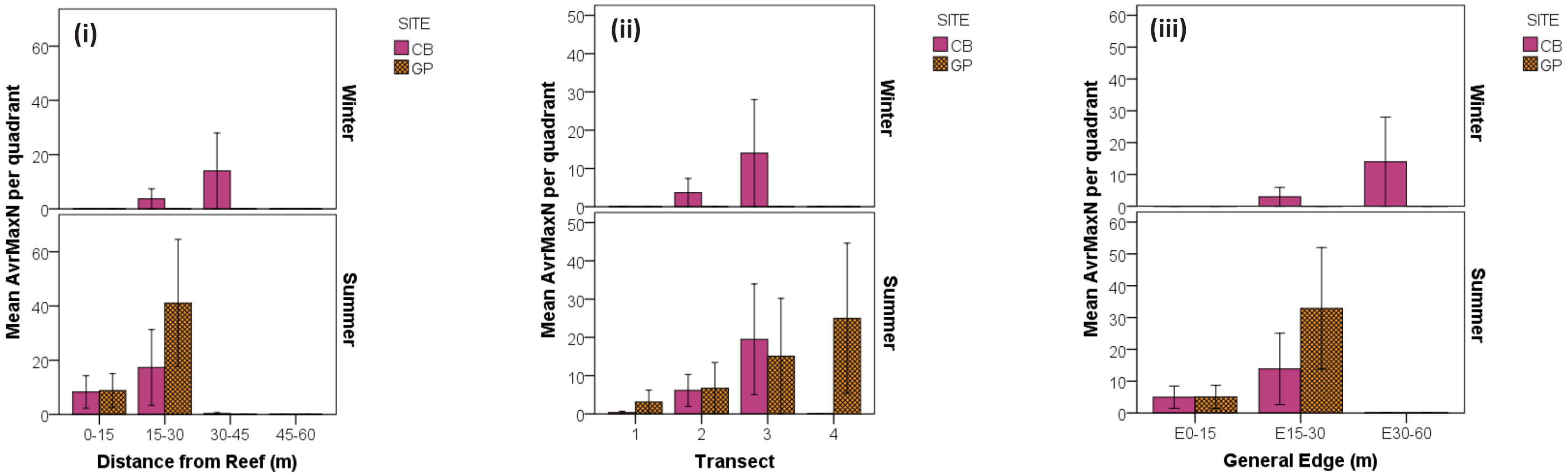


Fig C Distribution of *Ambassis jacksoniensis* during both seasons at both sites with increasing distance from (i) rocky reef, (ii) bare sediment (increasing transect number) and (iii) general edge.

Appendix V Individual taxa sampled by both methods by functional guild classification over both seasons at both sites.

Feeding Mode Functional Groups (FMFG):

Individual Species / Taxa	Method Sampled
CP – Piscivorous Carnivores	
Centropogon australis	SEINE
Gymnapistes marmoratus	SEINE
Siphaemia cephalotes	SEINE
CNP – Non Piscivorous Carnivores	
Bathygobius kreffti	SEINE
Brachaluteres jacksonianus	SEINE
Cheilodactylus spectabilis	SEINE, GOPRO
Enoplosus armatus	SEINE
Hardyhead (juv 2) – *Atherinosoma microstomata and Atherinomorus vaigiensis*	SEINE, GOPRO
Neoodax balteatus	SEINE
Pelates sexlineatus	SEINE
Pseudocaranx wright	GOPRO
Sillago ciliate	SEINE, GOPRO[1]
Sphyraena obtusata	GOPRO
Tetractenos glaber	SEINE, GOPRO
Upeneichthys lineatus	SEINE
Urolophus sp.	SEINE
Weed whitings – *Haletta semifasciata* and *Neoodax balteatus*	SEINE
ZP – Zooplanktivores	
Abudefduf sexfasciatus	SEINE
Ambassis jacksoniensis	GOPRO
Atypichthys strigatus	SEINE, GOPRO
Hardyhead (juv 1) – *Atherinosoma microstomata* and *Atherinomorus vaigiensis*	SEINE
Mugil cephalus (juv)	SEINE
Scorpis aequipinnis	SEINE
Spratelloides robustus	SEINE
Stigmatopora argus	SEINE

OV – Omnivores	
Aldrichetta forsteri	SEINE
Atherinomorus vaigiensis (adult)	SEINE
Hyporhamphus regularis	SEINE
Meuschenia freycineti	SEINE
Microcanthus strigatus	SEINE
Myxus elongates	SEINE
Rhabdosargus sarba	SEINE
Scobinichthys granulatus	SEINE
Trygonorrhina fasciata	GOPRO
[2]Mugilidae	GOPRO
[2]Sparidae	GOPRO
HV – Herbivores	
Acanthaluteres spilomelanurus	SEINE, GOPRO
Acanthaluteres vittiger	SEINE, GOPRO
Girella tricuspidata	GOPRO

[1] – Winter sampling session only

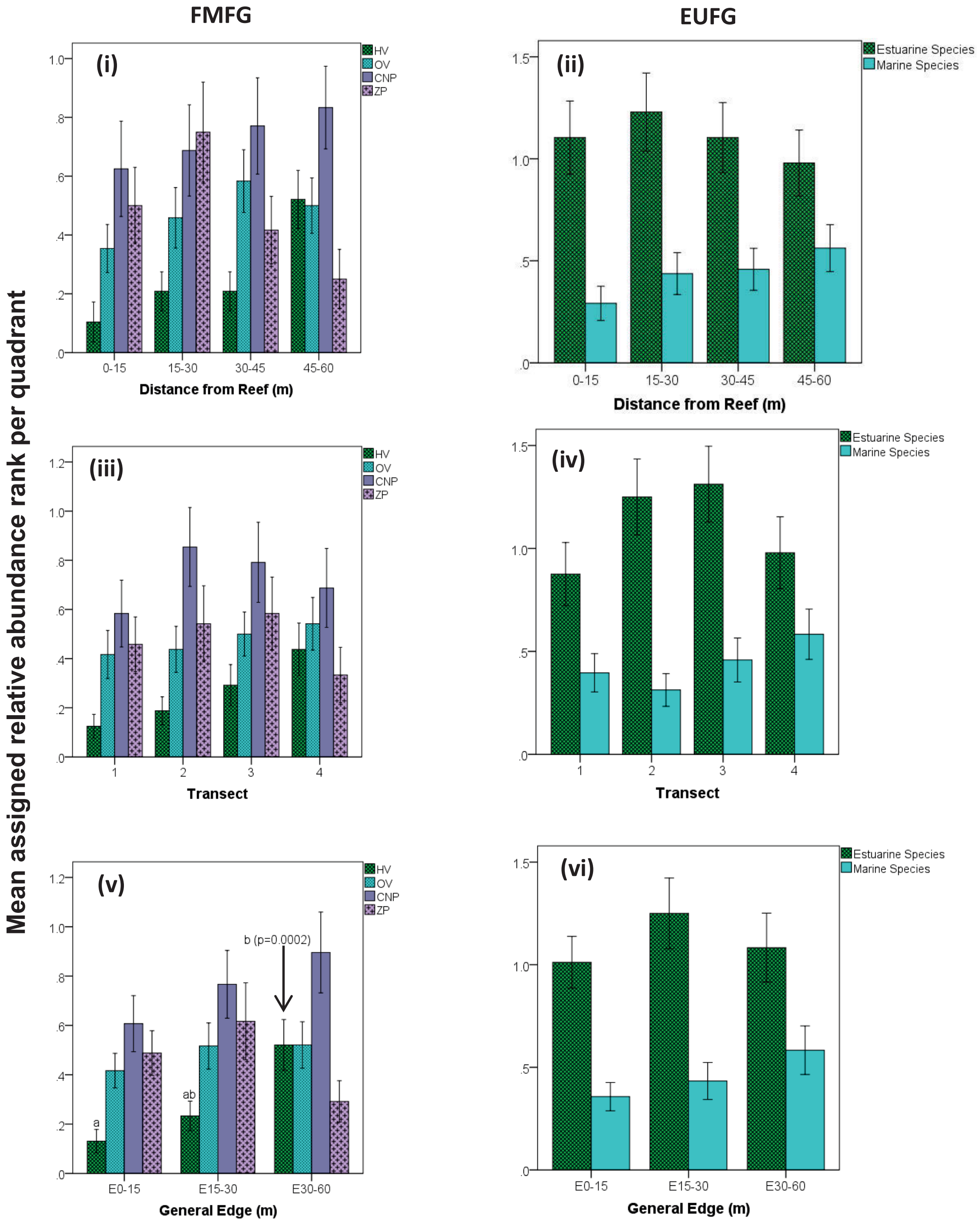
Estuarine Use Functional Groups (EUFG):

Individual Species / Taxa	**Method Sampled**
Estuarine Species (ES)	
EM – Estuarine Migrants	
Acanthaluteres spilomelanurus	SEINE, GOPRO
Acanthaluteres vittiger	SEINE,GOPRO
Ambassis jacksoniensis	GOPRO
Atypichthys strigatus	SEINE, GOPRO
Brachaluteres jacksonianus	SEINE
Centropogon australis	SEINE
Enoplosus armatus	SEINE
Hyporhamphus regularis	SEINE
Microcanthus strigatus	SEINE
Pelates sexlineatus	SEINE
Pseudocaranx wright	GOPRO

Scobinichthys granulatus	SEINE
Sillago ciliate	SEINE, GOPRO[1]
Sphyraena obtusata	GOPRO
Stigmatopora argus	SEINE
Tetractenos glaber	SEINE, GOPRO
Trygonorrhina fasciata	GOPRO
Upeneichthys lineatus	SEINE
Urolophus sp.	SEINE
ER – Estuarine Residents	
Atherinosoma microstomata and *Atherinomorus vaigiensis*	SEINE, GOPRO
Bathygobius kreffti	SEINE
Gymnapistes marmoratus	SEINE
Siphaemia cephalotes	SEINE
Weed whitings – *Haletta semifasciata* and *Neoodax balteatus*	SEINE
Marine Species (M)	
MM – Marine Migrants	
Aldrichetta forsteri	SEINE
Girella tricuspidata	GOPRO
Mugil cephalus (juv)	SEINE
Myxus elongates	SEINE
Rhabdosargus sarba	SEINE
Spratelloides robustus	SEINE
[2]Mugilidae	GOPRO
[2]Sparidae	GOPRO
MS – Marine Stragglers	
Abudefduf sexfasciatus	SEINE
Cheilodactylus spectabilis	SEINE, GOPRO
Meuschenia freycineti	SEINE
Scorpis aequipinnis	SEINE

[1] – Winter sampling session only; [2] – Taxa grouped in video analysis

Appendix VI Distribution of FMFG (left panel) and collated EUFG (right panel) guilds with distance from (i,ii) rocky reef (iii,iv) bare sediment and (v,vi) general edge with both sites, seasons and sampling methods (GoPro and seine) pooled using semi-quantitative data. *Increasing transect # represent increasing distance from bare sediment; different letters above bars indicate significant difference with the p value in brackets indicating pairwise comparison results with significantly varying distance category.*



Appendix VII Zooplankton taxonomic groups (Classification levels)

<u>Level 1 Grouping – Lowest level of classification (left most column) as observed and identified</u>

Hydrozoa	Class	Phylum	Cnidaria
Bivalve larvae	Class	Phylum	Mollusca
Smaller gastropods (generally 0.1 – 0.45mm) larvae	Class	Phylum	Mollusca
Larger gastropods (> 0.9mm) larvae	Class	Phylum	Mollusca
Strombidae	Family	Phylum Class Clade Clade Clade Superfamily Family	Mollusca Gastropoda Caenogastropoda Hypsogastropoda Littorinimorpha Stromboidea Strombidae
Mesogastropoda	Order	Phylum Class	Mollusca Gastropoda
Cephalopoda	Class	Phylum	Mollusca
Ostracods	Class	Phylum Subphylum Class	Arthropoda Crustacea Ostracoda
Decapods	Order	Phylum Subphylum Class Superorder Order	Arthropoda Crustacea Malacostraca Eucarida Decapoda
Mysidacea	Order	Phylum Subphylum Class Superorder Order	Arthropoda Crustacea Malacostraca Pericarida Mysidacea
Isopods – non parasitic	Order	Phylum Subphylum Class Superorder Order	Arthropoda Crustacea Malacostraca Pericarida Isopoda
Isopods – parasitic	Order	same as above	
Amphipod	Order	Phylum Subphylum Class Superorder Order	Arthropoda Crustacea Malacostraca Pericarida Amphipoda
Cumacea	Order	Phylum Subphylum Class Superorder Order	Arthropoda Crustacea Malacostraca Pericarida Cumacea

Euphausia	Order	Phylum Subphylum Class Superorder Order	Arthropoda Crustacea Malacostraca Eucarida Euphausiacea (krill)
Malacostraca (unid.)	Class	Phylum Subphylum Class	Arthropoda Crustacea Malacostraca
Crustacean nauplii	Subphylum	Phylum Subphylum	Arthropoda Crustacea
Copepoda – unidentified	Subclass	Phylum Subphylum Class Subclass	Arthropoda Crustacea Maxillopoda Copepoda
Calanoid	Order	Phylum Subphylum Class Subclass Order	Arthropoda Crustacea Maxillopoda Copepoda Calanoida
Cyclopoid – unidentified	Order	Phylum Subphylum Class Subclass Order	Arthropoda Crustacea Maxillopoda Copepoda Cyclopoida
Cyclopoid parasitic	Order	same as above	
Oithona sp.	Family	Phylum Subphylum Class Subclass Order Family Genus	Arthropoda Crustacea Maxillopoda Copepoda Cyclopoida Oithonidae *Oithona*
Lubbockiidae	Family	Phylum Subphylum Class Subclass Order Family	Arthropoda Crustacea Maxillopoda Copepoda Cyclopoida Lubbockiidae
Onaceaidae	Family	Phylum Subphylum Class Subclass Order Family	Arthropoda Crustacea Maxillopoda Copepoda Poecilostomatoida Onaceaidae

