ZOOPLANKTON COMPOSITION IN THE MANGROVES AND REEFS OF THE LAS PERLAS ARCHIPELAGO, PANAMA

by

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Abstract

Inshore areas of the tropical marine environment contain many unique and diverse ecosystems. Of particular interest to ecologists are highly productive mangrove forests and coral reefs. Mangroves are known to provide many ecosystem services, one of which – a nursery role for juvenile fish and crustaceans – has been the focus of much detailed and often contradictory research. In this baseline study, the zooplankton composition of a fringe mangrove and coral reef in the Las Perlas Archipelago, Panama was examined using a combination of plankton tows and nightlight lift net. It was found that zooplankton composition between mangroves and reefs differed significantly for some groups in the nightlight surveys. Additionally, a greater number of late-stage larval and juvenile fishes were obtained in the mangrove site than the reef. The utilisation of certain inshore habitats by fish and crustacean species at particular life-stages, and their dependence on other zooplankton, could be assessed in the Las Perlas Archipelago with the use of multiple sampling methodologies. This could provide vital information for management decisions and the conservation of inshore habitats.

Chapter 1 - Introduction

1.1 Background

Mangroves can be defined as woody plants that grow at the interface between land and sea (Kathiresan & Bingham, 2001). They are characteristic of tropical and subtropical coastlines and are closely associated with estuarine areas (Blaber, 2002). Mangroves are considered to be highly productive ecosystems which provide, amongst other benefits, a structurally complex area that traps sediment and organic material from land sources. They are thought to maintain water quality, nutrient balances, hydrodynamic characteristics and a habitat for fishes during different stages of their life cycle (Nickerson, 1999). The variability of physical conditions within mangroves – salinity, tidal exposure, turbidity and a complex prop root system – means they can support unique assemblages of flora and fauna.

It has been estimated that total worldwide mangrove coverage has been reduced by a third in the past 50 years (Alongi, 2002). Much like temperate estuaries they are a focus of anthropogenic stress – from shipping, industry, fisheries, farming - and the myriad environmental impacts this entails (Blaber, 2002). As populations rise and demand placed on tropical coastlines increases, similar pressures are having detrimental impacts on mangroves. This has led to calls to assess costs and values of products and services provided by mangroves, and in particular the relative values of preservation versus exploitation (Janssen and Padilla, 1999). In traditional subsistence economies the exploitation of mangrove resources is usually not intensive and settlement is quite sparse. However, in areas such as South East Asia the modernisation of technologies and farming methods, particularly aquaculture, has led to a boom in mangrove exploitation. In the Philippines alone already heavily reduced mangrove coverage was halved between 1970 and 1993 (Janssen and Padilla, 1999). During the 20th Century, India's mangroves were reduced by 40% (Kathiresan, 2000). There is concern that the impacts of removing such vast areas of mangroves, which provide so many services, may have far reaching social, economic and ecological consequences. The annual economic value of mangroves has been estimated to be $200,000 - $900,000 per hectare

(Wells *et al*, 2006). Their many economic benefits come in the form of capture fisheries, harvesting of the wood and as a site for extensive shrimp farming in some countries. They also provide protection against storm damage, trap and filter pollutants and stabilise coastal land by trapping sediment (Nickerson, 1999). But with the development of mangroves comes numerous physical consequences, including increased sedimentation and erosion, excess nutrient flow, altered food chains and changes in tidal flow (Alongi, 2002). These physical impacts may yet prove to have extensive ecological repercussions, which have only recently begun to be examined. Yet it is the possible connection between mangroves and juvenile fishes that is most often given as a key argument for their preservation, specifically that mangroves may act as a nursery area for many commercial and non-commercial fish and crustacean species. However, being an often inhospitable environment, there has been a relative lack of research within mangrove systems with biologists instead focusing on more appealing areas such as coral reefs (Blaber, 2002). Recently, however, there has been an upsurge in tropical estuarine research, driven by the need for food security and the conservation of biodiversity. In order for both of these issues to be dealt with effectively, knowledge is required of the ecology of tropical coastal fishes and crustaceans, particularly their dependence on mangroves for survival.

1.2 Mangroves as nurseries

Fish diversity in mangroves varies at global, latitudinal, regional, local and habitat scales; species composition in any one system represents the combined influences of factors operating at each of these scales (Blaber, 2007). Marine ecologists generally agree that inshore waters provide a crucial role for offshore fish populations in the provision of nursery and feeding areas (Sasekumar *et al*, 1992). Indeed, given their intertidal nature, few fish can utilise mangroves exclusively but instead must migrate in and out with the tide (Sheaves, 2003). Yet it has been pointed out that it is almost an “article of faith” amongst estuarine scientists that coastal wetlands, such as mangrove forests, are important nursery sites for juvenile fish and crustaceans in comparison to other habitats (Robertson & Duke, 1987). Much of the evidence that mangroves retain a nursery role was circumstantial but research over the past decade has provided greater clarification.

