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### **The effect of habitat on the ecology and fisheries of *Scylla* spp.in Vietnam and the Philippines**

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The effect of habitat on the ecology and fisheries of  
*Scylla* spp. in Vietnam and the Philippines.

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A thesis submitted in fulfilment of requirements for the degree of  
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## Summary

Catches by mud crab collectors were used to assess the distribution and movement of *Scylla* spp in replanted mangroves in Buswang, Philippines. Comparison of catches in traps set in the mangroves and a stakenet set in a mangrove creek suggested *S. olivacea* to be the most resident and most numerically dominant of the three mud crab species found at the replanted mangroves. No juveniles less than 3.25cm external carapace width (ECW) were caught inside the mangrove even though the gear mesh size suggested this was possible indicating recruitment into the mangroves occurs at a larger size. Stakenet catches suggest mature females are more mobile than mature males, and more likely to leave the mangroves at ebb tide. Catches contained both gravid and berried females suggesting that females do not spawn and release far offshore.

Trapping grids were used to compare the densities in typical natural, replanted and degraded habitats. Reforestation was demonstrated to be effective in restoring ecological function, as suggested by mud crab densities. The use of the trapping grid as a method for estimating the relative abundance of mud crabs was assessed using depletion fishing, single mark-recapture and multiple-mark single-recapture experiments and burrow excavation to estimate absolute abundance. Density estimations from these methods broadly agreed with CPUE suggest that trapping grids are a good method of comparing mud crab density.

A socio-economic study showed mangrove replanting to be a highly successful method of raising local incomes, ensuring food security and improving livelihoods at this site. The mangrove contributed 578-2568 kg of mangrove-associated fisheries products  $\text{ha}^{-1} \text{yr}^{-1}$  worth US\$463-2215  $\text{ha}^{-1} \text{yr}^{-1}$  to coastal and mangrove fisheries. Additional income of US\$41  $\text{ha}^{-1}$  from tourism and US\$61  $\text{ha}^{-1}$  from timber sales was

also raised annually. The fisheries productivity was similar to that of brackish water aquaculture ponds suggesting that it may not pay to convert mangroves to ponds. Benefits of the protective function of mangroves against storm and cyclone seawater inundation and erosion were not included in the analysis but the survey of mangrove benefits suggested that most of the fishers recognised coastal protection (95%) and the nursery function (91%) as being important mangrove benefits. Almost all of the fishermen (98%) wanted to protect the mangrove from aquaculture pond conversion.

Habitat partitioning by different life stages of *Scylla paramamosain* in the Mekong delta in Vietnam was examined using 5 different fishing methods. A single cohort was followed from recruitment to maturity. Crabs as small as 3mm ICW settled along the mangrove fringe attaching to the pneumatophores between December and February. Larger juvenile crabs were still found on the mud surface until 3cm internal carapace width (ICW) when they either began to dig burrows or live subtidally migrating into the mangroves daily with the tide. Just prior to maturity most live subtidally, and although offshore mating and spawning is important it is hypothesised that habitat partitioning maybe a factor as only 14% of females caught offshore had developed ovaries. This study highlights the importance of the mangrove fringe in maintenance of *S. paramamosain* stocks and the habitat partitioning by the different life stages.

The close association of both *S. olivacea* and *S. paramamosain* with mangroves emphasises the importance of mangroves for many commercially important species and the need for their conservation. The socio-economic survey highlights the value of the services replanted mangroves provide to the local community, which can be at least as great as those from natural mangroves and seafood production can be more than equivalent to that of brackish water aquaculture ponds.

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**Chapter 1:**

**General introduction to the biology and fisheries of *Scylla* spp.**

The mud crab *Scylla* sp is widely distributed throughout the Indo-Pacific from Eastern Africa to Australia (Fratini & Vannini, 2002; Keenan *et al.*, 1998) where it is commonly associated with brackish water and mangrove forests (Overton & Macintosh, 1997). Its fine tasting meat (Anon, 1998) and its coastal habitat have made it a target for artisanal fisheries. Increasing demand and rising prices have lead to greater pressure being applied to this resource (Cholik & Hanafi, 1992). In 1988 Malaysia and Singapore were reported to import 10 tonnes of live mud crab a day; other important markets include Hong Kong, Taiwan, Japan and USA (Millamena *et al.*, 1998). In 1995 estimated yearly landings in Asia peaked at 35,000 tons but declined over the next 2 years to 13,000 (SEAFDEC, 2001). Fisheries statistics are notoriously hard to interpret, but the decline is worrying and it is possible that the combination of over-fishing and loss of habitat have had a serious impact on the yields. Recent price increases and rising consumer demand may have exacerbated the situation.

The culture of mud crabs is on the increase. In the Philippines, pond production has almost doubled in the last 4 years, reaching 5000 tons *per annum* in 2000 (Anon, 2000). Problems with disease in the shrimp industry and the robust nature of mud crab to disease, water quality and live transportation have contributed to its attractiveness as a species for culture (Johnston & Keenan, 1999).

Unfortunately, the lack of a reliable supply of cost-effective hatchery-raised juveniles has meant that most pond-cultured mud crab is wild-sourced. The impact of the collection of juveniles is unknown. However, the high fecundity of the females that can produce up to 8 million eggs (Williams & Field, 1999) and short larval

development lasting as little as 21 days (Williams *et al.*, 1999) makes *Scylla* spp. a promising aquaculture candidate, based on hatchery production.

A recent revision of the genus *Scylla* that identified four species which can be recognized by characteristic morphological features (Keenan *et al.*, 1998) has eliminated much of the previous taxonomic confusion. However, difficulties in identifying the species prior to this classification means there is much work to do on the biology and ecology of the 4 species to help formulate fisheries management strategies and identify the individual culture requirements to help alleviate fishing pressure on the wild populations.

## **Taxonomy**

The genus *Scylla* (de Haan, 1883) is part of the portunid family, recognised by the adaptation of the fifth pereopod which is flattened to resemble a paddle-like structure to enable swimming (Estampador, 1949). The recent separation of the genus into different species is important as each species is likely to have different tolerances to physiochemical conditions such as salinity and temperature both as adults and larvae. They may also have different breeding strategies and inhabit different environments. These factors become crucial in aquaculture development, introducing fisheries policies and implementing restocking programs.



Table 1: Taxonomic history of *Scylla* spp. modified from Keenan *et al.* (1998).

Year	Author	Described
1775	Forskål	<i>Cancer serrata</i> .
1793	Fabricus	<i>Portunus tranquebarica</i> .
1833	De Haan	Genus <i>Scylla</i> .
1834	Milne-Edwards	<i>Lupea tranquebarica</i> .
1886	Dana	Recognises <i>S. oceanica</i> as a variety of <i>S. tranquebarica</i> .
1886	Miers	Recognises only <i>S. serrata</i> .
1907	Stimpson	Reports <i>S. serrata</i> and <i>S. tranquebarica</i> are synonymous, agreeing that <i>S. oceanica</i> was indeed a variety of <i>S. tranquebarica</i> .
1949	Estampador	Recognised three sp. <i>S. serrata</i> , <i>S. oceanica</i> , <i>S. tranquebarica</i> and a new variety <i>S. serrata</i> var. <i>paramamosain</i> .
1952	Serene	Agreed with Estampador working with Vietnamese populations.
1959	Stevenson & Campbell	Found only one form in Australia and suggested that the differences found by Estampador and Serene were environmental.
1964	Ong	Noticed differences in larval stages between species
1965	Ong	Agrees with Stevenson and Campbell that there is only one species, however notes that it is possible to sub-divide <i>S. serrata</i> to the 4 forms of Estampador
1981	Kathirvel	Two species in Cochin, India <i>S. oceanica</i> and <i>S. serrata</i>
1982	Radhakrishnan & Samuel	Two species in Cochin, India <i>S. serrata</i> and <i>S. serrata serrata</i>
1983	Joel & Sanjeevaraj	Two species from Pulicat lake, India, <i>S. serrata</i> and <i>S. tranquebarica</i>
1991	Oshiro	Described 3 species in Japan recognised by Estampador, <i>S. oceanica</i> , <i>S. serrata</i> and <i>S. tranquebarica</i>
1996	Fuseya & Watanabe	Determined that <i>S. oceanica</i> , <i>S. serrata</i> and <i>S. tranquebarica</i> are genetically different.
1997	Overton <i>et al.</i>	Distinguished 3 morphometrically separate forms with overlapping ranges from Thailand, Vietnam and Sarawak
1998	Keenan <i>et al.</i>	Recognised 4 species using both morphological criteria and 2 genetic methods: <i>S. serrata</i> , <i>S. paramamosain</i> , <i>S. olivacea</i> and <i>S. tranquebarica</i>

Keenan *et al* (1998) suggested the taxonomic confusion started when a specimen described as *Cancer serrata* by Forskal (1755) from material collected in the Red Sea was not sent to the museum in Denmark. This lack of a reference specimen may have caused the taxonomic problems that followed. Eighteen years later Fabricus (1793) described *Portunus tranquebarica*, that Kathirvel and Srinivasagum (1992) suggested

was named after the origin of one of the specimens collected from Tranquebar (Tarangambadi), India. In 1833 de Haan placed this species in a new genus, *Scylla*, named after a Greek mythological sea monster that guarded a tunnel entrance, in keeping with the hole guarding behaviour of *Scylla serrata* reported by Kraus in Estampador (1949). Table 1 shows some of the important taxonomic changes of *Scylla* sp.

