Western Australian Marine Science Institution (WAMSI)

Node 3 Project 3.1.2

Methods of monitoring the health of benthic communities at Ningaloo - Coral & Fish recruitment

FINAL REPORT

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Final Report by AIMS to WAMSI as contribution to deliverables for WAMSI project 3.1.2

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1. EXECUTIVE SUMMARY

Effective ecosystem management relies on continually assessing trends and changes in resident organisms (i.e. adaptive evidence-based management). Of particular importance are those organism groups that serve vital roles and functions within these ecosystems. Corals and fish are perhaps the most visually conspicuous and critical ecological components of coral reef ecosystems. Together, they provide essential habitat and perform a host of important tasks that maintain the health and integrity of these systems. Intricately linked to coral reef food webs, these organisms have significant value in generating, storing and providing energy within reef ecosystems. Given the importance of these roles and the responsibility of managers to maintain the health of these systems, it is vitally important that changes in these organisms are detectable. However, without a historical backdrop of baseline information on their abundance, species identity and structure across space and time, it is impossible to determine whether changes in these parameters are due to natural variability or are cause for concern.

At the core of marine biodiversity and ecosystem maintenance is the annual replenishment of individuals. Most marine organisms have a bipartite life cycle where larvae recruit into their juvenile and adult habitat from the open ocean. A complex process governed by regional and local reproductive output and oceanographic features, combined larval and juvenile mortality is upwards of 90% for corals and fish. Despite this, the recruitment process is a highly successful evolutionary strategy that underpins the supply of new individuals to reef ecosystems. Conveniently, it also provides a metric by which we can measure the potential success of an ecosystem on an annual basis, allowing us to forecast into the future and begin to understand the properties that govern replenishment patterns at local scales.

CORAL RECRUITMENT

This study has measured annual coral recruitment rates at Ningaloo Reef using deployed tiles, but also evaluated some alternative methods for coral juvenile census that provide complimentary data and may add flexibility into regional survey programs. Deploying, recovering and assessing tiles is labor intensive, requires use of SCUBA and a specialist using a microscope in the laboratory for census of the tiles. A key aim of this project has been to understand the tradeoffs associated with simplified and more cost-effective approaches. The objective was to assess methods that could still yield robust research data, yet utilize non-specialist regional DEC staff for routine field surveys, maximizing the effectiveness of Perth-based specialist research staff for more complex analytical tasks.

The abundance of newly settled corals following the 2009 and 2010 annual coral spawning peaks was measured in the northern half of Ningaloo Reef at eleven locations between Coral Bay, Tantabiddi and Bundegi. An annual influx of coral recruits were detected at all locations, using terracotta tiles deployed by divers on the reef. Surveys were precisely repeated in both years using permanent tile mounting fixtures, with tiles deployed prior to the major predicted spawning season, subsequently retrieved and counted under a dissecting microscope.

Recruitment rates spanned the range recorded for coral reefs elsewhere, with overall average numbers of recruits per tile in the medium range, but a few locations high and many locations low-medium relative to other similar Indo-Pacific studies. There was spatial and temporal variation in recruitment levels and taxonomic composition over the two annual cycles. Deployment and recovery of 198 tiles was repeated exactly in 2009 and 2010 to ensure the same microhabitats were resampled. In 2009 a total of 1999 recruits were counted, dominated by species in the family Acroporidae. In 2010 a total of 841 recruits were counted, a drop of 58% from the previous year, due largely to a drop in Acroporid recruits, with other taxa represented in similar levels between the two years. This result may reflect normal inter-annual variation in larval output, reduced larval production by the Acroporidae due to some selective stress effect during the preceding year, or a sampling artifact. Some degree of sampling artifact is plausible as 2010 saw a split coral spawning period, with significant Acroporid spawning one month earlier than the major spawning peak of most other species. In any long term monitoring of recruitment at Ningaloo approximately 50% of years will include a significant split spawning in the period between late February and early April. This should be factored into the future sampling designs.

Tiles proved useful to confirm larval supply and early recruitment, but do require use of SCUBA divers and laboratory analysis with microscopes. The deployment and recovery of tiles also require coordination in relation to annual spawning cycles and significant field effort, although deployments to bracket the entire spawning period, for example deployment in early-mid February each year and recovery late April-early May, would simplify logistics. Nonetheless, resource demands with this method are moderate to high in both field and laboratory and may not be easily met by regional staff. Additionally, given the spatial and interannual variability detected in this study, there needs to be an extension of this data set over more years before the level of covariance can be fully characterized and allow for reduction of sites to a minimum number of sentinel locations.

Spatial scales of kilometers, between sites within a region of Ningaloo, had the greatest effect on variability in the recruit data, followed by larger scale location differences between regions (Tantabiddi, Bundegi and Coral Bay). Within each study site, at scales of 50-100m and between groups of replicate tiles separated by only a few meters, variability in recruitment counts was generally much less, although there was typically a poor correlation between the abundance of live coral over the 100m site scale and the number of recruits. A more representative program of tile-based sampling could be achieved with the same resources by placing, for example, 6-10 tiles at each site rather than 18 in three groups of six, but establishing twice the number of sites within a few kilometers of each other.

The results suggests that recruits are being drawn from stocks of spawning corals at larger scale than the immediate vicinity of the recruitment tiles and this relationship is not well established for Ningaloo. However, new datasets, such as the hyperspectral derived coral habitat maps, along with improved fine scale circulations models for Ningaloo, could be used to develop predictive models elucidating the size of spawning coral stocks. This would allow a robust test of the stock recruitment relationships in different areas along the NMP.

Census of established juvenile corals, typically 6-12 months or older, using diver-based visual census or a variety of camera methods can provide an alternative to tiles. Both these methods assess the size of juvenile cohorts recruiting into the adult populations, in particular after the probably high mortality phase that occurs in the months after settlement, as opposed to using recruitment tiles which record a sample of newly arriving and settling coral larvae. The study explored each approach to elaborate the pros and cons in terms of resource demands and data quality.

Direct underwater visual census (UVC) by divers was effective in all habitats at recording juvenile corals, but there were some notable caveats. While *in situ* underwater visual census will generally detect a high percentage of the smaller corals (<2cm max diameter) if the habitat is structurally complex, the reliability of the data can be strongly influenced by inter-observer variability. A comparison of three experienced coral reef divers, all with marine science training on coral reefs at post-graduate level and moderate-high levels of coral specific knowledge, demonstrated significant inter-observer variation in juvenile counts and individual bias in relation to size estimates and taxonomic classification. The results demonstrated significant effects of knowledge and stress the importance of observer training and calibration. Consequently, unless all field staff are regularly calibrated or a specialist team is tasked with all recruit visual surveys, there is a high probability of introducing large discrepancies into the data over time.

Comparison between camera census of juveniles and diver UVC, indicated that in the most three dimensionally complex micro-habitats, such as the mixed foliaceos and thicket environments of Bundegi, divers could search edges and overhangs and find juveniles which a camera, taking a downward-looking planar view, simply could not detect. However, in the least complex environments, such as some back reef areas or the pavement like outer slope habitats, divers could underestimate juveniles relative to photo counts. This is likely due to a visual bias favouring detection of erect, three dimensional juveniles such as small Acroporid and Favid species, while underestimating subtly coloured encrusting species such as *Montipora* and *Porites*. The problem is exacerbated if divers are seeking to complete surveys as quickly as possible.

Using modern digital cameras was effective in capturing images adequate for counts of juveniles in low-moderate complexity habitats but performed less well in comparison to divers for counts of smaller corals <2-3cm diameter, especially as three dimensional complexity of the seabed increased. For both photo methods and UVC, development of a training data set will be useful for both field ID of juveniles and for image classification, otherwise significant inter-observer variability occurs with both approaches. Comparison between observers with different levels of knowledge indicates that inexperienced workers can be identifying non-coral features of the benthos as corals, but that an intermediate level of skill with corals and the marine environment is probably sufficient to record coral juvenile numbers accurately enough to maintain reasonable integrity in a long-term monitoring database. Standard protocols and rules for photo interpretation and measurement need to be used to minimize inter-observer variation.

Comparison of technical refinements to camera use, such as use of ambient light versus strobe illumination or, ambient light with camera stabilized on a tripod at fixed distance from the substrate, provided minimal differences in overall effectiveness for juvenile counts from the resulting photos. There was a slight but non-significant performance improvement using photos taking in ambient light from a tripod, suggesting that camera stability is a key factor in getting the sharpest images which then allow better discrimination of juveniles in the photos.

In agreement with other studies elsewhere, results show that in comparison to photo approaches UVC, if applied consistently by well trained and calibrated observers, will reliably detect as many or more of the smallest juvenile corals in most habitats. However, it requires significant underwater field time, expertise in coral identification and, in nearly all environments, the use of SCUBA. There is much less difference between UVC and imaging methods for medium to larger juvenile corals and in some habitat types photos may be more effective at detecting encrusting forms. Photos have a number of advantages over UVC in that they appear to allow for more objective assessment of the general benthos and detection of more species, especially encrusting forms, than divers trying to do a rapid UVC.

Secondly, provided standard field protocols for camera types, setting and use underwater are followed, non-technical staff could collect photo quadrats to an acceptable standard and these could be dispatched electronically to head office to allow specialist interpretation. In this way a core group of highly trained specialists could produce reliable data while not being required to undertake all regional field work.

Thirdly, the permanent archive that can be created with photos allows for retrospective reinterpretation and quality control, whereas UVC methods are completely dependent on the nature and quality of data collected by the field team.

For size measurements from photos some form of image calibration is required. In this study a negatively buoyant quadrat frame was deployed and photographed on the seabed. This provides excellent calibration of the image and subsequently the dimensions of all visible small corals. However it does require the diver to carry extra equipment and involves multiple steps deploying the quadrat or other scale reference, photographing the seabed ensuring it is in the frame, then recovering the reference scale before moving to a new sampling location and repeating. It would be desirable to simplify this protocol as much as possible, particularly if shallow surveys in lagoonal habitats are to be surveyed using snorkel divers rather than SCUBA.

There are very recent technical developments with consumer 3D cameras that may improve the in-water efficiency of gathering spatially calibrated imagery. A preliminary analysis of one retail example for which an underwater housing is also available, the Fuji W3 3D camera with RecSea housing, indicates that when taking images from a nominal distance of 60cm and at various angles, the errors in precision of target measurements are always less than 10% and typically much less. This level of precision is more than adequate for assigning juvenile corals to annual size classes. These types of camera system warrant further assessment as they may provide a very simple method to deliver high quality fully calibrated images in a single step and with minimal training for field users. Such images may then be transmitted to specialist staff for classification and measurement of the benthos, including juvenile corals.

As a whole, in most environments divers will detect more of the smallest juveniles, but the time taken to get the best results and the level of diver knowledge and training will be significant factors in the reliability of collected data *in situ*. These considerations therefore favour alternative approaches, such as the use of cameras with standard, simplified protocols, if non-specialist regional staff are to be used as part of routine recruitment monitoring programs. A robust, spatially and temporally extensive monitoring program is likely best served by use of specialist field methods (tiles, UVC) in a targeted way at selected regional sites, which provides calibration for a more extensive and regular collection of calibrated photographic surveys by generalist staff.

Fish Recruitment

Broadly speaking, methods to record fish recruitment fall into two main categories; collection approaches, such as light traps or some type of net to capture newly arrived recruits just before they reach the reef (e.g. Doherty 1987, McIllwain 2003) and underwater visual censusing (UVC) of newly settled individuals on the reef itself (e.g. Dorenbosch et al. 2006). There are advantages and disadvantages to both. This study used UVC of juveniles on the reef as its method of choice because 1) light trapping and other aggregation devices are very selective, 2) light traps and crest nets are logistically difficult to work with at many locations along Ningaloo, and 3) most mortality happens in the first few days (Sale 1991) and from a management perspective the important individuals are those that survive and contribute to the next generation. Juveniles that have already settled on the reef are therefore a more accurate measure of the individuals that will have an impact on ecosystem well-being through their trophic and reproductive activities.

Following an initial focus in 2009 on evaluating a range of UVC methods for censusing juvenile fishes including block designs, on-reef fish aggregation devices and different transect sizes (see Depczynski et al. 2009 for full details), this study measured annual fish recruitment rates at Ningaloo Reef using underwater visual census (UVC) based on 30 x 1 m transects. Belt transects of this size were found to have the highest level of precision, were logistically simple to use and therefore able to cover larger areas within the same time frame. In addition to trialing these techniques, extensive comparisons were also initially made on the consistency of inter-observer estimates of habitat characterisation, fish size and abundances to provide an understanding of the challenges that might present themselves in the transition towards an ongoing long-term monitoring program (see Depczynski et al. 2009). The report provided the following insights on the degree of skill needed to conduct accurate surveys of juvenile fishes;

- Gross percentage habitat characterisation estimates were immediately within an acceptable 15% between all four observers.
- Fish size estimates required 3-4 trials of 9 floating fish models before variation among observers reached an acceptable level (<5mm total length accuracy).
- There was no statistical difference between observers for juvenile fish abundances along identical transects.
- There was, however, a statistical difference for species richness but this was due to one of four observers and was quickly rectified indicating that calibration between observers and some basic taxonomic knowledge (to family level at the very least) is important.
- It took a considerable length of time before all observers could accurately identify all Ningaloo juvenile fishes to species suggesting that a regular team should conduct surveys each recruitment season.

The abundance, species richness and assemblage structure of juvenile fishes was quantified in 2009- 2011 at 20 locations extending from Bundegi to 3-Mile Camp, some 280km of the Ningaloo coastline. Within locations, both back reef and lagoonal reef zones that encompassed sanctuary and recreational management zones were censused. In total, 691 transects yielded 36,791 juvenile fishes from 120 species over the three recruitment years, providing an average of 53 individuals (± 2.6se) 30m^{-2} transect or 1.8m^{-2}. However, recruitment rates were far from uniform in time or space. There were stark differences in abundance between years. Transect abundance means in 2009 were 82 (±6.3se), 19 (±1.2se) in 2010 and 77 (±4.6se) in 2011. Remarkably this 75% drop in abundance in 2010 coincided with a small increase in mean species richness.

Fish recruitment patterns were compared at a number of different spatial levels including between locations, reef zones (back reef versus lagoon) and management zones (sanctuary versus recreational). Abundance means among the 20 locations were quite variable ranging from 111 recruits 30m^{-2} at Elle's back reef to just 10 at the Coral Bay south location. Overall, mean recruitment was strongest in the southern section of the Park (Cloates to 3-

Mile Camp) than at either the eastern (Bundegi) or northern sections (Jurabi to Norwegian Bay). Mean species richness mirrored abundance trends in Park sections, with the southern sections recording richer species diversity than either eastern or northern sections.

Abundance between reef zones varied considerably in years where recruitment was strong (2009 & 2011) but varied little in 2010 when recruitment strength was 25% that of 2009 & 2011. Overall, back reef sites contained higher mean abundances that lagoon sites with 67 (±4.0se) individuals 30m^{-2} transect and lagoonal sites 35 (±3.0se). For species richness, trends were more variable, but generally back reef and lagoonal sites held similar mean numbers of species ranging from 14.1 species in the 2010 lagoon samples to 5.5 in the 2011 lagoon samples with back reefs somewhere in between. Of note, species richness at both back reef and lagoonal sites was highest in 2010 when abundances were lowest indicating that species richness is unlikely to be affected by recruitment strength (i.e. numbers of individuals).

Sanctuary zones generally recorded marginally higher mean abundances and species richness than recreational zones in the strong recruitment years of 2009 and 2011 but were quite similar in 2010. On average across all years, sanctuary zones contained 59.7 (±4.1se) individuals and 10 (±0.29se) species 30^{-2} transect and recreational zones 44.1 (±2.8se) and 8.9 (±0.33se) respectively.

Taxonomic trends in recruitment identified the strong dominance of the Damselfishes and Wrasses in both back reef and lagoon reef zones. Other important families to both reef zones included the Parrot and Cardinal fishes. In spite of the ubiquity of these groups dominating patterns at the family level, there were many species that were unique to either back reef or lagoon reef zones. Of the 120 species recorded during the study, 19 were uniquely found in the lagoon and 16 unique to back reef sites with 68 having some margin of overlap. The remaining 17 species were considered to be nominal reef zone specialists because of their low numbers. Importantly, the recreationally targeted Emperors and functionally important Goat and Rabbitfishes were exclusively found at lagoonal sites foraging amongst the large Sargassum algae meadows that dominate the lagoon during the summer recruitment season. Percentage contributions from families varied considerably from year to year. For example, the Rabbit fishes were almost entirely absent in 2009 and 2010 (<0.1%) but made up 19% of recruits in the lagoon in 2011. Similarly, the Wrasses constituted 17% of the overall recruit assemblage on the back reef in 2009 but 34% in 2010 illustrating the variability in taxonomic composition in both space and time.

1.1 Project Date

July 2011

1.2 Project Title and Number

Methods of monitoring the health of benthic communities at Ningaloo - Coral & Fish recruitment. WAMSI Node 3 Project 1 (WAMSI project reference no. 3.1.2)

1.3 Project Leaders

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1.4 *PROJECT TEAM INCLUDING FIELDWORK*

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1.5 *DATES COVERED*

February 2009 – March 2011

2. KEY FINDINGS AND RECOMMENDATIONS

CORAL RECRUITMENT

When resources permit, specialist research divers that are well calibrated with regard to coral identification and underwater size estimation, will yield the best estimate of visible (5mm+) young of the year numbers, but there is little difference between photo-derived data and diver produced *in situ* data for corals of 2cm or greater in size. Consequently, photo census can provide a useful and robust measure of juvenile recruitment for corals typically older than one year and the level of detectability of corals will remain consistent within locations, but can vary significantly between locations with different levels of structural complexity. Over time, photo-derived recruitment data will provide valuable information on trends and norms in coral demography, while also providing an archive of general benthic condition. Our results show a positive relationship also between coral recruits detected on tiles with counts of older juveniles detected from photographs, but this correlation is specific to location.

The use of tiles, while labor intensive, does have a place in any recruitment monitoring study. Nonetheless, as it is resource intensive, efficiencies could be gained by applying these methods only in selected locations to confirm annual trends in larval supply. ***Our studies recommend that the most cost effective approach would include a mix of targeted specialist assessments using tiles and UVC at a few locations annually or biannually, within a broader program of long term repeated photographic monitoring of established transects sites by regional staff, using off the shelf digital cameras and simple operating procedures.*** Expertise for interpretation of imagery can be consolidated in one place with DEC and images transmitted electronically from the regions.

Improvements in camera resolution and the use of strobes beyond current consumer gear may deliver minimal additional benefit, but future stereo camera systems may enable further operational efficiencies by permitting automated image calibration and simplified field use.

FISH RECRUITMENT

Extensive field trials in 2009 showed that 9 underwater visual censuses along 30 x 1 m transects at each location x reef zone combination was the best method for censusing juvenile fish assemblages at Ningaloo.

This assessment is based on ease of use leading to higher levels of field efficiency and corresponding maximisation of geographic coverage within a given time frame as well as statistically more precise estimates of species richness and abundance. This method was also shown to minimise inter-observer differences in abundance and species richness measures and allows habitat data to be easily estimated at the end of each transect and/or benthic images to be taken at regular intervals along transects providing a unit of measure in each image frame.

Overall, 20 locations were chosen for repeated sampling in follow-up years (2010-2011) at back reef and lagoonal reef zones with 9 transects at each location x reef zone combination. Reef slope transects were deleted from the program post 2009 because of the paucity of juvenile fishes on these transects and the inefficiency of travel time to slope locations at Ningaloo. With three in-water field workers each running three transects, efficiency is very high using this technique allowing for better coverage within a fieldtrip.

Calibration of total lengths using floating fish models for new or inexperienced workers is advised to ensure juvenile size cut-off points are adhered to. Accurate taxonomic identifications to species level was an initial problem particularly among the wrasse and parrotfish families. Many juvenile fishes go through a series of ontogenetic changes in the way they look (colour, markings and stripe changes mostly) with little resemblance of juveniles to adults. This has been overcome by the development of underwater field sheets that identify Ningaloo juvenile fishes and highlight distinctive visual traits to look out for. It is also strongly advised that data be entered at the completion of each day's work so that any taxonomic issues are dealt with immediately among all workers for consistency among workers and to ensure data integrity. A Microsoft Access database for Ningaloo juvenile fishes has been developed and refined along the way for ease of data entry in the field and continuation of juvenile fish censusing into the future. Included within this database are convenient dropdown menus of all relevant data for each transect including location name, reef and management zones, GPS marks, fish abundance at the species level, habitat characteristics and live coral identification (Appendix B). Clicking on many species names within the database brings up a bitmap image of juveniles of that species if an additional check at the data entry stage is required.

Key findings are already dealt with, both in summary and in detail in the Executive Summary above and the main results within this report and will not be repeated here.

2.1 Objectives and Outcomes

WAMSI Node 3, Project 3.1.2 is one of four complementary but independent sub-projects aimed at investigating benthic biodiversity, reef monitoring techniques and patterns of whale shark migration at Ningaloo Reef. It was broadly aimed at providing a better understanding of spatial and temporal patterns of recruitment in corals and fish, the development of proven best-practice methodologies for a long-term monitoring program, and providing a comprehensive baseline dataset from which to build on by the Department of Conservation and Management. The specific objectives required for this project were to:

1) Establish recruitment monitoring sites across Ningaloo that could be incorporated into a long-term recruitment monitoring program.

2) Elaborate the influences spatial and temporal sampling variation could have in a recruitment monitoring program, giving consideration to levels of statistical power and financial constraints.

3) Provide baseline data on current levels of recruitment.

4) For the key groups of corals and fish, quantify background variation and the effects of changes in environmental conditions on size-structures and rates of recruitment.

5) Evaluate a variety of methods that could be used to gather meaningful data on recruitment in a cost effective way and ideally methods which are capable of utilizing regional staff capacity as part of the monitoring program.

In addition, a further 6 related questions have been put forward as important to the management of the NMP:

1) What are the key functional groups/species involved in herbivory and what is the nature and extent of associated herbivory?

2) What are the current levels of fish and coral recruitment?

3) How does this compare with other comparable reef systems?

4) What cost-effective methods should be used for long term monitoring of these factors (including indicator species / groups, temporal and spatial scales)?

5) What representative species/functional groups should be monitored over the long-term?

6) Are current management arrangements appropriate to maintain acceptable levels of coral and fish recruitment?

Each of these management objectives is discussed in more detail within the body and executive summary of the report and is additionally summarised in brief following the report's general conclusions at the end of this document.

2.2 Implications for Management – Recommendations

Implications for management are addresses in "Key management questions" at the end of this report.

Coral Recruitment

- Large spatial variation in recruitment was noted between sites in this study. Further spatial and temporal characterization of larval supply is recommended in order to ultimately select a subset of cost-effective sentinel sites where labour intensive specialist survey methods are utilized.

- Additional investigation into the scale of coral stock recruitment coupling is desirable in order to predict spatial extent of localized, ecological scale connectivity. The recently updated habitat mapping models derived for the Ningaloo hyperspectral database, combined with the latest fine scale circulation models should provide insights into locations where abundant coral and localized return eddy's combine to ensure maximal recruitment on a regular basis, (e.g. Bundegi, versus locations which rely on more transient or widely dispersed larval sources and which may therefore be strongly affected by annual local weather conditions etc).

- Consumer grade digital cameras and underwater housings provide an effective tool for detecting juvenile corals in many reef environments, particularly in less topographically complex habitats and for corals that are above 2-3cm in diameter. Consequently cameras are reliable for inter-annual repeated measures at specific locations, but may not be reliable tools for detecting small cryptic corals, especially in moderately or highly topographically complex habitats. The result means that camera surveys will provide a useful measure of multi-year trends and the abundance of corals mostly beyond one year old, but not young-of-the-year cohorts. Nor will they be able to detect changes in post-recruitment survival during the first 12 months of life. Those questions will require a combination of recruitment tiles, diver UVC and camera photo sampling to resolve process related questions that may be influencing the ultimate survival of small corals at particular locations.

- The use of cameras, notwithstanding the above described limitations, should permit acquisition of useful field data over time to monitor coral juvenile abundance by generalist field staff. GPS located transects may be surveyed simply, following a documented camera use protocol, and the resulting photos transmitted to the core marine research specialist for interpretation. Rules associated with image interpretation and reference images should be established to maximize inter-observer consistency.

Fish Recruitment

- The identification of commercially and functionally important species that recruit solely to either back reef coral dominated or algal dominated lagoonal areas cannot be overstated. From the premise that coral reef ecosystems rely on the combined input of a range of organisms to ensure and maintain ecosystem integrity, this finding argues strongly for the emphasis on future research to incorporate all biotypes within the Ningaloo reef ecosystem. Furthermore, it provides an excellent example of the co-evolution and co-dependency between biotic habitats and the organisms that live there.

- The underlying variability at both spatial and temporal levels argues strongly for the continuation of juvenile fish censuses into the future in order to reveal multi-year cycles in fish recruitment and correlate these with abiotic conditions such as annual temperature, strength and timing of Leeuwin and Ningaloo Currents.

- The increased abundance of fish recruits to sanctuary zones is a welcome outcome. Whether this is a function of sanctuary zones having originally been chosen on the basis of maximum habitat complexity (i.e. more structurally complex habitats tend to be more diverse and aesthetically pleasing) or some other more complex ecological reason (e.g. trophic cascades) remains unresolved. However, quantative data confirming the appropriateness of sanctuary zone positioning and its effects on maintaining biodiversity has its obvious advantages to adaptive management goals.

2.3 Other Benefits

This project provides a baseline census of coral and fish recruitment patterns in the Ningaloo Marine Park's and sheds light on their general ecology, habitat correlates and degree of spatial and temporal variability.

2.3.1 TOOLS, TECHNIQUES AND INFORMATION FOR IMPROVED ECOSYSTEM MANAGEMENT

A series of baseline coral and fish recruitment sites have been established that will facilitate future monitoring of recruitment and general reef health at Ningaloo. These sites include the establishment of baseplates for simple attachment of coral recruitment sampling tiles at 11 locations between Coral Bay and Bundegi.

The results provide recommendations on sampling tools and techniques to monitor the abundance of juvenile corals, including simplified approaches such as camera survey approaches and considerations which will facilitate involvement of regional staff in future monitoring.

2.4 PROBLEMS ENCOUNTERED

Resource constraints limited this projects spatial and temporal extent to two years of coral recruitment data and a focus on the northwestern half of the NMP.

No major problems were encountered with the fish recruitment component other than the initial identification of some species of juvenile fishes in the Wrasse and Parrotfish families which go through a series of changes in their colouration.

3.0 & 4.0 METHODS OF MONITORING THE HEALTH OF BENTHIC COMMUNITIES AT NINGALOO – CORAL & FISH RECRUITMENT

GENERAL INTRODUCTION

Background

The Ningaloo Marine Park (NMP) is Australia's largest fringing reef and one of the world's largest (MPRA CALM CCPAC 2005). Covering a total area of 4,566 km^2, it runs along 300 km's of Western Australia's remote coastline from Bundegi in the Exmouth Gulf (21°52.93'S, 114°08.95'E) to Red Bluff in the south (24°01.87'S, 113°26.25'E) and covers State and Commonwealth waters. The NMP has recently been awarded World Heritage Listing as a natural and unique environment of outstanding universal value. This increasing focus has coincided with additional research effort to elaborate the abundance, diversity and composition of biota within the NMP, particularly via WAMSI supported programs commencing in 2007. This project addresses knowledge gaps around levels of coral and fish recruitment and cost effective methods that may be developed to monitor recruitment, as one key indicator of ecosystem health and resilience. It aims are two-fold, firstly to facilitate effective design of a long term monitoring program for coral and fish recruitment that is logistically feasible, cost-effective and practical. Secondly, to provide a baseline database of coral and fish recruitment patterns at Ningaloo from which DEC can build upon in subsequent years. Together, these are aimed at providing management agencies with the necessary information to continue monitoring the health of Ningaloo's coral habitat into the future.

SCIENTIFIC AND MANAGEMENT RATIONALE

In most coral and fish communities a yearly influx of larval recruits is a key process sustaining and renewing reef dominated habitats. An understanding of larval recruitment levels, timing and trends can make a valuable contribution to the careful management of systems such as the Ningaloo Marine Park (NMP). Documenting recruitment processes provides a basis for understanding future demographic trends and spatial patterns of local and regional adult community structure (Hughes et al. 1999, 2000). Although coral and fish recruitment processes are affected by a plethora of biotic and abiotic interactions, making them notoriously variable from year to year, a number of firmly established and accepted ecological paradigms have now been established which illustrate the importance of documenting annual patterns of coral and fish recruitment and juvenile survivorship. Firstly, there is a direct, albeit complex, relationship between adults and larval input (i.e. stock-recruitment relationship) for a number of marine taxonomic groups including corals (Wallace 1985 & Penin et al. 2007, see Doherty & Williams 1988 for fish, Christy 1982 for crabs). Secondly, in spite of their dispersive larval phase, self-seeding of tropical reefs by corals and fish is emerging as a consistent and common theme in many geographic areas including Ningaloo Reef (Whitaker 2004, 2006, Underwood 2009). The evidence supporting the conclusion that Ningaloo Reef corals and fish are partly self-seeding is critical because it fundamentally illustrates the importance of maintaining healthy adult stocks and underscores the critical nature of management at the local scale. Thirdly, even small changes in inter-annual adult reproductive output (i.e. fecundity) can lead to disproportionately larger variations in recruitment cohort strength (Hughes et al. 1999, 2000).

Alongside these paradigms, documenting annual recruitment paves the way for exploring a number of key ecological processes. Given that Ningaloo Reef is potentially partly self-seeding (Whitaker 2004, 2006, Underwood 2009), patterns of recruitment provide insights into the spawning patterns of its adult corals and fish providing a link to the reproductive health of the overall system. In addition, rates of pre- and post-settlement mortality (Hughes et al. 1999) and forecasting the potential for recovery in the face of an acute disturbance event (e.g. severe bleaching, disease, cyclone, pollution spill) all rely on quantifying rates of larval input.

3.1 INTRODUCTION – CORAL RECRUITMENT

The many methods used to assess coral recruitment fall into two main categories; the use of artificial substrates for sampling numbers of newly recruited larvae (e.g. Babcock 1988, Harriott & Banks 1995, Edmunds et al. 2010) and *in situ* visual counts and measurements of young juveniles (e.g. Connell 1973, Sakai & Yamazato 1984, Roth & Knowlton 2009). Advances in underwater camera technology providing sharp high-resolution images from low cost consumer grade equipment, favour the use of photographic techniques, provided the resulting data can be demonstrated to provide useful and robust measurements for the environment. Imagery is able to be taken by workers with little or no taxonomic expertise and technology that detects and categorises benthic habitat is advancing rapidly (Lirman et al. 2007). The limited information assessing photographic methods for juvenile coral surveys (Edmunds et al. 1998; Burgess et al. 2009) have assessed varying methods from the research practitioner perspective. While some techniques may work better than others in certain situations (e.g. visual or imagery census for juveniles, settlement plates for larval recruits), in this study we also seek to evaluate various tradeoffs in data utility that might arise if some or all of the field surveys were to be conducted by non-specialist field staff.

Reporting in 2009 identified a number of interesting results in both census methodology trials and spatial patterns of coral recruitment. In summary, using an experienced marine biologist throughout, visual census outclassed photo imagery for abundances of the smaller (<30mm) size-classes, but results were variable for larger size-classes suggesting that coral juveniles of >30mm are adequately sampled using either method. However, photo imagery proved superior to visual counts on homogenous slope habitats, whereas on topographically complex and heterogeneous Ningaloo back reefs visual census methods provided very similar estimates of abundance. Interestingly for taxonomic richness and diversity, still photography proved vastly superior to rapid visual census techniques. Taken together, these results favored still photo imagery for juveniles in size-classes of >30mm and recording taxonomic diversity whereas visual census proved superior for <30mm size-classes.

For spatial patterns in larval recruitment the most significant finding was that both taxonomic composition and abundance of recruits varied enormously between Bundegi, Tantabiddi and Coral Bay areas. Patterns of recruitment at Bundegi sites were often more than an order of magnitude higher than those at Tantabiddi with Coral Bay being intermediate (Bundegi sites mean 30 recruits per tile, Tantabiddi sites 3 recruits per tile). Interestingly however, Tantabiddi recruitment was dominated by the family Pocilloporidae and disproportionately higher numbers from the family Poritidae, whereas the Acroporidae dominated the other two areas. This in itself showcases the complexities and subtleties of the recruitment processes taking place in the NMP.

2010 provided a repeat sampling of recruits to tiles at all sites, revisited the comparison of diver-based visual counts versus photos and in addition explored three key associated methodology issues; 1) the degree of diver observer bias in visual censuses, 2) the degree of expertise needed to adequately post-process imagery, and 3) the possibility of further refining camera settings and field protocols to improve image quality and hence data accuracy.

3.2 Materials & Methods - Coral Recruitment

Methods employed focused on the identification of efficient, cost effective and practical techniques to monitor coral and fish recruitment and long term coral resilience at Ningaloo Marine Park. Efforts in 2009 concentrated on combining established current coral recruitment monitoring techniques (terracotta settlement tiles) targeting newly settled larvae with *in situ* visual census and digital still photographic methods to assess the utility and logistical value of each technique (see Depczynski et al. 2009). Coral settlement and recruitment monitoring trials were started in February till April 2009 and built the first year's base-line data set on coral recruitment at Ningaloo for 11 sites at three locations (Bundegi, Tantabiddi & Coral Bay)(Fig 1a-d).