One of the first studies to compare habitats was in Australia using seagrass beds for comparison (Robertson & Duke, 1987). They demonstrated that species diversity and abundance varied between habitats and seasons, but that juvenile penaeid shrimps and post-larval, juvenile and small adult fish were more abundant in mangroves, particularly in the warm wet-season. There was a variation in abundance between mangrove sites indicating that mangrove areas differ in their nursery ground value. In Thailand, however, mangrove creeks and beach habitats both function as nursery sites for different fish species, but mangroves are utilised by a greater diversity of species (Ikejimaa *et al*, 2003). Nagelkerken *et al* (2000) found that mangroves, seagrass beds and shallow coral reefs (0-3m) appeared to be the main nursery biotopes for the juveniles of selected species, with some utilising individual habitats and many all three at any one time. Few if any juveniles were observed in deeper reef zones. In the Caribbean, Mumby *et al* (2004) found mangroves acted as vital intermediary habitats for non-resident, juvenile reef fishes. The herbivorous fish *Scarus guacamaia* incurred local extinction after the removal of mangroves as it had a functional dependency on them.

In eastern Australia mangroves were demonstrated to be of use to species of non-resident fish as well as 27 resident species compared to seagrass beds which only held 4 exclusive species (Laegdsgaard & Johnson, 1995). They also examined the role of mudflats as a habitat for juveniles and found evidence that they acted as transition zones between adult and juvenile habitats. Interestingly, species abundance and diversity was highest in summer. As salinity, temperature and turbidity were similar in all habitats another factor was thought to be influencing fish abundance and diversity. This leads to the question of what it is that attracts juveniles to mangrove habitats.

Several hypotheses have been proposed to explain why juvenile fishes are attracted to mangroves, and are either based on predator avoidance, food abundance or the interception of fish larvae (Nagelkerken *et al*, 2000). These hypotheses can be separated thus: (1) structural complexity provides shelter from predators; (2) they are often located at a distance from reefs and offshore waters and are therefore less frequented by predators; (3) turbid waters decrease foraging efficiency of predators; (4) they are highly productive and therefore provide a great abundance of food; and (5)

they cover extensive areas and therefore are more likely to intercept planktonic fish larvae more effectively than, say, shallow reefs. However, Cocheret de la Morinie *et al* (2002) found that in a Caribbean example, post-settlement life stages utilise mangroves out of choice and not simply through stochastic dispersal of their larvae.

In an attempt to experimentally determine what attracts juvenile fish to mangroves Laegdsgaard and Johnson (2001) created artificial reefs with different physical characteristics in eastern Australia. They found that artificial structures which were left to accumulate fouling algae had four times the number of fish than areas with no structure or a clean structure. Algae were linked to increased food availability and extra shelter both of which were desirable to different species. In laboratory experiments they found that predation pressure significantly influenced habitat choice in smaller fish. As fish grow they found a shift in habitat from mangroves to mudflats, possibly as a response to changes in diet, foraging efficiency and vulnerability to predators. This suggests a need to conserve multiple habitats in order to maintain healthy individual systems. However, it is difficult to make comparisons between tropical, subtropical and temperate habitats due to "differences in environment and community composition" (Laegdsgaard & Johnson, 1995). Often sampling methodologies are different making comparisons problematic (Beck *et al*, 2001)

1.3 Nearshore Tropical Zooplankton

While the importance of mangroves as a nursery area for fish and prawn species has become a focus for research, the zooplankton of mangroves are a major component of the trophic structure and should be equally valued within the research (Beck *et al*, 2001). However, the role of zooplankton in mangroves is virtually unknown despite their pivotal trophic role as intermediaries between alternative carbon sources (detritus) and higher consumers such as fish (McKinnon & Klumpp, 1998). Abundance within mangrove riverways may be up to an order of magnitude higher than in adjacent coastal waters. Little as yet is known of the trophic links within mangrove systems, particularly those supporting juvenile fishes. This poses a problem when determining effective management of mangrove areas as apparently small impacts may have widespread consequences due to lack of knowledge.

In some areas meroplankton, the larval stages of benthic invertebrates, can account for more than 50% of plankton biomass (McConaugh, 1992). Larval development of decapod crustaceans is perhaps one of the most important stages of their life cycle (Báez, 1997). It is generally thought that invertebrates have retained a planktonic larval phase as a mechanism for increased dispersal. It was found that there was significant interaction between the time of day, tidal stage and lunar cycle on the megalopa stage of decapod larvae (Báez, 1997). In Costa Rica, larvae were found to be exported from mangroves on outgoing tides and older larvae were imported back on incoming tides (Dittel & Epifanio, 1990).

Zooplankton in Indian mangroves where found to consist mainly of copepods, in some seasons up to 95% (Kathiresan, 2000). In the mangrove zooplankton of an estuary in Northeastern Australia the dominant group was also copepods, possibly indicating their importance as a food source for juvenile fishes (McKinnon & Klumpp, 1998).

Plankton also represents a major source of food to the coral reef community (D'Croz *et al*, 1999). In a landmark study on coral reef zooplankton, Emery (1968) examined the abundance and composition of zooplankton in sheltered versus exposed areas during the day. In one instance a nightlight mechanism was used which showed that plankton was much more abundant (4 times), and appeared to aggregate near the bottom of the water column, particularly crab zoea. Large swarms of copepods and mysids were also observed. This was the first time diurnally migrating zooplankton populations on reefs had been documented. Nocturnal near-reef plankton in Jamaica was found to be twice as dense as during the day (Heidelberg *et al*, 2004).