In the papers by Kathirvel and Srinivasagam (1992) and Fushimi and Watanabe (1999) descriptions of the species allow the species described to be reclassified according to Keenan *et al* (1998).

Currently the controversy continues with different nomenclatures still in use (Fushimi & Watanabe, 1999; Klinbunga *et al.*, 2000). Others have criticized the revision by Keenan *et al* (1998) suggesting it is confusing and that the descriptions of the neotypes do not correspond to those of Forskal (1775), Herbst (1776) and Estampador (1949) and therefore recommend the continued use of Estampador's 1949 revision (Ronquillo *et al.*, 1999). Subsequently a number of authors have suggested that at least two species were recognisable in India (Joel & Sanjeevaraj, 1983; Kathirvel, 1981; Radhakrishnan & Samuel, 1982) and in Japan various authors (Fuseya & Watanabe, 1995); (Fuseya & Watanabe, 1996; Oshiro, 1991; Watanabe & Fuseya, 1997) have adopted the nomenclature proposed by (Estampador, 1949), although there was confusion as to which phenotypic characters related to each species (Table 2). On examination of the morphometric and meristic characters of *Scylla* spp. populations from Vietnam, Thailand and Sarawak, Overton *et al* (1997) suggested there were three possible species.

Keenan *et al* (1998) employed two independent genetic techniques, allozyme electrophoresis and mitochondrial DNA sequencing to determine the genetic differences and relationships between different populations. They also identified certain typical morphological features that can be used to differentiate between the species (Table 3). They began with the *Scylla* population found in the Red Sea from which Forskal had originally obtained the specimen that he named *Cancer serratus*. Fortunately there is only one species of *Scylla* here and without doubt this was named, *Scylla serrata*.

Table 2: A comparison the nomenclature adopted by Keenan *et al* (1998) to that of other authors.

Keenan <i>et al</i> (1998)	<i>S. serrata</i>	<i>S. tranquebarica</i>	<i>S. olivacea</i>	<i>S. paramamosain</i>
<sup>a</sup> Forskal (1775)	<i>C. serratus</i>			
<sup>a</sup> Fabricus (1798)		<i>P. tranquebaricus</i>		
<sup>a</sup> Herbst (1798)			<i>C. olivaceous</i>	
<sup>a,b</sup> Estampador (1949)	<i>S. oceanica</i>	<i>S. tranquebarica</i>	<i>S. serrata</i>	<i>S. serrata</i> var. <i>paramamosain</i>
<sup>a</sup> Serene (1952)	<i>S. serrata</i> var. <i>paramamosain</i>	<i>S. tranquebarica</i>	<i>S. serrata</i>	<i>S. oceanica</i>
<sup>c</sup> Kathirvel (1981)	<i>S. oceanica</i>		<i>S. serrata</i>	
<sup>c</sup> Radhakrishnan & Samuel (1982)	<i>S. serrata</i>		<i>S. serrata serrata</i>	
<sup>c</sup> Joel & Sanjeevaraj (1983)	<i>S. tranquebarica</i>		<i>S. serrata</i>	
<sup>d</sup> Fuseya & Watanabe (1995 & 1996)	<i>S. oceanica</i>		<i>S. serrata</i>	<i>S. tranquebarica</i>
<sup>a</sup> Chen (1998)				<i>S. serrata</i>
<sup>d</sup> Fushumi & Watanabe (1999)	<i>S. oceanica</i>		<i>S. serrata</i>	<i>S. tranquebarica</i>

<sup>a</sup> (Keenan *et al*, 1998)

<sup>b</sup> (Estampador, 1949)

<sup>c</sup> (Kathirvel & Srinivasagam, 1992)

<sup>d</sup> (Fushimi & Watanabe, 1999)

With the exception of the authors named above (Tables 1 & 2), it is difficult to be certain which species authors were reporting prior to the revision by Keenan *et al* (1998). However, there are exceptions in geographical areas where only one species occurs. These include the populations of the Red Sea, South Africa and East Africa. Populations from Queensland are almost exclusively *S. serrata*, however *Scylla olivacea* occurs in some areas where the salinity is less than 35 psu during the dry season and extremely low during the rainy season (Keenan *et al.* 1998).

*Scylla* spp. are thought to have originated in the west Pacific less than 1 million years ago, during the early Pleistocene, and have since spread rapidly. (Gopurenko *et al.*, 1999) report that analysis of mitochondrial DNA suggests there is no genetic separation between populations in the Pacific and Indian oceans. However, the Northern Australian population appears to be different and might be the result of an earlier separation, prior to the radiation of *Scylla* throughout the Indian and Pacific Oceans. In a similar study on a *S. serrata* population from the East African coast, Fratini & Vannini (2002) suggested that *Scylla* was typical of other crustacean species with marine larvae and that the mtDNA variation indicated both a high reproductive potential and a large effective maternal population. Conversely, they also report the populations were not genetically homogenous, which may be the result of limited gene flow. This is surprising considering the strong dispersive ability of both the adult crabs and the larval planktonic stage. In addition, they cautiously proposed the populations of the Red Sea, Mauritius, and South Africa to be genetically separate. In apparent agreement with the timing of the rapid radiation proposed by Gopurenko *et al* (1999) and Fratini & Vannini (2002), the early Pleistocene Port Durnford



Formation in South African has yielded large quantities of decapod fossils including those of *S. serrata* (Cooper & Kensley, 1991).

## Biology

### Morphology

Important features of *Scylla* spp. include an oval carapace, 4 frontal lobes between the eye sockets, anterior-lateral border convex divided into 9 nearly equal teeth, massive smooth chelipeds that are longer than their legs with the merus topped by 3 spines and the carpus possessing 1 internal margin spine and 1-2 outer margin spines of varying prominence. The legs are stout, moderately compressed with 3 pairs being ambulatory and the 4<sup>th</sup> pair having a merus and carpus flattened for swimming. The carapace colour varies from dark brown or purple to light green and the walking legs can be with/with out polygonal patterning (Estampador, 1949; Keenan *et al.*, 1998). Keenan *et al* (1998) identified morphological traits that typified the 4 species differentiated by allozyme electrophoresis and mtDNA analysis (Table 3).

Table 3: Diagnostic features of the 4 *Scylla* spp. from Keenan *et al* (1998)

Species	Frontal spines	Outer carpus spines	Polygonal pattern	Colour
<i>S. serrata</i>	blunt & high	2 obvious & pointed	prominent on all legs and abdomen of adult females	Variable
<i>S. tranquebarica</i>	blunt & medium height	2 obvious & pointed	prominent only on back pair of legs	Variable
<i>S. paramamosain</i>	triangular, sharp & high	1 blunt, in juveniles spinous	Weak	Variable
<i>S. olivacea</i>	blunt & low	1 blunt or absent, may be spinous in juveniles	None	variable, claws and legs rusty red

## Distribution

The mud crab is found throughout the Pacific and Indian Oceans from South Africa to the Red Sea, from Okinawa, Japan to Tahiti and down to Queensland in Northern Australia (Gopurenko *et al.*, 1999; Keenan *et al.*, 1998). To date there have been no reports of their appearance in the Americas although Poss (2001) documented a specimen reportedly caught in the Gulf of Mexico. As mentioned above, *S. serrata* is the only species found in South Africa, in Queensland (apart from small pockets of *S. olivacea*) and in the Red Sea (Keenan *et al.*, 1998). Fratini & Vannini (2002) report that *S. serrata* is the only species in the Indian Ocean, in direct contrast to Kathirvel & Srinivasagam (1991) who reported 3 species present in Kerala, India.

*Scylla* is a predominantly estuarine and coastal genus (Macnae 1968) and its distribution closely follows that of mangroves with which they are associated (Delathiere, 1992) but not restricted to (Robertson, 1996). In India they have been reported inhabiting algal and seagrass beds adjacent to the mangroves of Picharvaram (Chandrasekaran & Natarajan, 1994). In Singapore they are found on reefs of coral rubble (Keenan *et al.*, 1998). In Java, highest densities were found in mangroves compared with brackish waters and estuaries (Wahyuni & Ismail, 1987). They live subtidally from 0 – 10m (Delathiere, 1992) or in burrows in the intertidal zone (Varley & Greenaway, 1992), although spawning female *S. serrata* have been caught up to 95kms from the shore and at depths of 60m in South Africa (Hill, 1994) and 50km off New Caledonia and at depths of 300m (Delathiere, 1992). Oshiro (1991) describes the habitats of the three species found in Japan; *S. olivacea* lives in the inner mangrove forests on a muddy substrate, *S. serrata* is more oceanic and lives on sandy muddy substrates while another undetermined *Scylla* species inhabits an intermediate

area. Their distribution is presumably associated with salinity and temperature tolerances in combination with availability of suitable habitat and food resources.

Burrowing behaviour appears to vary between species and between individuals of the same species of all sizes. *S. serrata* from South Africa construct burrows from which juveniles and some adults make limited movements always returning to the burrow in the intertidal zone (Hill, 1978). Subtidal burrows were found to be extremely rare and a study tracking adults suggested that although some were free-ranging and occupied different positions in the studied estuary each day (Hill, 1978), most crabs remained in the same general area (Hill, 1975). More recently burrow occupancy by *S. serrata* in East Africa was estimated to be 10.7% in the mangrove fringe and 5% in the inner mangrove forest (Barnes *et al.*, 2002). In West Bengal, burrow occupancy in the upper littoral zone was found to be much greater at 89% (Nandi & DevRoy, 1990) although this is probably a different species.