Efforts in 2010 combined core coral recruitment monitoring (terracotta settlement tiles) at the exact same sites and locations as 2009 to provide a second year's base data plus further exploration of new camera techniques, inter-observer comparisons and further refinements to still photography. In contrast to 2009, 2010 was a pronounced split spawning event, an event that happens every few years at Ningaloo. Coral spawning took place around the 9th March and again around the 8th April. In summary, data gathering activities in 2010 included the following;

1) **Camera technique comparisons** to isolate the best possible settings and camera orientation necessary for maximum clarity of photo images and identification of coral recruits across different size-classes.

2) **Expert, intermediate and inexperienced inter-observer comparisons of photo quadrats** for measurements of abundance and size-class distribution to indicate the level of expertise necessary for accurate post processing of images (counts and size-classes).

3) **Diver visual census comparisons, using three divers simultaneously,** for measures of abundance and size-class distribution and taxonomic identification. This explored the sorts of data error which might be expected from having a number of observers collecting data.

4) **Stock-recruitment relationships** to assess the relationship between recruitment and existing habitat (i.e. is there evidence for stock-recruitment relationships at Ningaloo?).

5) **Settlement tile deployment** at the exact same sites and locations as 2009 to enable density and taxonomic composition comparisons to be made at both a number of spatial levels and between 2009 and 2010.

1) Camera technique comparisons

As the objective was to provide guidance on simple, robust and cost effective methods, wherever possible hardware and software used were readily available and required no specialized or customized support or maintenance. Off-the-shelf contemporary underwater cameras were used in this study. The model selected was a Sea & Sea DX1G, consisting of a compact polycarbonate housing and 10 megapixel (Sensor size 1/1.75" (7.36 x 5.52 mm)) compact digital camera, equipped with a 24-72mm (35mm equivalent) wide angle lens. The camera was operated by a SCUBA diver, holding it pointing downwards directly at the seabed, in order to capture a rectangular "image quadrat". In preliminary trials it was found that this camera, operated at maximum wide angle and held at 50cm off the seabed, would capture an image representing an area of around 35 x 50cm, slightly larger than a sheet of A3 paper. This was deemed a useable photo quadrat size, manageable by a diver hovering within arms length of or kneeling on the seabed, that provided both a reasonable sized sample of the seabed but still close enough to allow good resolution of elements with each photo.

Three camera techniques were trialed to determine the best photographic method for censusing newly recruited and juvenile corals; 1) camera held at waist height using ambient light, 2) camera held at waist height using flash and, 3) camera using ambient light, mounted 50cm off the substrate under a tripod located on the seabed.

To enable equitable comparison of the three camera techniques, a benthic transect was marked out at each location using a tape measure and a negatively buoyant quadrat with dimensions of 30 x 45cm allowed to fall onto the substrate adjacent to the tape. This quadrat frame provided a scale reference in each photo. Three camera systems, set up as above, were then used to take an image of the seabed that included the calibration quadrat before relocating it further along the tape and repeating the exercise. In total, 10 sets of replicate images for each of the three techniques were taken of 30 x 45cm quadrats laid haphazardly along the reef at four Bundegi, four Tantabiddi and four Coral Bay sites. This provided a total of 30 images for each of the 12 sites (total n=360).

Images were post-processed by a single skilled observer, familiar with coral reef communities, using the Coral Point Count with Excel extensions (CPCe) program established by Kohler & Gill (2006). CPCe is a Visual Basic program which partially automates the data collection process and permits straightforward size calibration within images (e.g. using a known size quadrat within images). Using the 'area/length analysis' tool within CPCe the length of the broadest part (maximum diameter) of each juvenile coral was measured and placed into one of four size-class categories; <2cm, 2-5cm, 5-10cm and >10cm. Since the objective was simply to test the three techniques against each other, comparisons were made by summing the total number of corals recorded in each size class for each technique, providing a comparative assessment of the most accurate camera method for detecting juvenile and coral recruits.

2) Expert, intermediate and inexperienced observer comparisons of photo quadrats

The quality of data derived from interpretation of images can be influenced not only by image quality, but notably by the level of training, experience, concentration and so on of the observer. Every individual will inevitably develop biases over time in assigning identifications to organisms. To assess the effect of coral expertise on accurately post-processing images for juvenile coral counts, a subset of 116 quadrat images was processed by an expert (20+ years specialist coral experience), intermediate (15+ years general tropical marine biologist) and inexperienced (general marine science graduate) observer. Images were a random subset of quadrat images from Bundegi, Tantabiddi and Coral Bay areas. Observations were placed into one of four size-class categories; <2cm, 2-5cm, 5-10cm and >10cm using CPCe (see above). Comparisons between observers were directly compared graphically and analysed statistically using a Poisson distribution General Linear Model on basic count data at the location level (n=3).

3) Diver visual census comparisons

To investigate the expected variance amongst different observers, three divers simultaneously but independently counted all juvenile corals they could see in a fixed 30 x 45cm quadrat. The divers counted and identified to family level juvenile corals into the size-class categories; <2cm and 2-5cm. The three SCUBA divers were all experienced with underwater coral reef field workers (PhD or MSc). In total, 116 sets of replicate quadrats for each of three divers were taken of 30 x 45cm quadrats laid haphazardly along the reef at two Bundegi (n=16 & 20 quadrat sets per site), two Tantabiddi (n=20 & 20) and two Coral Bay (n=20 & 20) sites (Total quadrats censused n=348). Comparisons between observers were graphically presented and degree of variation estimated statistically by using a generalised linear model (GLM) with two nested levels, location and observer. As the count data deviated from a normal distribution, the GLM was used in conjunction with a Poisson log-link fitting function. Testing for goodness of fit and model defiance were conducted on model residuals by a) scrutinizing hat and cooks distances in leverage plots b) q-q plots. No outlying points were found.

4) Stock-recruitment relationships

To provide an understanding of the relationship between patterns of coral recruitment and existing reef habitat, gross % cover was estimated from the 116 images used in the diver visual census comparisons (see above). Estimates of % cover was recorded using a 20-point stratified random overlay using the CPCe program. Habitat was grouped into one of eight different categories; coral, algae, soft coral, sponge, other, indeterminate, seagrass and abiotic. The habitat type falling under each of the 20 points was recorded and then converted to % cover summed to 100% for each quadrat. Stock-recruitment relationships were analysed by combining this information with the identical quadrats from the diver visual census data. Relationships between existing habitat and coral recruitment was analysed using a penalized regression spline method (Hastie and Tibshirania1990, Wood 2006). This analysis conducted automated fitting procedure via the function "gam" in the CRAN R software package (v 2.12) and using the library "mgcv".

5) Settlement tile deployment

Settlement tile deployment repeated that of 2009. Eleven sites at three locations in the northern and central sections of the Ningaloo Marine Park (NMP) were chosen to continue baseline data gathering for monitoring coral settlement and community resilience. Three fixed sites (repeated measures annually) were established at Bundegi, three at Tandabiddi and five at Coral Bay in depths between 1-9m. Three groups of six terracotta tiles (group spacing at 50 m, tile spacing at1-2 m, tiles measured 110 x 110 x 10 mm) were fastened to the substrate on stainless steel plates (following Mundy 2000) using a pneumatic drill operated by a SCUBA cylinder and custom regulator at each of these fixed sites, providing

18 tiles per site (6 tiles x 3 sites). Tiles were marked by a small sub-surface buoy and GPS positions recorded (Appendix C). Sequential tile deployment took place between March 6th-14th 2010.

Settlement tiles were retrieved in the same sequential order between May 10th-14th following the split spawning episode. The stainless base plates fastened to the reef were left behind and loaded with replacement cement board tiles so that subsequent 2011 tiles could be placed on exactly the same base plate as those in 2009 / 10. This strict spatial control is important because it allows accurate temporal comparisons to be made between tiles as the orientation and micro-environment of tiles may have a large effect on rates of recruitment. On retrieval, tiles were handled by the corner edges only and placed onto a metal rod with small foam spacers between each tile to ensure that physical damage to recruits was minimized. Metal rods with tiles were then placed in a bubble-wrap lined plastic bin for transport to a land-based camp where they were soaked in household grade bleach diluted to 33-50% for up 10 hours to remove all biological material from them. Tiles were then rinsed thoroughly in fresh water, dried, packaged in bubble wrap and labeled in readiness for censusing back at the laboratory.

Back in the laboratory, each tile was thoroughly searched (i.e. top, bottom, sides) under a stereo-dissecting microscope at 40 x magnification using a 10 x 10 mm grid placed over the surface. Locations of individual settled corals on each tile were mapped and positions recorded. Settled corals (4 to 8 weeks old) were identified according to Babcock et al. (2003) into the following families; Acroporidae, Pocilloporidae, Poritidae, Isoporidae and "other" (unidentified) corals, many of which were probably from the family Faviidae and the subgenus *Isopora* (Babcock et al. 2003; English et al. 1994).

Variation in spatial and temporal patterns of recruitment were analysed using a repeated measures hierarchical variance partitioning. This is a modified version of GLM (Mac Nally 2000). This method calculates goodness of fit measures and, using the partition function, applies the hierarchical partitioning algorithm of Chevan and Sutherland (1991).

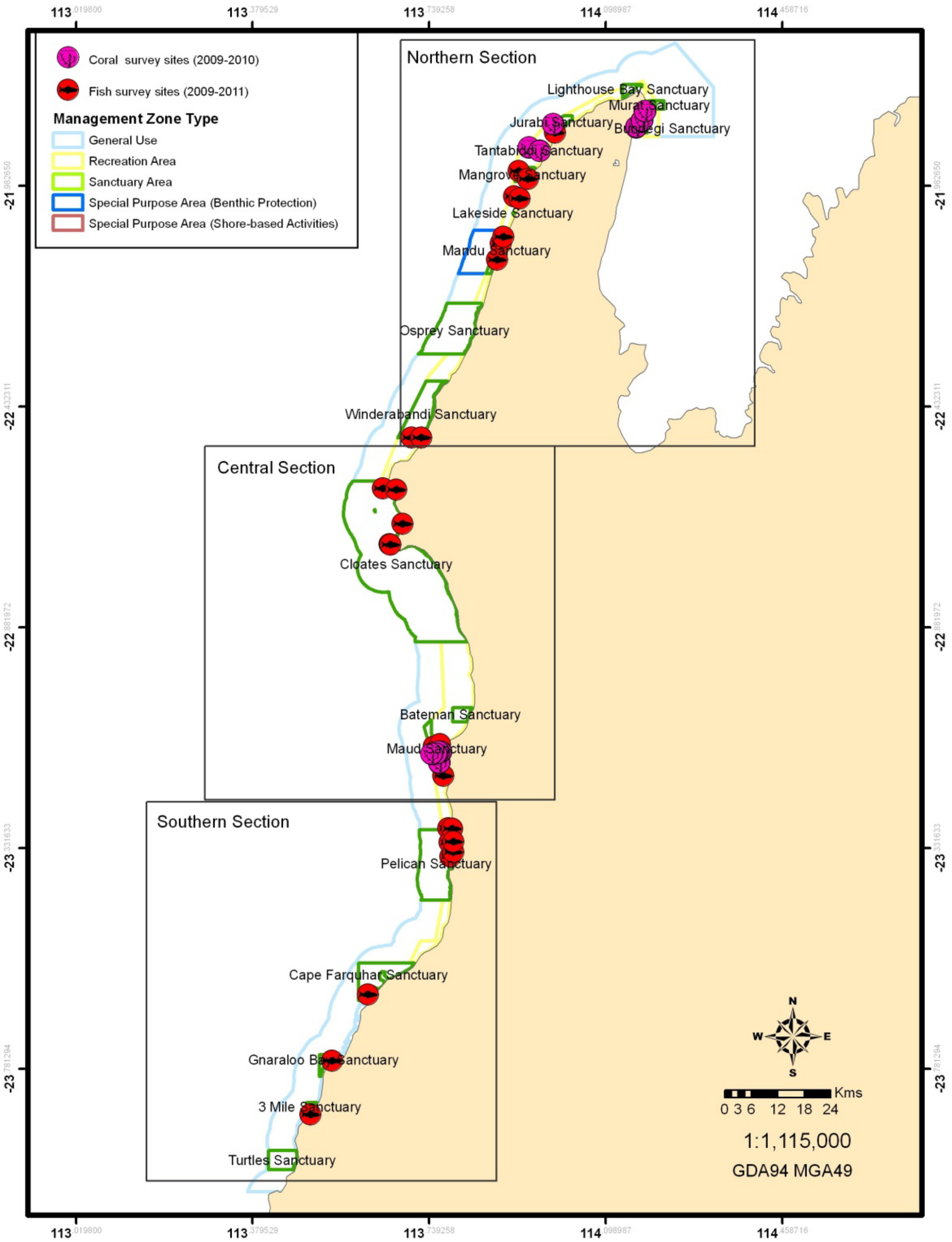


Figure 1a: Sampling sites for coral recruitment tiles, coral recruitment census and juvenile fish census for the years 2009-2010 (corals) and 2009-2011 (fish). Sections of the marine park are split up here to reference the next 3, higher resolution and more detailed figures in this report.

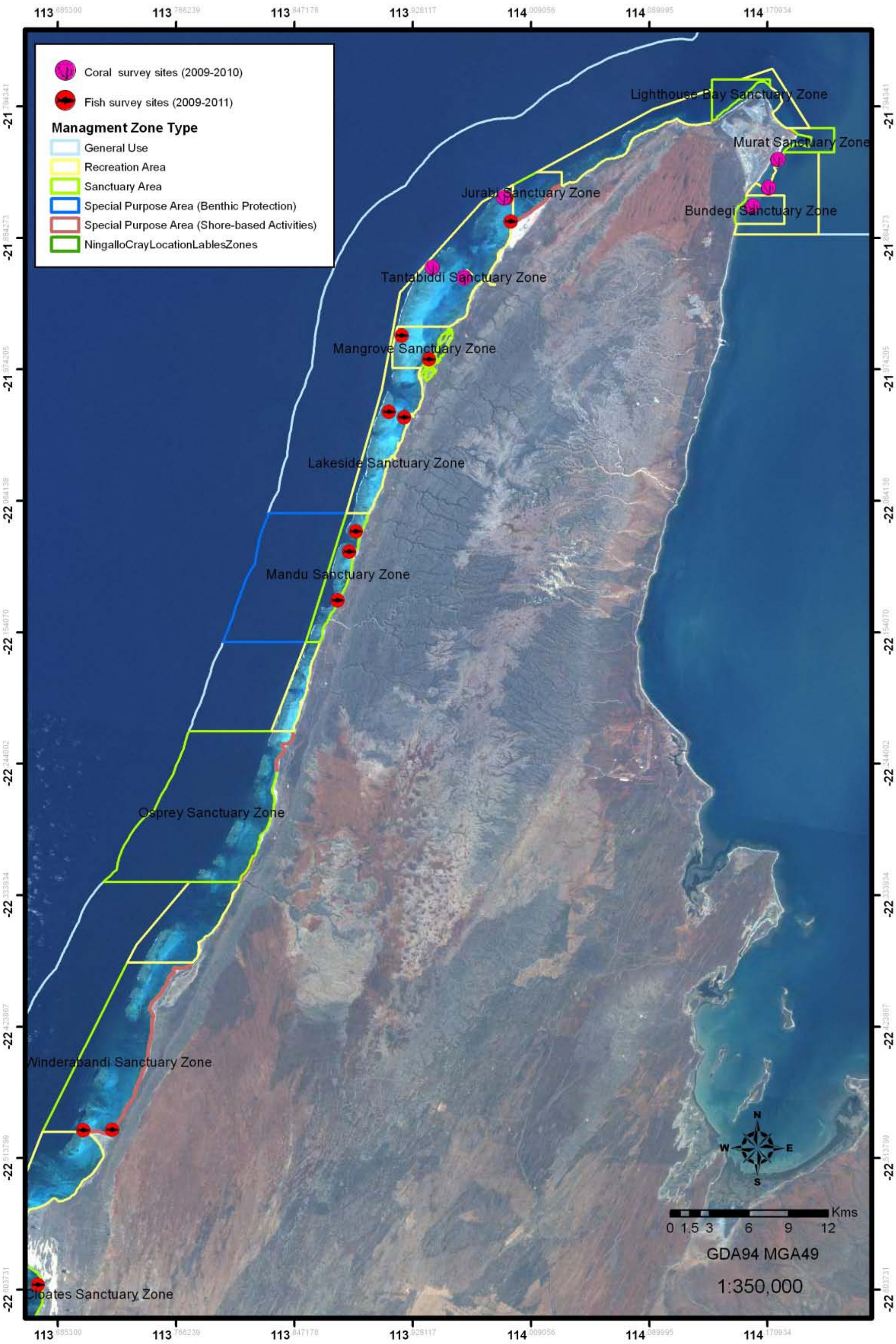


Figure 1b: Northern section of the Ningaloo Marine Park showing coverage of coral and fish recruitment sites.

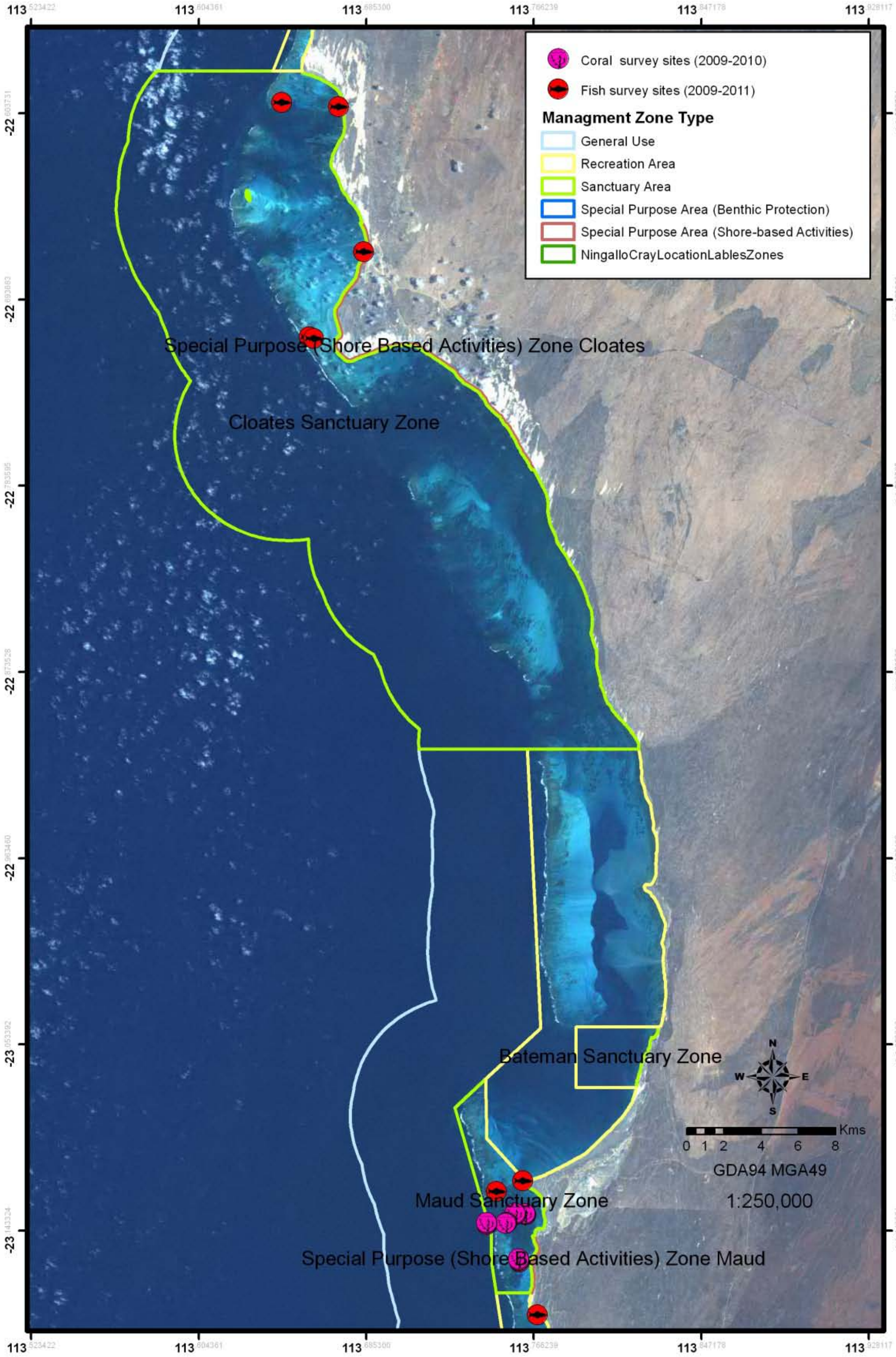


Figure 1c: Central section of the Ningaloo Marine Park showing coverage of coral and fish recruitment sites.

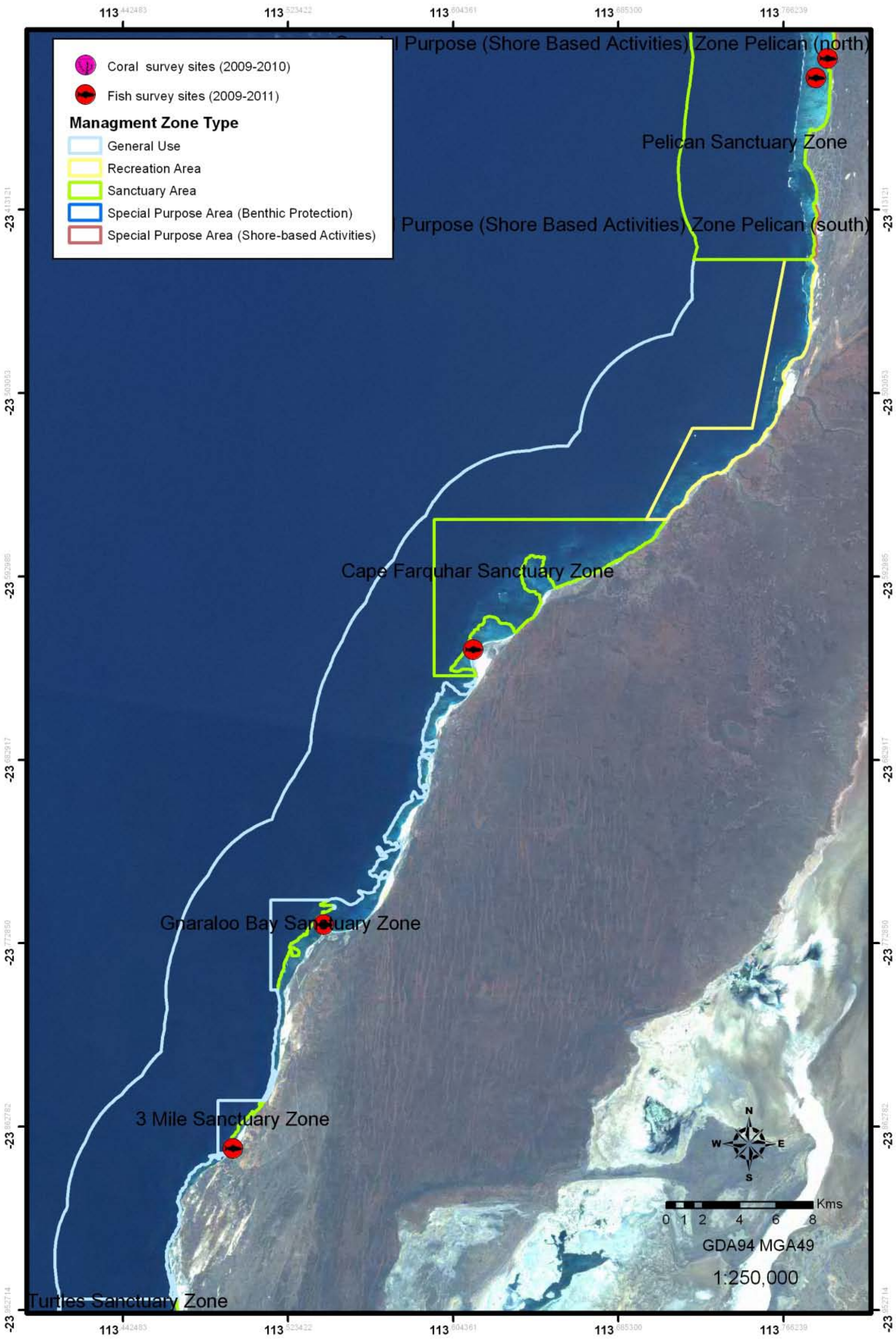


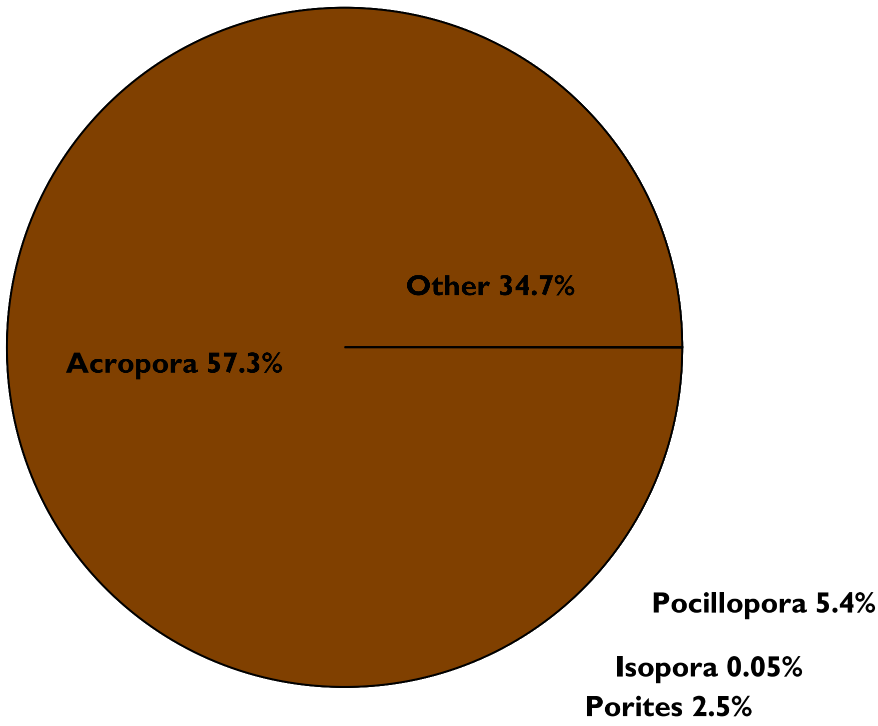
Figure 1d: Southern section of the Ningaloo Marine Park showing coverage of coral and fish recruitment sites.

3.3 RESULTS – CORAL RECRUITMENT

3.3.1 RECRUITMENT CENSUS USING TILES

The abundance and composition of coral recruits counted on the tiles varied greatly between the two years, despite the locations for tile deployment being exactly repeated. In 2009 recruitment was much greater and corals in the family Acroporidae dominated the sample, while in 2010 the total number of recruitments was less than half the 2009 levels and non-Acroporid species dominate the counts (see Figure 2). In both years, the majority of recruits were found on the undersides and narrow vertical side edges of the tiles, although the underside was particularly important in the 2010 census (Figure 3 & 4). This result may be due to a combination of fewer Acroporids in 2010 and the fact that the tile deployment period was longer. A longer deployment means a greater amount of post-settlement mortality will have occurred prior to recovery of the tiles to the laboratory. In other studies, post-settlement mortality has been higher on the upper tile surfaces (Heyward and Smith, unpublished data). The variation between years in both abundance and relative composition of recruits may simply reflect interannual changes in reproductive output of all corals. However, the most distinctive aspect is associated with a marked reduction in recruits from the family *Acropora* (Figures 2 & 5).

Taxonomic breakdown of coral settled on tiles Year 1 (n=2012)



Taxonomic breakdown of coral settled on tiles Year 2 (n=829)

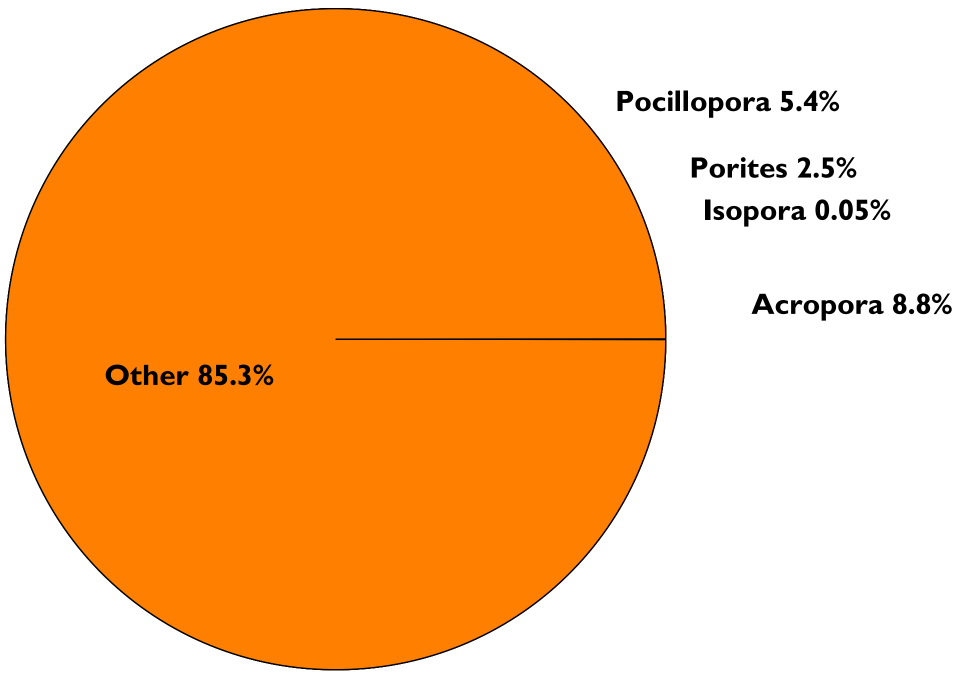


Figure 2: 2009 and 2010 recruitment by the major taxonomic groups.

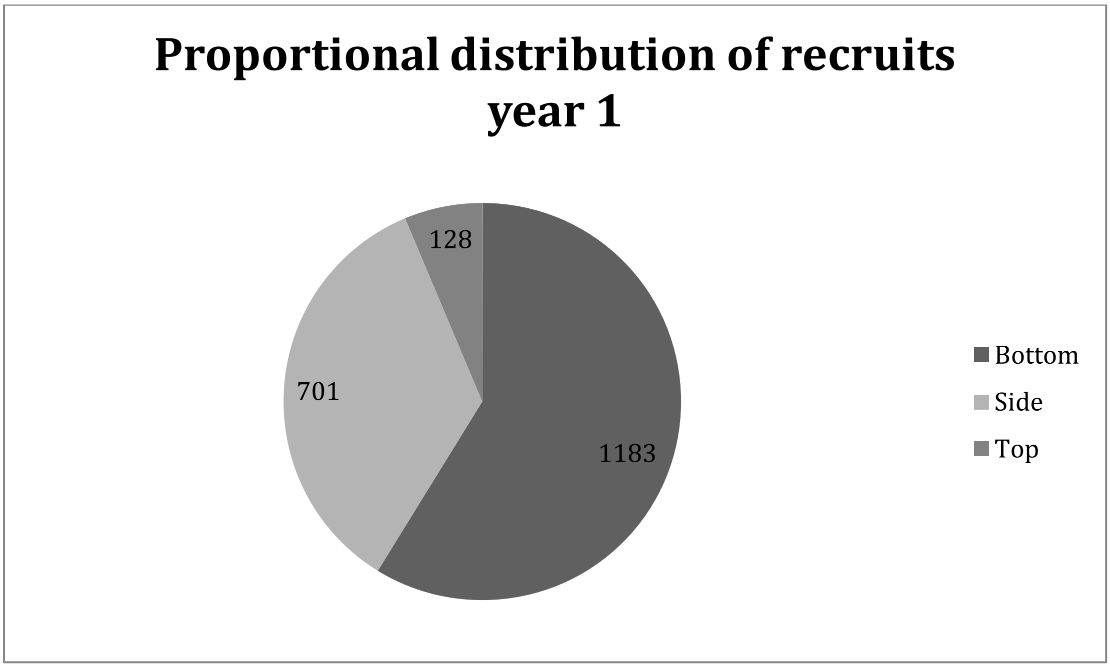


Figure 3: Recruit distribution over settlement tile in 2009.