Many zooplankton species are highly mobile, which may lead to habitat choice, rather than remaining as "passive drifters" (Wiafe & Frid, 1996). Indeed, fish larvae have been shown to swim up to 30cm/min and can detect potentially suitable habitats over 1km (Leis *et al*, 1996). Copepods have also been shown to swim up to 60 cm/min, allowing for greater dispersal ability and predator avoidance (Ferrari *et al*, 2003). The demonstration of such agility and escape responses means that some zooplankton taxa are not well sampled by net tows (Meekan *et al*, 2001). Therefore, tows can only provide information on plankton above and not closely associated with a reef or

mangrove (Heidelberg *et al*, 2004). However, as lights attract zooplankton, the use of nightlight lift nets may, coupled with other methodologies, provide a clearer understanding of zooplankton composition associated with a reef (Rooker et al, 1996). Thus photopositive organisms will be sampled by a nightlight lift net while tows will sample non-photopositive ones (Doherty, 1987).

1.4 Aims

This study aimed to determine the zooplankton composition of mangroves and, for comparison, coral reefs of the Las Perlas Archipelago, a group of islands on the Pacific side of Panama, 40 miles south of Panama City. Using these data, invertebrate life-histories and their uses of different habitats may be clarified. This was achieved using plankton tows during the day and nightlight lift net in a fringe and a reef area at night. By using both methodologies it was hoped that the limitations of one would be offset by the use of the other. In particular, the use of nightlighting has been shown to attract juvenile and larval fishes, which allows a comparison of fish diversity between a reef and a mangrove to be made. Ultimately, this baseline survey can provide information upon which further research may be directed. This is due in part to the relatively small amount of anthropogenic disturbance within the Las Perlas Archipelago; if baseline data are gathered now they can be used as reference on the areas undisturbed state. This is particularly pertinent with the declaration of the area for Special Management status (Law 18, 2007), which has afforded the Archipelago some protection but, if based on sound scientific research, may be farther reaching.

Chapter 2 - Materials and Methods

2.1 Study Area

Net tows were undertaken in multiple sites around the Las Perlas Archipelago from the 6th -12th May 2007. A mixture of fringe mangroves, estuarine mangroves and coral reef sites were chosen (Figure 1).

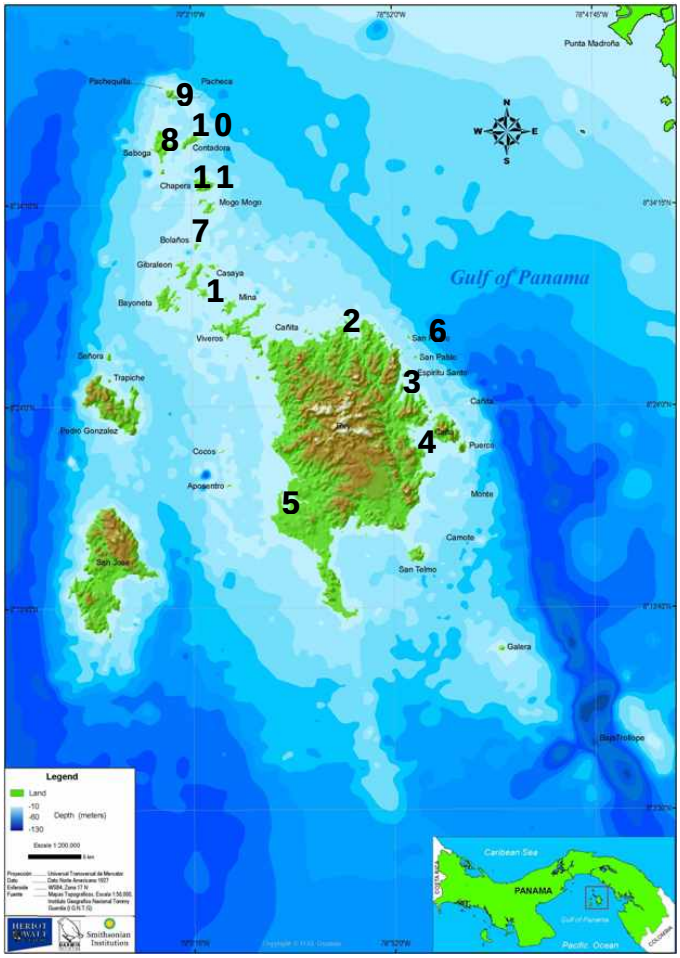


Figure 1 - Sampling locations: Fringe Mangrove (1, 11), Estuarine Mangroves (2-5) and Coral Reefs (6-10). Nightlight sampling was undertaken at sites 10 and 11.

Night sampling took place on the 11th May 2007, during the third quarter of the moon. The safety of the survey vessel and its crew dictated the location of the sampling sites, as working at sea in darkness has inherent dangers. Thus a reef north of Contadora (08°38.910N 079°01.693W) and a fringe mangrove in an inlet on the north of Chapera (08°35.611N 079°01.879W) were chosen due to prior knowledge of the area and their

proximity to inhabited areas of the Archipelago (Figure 1). Before and after sampling weather conditions, sea state and depth of water were all noted.

2.2 Sampling design

2.2.1 Net Tows

Tows were undertaken using a 250µm mesh plankton net, 1metre long and 50 centimetre in diameter with a 500ml collecting jar at the bottom. Tow duration was kept to 5 minutes at a speed of 1.5 to 2 knots. For estuarine areas, tows were taken at the head, mid- and mouth of the estuary. In fringe mangrove sites tows were carried out, safety permitting, 10 metres from the edge of the forest. A minimum of three tows were taken at each site.