Using a combination of shelters (roof tiles), traps and nets at different tidal heights Hill *et al.* (1982b) determined that adult *S. serrata* are mostly sub-tidal, while sub-adults (100-149mm carapace width (CW)) move up and down with the tide to feed in the intertidal zone. Juveniles (<80mm CW) were reported to be permanent residents in the mangrove zone in agreement with Oshiro (1991) who suggested that juveniles are easily found under fallen leaves in the mangrove zone.

A mark-recapture study in Vietnam working with *S. paramamosain* suggested this species was also highly mobile, with the juveniles inhabiting the intertidal zone and the adults living offshore (Ut, 2002). In the Philippines, *S. olivacea* was reported by

fishermen to be a 'hole dweller' in contrast to the more mobile species with the polygonal markings (*S. serrata* and *S. tranquebarica*) (Estampador, 1949).

### **Salinity, temperature and emersion**

There are some detailed studies on the effects of salinity and temperature on *Scylla* although in many cases the species examined is questionable due to the unresolved taxonomy of *Scylla* prior to Keenan *et al* (1998).

Chen & Chia (1997) used crabs from a farm in Taiwan, while Davenport & Wong (1987) used crabs from a market in Penang, Malaysia. No anatomical description is given by either author however both report the species as *S. serrata*. Chen & Chia (1997) report *Scylla* spp. to be an osmoregulator at salinities below 34.4 psu becoming an osmoconformer above that level at 22°C. Davenport & Wong (1997) found the change from osmoconformer to osmoregulator to be slightly lower at 32 psu at 28-30°C. In freshwater 100% survival was recorded after 6 hours, this decreased to 10% after 24hrs. If salinity was increased to 1psu mortality was only 40% after 48 hours and did not increase 168 hours after immersion (Davenport & Wong, 1987). In choice experiments crabs showed no particular preference between water of 0psu and 32psu (Davenport & Wong, 1987). An earlier study demonstrated that *Scylla* is typical of many decapod crustaceans in osmoregulating at low salinities through the catabolism of amino acids and production of ammonia to reduce their osmotic potential, shifting to the more energy expensive ureotelism at high salinities to increase osmolarity (Chen & Chia, 1996).



Hill (1974) found when first stage zoea from South African *S. serrata* broodstock were immersed in varying salinities and temperatures, larvae were still active with >90% survival after 24hrs only at temperatures of 14-20°C and at salinities >17.5psu. He concluded that the zoea were unsuited for estuarine conditions but adapted to waters a few kilometres off the south-eastern coast of South Africa where both temperature and salinity were optimal. However, the adults in the St. Lucia system survived 4 months at 2psu and could tolerate salinities of up to 60psu (Hill, 1979b) and other researchers report optimal growth at 27°C (Heasman & Fielder, 1983).

The tolerance of adults to low salinities enables *Scylla* spp. to live in highly productive estuarine environments and survive the large tidal salinity changes that occur. The high salinity tolerance would enable adults to cope with the conditions in intertidal pools and in hyper-saline lagoons (Hill, 1979b). The powerful osmoregulatory ability of *Scylla* spp. and its apparent indifference to low salinities suggest that its distribution is not controlled by salinity, at least as an adult. However, Keenan *et al* (1998) reported *S. serrata* to be the least tolerant of the 4 species, preferring areas of higher salinity.

Hill (1980) found that low temperatures (12 & 16°C) significantly decreased activity and feeding rates compared with water temperatures above 20°C. Hamunante *et al* (1979) also exposed *Scylla* spp. from Kerala, India to 40°C for 3 hours with 100% survival and concluded that glands in the eye stalk were producing a chemical responsible for its thermo-tolerance. Larval tolerances may explain the northern limits of the distribution of *Scylla* spp. if all species are similar. *S. serrata* larvae in South

Africa were inactive below 10°C and hatching is suggested to take place only in water warmer than 12°C (Hill, 1974).

Hill & Koopowitz (1975) reported *S. serrata* was able to survive in air for 7 days at 20°C at 95% humidity, this ability to survive emersion is due to a reduction in oxygen consumption to a tenth of the pre-emersion value (Veeranan, 1972). The reduced consumption is not aided by anaerobic metabolism (Varley & Greenway, 1992), but achieved by quiescence and lowering of the heart rate (Hill & Koopowitz, 1975). *Scylla* spp. from Malaysia were found to die after 30mins immersion in water with an oxygen tension of less than 4.2mm Hg or 5599.53 Pa (Davenport & Wong, 1987) which is surprising given that hypoxia may well be encountered in the burrows at low tide and on the ebbing and flooding tide on the tidal mudflats. However, Davenport & Wong (1987) suggest that they overcome this problem by partial immersion and by bubbling a mixture of air and water through the branchial chambers.

## Diet

Arriola (1940) describes a *Scylla* spp. which from the reported reddish claws was probably *S. olivacea*, as a scavenger and cannibal. Hill (1976) working with *S. serrata* from South Africa and Australia reported this species to feed on slow moving benthic invertebrates (mostly molluscs) with fish and prawns were rarely eaten unless incapacitated in some manner. Prey availability probably determined gut contents and plant material may be a part of the juvenile diet (Hill, 1976). Small grapsid crabs formed approximately 20% of the diet of both populations. In a later study, (Hill, 1979a) measured both the ratio of occurrence of molluscs and grapsid crabs (15.4:1) and their frequency in the guts and concluded that although grapsid crabs were much

rarer they were found in 22% of all guts. This suggests they are selectively preyed upon. Hill (1979a) indicated that prey selection may be passive. *Scylla* spp. remains immobile for long periods and the mobility of small crabs would bring them into contact while sessile molluscs are unavailable. Indeed these grapsid crabs show no avoidance of *Scylla* spp. However field observations in India suggest that *Scylla* spp. are proportionally mobile for longer than the time they remain buried (Prasad *et al*, 1985).

Tank experiments showed *Scylla* spp. to remain buried during the day, emerging at night to feed (Hill, 1976; Prasad *et al*, 1985) and Oshiro (1991) suggests that megalopa are also more nocturnal. Contact chemoreception was found to be the main method of locating prey, olfactory reception being less important. This corroborated evidence suggesting most of their movements were slow (10-19 metres per hour) which allowed plenty of time for exploring the substratum (Hill, 1978).

The stomach contents of a range of sizes of *Scylla* spp. from Sri Lanka showed small crustaceans to be the most important food for smaller *Scylla* spp. (4-7cm CW). The frequency of both molluscs and fish and small crabs (eg grapsids and *Scylla* spp. juveniles) in the diet increased with size (Jayamanne & Jinadasa, 1991) in agreement with Arriola (1940), who also noted their cannibalistic nature. Sand was found in all small and in most larger crabs (~75%), while in accordance with Hill (1976) algae was only found in smaller crabs (<4cm CW). In contrast, the occurrence of plant material was >90% in both mature (>120mm CW) and immature (<70mm CW) *Scylla* spp. from Lawele Bay, Indonesia, although the frequency of occurrence of both gastropods and other molluscs increased with size (La Sara, 2001). In India, detritus was thought

to be an important constituent of the diet of smaller mud crabs (48-52.6mm CW) and fish was more common in the guts of larger crabs (57.2-66.4 and >85.5mm CW). (Prasad *et al.*, 1985)

Delathiere (1992) describes *Scylla* spp. from New Caledonia to be an opportunistic feeder. Stomach content analysis revealed bivalve molluscs, small crabs, young fish, marine plants and algae as prey items, in agreement with Hill (1976). *Scylla* spp. was reported only to eat freshly dead but never decaying animals (Delathiere, 1992) although detritus was commonly encountered in their guts (Arriola, 1940; Hill, 1976). To date there have been no reports of resource partitioning in sympatric *Scylla* spp. however stable isotope ratios may be a suitable approach as this method has been used successfully with peneid shrimp to trace the source of carbon and nitrogen in the diet (Chong *et al.*, 2001; Primavera, 1996).

Feeding activity was found to decline prior to moulting, when water temperatures were below 20°C (Delathiere, 1992) and prior to spawning (Arriola, 1940) but not when females were carrying an egg mass (Hill, 1975). Delathiere (1992) stated that the females do not eat when berried. In contrast Heasman (1980) reported only a reduction in appetite and Hill (1975) caught several berried females in traps indicating they do feed and certainly in captivity they been observed feeding (pers. obs.).

## Reproduction

Mating is typically between a hard-shelled male and a soft-shelled female as in other portunid crabs (Hartnoll, 1969). Males are probably attracted by a pheromone excreted by the female up to 5 days before the pubertal moult and up to 3 days after,



Mating has been observed to take place when males are placed in tanks with females that have moulted within 3 days while the shell was still hardening (Ong, 1966). Males are frequently found grasping a female prior to the pubertal moult (Arriola, 1940). According to Ong (1966) the embrace starts 3-4 days before the moult, the female is then released and re-embraced following the pubertal moult. This behaviour is beneficial to both; the female gains protection and the male ensures paternity (Hartnoll, 1969). Mating was found to take place both in burrows (Nandi & Dev Roy, 1990) and in the open as trapping often catches 'couplers' (Robertson & Kruger, 1994). Insemination rates are high. In Australia, >90% of all mature females were found to possess spermatophores in the spermathecum (Hill, 1982).