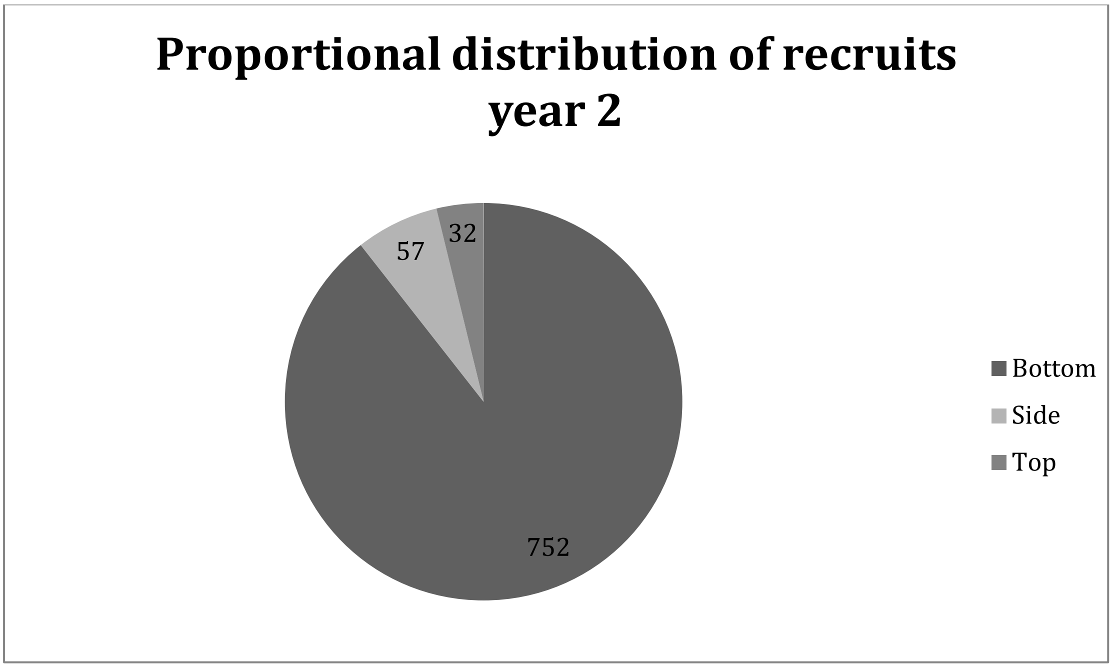
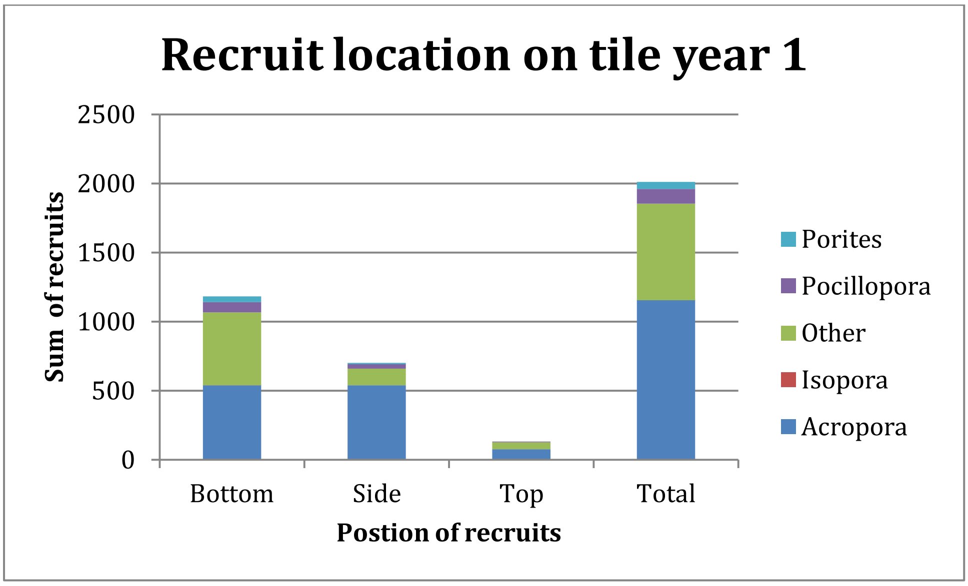


Figure 4: Recruit distribution over settlement tiles in 2010.



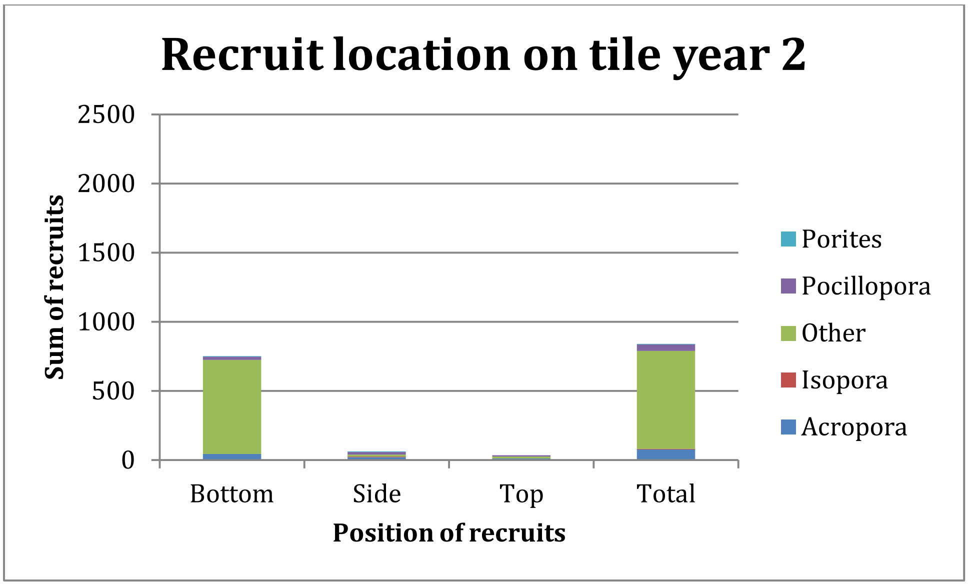


Figure 5: Comparison of recruit distribution on settlement tiles by major taxonomic groups for the two annual sampling periods.

Stock-recruitment relationship

Strong evidence of stock-recruitment relationships linking recruit counts to the abundance of coral in immediately adjacent coral communities (i.e., whether coral recruits exhibited a settlement preference in areas of high live coral cover) was elusive. At Bundegi and Coral Bay, no relationship appears to exist although it appears that Coral Bay starts with an initial positive response to adult coral cover before a stronger negative trend persists. (Figure 6a & c). At Tantabiddi, evidence indicates a positive linear relationship between the two with a reasonable 35% of variation explained by the regression spline model (Bundegi 16%, Coral

Bay 13%)(Figure 6b). Tantabiddi was the only location that was statistically proven to have a stock-recruitment relationship.

Because vacant real estate is at such a premium on coral reefs, the next step was to see if a relationship exists between coral recruitment and bare abiotic substrate. This analysis was conducted at two locations (Tantabiddi and Bundegi) where supporting information was available. The regression spline models (Figure 7a-b) indicated no significant relationships exist between abiotic substrate and recruitment for Tantabiddi or Bundegi locations.

These results suggest that factors beyond the availability of bare substrate or the abundance of coral along a particular transect are more important in determining recruitment rates. Larger scale phenomena, such as the capture of spawning slicks and larval cohorts into eddy systems of 100s of meters to kilometers in diameter are likely to play a significant role in dispersal or retention of coral larvae to natal reef areas. Large sections of reef crest and lagoon can be linked in unidirectional current cycles along the lagoons and out through the channel gaps in parts of Ningaloo. Coral spawn may well be captured and cycled in these gyres until competent to settle. At the very fine scale, the condition of the microhabitat, particularly abundance of fine algae, sediments and sessile benthic competitors may also play a strong role in recruit settlement and persistence which varies from location to location.

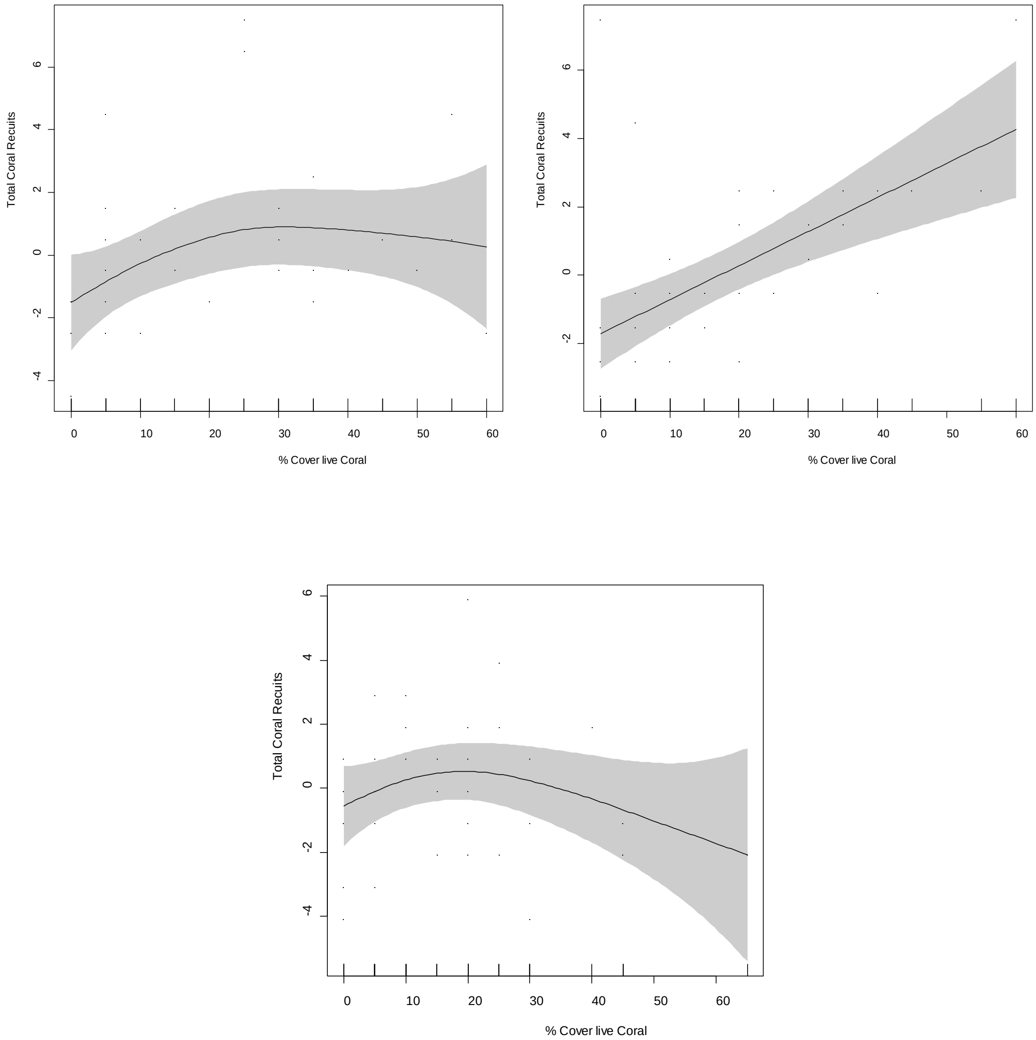
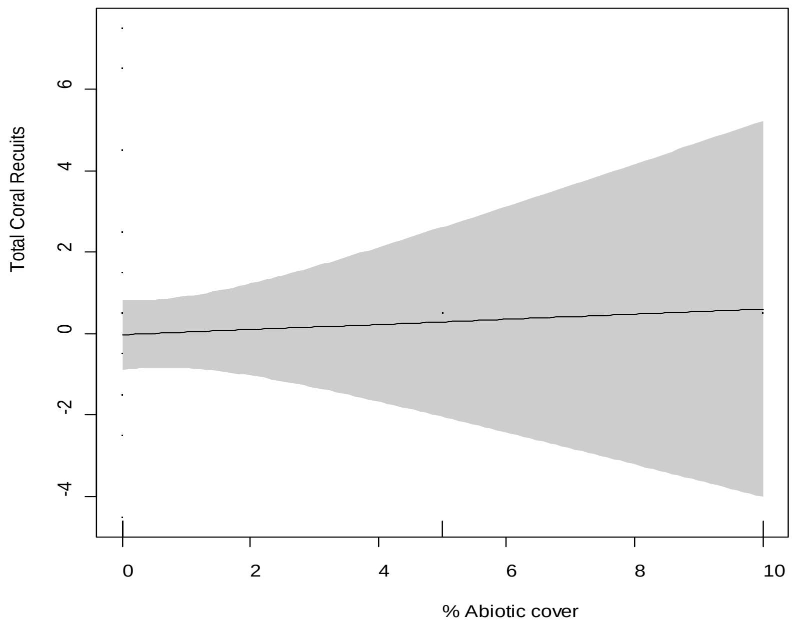
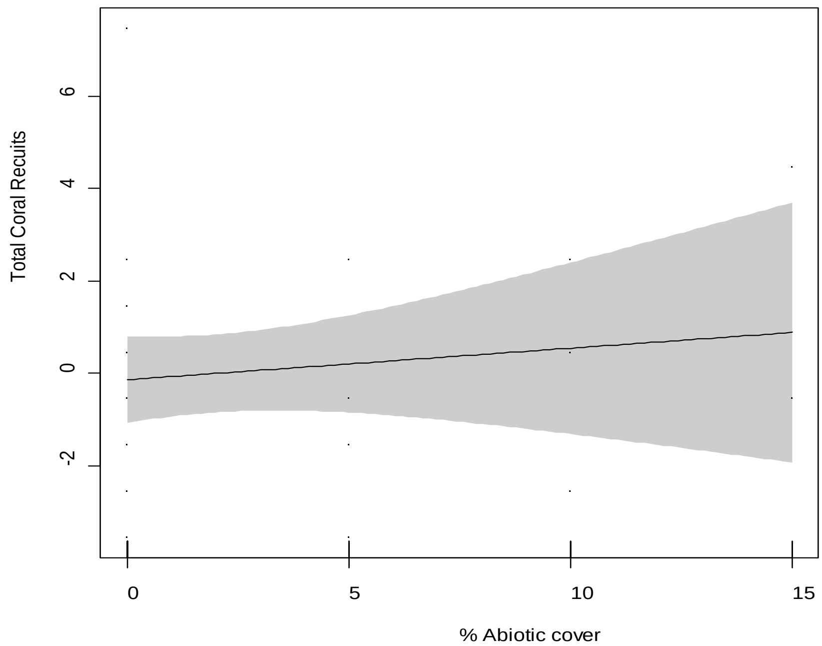


Figure 6a-c: Stock-recruitment relationships at a) Bundegi, b) Tantabiddi and c) Coral Bay showing the nature of the relationships (or not) between numbers of recruits / juveniles and percentage live coral cover. With the exception of Tantabiddi, no real consistent relationship exists. Tantabiddi shows a positive linear stock-recruitment relationship with 35% of deviance explained by the model (Bundegi 16%, Coral Bay 13%).



a)

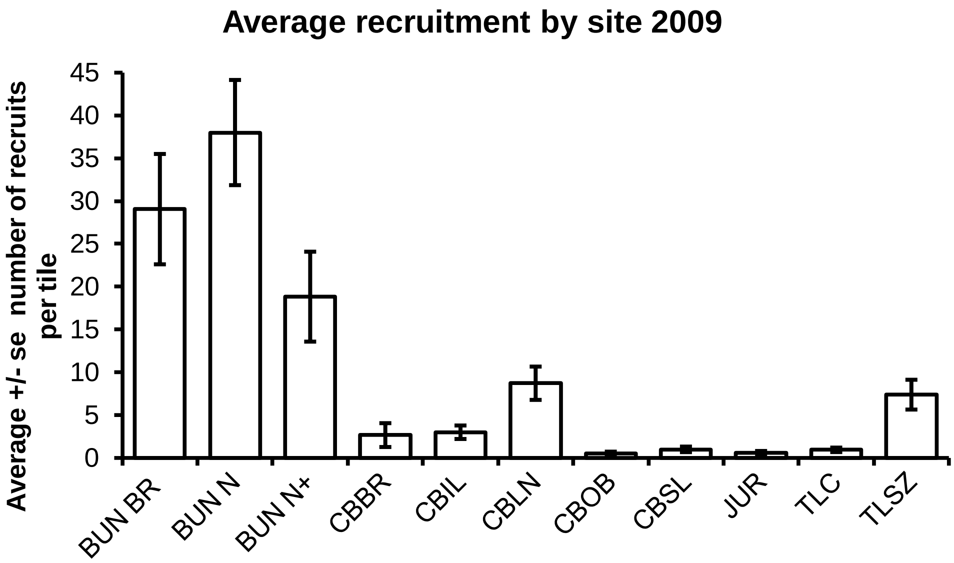


b)

Figure 7a-b: Stock-recruitment relationships at a) Bundegi, b) Tantabiddi showing the nature of the relationships (or not) between numbers of recruits / juveniles and percentage abiotic cover. No significant relationships exist between abiotic cover and recruitment.

Coral settlement tiles – spatial and temporal patterns of recruitment

In 2009 the total number of new coral recruits on the 198 settlement tiles was 1999. In 2010 the number was 841, a drop of 58% from the previous year. This was investigated in more detail with repeated measures hierarchical variance partitioning analysis of Location, Site, Site Rep, Paver and Year. The results from this analysis (Figure 8) indicate that recruitment at the site level combined with year accounts for about 50% of the independent explained variation in the data. For 2010 there was generally higher variation at all spatial scales below location.



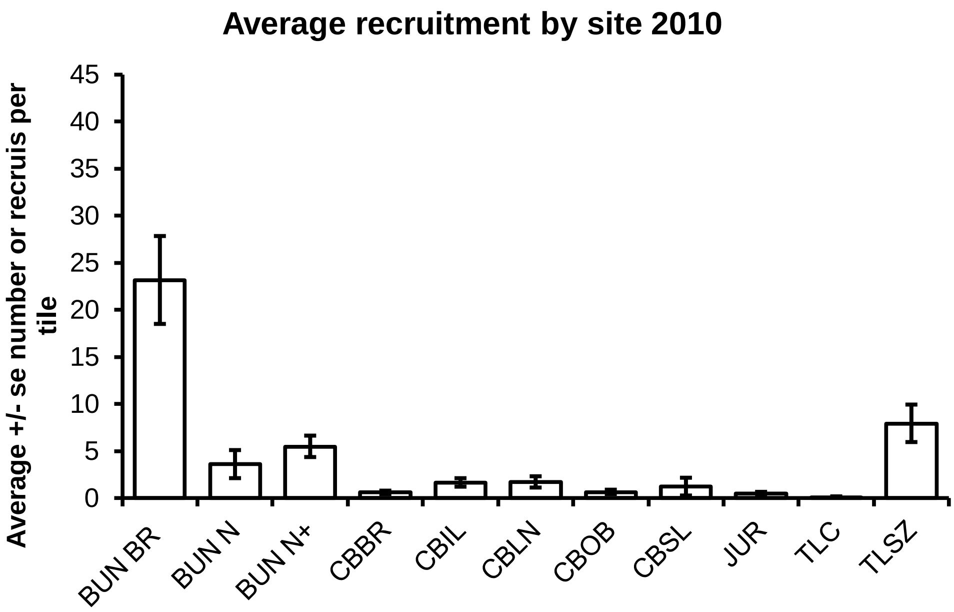


Figure 8: Coral recruitment to tiles by site for two annual sampling periods, 2009 & 2010.

The most obvious difference between the two sampling years was the change in total number of recruits, with the reduced 2010 numbers mostly associated with changes in the Acroporidae. Furthermore, Figure 8 shows that when comparing average recruits per tile at all eleven sampling sites, this reduction was particularly pronounced for the two northern-most sites at Bundegi. This may be due to a general interannual variability effect in Acroporid recruitment across all sites, but with additional effects at Bundegi. It was noted in 2009 that these sites were affected by some coral bleaching, which raises the possibility that this stress event compromised the 2010 reproductive output of sensitive species such as the Acropirids.

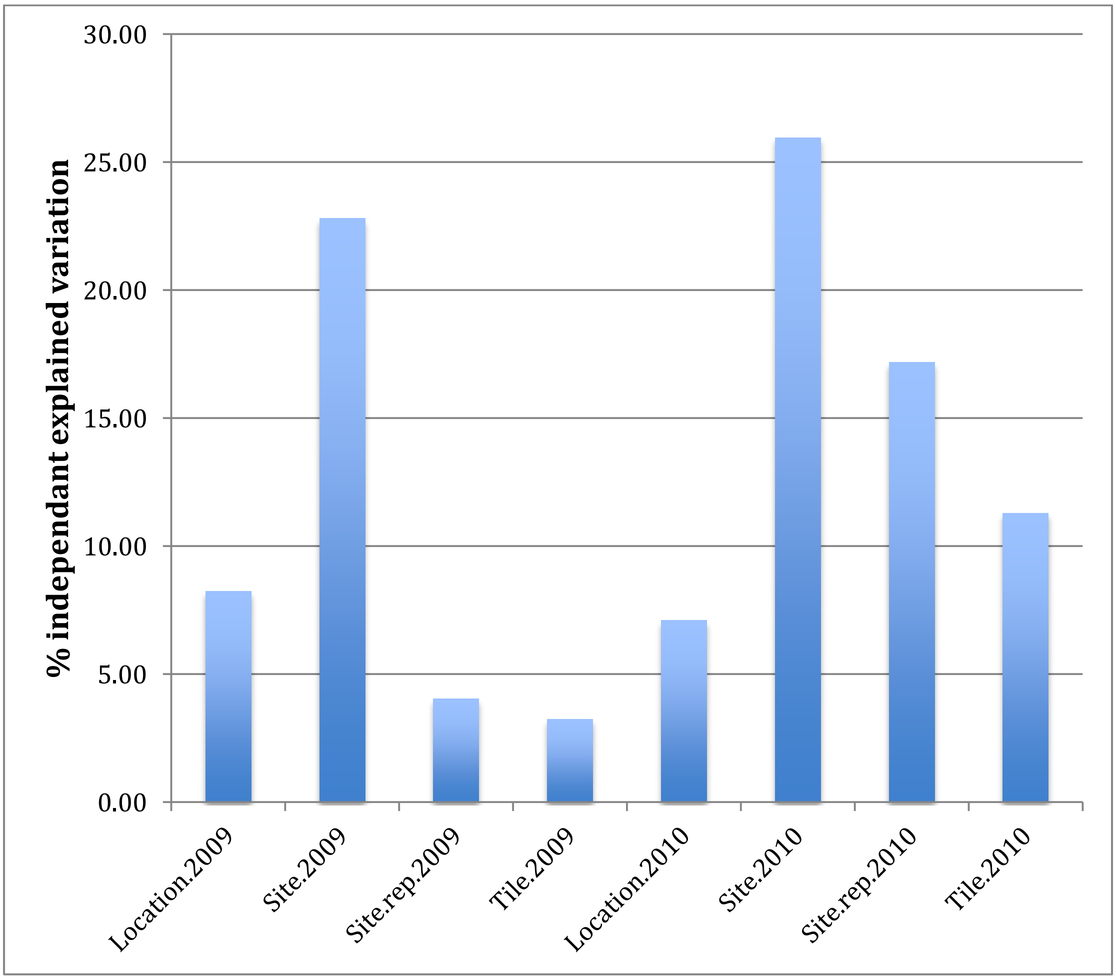


Figure 9: Hierarchical variance partitioning analysis of spatial and temporal patterns of coral recruitment to settlement tiles. Results indicate that most variation occur between years at the level of site.

Significant variation in recruitment was recorded between the three broad regions used in the study (Coral Bay, Tantabiddi and Bundegi), but the most significant spatial influence was the effect of the replicate sites within these regional locations (Figure 9). At Bundegi the three sites were located in a line over 4km, nominally around 2km apart, while at the general Tantabiddi location the three sites covered around 6km. Variation between the individual 6 tiles grouped within a few meters or between the three replicate tile groups placed 50m apart along a 100m transect was less that between sites or the regional locations. Variance was greater at all levels in 2010 than in 2009. These results suggest that in order to reduce sampling variance, it would be most cost effective to increase the replication at the level of site and if necessary reduce the number of tiles or site replicates. Consequently, a more representative program of tile-based sampling could be achieved with the same resources by placing, for example, 6-10 tiles at each site rather than 18 in three groups of six, but establishing twice the number of sites within a few kilometers of each other.

3.3.2 CAMERA TECHNIQUE COMPARISONS

A general linear model indicated that all three camera techniques picked up comparable numbers of coral juveniles across the size-class ranges and, where present, size-class estimations of coral individuals did not differ among these techniques (Table 1a-b). A closer look at the patterns of abundance shows that the tripod ambient light technique perhaps outclassed the others at two of three locations (Figure 10) but these differences were minor and not statistically different. This indicates quite clearly that any of the three camera techniques will provide a suitable level of image resolution provided the settings (focus, megapixel size) are appropriate. Depczynski et al. (2009) outlined a 10 megapixel camera set at the widest angle with aperture at F4.6-5.1 and 1/100th second or greater shutter speeds. However, each camera model may differ and may require fine-tuning to assess the most appropriate setting for each model. The performance of the tripod attached camera suggests that reducing camera shake and movement will make a useful contribution, but if not feasible then camera selection should favour systems with good optics, a fast low aperture lens to permit high shutter speeds with ambient light and ideally a sensor with both adequate pixel count of 10^{6}+ and relatively low pixel density on the sensor.

Table 1: General Linear Model between the three camera techniques at the location level indicating, Table A: all three camera techniques are equally good at picking up coral juveniles when present and Table B: when coral juveniles are present, estimations of their size do not differ between the three camera techniques.

Table A: Size class	Response	LR Chisq	Df	Pr(>Chisq)	Sig. Level
> 2 cm presence/absence	Location	3.876	2	0.14399	
	Method	0.4222	2	0.80969	
	Location:Method	7.8359	4	0.09778	.
2-5 cm presence/absence	Location	12.6302	2	0.001809	**
	Method	2.8863	2	0.236185	
	Location:Method	7.4014	4	0.116137	
5-10 cm presence/absence	Location	15.4648	2	0.0004384	***
	Method	1.0391	2	0.5947933	
	Location:Method	0.5647	4	0.9669061	
>10 cm presence/absence	Location	6.4648	2	0.03946	*
	Method	0.3385	2	0.84431	
	Location:Method	2.0418	4	0.72806	

Table B: Size class	Response	LR Chisq	Df	Pr(>Chisq)	
> 2 cm abundance when present	Location	3.846	2	0.14617	
	Method	0.4177	2	0.81151	
	Location:Method	7.9382	4	0.09387	.
2-5 cm abundance when present	Location	12.8993	2	0.001581	**
	Method	2.8302	2	0.242907	
	Location:Method	6.8527	4	0.143877	
5-10 cm abundance when present	Location	14.928	2	0.0005733	***
	Method	0.984	2	0.6114135	
	Location:Method	0.5875	4	0.9644429	
>10 cm abundance when present	Location	6.8055	2	0.03328	*
	Method	0.3313	2	0.84736	
	Location:Method	1.9393	4	0.74692	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05

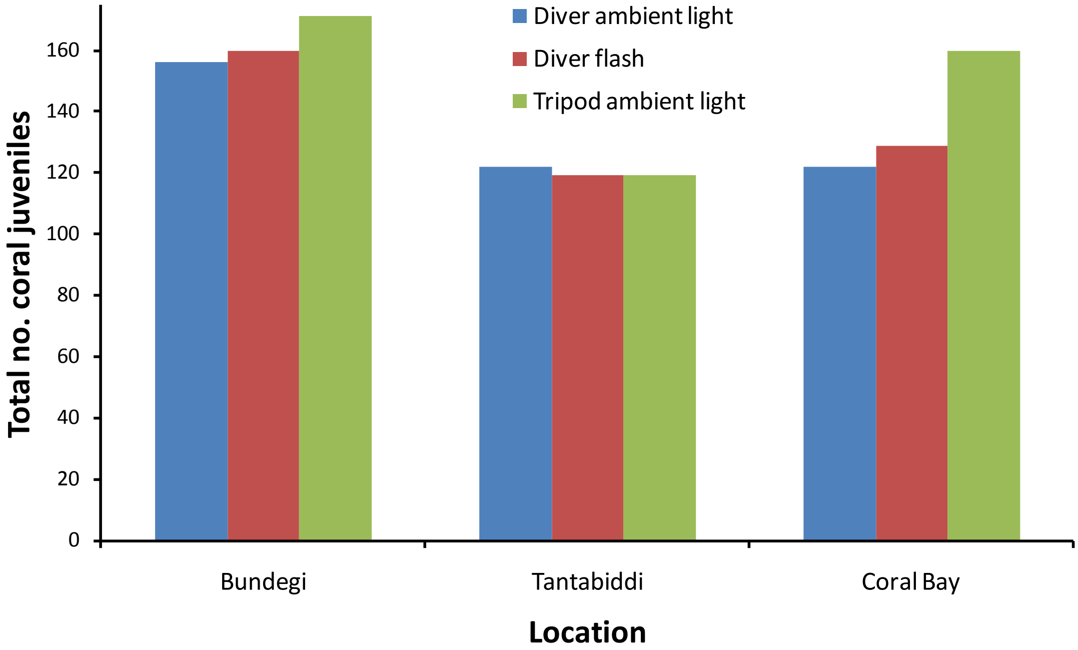


Figure 10: Frequency of juvenile corals detected from images using the three different camera techniques. Data is pooled at the location level as there was no significant difference detected in abundance counts between locations.

Expert, intermediate and inexperienced observer comparisons of photo quadrats

Overall, significant differences were detected between workers in all size-classes except the >10cm size-class (Table 2). However and despite this, there was reasonable concordance among workers for both abundance and size-class distribution (Figures 11-12). In total, the inexperienced volunteer counted 574 coral juveniles across all size-classes, intermediate 496 and expert coral ecologist 533 equating to 36%, 31% and 33% of sum totals (1603 coral juveniles counted) respectively. This indicates that inexperienced workers may be identifying non-coral features of the benthos as corals but that an intermediate level of skill with corals and the marine environment is probably sufficient to record coral juvenile numbers accurately enough to maintain reasonable integrity in a long-term monitoring database.

Concordance among workers was also graphed separately for each location because each is quite different in benthic composition and heterogeneity (Figure 12a-c). Although variation among workers was similar, the structurally most complex and heterogeneous of the three locations (Bundegi – Figure 12a) was also the most variable indicating that accuracy may diminish with increasing complexity and heterogeneity of the benthos. Here the inexperienced worker consistently recorded higher numbers than the more experienced workers, further suggesting misidentifications contributing to higher juvenile coral counts. With the exception of perhaps the smallest size-class (<2cm), proportional contributions of each worker towards each size class (measured as % of total contribution from each worker towards a particular size-class) was also fairly even although counts by the expert in the <2cm size-class were down by 13% from the inexperienced worker (Figure 11).

Table 2: General linear model of observer bias on count data at the location level indicating bias between workers in all but the largest size-class (>10cm).

Size class	Response	LR Chisq	Df	Pr(>Chisq)	Sig. level
<2 cm	Location	11.877	2	0.002636	**
2-5 cm	Location	19.153	2	6.93E-05	***
5-10 cm	Location	23.124	2	9.52E-06	***
>10 cm	Location	4.055	2	0.131667	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05

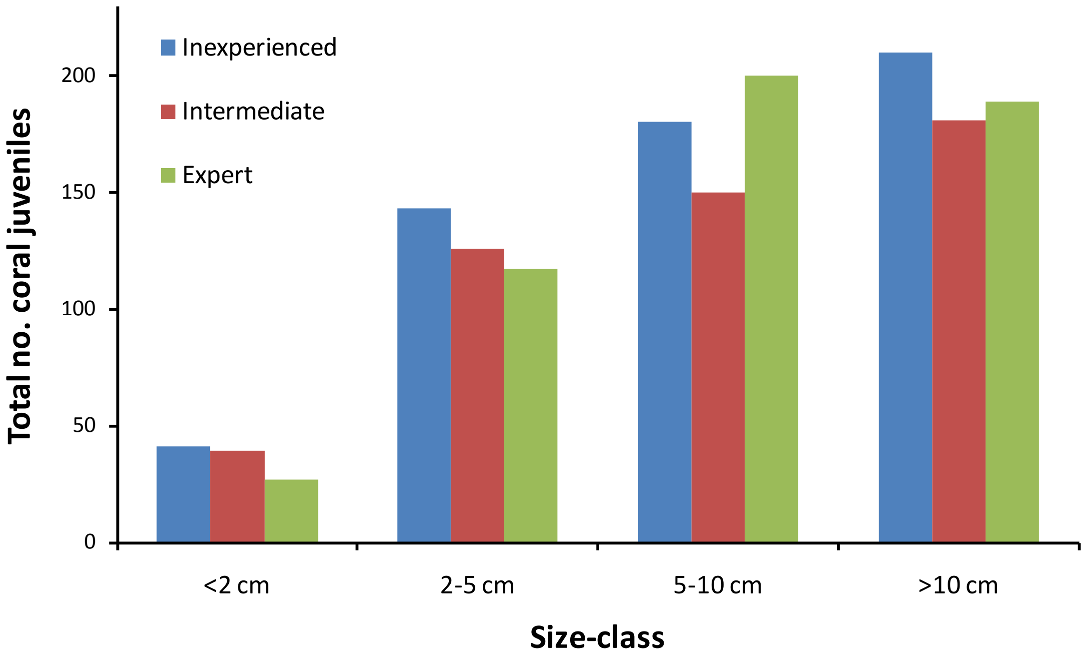


Figure 11: Total abundance and size-class distribution of coral juveniles counted from quadrat photos (n=114 for each worker) of all three sites combined by an inexperienced volunteer, intermediate and expert coral ecologists.

In the course of analyses it became clear that the observer had to make judgments about a variety of image attributes which had potential for confusion or inconsistent approaches between multiple observers. A common example involved corals which lay only partially within the quadrat boundaries. In this case a rule needs to be applied, such as only counting colonies that were at least 50% inside the sample area, in order to keep counts consistent between observers. Additional guidelines need to be established for selecting measurement points on corals in the images. These sorts of protocols, along with instructions on camera setup, and the provision of training images for coral identification, should be documented into a Standard Operating Procedure to minimize sources of inter-observer variation and maximize data quality.