Once a tow was completed, the net was carefully backwashed with sea water so that captured organisms were caught in the collecting jar. The contents of the jar were poured into a clean 1 litre plastic bottle and fixed with 100ml of 40% formalin before being topped up with fresh sea water to make a solution of 4% formalin. Bottles were labelled clearly with date, site name, sample number and fixative.

2.2.2 Nightlight sampling

A 250µm mesh plankton net 1metre long and 50 centimetre diameter was fitted with a battery operated marine light 1 metre from the top of the net (Figure 2). At the bottom of the net was a 500ml weighted collecting jar. The net was carefully lowered by hand into the water so that the tip of the light sat in the water with the net 1m below the surface. It was held in this position for 5 minutes, while observations on fauna visible at the surface were made, then pulled up. As with the net tows, the net was backwashed and the contents of the jar fixed in a 1 litre plastic bottle with 100ml of 40% formalin. Backwashing was done on the opposite side of the boat from sampling so as not to disturb organisms attracted to the area by the light. This process was repeated 3 times at each site.

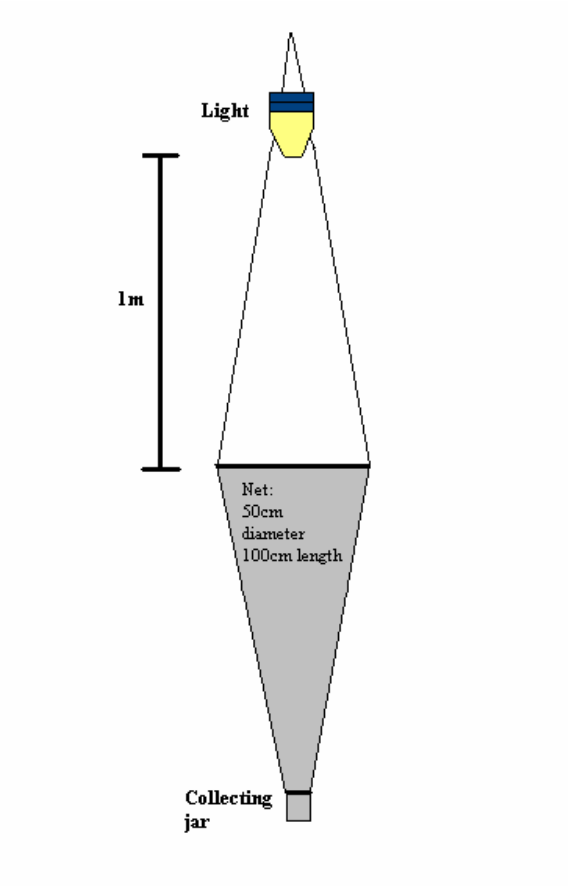


Figure 2 – Diagram of the nightlight net.

2.2.3 Sample Preparation

In order to reduce the solution volume and to preserve the samples in 70% ethanol, samples were emptied onto a 250µm mesh sieve (Figure 3) and washed thoroughly in fresh water to remove residual formalin before being carefully backwashed into 100ml plastic containers using 70% ethanol.

Figure 3 – Plankton sample in sieve set-up prior to washing.

Due to difficulty in exporting samples from Panama, time was restricted for analysis. It was therefore decided to prioritise samples, and as such nightlight samples were analysed first with the day and night tows on the same reef site (Contadora) analysed for comparison of fish composition. As it was another fringe mangrove area a sample from site 1 (Casaya) was used for comparison with the mangrove nightlight samples.

To ascertain zooplankton composition, samples were poured into a 1cm^2-demarked Petri dish for ease of counting. Organisms were separated into major groups of taxa (after D'Croz *et al*, 1999), these being: Amphipods, Chaetognaths, Copepods, Decapods, Eggs, Gammarids, Gastropod larvae, Hyperiids, Isopods, Larvaceans, Megalopa larvae, Nereis Spp., Ostracods, Penaeus Spp., Stomatopods and Zoea Larvae. Key features were used to identify organisms (Newell & Newell, 1973; Smith & Johnson, 1996; Wickstead, 1965). Time constraints and a lack of published literature on identification of juvenile and larval fish of Panama or the Central Pacific, meant that identification of fish species were outside the scope of this study. Instead distinguishing features such as spine and fin counts were used to separate fish into 'Species 1-9'. Early stage larval fish have few distinguishing features to the untrained eye. As such they were all classified as 'Fish Larvae'.