Onacea waldemari	Genus species	Phylum	Arthropoda
		Subphylum	Crustacea
		Class	Maxillopoda
		Subclass	Copepoda
		Order	Poecilostomatoida
		Family	Onaceaidae
		Genus	*Onacea*
		Species	*waldemari*
Sappharinidae	Family	Phylum	Arthropoda
		Subphylum	Crustacea
		Class	Maxillopoda
		Subclass	Copepoda
		Order	Poecilostomatoida
		Family	Sappharinidae
Corycaeidae	Family	Phylum	Arthropoda
		Subphylum	Crustacea
		Class	Maxillopoda
		Subclass	Copepoda
		Order	Poecilostomatoida
		Family	Corycaeidae
Harpacticoid	Order	Phylum	Arthropoda
		Subphylum	Crustacea
		Class	Maxillopoda
		Subclass	Copepoda
		Order	Harpacticoida
Copepoda – juvenile	Subclass		
Cirrepedia (barnacle larvae)	Infraclass	Phylum	Arthropoda
		Subphylum	Crustacea
		Class	Maxillopoda
		Subclass	Thecostraca
		Infraclass	Cirrepedia
Cladocera – unidentified	Order	Phylum	Arthropoda
		Subphylum	Crustacea
		Class	Branchiopoda
		Order	Cladocera
Penilia avirostris	Genus species	Phylum	Arthropoda
		Subphylum	Crustacea
		Class	Branchiopoda
		Subclass	Phyllopoda
		Order	Diplostraca
		Suborder	Cladocera
		Family	Sididae
		Genus	Penilia
		Species	avirostris
Evadne sp.	Genus	Phylum	Arthropoda
		Subphylum	Crustacea
		Class	Branchiopoda
		Subclass	Phyllopoda

		Order Suborder Family Genus	Diplostraca Cladocera Podonidae *Evadne*
Crustacean – unidentified	Subphylum		
Sagitta spp	Genus	Superphylum Phylum Class Order Family Genus	Deuterostomia Chaetognatha Sagittoidea Aphragmorphora Sagittidae *Sagitta*
Chaetognatha – unidentified	Phylum	Superphylum Phylum	Deuterostomia Chaetognatha
Appendicularia	Class	Phylum Class	Urochordata Appendicularia
Oikopleura dioica	Genus species	Phylum Class Order Family Genus Species	Urohordata Appendicularia Copelata Oikopleuridae *Oikopleura* (Vexillaria) *dioica*
Ascidiacea	Class	Phylum Class	Urohordata Ascidiacea
Echinodermata	Phylum	Superphylum Phylum	Deuterostomia Echinodermata
Noctiluca	Genus	Phylum Class Order Family Genus	Dinoflagellata Noctiluciphyceae Noctilucales Noctilucaceae Noctiluca
Spionidae	Family	Phylum Class Subclass Order Suborder Family	Annelida Polychaeta Palpata Canalipalpata Spionida Spionidae
Syllidae	Family	Phylum Class Order Superfamily Family	Annelida Polychaeta Phyllodocida Nereidoidea Syllidae
Aphroditidae	Family	Phylum Class Order Superfamily Family	Annelida Polychaeta Phyllodocida Aphroditoidea Aphroditidae
Other Polychaete larvae	Class	Phylum Class	Annelida Polychaeta

Phoronidae	Family	Phylum	Phoronida
		Family	Phoronidae
All unidentified eggs			
All other unidentified larvae			
Unknown			

<u>Level 2 Grouping – Intermediate level classification (used in community analysis in current study)</u>

Hydrozoa	Class
Bivalves	Class
All gastropods	Class
All ostracods	Class
All Eucarida	Superorder
All Pericarida	superorder
All crustacean nauplii	subphylum
All Calanoid	Order
All Cyclopoid	Order
All Poecilostomatoida	Order
All Harpacticoida	Order
Copepod juveniles	Subclass
Copepod unidentified	Subclass
Cirrepedia (barnacle larvae)	Infraclass
Cladocera (total)	Order
Chaetognatha (total)	Phylum
Urochordata (total)	Phylum
Echinodermata	Phylum
Dinoflagellata – Noctilucales	Order
Phoronidae	Family
Annelida (total)	Phylum
All unidentified eggs	
All unidentified larvae	
Unknown	

Level 3 Grouping – Higher level of classification considered

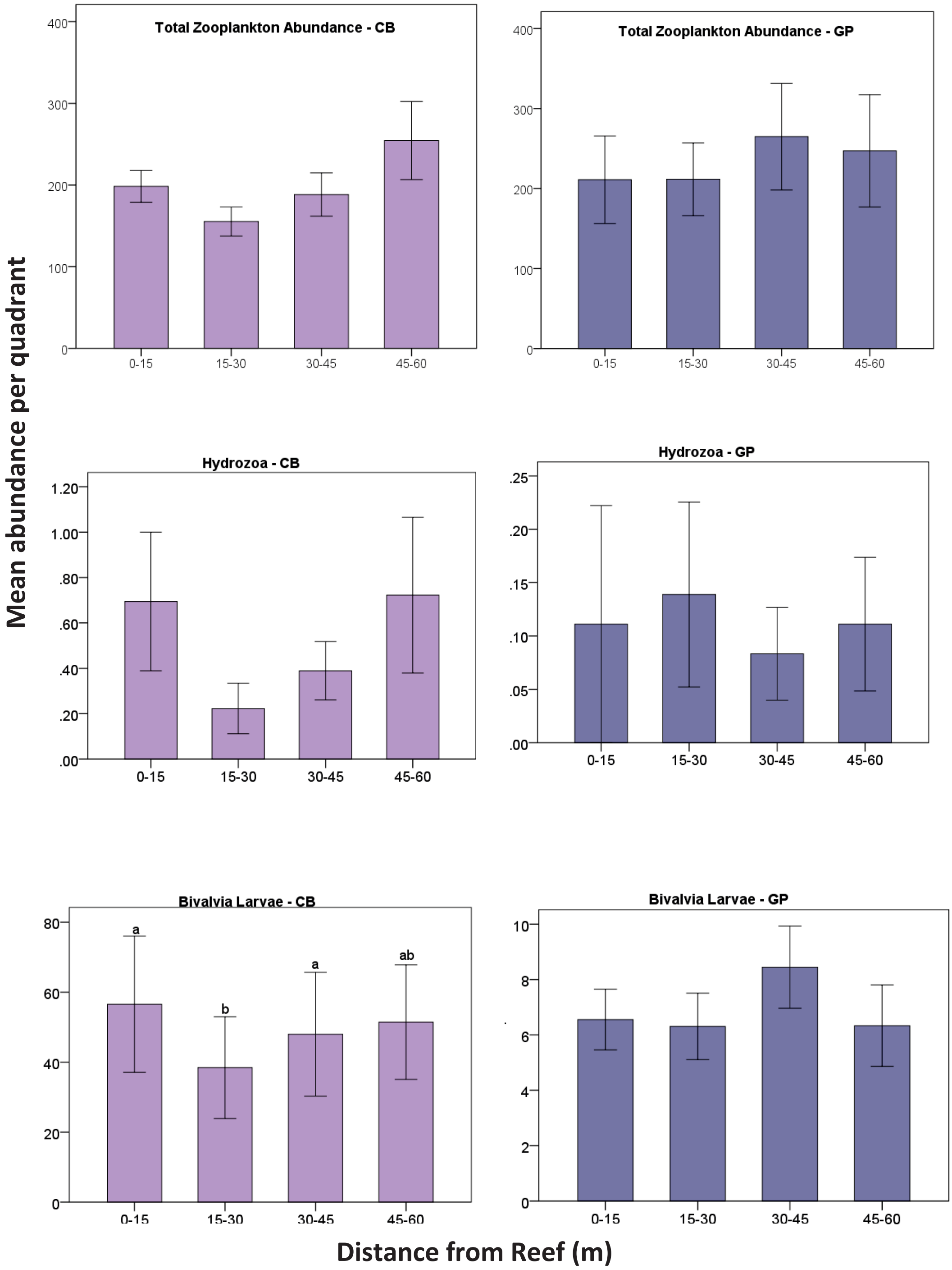
Hydrozoa	Class
All Mollusca	Phylum
Crustacean nauplii	Subphylum
Malacostraca (minus crustacean nauplii)	Class
All Copepoda	Subclass
Cirrepedia	Infraclass
Non-copepod, non-cladoceran Crustaceans	Subphylum
Cladocera	Order
Chaetognatha	Phylum
Urochordata	Phylum
Echinodermata	Phylum
Dinoflagellata – Noctilucales	Order
Annelida	Phylum
Phoronidae	Family
Unidentified eggs and larvae	
Unknown	

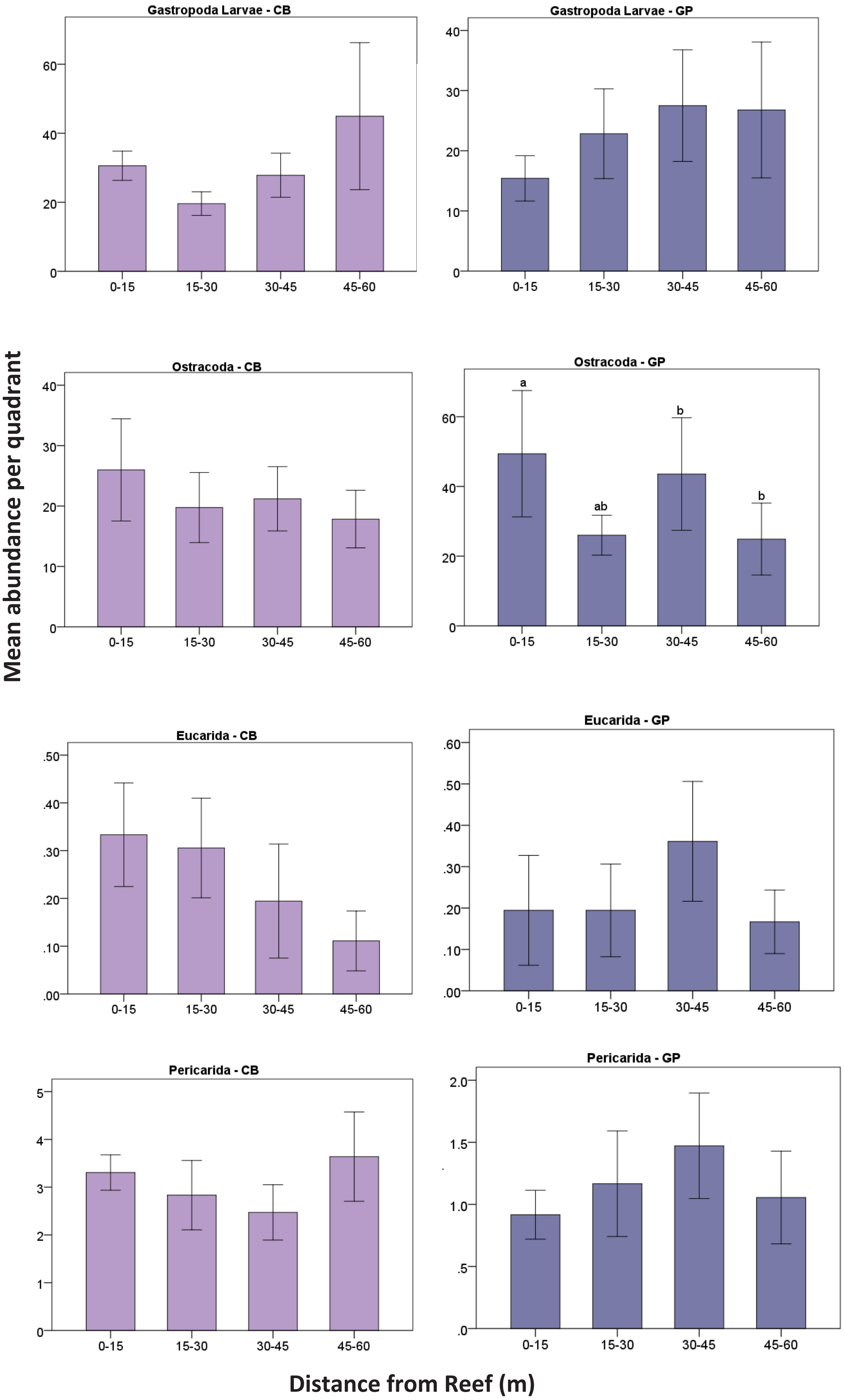
Level 4 Grouping – Highest level of classification considered