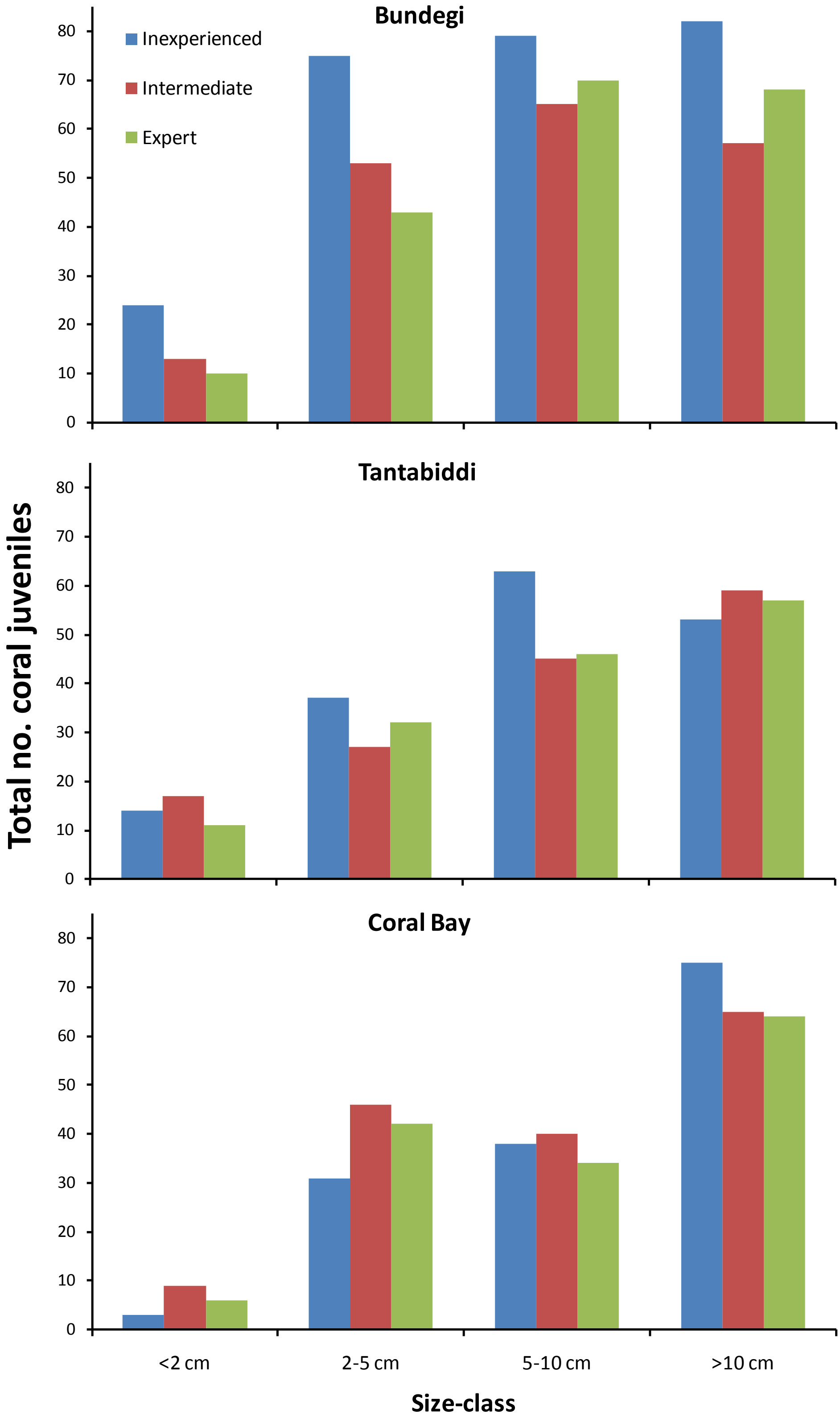


Figure 12a-c: Summary breakdown of the abundance and size-class distribution of coral juveniles from Bundegi, Tantabiddi and Coral Bay sites from quadrat images (n=38 for each location) by inexperienced, intermediate and expert coral ecologists

Diver visual census comparisons

There were major discrepancies between the three observers even when means were presented over all quadrats combined (n=116 identical quadrats for each observer) for family x size-class combinations (Figure 13). Generalised linear model results at the location level indicated significant differences in main effects (locations & observers) with a number of interactions highlighting the inconsistencies among observers depending on location (Table 3). A closer look at the family (Figure 14) and size-class (Figure 15) comparisons on their own indicated that, perhaps with the exception of the <2cm size class, all three observers were quite different in assigning corals to particular families and / or size-classes. However, counts also differed between observers (196, 178 & 103) making comparisons difficult to interpret by inflating discrepancies among workers. Unfortunately, a further look at the proportion of counts allocated to family (Figure 16) and size-classes (Figure 17) for each observer still shows a high degree of variation among observers (except perhaps the Acroporiidae).

Table 3: Analyses indicating statistical differences in main effects (locations & observers) and interactions between these for family x size-class comparisons at the location level.

Family/Size class	Response	LR Chisq	Df	Pr(>Chisq)	Sig. Level
Acroporid < 2	Location	4.5214	2	0.10428	
	observer	5.0951	2	0.07827	.
	Location:observer	3.492	4	0.4791	
Acroporid 2-5	Location	59.403	2	1.26E-13	***
	observer	17.577	2	0.0001525	***
	Location:observer	8.854	4	0.064866	.
Favid < 2	Location	10.115	2	0.0063613	**
	observer	7.885	2	0.0194035	*
	Location:observer	2.767	4	0.5976257	
Favid 2-5	Location	4.521	2	0.1042751	
	observer	5.095	2	0.0782729	.
	Location:observer	3.492	4	0.4790975	
Poritid < 2	Location	8.24	2	0.0162438	*
	observer	9.198	2	0.0100606	*
	Location:observer	4.598	4	0.3311215	
Poritid 2-5	Location	21.895	2	1.76E-05	***
	observer	4.709	2	0.0949299	.
	Location:observer	20.244	4	0.0004469	***
Pocillopora < 2	Location	3.425	2	0.1804066	
	observer	6.256	2	0.0438002	*
	Location:observer	8.841	4	0.0652106	.
Pocillopora 2-5	Location	0.59	2	0.7443506	
	observer	12.32	2	0.0021121	**
	Location:observer	0.654	4	0.9569038	
Other < 2	Location	4.2409	2	0.12	
	observer	4.3074	2	0.1161	
	Location:observer	0.5065	4	0.9729	
Other 2-5	Location	1.9963	2	0.36856	
	observer	1.4791	2	0.47732	
	Location:observer	12.0128	4	0.01726	*

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

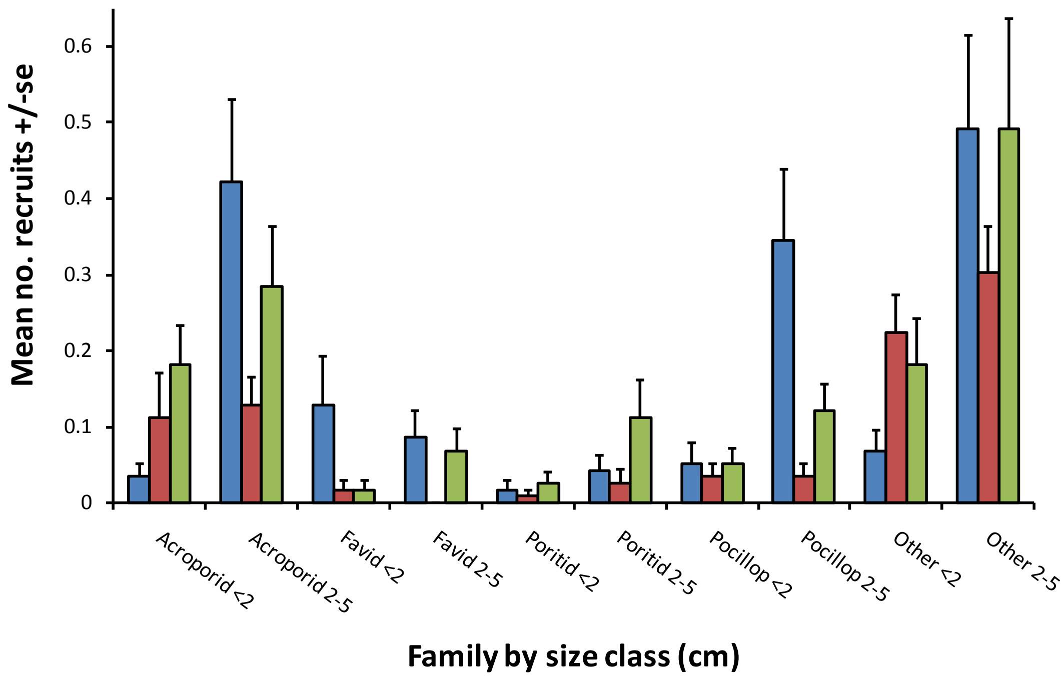


Figure 13: Summary of the mean number of recruits (±se) sampled in each family x size-class category by each of the three workers over all quadrats (n=116). Total abundance (i.e. all juveniles counted) differed considerably between observers (196, 178 & 103), as did the allocation of these numbers to each of the different family groups.

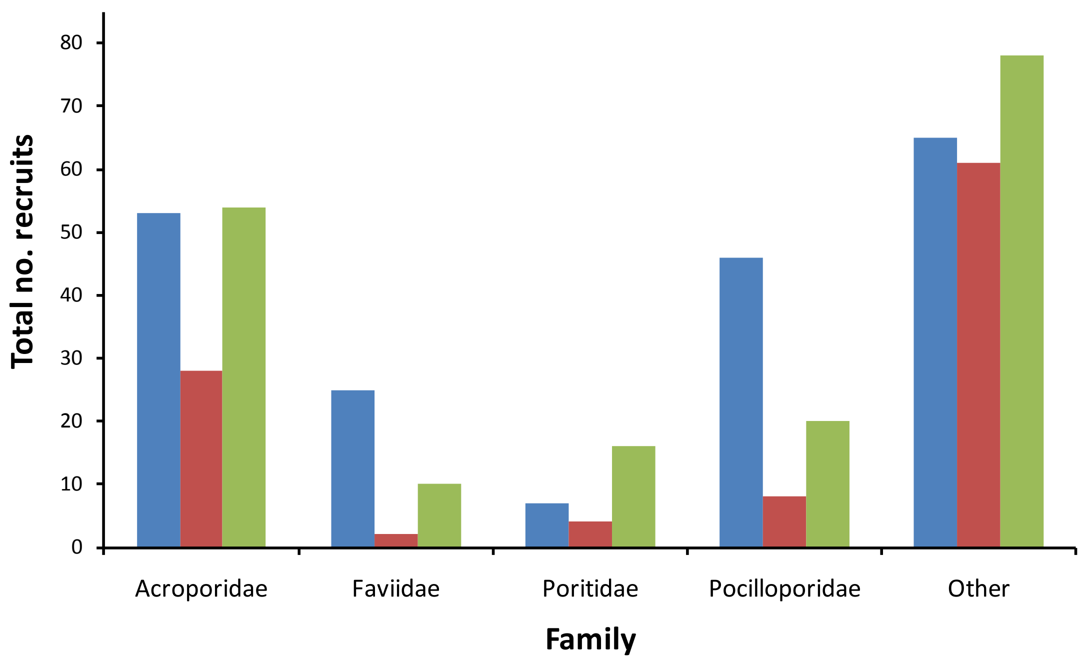


Figure 14: Total number of recruits censused by family to show variation among the three observers (different coloured bars) in the taxonomic identification of juvenile corals.

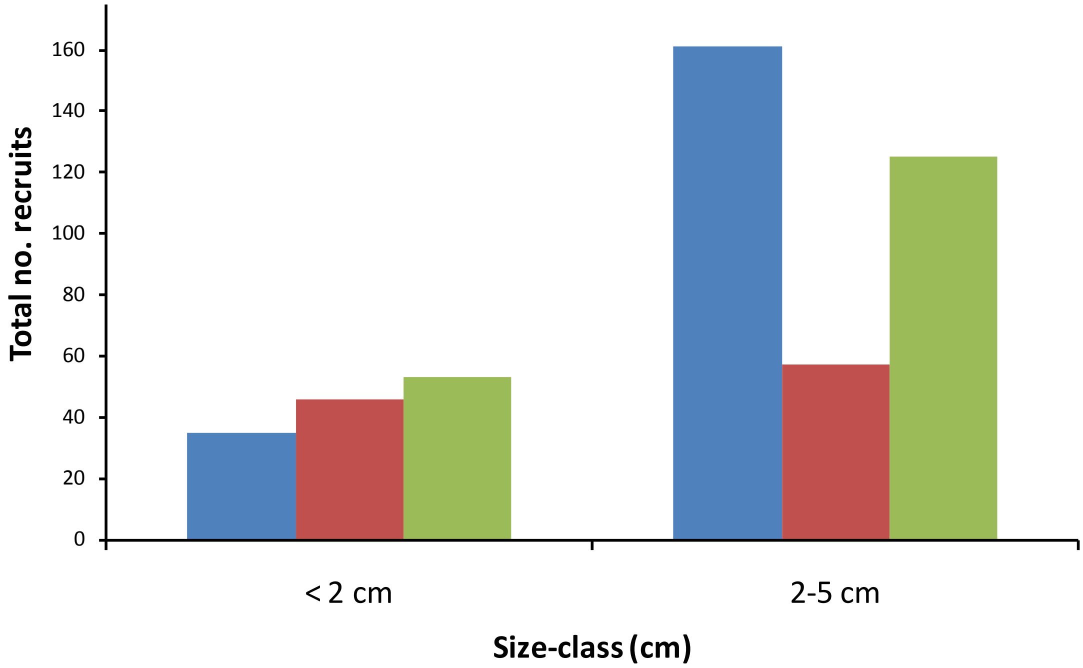


Figure 15: Total number of recruits censused by size-class to show variation among the three workers (different coloured bars) in visually estimating the size of juvenile corals.

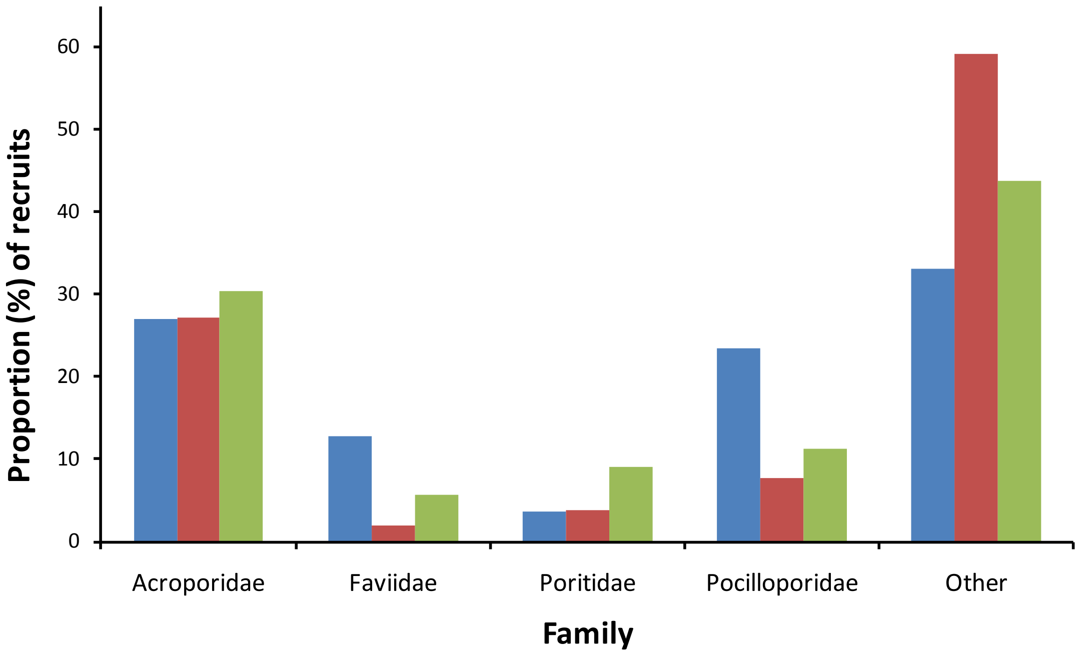


Figure 16: Proportion of recruits censused by family to show variation among the three observers (different coloured bars) in visually estimating the size of juvenile corals.

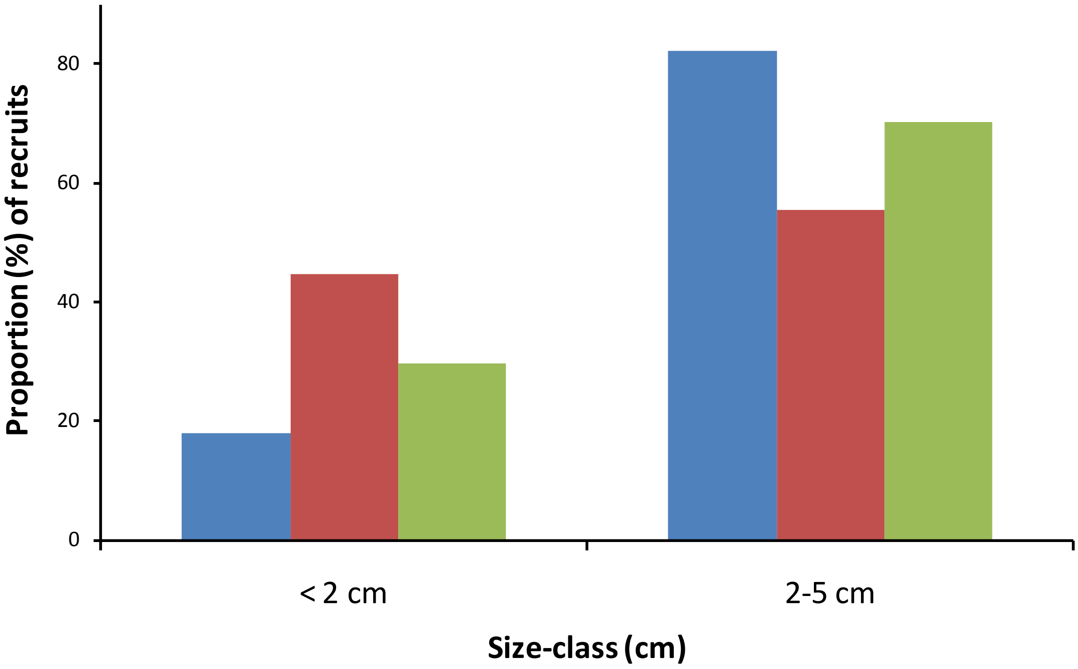


Figure 17: Proportion of recruits censused using UVC by size-class to show variation among the three workers (different coloured bars) in estimating the size of juvenile corals.

3.4 Discussion – Coral Recruitment

This final report provides quantitative estimates of coral recruit abundance, taxonomic identity and juvenile size-class distribution for several key areas of nearshore Ningaloo Reef. It sets out a blueprint for further monitoring of coral recruitment processes that has been specifically designed with the logistics and challenges that Ningaloo presents in mind. This includes a range of comparative studies that identifies the best possible methodology to ensure data integrity, an estimate of variation (error) likely to be encountered depending on the expertise of workers, and the setup of sites and locations that already have baseplates for repeating annual recruitment surveys. It also provides a baseline dataset from which to build on.

It is important to note that, for the purposes of methodological comparisons we have used three quite different locations, Bundegi, Tantabiddi and Coral Bay. The levels of larval settlement detected varied between these locations, as did the counts for abundance of 1-2 year old juveniles. Consequently, even from this small study, it is clear that for a fully representative monitoring of coral recruitment in the NMP, a number of sites will be required. Our results suggest that sampling replication needs to address high levels of recruitment variation at scales of a few kilometers within areas bounded by features such as physical embayments or persistent local eddies. Furthermore, very significant components of the coral community at Ningaloo occur on the reef crest and outer slope.

These were not a focus of this report, although the limited data generated from the slope habitat do suggest significant levels of recruitment occur there. The outer slope areas are more difficult to monitor and access can be constrained by weather, but the overall contribution of these communities to recruitment more broadly (including into the back reef and lagoon areas) does require some assessment. Hydrodynamics at Ningaloo indicate a strong and persistent water flow across the reef crest into the lagoon, which will facilitate larval exchange between outer reef areas and lagoon, as well as in some situations create persistent recirculation of surface waters to enhance retention of larvae close to the natal reef.

4.1 INTRODUCTION – FISH RECRUITMENT

Broadly speaking, methods to record fish recruitment fall into two main categories; the use of light traps or some type of net to capture newly arrived recruits just before they reach the reef (e.g. Doherty 1987, McIllwain 2003) and underwater visual censusing (UVC) of newly arrived individuals on the reef itself (e.g. Dorenbosch et al 2006). There are advantages to both. This study uses UVC as its method of choice because 1) light trapping is very selective, 2) light traps are logistically difficult to work with at Ningaloo, and 3) most mortality happens in the first few days (Sale 1991) and from a management perspective the important individuals are those that survive and contribute to the next generation.

A number of techniques were extensively trialed in the first year of fish recruitment studies (2009) including underwater visual census (UVC – transect versus block designs) and fish aggregation devices (Figure 18a-c)(see Depczynski et al. 2009 for full details). To summarise, results clearly identified that 30 x 1m belt transects were the best method of evaluating patterns of fish recruitment because they provided robust estimates of abundance, more extensive geographic coverage, higher levels of field efficiency and more precise estimates of species richness. Fish aggregation devices were not found to be appropriate sampling units for Ningaloo for much the same reasons that light traps were also excluded from the outset of this study. They are logistically demanding, taxonomically selective and, in the case of the aggregation devices, were quite unsuccessful at catching a representative range of juvenile fishes irrespective of their location or distance from the substrate.

In addition to trialing these techniques, extensive comparisons were also made on the consistency of inter-observer estimates of habitat characterisation, fish size and abundances to provide an understanding of the challenges that might present themselves in the transition towards an ongoing long-term monitoring program (see Depczynski et al. 2009) (Figure 19 of swimming pool). The report provided the following insights on the degree of skill needed to conduct accurate surveys of juvenile fishes;

- Gross percentage habitat characterisation estimates were immediately within an acceptable 15% between all four observers.
- Fish size estimates required 3-4 trials of 9 floating fish models (Figure 19) before variation among observers reached an acceptable level (<5mm total length accuracy).
- There was no statistical difference between observers for juvenile fish abundances along identical transects.
- There was, however, a statistical difference for species richness but this was due to one of four observers and was quickly rectified indicating that calibration between observers and some basic taxonomic knowledge (to family level at the very least) is important.

- It took a considerable length of time before all observers could accurately identify all Ningaloo juvenile fishes to species suggesting that a regular team should conduct surveys each recruitment season.

Overall, this initial field report pinpointed the suitability of the methodology and techniques chosen to accurately quantify juvenile fish recruitment at Ningaloo into the future. The problem with accurate species identification has also largely been addressed through the development of Ningaloo specific underwater "cheat sheets" that contain images of all the most common juvenile fishes encountered at Ningaloo throughout the 3 year duration of the study (Appendix D).

Initially targeting reef slope and back reef areas in 2009, the lack of juvenile fish recruits on the reef slope and the identification of lagoonal areas as key recruitment sites for many fish species switched sampling to back reef and lagoon sites. It was thought that the reason for this was the significant wave energy and lack of complex habitat (see Wilson et al. 2010) found at slope sites likely results in the inability of small juvenile fishes to maintain station on reef slope areas (and hence shelter) causing high mortality rates from predators.

Figure 18a-c: a) Benthic and mid-water fish aggregation devices trialed and deployed to ensure that as wide a range of species as possible was included in juvenile fish counts. b) benthic design of plastic sieve filled with coral rubble and protected from medium and large predators with wire. c) mid-water SMURF design made of plastic barrier fencing encased in a hard plastic gutter guard mesh.

Figure 19: Size estimate calibrations between observers using fish cutouts in a pool.

4.2 MATERIALS & METHODS – FISH RECRUITMENT

Following the establishment of the most appropriate methodology, 20 locations were established and sampled consistently through the following two years (Fig1a-d). In addition, because patterns of fish recruitment are quite variable over time as well as space, the location sequence and dates of censusing in 2010 and 2011 were adhered to as strictly as was logistically possible in an effort to exclude this as a source of variation. In hindsight, dates would have best been allied to lunar timings in each particular year rather than calendar dates *per se* (e.g. each location censused x numbers of days past new moon). To deploy transects, each of three divers lay a continuous 100 m tape across the reef (Figure 20). Divers then worked backwards along the tape recording the numbers and species identity of all juvenile fishes a half metre either side of the transect tapes at the 100-70, 65-35 and 30-0m marks. This provided a total of 9 transects per site among the three divers (3 x 3). To ensure that counts were made on that particular years cohort only (i.e. newly recruited individuals) a series of cut-off lengths (Total length in mm) were established for each family of fishes (Table 4). At the completion of each set of three transects, each diver made an assessment of gross habitat percentage-cover of the substratum using a number of appropriate categories (see Table 5) with the “live coral” category further broken down to provide percentage estimates (∑ = 100%) of coral morphologies and taxonomic types to investigate selectivity among juvenile fishes.

Figure 20: An example of a typical transect swum at a back reef site.

Table 4: Cut-off point (mm - Total length) at which fish families were no longer considered to be from that particular year's cohort (i.e. excluded from counts).

Family	Cut-off point (TL)
Apogonidae	30mm
Ostracodiidae	30mm
Blenniidae	40mm
Caesionidae	40mm
Chaetodontidae	40mm
Monocanthidae	40mm
Pomacentridae	40mm
Pseudochromidae	40mm
Zanclidae	40mm
Acanthuridae	60mm
Labridae	60mm
Lethrinidae	60mm
Lutjanidae	60mm
Mullidae	60mm
Nemipteridae	60mm
Scaridae	60mm
Serranidae	60mm
Siganidae	60mm
Pomacanthidae	60mm
Platycephalidae	100mm
Fistularidae	100mm
Rhinobatidae	100mm

Table 5: Gross habitat categories used in juvenile fish surveys. Each transect recorded percentage-cover of gross habitat and a further breakdown of live hard coral into morphological and taxonomic types.

Gross habitat (∑=100%)	Live hard coral (∑=100%)
Algae	
	Acropora branching
Pavement	A. corymbose
	A. digitate
Sand	A. encrusting
	A. foliaceous
Dead hard coral	A. plating
Seagrass	
	Coral branching
Live hard coral →	C. digitate
	C. encrusting
Sponge	C. foliaceous
	C. plating
Live soft coral	C. massive
	Free-living
Rubble	

To investigate patterns of fish recruitment within the park, results are presented in sections in the following sequence; patterns through time, patterns through space, taxonomic trends in fish recruitment, importance of reef zone habitat to recruitment identity, family contributions to overall assemblages, reef zone habitat characteristics and assemblage structure in fish recruitment. Abundance data was firstly log transformed (log x + 1) to deal with the large number of zeros and meet underlying assumptions before linear regressions comparing year versus reef zone, year versus management zones and over locations were generated. Species data did not suffer from this problem (zeros) and a Poisson regression was used on the number of species comparing year versus reef zone, year versus management zones and among locations. In addition, t-tests were conducted to identify where statistical differences were located. To investigate patterns in species assemblages in relation to years and reef zones, a Redundancy analysis (RDA) was generated using Hellinger transformed 2010 and 2011 data overlayed with species and gross habitat data using the following criteria. Analysis was based on all species and species with loadings of >0.15 and an abundance of >50 individuals during the course of the study were displayed in the biplot for ease of interpretation. All analysis was conducted in R.

4.3 RESULTS – FISH RECRUITMENT

In total, 691 transects from 20 locations yielded 36,791 juvenile fishes over the three recruitment years from 2009-2011(Table 6) providing an average of 53.24 (± 2.66se) individuals per 30 x 1m transect or $1.8m^{-2}$. Overall, 168 transects were run in 2009, 245 in 2010 and 278 in 2011 with the total number of species over all three years totalling 120 from 22 families of reef fish.

Table 6: Locations, reef and management zones, years sampled and total number of transects per location censused throughout the course of the study. Unequal sampling was mostly due to whether a particular location contained both back reef (BR) and lagoonal (LG) sites and how many years each location was sampled.

Location	Reef zone	Management zone	Years sampled	Total transects
Bundegi BR	BR	Sanctuary	2009-2011	18
Bundegi N	BR	Recreation	2010-2011	15
Jurabi	BR, LG	Recreation	2009-2011	33
Mangrove Bay	BR, LG	Sanctuary	2010-2011	36
Mesa	BR, LG	Recreation	2010-2011	36
Mandu	BR	Sanctuary	2011	9
Turquoise Bay	BR	Sanctuary	2010-2011	18
Oyster Stacks	BR	Sanctuary	2011	9
Winderabandi	BR, LG	Recreation	2009-2011	53
Norwegian Bay	BR, LG	Sanctuary	2009-2011	39
Ningaloo Homestead	LG	Sanctuary	2009-2010	42
Cloates	BR, LG	Sanctuary	2009-2011	57
Coral Bay North	BR, LG	Sanctuary	2010-2011	36
Coral Bay South	BR, LG	Recreation	2010-2011	52
14-Mile North	BR, LG	Recreation	2009-2011	70
14-Mile South	BR, LG	Sanctuary	2009-2011	54
Elle's	BR, LG	Sanctuary	2009-2011	60
Cape Farquhar	BR	Sanctuary	2010-2011	18
Gnaraloo	BR	Sanctuary	2010-2011	18
3-Mile	BR	Sanctuary	2010-2011	18
Total				**691**

Fish recruitment patterns through time

At the reef zone level (back reef versus lagoon) there were significant differences in both the number of juveniles and species over the three study years (Fig 21a- b, Table 7). A significant year x reef zone interaction indicated the importance of considering both factors in unison when making comparisons. For abundance, striking differences were found between 2010 and the other years with juvenile numbers in 2010 a fraction of those seen in 2009 and 2011 at both back reef and lagoon reef zones (Table 8). During high recruitment years (2009 & 2011) the back reef zone held significantly higher numbers of recruits than the lagoon (Table 9). However, during 2010 this pattern switched with the recruitment to lagoonal sites marginally higher than back reef sites.

Species richness somewhat mirrored the patterns seen in abundances (Figure 21b, Table 7) with three important distinctions. Firstly, the degree of difference between back reef and lagoon reef zones was not as pronounced as those seen in abundances. Secondly, although 2011 represented the best of the three years for recruitment abundance at back reef sites, this abundance was composed of relatively few species. Despite the very poor recruitment season in 2010, species richness remained strong whereas 2011 saw a sharp drop in species numbers. In fact, 2010 had the lowest abundances but the highest species richness among the three years with the lagoon species richness mean having marginally more species per transect that the back reef. T-tests indicated significant differences in species richness between 2011 and all other years for both back reef and lagoon habitats (Table 8) with reef zones differing from each other in all years (Table 9).

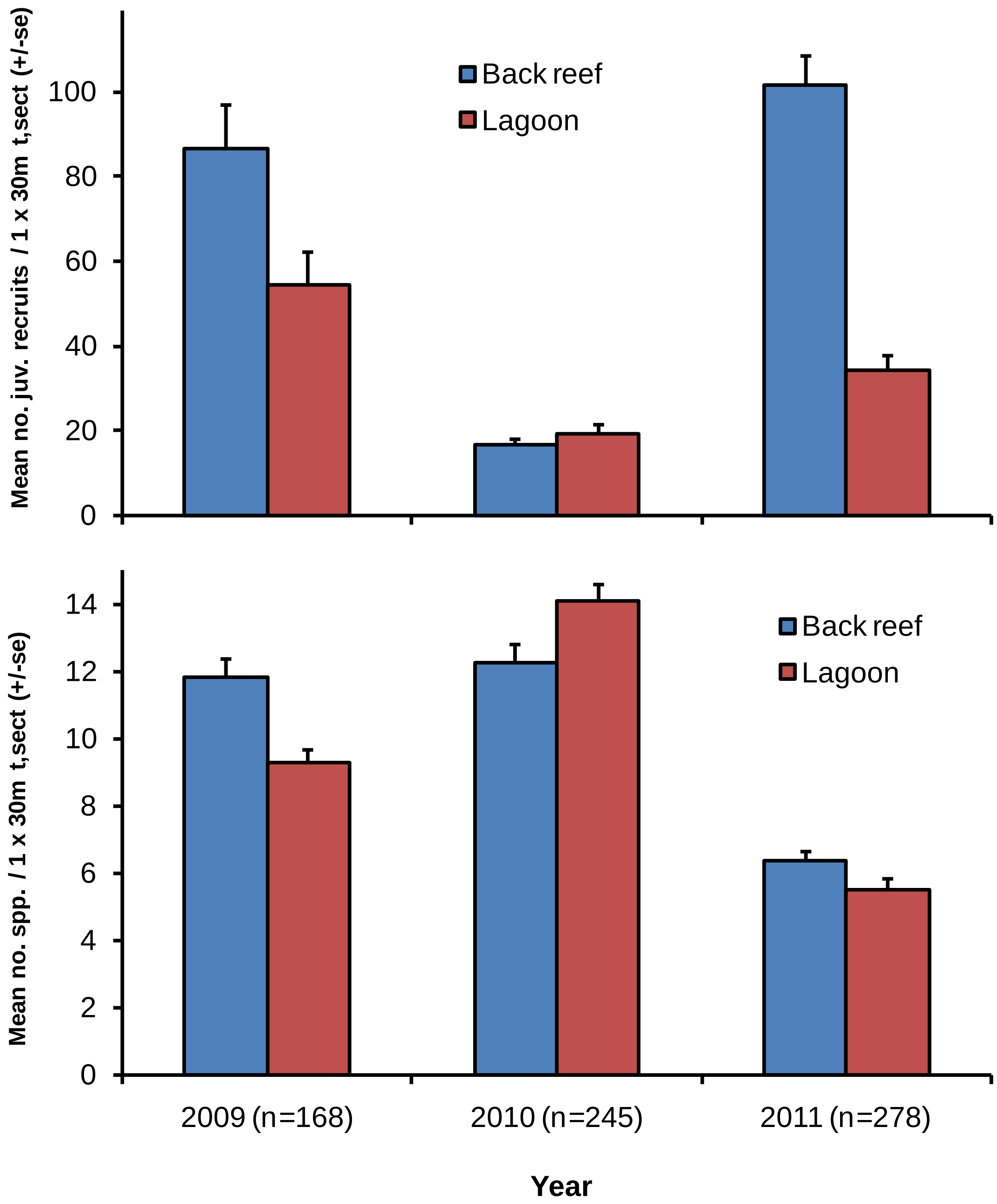


Figure 21a-b: a) Mean abundance and b) species richness per 30m^2 transect (+/-se) by sampling year at back reef and lagoon reef zones. A striking drop in abundance was seen in 2010 at both reef zones. This contrasted sharply in species richness (Figure 21b) where the opposite trend prevailed. Here species diversity was highest despite the severe drop in abundance.