During mating the female is inverted in a horizontal position under the male, and gonopods deposit the spermatophores in the spermathecum or seminal receptacle as in other portunids (Escritor, 1972). Ovarian maturation is stimulated by the deposition of the spermatophores which causes a change in the spermathecum from a translucent white sac to a much thickened and bulging form. Presence of a Stage II ovary could be considered as the first sign of mating. (Ezhilarasi & Subramoniam, 1980). It may be the pressure on the spermathecum by the seminal fluid that causes the glands to rupture, releasing substances into the lumen. These substances or products of the seminal fluid may promote the release of gonad stimulating hormone and control the gonad inhibiting hormone (Ezhilarasi & Subramoniam, 1980). However, in direct contrast mature females that had been separated from males whilst still immature were still found to spawn though the eggs were infertile (Robertson & Kruger, 1994).

The pubertal moult is often thought of as the terminal moult (Arriola, 1940, Hartnoll, 1982) and the wide variety of sizes found in mature crabs may vary according to the number of pre-pubertal instars which in turn is thought to be dependant on the food availability (Hartnoll, 1982). However, there are many brachyurans that continue to moult after sexual maturity. This has adaptive significance as the variation in size increases the range of resources available (Hartnoll, 1982). Robertson & Kruger (1994) trapped mature intermoult females in copulatory embrace and witnessed the moulting of 16 out 56 mature captive females, one of which was reported to have moulted twice. In addition they reported that Heasman (1980) had also observed the moulting of a mature female and commented on the occurrence of limb buds in 4% of mature females suggesting they were about to moult. Hard shelled mating has not been observed in *Scylla* spp. However it is seen in another portunid, *Thalamita sima* (Norman, 1996).

Mating can also take place prior to the pubertal moult. Three of five females of intermediate abdominal shape (between mature “U” shape fringed with setae and the immature “V” shape) were found to have sperm in the seminal receptacle, one produced eggs, but none hatched (Robertson & Kruger, 1994).

Size at maturity has been studied in a number of populations, however, the methods used have varied. These include abdominal width, presence of spermatophores and presence of eggs (in females) and the presence of spermatozoa in the vas deferens, coupling males and mating scars (in males) (see tables 5 & 6 in Robertson & Kruger, 1994).

Studies in Australia and South Africa suggest that females characterized as mature on the basis of a mature abdomen are generally smaller than berried females with mated females being of intermediate size (Heasman *et al*, 1994), although this is not typical of other studies. Minimum size at maturity also varies. Generally the size at maturity increases with latitude, with the exception of populations like Ponape where the minimum size is 150mm CW (Perrine, 1978). Studies in Asia (where the sample size >10) suggest that females start maturing between 85 – 99mm CW (Ong, 1966; Varikul *et al*, 1972; Ezhilarasi & Subramoniam, 1980; Prasad & Neelakantan, 1989) although Lavina & Fe (1980) reported females with a mature abdomen as small as 62mm CW. Females in Australia began to mature at approximately 140mm CW (Heasman, 1980 in Robertson & Kruger, 1994), while in S. Africa it varied between 104-141mm CW (Du Plessis, 1971; Robertson & Kruger, 1994). The increase in size at maturity with latitude suggested by Robertson & Kruger (1994) is maybe exaggerated by the species distribution as *S. olivacea* appears to mature at the smallest size and *S. paramamosain* at an intermediate size. In Ban Don Bay, Thailand 50% of female *S. olivacea* matured at 91mm CW while female *S. paramamosain* matured at 101mm CW (Overton & Macintosh, 2002)

There are less data available for male maturity as morphological changes eg. chela allometry (Prasad & Neelakantan, 1990) are more difficult to discern. However, the same trends with latitude are observed. Generally, maturity in males when based on presence of sperm in the vas deferens resulted in a smaller minimum size than those crabs observed mating while those with mating scars were of intermediate size (Robertson & Kruger, 1994). Males started to mature in the Philippines at 68mm CW (Lavina & Fe, 1980) and at 127mm CW in Ponape (Perrine, 1978). This increase in

size with latitude may be the result of *S. serrata* being the dominant species in Australia and South Africa, whereas the other smaller species are more prevalent closer to the Equator (Keenan *et al*, 1998). Functional maturity is often used to describe the ability to mate successfully (Conan & Comeau, 1986) and it might be that not all males with spermatozoa are functionally mature as competition for females may prevent the smaller males from mating.

Sperm in the spermatophores remains viable for more than 5 months as berried crabs maintained in the laboratory were able to undergo successive spawnings without mating (Ong, 1966). For an extensive description of spermatogenesis and oogenesis see Estampador (1949). Ovarian development may be accompanied by a change in colour from translucent through yellow to orange. Duplessis (unpublished data in Heasman *et al*, 1985) found there was a relationship between ovarian colour, nutritional status and larval viability. Further trials on *S. serrata* in the Philippines also reported a correlation between egg colour and the rate of larval development and larval survival (Ronquillo *et al.*, 1999). However, Heasman *et al* (1985) could find no evidence to support this. Although, ovarian colour is linked to the stage of embryonic development (Roberston & Kruger, 1994) and nutritional status certainly affects viability (Millamena & Qunitio, 2000).

Ovarian maturation may also be controlled by circa-lunar rhythms and be influenced differently by light at different times of the lunar/tidal phases. Nagabhushanam & Farooqui (1980) observed that illumination during high tide was successful in promoting ovarian development. Certainly Perrine (1979) found that spawning migrations followed a lunar cycle in the Caroline Islands, however he also reported



they were stimulated by decreases in salinity in agreement with Heasman *et al* (1985), who associated spawning with freshwater inputs. Low feeding levels and low temperatures did not result in loss of ovarian condition for crabs from Moreton Bay, Australia (Heasman *et al*, 1985). They reported that Duplessis (unpubl.) observed well-developed ovaries year round in mature females maintained in the laboratory, but they only spawned in the late spring and early autumn.

Eggs are extruded between 1-5 weeks after mating unless conditions are unfavourable, in which case they may be released up to 7 months later (Delathiere, 1992). During extrusion, sperm from the seminal receptacle mixes with the eggs but gamete activation and fertilization only takes place in seawater (Ronquillo *et al.*, 1999). When spawning the body is vertical with the abdomen open. As the eggs are released they are covered by a sticky secretion, currents from the inhalant chamber move the eggs into a basket-like structure formed by the endopodites and abdominal flap where they become attached to the endopodite setae of the pleopods to form a 'sponge' (Estampador, 1949). The number of eggs released is dependant on size, Prasad & Neelakantan (1989) reported a direct relationship between fecundity and weight for crabs between 180-340g (90-140mm CW) resulting in egg numbers increasing from 0.5-1.3 million eggs. Between 520g & 1360g (145-185mm CW) the number of eggs only increased from 1.5-2.0 million. However up to 7.5 million eggs have been produced in a single spawning (Delathiere, 1992) and egg number may also be dependant on conditions and the number of previous spawnings (Ong, 1966).

The incubation periods varies from 12d at 28°C & 31psu (*Scylla* spp.) (Ong, 1964) to 30d at 20°C & 30psu (*S. serrata*) (Heasman & Fielder, 1983) during which time the

migration begins (Delathiere, 1992). For *S. paramamosain* embryos developed between 15-35°C, but 20-30°C was considered optimal, while below 15°C development was incomplete (Zeng *et al.*, 1991). Initially the egg mass is yellow and compact but the colour changes to greyish yellow and finally becoming dark grey due to the development of the eyes and chromatophores with the eggs being less tightly bound (Ong, 1964). In brachyurans the stereo-typical behaviour of abdominal pumping causes the eggs to break open and synchronizes hatching. Pheromones are thought to control the pumping and are released by the eggs in increasing amounts as the embryos develop (Tankersley *et al.*, 2002). Over a period of half an hour the majority of the eggs hatch directly to the first zoeal stage (Ong, 1964); Hill, 1974) although initially a few pre-zoea may be released (Ong, 1964).

Arriola (1940) was the first to report that sponge-bearing *Scylla* and larvae were predominantly found in river mouths and along the coast between June and September. Since then other workers have recorded the seasonal occurrence of berried crabs from around the Indo-Pacific region (Table 4). However with the exception of the studies in Australia & South Africa on *S. serrata* and that of Le Vay *et al* (2001) on *S. paramamosain*, the species in question is uncertain. Quinn & Kojis (1987) and Heasman *et al* (1985) both reviewed the published material on spawning timing suggesting that although it was seasonal throughout its distribution, the peaks were more prominent with increasing latitude as the seasons became more defined and contrastingly more protracted with decreasing latitude. Heasman *et al* (1985) concluded that the small reproductive peaks in the Tropics were due to periods of high productivity in tropical estuaries, due to seasonal monsoons or cyclones during the summer months or by post-monsoonal up welling (Pillai & Nair, 1968).

Unfortunately few studies have recorded temperature. However both Brick (1974) and Heasman *et al* (1985) report that females spawn in temperatures of 24-28°C which coincides well with the optimal temperature (27°C) required for successful incubation and larval development (Heasman & Fielder, 1983).

Table 4: The seasonal reproductive activity of *Scylla* spp. (adapted from Robertson and Kruger, 1994).