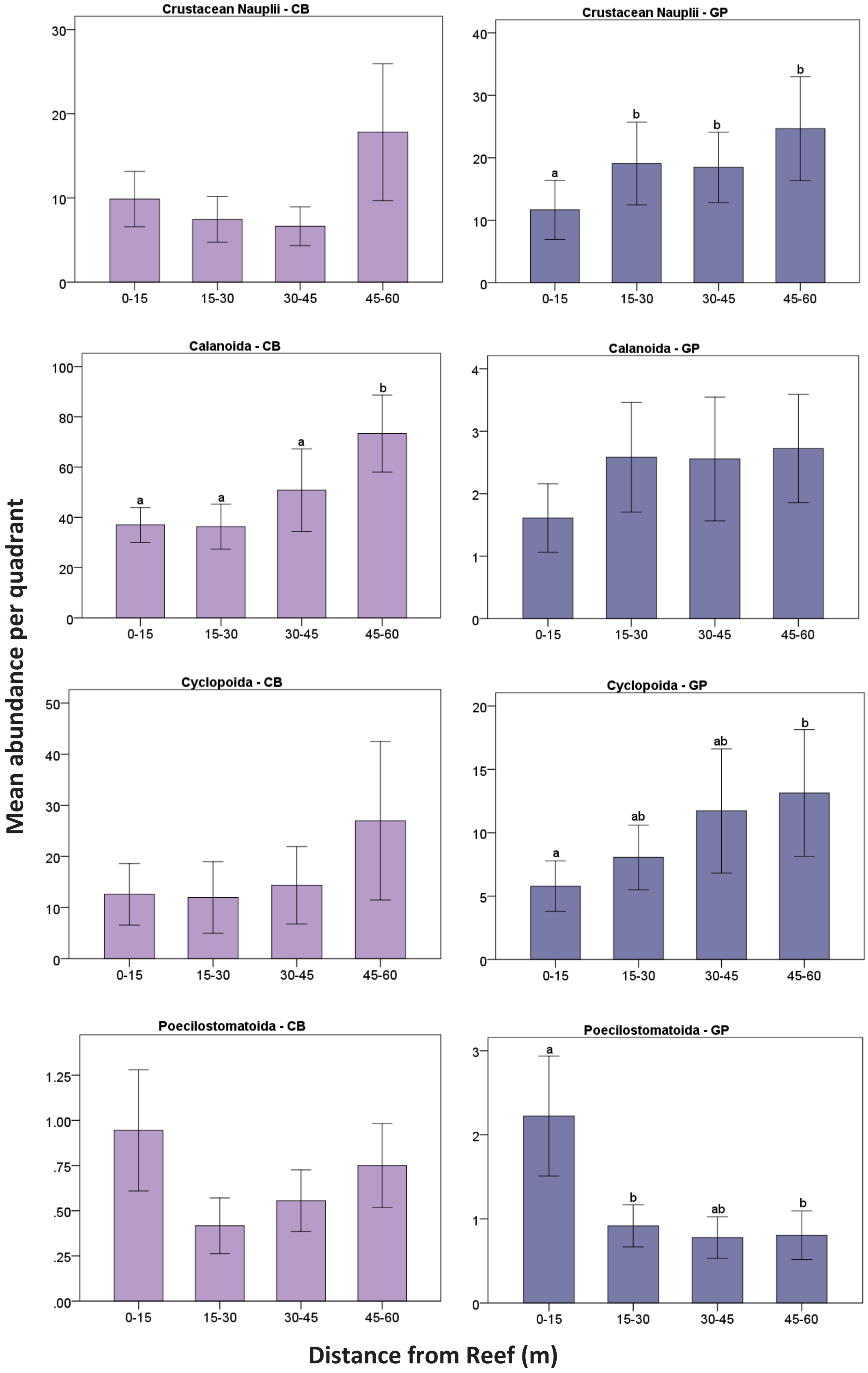
Hydrozoa	Class
All Molluscs	Phylum
All Crustaceans	Subphylum
Chaetognaths	Phylum
Urochordata	Phylum
Echinodermata	Phylum
Dinoflagellata – Noctilucales	Order
Annelidae	Phylum
Phoronidae	Family
Unidentified eggs and larvae	
Unknown	

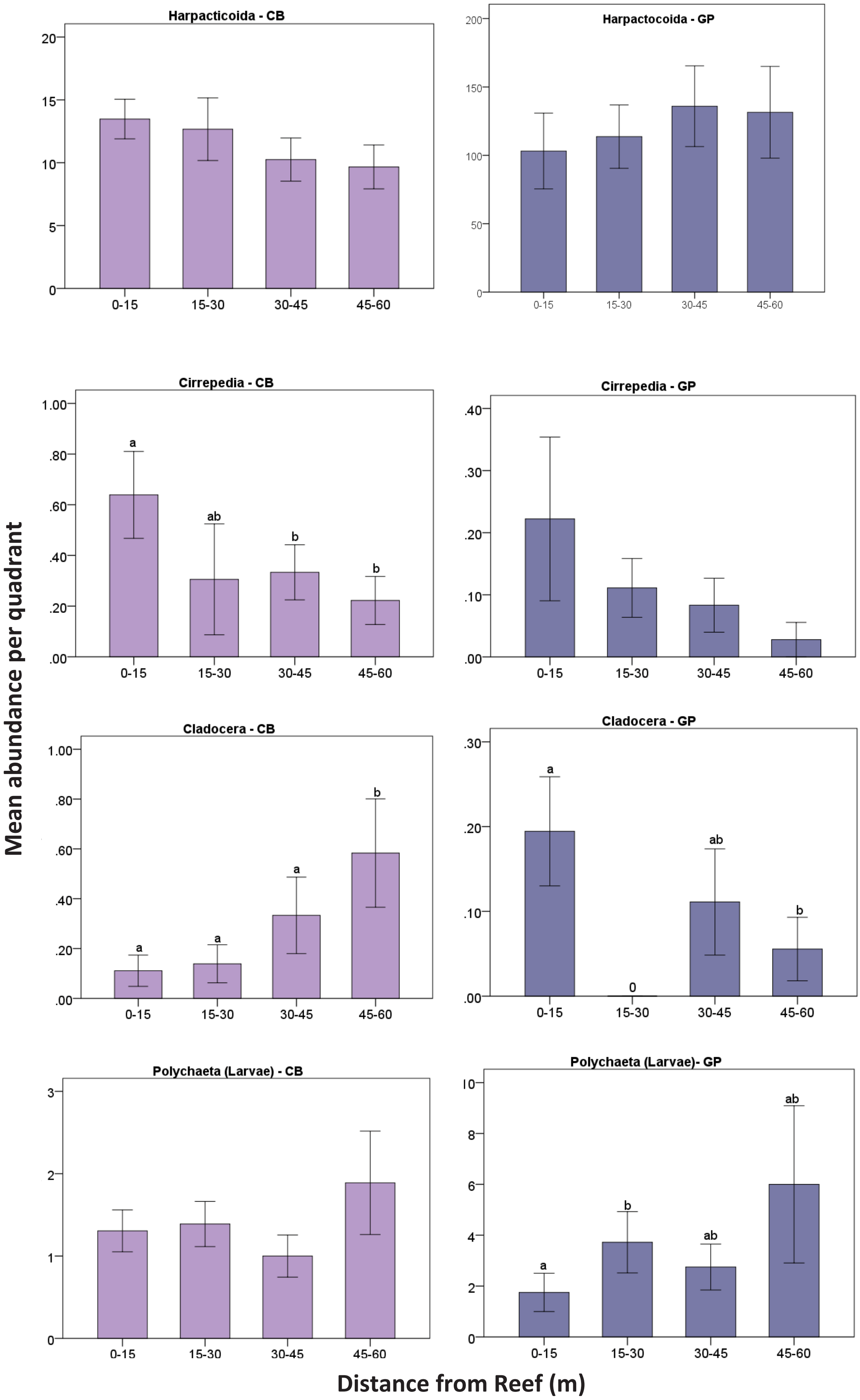
Appendix VIII Total zooplankton abundance and that of main zooplankton taxa with increasing distance from reef, bare sediment and general edge.