Table 7: Linear and Poisson regressions comparing abundance (Log (*x* + 1) data) and species richness (raw data) respectively between years (2009-2011) and reef zones (back reef versus lagoon). Results indicate statistical differences at all levels of comparison for both abundance and species richness including a significant Year x Reef zone interaction.

Source	Abundance				Species richness			
	Slope	SE	t	p-value	Slope	SE	t	p-value
(Intercept)	-896.996	173.097	-5.182	**<0.0001**	769.016	44.968	17.101	**<0.0001**
Year	0.448	0.086	5.203	**<0.0001**	-0.381	0.022	-17.05	**<0.0001**
Reef.zone	1227.8	239.994	5.116	**<0.0001**	-346.523	64.228	-5.395	**<0.0001**
Year * Reef.zone	-0.611	0.119	-5.119	**<0.0001**	0.172	0.032	5.394	**<0.0001**

Table 8: T-tests comparing mean abundance and mean species richness between each combination of years for the back reef and lagoon reef zones. Results indicate that mean abundances at both reef zones varied between 2010 and 2009 / 2011. For mean species richness, differences were found between 2011 and 2009 / 2010 in the back reef and between all years for the lagoon.

Abundance	Back reef			Lagoon		
Year	t	df	p-value	t	df	p-value
2009 vs 2010	12.817	135.15	**<0.0001**	4.895	171.39	**<0.0001**
2010 vs 2011	-18.76	305.81	**<0.0001**	-3.172	201.61	**0.002**
2009 vs 2011	-1.627	129.04	0.1062	1.964	190.66	0.051

Species richness	Back reef			Lagoon		
Year	t	df	p-value	t	df	p-value
2009 vs 2010	-0.544	198.545	0.587	-7.352	192.521	**<0.0001**
2010 vs 2011	9.068	203.74	**<0.0001**	14.648	167.295	**<0.0001**
2009 vs 2011	9.03	108.062	**<0.0001**	7.138	177.776	**<0.0001**

Table 9: T-tests comparing mean abundance and mean species richness between reef zones within each year of sampling. Mean abundance varied between back reef and lagoon reef zones in 2009 and 2011 while mean species richness varied for all sampling years.

	Abundance			Species richness		
Year	t	df	p-value	t	df	p-value
2009	4.4782	163.537	**<0.0001**	3.704	144.58	**0.0003**
2010	-0.1157	198.282	0.908	-2.414	242.923	**0.017**
2011	10.0988	176.91	**<0.0001**	2.092	244.75	**0.037**

Comparisons of mean abundance between management zones varied considerably over the three years (Fig 22a-b Table 10). At back reef sites, higher numbers of juvenile recruits were found in sanctuary zones in the years where the highest recruitment took place (2009 & 2011), however this was statistically significant for 2011 only (Table 11). For the lagoon, mean abundances remained much the same for 2010 and 2011 with only 2009 seeing a significant difference in juvenile numbers. In 2010, recruitment was similarly poor at both sanctuary and recreation management zones irrespective of reef zone and were statistically different to 2009 / 2011 (Table 12). At the lagoon, sanctuary zones clearly held higher numbers than recreational zones in 2009 only, despite the fact that 2011 was also a strong recruitment year (Table 13).

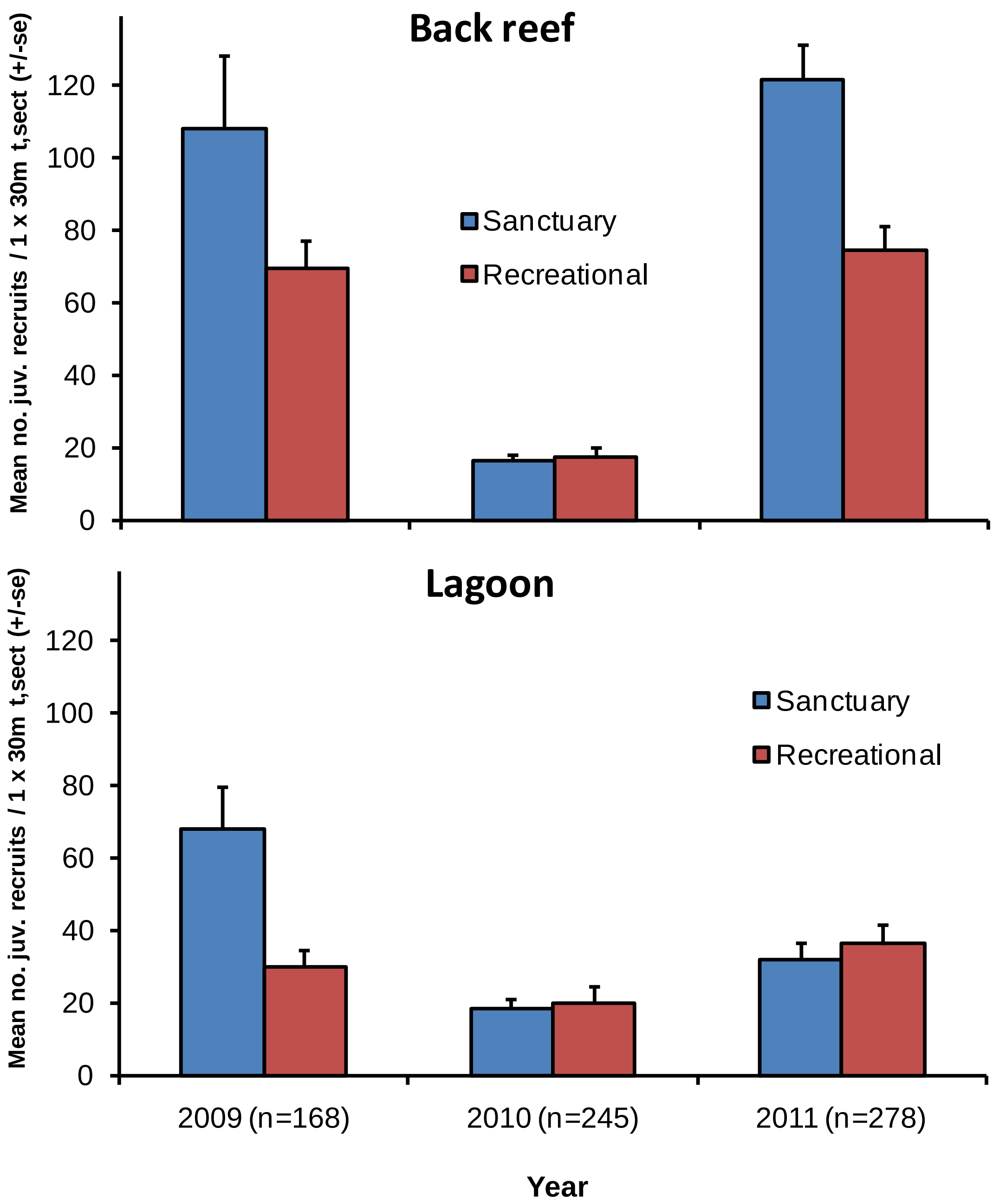


Figure 22a-b: Mean abundance per 30m^2 transect (+/-se) by sampling year at a) sanctuary and b) recreational management zones. A striking drop in abundance in both management zones was seen in 2010 at the back reef. In comparison, the lagoon showed little variation in recruitment abundance with the exception of 2009 where more recruits were censused in sanctuary zones.

Table 10: Linear regressions comparing abundance (Log (x + 1) data) between years (2009-2011) and management zones (sanctuary versus recreational) at each reef zone. Results indicate a significant Year x Reef zone interaction at both back reef and lagoon reef zones.

Abundance	Back reef				Lagoon			
	Slope	SE	t	p-value	Slope	SE	t	p-value
(Intercept)	-334.997	226.258	-1.481	0.14	-362.7	253.076	-1.433	0.153
Year	0.168	0.113	1.496	0.135	0.182	0.126	1.444	0.15
M'ment zone	-855.46	314.764	-2.718	**0.007**	1148.78	335.022	3.429	**0.001**
Year x M'ment zone	0.426	0.157	2.718	**0.007**	-0.571	0.167	-3.428	**0.001**

Table 11: T-tests comparing mean abundance for each year between sanctuary and recreational management zones at back reef and lagoon reef zones. Mean abundance varied between management zones in 2011 for back reef sites and in 2009 for lagoonal sites.

Abundance	Back reef			Lagoon		
Year	t	df	p-value	t	df	p-value
2009	-1.774	67.122	0.081	-3.098	64.626	**0.003**
2010	0.099	88.551	0.922	-1.163	64.633	0.249
2011	-4.005	146.656	**<0.0001**	0.738	104.395	0.462

Table 12: T-tests comparing mean abundance in sanctuary and recreational management zones for each combination of years on the back reef. Results indicate that mean abundances at both sanctuary and recreational management zones varied between 2010 and 2009 / 2011.

Abundance (Back reef)	Sanctuary			Recreational		
Year	t	df	p-value	t	df	p-value
2009 vs 2010	10.533	52.587	**<0.0001**	7.602	80.788	**<0.0001**
2010 vs 2011	-17.34	193.11	**<0.0001**	-9.261	97.811	**<0.0001**
2009 vs 2011	-1.285	50.177	0.205	-0.373	76.743	0.71

Table 13: T-tests comparing mean abundance in sanctuary and recreational management zones for each combination of years in the lagoon. Results indicate that mean abundances at sanctuary zones varied between 2009 and 2010 / 2011. For recreational zones there were significant differences between 2010 and 2011 only.

Abundance (Lagoon)	Sanctuary			Recreational		
Year	t	df	p-value	t	df	p-value
2009 vs 2010	5.499	104.822	**<0.0001**	1.373	65.827	0.175
2010 vs 2011	- 1.476	88.672	0.144	-2.939	84.457	**0.004**
2009 vs 2011	3.276	111.192	**0.001**	-1.039	62.68	0.302

Patterns in mean species richness were less obvious for both back reef and lagoon zones but there were some differences nonetheless (Figure 23a-b). For the back reef, both year and management zone affected patterns (Table 14) whilst in the lagoon, there was very little variation between management zones but there was between years. At back reef sites, higher numbers of species were generally found in sanctuary zones although this was only statistically supported for 2009 (Table 15). In both sanctuary and recreational zones, 2011 differed from the other two years at back reef sites (Table 16) with lagoon sites differing between all combination of years (Table 17). Once again, the sheer diversity of species in 2010 in comparison to the other years is apparent and interesting considering the very low abundances seen for that year.

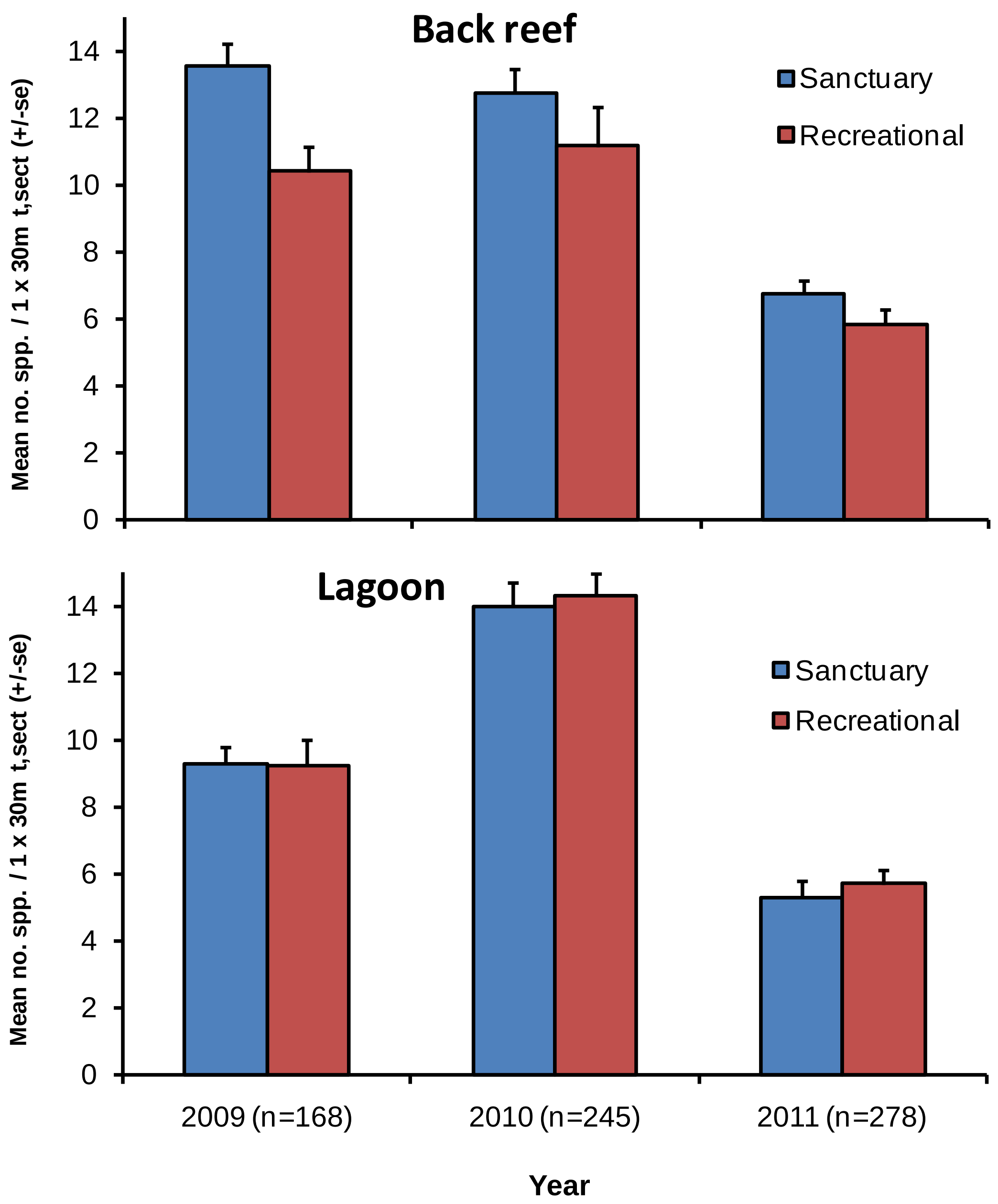


Figure 23a-b: Mean species richness per 30m^2 transect (+/-se) by sampling year at a) back reef and b) lagoon management zones. Notably, the richness in 2010 is remarkable considering that 2010 held such low numbers of juvenile recruits.

Table 14: Poisson regressions comparing species richness (raw data) between years (2009-2011) and management zones (sanctuary versus recreational) at each reef zone. Results indicate a significant Year x Reef zone interaction at the back reef and significant differences between years at the lagoon.

Species richness	Back reef				Lagoon			
	Slope	SE	t	p-value	Slope	SE	t	p-value
(Intercept)	588.212	65.779	8.942	**<0.0001**	477.119	70.06	6.81	**<0.0001**
Year	-0.292	0.033	-8.909	**<0.0001**	-0.236	0.035	-6.778	**<0.0001**
M'ment zone	171.915	87.049	1.975	**0.048**	-96.424	93.039	-1.036	0.3
Year x M'ment zone	-0.085	0.043	-1.972	**0.049**	0.048	0.046	1.036	0.3

Table 15: T-tests comparing mean species richness for each year between sanctuary and recreational management zones at back reef sites. Mean species richness varied between management zones in 2009 only.

Species richness	Back reef		
Year	t	df	p-value
2009	-3.154	68.973	**0.002**
2010	-1.212	77.901	0.229
2011	-1.669	148.789	0.097

Table 16: T-tests comparing mean species richness in sanctuary and recreational management zones for each combination of years on the back reef. Results indicate that mean abundances at both sanctuary and recreational management zones varied between 2011 and 2009 / 2010.

Spp. richness (Back reef)	Sanctuary			Recreational		
Year	t	df	p-value	t	df	p-value
2009 vs 2010	0.817	94.71	0.416	-0.557	76.442	0.58
2010 vs 2011	7.972	145.349	**<0.0001**	4.331	59.031	**<0.0001**
2009 vs 2011	9.062	49.631	**<0.0001**	5.292	63.751	**<0.0001**

Table 17: T-tests comparing mean species richness in sanctuary and recreational management zones combined for each combination of years in the lagoon. Management zones were pooled because there was no significant difference in species richness between sanctuary and recreational management zones (Table 14). Results indicate that mean abundances at management zones varied between all combinations of years.

Spp. richness (Lagoon)	Sanctuary AND Recreational		
Year	t	df	p-value
2009 vs 2010	-7.352	192.521	**<0.0001**
2010 vs 2011	14.648	167.295	**<0.0001**
2009 vs 2011	7.138	177.776	**<0.0001**

Fish recruitment patterns through space

Recruitment strength was quite mixed among locations for both back reef and lagoon reef zones (Figure 24a-b) although initially there was no statistical difference between locations. A more thorough investigation of the data through box plots indicated a number of outliers playing a large role in the analysis (Appendix E). Transect outliers were identified and found to have a large component of schooling or highly abundant species precluding statistical differences by substantially increasing variances. Re-analyses following their removal indicated a statistical difference among locations at both back reef and lagoon reef zones ($p<0.05$)(Table 18). Species that were removed from the reanalysis in back reef habitats included the schooling Cardinalfish *Apogon wassinki* and Damselfish *Chromis viridis* and the superabundant Damselfishes *Pomacentrus molluccensis* and *P. coelestis,* all of which are irregularly found on transects in very large abundances. In lagoon habitats, the schooling Cardinalfishes *Apogon rueppellii* and *A. cooki,* and the Rabbitfishes drove this variation and were also removed to provide a more objective view of locational differences among reef zones.

In general, the southern section of the Ningaloo Marine Park (i.e. Warroora and Ningaloo Station areas) held the highest abundances for both reef zones. At a broad level, location abundance trends were replicated in both back reef and lagoon sites with Cloates, 14-Mile South and Elle's having the highest abundances. The lowest abundances were found at Bundegi N, Mangrove Bay and Cape Farquhar for the back reef, and Coral Bay South, Jurabi and Norwegian Bay for the lagoon. Species richness among locations in the back reef were statistically different and closely mirrored abundance trends (Figure 25a-b, Table 18). However, at lagoon sites, species richness levels were quite stable in relation to abundances with high numbers of species present irrespective of abundance levels and were not statistically different between locations. .

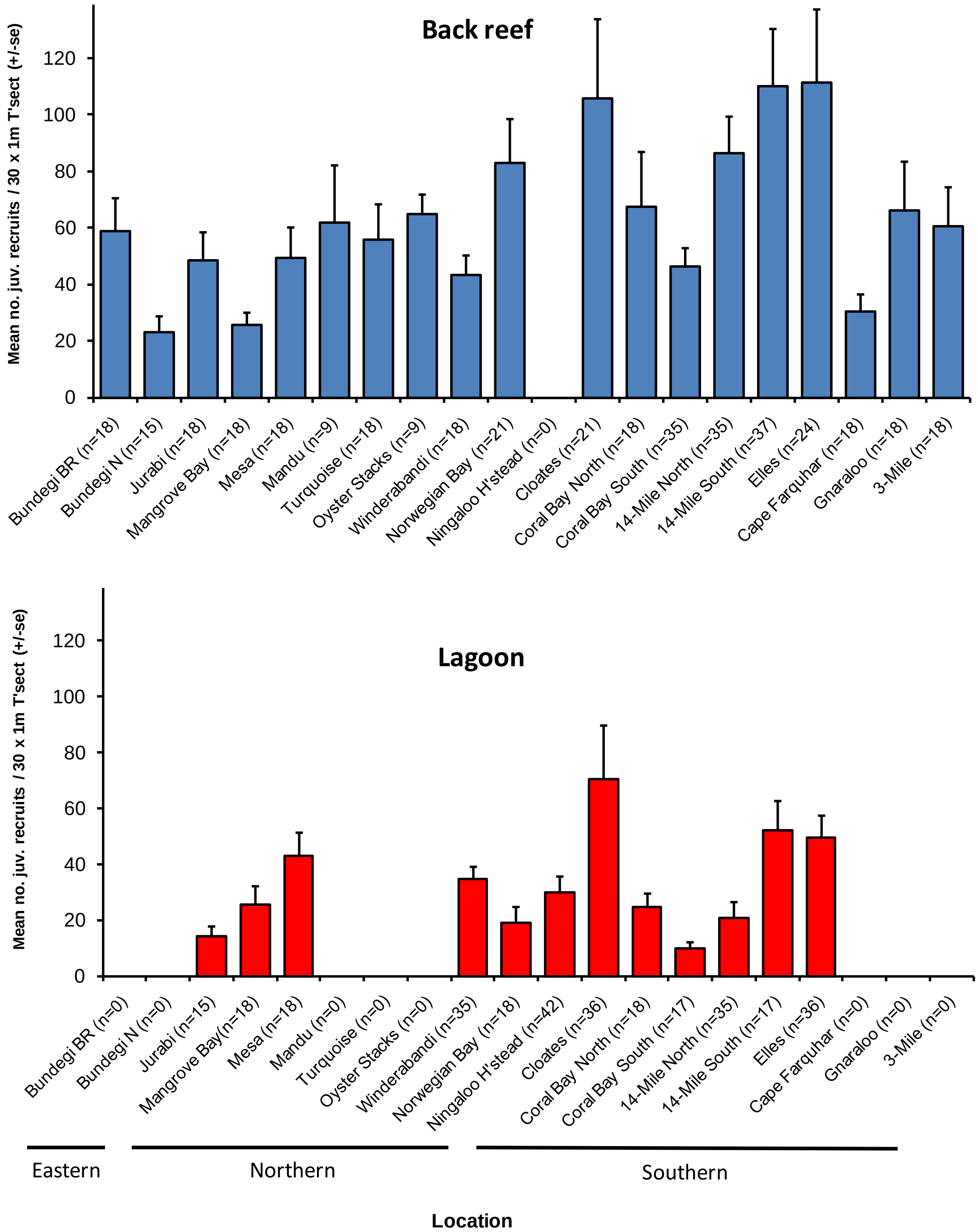


Figure 24a-b: Mean abundance per 30m^2 transect (+/-se) across the 20 locations at a) back reef and b) lagoon zones. Missing bars indicate the absence of either back reef or lagoon sites at that location. In general, the back reef and the southern half of the Ningaloo Marine Park held higher abundances than the eastern and northern sites for both reef zones with Cloates, 14-Mile South and Elle's having the greatest recruitment strength for the marine park.

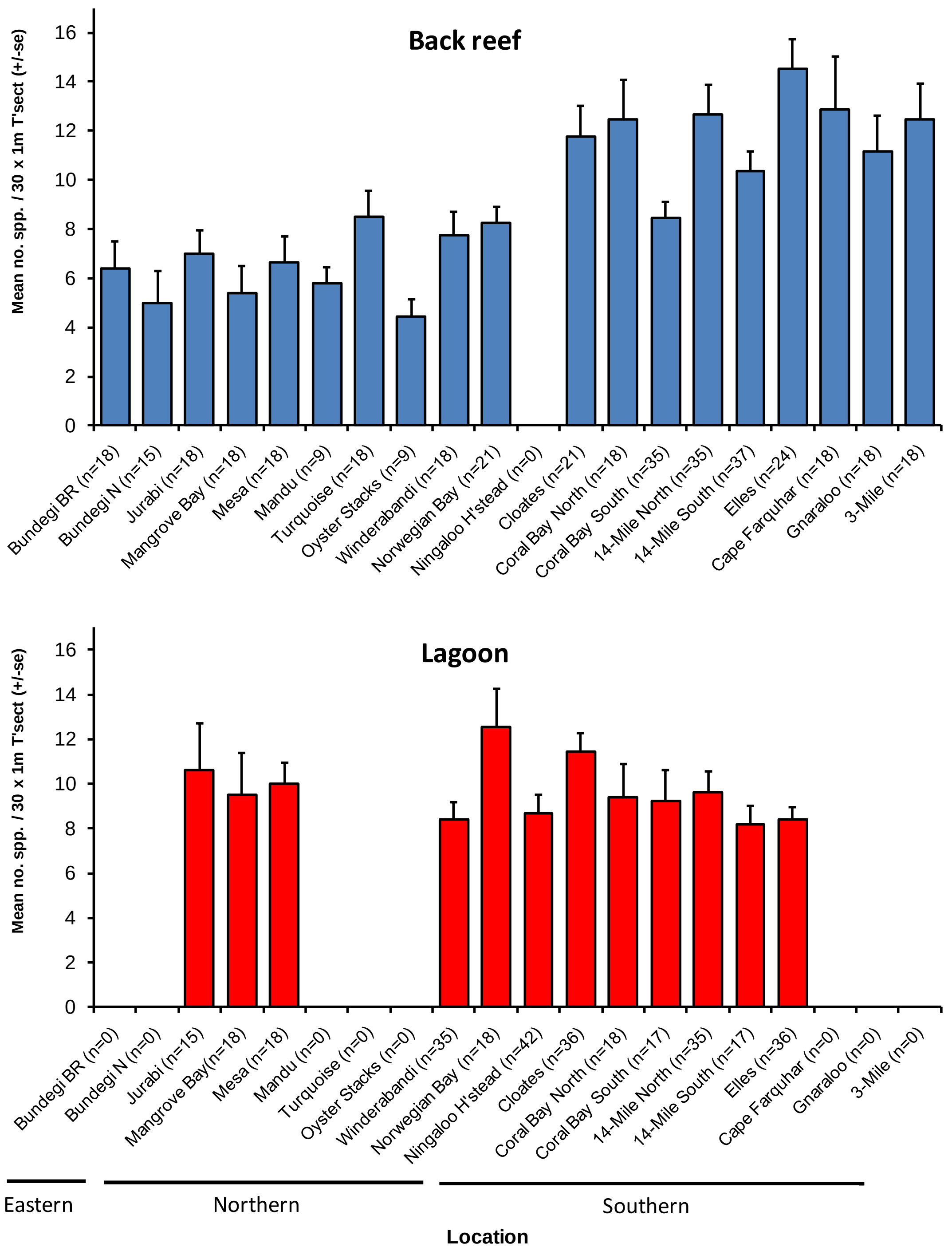


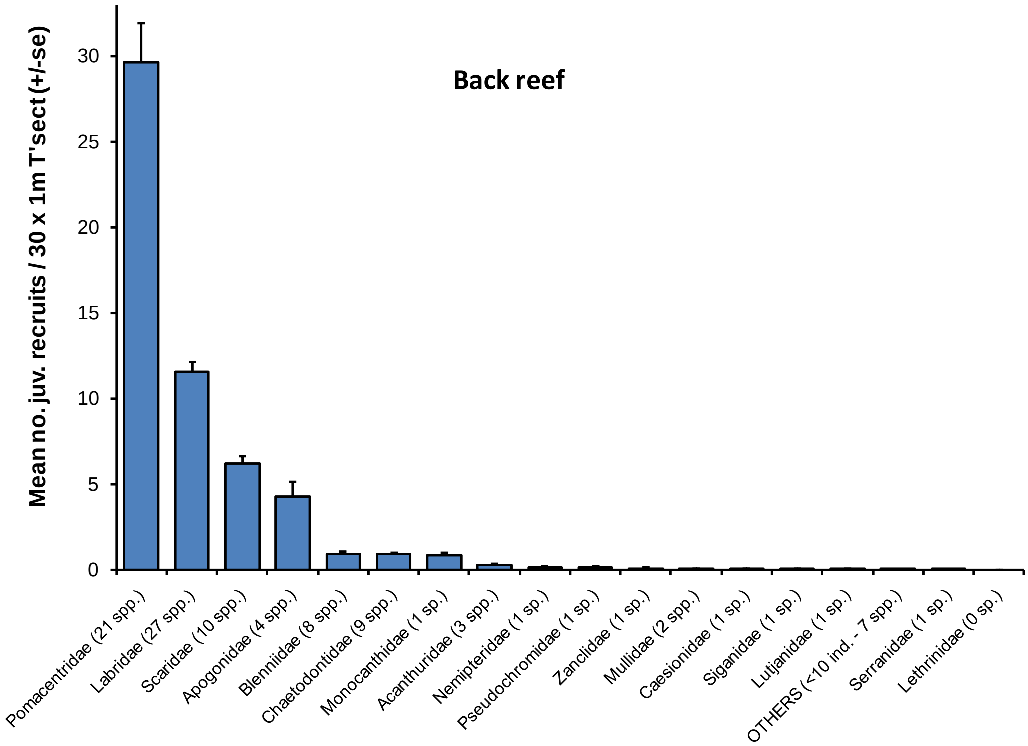
Figure 25a-b: Mean species richness per 30m^2 transect (+/-se) across the 20 locations at a) back reef and b) lagoon zones. Missing bars indicate the absence of either back reef or lagoon sites at that location. Similar to abundances, the southern part of the marine park held the highest levels of diversity. However, unlike abundances where abundances at the lagoon sites were generally lower than at the back reef, higher levels of species richness were maintained at lagoon sites with the back reef more variable among locations.

Table 18: Linear and Poisson regressions comparing abundance (Log (*x* + 1) data) and species richness (raw data) respectively (2009-2011) at back reef and lagoon reef zones. Results indicate statistical differences in abundances and species richness for the back reef and in abundance only for the lagoon.

	Back reef				Lagoon			
	Slope	**SE**	**t**	**p-value**	**Slope**	**SE**	**t**	**p-value**
Abundance	0.005	0.006	2.001	**0.007**	0.0015	0.008	8.788	**<0.0001**
Species richness	-0.027	0.003	-8.835	**<0.0001**	-0.005	0.005	-1.035	0.301

Taxonomic trends in fish recruitment

The family Pomacentridae overwhelmingly dominated the Back reef sites followed by the Labridae, Scaridae and schooling Apogonidae all contributing >4 individuals per 30m^2 transect over the course of the three year study (Figure 26a). For the lagoon, the Labridae dominated the assemblage followed marginally by the Pomacentridae, Apogonidae and Scaridae with more minor but significant contributions made by the Mullidae and Siganidae (Figure 26b).



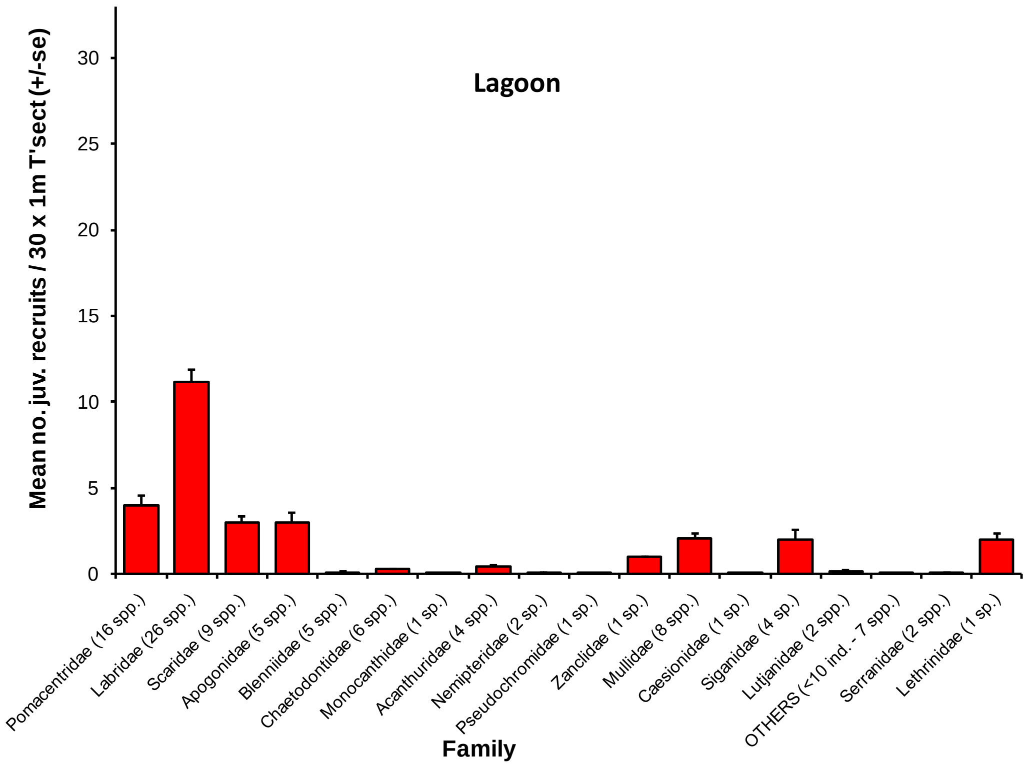


Figure 26a-b: Mean abundance by family (+/-se) shows the influence of the damselfish and wrasses (Pomacentridae & Labridae) within the data set. The category "others" include species from the families Caesionidae, Carharhinidae, Fistulariidae, Lutjanidae, Ostracodidae, Platycephalidae, Pomacanthidae, Pseudochromidae and Siganidae where less than 5 individuals were counted over the 211 transects surveyed.