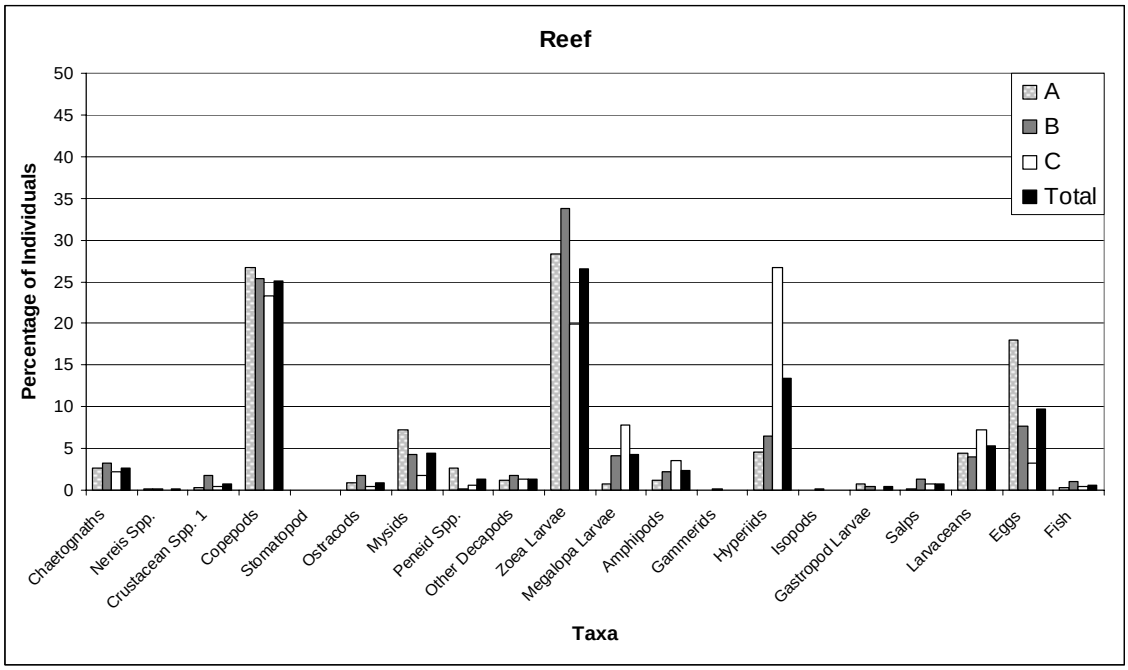
Chapter 3 – Results

Sea conditions during nightlight sampling were slightly choppy with a prevailing northerly wind from which the mangrove inlet was sheltered but the reef was exposed. Sampling took place at 21.30 on the reef and 23.00 on the mangrove. As high tide occurred at 22.58 this allowed the survey vessel to moor as close as possible to the edge of the mangrove while taking advantage of the ebb tide for movement of plankton out of the prop roots. During sampling in the mangrove water depth decreased from 3.5m to 2m. Depth at the reef was 5 metres.

3.1 Zooplankton Composition

Zooplankton composition was found to vary between the mangrove and reef when sampled with a nightlight lift net, with some groups represented more consistently in either the mangrove or the reef (see Appendix 1). While this was not immediately obvious for some groups, when represented as a percentage of total catch number it became apparent (Figure 4).

(a)



(b)

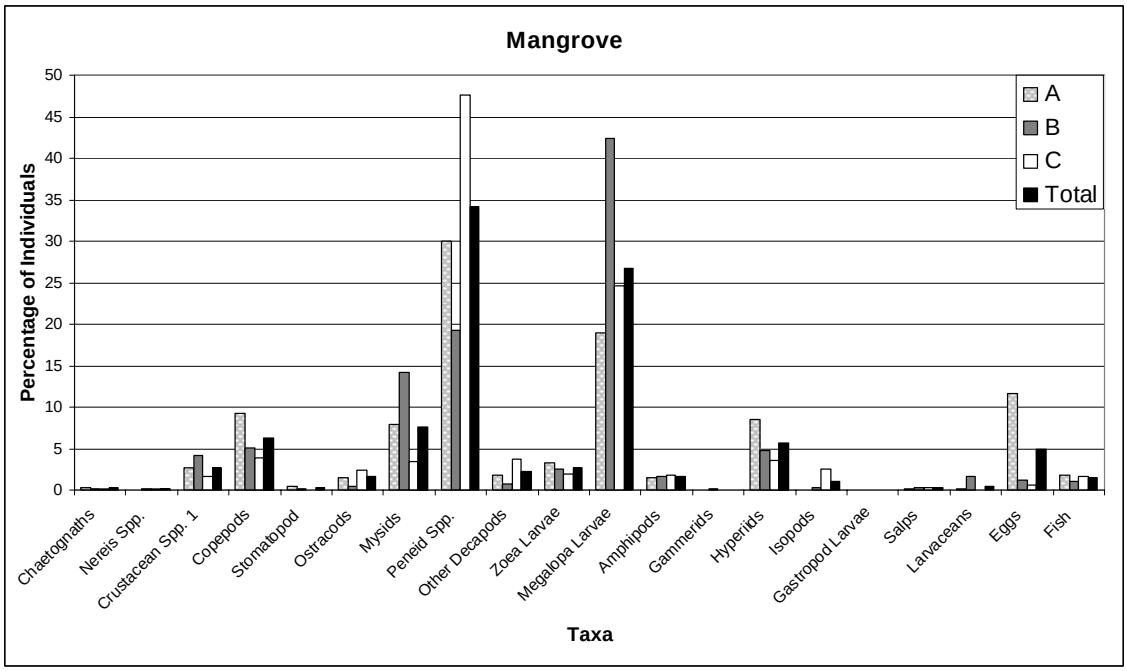


Figure 4 – Percentage of the main plankton groups in (a) reef and (b) mangrove samples. Individual samples A-C and the total for all three hauls are shown.

An ANOVA was conducted to assess whether there was a significant difference between catch composition of the reef and mangrove samples. No significant

difference was found (p=0.57). However, when individual plankton groups were analysed, several showed significant differences between both locations (Table 1). Numbers of zoea larvae, larvaceans, copepods and chaetognaths were significantly higher in reef samples while Crustacean Spp. 1 and Penaeus Spp. were significantly higher in mangrove samples.