Country	Occurrence of Berried ♀	Peak Berried ♀	Temp. °C	Latitude	References
Ponape	All year	No peaks		7°N	Perrine (1978)
Papua New Guinea	All year	Apr – June & Sep – Oct		7°N	Quinn & Kojis (1987)
Thailand	Unknown	July – Dec		12°N	Varikul <i>et al</i> (1972)
Thailand	All year	Aug – Oct		-	Mackintosh <i>et al</i> (2002a)
India	All year	Dec – Feb		13°N	Pillai & Nair (1968), Devi (1985)
Philippines	All year	June – Sept		15°N	(Arriola, 1940)
Vietnam	Ovigerous	Aug - Sept		9°N	Le Vay <i>et al</i> (2001)
Hawaii	Unknown	May – Oct	24-28 (25.8)	20°N	(Brick, 1974)
Australia		Oct – Nov		14°S	Hill (1994)
New Caledonia	Unknown	Nov – March		25°S	Delathiere (1992)
Australia	Sep – March	Nov – Dec	24-28	28°S	Heasman <i>et al</i> (1985)
South Africa	GSI high all year	GSI peaks Oct		29°S	Robertson & Kruger (1994)
South Africa	Nov – March	Unknown		34°S	Hill (1975)

GSI – Gonadosomatic index

Spawning is normally accompanied by migration from the estuaries to the open sea where the salinity, temperature and predation rates may be more favourable for larvae (Hill, 1974, 1994) and may lead to increased larval dispersal (Hill, 1994). Migration distances vary and this may be due the species present, or as Heasman *et al* (1985) suggested due to the local hydrography or local topography. Nearshore captures of berried *Scylla* have been reported from the Philippines (Arriola, 1940), Malaysia (Ong, 1966), Hawaii (Brick, 1974), Ponape (Perrine, 1978) South Africa (Hill, 1975) and Australia (Hill, 1994) but captures have also been reported more than 50km from

the coast at depths of up to 300m (Delathiere, 1992). It is generally accepted that *S. serrata* requires high salinity for spawning, however, the requirements of the other 3 species are not so well defined.

## Larvae

There are five zoeal stages with each stage lasting between 2-5 days, 14-20 days in total (Ong, 1964; Heasman & Fielder, 1983; Ronquillo *et al.*, 1999). However the number of larval stages may be plastic depending on diet and other environmental variables with Zeng *et al.* (1991) observing up to six zoeal stages. For *S. serrata*, the rate of zoeal development was not significantly different between 20-40psu salinity at 27°C, however, 15psu resulted in total mortality of zoea 1 after 5 days and best survival was recorded at 33-34psu (Ronquillo *et al.*, 1999). All zoeal stages are photopositive (Ong, 1964) which Dittel & Epifanio (1982) suggest may aid in seaward dispersal. Laboratory experiments revealed that feeding is passive during the early stages becoming more active later (Ronquillo *et al.*, 1999).

The megalopa stage appears approximately 19 days after hatching at 20-40psu and 27°C (Ronquillo *et al.*, 1999) and lasts 10-12 days at 31psu and only 7-8 days at 24psu (Ong, 1964) and 27psu (Heasman & Fielder, 1983) before metamorphosis to the first crab stage (instar 1). This reduction in intermoult period may suggest a preference for lower salinity water. Megalopa pleopods are used for swimming and Ong (1964) recorded them occasionally attached to the surface tension, but mostly resting on the tank bottom. The surface tension attachment may be a method of effecting movement into the estuaries. Certainly megalopae use ascent into the water column during flood tide to aid up-estuary transport (Tankersley *et al.*, 1995). However survival was very low (<15% from megalopa to crab 1) suggesting that the



behaviour observed by Ong (1964) may not be typical of more healthy larvae. Although healthy megalopa have also been described as mostly benthic with an affinity for attachment to objects in the water column (Ronquillo *et al.*, 1999).

Recruitment of mud crab has not been well documented and quantitative studies are few. Plankton tows by Hill (1982) in Queensland caught large numbers of megalopa but very few *Scylla* spp. In the Philippines plankton tows in the river mouths and in the coastal area catch zoea and megalopa between June to September, but not in the rivers and milkfish ponds where salinity is lower (Arriola, 1940). Plankton tows in the St. Lucia estuary in South Africa showed greater abundance of *Scylla* sp. megalopa during the summer (January to April) suggesting recruitment is seasonal (Forbes & Hay, 1988). Megalopa collectors in the Ranong mangroves in Thailand suggested that portunid settlement was greatest at flood tides during a waxing moon (Moser & Macintosh, 2001), however they did not distinguish *Scylla* spp. from other species or describe the depth of the collectors. In Taiwan megalopa are collected from the wild by trapping against tidal currents or by seining in the evening (Chen, 1990).

*Scylla* spp. megalopae use their pereopods for walking and have chelae that are used for feeding and catching prey (Ong, 1964). Canibalism becomes a problem at this stage in culture (Motoh *et al.*, 1977; Ong, 1964) but may not be as important in the wild as densities are presumably lower.

## Juveniles

Metamorphosis to crab 1 results in juveniles of 3.4mm CW or <5mm (Ong, 1966 and Delathiere, 1992, respectively). Studies in Japan revealed that juveniles of <5mm CW preferred a substratum with a particle size of 0.063mm while larger individuals

preferred 0.063-0.125mm particle size and reported that burrowing was quicker in a mud with a larger particle size (Minagawa *et al.*, 2002), suggesting that estuarine tidal flats are suitable habitats for juvenile mud crabs. In the Philippines, young crabs (16-48mm CW) appeared in estuaries at the end of September (Arriola, 1940). Their migration rate was reported to be affected by tidal amplitude, but no evidence was provided. In S.E. India, although recruitment appears to occur year-round, juvenile crabs are most abundant in February, 4 months after the heavy rains when the salinity had returned to >20psu (Chandrasekaran & Natarajan, 1994). Quinn & Kojis (1987) also report recruitment to be continuous in Papua New Guinea due to the non-seasonal nature of reproduction.

Hill *et al* (1982) reported that juveniles (20-99mm CW) live predominantly in the intertidal zone, taking refuge in between roots and pneumatophores of mangroves, under stones and in seagrass beds as well as in small creeks. Dittel *et al* (1995) found that juvenile blue crabs used shallow water habitats as a refuge from predation in tanks based experiments and tethered juveniles experienced much greater mortality in deeper water. However, the reason for the distribution of juvenile mud crabs is unclear and maybe related to both refuge and prey availability.

## Growth

As in all crustaceans with a hard exoskeleton, growth takes place through a series of moults where the old exoskeleton is shed. The time between moults is known as the intermoult period while the moult increment is the increase in size between one intermoult period and the next. As a result when growth curves are constructed a typical stepped plot is seen (Hartnoll, 1982). It is not known whether moulting is

synchronous in the wild, but in the Philippines the moulting of stocked *Scylla* spp. coincides with the occurrence of neap tides (Lijauco *et al.*, 1980).

The behaviour of the crab changes 2-3 days before moulting. It stops feeding and hides (Delathiere, 1992). Moulting crabs are frequently found in burrows (Nandi & Dev Roy, 1990). Prior to moulting white air spaces become visible under the carapace (E.T. Quinitio, pers. comm.) and the membranes between the legs and the body swell. A crack appears around the carapace starting by the gill chambers spreading to the dorsal suture between the abdomen and posterior carapace, through which the crab emerges backwards leaving behind the outside walls of the gills, the gut lining and eye lenses (Fielder & Heasman, 1978). Liberated, the crab increases in size taking up water to expand the new soft shell. Due to its vulnerability at this stage, high mortality may occur (Fielder & Heasman, 1978).

Both intermoult period and moult increment are controlled by environmental variables; temperature, salinity and nutritional status and by the age/size and loss of limbs of the animal (Hartnoll, 1982). Hill (1975) reported the growth of *S. serrata* in South Africa was faster during the initial 18 months of life, slowing thereafter and was reduced during the winter. The intermoult period tends to become longer and the percentage moult increment smaller as the crab ages and growth is much reduced once maturity is achieved (Arriola, 1940, Ong, 1966). However for *S. olivacea* in Ranong, Thailand percentage increment was reported to be independent of both size and sex with only intermoult period increasing with size (Moser *et al.*, 2002).

Juvenile growth rates for *Scylla* spp. stocked in ponds are similar with the exception of Bangladesh where the salinities were extremely low (Table 5). Growth rates from wild populations in India were both based on cohort analysis which considering the continual breeding of *Scylla* populations in the tropics discussed earlier, may account for the apparent low growth rate. Growth rates from a mark recapture study in on a wild population in Vietnam were not found to be significantly different to those cultured in ponds (Ut, 2002).

Table 5: Growth rates of juvenile *Scylla* spp. from pond culture and wild populations.

Species	Country	Location	Temp. °C	Salinity	Size Range	Growth CW (mm /month)	Reference
<i>Scylla</i> spp.	Philippines	Ponds	25-34	13-32	35-73	18	(Baliao <i>et al.</i> , 1981)
<i>Scylla</i> spp.	Philippines	Alone	-	-	31-74	23	Arriola (1940)
<i>S. serrata</i> & <i>S. tranquebarica</i>	Philippines	Ponds	25-27	25-29	27-130	33	Trino <i>et al</i> (1999)
<i>S. serrata</i>	Philippines	Pens		27-31	53-116	15	Trino & Rodrigues (2002)
<i>Scylla</i> spp.	Bangladesh	Ponds	29-33	2-18	23-53	13	(Saha <i>et al.</i> , 1997)
<i>S. olivacea</i>	India	Wild	-	-	73-118	7.5	(Thomas <i>et al.</i> , 1987)
<i>Scylla</i> spp.	India	Wild			32-73 33-63	10 (♀) 7 (♂)	(Devi, 1985)
<i>S. paramamosain</i>	Vietnam	Wild Pond				22 26	Ut (2002)
<i>Scylla</i> spp.	Malaysia	Alone		21-25	29-71	9	Ong (1966)
<i>S. olivacea</i>	Thailand	Wild			50-90	10	Moser <i>et al.</i> (2002)

The crabs reared in isolation by Ong (1966) grew slowly (Table 5). It is unclear whether this is a reliable estimate of growth as the water was only changed once a week therefore conditions may not have been ideal. However he observed that the number of instars was not fixed and while some females achieved maturity and the copulatory moult at instar 15, others did not mature until the 18<sup>th</sup> instar (91-119mm CW).