Importance of reef zone habitat to recruitment identity

Of the 120 species censused over the three years, 19 species were unique to lagoonal habitats, 16 to back reefs with 68 clearly overlapping into both reef zones (Table 19). The remaining 17 species are here described as "nominal" habitat specialists under the criteria that species either; 1) only had a single record (and therefore can only possibly be found in one habitat) OR, 2) a species with a mid to high presence in one habitat but also with a single observation in the other. Of these, 10 were marginal to lagoonal habitats and 7 to back reef ones.

The most ubiquitous species across both reef zones was *Stethojulis bandanensis* (412 out of 691possible records), *Stethojulis interrupta* (407), *Pomacentrus moluccensis* (306), *Thalassoma lunare* (288) *and Chlorurus sordidus* (238); for the back reef, *Pomacentrus moluccensis* (291 out of 305 possible records), *Stethojulis bandanensis* (290) and *Thalassoma lunare* (259), and for the lagoon sites, the most frequently occurring species were *Stethojulis interrupta* (174 out of 386 possible records), *Stethojulis bandanensis* (122), *Halichores nebulosus* 120) and *Lethrinus atkinsoni* (119). Of these only *L. atkinsoni* was a habitat specialist. Other notable groups include the fidelity of the goatfishes to lagoon sites,

Table 19: Habitat specificity of the 120 species from 22 families censused during the three year duration of the study. Numbers refer to the number of transects where the species was present in a particular year and reef zone (i.e. presence of species on transects not abundances). "Unique habitat" refers to a species only occurring on a single reef zone over the three years (marked either "Back reef" or "Lagoon) and "No" indicates significant overlap between both reef zones for that species. Reef zones marked with an asterisk* represent nominal fidelity to that reef zone by a particular species because it either has a single record in a single habitat OR it has a mid-high presence in one habitat and a single observation in the other.

		2009		2010		2011		
Family	**Species**	**Back Reef**	**Lagoon**	**Back Reef**	**Lagoon**	**Back Reef**	**Lagoon**	**Unique habitat**
Acanthuridae	*Acanthurus dussumieri*				8	15	8	No
	Acanthurus grammoptilus	1	21	1	4	1	5	No
	Acanthurus triostegus	2	1	1		24	1	No
	Acanthurus sp. 1		8		4			Lagoon
	Zebrasoma veliferum	1	1	2		17		No
Apogoniidae	*Apogon rueppellii*				12		2	Lagoon
	Apogon cookii	15	11		4	3	2	No
	Apogon wassinki	18	13	11	10	41	11	No
	Apogon sp. 1	2	4		11	3	9	No
	Cheilodipterus quinquelineatus			19		27	3	No
Blenniidae	*Atrosalarias fuscus*	4	5	10		54		No
	Cirripectes sp. 1	5		1		16		Back reef
	Ecsenius oculus	2						Back reef
	Ecsenius yaeyamaensis	12	3			1		No
	Meiacanathus grammistes	1	1	1		25		No
	Plagiotremus rhinorhynchos	4	4	4	3	8	2	No
	Salarias fasciatus		4					Lagoon
	Salarias ramosus	4						Back reef
Caesionidae	*Pterocaesio marri*		1			2		No
Chaetodontidae	*Chaetodon assarius*	1	8		24	4	14	No
	Chaetodon aureofasciatus	6				3		Back reef
	Chaetodon auriga	1	4	2	2	9	4	No
	Chaetodon kleinii	2	1		2			No

	Chaetodon plebeius	34	8	44		59		No
	Chaetodon trifascialis	3		9		14		Back reef
	Chaetodon trifasciatus	4						Back reef
	Chaetodon vagabundus		1					*Lagoon
	Chaetodon sp. 1		2			9		No
	Parachaetodon ocellatus					3		Back reef
Fistulariidae	*Fistularia commersonii*		1		1			Lagoon
Labridae	*Anampses geographicus*			13	31	4	2	No
	Anampses meleagrides			5		1		Back reef
	Cheilinus trilobatus			9	4	14	5	No
	Chelio inermis			1	1		35	*Lagoon
	Choerodon vitta		1					*Lagoon
	Coris aygula	1		3				Back reef
	Coris caudimacula	21	33	12	45	3	14	No
	Gomphosus varius	9	3	2		27		No
	Halichoeres marginatus			11	1	52		*Back reef
	Halichoeres nebulosus	2	15	12	48	36	57	No
	Hemigymnus fasciatus	5		4		4		Back reef
	Hemigymnus melapterus	16	5	9		76		No
	Hologymnosus annulatus	1		11	1	10		*Back reef
	Labrichthys unilineatus	24	6	35	1	85		No
	Labroides dimidiatus	10	5	9	1	38		No
	Macropharyngodon meleagris	16	9	3	1		1	No
	Macropharyngodon ornatus			15	4	21	3	No
	Stethojulis bandanensis	60	76	100	20	130	26	No
	Stethojulis interrupta	65	77	79	51	89	46	No
	Stethojulis strigiventer	1		26	63	53	54	No
	Thalassoma hardwicke	21	6	7		56		No
	Thalassoma lunare	56	20	73	2	130	7	No
	Thalassoma lutescens	1		19	2	80		No
	Labrid sp. 1	1	10	1		8		No
	Labrid sp. 2		7					Lagoon
	Labrid sp. 3		3					Lagoon
	Labrid sp. 4		3	30	49			No
	Labrid sp. 5	7	25	3	1			No
	Labrid sp. 6	37	55	2	1			No
Lethrinidae	*Lethrininus atkinsoni*		31		24		64	Lagoon
Lutjanidae	*Lutjanus fulviflamma*						2	Lagoon
	Lutjanus sp. 1	1	2			4	13	No
Monocanthidae	*Oxymonacanthus longirostris*	3	2	2		75	1	No
Mullidae	*Parupeneus barberinoides*		23	1	15	10	52	No
	Parupeneus barberinus		2					Lagoon
	Parupeneus indicus		4		1	1	15	*Lagoon
	Parupeneus spirulus		32		29		10	Lagoon
	Upeneus moluccensis				1			*Lagoon
	Upeneus tragula				1			*Lagoon
	Mullid sp. 1		6		1			Lagoon
	Mullid sp. 2		3					Lagoon
Nemipteridae	*Scolopsis bilineatus*	6	4	2	1	35	1	No
	Scolopsis margaritifer		1		1			Lagoon

Ostracodiidae	*Ostracion cubicus*	1						*Back reef
Platycephalidae	*Thysanophrys sp. 1*		1					*Lagoon
Pomacanthidae	*Centropyge tibiscen*			1				*Back reef
	Pomacanthus semicirculatus			1		1	2	No
	Pomacanthus sp. 1				2			Lagoon
Pomacentridae	*Abudefuf sexfasciatus*	6	5	5	4	22	10	No
	Cheiloprion labiatus	6	4	4		25		No
	Chromis viridis	20	2	23	1	59		No
	Dascyllus aruanus	22	16	51	3	91	3	No
	Dascyllus reticulatus	17	3	24		33	1	No
	Dascyllus trimaculatus	1	4	3	2	4	2	No
	Dischistodus prosopotaenia		3	5		31		No
	Dischistodus perspicillatus	3	6	3				No
	Neoglyphidodon melas	9	9	16		46		No
	Neoglyphidodon nigroris	4	1	10		14		No
	Neopomacentrus azysron			2		1		Lagoon
	Plectroglyphidodon johnstonianus	2		2		1		Lagoon
	Plectroglyphidodon lacrymatus	26	7	21		102		No
	Pomacentrus coelestis	33	31	41	25	72	21	No
	Pomacentrus milleri	12		11	2	18	3	No
	Pomacentrus moluccensis	50	15	91		150		No
	Pomacentrus vaiuli	18	3	19		95		No
	Pomacentrus sp. 1	1				2		Back reef
	Stegastes nigricans	3	3			29		No
	Stegastes obreptus	8		4	2	31		No
Pseudochromidae	*Pseudochromis fuscus*	1	1	5		31		*Back reef
Rhinobatidae	*Rhinobatos batillum*		1					*Lagoon
Scaridae	*Chlorurus microrhinos*			14	1	36	1	No
	Chlorurus sordidus	39	15	66	1	116	1	No
	Leptoscarus vaigiensis		25	2	38	2	34	No
	Scarus chameleon	22	12	25	6	37	4	No
	Scarus frenatus	3	2	30		43	1	No
	Scarus prasiognathos	1		30		75		Back reef
	Scarus sp. 1					32	1	*Back reef
	Scarus sp. 2	2	1	39	11	22	1	No
	Scarus sp. 3	40	38	5				No
Serranidae	*Epinephelus fasciatus*	1						*Back reef
	Epinephelus rivulatus		9					Lagoon
	Epinephelus spilotoceps		1					*Lagoon
Siganidae	*Siganus argenteus*		1			9	31	No
Zanclidae	*Zanclus cornutus*				2			Lagoon
Other	*Additional species 1*					3		Back reef
	Additional species 2					10		Back reef
	Additional species 3					2		Back reef
	Additional species 4						2	Lagoon
	Additional species 5					6		Back reef
	Additional species 6						1	*Lagoon

Family contributions to overall assemblage

Trends among years show some disparity in recruitment strength among families as a percentage contribution to the overall assemblage (Table 20). For example, there was marked variation in the schooling Siganidae among years with very low numbers (<0.1% of assemblage contribution) recorded in 2009 and 2010 and very high numbers (>19%) recorded in 2011. Similarly, the Lethrinidae made up <25 in 2010 but >13% of the assemblage in 2011. Other notable fluctuations include the Pomacentridae, Scaridae, Apogoniidae, Acanthuridae and Mullidae.

Table 20: Contribution from each fish family to total juvenile assemblages at back reef and lagoon sites each study year. The category "OTHERS" include species from the families Fistulariidae, Ostracodidae, Platycephalidae, Pomacanthidae, where less than 5 individuals were counted over the 691 transects surveyed. Large fluctuations were seen in some families among years (in bold).

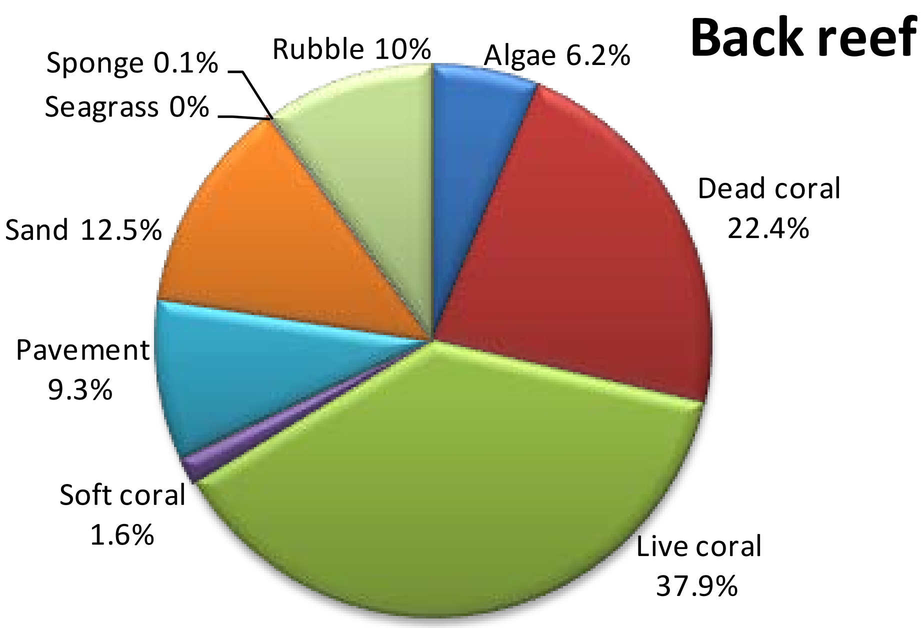
	Back reef			Lagoon		
Percentage of total	**2009**	**2010**	**2011**	**2009**	**2010**	**2011**
Pomacentridae	58.31	42.27	54.25	**20.60**	**8.82**	**9.33**
Labridae	**17.43**	**34.04**	**20.06**	42.19	49.30	30.56
Scaridae	12.41	14.74	10.27	**14.54**	**8.60**	**6.69**
Apogoniidae	8.20	6.02	7.92	**6.43**	**25.96**	**7.21**
Blenniidae	1.04	0.45	2.06	0.66	0.08	0.07
Chaetodontidae	2.12	2.21	1.36	1.08	1.14	0.75
Monocanthidae	**0.12**	**0.06**	**2.26**	0.05	0.00	0.10
Acanthuridae	0.12	0.07	0.63	**2.23**	**0.91**	**0.68**
Nemipteridae	0.12	0.03	0.34	0.18	0.48	0.03
Pseudochromidae	0.02	0.07	0.36	0.05	0.00	0.00
Zanclidae	0.02	0.03	0.19	0.03	0.00	0.00
Mullidae	0.00	0.01	0.09	**7.40**	**2.94**	**9.65**
Caesionidae	0.00	0.00	0.09	0.03	0.00	0.00
Siganidae	0.00	0.00	0.07	**0.00**	**0.07**	**19.44**
Lutjanidae	0.04	0.00	0.04	0.00	0.04	1.63
OTHERS (< 10 ind.)	0.02	0.01	0.01	0.05	0.02	0.10
Serranidae	0.02	0.00	0.00	0.29	0.00	0.00
Lethrinidae	0.00	0.00	0.00	**4.07**	**1.76**	**13.76**

Reef zone habitat characteristics

The benthic composition of back reef and lagoon reef zones differ substantially from one other (Figure 27a-b). Back reef areas were clearly dominated by live and dead coral cover making up >60% of habitat with significant contributions also being made by sand patches, pavement, rubble and algae (>10% of benthos)(Figure 27a). In contrast, the benthic makeup of the lagoon areas was primarily composed of algae and sand (37 & 31% of benthos) with pavement and rubble also making significant contributions to the benthos.

Breaking down the live coral component into coral morphs also showed varying patterns among reef zones (Figure 28a-b). At the back reef site, live coral represented 38% of total benthos with Acropora corymbose, A. plating and massives making up 28, 23 and 11% of live coral respectively (Figure 28a). However, at lagoon sites, live coral cover only represented 4.4% of the total benthos and was primarily composed of massive corals (42%) with Acroporid morphs making up the majority of remaining live coral composition (Fig 28b).

Here, live coral was predominantly found on small isolated bommies with the exception of massives which were almost always quite small (<5cm) and appeared to be randomly distributed across the seabed.



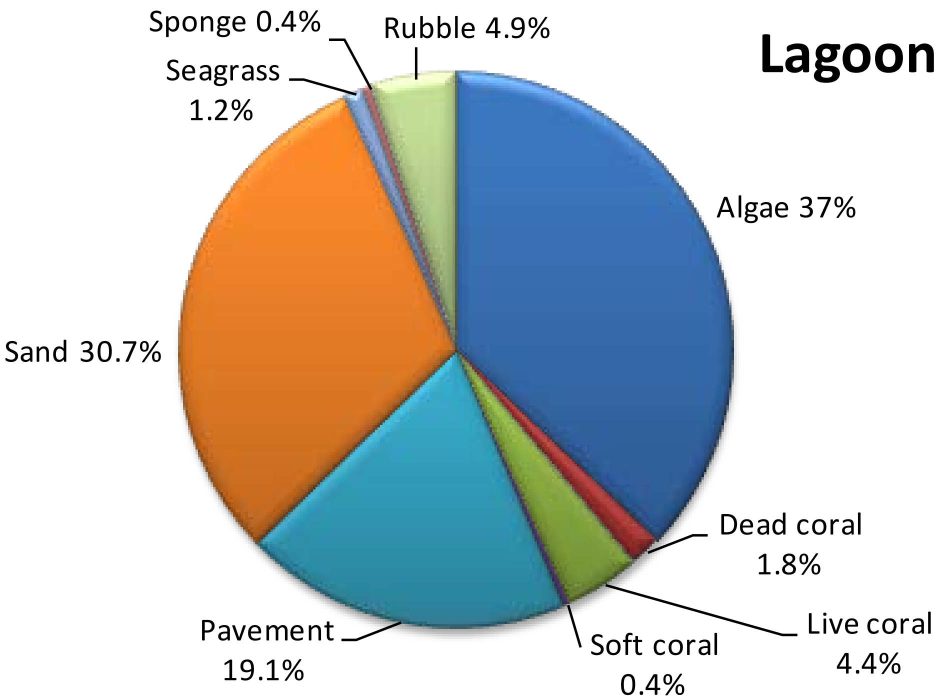


Figure 27a-b: Gross habitat percentage cover breakdown at a) back reef, and b) lagoon reef zones showing the vast differences between the benthic makeup of each reef zone. Whilst live and dead corals dominate the Back reef habitat, algae, sand and pavement dominated in the lagoonal habitats.

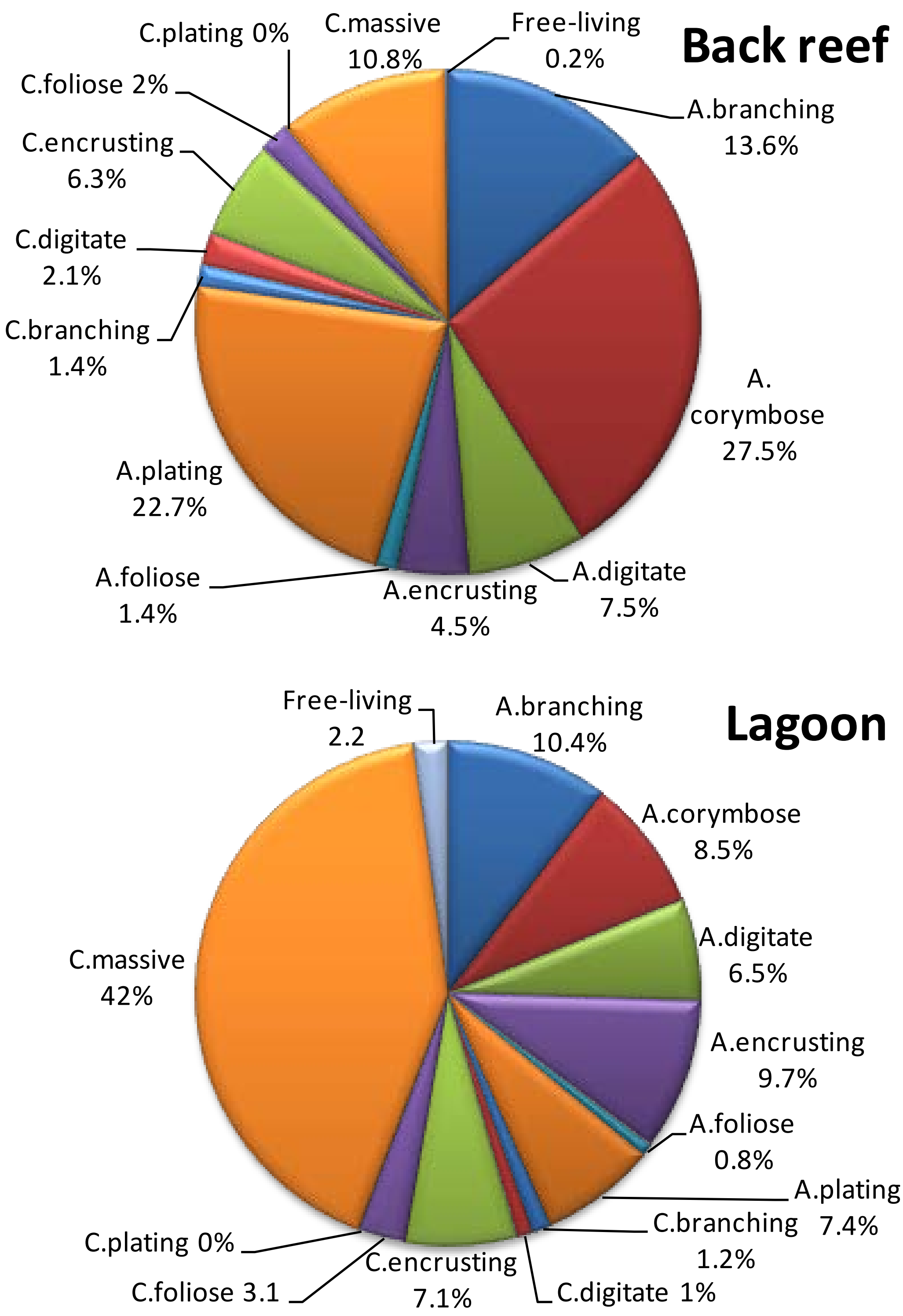


Figure 28a-b: Percentage live coral cover breakdown by morphology at a) back reef, and b) lagoon reef zones. Sharply contrasting, live coral cover represents 38% of total benthic cover on the back reef but only 4.4% in the lagoon. A. and C. represent Acroporid or all other coral forms respectively. Whilst Acropora corymbose, A. plating and A. branching dominate live coral morphs at the back reef, Coral massives, A. branching and A. encrusting dominate in the lagoonal areas.

Assemblage structure in fish recruitment

Species assemblage structure, or species composition, showed the nature of fish assemblages to reef zones and habitat type among years (Figure 29). There was marked and distinct separation in species assemblages into four areas of the biplot between years and reef zones. Species with high abundances that were predominantly or exclusively found in either back reef or lagoonal reef zones drove patterns in the analysis. In particular, species such as the parrotfish *Leptoscarus vagiensis,* wrasse *Halichores nebulosus,* goatfish *Parupeneus barberinoides,* rabbitfishes and emperors dominated trends for the lagoon whereas highly abundant strongly reef associated species such as the damselfishes *Pomacentrus moluccensis* and *Chromis viridis,* wrasses *Thalassoma lunare* and *T. lutescens,* the leatherjacket *Oxymonacanthus longirostris,* and most of the parrotfishes drove patterns in the back reef. Patterns among years also indicated some degree of variation in assemblage structure. However, the distinctions between years was less pronounced with a spread of data across the vertical RDA 2 than that found between reef zonation on the horizontal RDA1 axis which represents a larger proportion of the variability within the dataset.

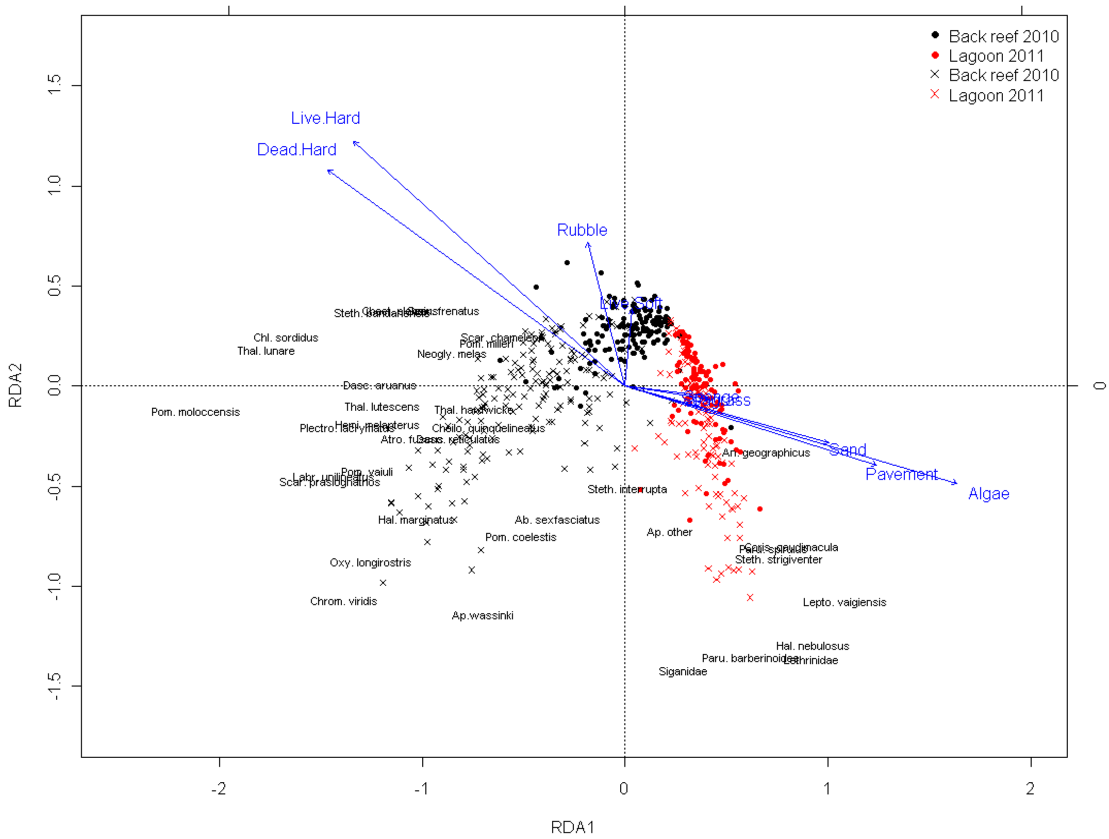


Figure 29: Redundancy analysis showing the nature of fish assemblages in relation to years, reef zones and gross habitat characteristics. Distinction at each of the four year x reef zone combinations appear quite clear in the biplot although assemblage distinction is more pronounced at the reef zone level along the horizontal RDA1axis than between years where the majority of segregation lies along the vertical RDA2 axis.

4.4 Discussion – Fish Recruitment

This work provides quantitative estimates of fish recruit abundance, species richness, taxonomic identity and assemblage structure from three years of fieldwork at 20 locations along the length of the Ningaloo Marine Park. It has explored a range of techniques in which to sample juvenile fish assemblages and has identified and provided solutions for the difficulties and potential pitfalls encountered in the field and in assessing patterns of fish recruitment. It has also established a three year data set from which monitoring can progress and a series of photographic underwater field sheets for abundant and difficult to identify juvenile fishes of Ningaloo.

The main ecological features of this dataset at present are the degree of recruitment variability seen at both spatial and temporal scales. From three years of data, there were two similarly strong recruitment years (2009 & 2011) and one very weak year (2010) where recruitment strength was 25% of the previous and following years. Having said this, each year is unique and produced a very distinct community assemblage. A simple example of this is 2010 which, despite its 75% drop in abundance, recorded the highest level of mean species richness over the course of the study. Generally, back reef sites contained more juveniles than lagoon sites even within the same locations but roughly the same numbers of species. Despite this, the species composition of these two reef zones varied markedly considering these two biotypes are often found within close proximity (metres) of each other and highlights the critical nature of habitat structure on patterns of recruitment and recruit identity. Many fundamentally important species were uniquely found in either back reef or lagoonal sites identifying the importance of different biotypes towards whole coral reef ecosystem health and function.

The main implications of this work are firstly in revealing the importance of the continuation of monitoring juvenile assemblages over multi-year cycles in order to uncover recruitment patterns and correlate these to abiotic features. The influence of El Nino or La Nina years and the corresponding strength, timing and temperature of the southward flowing Leeuwin Current will have an impact on pelagic larval distribution and survivorship. Similarly, the northward flowing summer Ningaloo Current will impact young recruits that have returned to the reef for the same reasons. These factors also no doubt play a large role in regulating the amount of self recruitment to natal reefs as opposed to regional recruitment from afar and hence the species composition and genetic diversity of reef fish species from year to year. Secondly and of particular note, is the dependence of some juvenile fish species on very specific habitats. For example, *Sargassum* fields in the lagoon are critical to juvenile Emperors, Goat and Rabbitfish recruitment and juvenile growth and provide us with a wonderful example of the co-evolutionary process in action on a coral reef system. Not only are these macroalgal fields unique habitat for selected species but their maximum growth and strength is reached during the summer fish recruitment season providing shelter from predation at this sensitive life history stage and trapping food for recruits. No less important are the species that overlap between reef biotypes. Many species also make a shift from one biotype to another as they grow, for example relying on macroalgal lagoons where predation pressure may be lower as young juveniles and moving on to reefs as they mature and grow to adulthood. All species fulfill role niches in an ecosystem just like lawyers, accountants and council workers do in our society. Hence any loss of essential habitat has a corresponding effect on ecosystem function. These examples are an important reminder of the fragile nature of these relationships and ecosystem health.

5. GENERAL CONCLUSIONS AND FUTURE DIRECTIONS

This study specifically provides valuable baseline information on the recruitment characteristics and trends of corals and fish at Ningaloo through time and space. The overarching message from this study is that there is a large degree of natural variability associated with recruitment at Ningaloo, a pattern that is common to coral reef systems throughout the world. For both corals and fish there were marked differences between years, locations, reef zones, management zones and taxonomic composition. Although this general finding lacks a specific management alarm-signalling threshold (i.e whether a significant change is cause for concern), a closer look highlights a number of key findings that have important implications to the way in which monitoring and research for management is directed. Moreover, this study has developed, tested and fine-tuned a range of techniques for assessing coral and fish recruitment that is simple, clear and Ningaloo-specific. This includes the timing of annual data collection, best practice methodologies and protocols, establishment of permanent monitoring sites, the identification of sources of potential observer and methodological error and how to avoid or minimise these. In addition, there is now a comprehensive three year data set for fish recruitment and two years for corals.

Until the implementation of this project, there was no long-term monitoring of biological communities at Ningaloo. As such, this project represents a solid start towards this for the important coral and fish groups and a blueprint for future monitoring of the biodiversity within the Ningaloo Marine Park. It has identified appropriate site locations and cast some light on the natural levels of variability for these groups. It is envisioned that a suite of organism groups and corresponding habitats may be simultaneously sampled at each or at least some of these locations (e.g. corals, fish, drupella, coral disease, macroalgae) on an annual basis thereby streamlining field time and providing a more comprehensive overview of organism, habitat and ecosystem health. Perhaps an annual ecosytem “health checklist” may be developed as a long term goal for DEC that is adaptable in other Western Australian ecosystems.

KEY MANAGEMENT QUESTIONS

The following are summary point form answers to questions identified by the Department of Environment and Conservation (DEC) as being important to the management of the Ningaloo Marine Park;

1) What are the key functional groups/species involved in herbivory and what is the nature and extent of associated herbivory?

   An in-depth assessment of the characteristics of herbivory at Ningaloo can be found in Johansson et al. (2010) who was indirectly supported in her PhD studies by this WAMSI research program. In summary, the key groups involved in herbivory at Ningaloo are fishes and urchins. Herbivory between the two groups is somewhat spatially segregated with sea urchins appearing to dominate herbivory on the reef slopes and fishes all other areas. Although not unique at a global level, this division of herbivory is quite different to that found on the Great Barrier Reef where fishes largely dominate herbivorous activities.

2) What are the current levels of coral recruitment?

   Recruitment at Ningaloo, like elsewhere in the world, is highly variable through both time and space. For fishes, the range at Ningaloo was anywhere between 23 and 111 juvenile recruits *and we witnessed a 75% drop in abundance in 2010. For corals, 4-10 recruits per tile were found and there was also a 58% drop in abundance in 2010. These figures put recruitment for both corals and fish in the low to medium range overall. Details have been addressed above.*

3) How does this compare with other comparable reef systems?

Recruitment of both corals and fish are comparable to those in other global locations. Having said this, recruitment ranges within specific reef systems themselves are extremely plastic due to the high natural variability inherent in the process making reliances on direct comparisons erroneous. The generation of a long-term, system specific, recruitment data-set is a considerably better yardstick than direct comparisons among disparate locations because of the unique set of oceanographic, geomorphological and biotic conditions found within each system.

4) What cost-effective methods should be used for long term monitoring of these factors (including indicator species / groups, temporal and spatial scales)?

This project has provided in-depth and comprehensive analysis and assessments on a wide range of strategies to cost-effectively sample coral and fish recruitment. The conclusions drawn from these comparisons are outlined in detail above and in the final report. However, to briefly summarise, for fish 30 x 1m transects at key locations within back reef and lagoon habitats easily provided the most precise estimates of abundance and species diversity and the best geographic coverage.

For corals, it is a little more complex. A number of methodologies have been presented that target different life-history stages, either larval supply through recruitment tile deployment at key locations or juvenile censusing via a number of observer or photo-based methods. Photo-quadrat methods will not detect 1 year old corals, but perform adequately once corals reach 20-30mm diameters in all but the most complex microhabitats. Standard operating procedures should be documented for field use of cameras and also applied to image interpretation to minimize sources of inter-observer error.

Diver-based UVC can be the most effective means to detect corals in complex habitats, but divers may also be prone to underestimate semi-crypitic encrusting juvenile corals in certain habitats, such as pavement environments in the reef slope and back reef areas. Divers need training and calibration in coral detection, identification and size estimation if rapid surveys are to be conducted efficiently and inter-observer biases and error are to be minimized. Nonetheless, rapid diver survey, even if well calibrated for coral juvenile census, may not allow enough time for measurement of other biodiversity attributes.

Coral tiles performed well as a tool for sampling annual recruits. Deployment and recovery periods in relation to lunar cycles, particularly considering years with significant split spawning, need to be standardized if consistent long term trend are to be relied on. It may therefore simplify logistics to deploy tiles in February and recover in late April each year. If efficiencies are required in processing of tiles, then analysis of only the bottom surfaces would provide a consistent representative sample of each year's recruitment.

A combination of regular repeated photo transect surveys by general field staff, but with images transmitted to specialist staff for interpretation will provide useful trend data over time. In combination, selected specialist UVC surveys and tile deployments at some of the same locations, on an annual or biannual basis could be used to provide additional site specific data and cross calibration of the photo transect results. Future developments in consumer stereo camera equipment shows promise to further simplify capture of automatically calibrate filed images for use in recruit measurement.

Because the choice of technique is heavily dependent on the objectives of particular studies, field time allocation, degree of expertise, life history stage targeted, budget and post-processing resources, future workers are strongly urged to measure up the pros and cons of each technique before adopting one or more approach. For both coral and fish recruitment, it is strongly advised that annual censuses of both groups be continued so that a long-term, system-specific data-set can be recorded. Only in this way can patterns of recruitment and the causative factors for variation be assessed and management strategies directed towards the maintenance or enhancement of larval input. Finally, it should be noted that it is unlikely management can directly influence larval input into Ningaloo. Instead, the best tactic is a preventative one in which the health of reproductive adults and the general well-being of the ecosystem is the first priority.