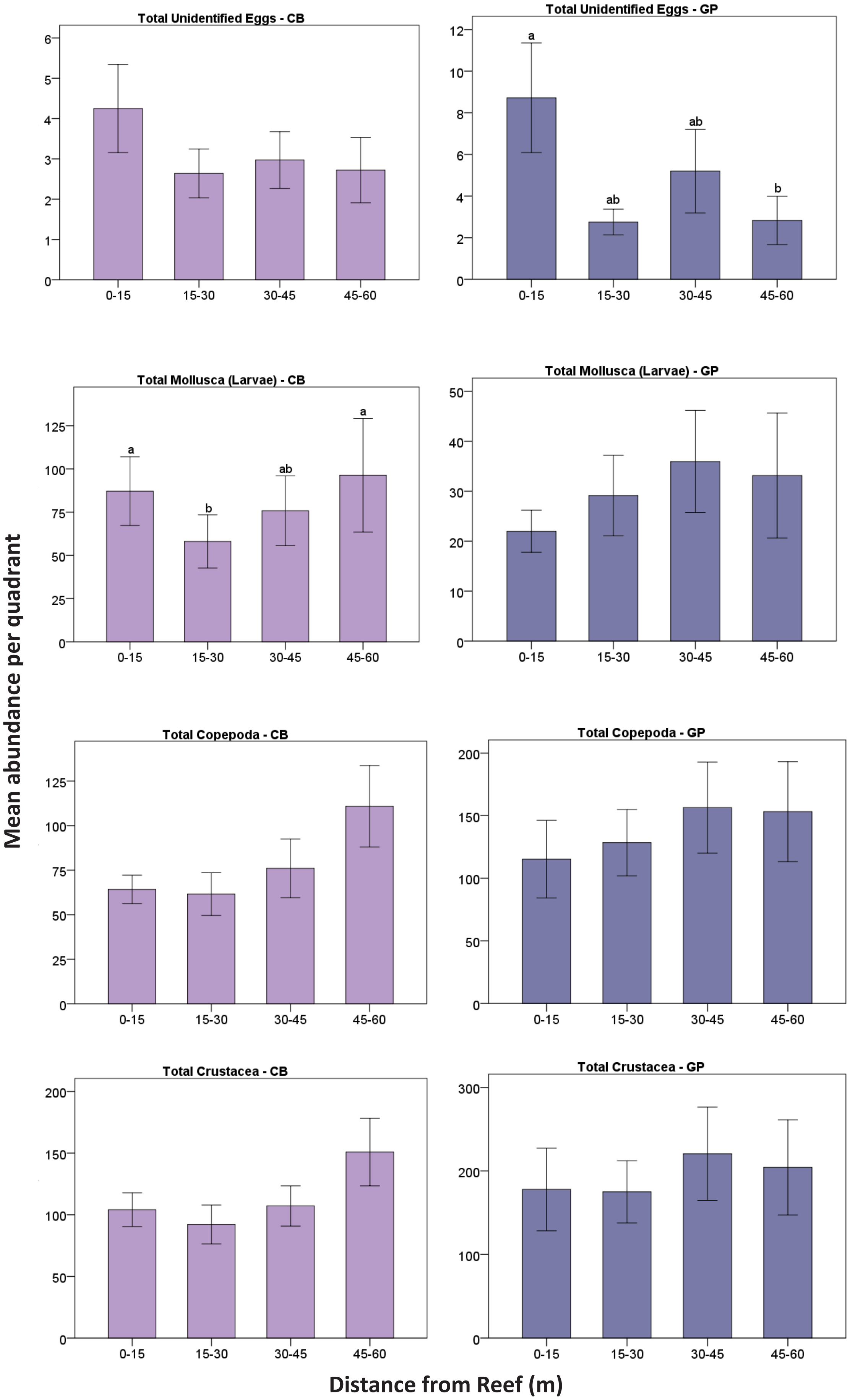
Distance from Reef

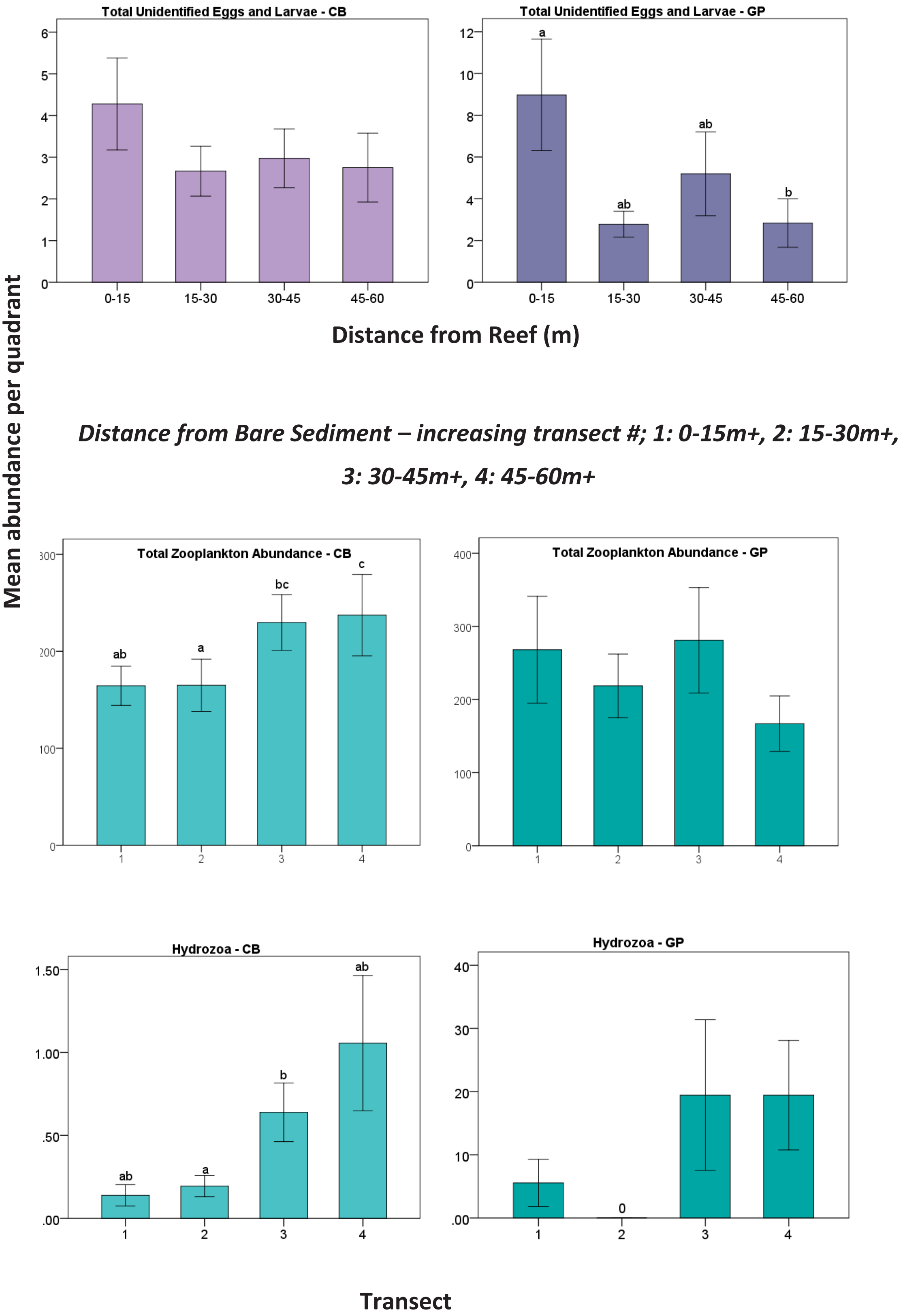


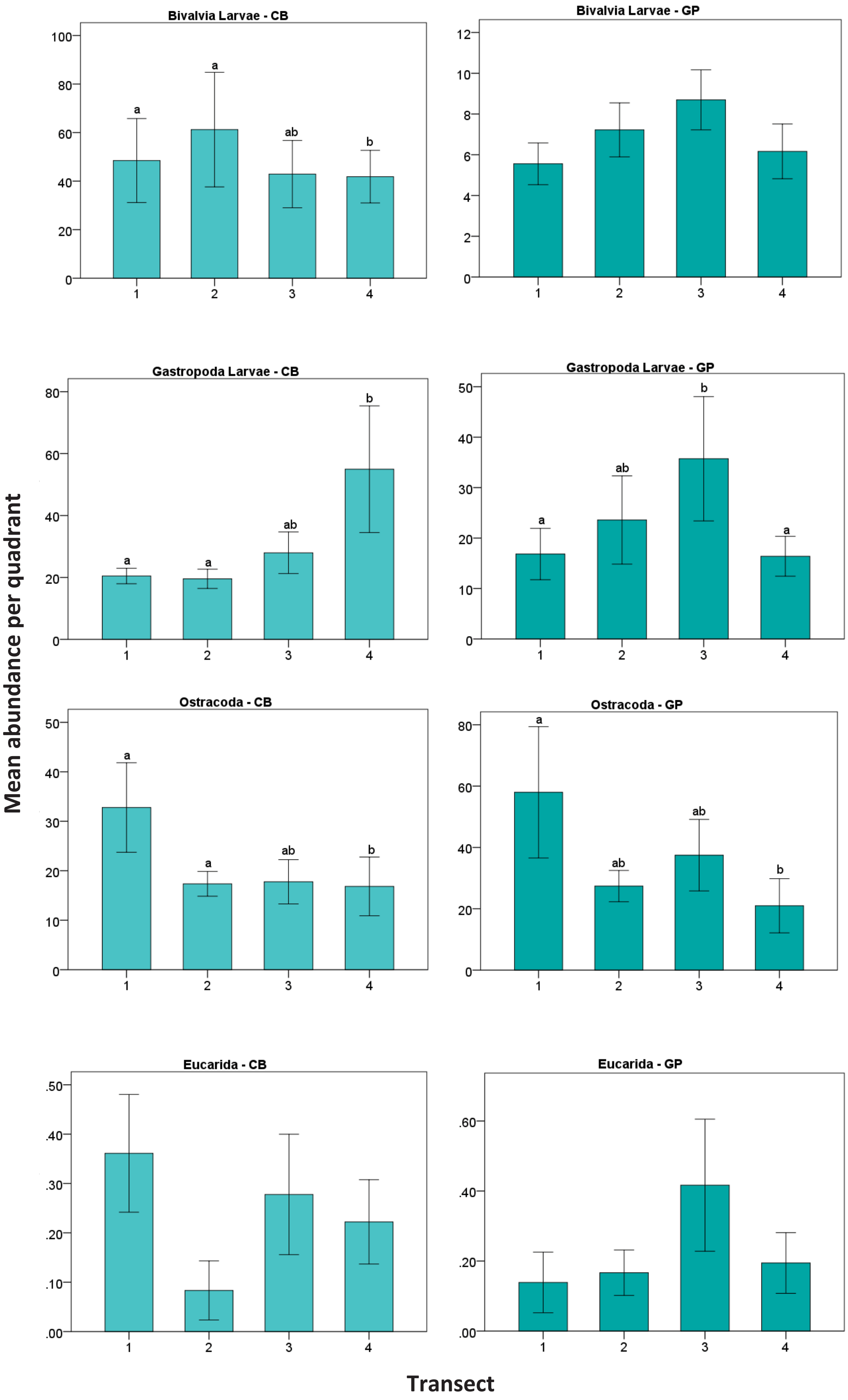

Gastropoda Larvae - CB
0
20
40
60
0-15
15-30
30-45
45-60
Gastropoda Larvae - GP
0
10
20
30
40
0-15
15-30
30-45
45-60
Mean abundance per quadrant
Ostracoda - CB
0
10
20
30
40
0-15
15-30
30-45
45-60
Ostracoda - GP
a
ab
b
b
0
20
40
60
0-15
15-30
30-45
45-60
Eucarida - CB
.00
.10
.20
.30
.40
.50
0-15
15-30
30-45
45-60
Eucarida - GP
.00
.10
.20
.30
.40
.50
.60
0-15
15-30
30-45
45-60
Pericarida - CB
0
1
2
3
4
5
0-15
15-30
30-45
45-60
Pericarida - GP
.0
.5
1.0
1.5
2.0
0-15
15-30
30-45
45-60
Distance from Reef (m)

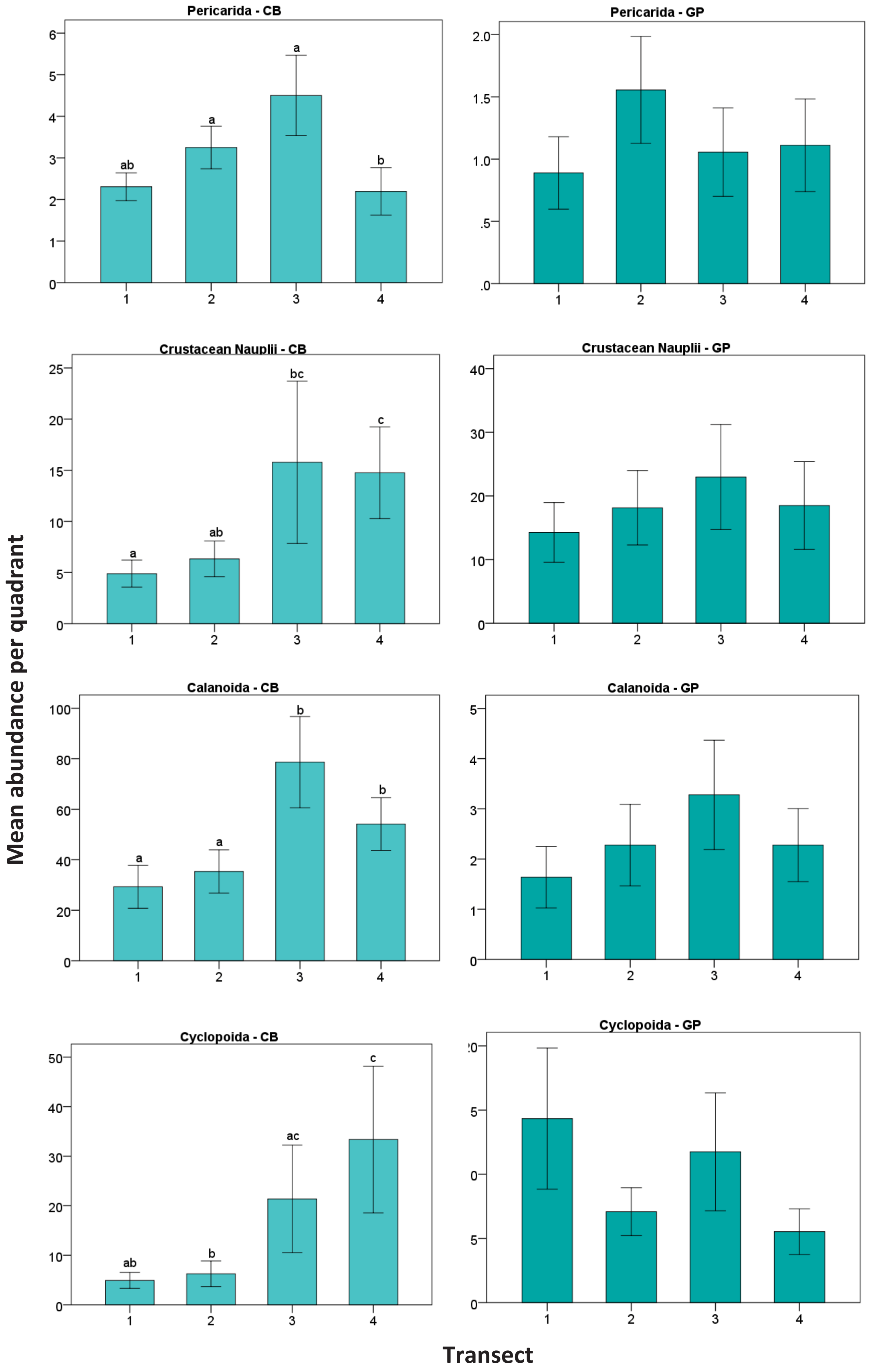

Crustacean Nauplii - CB
0
10
20
30
0-15
15-30
30-45
45-60
Crustacean Nauplii - GP
0
10
20
30
40
a
b
b
b
0-15
15-30
30-45
45-60
Calanoida - CB
0
20
40
60
80
100
a
a
a
b
0-15
15-30
30-45
45-60
Calanoida - GP
0
1
2
3
4
0-15
15-30
30-45
45-60
Cyclopoida - CB
0
10
20
30
40
50
0-15
15-30
30-45
45-60
Cyclopoida - GP
0
5
10
15
20
a
ab
ab
b
0-15
15-30
30-45
45-60
Poecilostomatoida - CB
.00
.25
.50
.75
1.00
1.25
0-15
15-30
30-45
45-60
Poecilostomatoida - GP
0
1
2
3
a
b
ab
b
0-15
15-30
30-45
45-60
Mean abundance per quadrant
Distance from Reef (m)

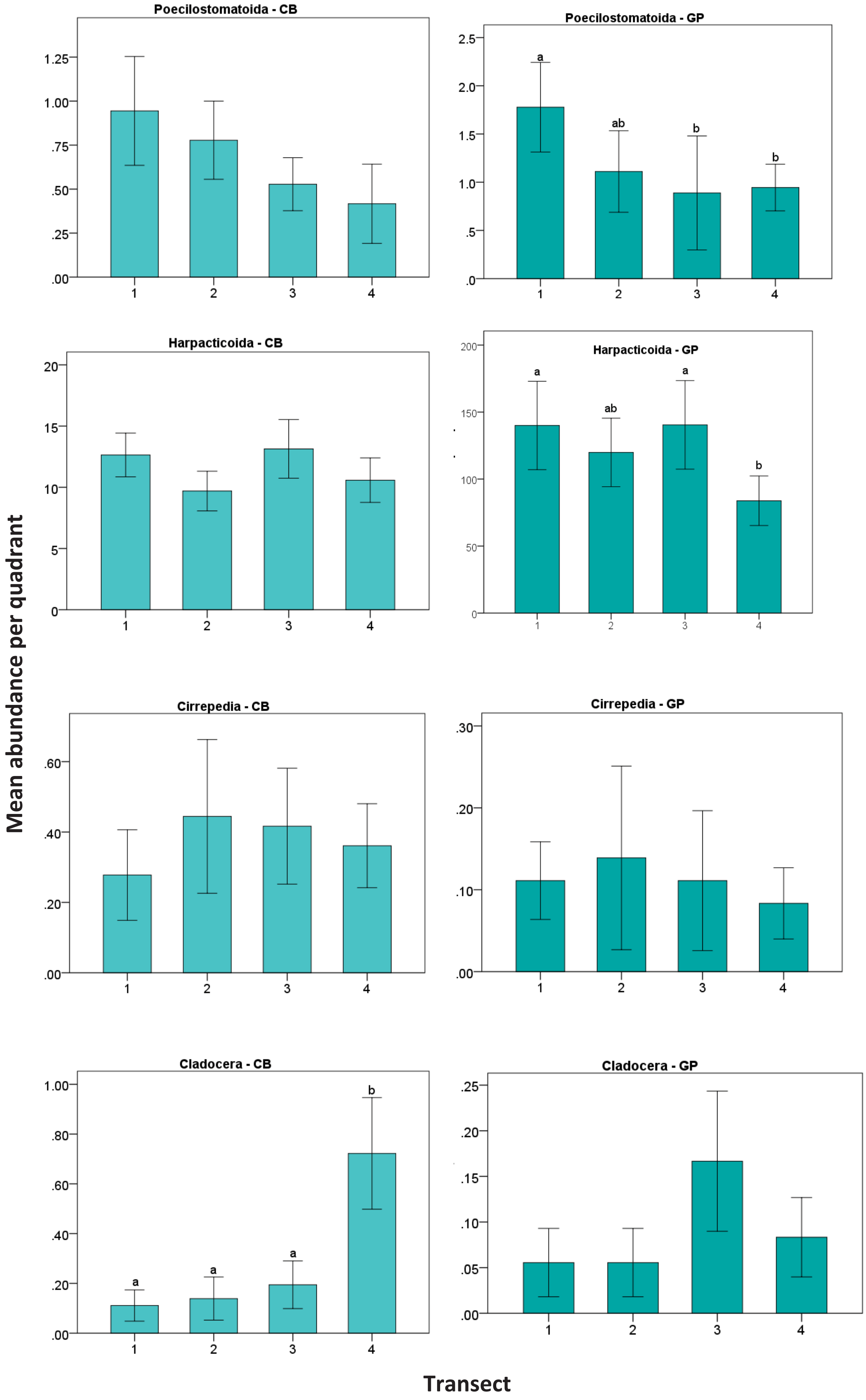

Harpacticoida - CB
0
5
10
15
20
0-15
15-30
30-45
45-60
Harpactocoida - GP
0
50
100
150
200
0-15
15-30
30-45
45-60
Cirrepedia - CB
.00
.20
.40
.60
.80
1.00
a
ab
b
b
0-15
15-30
30-45
45-60
Cirrepedia - GP
.00
.10
.20
.30
.40
0-15
15-30
30-45
45-60
Cladocera - CB
.00
.20
.40
.60
.80
1.00
a
a
a
b
0-15
15-30
30-45
45-60
Cladocera - GP
.00
.10
.20
.30
a
0
ab
b
0-15
15-30
30-45
45-60
Polychaeta (Larvae) - CB
0
1
2
3
0-15
15-30
30-45
45-60
Polychaeta (Larvae)- GP
0
2
4
6
8
10
a
b
ab
ab
0-15
15-30
30-45
45-60
Mean abundance per quadrant
Distance from Reef (m)