Plankton Group	F-Value	F crit	P-value
All	0.33	3.92	0.57
Amphipods	0.56	7.71	0.50
Chaetognaths	199.89	7.71	0.00
Copepods	27.52	7.71	0.01
Crustacean Spp 1	14.43	7.71	0.02
Decapods	0.64	7.71	0.47
Eggs	0.54	7.71	0.50
Fish	5.95	7.71	0.07
Gammarids	0.20	7.71	0.68
Gastropod larvae	3.38	7.71	0.14
Hyperiids	0.78	7.71	0.43
Isopods	1.21	7.71	0.33
Larvaceans	10.26	7.71	0.03
Megalopa Larvae	0.03	7.71	0.87
Nereis Spp.	0.25	7.71	0.64
Ostracods	0.83	7.71	0.42
Penaeus Spp.	7.82	7.71	0.05
Stomatopods	2.25	7.71	0.21
Zoea Larvae	97.51	7.71	0.00

Table 1 - Results of ANOVAs for total catch and individual plankton groups. Those that showed a significant difference are highlighted.

3.2 Larval fish

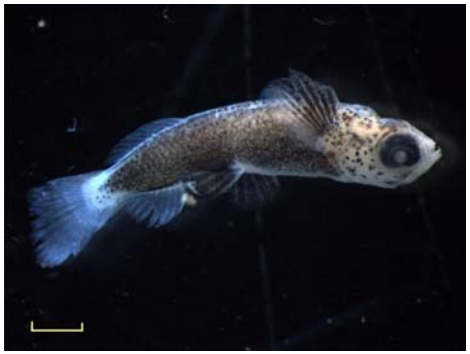
Overall nine different species of late stage larval fish were identified in the reef and mangrove samples, as well as many early stage larvae (Table 2).

Table 2 - Fish species 1-9 and an example of early stage larvae collected from the night-light samples.

Species 1

Scale Bar = 1mm

Species 2



Scale Bar = 0.5 mm

Species 3

Scale Bar = 1 mm

Species 4

Scale Bar = 1 mm

Species 5

Scale Bar = 1 mm

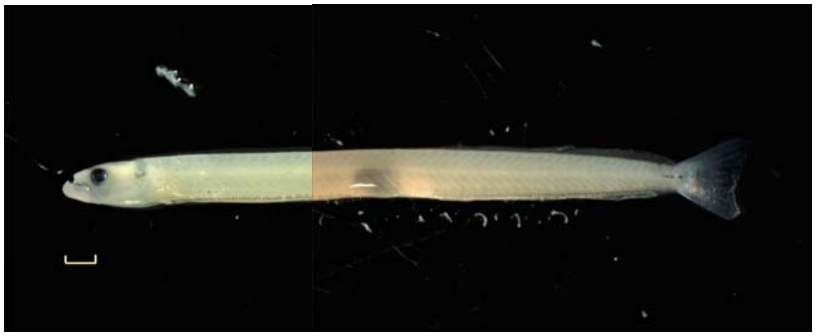
Species 6 (ventral and dorsal view)

Scale Bar = 0.5 mm

Species 7

Scale Bar = 1 mm

Species 8



Scale Bar = 1mm

Species 9

Scale Bar = 1 mm

Larvae

Scale Bar = 0.5 mm

There appeared to be a greater diversity of species in the mangrove while the reef night and day samples were reduced (Figure 5). However, no early stage larvae were found in the mangrove night samples. In total, Species 1, 2, 3, 4, 7 and 8 were found in one or more of the mangrove hauls while on the reef Species 1, 4, 5, 6, and 7 and 10 larvae were taken. In comparison, reef day and night tows contained 77 and 17 larvae respectively, and an individual of Species 9 in the night tow. The mangrove day tow contained 1 larval fish and 1 Species 1.