In Queensland, Australia, sub-adult growth was found to be seasonal, occurring during the spring and summer (Hill *et al.*, 1982a) probably as a result of the elevated water temperatures. Hill *et al.* (1982a) also reported that crabs achieved 8-10cm CW in the first year and 13-16cm during the second. Fielder & Heasman (1978) suggested only 15 moults were required to reach maturity at 150mm CW.

The absence of persistent hard parts due to moulting and the lack of otoliths and scales that are customarily used in ageing fish prevent an accurate assessment of age in wild caught crabs. Size is also considered unreliable as the growth rate is dependant on a number of factors discussed earlier and especially once maturity is reached due to the possible cessation of growth.

### **Limb regeneration**

Crabs have the ability to shed both claws and legs (autotomy) when either held by a predator or when damaged. A membrane rapidly covers the wound and a limb bud forms encasing a developing limb. At the following moult the limb emerges, although succeeding moults may be required before the limb is fully formed. If a crusher claw is lost, the cutter claw becomes the crusher at the following moult while the regenerating claw develops to become the cutter (Fielder & Heasman, 1978). Depending on the intermoult stage and the amount of appendages lost, limb loss may either shorten or lengthen intermoult period but moult increment is generally reduced due to the diversion of resources for regeneration (Hartnoll, 1982).

## Mortality

Large mud crabs have few natural enemies, owing to their aggressive nature. La Sara (2001) observed monitor lizards and wild boar feeding on *S. serrata*, while water-mongoose and crocodiles are reported to feed on mud crab in South Africa (Hill, 1979b). Fielder and Heasman (1978) suggested large fish, sharks and turtles may also eat mud crab, but it's most frequent predator was man.

Juvenile crabs probably suffer mortalities from herons (Mukherjee, 1972 in Hill, 1982), many species of mangrove fish and other crabs (Fielder & Heasman, 1978). Cannibalism is known to be a problem in pond culture (Trino *et al.*, 1999), and in the wild, juvenile mud crabs were found to be a dietary component of larger mud crabs (Prasad & Neelakantan, 1990). In laboratory studies, Ito (1997) showed that depending on relative size, the grapsid crab *Hemigrapsus penicillatus* was either a predator or a prey item. Moulting crabs are extremely vulnerable to predation being relatively immobile and unable to defend themselves. Increased stress and problems from incomplete shedding of the integument may result in increased mortality rates during this period. This phenomenon has also been reported in *Portunus pelagicus* (Ingles, 1996 in La Sara, 2001).

Little is known about the planktonic stage, but it is probable that heavy larval mortalities are suffered through predation by planktivorous predators (Fielder & Heasman, 1978) and through the lack of suitable habitat for settlement upon metamorphosis to megalopa.

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## Disease and parasitism

Heavy infestations of the gill by the parasitic barnacle *Octolasmis cor*, and by protozoans *Epistylis* sp. and *Acineta* sp. may interfere with respiratory activity. Hudson & Lester (1994) reported that these gill infestations have increased mortality of other crab species when in situations of increased stress. The occurrence and density of parasitic infestation vary with locality. *Octolasmis* sp. settlement increased with size in a population from Thailand (Jeffries *et al.*, 1992) in agreement with (Hashmi & Zaidi, 1965) who found that 90% of crabs >7.5cm CW collected from around Karachi, Pakistan were infected by *Lepas* sp. Profuse settlement on the gills caused death in the laboratory due to respiratory problems and dead crabs collected from the shore also showed heavy infestation suggesting this is a problem in some areas. However Quinn & Kojis (1987) observed no correlation between infestation rate of *Octolasmis* sp. and reduction of biological functions such as gonad weight or GSI.

The parasitic barnacle *Loxothylacus* sp forms a reproductive body in the same place as the egg mass, which prevents reproduction and feminizes the males (Knuckey *et al.*, 1995). However the incidence of such parasitism appears to be extremely low. In Queensland out of 389 females examined, none were found to be infected (Hill, 1994 61), while in the Northern territories the infection rate was 2.1%. The rate could be higher as internae are difficult to detect and parasitized crabs are generally smaller than their uninfected counterparts and therefore may be selected against in traps with a 130mm mesh size (Knuckey *et al.*, 1995).

Little is known about the incidence or importance of disease in wild populations. (Ji & Huang, 1998) discovered “yellow body” disease to be caused by *Moraxella nonliguefaciens*. “Orange crab” is another acute disease of *Scylla* which can cause high mortality rates in cultured crabs and causes the haemolymph to turn milky. This is thought to be caused by either *Vibrio alginolyticus* or *V. parahaemolyticus* and can be treated with the addition of antibiotics to the food (Chung & Mee, 1986). (Andersen *et al.*, 2000) discovered some non-contagious rust spot lesions on the carapace but could find no internal damage. *Haematodinium* sp. the causative agent of bitter crab disease in *Chionoecetes bairdi* has also been discovered in mud crab stocks in Australia, however, the incidence rate is low (1.5%) (Hudson & Lester, 1994). The lack of disease suggests this is probably not an important factor in natural mortality rates, although catch rates of diseased crab may be lower and hence infection rates may be under-represented.

## **Fisheries**

### **Methods**

The variety of fishing methods used throughout the range of *Scylla* remains remarkably similar. Methods reported include baited traps or pots constructed of different materials (Arriola, 1940; Fielder & Heasman, 1978; Cholik & Hanafi, 1992; Chandrasekaran & Natarajan, 1994; La Sara, 2001), baited lift nets of different sizes (Arriola, 1940; Chhapgar, 1962; Fielder & Heasman, 1978; Cholik & Hanafi, 1992), hooks that are using in extracting crabs from burrows (Arriola, 1940; Chhapgar, 1962; Fielder & Heasman, 1978; Quinn & Kojis, 1989; Cholik & Hanafi, 1992; Barnes *et al.*,



2002), gill nets (Arriola, 1940; Devi, 1985; La Sara, 2001) , long lines with bait tied periodically either directly on or to additional lines tied to the main rope (Chhapgar, 1962; Devi, 1985; La Sara, 2001), scoop nets and torches at night (Fielder & Heasman, 1978; Barnes *et al*, 2002) scoop nets at low tide (Quinn & Kojis, 1989; Cholik & Hanafi, 1992), scissor nets (Arriola, 1940), seine nets (Devi, 1985), baited lines attached to cane (Chhapgar, 1962; Cholik & Hanafi, 1992) and sometimes mud crabs are caught by prawn trawlers as by-catch (Hill, 1994)

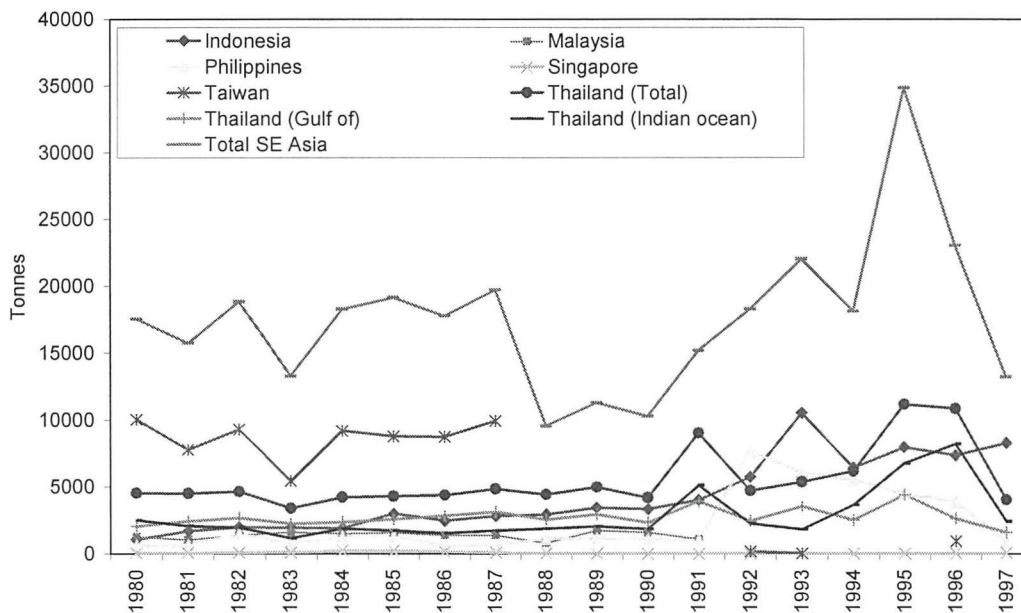
### **Mud Crab Fishery Landings**

The fisheries statistics for mud crab indicate that the main populations are centred in SE Asia around Indonesia, Philippines, Thailand and at one time Taiwan (Figure 1). *Scylla* spp. lives in muddy estuaries, mud flats, seagrass beds and mangroves; therefore it is not surprising to find that the areas where they are most exploited are countries with a large land mass and high enough rainfall to support this kind of environment. Taiwan appears to be the only exception and it may be that the fishery figures include landings from surrounding countries.