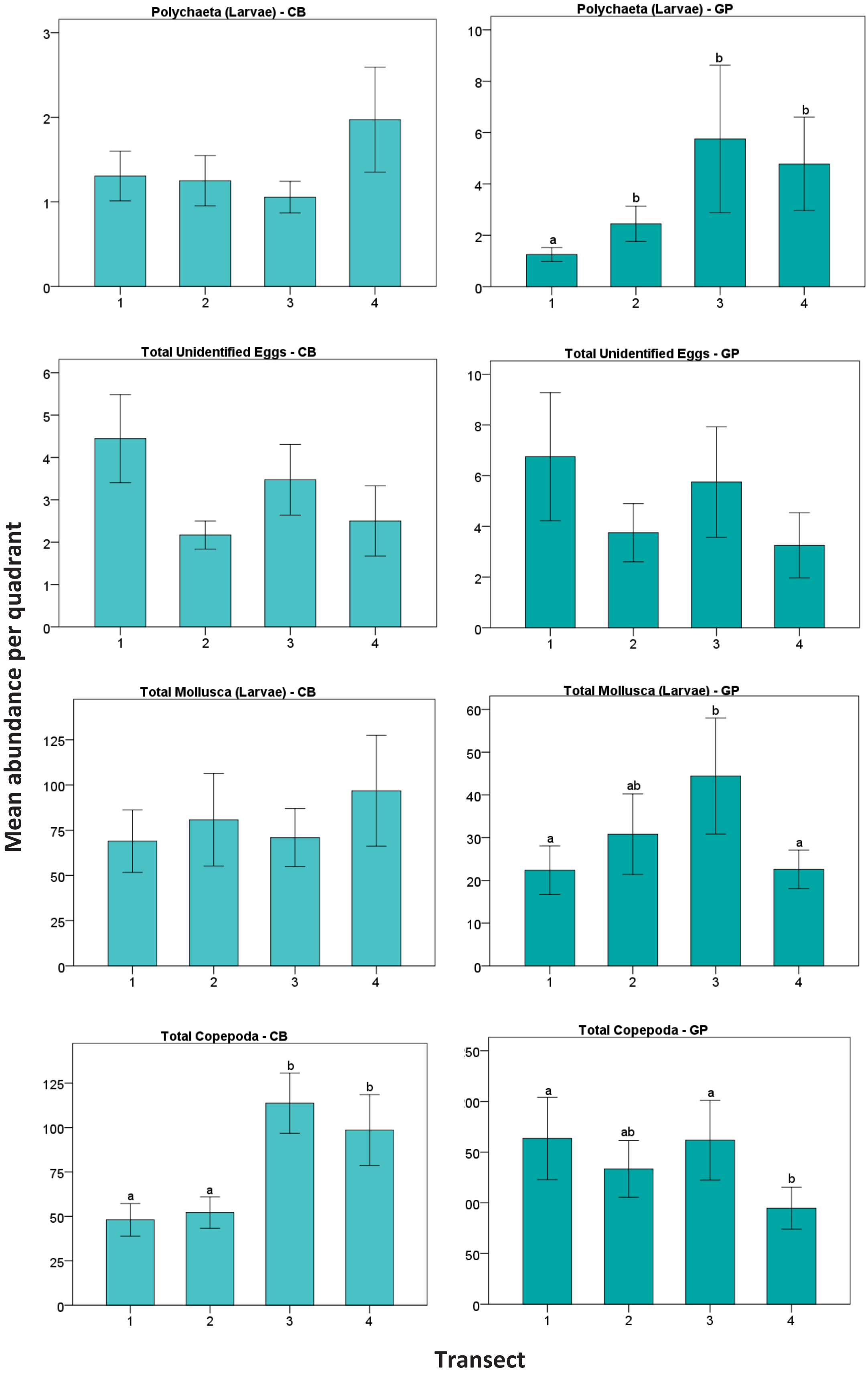

Total Unidentified Eggs - CB
0
1
2
3
4
5
6
Total Unidentified Eggs - GP
0
2
4
6
8
10
12
a
ab
ab
b
Total Mollusca (Larvae) - CB
0
25
50
75
100
125
a
b
ab
a
Total Mollusca (Larvae) - GP
0
10
20
30
40
50
Total Copepoda - CB
0
25
50
75
100
125
Total Copepoda - GP
0
50
100
150
200
Total Crustacea - CB
0
50
100
150
200
Total Crustacea - GP
0
100
200
300
0-15
15-30
30-45
45-60
Mean abundance per quadrant
Distance from Reef (m)

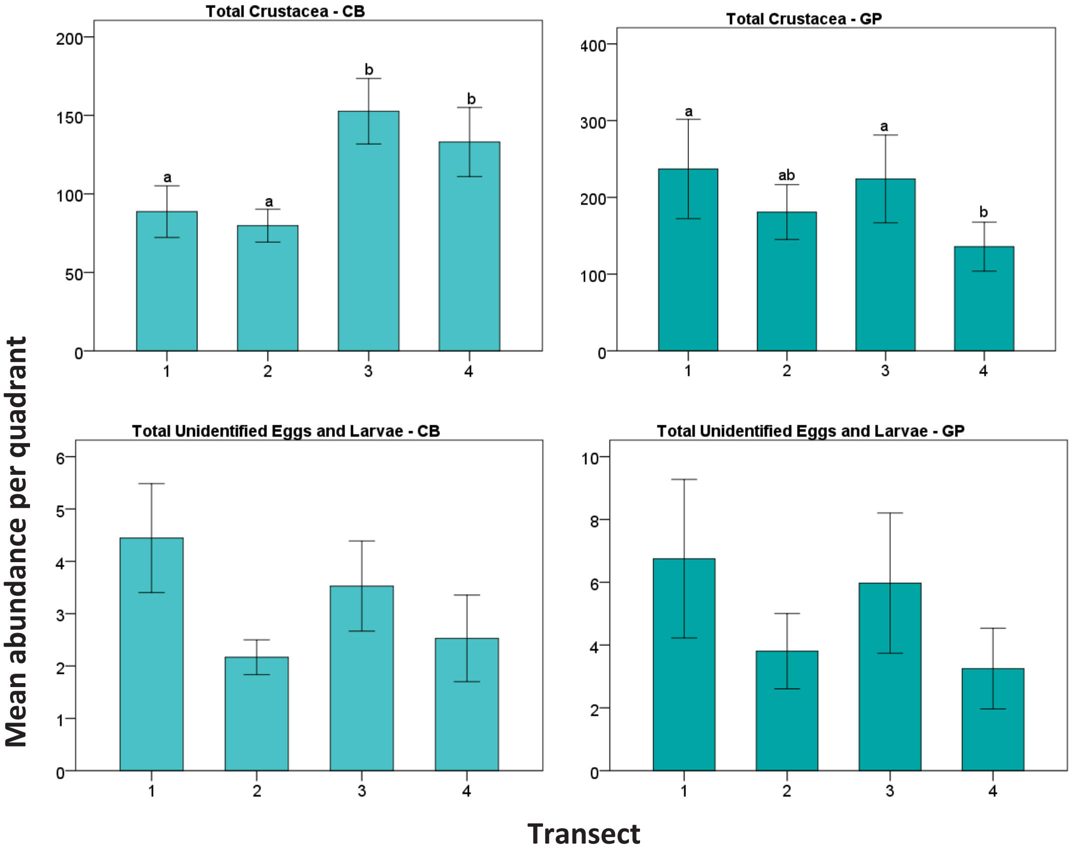

Mean abundance per quadrant
Total Unidentified Eggs and Larvae - CB
0
1
2
3
4
5
6
0-15
15-30
30-45
45-60
Total Unidentified Eggs and Larvae - GP
0
2
4
6
8
10
12
a
ab
ab
b
0-15
15-30
30-45
45-60
Distance from Reef (m)
Distance from Bare Sediment – increasing transect #; 1: 0-15m+, 2: 15-30m+, 3: 30-45m+, 4: 45-60m+
Total Zooplankton Abundance - CB
0
100
200
300
ab
a
bc
c
1
2
3
4
Total Zooplankton Abundance - GP
0
100
200
300
400
1
2
3
4
Hydrozoa - CB
.00
.50
1.00
1.50
ab
a
b
ab
1
2
3
4
Hydrozoa - GP
.00
10
20
30
40
0
1
2
3
4
Transect


Bivalvia Larvae - CB
100
80
60
40
20
0
a
a
ab
b
1
2
3
4
Bivalvia Larvae - GP
12
10
8
6
4
2
0
1
2
3
4
Gastropoda Larvae - CB
80
60
40
20
0
a
a
ab
b
1
2
3
4
Gastropoda Larvae - GP
50
40
30
20
10
0
a
ab
b
a
1
2
3
4
Ostracoda - CB
50
40
30
20
10
0
a
a
ab
b
1
2
3
4
Ostracoda - GP
80
60
40
20
0
a
ab
ab
b
1
2
3
4
Eucarida - CB
.50
.40
.30
.20
.10
.00
1
2
3
4
Eucarida - GP
.60
.40
.20
.00
1
2
3
4
Mean abundance per quadrant
Transect

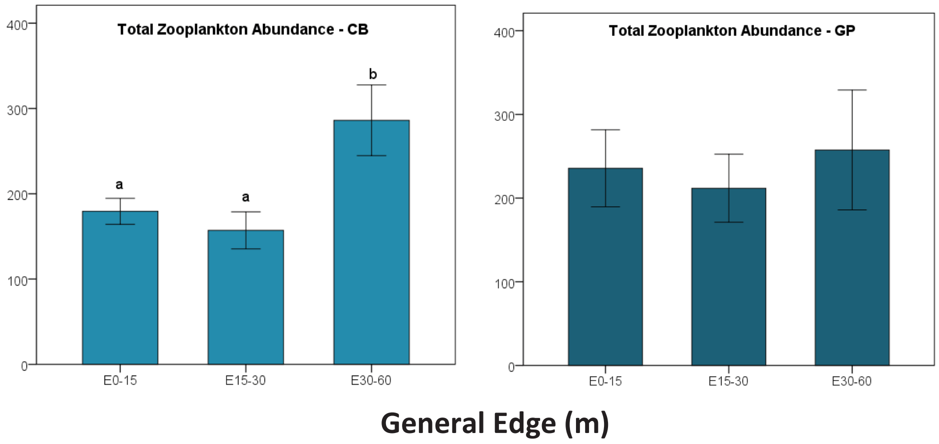

Mean abundance per quadrant
Transect
Pericarida - CB
ab
a
a
b
Pericarida - GP
Crustacean Nauplii - CB
a
ab
bc
c
Crustacean Nauplii - GP
Calanoida - CB
a
a
b
b
Calanoida - GP
Cyclopoida - CB
ab
b
ac
c
Cyclopoida - GP
1
2
3
4