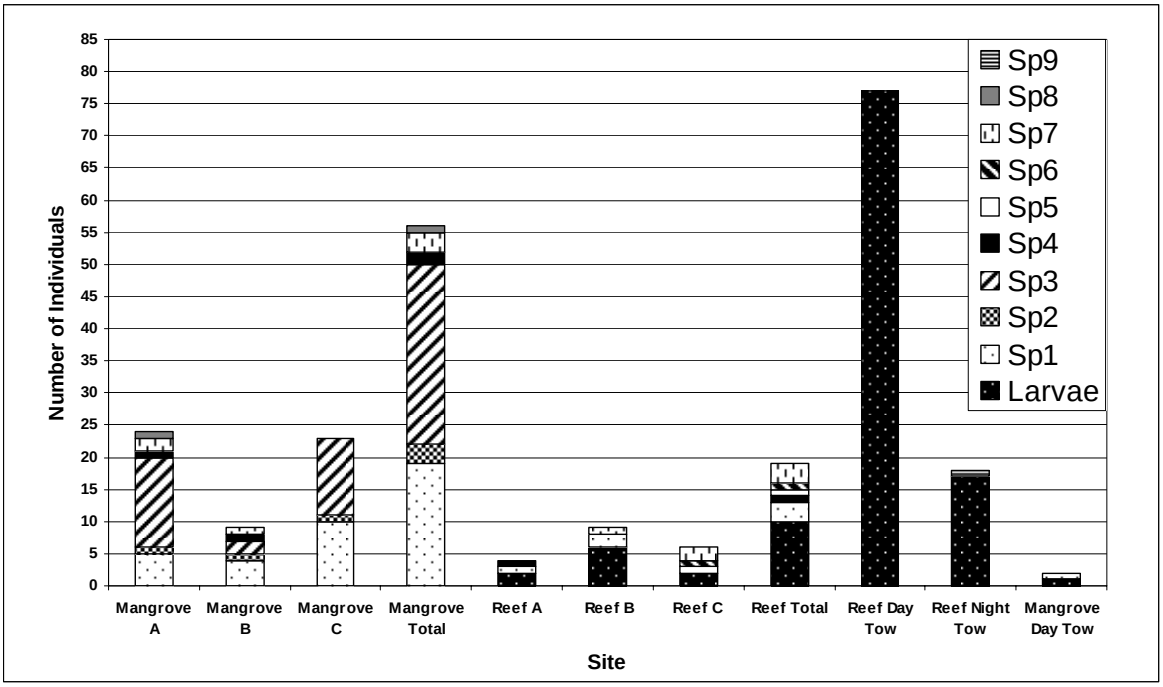


Figure 5– Number of individuals of fish species 1-9 and fish larvae in mangrove and reef nightlight samples and from reef day and night tows and a mangrove day tow.

Chapter 4 – Discussion

The variability of zooplankton composition between a mangrove and a reef were not unexpected given the differences in habitats: an exposed reef site in 5 metres of water and a sheltered fringe mangrove on an ebb tide. The composition of zooplankton caught in the reef areas was consistent with other studies on reef habitats (Emery, 1968; Heidelberg *et al*, 2004). The high abundance of copepods, decapod larvae and hyperiids and the occurrence of all the other groups in low numbers are typical of the reef zooplankton composition. Nocturnal near-reef plankton sampled in Jamaica were found to be twice as dense as during the day and contained an average of 89% copepods, few of which were of demersal origin, with a highly variable mixture of other plankton groups (Heidelberg *et al*, 2004). The reduced number of copepods in the mangrove samples may be due to the migration of copepods from their swarming daytime prop root habitat to night-time dispersal out of the prop root habitat (Ferrari *et al*, 2003). Zooplankton in Indian mangroves were found to consist mainly of copepods (up to 95%) but densities were much lower during monsoon season (Kathiresan, 2000). Sampling for the current study took place at the start of the rainy season in Panama; however it is not possible to tell whether this would have an effect on zooplankton distribution or composition, being an isolated survey.

While the abundance of zoeal larvae was significantly higher in reef samples the numbers of megalopa were high in the mangrove though not significant. Temporal variations in brachyuran larvae have been established in previous studies, with species timing hatching and export from the mangroves with specific tides and lunar cycles (Paula et al, 2004). Most were found to export during ebb tides with little return in the following floods. It is possible that if the larval stages were to be further separated into different taxa there may be significant differences in their abundances in either habitat.

Penaeid shrimp juveniles have been shown to exhibit a strong diel periodicity, where they are active at night and burrow during the day (Honculada-Primavera & Lebata, 1995). In the mangroves of Southeast India there were significantly more penaeid postlarvae caught at low tide than high and during night than day (Kathiresan, 2000). This may explain the high number of postlarval penaeids in the mangrove samples.

Interestingly, much of the work on penaeid species has examined their occurrence in estuarine mangroves but these results may indicate the value of fringe mangroves as a habitat. It has been suggested that there is a correlation between offshore catches of penaeid prawns and estuarine mangroves (Hatcher *et al*, 1989). Yet in Malaysia juvenile penaeids were also found in abundance in fringe mangroves where no significant freshwater input occurred (Sasekumar *et al*, 1992). The abundance of a variety of food sources and turbidity of the water appear to be the main contributing factors. Further night sampling in estuarine areas and other fringe mangrove locations would establish the value of fringe versus estuarine habitats for postlarval penaeids.

Planktivory is an important source of energy and nutrients for reef corals – up to 10% of their daily energy requirement may be gained through the consumption of zooplankton (D'Croz *et al*, 1999). Stomach analysis has revealed copepods and meroplanktonic larvae in a Caribbean coral. Decapod larvae also consume large quantities of copepods and other meroplanktonic larvae and in turn are readily consumed by fish of all life history stages and also by invertebrate predators. This highlights the significance of coastal zooplankton communities as part of the trophic web.

The number and diversity of larval fish caught with the nightlight lift net was surprising; given that much of the research has been focused on their use of estuarine mangroves, it was uncertain whether few if any would be found in the fringe mangrove. This may be another example of the factors effecting habitat choice for larval and juvenile fish, that is to say, the possibly those factors which both estuarine and fringe mangroves share - such as the complexity of prop roots rather than other physical factors such as salinity - are those that juvenile fish prefer. The fact that fewer juveniles, and a greater abundance of early-stage larvae were caught on the reef may be explained by Nagelkerken *et al* (2000) who found that the initial factor for habitat preference in juvenile fishes was a shallow depth (less than 3 metres). As the reef used in this study was approximately 5 metres, perhaps juveniles did not occur in such densities as a shallower reef. Several other studies have also demonstrated that shallow waters per se are important habitats for juvenile fishes (Sheaves, 2005). The large number of early stage larvae in reef day tows may represent the importance of fish size on habitat preference.

Robertson & Duke (1987) found in northern Australian mangroves that while commercial species did not directly use mangroves to complete their life cycle, some of their prey species did. The complexity of trophic relationships must not be underestimated. Instead it is perhaps best to err on the side of caution when quantifying the importance of mangroves, rather than taking a simplistic approach and basing value on the occurrence of commercially valuable species alone.