5) Are current management strategies appropriate to maintain acceptable levels of coral and fish recruitment?

This is a very difficult question to which there is no concrete answer at present. In my opinion, both coral and fish recruitment levels, although highly variable, are natural and adequate to maintain the health of the system as it now stands. Once again, the continuation of annual recruitment monitoring is key to answering this question and should be a priority for management. By recording recruitment and comparing future levels of ecosystem and general adult coral and fish abundance and health, a comparative assessment could certainly be made with some level of confidence.

6. COMMUNICATION AND OUTPUTS

6.1 COMMUNICATION ACHIEVEMENTS

6.1.1 STUDENTS SUPPORTED

Charlotte Johansson, AIMS@JCU PhH Candidate

6.1.2 THESES AND DISSERTATIONS

Charlotte Johansson (expected 2012) Herbivory at Ningaloo Reef, Western Australia

6.1.3 PUBLICATIONS

Johansson CL, Bellwood DR, Depczynski M (2010) Sea urchins, macroalgae and coral reef decline: a functional evaluation of an intact reef system, Ningaloo, Western Australia. Mar Ecol Progr Ser 414: 65-74

Wilson, SK, Depczynski M, Fisher R, Holmes TH, O'Leary RA, Tinkler P (2010) Habitat associations of juvenile fish at Ningaloo Reef, Western Australia: the importance of coral and algae. PloS One 5 (12): e15185. Doi:10.1371/journal.pone.0015185

6.1.4 PLANNED PUBLICATIONS

It is expected that collection of further annual recruitment data will eventually provide adequate information for publication related to coral recruitment rates in northern NMP. Further fish recruitment papers are also planned for 2011-2012.

6.1.5 PRESENTATIONS

1) Depczynski M, Heyward A, Birrell C, Colquhoun J, Radford B, Wilson S, Holmes T (Dec 2009) Coral and fish recruitment at Ningaloo. Presentation to joint AIMS/CSIRO audience, CSIRO Floreat.

2) Depczynski M, Heyward A, Colquhoun J, Radford B, Wilson S, Holmes T (Nov 2010) Coral and fish recruitment at Ningaloo. Presentation to the public, Exmouth.

3) Wilson S, Depczynski M, Fisher R, Holmes T, O'Leary R, Tinkler P (Sept 2010) Coral reefs and algal meadows as essential habitat for juvenile fish. Presentation to the Australian Coral Reef Society, Coffs Harbour

4) Depczynski M, Wilson S, Holmes T, Tinkler P, Case M, Heyward A, Radford B (Aug 2011) Juvenile fish assemblages of Ningaloo Reef. Poster presented to the Australian Coral Reef Society

5) Depczynski M, Wilson S, Holmes T, Tinkler P, Case M, Heyward A, Radford B (Sept 2011) Methods for monitoring the health of benthic communities at Ningaloo. Presentation to the WAMSI Conference

6.2 Project outputs

- Annual Field Report (December 2009) - Methods for monitoring the health of benthic communities. Field report WAMSI Node 3 Project 1 (WAMSI project reference no. 3.1.2).
- Final Report (June2011) - Methods for monitoring the health of benthic communities. Final report WAMSI Node 3 Project 1 (WAMSI project reference no. 3.1.2)
- Synthesis Report (July 2011) for monitoring the health of benthic communities. Synthesis report WAMSI Node 3 Project 1 (WAMSI project reference no. 3.1.2)

6.3 Data management

Baseline coral and fish recruitment information including;

Fish recruitment

1) 2009-2010 Fish recruitment database (Microsoft Access .accdb)
2) WayPoint file of fish recruitment site locations (.wpt)
3) Juvenile fish field identification sheets (Microsoft Word .doc)

Coral recruitment

4) 2009-2010 Coral settlement tile database (Microsoft Excel .xlsx)
5) WayPoint file of coral settlement tile site locations (.wpt)
6) 2009-2010 UVC data (Microsoft Excel .xlsx)
7) Raw image collections (.jpg)

Accesses to these files are managed and available through AIMS.

Survey site waypoint data, coral tile census data, UVC raw data, raw image collections and all analytical data are managed by AIMS.

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APPENDICES

APPENDIX A: INITIAL EVALUATION OF MEASUREMENT PRECISION USING FUJI W3 STEREO CAMERA

- Using CAL (SeaGIS Pty Ltd), the Fuji W3 stereo camera was calibrated in air (Fig 1). CAL is a photogrammetric bundle adjustment program. It performs a photogrammetric bundle adjustment using optional inner constraints to provide a datum, and also implements an optional stereo constraint specifically for calibrating stereo camera systems.
- The results of the calibration are detailed in Table 1.

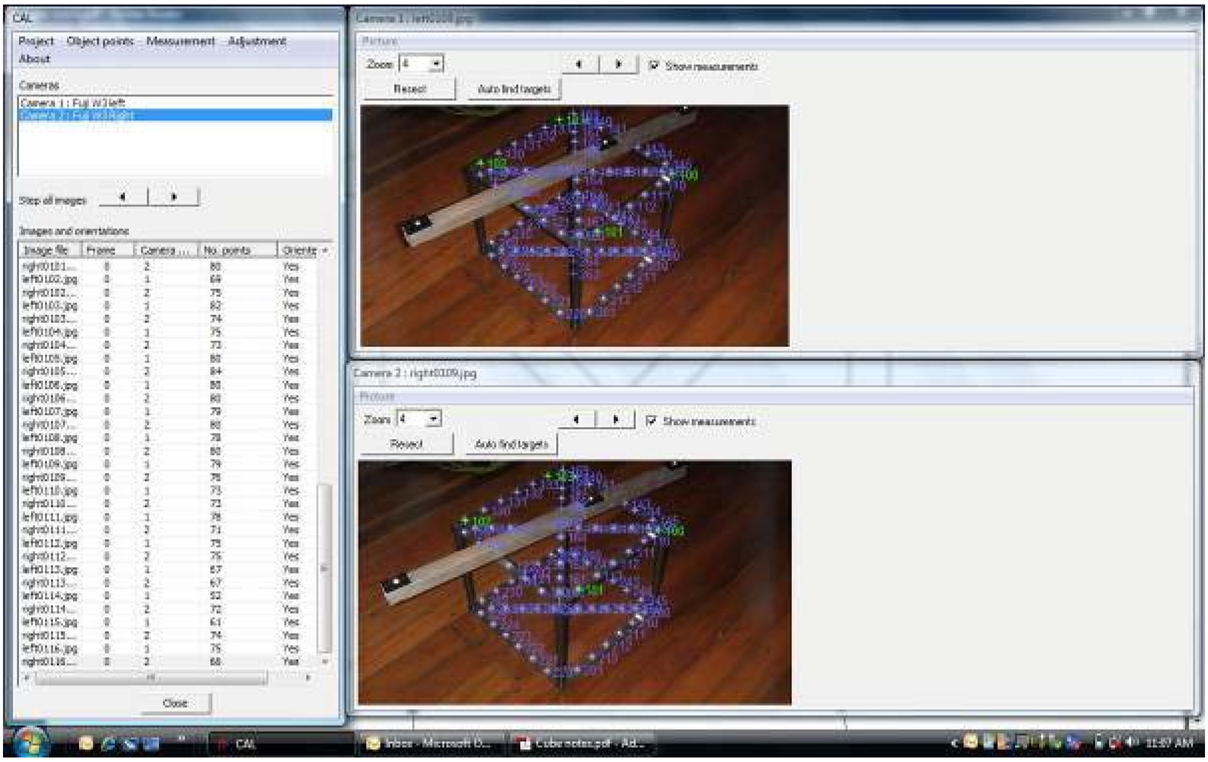


Figure A 1: Screen grab of CAL calibration process. Calibration was performed using 36 images of the calibration cube (1 stereo image set from 4 camera rotations, from 9 different views of the calibration cube). All images were captured at approximately 60cm from the calibration cube.

- The synchronisation was also checked for the camera. 74 images of a digital clock display were captured to examine any differences in the cameras shutter lag (for each lens) (Fig 2.). The camera was also rotated randomly during the process. No obvious difference in synchronisation was observed in any of the 74 images captured.

Figure A 2: Images showing the process of checking the synchronisation of the camera. The two images represent the left and right images captured by the FUJI camera.

Table A1: Stereo constraints resulting from camera calibration, showing relative orientations of the camera. Note, the base separation is slight smaller than the reported 77mm separation.

Name	Value	Units	Precision
Parameter source	Camera positions and orientations		
No. constraints	36		
Base separation (X)	75.2211	mm	197.8 (micron)
Delta Omega	-0.14388	Degrees	47.3 (Seconds)
Left Phi	-0.28831	Degrees	710.3 (Seconds)
Left Kappa	-0.21139	Degrees	601.1 (Seconds)
Right Phi	-0.39926	Degrees	703.3 (Seconds)
Right Kappa	-0.46019	Degrees	599.6 (Seconds)

To examine the ability of the Fuji camera is making accurate and precise measurements. A high precision calibration bar was included (see screen grab above) in the images captured of the calibration cube. Three distances are able to be measured using the bar (namely: D1=447.244mm, D2=694.644mm, and D3=247.401mm). In all images where a distance measurement could be made (within the set of 36 stereo image pairs), the distance was measured and compared to the actual distance. The results are detailed in Table 2. All images were captured at an average distance from subject of 876 mm ± 23 mm (SE), with distance to subject ranging from 538 mm to 1289 mm.

It should be noted that independence in the measurements is violated using the above methodology, as the scale bar was measured using the images utilised for the calibration. A true test would use a separate set of images of the scale bar.

Table A2: Results of actual vs. measured distance of the calibration bar, using the stereo Fuji camera.

Cal_Bar	Length (mm)	Mean Error (mm)	SE (mm)	Mean Error (%)	SE (%)	n
D1	447.244	-1.188631579	1.56158	-0.265768032	0.349	19
D2	694.644	-2.691333333	1.96164	-0.387440665	0.282	15
D3	247.401	-2.07073913	1.42168	-0.836997074	0.575	23

To perform the assessment using an independent set of measurements (using a scale bar – albeit not as precise as the Calibrated scale bar). Images of a ruler were captured, and measurements of length were made along the graduations on the ruler (at 1cm, 2cm and 5cm). Images used for measurements were taken from three different points of views (overhead, side on at a 45 deg angle and front on at 45 deg angle). Table A3 details the results.

- Results will have a certain level of error based on the precision of the graduations of the ruler. Image matching procedures where used to match points within the image to reduce human error (in selecting like matches across the stereo images)

Table A3: Actual vs. Measured ruler graduations using images captured by the Fuji W3 camera.

Distance	Length (mm)	Mean Error (mm)	SE (mm)	Mean Error (%)	SE (%)	n
10mm	10	-0.276	0.33092	-2.76	3.309	5
20mm	20	0.21	0.24817	1.05	1.241	5
50mm	50	0.233333333	0.12425	0.466666667	0.248	6

To understand the suitability of the Fuji camera for measuring coral recruits. A set of coins were photographed once from three angles: overhead, front on at a 45 degree angle, and from the side at a 45 degree angle. Using EventMeasure (SeaGIS Pty Ltd), the measured diameter was then compared to the actual diameter of the coins (note surface area could be measured if needed using software from SeaGIS). The results are detailed in Table 4.

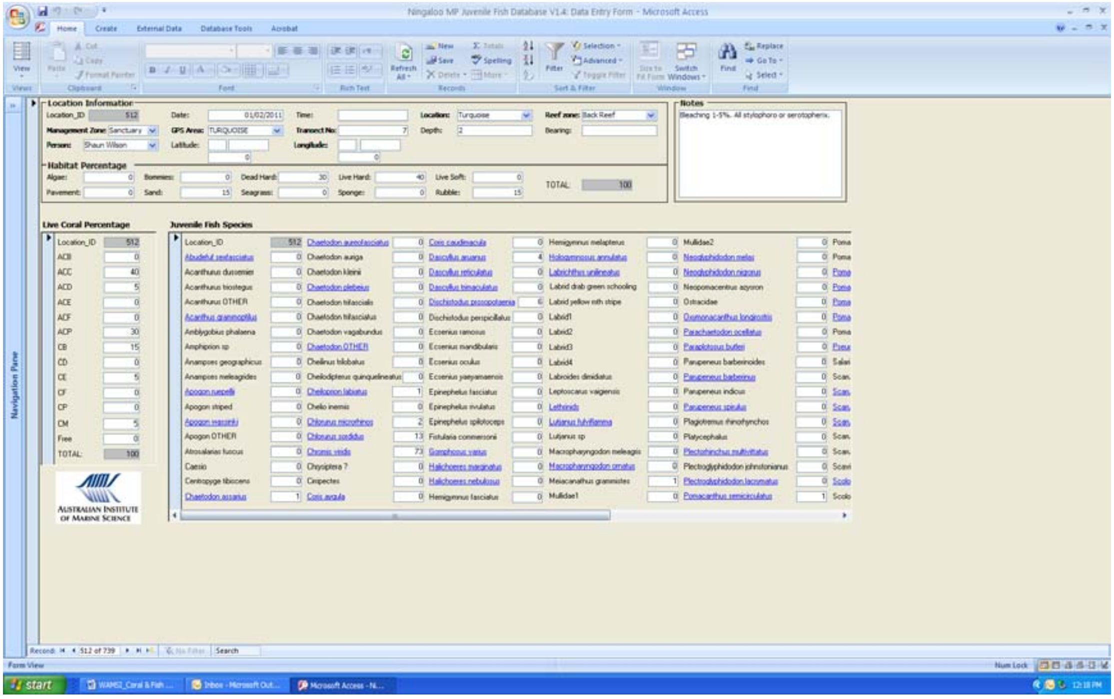
- A large proportion of the error associated with the measurements of the coins will be related to the operator's selection of the initial point of measuring (again the image matching routine was used for selecting points across the stereo image pairs).

Table A4: Actual vs measured diameter of 6 coins of various sizes using the Fuji stereo camera.

Coin	Diameter (mm)	Mean Error (mm)	SE (mm)	Mean Error (%)	SE (%)	n
2	20.5	1.926666667	0.65172	9.398373984	3.179	3
1	25	1.943333333	0.14655	7.773333333	0.586	3
50	31.51	1.176666667	0.54333	3.734264255	1.724	3
20	28.52	2.573333333	1.46167	9.022907901	5.125	3
10	23.6	1.843333333	0.62462	7.810734463	2.647	3
5	19.41	1.653333333	0.98925	8.517946076	5.097	3

Overall, given the cost of the camera - it represents an affordable methodology to employ in the field which has a relatively high accuracy (at worst the average error was ~10% of the measured distance).

APPENDIX B: ACCESS DATA BASE GENERATED AND REFINED FOR JUVENILE FISH ASSEMBLAGES



Appendix C: Field work locations for coral and fish recruitment sites

Complete list of coral and fish recruitment field work locations from north to south, reef and management zones, years sampled, method(s) utilised and GPS coordinates completed at the Ningaloo Marine Park in 2009-2011.

Coral recruitment

Section	Locations	Reef zone	M'ment zone	Years	Technique	Position
Eastern	BUN BR1	Back reef	Sanctuary	2009-2010	Tiles, UVC & Photo	S21 51.788 E114 09.615
Eastern	BUN BR2	Back reef	Sanctuary	2009-2010	Tiles, UVC & Photo	S21 51.761 E114 09.626
Eastern	BUN BR 3	Back reef	Sanctuary	2009-2010	Tiles, UVC & Photo	S21 51.748 E114 09.645
Eastern	BUN N1	Back reef	Recreational	2009-2010	Tiles, UVC & Photo	S21 51.025 E114 10.294
Eastern	BUN N2	Back reef	Recreational	2009-2010	Tiles, UVC & Photo	S21 51.001 E114 10.299
Eastern	BUN N3	Back reef	Recreational	2009-2010	Tiles, UVC & Photo	S21 50.974 E114 10.307
Eastern	BUN N PLUS 1	Back reef	Sanctuary	2009-2010	Tiles, UVC & Photo	S21 49.866 E114 10.655
Eastern	BUN N PLUS 2	Back reef	Sanctuary	2009-2010	Tiles, UVC & Photo	S21 49.838 E114 10.671
Eastern	BUN N PLUS 3	Back reef	Sanctuary	2009-2010	Tiles, UVC & Photo	S21 49.829 E114 10.692
Northern	JUR1	Back reef	Recreational	2009-2010	Tiles, UVC & Photo	S21 51.445 E113 59.438
Northern	JUR 2	Back reef	Recreational	2009-2010	Tiles, UVC & Photo	S21 51.417 E113 59.421
Northern	JUR 3	Back reef	Recreational	2009-2010	Tiles, UVC & Photo	S21 51.394 E113 59.412
Northern	TLC1	Back reef	Recreational	2009-2010	Tiles, UVC & Photo	S21 54.304 E113 56.495
Northern	TLC2	Back reef	Recreational	2009-2010	Tiles, UVC & Photo	S21 54.274 E113 56.490
Northern	TLC3	Back reef	Recreational	2009-2010	Tiles, UVC & Photo	S21 54.256 E113 56.478
Northern	TLSZ 2	Lagoon	Sanctuary	2009-2010	Tiles, UVC & Photo	S21 54.692 E113 57.803
Northern	TLSZ 3	Lagoon	Sanctuary	2009-2010	Tiles, UVC & Photo	S21 54.663 E113 57.798
Northern	TLSZ1	Lagoon	Sanctuary	2009-2010	Tiles, UVC & Photo	S21 54.722 E113 57.801
Southern	CBBR1	Back reef	Sanctuary	2009-2010	Tiles, UVC & Photo	S23 09.477 E113 45.527
Southern	CBBR2	Back reef	Sanctuary	2009-2010	Tiles, UVC & Photo	S23 09.452 E113 45.529
Southern	CBBR3	Back reef	Sanctuary	2009-2010	Tiles, UVC & Photo	S23 09.425 E113 45.525
Southern	CBSL1	Slope	Recreational	2009-2010	Tiles, UVC & Photo	S23 08.422 E113 44.599
Southern	CBSL2	Slope	Recreational	2009-2010	Tiles, UVC & Photo	S23 08.396 E113 44.597
Southern	CBSL3	Slope	Recreational	2009-2010	Tiles, UVC & Photo	S23 08.374 E113 44.590
Southern	CBIL1	Back reef	Sanctuary	2009-2010	Tiles, UVC & Photo	S23 08.147 E113 45.727
Southern	CBIL2	Back reef	Sanctuary	2009-2010	Tiles, UVC & Photo	S23 08.125 E113 45.711
Southern	CBIL3	Back reef	Sanctuary	2009-2010	Tiles, UVC & Photo	S23 08.106 E113 45.701
Southern	CBLN1	Back reef	Sanctuary	2009-2010	Tiles, UVC & Photo	S23 08.136 E113 45.436
Southern	CBLN2	Back reef	Sanctuary	2009-2010	Tiles, UVC & Photo	S23 08.121 E113 45.424
Southern	CBLN3	Back reef	Sanctuary	2009-2010	Tiles, UVC & Photo	S23 08.093 E113 45.421
Southern	CBOB1	Back reef	Sanctuary	2009-2010	Tiles, UVC & Photo	S23 08.359 E113 45.173
Southern	CBOB2	Back reef	Sanctuary	2009-2010	Tiles, UVC & Photo	S23 08.383 E113 45.164
Southern	CBOB3	Back reef	Sanctuary	2009-2010	Tiles, UVC & Photo	S23 08.389 E113 45.140

Fish recruitment

Section	Locations	Reef zone	M'ment zone	Years	Technique	Position
Eastern	Bundegi BR	Back reef	Sanctuary	2009-2011	UVC	S21 51.788 E114 09.615
Eastern	Bundegi N	Back reef	Recreation	2010-2011	UVC	S21 51.025 E114 10.294
Northern	Jurabi	Back reef	Recreation	2009-2011	UVC	S21 51.423 E113 59.534

Northern	Jurabi	Lagoon	Recreation	2009-2011	UVC	S21 52.384 E113 59.709
Northern	Mangrove Bay	Back reef	Sanctuary	2010-2011	UVC	S21 57.068 E113 55.235
Northern	Mangrove Bay	Lagoon	Sanctuary	2010-2011	UVC	S21 58.049 E113 56.351
Northern	Mesa	Back reef	Recreation	2010-2011	UVC	S22 00.206 E113 54.707
Northern	Mesa	Lagoon	Recreation	2010-2011	UVC	S22 00.429 E113 55.336
Northern	Mandu	Back reef	Sanctuary	2011	UVC	S22 05.112 E113 53.357
Northern	Turquoise Bay	Back reef	Sanctuary	2010-2011	UVC	S22 05.936 E113 53.087
Northern	Oyster Stacks	Back reef	Sanctuary	2011	UVC	S22 O7.939 E113 52.596
Northern	Winderabandi	Back reef	Recreation	2009-2011	UVC	S22 29.689 E113 42.169
Northern	Winderabandi	Lagoon	Recreation	2009-2011	UVC	S22 29.678 E113 43.350
Northern	Norwegian Bay	Back reef	Sanctuary	2009-2011	UVC	S22 35.902 E113 38.656
Northern	Norwegian Bay	Lagoon	Sanctuary	2009-2011	UVC	S22 36.033 E113 40.301
Northern	Ningaloo H'stead	Lagoon	Sanctuary	2009-2010	UVC	S22 40.228 E113 41.037
Southern	Cloates	Back reef	Sanctuary	2009-2011	UVC	S22 42.698 E113 39.461
Southern	Cloates	Lagoon	Sanctuary	2009-2011	UVC	S22 42.739 E113 39.586
Southern	Coral Bay North	Back reef	Sanctuary	2010-2011	UVC	S23 07.453 E113 07.876
Southern	Coral Bay North	Lagoon	Sanctuary	2010-2011	UVC	S23 07.149 E113 45.641
Southern	Coral Bay South	Back reef	Sanctuary	2010-2011	UVC	S23 09.500 E113 45.553
Southern	Coral Bay South	Lagoon	Recreational	2010-2011	UVC	S23 11.029 E113 46.066
Southern	14-Mile North	Back reef	Recreational	2010-2011	UVC	S23 17.440 E113 46.645
Southern	14-MileNorth	Lagoon	Recreational	2010-2011	UVC	S23 17.491 E113 47.097
Southern	14-Mile South	Back reef	Sanctuary	2009-2011	UVC	S23 19.136 E113 46.786
Southern	14-Mile South	Lagoon	Sanctuary	2009-2011	UVC	S23 19.069 E113 47.246
Southern	Elle's	Back reef	Sanctuary	2009-2011	UVC	S23 20.901 E113 46.920
Southern	Elle's	Lagoon	Sanctuary	2009-2011	UVC	S23 20.335 E113 47.266
Southern	Cape Farquhar	Back reef	Sanctuary	2010-2011	UVC	S23 37.727 E113 36.843
Southern	Gnaraloo	Back reef	Sanctuary	2010-2011	UVC	S23 45.817 E113 32.452
Southern	3-Mile	Back reef	Sanctuary	2010-2011	UVC	S23 52.403 E113 29.779

APPENDIX D: UNDERWATER IDENTIFICATION SHEETS FOR JUVENILES FISHES OF NINGALOO

POMACENTRIDS

Abudefduf bengalensis

Found: All areas
Notes: Fat tail

Abudefduf sexfasciatus (c)

Found: All areas, water column
Notes: Black forked tail

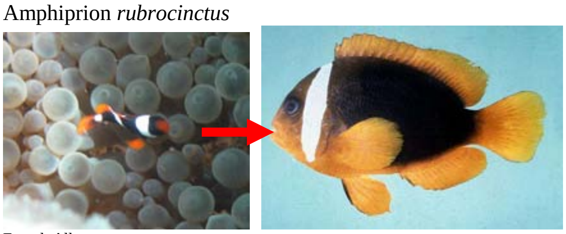
Abudefduf vaigiensis (c)

Found: All areas
Notes: Yellow dorsal colouration

Amphiprion clarkii

Found: All areas, anemone
Notes: 2 bands, yellow tail

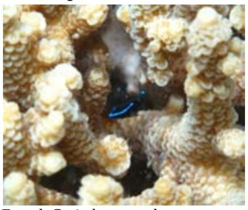
Amphiprion *rubrocinctus*



Found: All areas, anemone
Notes: 3 bands, orange/red tail

Notes: 1 band, sometimes faint

Cheiloprion labiatus



Found: Corimbose coral
Notes: Neon blue head halo

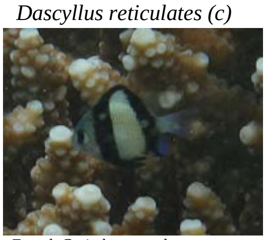
Chromis viridis (c)

Found: Coral
Notes: Bright blue

Dascyllus aruanus (c)

Found: Corimbose coral
Notes: Bl/wh bands, blue pectoral margin

Dascyllus reticulates (c)



Found: Corimbose coral
Notes: Bl/tan bands

Dascyllus trimaculatus (c)

Found: Corimbose coral, anemone
Notes: 2-3 white dots

Dischistodus prosopotaenia

Found: Rubble, dead coral
Notes: Br/wh bands, black ocellus

Neoglyphidodon melas

Found: Coral, soft coral
Notes: Yellow head, blue pectoral fins

Neoglyphidodon nigroris

Found: Coral (mostly Bundegi)
Notes: Yellow/bl stripes, long tail

Neopomacentrus azysron

Found: Coral, water column
Notes: Yellow/orange long tail

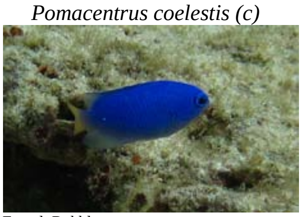
Neopomacentrus cyanomos

Found: Coral, water column, overhangs
Notes: White rear dorsal spot, long tail

Plectroglyphidodon lacrymatus (c)

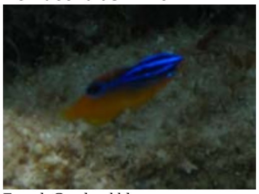
Found: Coral, rubble
Notes: Bright blue spots

Pomacentrus coelestis (c)



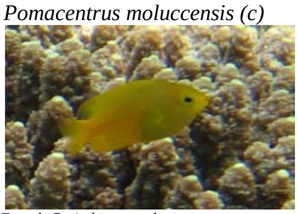
Found: Rubble
Notes: Yellow tail, ventral side

Pomacentrus milleri



Found: Coral, rubble
Notes: Blue stripes on head margin

Pomacentrus moluccensis (c)



Found: Corimbose coral
Notes: Yellow

Pomacentrus vaiuli(c)

Found: All areas, rubble, dead coral
Notes: Orange head

Stegastes fasciolatus

Found: Exposed coral
Notes: Bl ocellus, yellow dorsal

Stegastes nigracans

Found: ?
Notes: ?

Stegastes obreptus (c)

Found: All areas
Notes: Black dorsal ocellus, yellow colour, fading to brown as gets older

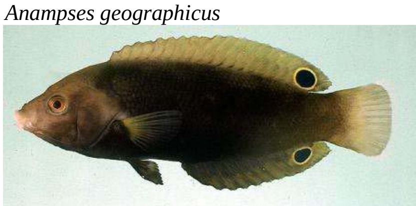
LABRIDS

Anampses caeruleopunctatus

Found: Coral, rubble
Notes: Mottled, floating leaf form

Notes: Yellow, speckled, deep bodied

Anampses geographicus

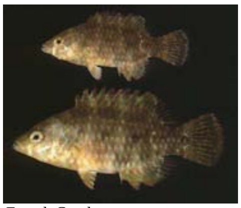


Found: Algal areas
Notes: Dorsal/ventral ocelli, distinct tan/yellow dorsal side, in mixed schools

Cheilinus chlorurus

Found: Coral, overhangs overhangs
Notes: Mottles, white spots

Cheilinus trilobatus



Found: Coral, crevaces

Notes: Mottled, pointed nos

Cheilio inermis

Found: Algal areas

Notes: Long, thin, pointed nose, brown/tan

Coris aygula

Found: Rubble, dead coral,

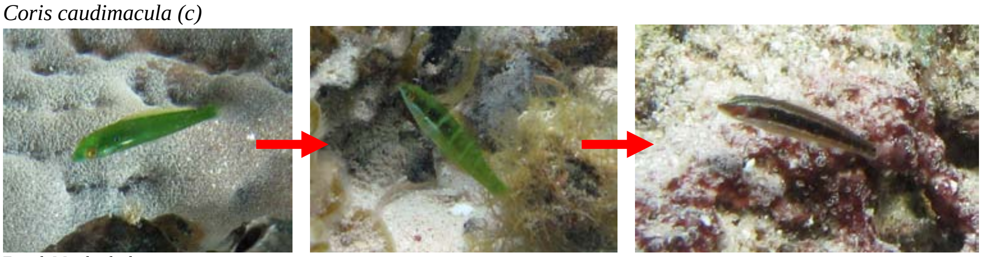
Notes: Solitary, bright colours

Gomphosus varius

Found: Mostly coral, rubble, dead coral
Notes: Green dorsal, bl stripe, pointed nose

Notes: Long nose, red nose tip

Coris caudimacula (c)



Found: Mostly algal areas
Notes: Bright green, bl opercula dot

Notes: Wh bands, neon blue strip under eye

Notes: Wh bands. Wh/blue stripes, brown/bl stripes

Halichoeres marginatus

Found: Coral areas
Notes: Red/brown, wh/yellow colour, blue ocellus

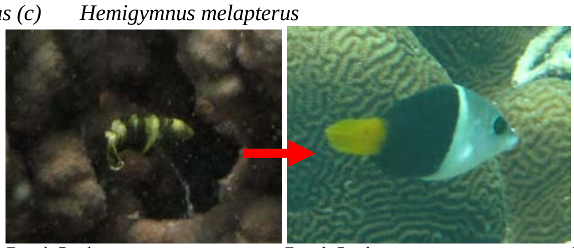
Notes: Bl, white, yellow stripes, bl ocellus

Notes: Brown colour, didtinct bl mid-dorsal ocellus

Halichoeres nebulosus (c)

Found: Algae, rubble
Notes: Mottled colour

Hemigymnus melapterus



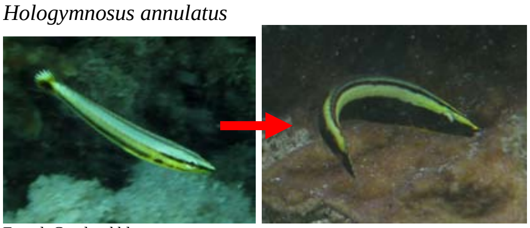
Found: Coral, areas, crevaces
Notes: Brown/tan mottled, leaf like

Found: Coral areas
Notes: Two toned colour

Hemigymnus fasciatus

Found: Coral areas
Notes: Bands ?

Hologymnosus annulatus



Found: Coral, rubble
Notes: Slender, yellow/bl/wh stripes

Notes: Slender, Bl/yellow stripes

Labroides dimidiatus

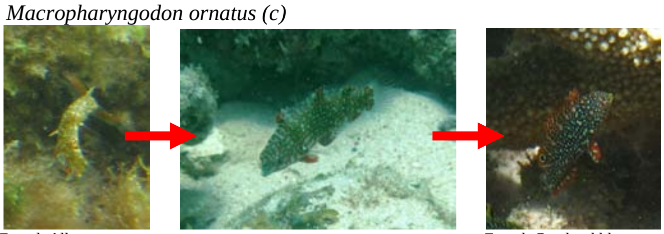
Found: Coral, water column
Notes: Slender, Bl with neon blue stripe

Notes: Slender, Bl/blue/white colour

Labrichthys unilineatus

Found: Coral
Notes: Wh stripe

Macropharyngodon ornatus (c)



Found: All areas
Notes: Mottled, ornate, leaf like, rear dorsal and ventral ocelli

Found: Coral, rubble
Notes: Bright colours

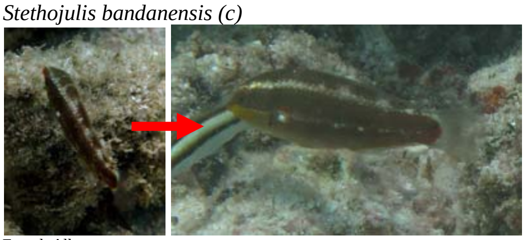
Pseudocheilinus hexataenia

Found: Coral, overhangs
Notes: Orange/pink stripes, green tail

Pterogogus sp.