It is difficult to draw conclusions from fisheries data as there is no measure of effort and variations in catches may be due to an increase in fishing effort driven by price increases/decreases or the economic situation in the country. However the general trend suggests that the crab stocks may have been over exploited in the mid 1990's. Certainly in recent years catches have fallen although this may also be partly due to habitat loss.



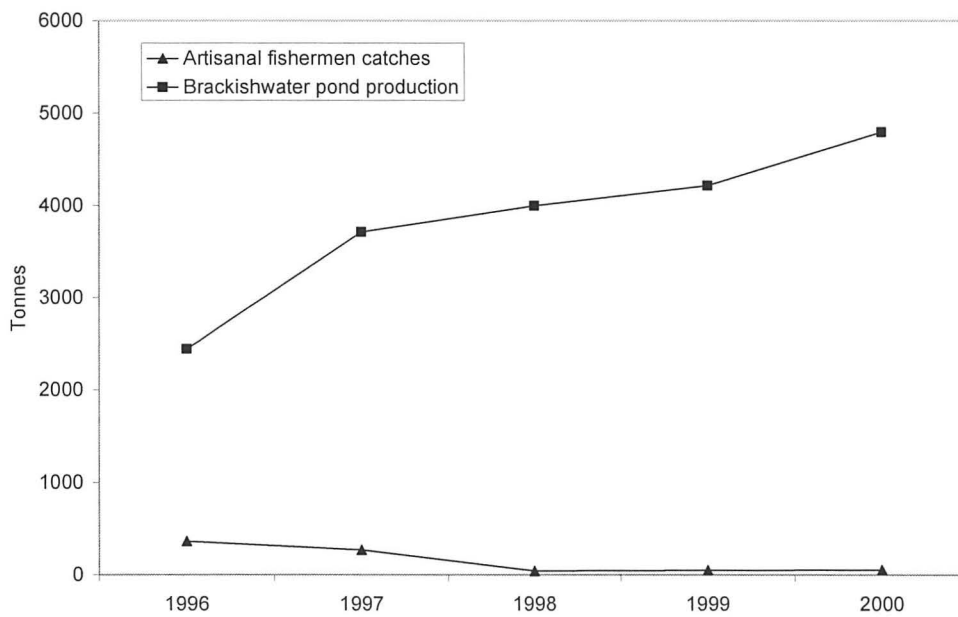
Figure 1: Mud crab landings from S.E. Asian countries (SEAFDEC, 2001).



The Philippines is an example of a country where mangroves have been lost at an alarming rate. In the early 1900's there was 450,000ha of mangroves in the Philippines (Brown & Fisher, 1918). By 1995 this had declined to 120,000ha (Primavera, 2000). Mangroves are used for a variety purposes from firewood and construction to the extraction of tannins for the leather industry, but coastal lands are often valuable and in the past mangroves have been cleared for agriculture, salt ponds, houses, access to the sea and for industry. Of the 297,000 ha lost between 1951 and 1988 nearly half has been excavated for the construction of aquaculture ponds. Indeed 95% of brackish-water ponds constructed between 1952 and 1987 were in areas derived from mangroves (Anon, 1991). Although aquaculture may not have been entirely responsible for clearing the mangroves, the transference of coastal land from public to private ownership has prevented the possible return to its original state.

The importance of aquaculture in the Philippines is demonstrated by the annual production figures for mud crabs, with production from brackish water ponds becoming increasingly dominant compared to landings from artisanal fisheries (Figure 2) (Anon, 2000).

Figure 2: Mud crab production in the Philippines.



However this may not be a true comparison as pond production is much easier to quantify. Many of the mud crabs caught in the Philippines, especially the small crabs are eaten by the fishermen themselves or exchanged for other goods and may never enter the market.

Estimation of mortality rates is difficult as the lack of permanent calcified parts makes aging difficult, as mentioned earlier. However, Hill (1975) used catch per unit effort data (CPUE) from a population in the Kleinmond estuary in South Africa where a sand bar closed the estuary mouth hindering population exchange and there was no fishing activity. He estimated natural mortality to be 41% in the first year and 60% in the second. Recently figures from Thailand have show that the percentage of immature mud crabs (<9mm CW) has increased from 37% in 1989 to 87% in 1998 (Tienkongrum & Pratoomchat, 1999). The authors report the instantaneous rate of the fishing mortality was 8.1 while the instantaneous rate of natural mortality was 3.4 which suggest the stock is being seriously over-fished.

Even in Queensland, Australia where there are a substantial number of fisheries officers and extensive regulations governing the size, sex, number of pots and rights to sell mud crabs, legally sized males are being over-fished and there exists a substantial illicit trade in females and undersized crabs (Heasman & Fielder, 1977).

### **Methods of Assessment**

The lack of reliable data and length frequency information has driven researchers to conduct their own field studies. However, most of the gears used for catching crabs involve a passive form of capture where the gear remains stationary and it is the behaviour of the animal that enables them to be caught eg. baited traps, lift nets, long line and gill nets. Due to the fact that it is the behaviour of the animal that determines whether or not it is caught, these gears are highly selective. Factors that may influence the behaviour of a crab include; day/night, tides, temperature, sex, moulting, food

availability and salinity. The gear may itself also be size-selective due to the trap mouth size or mesh size.

Active forms of fishing may also be selective depending on the area fished for example burrow searching using hooks may result in the capture of juvenile and sub-adults, whereas adults are normally caught sub-tidally (Hill, 1982).

Gear saturation and soak time can also affect the catch rate. Gear saturation describes the asymptotic number of animals caught per trap and is determined by the antagonistic behaviour and chemical signals that reduce entry rate with increasing numbers caught in the trap (Miller, 1990). However in certain crustacean fisheries (eg. blue crab and spiny lobster) there is gregarious behaviour and the greater the number of trapped animals the greater the catch rate which is only limited by the size of the trap (Miller, 1990). The catch rate normally decreases with increasing soak time as both the local abundance of the target organism and the bait attractiveness decreases (Fogarty & Addison, 1997). Soak time may also increase selectivity; female spanner crabs (*Ranina ranina*) were found to respond to food much faster than males and big males were more aggressive than smaller crabs, suggesting shorter soak times may favour smaller females, while longer soak times favours bigger males (Skinner & Hill, 1987). Some caution is needed in the design and interpretation of CPUE studies that employ traps as crab behaviour, trap selectivity, soak times and size can all influence the resulting catch.

Traps are commonly used in catching crabs as they are both cost-effective and efficient (Miller, 1990). Hill (1975) used baited traps for CPUE estimates in a mark-

recapture study. Numbered Floy FD67 tags were inserted at the carapace/abdominal junction where they were less likely to be lost during moulting. No effort was made to assess tag loss or the effect of tagging on behaviour or mortality rates although tagged crabs were found to have re-entered traps 30 minutes after tagging. The mark recapture study estimated a density 81 trappable crabs per hectare in the Kleinemonde Estuary, South Africa, giving a standing stock of  $4.5\text{g m}^{-2}$  and, assuming an average age of 16 months, an annual production of  $3.4\text{g } S. serrata \text{ m}^{-2}$ . Tagging also enabled an estimation of growth rates and showed that crabs were often caught close to the release site. Analysis of the modal peaks in the size-frequency can also be used for an assessment of growth and mortality rates. However, this is only possible in populations where there is a defined spawning or larval recruitment period and may not be possible for tropical mud crab populations where the spawning is continuous throughout the year (Quinn & Kojis, 1987).

The reliability of mark-recapture models were investigated by Robertson & Piper (1991) who suggested most mark-recapture models violated the assumption of equal probability of capture as this depends on the feeding response of the animal. They criticised the Burnham & Overton model used by Williams & Hill (1982) which allows for heterogeneity of capture but underestimates population size if the recapture percentage is low and proposed an alternative more reliable model by Chao (1978). The estimated densities of mud crabs between 80 and 140cm CW were 44 crabs/ha in the Mhlunga estuary and 53 crabs/ha in the Msimbazi estuary in South Africa.

More recently coded microwire tags were injected in to the coxal muscle of the 3<sup>rd</sup> leg to identify crabs in batches separated by size, sex and date of release to assess a



population of juvenile *S. paramamosain* in the Mekong delta, Vietnam (Ut, 2002). The crabs were collected non-selectively by hand at night over an area of 15000 ha of tidal mud flat and mangrove. Densities were calculated at approximately 100 crabs/ha, growth rates, recruitment and mortality were also estimated.

Adult mud crabs in the Kowie estuary, South Africa were caught using traps and released with ultrasonic transmitters clamped to the dorsal surface in order to track movements. Hill (1978) found that crabs were mostly active at night and movement was slow (10-19m/hr) travelling an average 461m night<sup>-1</sup>. Movement between different habitats by *S. serrata* was also studied in Moreton Bay, Australia using Floy tags. Most individuals were found to move less than 10km regardless of the time at liberty and the size of crab, with the exception of some females that migrated out of the bay (Hyland *et al.*, 1984). Crabs in mangroves were observed to be less mobile than those on mud flats.