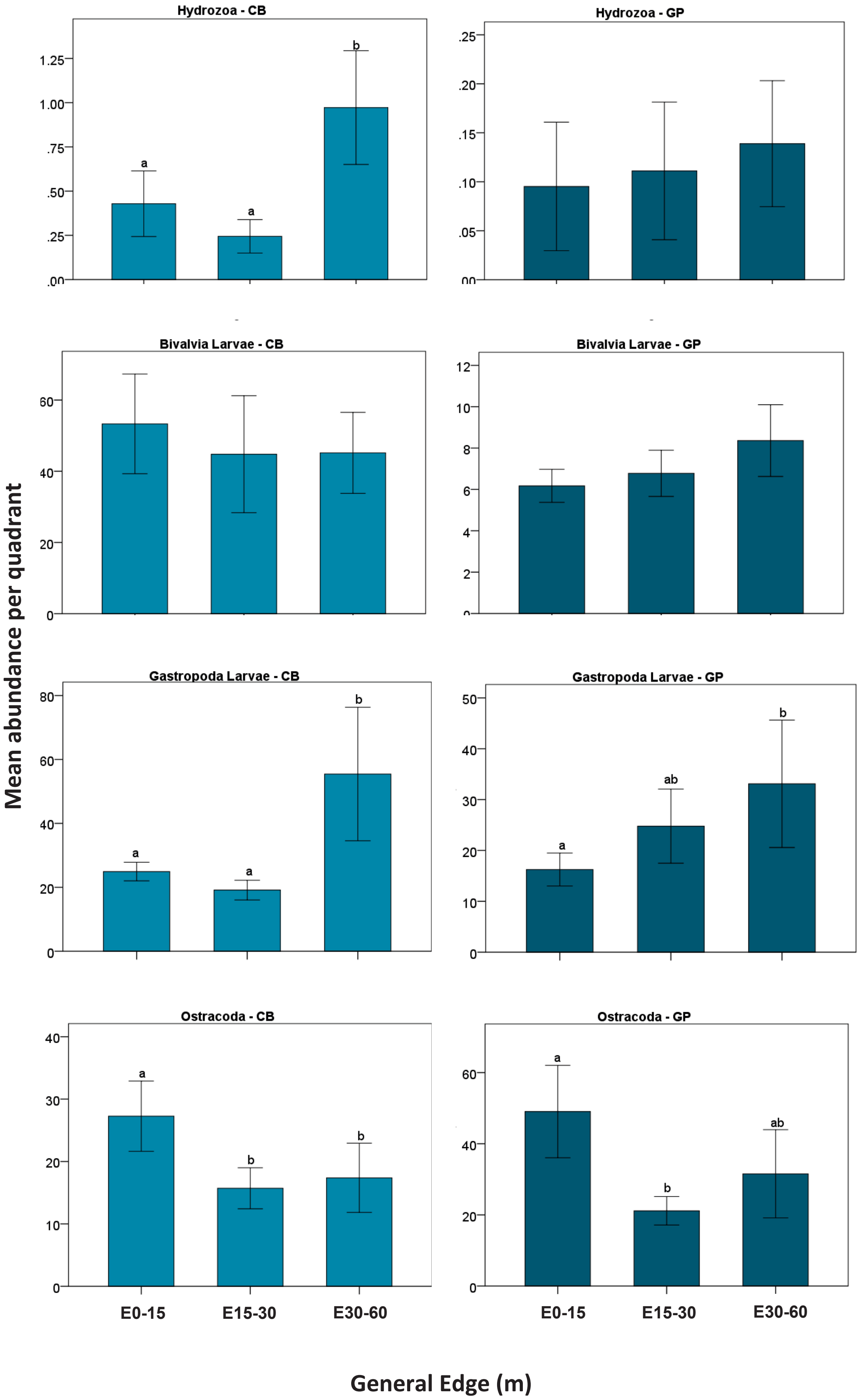

Poecilostomatoida - CB
1.25
1.00
.75
.50
.25
.00
1
2
3
4
Poecilostomatoida - GP
2.5
2.0
1.5
1.0
.5
.0
a
ab
b
b
1
2
3
4
Harpacticoida - CB
20
15
10
5
0
1
2
3
4
Harpacticoida - GP
200
150
100
50
0
a
ab
a
b
1
2
3
4
Cirrepedia - CB
.60
.40
.20
.00
1
2
3
4
Cirrepedia - GP
.30
.20
.10
.00
1
2
3
4
Cladocera - CB
1.00
.80
.60
.40
.20
.00
a
a
a
b
1
2
3
4
Cladocera - GP
.25
.20
.15
.10
.05
.00
1
2
3
4
Mean abundance per quadrant
Transect

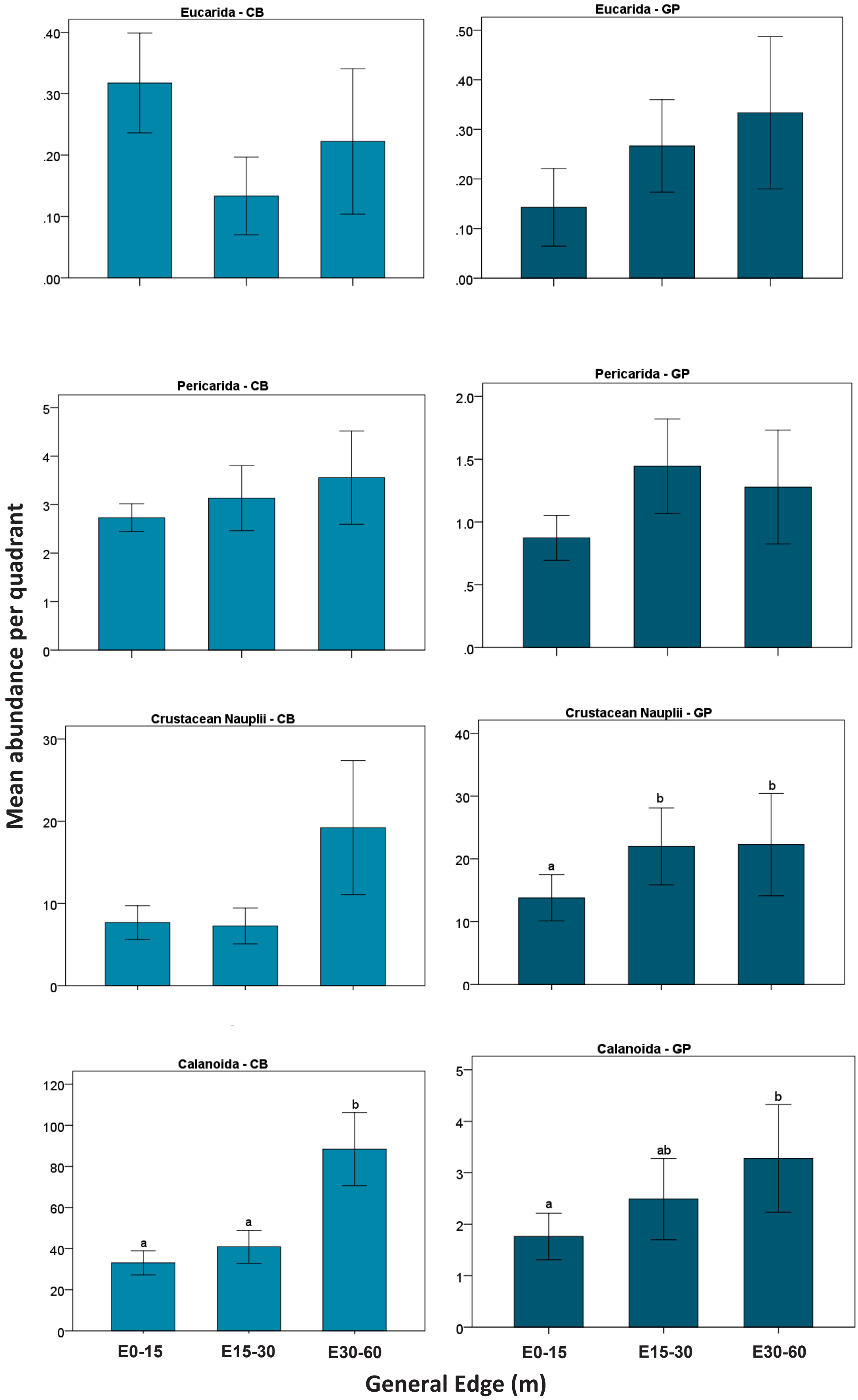

Mean abundance per quadrant
Transect
Polychaeta (Larvae) - CB
0
1
2
3
1
2
3
4
Polychaeta (Larvae) - GP
0
2
4
6
8
10
a
b
b
b
1
2
3
4
Total Unidentified Eggs - CB
0
1
2
3
4
5
6
1
2
3
4
Total Unidentified Eggs - GP
0
2
4
6
8
10
1
2
3
4
Total Mollusca (Larvae) - CB
0
25
50
75
100
125
1
2
3
4
Total Mollusca (Larvae) - GP
0
10
20
30
40
50
60
a
ab
b
a
1
2
3
4
Total Copepoda - CB
0
25
50
75
100
125
a
a
b
b
1
2
3
4
Total Copepoda - GP
0
50
00
50
00
50
a
ab
a
b
1
2
3
4