Found: Algal associated
Notes: Mottled, cryptic

Stethojulis bandanensis (c)



Found: All areas
Notes: Red/brown mottled, wh stripes and saddles, orange spot above pectoral base

Stethojulis interrupta (c)

Found: All areas
Notes: Rear dorsal, ventral and caudal spot; brown/bl/wh stripes

Found: Algal areas
Notes: Slender, yellow nose, drab green/wh body

Stethojulis strigiventer (c)

Found: Mostly algal areas
Notes: Brown/tan, rear dorsal, ventral, caudal spot

Notes: Neon blue stripe under eye, tan/green stripes on ventral body

Thalassoma amblycephalum

Found: Coral, water column
Notes: Slender; bl/wh stripes; blunt nose

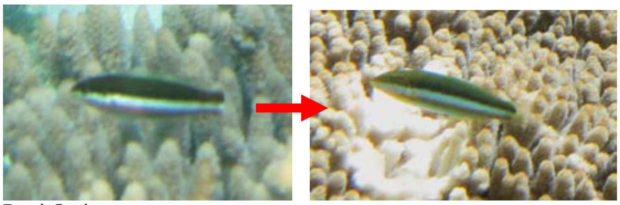
Thalassoma hardwicke

Found: Coral areas
Notes: Bl saddles

Thalassoma lunare (c)

Found: All areas
Notes: Green/blue/red colouration; mid dorsal occelus

Thalassoma lutescens



Found: Coral areas
Notes: Green/wh/tan stripes; short nose

Notes: Green/wh/tan stripes; yellow hue

Thalassoma quinquevittatum

Found: Exposed Coral areas
Notes: Green/wh/red colouration; wh saddles

SCARIDS

Chlorurus microrhinos

Found: All areas
Notes: Wide bl with thin wh/yellow stripes; dark dorsal/ventral fins

Chlorurus sordidus (c)

Found: All areas
Notes: Equal sized brown/wh stripes

Leptoscarus vaigiensis

Found: Algal associated
Notes: Mottled tan; blunt nose; UGLY

Scarus chameleon

Found: Coral
Notes: brown/grey colour, blunt yellow nose stripes

Scarus frenatus (c)

Found: Coral, dead coral, rubble
Notes: Bright green; stripes and saddles

Notes: Blue tail, brown/red head, faint

Scarus prasiognathus

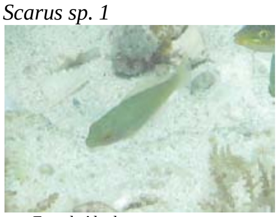
Found: Coral, rubble
Notes: Bl with wh lattice colouration

Notes: Mottled bl/blue/green/yellow

Scarus psittacus ?

Found: Coral, dead coral, rubble
Notes: Dark red with distinct white nose

Scarus sp. 1

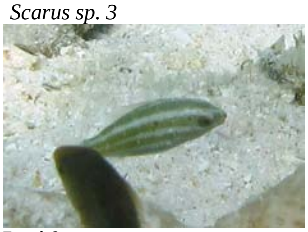


Found: Algal areas
Notes: Pale green

Scarus sp. 2

Found: ?
Notes: Wide brown stripes

Scarus sp. 3



Found: ?
Notes: Wide tan/brown stripes

Scarus sp. 4

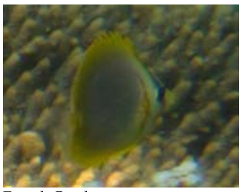
Found: ?
Notes: Tan/brown stripes; wh saddles

CHAETODONTIDS

Chaetodon assarius

Found: Algal areas, sponges
Notes: Pale vertical dotted lines

Chaetodon aureofasciatus



Found: Coral areas
Notes: Distinctive shape, no body marks

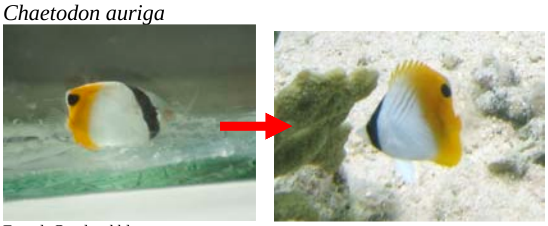
Chaetodon kleinii

Found: ?
Notes: Single bl line through eye

Chaetodon lunula

Found: ?
Notes: Wh & Bl lines on head

Chaetodon auriga



Found: Coral, rubble
Notes: Bl ocellus; bl line through eye; faint diagonal lines on body

Chaetopod lunulatus

Found: Coral
Notes: Distinctive colour and shape

Chaetodon melannotus

Found: ?
Notes: Bl caudal; diagonal lines on body

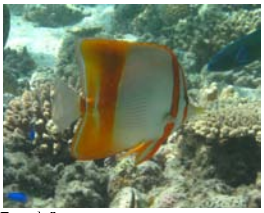
Chaetodon plebius

Found: Corimbose coral
Notes: Bl caudal; bl line through eye

Chaetodon trifascialis

Found: Plating coral
Notes: Triangular lines on body

Chelmon marginalis



Found: ?
Notes: Elongate nose

Parachaetodon ocellatus

Found: Algal areas, sponges
Notes: Triangle shape; 4 vertical bands

Heniochus acuminatus

Found: ?
Notes: Shortened banner; wide bl bands

POMACANTHIDS

Pomacanthus semicirculatus

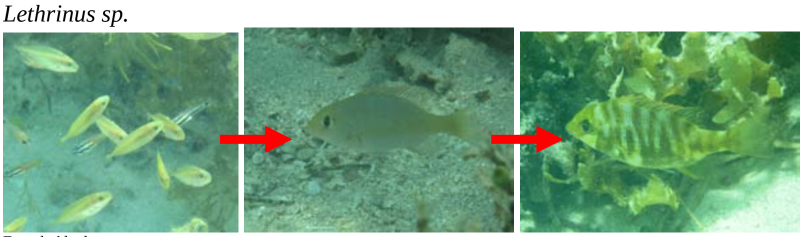
Found: All areas, caves, overhangs
Notes: Crescent shaped lines

Pomacanthus sextriatus

Found: All areas, caves, overhangs
Notes: Straighter lines

LETHRINIDS

Lethrinus sp.



Found: Algal areas
Notes: Brown/green; in schools above substrate

Notes: Distinctive shape; variable colour (yellow); bl line through eye

Lethrinus variegates

Found: Algal areas
Notes: Single vertical stripe

LUTJANIDS

Lutjanus sp.

Found: Base of hard substrate
Notes: Slight yellow colour; single stripe; dot on rear body

HAEMULIDS

Plectorhinchus multivittatus

Found: Algal, seagrass areas
Notes: Discontinuous yellow stripes on body

MULLIDS

Parupeneus barberinoides

Found: Algal areas, sand, rubble
Notes: Dark red and yellow colouration

Parupeneus spilurus

Found: Algal areas, sand, rubble
Notes: Distinctive striped pattern; Bl dot on caudal

Upeneus tragula

Found: Algal areas, sand
Notes: Mottled; Single brown stripe, striated tail

ACANTHURIDS

Acanthurus grammoptilus

Found: Algal areas
Notes: Wh dot on caudal peduncle

Acanthurus dussumieri

Found: Algal areas
Notes: Wh band through tail

Acanthurus triostegus

Found: Coral, rubble
Notes: 5 thin vertical bands

Zebrasoma scopus

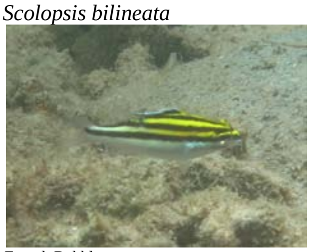
Found: Coral areas
Notes: Tan/brown colour; faint thin bands

Zebrasoma veliferum

Found: Coral areas
Notes: Very yellow when young; wider yellow and brown bands

NEMIPTERIDS

Scolopsis bilineata



Found: Rubble
Notes: Yellow dorsal; bl stripes; bl dot at front of dorsal fin

PSEUDOCHROMIDS

Pseudochromis fuscus

Found: All areas
Notes: Slender; drab brown/tan/yellow colour

BLENNIES

Meiacanthus grammistes

Found: Coral areas, water column
Notes: Yellow head; blunt nose

Plagiotremus rhinorhynchos

Found: Coral areas, water column
Notes: Elongate; 2 neon blue stripes; short pointed nose; fangs

PLOTOSIDS

Paraplotosus butleri

Found: All areas, caves, overhangs
Notes: Bl with wh margins; long tail

Plotosus lineatus

Found: All areas, caves, overhangs
Notes: Large schools; bl with thin wh/yellow stripes

APOGONIDS

Apogon angustatus

Found: All areas, hard substrate, overhangs
Notes: 4 bl stripes; bl caudal spot

Apogon aureus (c)

Found: All areas, hard substrate, overhangs
Notes: Blue lines through eye

Apogon cooki (c)

Found: All areas, hard substrate
Notes: Multiple thin stripes

Apogon rueppellii

Found: Algal, seagrass areas
Notes: Dots along lateral line

Apogon wassinki (c)

Found: All areas, hard substrate, overhangs
Notes: Silver lines; yellow back half

Cheilodipterus quinquelineatus

Found: All areas, hard substrate, overhangs
Notes: 5 bl straipes; yellow tail; bl caudal spot

SERRANIDS

Epinephelus bilobatus

Found: All areas
Notes: 3 distinctive bl saddles on back

Epinephelus fasciatus

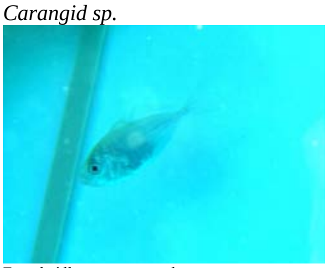
Found: Coral areas
Notes: Brown/red colouration; multiple bands

Epinephelus rivulatus

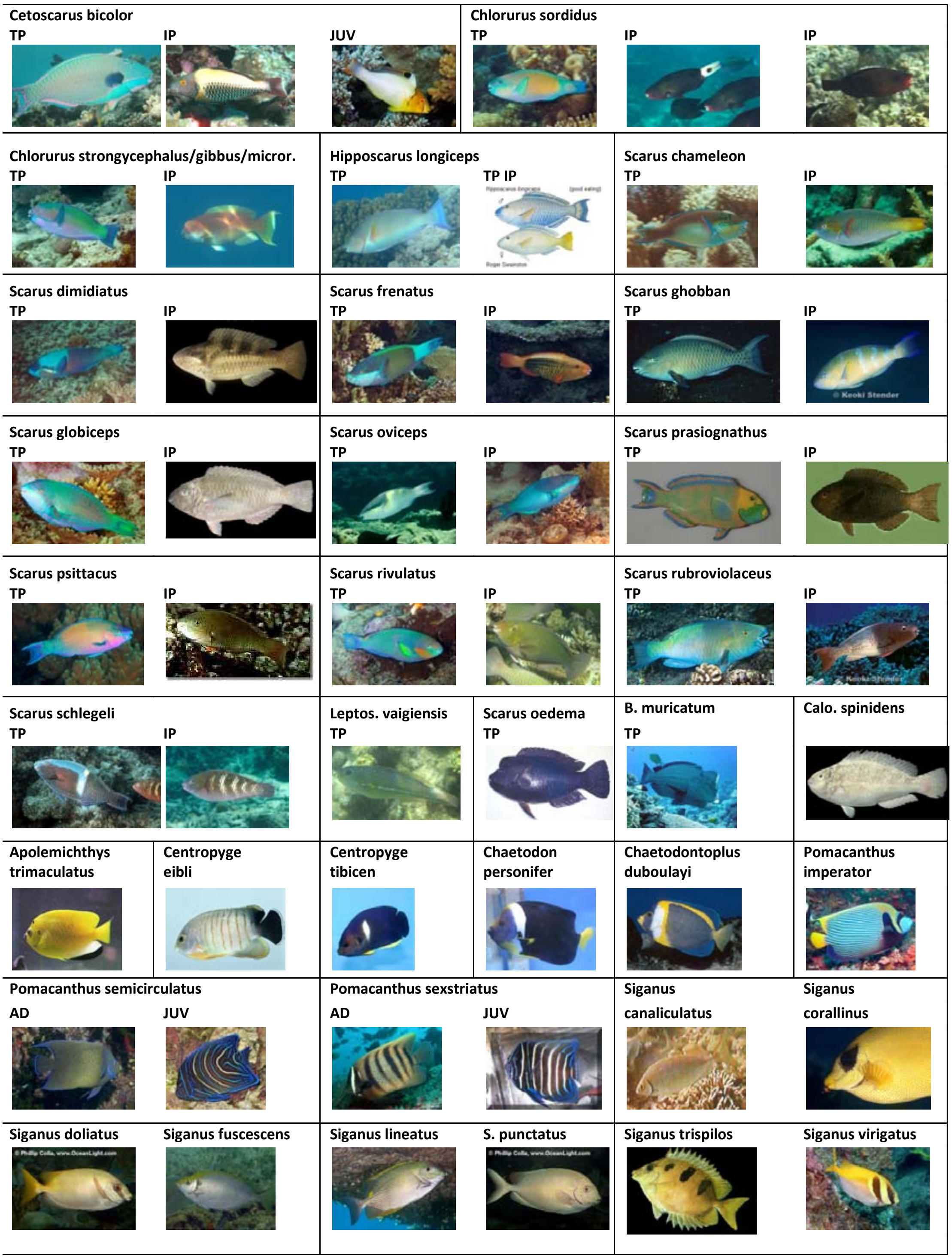
Found: Algal areas, pavement
Notes:Tan/green colour; bands; yellow margin to dorsal

CARANGIDS

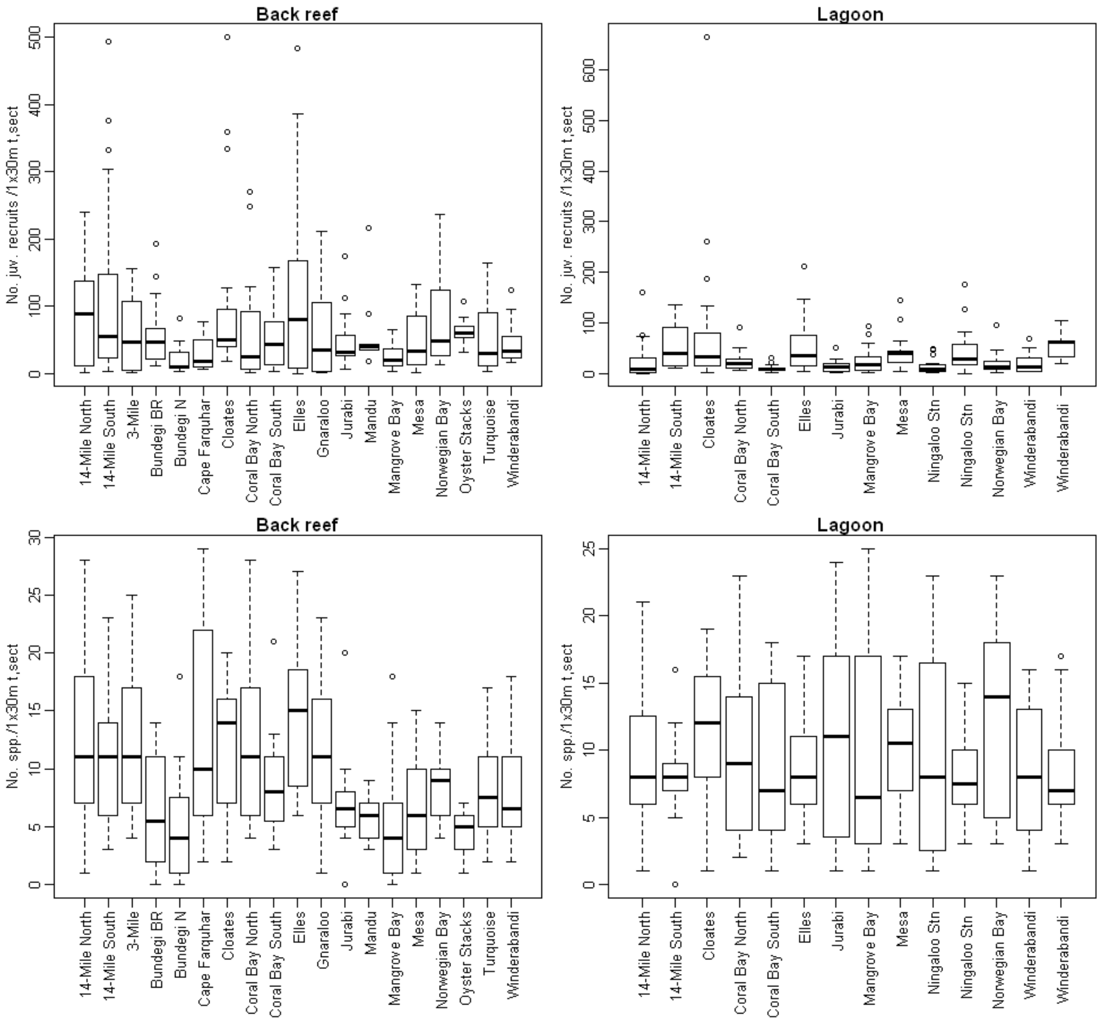
Carangid sp.



Found: All areas, water column
Notes: Silver/transparent colour

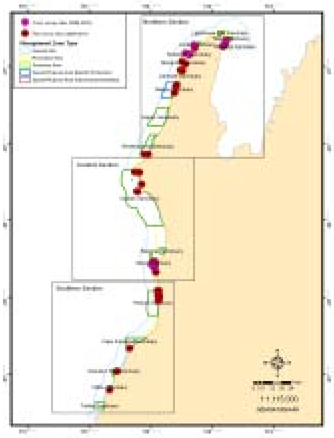

Cetoscarus bicolor
TP
IP
JUV
Chlorurus sordidus
TP
IP
IP
Chlorurus strongycephalus/gibbus/micror.
TP
IP
Hipposcarus longiceps
TP
TP IP
Scarus chameleon
TP
IP
Scarus dimidiatus
TP
IP
Scarus frenatus
TP
IP
Scarus ghobban
TP
IP
Scarus globiceps
TP
IP
Scarus oviceps
TP
IP
Scarus prasiognathus
TP
IP
Scarus psittacus
TP
IP
Scarus rivulatus
TP
IP
Scarus rubroviolaceus
TP
IP
Scarus schlegeli
TP
IP
Leptos. vaigiensis
TP
Scarus oedema
TP
B. muricatum
TP
Calo. spinidens
Apolemichthys trimaculatus
Centropyge eibli
Centropyge tibicen
Chaetodon personifer
Chaetodontoplus duboulayi
Pomacanthus imperator
Pomacanthus semicirculatus
AD
JUV
Pomacanthus sexstriatus
AD
JUV
Siganus canaliculatus
Siganus corallinus
Siganus doliatus
Siganus fuscescens
Siganus lineatus
S. punctatus
Siganus trispilos
Siganus virigatus

APPENDIX E: BOX PLOTS INDICATING THE DOMINATING FORCE OF OUTLIERS ON TRANSECTS THAT CONTAINED UNUSUALLY LARGE NUMBERS OF SCHOOLING OR SUPERABUNDANT FISHES.



APPENDIX F: AIMS MEST METADATA INPUT.

Juvenile fish recruitment surveys, Ningaloo Reef, Western Australia (WAMSI Node 3 Project 3.1.2)



Citation

Title	Juvenile fish recruitment surveys, Ningaloo Reef, Western Australia (WAMSI Node 3 Project 3.1.2)

Date

Date	2009-02-04
Date type	**creation**: date identifies when the resource was brought into existence

Cited responsible party

Individual name	Depczynski, Martial, Dr
Organisation name	Australian Institute of Marine Science
Position name	Research Scientist

Contact info

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OnLine resource	http://www.aims.gov.au
Hours of service	0800 to 1640 UTC+10: Monday to Friday
Role	**principalInvestigator**: key party responsible for gathering information and conducting research
Data Summary	The abundance, species richness and assemblage structure of juvenile fishes was quantified in 2009- 2011 at 20 locations extending from Bundegi to 3-Mile Camp, some 280km of the Ningaloo coastline. Within locations, both back reef and lagoonal reef zones were censused that encompassed sanctuary and recreational management zones. In total, 691 transects yielded 36,791 juvenile fishes from 120 species over the three recruitment years providing an average of 53 individuals (± 2.6 se) 30m-2 transect or 1.8 m-2.
Purpose	This study measured annual fish recruitment rates at Ningaloo Reef using underwater visual census (UVC) based on 30 x 1 m transects for 2009 - 2011. Belt transects of this size were found to have the highest level of precision, were logistically simple to use and therefore able to

	cover larger areas within the same time frame. In addition to trialling these techniques, extensive comparisons were also initially made on the consistency of inter-observer estimates of habitat characterisation, fish size and abundances to provide an understanding of the challenges that might present themselves in the transition towards an ongoing long-term monitoring program.
Credit	Depczynski, Martial: AIMS (Project Leader and Principal Investigator)
Credit	Heyward, Andrew: AIMS (Project Leader)
Credit	Case, Mark: AIMS
Credit	Colquhoun, Jamie: AIMS
Credit	O'Leary, Rebecca: AIMS
Credit	Radford, Ben: AIMS
Credit	Wilson, Shaun (DEC WA)
Credit	Holmes, Tom (DEC WA)
Status	**completed**: production of the data has been completed

Point of contact

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Position name	Data Manager, AIMS Data Centre

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Hours of service	0800 to 1640 UTC+10: Monday to Friday
Role	**pointOfContact**: party who can be contacted for acquiring knowledge about or acquisition of the resource

Descriptive keywords

Oceans | Coastal Processes | Coral Reefs , Biological Classification - Animals/Vertebrates - Fish (Type: theme) (Thesaurus Name: Global Change Master Directory (GCMD) Version 6).

Resource maintenance

Maintenance information

Maintenance and update frequency	**asNeeded**: data is updated as deemed necessary

Resource format

Name	Microsoft Access Database
Version	Access 2007

Resource constraints

Legal constraints

Use limitation	All AIMS data, products and services are provided "as is" and AIMS does not warrant their fitness for a particular purpose or non-infringement. While AIMS has made every reasonable effort to ensure high quality of the data, products and services, to the extent permitted by law the data, products and services are provided without any warranties of any kind, either expressed or implied, including without limitation any implied warranties of title, merchantability, and fitness for a particular purpose or non-infringement. AIMS make no representation or warranty that the data, products and services are accurate, complete, reliable or current. To the extent permitted by law, AIMS exclude all liability to any person arising directly or indirectly from the use of the data, products and services.
Other constraints	Ownership of all Intellectual Property Rights in the data remains with the Australian Institute of Marine Science (AIMS) and all use of the data must acknowledge AIMS.

Other constraints: All users of AIMS data must acknowledge the source of the material in the following manner: "Data was sourced from the Australian Institute of Marine Science (AIMS)."

Other constraints: Format for citation of data sourced from Australian Institute of Marine Science (AIMS) in a list of reference is as follows: "Australian Institute of Marine Science. [year-of-data-download], [Title], [data-access-URL], accessed (date-of-access]".

Other constraints: Use of the AIMS data is for not-for-profit applications only. All other users shall seek permission for use by contacting AIMS. Acknowledgements as prescribed must be clearly set out in the user's formal communications or publications.

Resource constraints

Security constraints

Classification: **unclassified**: available for general disclosure

Language: English

Character set: **utf8**: 8-bit variable size UCS Transfer Format, based on ISO/IEC 10646

Topic category

Topic category code: oceans

Topic category

Topic category code: biota

Environment description: Access database using XP, backup on Titiko WA Server

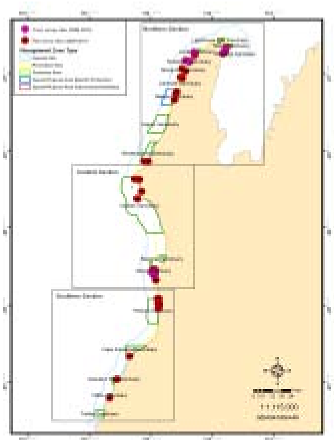
Sampling Frequency: **asNeeded**: data is updated as deemed necessary

Extent

Geographic element

Geographic bounding box

North bound latitude -21.47
South bound latitude -23.76
East bound longitude 114.16
West bound longitude 112.99



Vertical element

Vertical extent

Minimum value: 0 Maximum value: 30

Temporal element

Temporal Extent (MCP)

Extent

Begin date	2009-02-04T16:06:00
End date	2011-02-05T00:00:00
Temporal Currency	**mostRecent**: resource currency is most recent
Temporal Aggregation	**none**: aggregation unit is none

Distribution and On-line Resource(s)

Distribution format

Name	Microsoft Office Access Database
Version	Access 2007

Distributor

Distributor

Distributor contact

Organisation name	Australian Institute of Marine Science
Position name	Data Manager, AIMS Data Centre

Contact info

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OnLine resource	http://www.aims.gov.au/adc
Hours of service	0800 to 1640 UTC+10: Monday to Friday
Role	**distributor**: party who distributes the resource
OnLine resource	Point of truth URL of this metadata record

Data quality info

Scope

Hierarchy level	**dataset**: information applies to the dataset

Lineage

Statement	Data set full of zeros

Process step

Process step

Description	Exploratory stage

Data quality info

Scope

Hierarchy level	**attribute**: information applies to the attribute class

Metadata constraints

Legal constraints

Other constraints	All users of AIMS metadata must acknowledge the source of the material in the following manner: "Metadata was sourced from the Australian Institute of Marine Science (AIMS)."
Other constraints	Format for citation of metadata sourced from Australian Institute of Marine Science (AIMS) in a list of reference is as follows: "Australian Institute of Marine Science. [year-of-data-download], [Title], [data-access-URL], accessed (date-of-access]".

Metadata constraints

Security constraints

Classification **unclassified**: available for general disclosure

Metadata maintenance

Maintenance information

Maintenance and update frequency **asNeeded**: data is updated as deemed necessary

Metadata Info

File identifier	963d2acd-0a19-441c-bde1-4150e14b2e77
Language	English
Character set	**utf8**: 8-bit variable size UCS Transfer Format, based on ISO/IEC 10646
Hierarchy level	**dataset**: information applies to the dataset

Contact

Organisation name	Australian Institute of Marine Science
Position name	Data Manager, AIMS Data Centre

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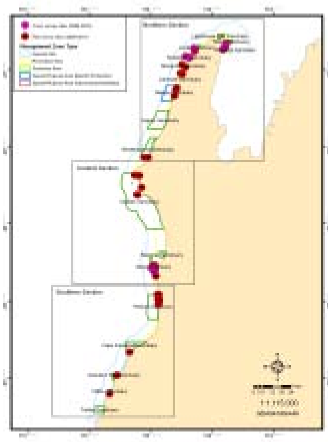
OnLine resource	http://www.aims.gov.au/adc
Hours of service	0800 to 1640 UTC+10: Monday to Friday
Role	**custodian**: party that accepts accountability and responsibility for the data and ensures appropriate care and maintenance of the resource
Date stamp	2011-07-28T11:33:39
Metadata standard name	AIMS version of the Australian Marine Community Profile of ISO 19115:2005/19139
Metadata standard version	MCP:AIMS_BlueNet V1.4
Revision Date	2011-07-29T14:42:34

Appendix ??

Coral recruitment surveys, Ningaloo Reef, Western Australia (WAMSI Node 3 Project 3.1.2)



Identification info

Citation

Title	Coral recruitment surveys, Ningaloo Reef, Western Australia (WAMSI Node 3 Project 3.1.2)

Date

Date	2009-03-04
Date type	**creation**: date identifies when the resource was brought into existence

Cited responsible party

Individual name	Depczynski, Martial, Dr
Organisation name	Australian Institute of Marine Science
Position name	Research Scientist

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Email	reception@aims.gov.au
OnLine resource	http://www.aims.gov.au
Hours of service	0800 to 1640 UTC+10: Monday to Friday
Role	**principalInvestigator**: key party responsible for gathering information and conducting research
Data Summary	The abundance of newly settled corals following the 2009 and 2010 annual coral spawning peaks was measured in the northern half of Ningaloo Reef at eleven locations between Coral Bay, Tantabiddi and Bundegi. An annual influx of coral recruits were detected at all locations, using terracotta tiles deployed by divers on the reef using permanent tile mounting fixtures, then subsequently retrieved and counted under a dissecting microscope.
Purpose	This study has measured annual coral recruitment rates at Ningaloo Reef using deployed tiles, but has also had a particular focus on evaluating some alternative methods for coral juvenile census. Deploying, recovering and assessing tiles is labor intensive, requires use of SCUBA and a specialist using a microscope in the laboratory for census of the tiles. A key aim of this project has been to understand the tradeoffs associated with simplified and more cost-effective approaches. The objective was to assess methods that could still yield robust research data, yet utilize non-specialist regional DEC staff for routine field surveys, maximizing the effectiveness of Perth-based specialist research staff for more complex analytical tasks.
Credit	Depczynski, Martial: AIMS (Project Leader and Principal Investigator)
Credit	Heyward, Andrew: AIMS (Project Leader)
Credit	Case, Mark: AIMS
Credit	Colquhoun, Jamie: AIMS
Credit	O'Leary, Rebecca: AIMS
Credit	Radford, Ben: AIMS
Credit	Wilson, Shaun (DEC WA)
Credit	Holmes, Tom (DEC WA)
Status	**completed**: production of the data has been completed

Point of contact

Organisation name	Australian Institute of Marine Science
Position name	Data Manager, AIMS Data Centre

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OnLine resource	http://www.aims.gov.au/adc
Hours of service	0800 to 1640 UTC+10: Monday to Friday
Role	**pointOfContact**: party who can be contacted for acquiring knowledge

	about or acquisition of the resource

Descriptive keywords

Oceans - Coastal Processes - Coral Reefs , Biological Classification - Animals/Invertebrates - Cnidarians , Anthozoans/Hexacorals , Hard Or Stony Corals , Biological Classification - Animals/Invertebrates - Cnidarians , Anthozoans/Octocorals , Soft Corals (Type: theme) (Thesaurus Name: NASA/Global Change Master Directory (GCMD) Science Keywords Version 6.0.0.0.0).

Resource maintenance

Maintenance information

Maintenance and update frequency	**asNeeded**: data is updated as deemed necessary

Resource format

Name	Microsoft Office Excel
Version	Excel 2007

Resource constraints

Legal constraints

Use limitation	All AIMS data, products and services are provided "as is" and AIMS does not warrant their fitness for a particular purpose or non-infringement. While AIMS has made every reasonable effort to ensure high quality of the data, products and services, to the extent permitted by law the data, products and services are provided without any warranties of any kind, either expressed or implied, including without limitation any implied warranties of title, merchantability, and fitness for a particular purpose or non-infringement. AIMS make no representation or warranty that the data, products and services are accurate, complete, reliable or current. To the extent permitted by law, AIMS exclude all liability to any person arising directly or indirectly from the use of the data, products and services.
Other constraints	Ownership of all Intellectual Property Rights in the data remains with the Australian Institute of Marine Science (AIMS) and all use of the data must acknowledge AIMS.
Other constraints	All users of AIMS data must acknowledge the source of the material in the following manner: "Data was sourced from the Australian Institute of Marine Science (AIMS)."
Other constraints	Format for citation of data sourced from Australian Institute of Marine Science (AIMS) in a list of reference is as follows: "Australian Institute of Marine Science. [year-of-data-download], [Title], [data-access-URL], accessed (date-of-access)".
Other constraints	Use of the AIMS data is for not-for-profit applications only. All other users shall seek permission for use by contacting AIMS. Acknowledgements as prescribed must be clearly set out in the user's formal communications or publications.

Resource constraints

Security constraints

Classification	**unclassified**: available for general disclosure
Language	English
Character set	**utf8**: 8-bit variable size UCS Transfer Format, based on ISO/IEC 10646

Topic category

Topic category code	oceans

Topic category

Topic category code	biota
Environment	Excel spread sheets using XP, backup on Titiko WA Server

description

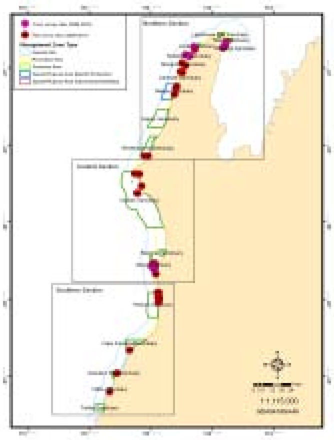
Sampling Frequency **asNeeded**: data is updated as deemed necessary

Extent

Geographic element

Geographic bounding box

North bound latitude -21.47
South bound latitude -23.76
East bound longitude 114.16
West bound longitude 112.99



Vertical element

Vertical extent

Minimum value 0 Maximum value 30

Temporal element

Temporal Extent (MCP)

Extent

Begin date 2009-03-04T16:06:00
End date 2010-05-13T00:00:00
Temporal Currency **mostRecent**: resource currency is most recent
Temporal Aggregation **none**: aggregation unit is none

Distribution and On-line Resource(s)

Distribution format

Name Microsoft Excel
Version Excel 2007

Distributor

Distributor

Distributor contact

Organisation name Australian Institute of Marine Science
Position name Data Manager, AIMS Data Centre

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OnLine resource	http://www.aims.gov.au/adc
Hours of service	0800 to 1640 UTC+10: Monday to Friday
Role	**distributor**: party who distributes the resource
OnLine resource	Point of truth URL of this metadata record

Metadata constraints

Legal constraints

Other constraints	All users of AIMS metadata must acknowledge the source of the material in the following manner: "Metadata was sourced from the Australian Institute of Marine Science (AIMS)."
Other constraints	Format for citation of metadata sourced from Australian Institute of Marine Science (AIMS) in a list of reference is as follows: "Australian Institute of Marine Science. [year-of-data-download], [Title], [data-access-URL], accessed (date-of-access]".

Metadata constraints

Security constraints

Classification	**unclassified**: available for general disclosure

Metadata maintenance

Maintenance information

Maintenance and update frequency	**asNeeded**: data is updated as deemed necessary

Metadata Info

File identifier	d395ccc1-8d4a-4236-9304-7a45961a9c77
Language	English
Character set	**utf8**: 8-bit variable size UCS Transfer Format, based on ISO/IEC 10646
Hierarchy level	**dataset**: information applies to the dataset

Contact

Organisation name	Australian Institute of Marine Science
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OnLine resource	http://www.aims.gov.au/adc
Hours of service	0800 to 1640 UTC+10: Monday to Friday
Role	**custodian**: party that accepts accountability and responsibility for the data and ensures appropriate care and maintenance of the resource
Date stamp	2011-07-28T13:26:53
Metadata standard name	AIMS version of the Australian Marine Community Profile of ISO 19115:2005/19139
Metadata standard version	MCP:AIMS_BlueNet V1.4
Revision Date	2011-07-29T08:24:48