Much of the previous research done has compared mangroves with seagrass beds and stressed their importance as an intermediary habitat (Mumby et al, 2006; Jelbart *et al*, 2007). However, Las Perlas does not contain extensive seagrass beds like the Caribbean or Australia where much of the research has taken place. As such, it would be interesting to examine other potential habitats for connectivity between mangroves and reefs.

This study could not examine seasonal variation in fish larvae abundance but it would be an essential part of any further research. In the San Blas Archipelago on the Caribbean side of Panama, D'Croz *et al* (1999) collected numerous fish larvae in nearshore areas in the dry season, but during the rainy season fish larvae were spread more evenly across the shelf and into the nearshelf waters. In their study on the spatial and temporal variation in fish community structure in Tanzania Lugendo *et al* (2007) noted that many species disappeared from estuarine mangroves during the rainy season and those that persisted decreased in density.

The nightlight lift net may have limitations when compared to other methods such as fixed or drifting traps. However, for this study it is a simplistic yet reliable way of sampling in an isolated and structurally complex habitat. In future studies perhaps other methods could be employed in conjunction with net tows, such as small light traps which can catch a greater diversity of species than large traps (Meekan *et al*, 2001). These data could be compiled to provide a comparison of the spatial and temporal variation in zooplankton diversity and composition within the Las Perlas Archipelago.

Using a case study of a mangrove reserve in Malaysia, an attempt was made to gauge the economic benefit of preserving the forest in its current state (Bennett & Reynolds,

1993). Conversion of the mangroves at a level seen in other countries such as the Philippines would lead to large economic losses in addition to a loss of coastal protection, environmental damage and a decrease in tourism. While Las Perlas is not as developed as the study area described in Malaysia, it is the focus of possible development which would alter the natural state of some of the islands. What impact this would have on zooplankton community and diversity is uncertain but initiating research now may provide reliable information on the ecology of plankton communities which in turn can be used for management decisions in the future.

Chapter 5 - Conclusion

Caution must be used when attempting to draw any further conclusions from these data. As a stand alone, baseline survey it provided interesting results on the use of nightlight lift net from which further studies within the Las Perlas Archipelago could be directed. It was unfortunate that more of the mangrove day tow samples could not be analysed, but these could be integrated with future work. Understanding how zooplankton populations utilise coastal habitats and what conditions influence them is vital in determining management of the coastal zone. They are both sources of juveniles for recruitment to adult populations and a food source for upper trophic levels. Further research would not only provide essential information on the zooplankton composition of estuarine and fringe mangroves but also on the distribution and abundances of larval fishes. If done over a prolonged period encompassing seasonal variations in temperature, rainfall, salinity and other physical parameters, this may also yield information on not only resident species but also those which utilise mangroves for certain parts of their lifecycle. While it may be difficult to comprehensively determine the role of mangroves and other habitats as nurseries, it is perhaps wisest to err on the side of caution (Beck et al, 2001). Current evidence may not be absolute but it is better to act upon it with the limited resources available, rather than wait for irrefutable proof. The designation of Las Perlas as a site of special management is certainly a promising beginning for its protection. But with further dedicated research perhaps conclusive evidence may be established from which dedicated protective measures could be implemented.

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Appendix 1

Taxa	Reef Samples				Mangrove Samples			
	A	**B**	**C**	**Total**	**A**	**B**	**C**	**Total**
Chaetognatha	35	30	30	95	5	1	3	9
Polycheatae								
Nereis Spp.	1	2	1	4	0	1	2	3
Crustacea								
Crustacean Spp. 1	4	17	6	27	36	37	23	96
Copepod	348	235	319	902	128	45	54	227
Stomatopod adult	0	0	0	0	7	1	1	9
Stomatopod larvae	5	23	6	34	14	0	4	18
Ostracod	11	16	7	34	21	4	33	58
Mysid Spp. 1	12	14	10	36	23	3	13	39
Mysid Spp. 2	81	17	14	112	16	121	34	171
Mysid Spp. 3	2	0	0	2	2	1	0	3
Mysid Spp. 4	0	9	0	9	67	1	0	68
Decapod Spp. 1	9	13	18	40	5	0	8	13
Decapod Spp. 2	0	0	0	0	2	0	2	4
Decapod Spp. 3	0	0	0	0	7	0	2	9
Decapod Spp. 4	6	4	0	10	7	6	41	54
Peneid Spp. (postlarvae)	35	2	9	46	413	170	664	1248
Zoea larvae	364	295	269	928	35	22	24	81
Megalopa larvae	9	35	103	147	257	376	343	976
Amphipod Spp. 1	9	17	30	56	11	6	12	29
Amphipod Spp. 2	0	0	1	1	0	2	6	8
Gammeriid Spp. 1	0	0	0	0	0	1	0	1
Gammeriid Spp. 2	0	2	0	2	0	0	0	0
Hyperiids	66	63	382	511	127	48	55	230
Isopod Spp. 1	0	0	0	0	0	0	3	3
Isopod Spp. 2	0	1	0	1	0	3	32	35
Mollusca								
Gastropod larvae	9	4	1	14	1	0	0	1
Urochordata								
Salps	1	13	11	25	3	3	4	10
Larvaceans	58	37	98	193	2	14	0	16
Other								
Eggs	235	71	45	351	160	11	8	179

Table 3 - Number of individuals from plankton groups in samples from a reef and a mangrove area.