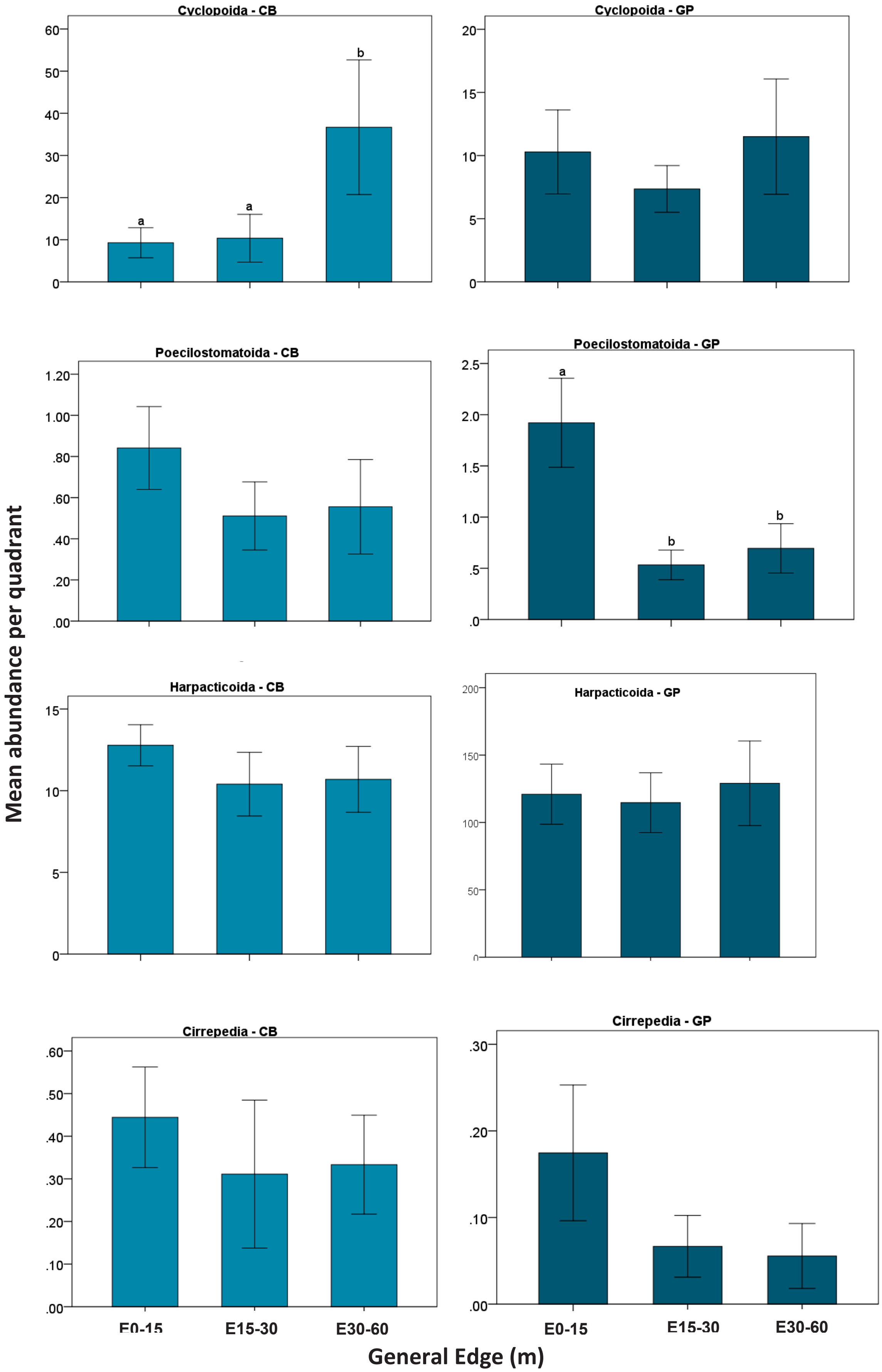


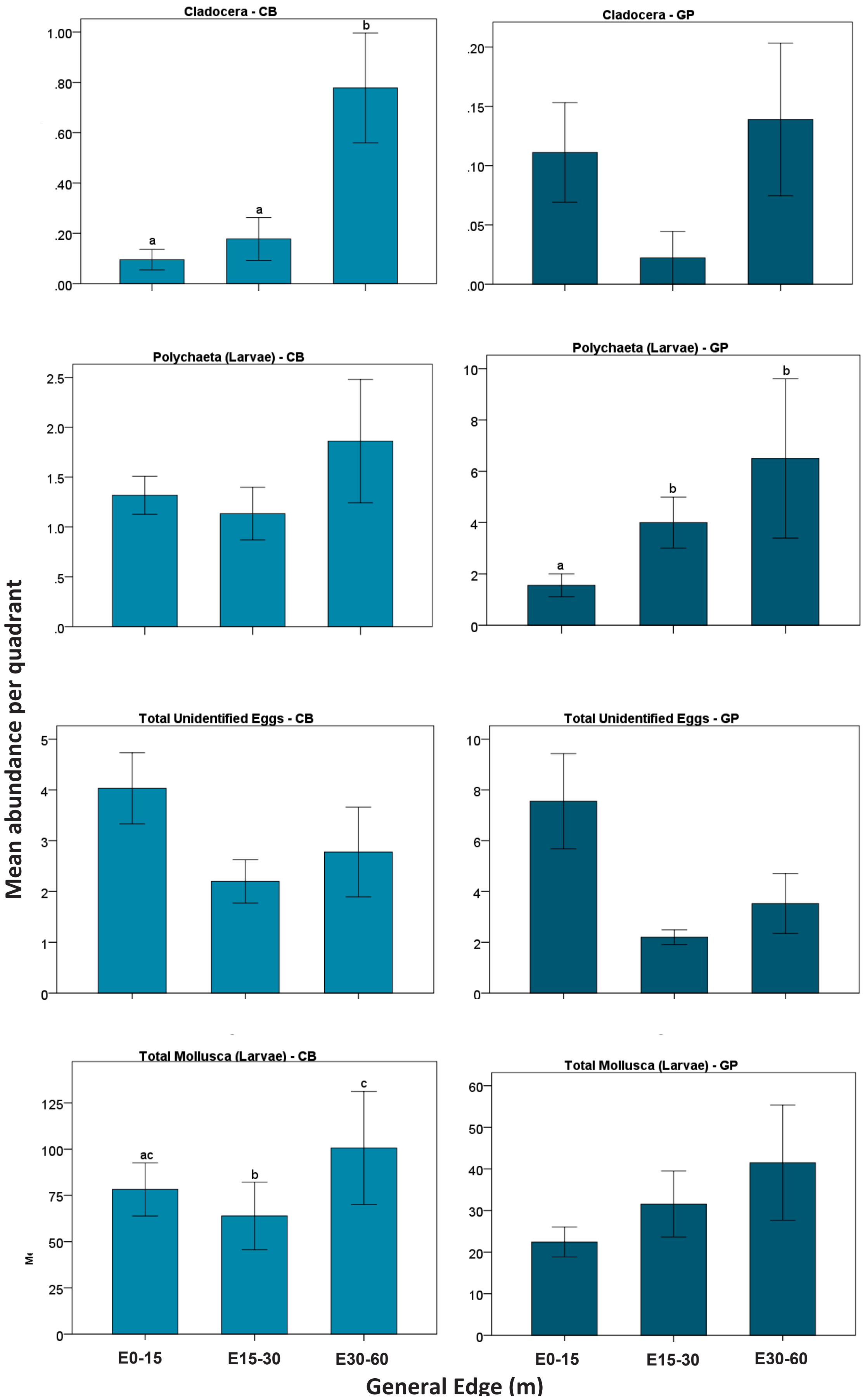
Distance from General Edge

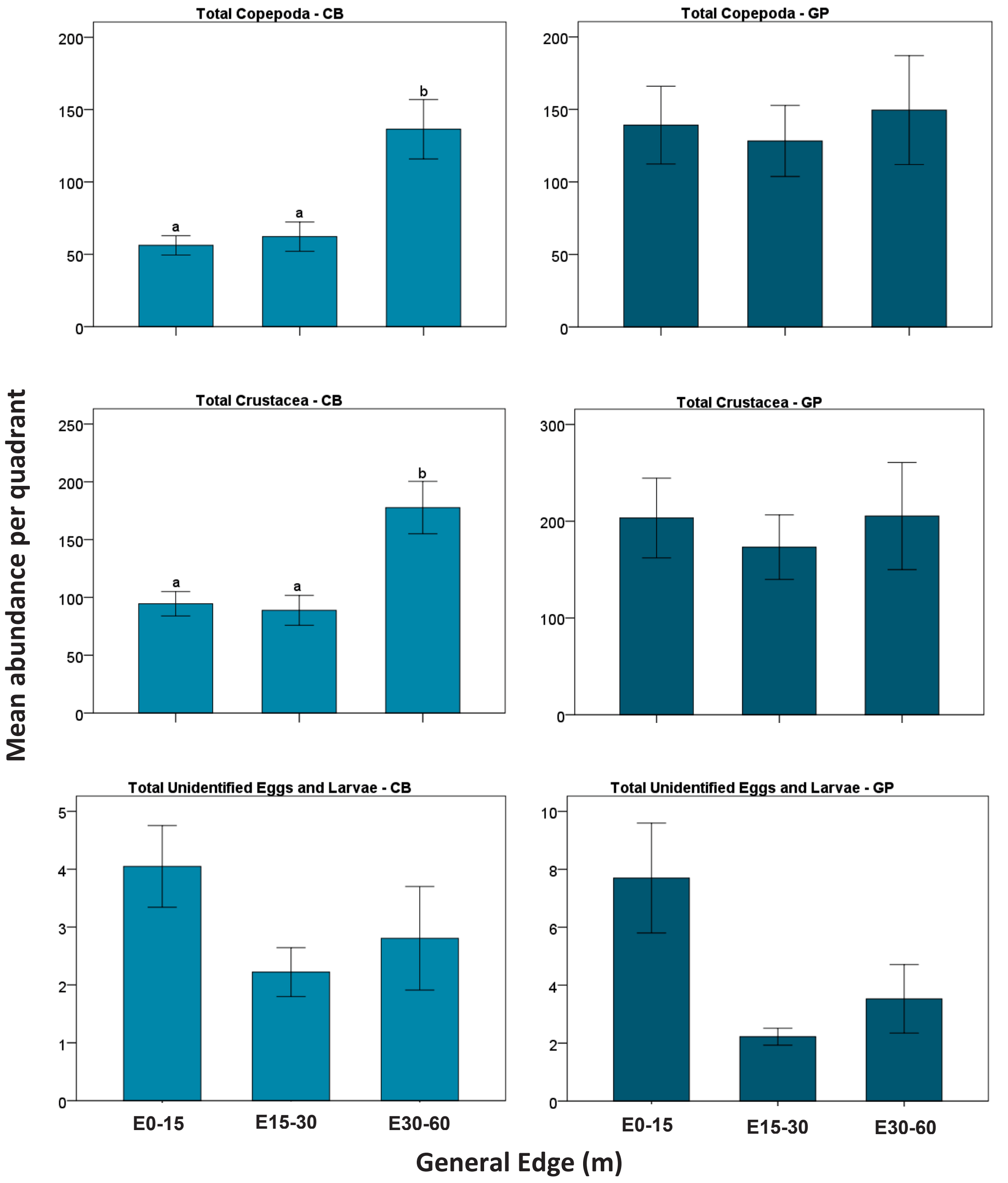



Hydrozoa - CB
1.25
1.00
.75
.50
.25
.00
a
a
b
Hydrozoa - GP
.25
.20
.15
.10
.05
.00
Bivalvia Larvae - CB
60
40
20
0
Bivalvia Larvae - GP
12
10
8
6
4
2
0
Gastropoda Larvae - CB
80
60
40
20
0
a
a
b
Gastropoda Larvae - GP
50
40
30
20
10
0
a
ab
b
Ostracoda - CB
40
30
20
10
0
a
b
b
Ostracoda - GP
60
40
20
0
a
b
ab
Mean abundance per quadrant
E0-15
E15-30
E30-60
E0-15
E15-30
E30-60
General Edge (m)


Eucarida - CB
.40
.30
.20
.10
.00
Eucarida - GP
.50
.40
.30
.20
.10
.00
Pericarida - CB
5
4
3
2
1
0
Pericarida - GP
2.0
1.5
1.0
.5
.0
Crustacean Nauplii - CB
30
20
10
0
Crustacean Nauplii - GP
40
30
20
10
0
a
b
b
Calanoida - CB
120
100
80
60
40
20
0
a
a
b
Calanoida - GP
5
4
3
2
1
0
a
ab
b
E0-15
E15-30
E30-60
E0-15
E15-30
E30-60
Mean abundance per quadrant
General Edge (m)


Cyclopoida - CB
60
50
40
30
20
10
0
a
a
b
Cyclopoida - GP
20
15
10
5
0
Poecilostomatoida - CB
1.20
1.00
.80
.60
.40
.20
.00
Poecilostomatoida - GP
2.5
2.0
1.5
1.0
.5
.0
a
b
b
Harpacticoida - CB
15
10
5
0
Harpacticoida - GP
200
150
100
50
0
Cirrepedia - CB
.60
.50
.40
.30
.20
.10
.00
Cirrepedia - GP
.30
.20
.10
.00
E0-15
E15-30
E30-60
E0-15
E15-30
E30-60
Mean abundance per quadrant
General Edge (m)


Cladocera - CB
1.00
.80
.60
.40
.20
.00
a
a
b
Cladocera - GP
.20
.15
.10
.05
.00
Polychaeta (Larvae) - CB
2.5
2.0
1.5
1.0
.5
.0
Polychaeta (Larvae) - GP
10
8
6
4
2
0
a
b
b
Total Unidentified Eggs - CB
5
4
3
2
1
0
Total Unidentified Eggs - GP
10
8
6
4
2
0
Total Mollusca (Larvae) - CB
125
100
75
50
25
0
ac
b
c
Total Mollusca (Larvae) - GP
60
50
40
30
20
10
0
E0-15
E15-30
E30-60
E0-15
E15-30
E30-60
Mean abundance per quadrant
General Edge (m)



Letters above bars represent the results of pairwise comparisons of log-transformed data with distance categories lacking similar letters being significantly different from each other.

Appendix IX First habitat combination section and assigned homogeneity-complexity level selected by each individual of each of four tested species in "no predator" and "predator" trials.

Table A Habitat combination section of tank first selected upon release by each individual test fish of each species in "no predator" and "predator" trials. *Each row represents an individual fish and its choice in both trials. N/A – loss of data due to corrupted GoPro file for that trial. 0 – no section chosen by that individual (remained at the centre of tank for duration of trial).*

Species	**First habitat combination section selected upon release**	
	"No Predator" trials	**"Predator" trials**
A. spilomelanurus	seagrass	N/A
A. spilomelanurus	seagrass	seagrass-rock
A. spilomelanurus	seagrass	seagrass-rock
A. spilomelanurus	seagrass	seagrass-rock
A. spilomelanurus	seagrass	seagrass-rock
A. spilomelanurus	seagrass	rock-sand
A. spilomelanurus	rock	rock-sand
A. spilomelanurus	seagrass-rock	rock
A. spilomelanurus	seagrass-rock	rock-sand
A. spilomelanurus	seagrass-sand	seagrass-sand
A. spilomelanurus	seagrass-sand	seagrass-rock
A. microstomata	seagrass	seagrass
A. microstomata	seagrass	seagrass
A. microstomata	seagrass	seagrass
A. microstomata	seagrass	seagrass-rock
A. microstomata	seagrass	rock-sand
A. microstomata	seagrass	rock
A. microstomata	rock	seagrass-sand
A. microstomata	rock	seagrass-sand
A. microstomata	rock	seagrass-sand
A. microstomata	rock	sand
A. microstomata	rock	seagrass-rock
A. microstomata	rock	seagrass-rock
A. microstomata	sand	rock
A. microstomata	sand	rock
A. microstomata	sand	seagrass
A. microstomata	sand	seagrass
A. microstomata	sand	seagrass-sand
A. microstomata	sand	seagrass-sand
A. microstomata	sand	seagrass-rock
A. microstomata	seagrass-rock	seagrass-sand
A. microstomata	seagrass-rock	seagrass-rock
A. microstomata	seagrass-rock	seagrass-rock

Species	**“No Predator” trials**	**“Predator” trials**
A. microstomata	seagrass-rock	rock
A. microstomata	seagrass-rock	rock-sand
A. microstomata	seagrass-sand	rock-sand
A. microstomata	seagrass-sand	rock-sand
A. microstomata	seagrass-sand	seagrass
A. microstomata	rock-sand	rock
A. microstomata	rock-sand	rock
A. microstomata	rock-sand	seagrass-rock
A. microstomata	rock-sand	seagrass-rock
A. microstomata	rock-sand	seagrass
A. microstomata	rock-sand	seagrass-sand
A. microstomata	rock-sand	seagrass-sand
A. microstomata	rock-sand	sand
A. microstomata	rock-sand	rock-sand
A. microstomata	rock-sand	rock-sand
S. argus	seagrass	seagrass-rock
S. argus	seagrass	seagrass
S. argus	seagrass	seagrass
S. argus	seagrass	rock
S. argus	seagrass	seagrass-sand
S. argus	seagrass	seagrass
S. argus	seagrass	seagrass-sand
S. argus	seagrass	seagrass
S. argus	seagrass	seagrass-sand
S. argus	seagrass	sand
S. argus	rock	seagrass
S. argus	rock	seagrass-sand
S. argus	rock	seagrass-sand
S. argus	sand	seagrass-sand
S. argus	sand	rock-sand
S. argus	sand	sand
S. argus	seagrass-rock	seagrass-sand
S. argus	seagrass-rock	seagrass
S. argus	seagrass-rock	seagrass
S. argus	seagrass-rock	rock-sand
S. argus	seagrass-sand	seagrass-sand
S. argus	seagrass-sand	rock
S. argus	seagrass-sand	seagrass
S. argus	seagrass-sand	seagrass-sand
S. argus	seagrass-sand	seagrass-rock
S. argus	seagrass-sand	rock-sand
S. argus	rock-sand	N/A
S. argus	rock-sand	rock
P. sexlineatus	seagrass	seagrass-rock
P. sexlineatus	seagrass	seagrass-sand
P. sexlineatus	seagrass	seagrass
P. sexlineatus	seagrass	0
P. sexlineatus	seagrass	sand

Species	**“No Predator” trials**	**“Predator” trials**
P. sexlineatus	seagrass	sand
P. sexlineatus	seagrass	seagrass
P. sexlineatus	seagrass	rock-sand
P. sexlineatus	seagrass	seagrass-sand
P. sexlineatus	seagrass	seagrass-rock
P. sexlineatus	rock	seagrass-sand
P. sexlineatus	rock	rock
P. sexlineatus	rock	seagrass-rock
P. sexlineatus	rock	rock
P. sexlineatus	rock	sand
P. sexlineatus	rock	sand
P. sexlineatus	rock	rock-sand
P. sexlineatus	rock	rock
P. sexlineatus	rock	sand
P. sexlineatus	sand	seagrass-sand
P. sexlineatus	sand	rock
P. sexlineatus	sand	seagrass-sand
P. sexlineatus	sand	rock
P. sexlineatus	sand	N/A
P. sexlineatus	sand	rock-sand
P. sexlineatus	sand	seagrass
P. sexlineatus	seagrass-rock	rock-sand
P. sexlineatus	seagrass-rock	seagrass
P. sexlineatus	seagrass-rock	seagrass
P. sexlineatus	seagrass-rock	rock
P. sexlineatus	seagrass-rock	seagrass
P. sexlineatus	seagrass-sand	seagrass
P. sexlineatus	seagrass-sand	sand
P. sexlineatus	seagrass-sand	seagrass-rock
P. sexlineatus	seagrass-sand	seagrass
P. sexlineatus	seagrass-sand	rock-sand
P. sexlineatus	rock-sand	sand
P. sexlineatus	rock-sand	seagrass-rock
P. sexlineatus	rock-sand	seagrass-sand
P. sexlineatus	rock-sand	sand
P. sexlineatus	rock-sand	rock-sand
P. sexlineatus	rock-sand	seagrass
P. sexlineatus	rock-sand	N/A
P. sexlineatus	rock-sand	seagrass-rock
P. sexlineatus	rock-sand	rock-sand
P. sexlineatus	rock-sand	seagrass-sand
P. sexlineatus	rock-sand	rock-sand

Table B Assigned homogeneity-complexity level first selected upon release by each individual test fish of each species in “no predator” and “predator” trials. *Each row represents an individual fish and its choice in both trials. N/A – loss of data due to corrupted GoPro file for that trial. 0 – no section chosen by that individual (remained at the centre of tank for duration of trial).*

Species	**First homogeneity-complexity level selected upon release**	
	“No Predator” trials	**“Predator” trials**
A. spilomelanurus	homogen-2	N/A
A. spilomelanurus	homogen-2	heterogen-2
A. spilomelanurus	homogen-2	heterogen-2
A. spilomelanurus	homogen-2	heterogen-2
A. spilomelanurus	homogen-2	heterogen-2
A. spilomelanurus	homogen-2	heterogen-1
A. spilomelanurus	homogen-2	heterogen-1
A. spilomelanurus	heterogen-1	heterogen-1
A. spilomelanurus	heterogen-1	heterogen-2
A. spilomelanurus	heterogen-2	homogen-2
A. spilomelanurus	heterogen-2	heterogen-1
A. microstomata	homogen-1	homogen-2
A. microstomata	homogen-1	homogen-2
A. microstomata	homogen-1	homogen-2
A. microstomata	homogen-1	homogen-2
A. microstomata	homogen-1	heterogen-1
A. microstomata	homogen-1	heterogen-1
A. microstomata	homogen-1	heterogen-2
A. microstomata	homogen-2	heterogen-1
A. microstomata	homogen-2	heterogen-1
A. microstomata	homogen-2	heterogen-1
A. microstomata	homogen-2	homogen-1
A. microstomata	homogen-2	heterogen-2
A. microstomata	homogen-2	heterogen-2
A. microstomata	homogen-2	homogen-2
A. microstomata	homogen-2	homogen-2
A. microstomata	homogen-2	homogen-2
A. microstomata	homogen-2	heterogen-2
A. microstomata	homogen-2	heterogen-1
A. microstomata	homogen-2	homogen-2
A. microstomata	heterogen-1	heterogen-1
A. microstomata	heterogen-1	heterogen-1
A. microstomata	heterogen-1	homogen-2

Species	**"No Predator" trials**	**"Predator" trials**
A. microstomata	heterogen-1	homogen-2
A. microstomata	heterogen-1	homogen-2
A. microstomata	heterogen-1	heterogen-2
A. microstomata	heterogen-1	heterogen-2
A. microstomata	heterogen-1	homogen-2
A. microstomata	heterogen-1	heterogen-1
A. microstomata	heterogen-1	heterogen-1
A. microstomata	heterogen-1	homogen-1
A. microstomata	heterogen-1	heterogen-1
A. microstomata	heterogen-1	heterogen-1
A. microstomata	heterogen-2	heterogen-1
A. microstomata	heterogen-2	heterogen-2
A. microstomata	heterogen-2	heterogen-2
A. microstomata	heterogen-2	homogen-2
A. microstomata	heterogen-2	heterogen-1
S. argus	homogen-1	N/A
S. argus	homogen-1	homogen-2
S. argus	homogen-1	heterogen-1
S. argus	homogen-1	homogen-1
S. argus	homogen-1	homogen-1
S. argus	homogen-2	homogen-2
S. argus	homogen-2	heterogen-1
S. argus	homogen-2	heterogen-1
S. argus	homogen-2	heterogen-2
S. argus	homogen-2	homogen-2
S. argus	homogen-2	homogen-2
S. argus	homogen-2	homogen-2
S. argus	homogen-2	heterogen-1
S. argus	homogen-2	homogen-2
S. argus	homogen-2	heterogen-1
S. argus	homogen-2	homogen-2
S. argus	homogen-2	heterogen-1
S. argus	homogen-2	homogen-1
S. argus	heterogen-1	heterogen-1
S. argus	heterogen-1	homogen-2
S. argus	heterogen-1	homogen-2
S. argus	heterogen-1	heterogen-1
S. argus	heterogen-1	heterogen-2
S. argus	heterogen-1	homogen-1
S. argus	heterogen-2	heterogen-1
S. argus	heterogen-2	homogen-2
S. argus	heterogen-2	homogen-2
S. argus	heterogen-2	homogen-1

Species	**“No Predator” trials**	**“Predator” trials**
P. sexlineatus	homogen-1	heterogen-1
P. sexlineatus	homogen-1	homogen-2
P. sexlineatus	homogen-1	heterogen-1
P. sexlineatus	homogen-1	homogen-2
P. sexlineatus	homogen-1	N/A
P. sexlineatus	homogen-1	heterogen-1
P. sexlineatus	homogen-1	homogen-2
P. sexlineatus	homogen-2	heterogen-1
P. sexlineatus	homogen-2	homogen-2
P. sexlineatus	homogen-2	heterogen-2
P. sexlineatus	homogen-2	homogen-2
P. sexlineatus	homogen-2	homogen-1
P. sexlineatus	homogen-2	homogen-1
P. sexlineatus	homogen-2	heterogen-1
P. sexlineatus	homogen-2	homogen-2
P. sexlineatus	homogen-2	homogen-1
P. sexlineatus	homogen-2	heterogen-2
P. sexlineatus	homogen-2	heterogen-1
P. sexlineatus	homogen-2	homogen-2
P. sexlineatus	homogen-2	0
P. sexlineatus	homogen-2	homogen-1
P. sexlineatus	homogen-2	homogen-1
P. sexlineatus	homogen-2	homogen-2
P. sexlineatus	homogen-2	heterogen-1
P. sexlineatus	homogen-2	heterogen-1
P. sexlineatus	homogen-2	heterogen-2
P. sexlineatus	heterogen-1	homogen-2
P. sexlineatus	heterogen-1	homogen-1
P. sexlineatus	heterogen-1	heterogen-2
P. sexlineatus	heterogen-1	homogen-2
P. sexlineatus	heterogen-1	heterogen-1
P. sexlineatus	heterogen-1	homogen-1
P. sexlineatus	heterogen-1	heterogen-2
P. sexlineatus	heterogen-1	heterogen-1
P. sexlineatus	heterogen-1	homogen-1
P. sexlineatus	heterogen-1	heterogen-1
P. sexlineatus	heterogen-1	homogen-2
P. sexlineatus	heterogen-1	N/A
P. sexlineatus	heterogen-1	heterogen-2
P. sexlineatus	heterogen-1	heterogen-1
P. sexlineatus	heterogen-1	heterogen-1
P. sexlineatus	heterogen-1	heterogen-1
P. sexlineatus	heterogen-2	heterogen-1

Species	**“No Predator” trials**	**“Predator” trials**
P. sexlineatus	heterogen-2	homogen-2
P. sexlineatus	heterogen-2	homogen-2
P. sexlineatus	heterogen-2	homogen-2
P. sexlineatus	heterogen-2	homogen-2

Appendix X List of fish taxa found within the rocky reef habitat from GoPro video footage in the summer sampling session.

Scientific Name	**Common name**	**Site**	**FMFG**	**EUFG**
Tetractenos spp	toadfish	CB	CNP	EM
Sillago ciliata	sand whiting	CB	CNP	EM
Brachaluteres jacksonianus	pygmy leatherjacket	CB	CNP	EM
Mugilidae	mullet	CB,GP	OV	MM
Atherinidae	hardyhead	CB,GP	CNP	ER
Ambassis jacksoniensis	glassfish	CB,GP	ZP	EM
Achoerodus viridis	Eastern blue grouper	GP	CNP	MM
Girella tricuspidata	luderick	GP	HV	MM
Acanthopagrus australis	yellowfin bream	GP	OV	MM
Neoodax balteatus	little weed whiting	GP	CNP	ER
Atypichthys strigatus	mado	GP	ZP	EM

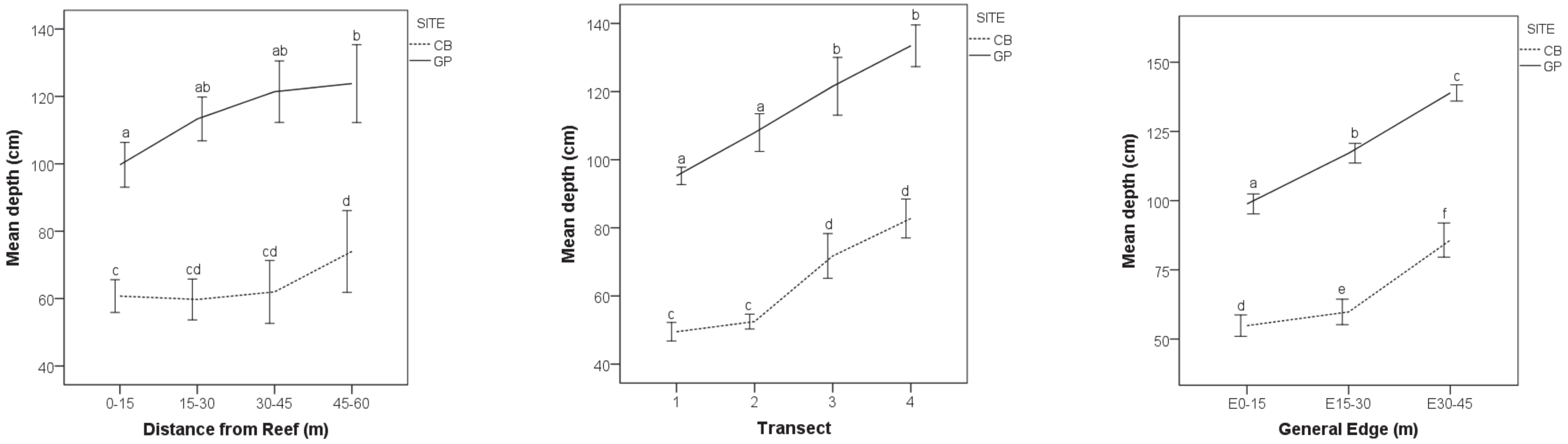
where CB=Callala Bay; GP=Greenpoint; FMFG=Feeding Mode Functional grouping (CNP – non-piscivorous carnivores, OV – omnivores, ZP – zooplanktivores, HV – herbivores); EUFG=Estuarine Use Functional Groups (ER – estuarine residents, EM – estuarine migrants, MM – marine migrants)

Appendix XI Variation in and with water depth at both sampling sites

Table A Summary of (i) PERMANOVA results and (ii) p-values at significant pairwise comparisons of water depth with distance from reef, bare sediment and general edge across both and at each individual site (CB – Callala Bay, GP – Greenpoint). *D1 – 0-15m; D2 – 15-30m; D3 – 30-45m; D4 – 45-60m from reef; T1 – 0-15m+; D2 – 15-30m+; D3 – 30-45m+; D4 – 45-60m+ from shore and bare sediment and E1 – E0-15m; E2 – E15-30m; E3 – 30-60m from general edge; * significance level set at p < 0.01 as variances were not homogeneous around particular factor*

	df			**MS**			**Pseudo-F**			**P**		
	Both	**CB**	**GP**	**Both**	**CB**	**GP**	**Both**	**CB**	**GP**	**Both**	**CB**	**GP**
Reef	3	3	3	2825.7	1027.5	2825.7	4.9954	3.9069	3.027	0.1238	0.0111*	**0.0317**
Bare Sediment	3	3	3	9740.5	4437.5	9740.4	54.482	34.563	12.168	**0.0142**	**0.0001***	**0.0001**
General Edge	2	2	2	16700	6896.8	16700	30.368	57.249	21.722	0.074	**0.0001**	**0.0001***

	Site	**D2**	**T2**	**E2**	**D3**	**T3**	**D4**	**T4**	**E3**
D1	CB						0.0072*		
	GP						0.0032		
T1	CB					0.0001*		0.0001*	
	GP					0.0002		0.0001	
E1	CB			0.0173					0.0001
	GP			0.0175*					0.0001*
D2	CB								
	GP								
T2	both							0.0294	
	CB					0.0001*		0.0001*	
	GP					0.0141		0.0001	
E2	CB								0.0001
	GP								0.0003*



(i) **(ii)** **(iii)**

Fig A Change in water depth (cm) at sampling positions with distance from (i) reef, (ii) bare sediment and (iii) general edge at both sites – Callala Bay (CB) and Greenpoint (GP) at summer mean low tide. *Letters above error bars represent the results of pairwise comparisons with distance categories lacking similar letters being significantly different from each other.*

Table B Summary of Pearson Correlations performed in SPSS Statistics 22 between water depth (range 44 – 146 cm) and *P. australis* blade metrics and epiphyte load at both sites. *CB – Callala Bay, GP – Greenpoint.*

Pearson Correlations

		Leaf length	Leaf width	Leaf area	Epiphyte/seagrass (g/g)	Epiphyte load index
Depth (CB)	Pearson Correlation	**0.821****	**0.866****	**0.836****	**0.738****	**0.810****
	Sig. (2-tailed)	**<0.0001**	**<0.0001**	**<0.0001**	**0.001**	**.0001**
	N	16	16	16	16	16
Depth (GP)	Pearson Correlation	.332	.472	.419	-.059	.165
	Sig. (2-tailed)	.209	.065	.107	.828	.542
	N	16	16	16	16	16

** Correlation is significant at the 0.01 level (2-tailed). *Shapiro-Wilk test performed to ascertain normal distribution of each variable*.

Appendix XII (Ollivier et al 2015) Benthic invertebrate (mollusc) distribution in *P. australis* at Callala Bay with distance from both adjacent habitat edges i.e. rocky reef and bare sediment.

“Are the effects of adjacent habitat type on seagrass gastropod communities being masked by previous focus on habitat dyads?”

Q. R. Ollivier , N. A. Bramwell, E. Hammill, C. Foster-Thorpe and D. J. Booth

View/Download from: Publisher’s site