Two separate studies by Williams & Hill (1982) and Robertson (1989) have evaluated the factors effecting pot catches. The equation:

$$\text{Number of crabs caught per 10 traps} = -23.189 + 3.688T - 1.199M$$

explained 66% of the variation in catches, where T = temperature and M = proportion of the population moulting (Williams & Hill, 1982). Larger crabs were more susceptible to trapping (Williams & Hill, 1982). These authors used Floy tags for a mark-recapture study to provide monthly population estimates (up to 12 crabs per hectare) which were highly correlated with CPUE and to try and estimate the size of the population vulnerable to trapping and the degree of bias of the capture method. The distance between traps was also found to influence catch; traps 50m apart fished

competitively while those 100 and 200m distant did not (Williams & Hill, 1982). CPUE may be derived from non-competitively fishing traps, while only pots fishing competitively should be used for estimating population size (Morrissy, 1975).

Robertson (1989) found that catches reached an asymptote in traps suggesting the catch rate slowed with increasing soak time. In the Alusaf canal and in Mlalazi Estuary, South Africa catches in cleared pots were 4.5 times and 2.2 times higher than in uncleared pots indicating the aggressive behaviour of the trapped crabs was preventing further entrants. Clearing the traps regularly or reducing soak times in high density areas was suggested as a method for reducing trap saturation. Robertson (1989) also found catches during the day and night to be similar and enclosed or exposed baits were equally attractive to the crabs.

In Pumicestone Passage in northern Australia, Hill *et al* (1982) suggested that the smaller crabs (2-7cm CW) do not move from the upper inter-tidal zone, sub-adults (8-13cm CW) live sub-tidally but feed in the intertidal zone during high tide and adults live and feed sub-littorally.

Mud crab abundance has also been investigated using occupancy rates and burrow density. In the Hooghly and Matla estuaries in India, burrows of mud crabs were identified by their size, shape and/or mound formation, 120 were excavated of which 108 contained a total of 111 crabs (Nandi & Dev Roy, 1990). The authors estimated densities of between 4800 – 6000 crabs/ha of 40-120cm CW of which the majority were 50 – 90cm CW. Using the same method, Barnes *et al* (2002) found occupancy rates to be much lower at Utende, Tanzania, with only 10.7% occupancy of burrows

in the mangrove fringe and 5.0% in the inner mangrove forest, producing density estimates of 1228 crabs/ha and 324 crabs/ha respectively. However, estimates of population density using burrow occupancy does not include those crabs that use the intertidal zone during high tides.

Using active fishing gears (cast nets and drag nets) the density of mud crabs has also been assessed in Pichivarum mangrove, S.E. India by dividing the number of crabs caught by the area fished by the gear (Chandrasekaran & Natarajan, 1994). Density estimates ranged from 0 crabs/ha when salinity was almost 0psu to 4000 crabs/ha during the dry season 4 months later, once the salinity had reached 20 psu. Averaged values were 800crabs/ha (8-80mm CW) of which 48% were 20-30cm CW. Juvenile crabs were more frequently encountered in seagrass communities than amongst mangrove pneumatophores.

### **Stock protection**

In most countries where mud crabs occur there appears to be little in terms of fishery regulation. In Queensland, laws governing the mud crab fishery include; the protection of all crabs below 150mm CW, protection of mangrove areas, prevention of destructive fishing practices, limits on the number of people allowed to sell crabs (Heasman & Fielder, 1977) and the protection of all female crabs (Hay & Calogeras, 2000). In the Northern Territories, Australia, management controls are similar with additional restrictions on recreational fishing (Hay & Calogeras, 2000). In South Africa, there is a minimum size limit of 114-115cm CW for both sexes (Robertson & Kruger, 1994). They argue that with the larger crabs being taken there may be a reduction in growth rate and a decrease in the size at which maturity is reached, if the

larger crabs are the fastest growers. However, they also cited (Pollock, 1993) who suggested that if growth and survival are density-dependent, as in spiny lobster populations, then a reduction in density should result in an increase in both growth rates and size at maturity. Liong (1993) points out that if standard conservation measures were enforced in Asia, such as the introduction of a minimum size limit, the culture industry would collapse as wild juveniles remain the only source of seed and banning the sale of gravid females would also destroy the livelihood of many farmers.

In the Philippines there are no controls at present and even in protected mangroves crab fishing is completely unregulated. The loss of mangroves with which mud crabs are intimately associated may be the greatest threat to future stocks. More than 70% of Philippine mangroves have been cleared since the turn of the century due to over exploitation for wood and charcoal and their clearance for conversion to agriculture, aquaculture and for settlements (Primavera, 2001). This will have greatly reduced the area of habitat available for *Scylla* spp. There has been some progress in mangrove protection and some of the pristine mangrove areas have now been declared reserves (Primavera, 2001). However, in the Philippines, enforcement is a major problem. In 1981, all mangrove forests in Palawan were declared a forest reserve by Presidential Proclamation 2152, but in reality it has not made much difference and exploitation continues (Ashton, 2001). In 1987, 50m mangrove buffer zones fronting the sea and 20m along river banks were set up by the DENR (Department of Environment and Natural Resources). Owners of areas already exploited had to replant these buffer zones, however this order has had little effect due to poor enforcement (Ashton, 2001). Other laws that should ensure mangrove protection in the Philippines are shown in Table 6. However, there have been a number of mangrove reforestation



programs put in to action (Table 7). One of the most successful has been the Buswang Mangrove reforestation project in Kalibo, Aklan province.

Table 6: Philippine laws on mangrove conservation and rehabilitation (Primavera, 2002).

P.D. 705 (1975)	Revised Forestry Code: Mangrove strips in islands providing protection from high winds, typhoons shall not be alienated
P.D. 953 (1976)	Fishpond/mangrove lease holders required to retain or replant 20-m mangrove strip along rivers, creeks
P.P. 2146 (1982)	Prohibition on mangrove cutting
BFD Cir. 13 (1986)	Processing of applications prohibited for mangrove lands which are part of forest lands
MNR A.O. 42 (1986)	Expansion of mangrove belt in storm surge, typhoon areas: 100 m along shorelines, 50 m along riverbanks
P.D. 1067	3 to 20 m of riverbanks, seashore for public use: recreation, navigation, floatage, fishing and salvage; building of structures not allowed
Exec. Order 192 (1987)	Mangroves and swamplands in public forests placed under DENR
DENR A.O. 76 (1987)	Establishment of buffer zone: 50 m fronting seas, oceans and 20 m along riverbanks; lessees of FLA ponds required to plant 20-50 m-mangrove strip
R.A. 8550 (1998)	(Revised) Fisheries Code: FLA holders to reforest riverbanks, Bays, seashore areas fronting ponds; abandoned, undeveloped or underutilized ponds under lease to be reverted to mangrove, if feasible
DENR A.O. 15 (1990)	Policies on communal forests, plantations, tenure through Mangrove Stewardship Contracts; revert abandoned ponds to forest; ban cutting of trees in FLA areas; prohibit further conversion of thickly vegetated areas
DENR Memo Cir. 7 (1991)	Prohibits mangrove cutting in FLA area if $\geq 10\%$ canopy cover and/or capable of natural regeneration
DENR A.O. 3 (1991)	Policies and guidelines for Mangrove Stewardship Agreement
DA-DENR Gen. M.O. 3 (1991)	Mangrove areas released to BFAR but not utilized or abandoned 5 years from release to be reverted to forest land category
R.A. 7160 (1991)	Local Government Code: devolved management/implementation of community forestry projects, communal forests <500 ha, enforcement of community-based laws
DENR A.O. 6 (1992)	Reversion to forest land category portions of mangroves in Bohol declared Alienable or Disposable for ponds
DENR A.O. 13 (1992)	Same as MNR A.O. 42 (see above)
DENR A.O. 23 (1993)	Combined 3-yr Mangrove Reforestation Contract and 25-yr Forest Land Management Agreement into new 25-yr FLMA for families (1-10 ha) and communities (10-1,000 ha)
DENR A.O. 30 (1994)	Community-Based Mangrove Forest Management; NGO assistance

A.O. – Administrative Order, BFAR – Bureau of Fisheries and Aquatic Resources, BFD – Bureau of Forest Development, DENR – Department of Environment and Natural Resources, MNR – Ministry of Natural Resources, P.D. – Presidential Decree, R.A. – Republic Act



Table 7: Mangrove reforestation projects in the Philippines (Primavera, 2001).

	Location	Area (ha)	Year	Remarks
1.	Daco Is., Bais, Negros Oriental	—	1930s-40s	Backyard planting
2.	Bais Bay, Negros Oriental	—	1940s-50s	“Hacienda” (along edges) planting
3.	Pagangan Is., Calape, Bohol	2 km long × 8 m wide	1956-66 1974-83	Organized by school teachers, students
4.	Banacon Is., Jetafe, Bohol	400	1957-58 1964-70	Community participation
5.	Marungas, Sulu	150	1981	First large-scale government project
6.	Basilan, Sulu	50	1985	Bureau of Forestry Development project
7.	CVRP: 5 sites in Bohol, Cebu, Negros Oriental	650	1984	Central Visayas Regional Project: World Bank US\$3.5 million (nearshore fisheries); awarded Stewardship Contracts
8.	Community-based: Negros Oriental, Cebu, Bohol	14 365 562	(as of 1986)	57 planters, 2 towns 384 planters, 5 towns 870 planters, 10 towns
9.	Kalibo, Aklan	50	1989	P560,000 govt. project; NGO – contracted
10.	Aborlan, Palawan	>70	1990	200,000 seedlings planted, ADB-funded Japanese NGO, natl/local govt. support
11.	Bais City, Negros Oriental	55	1991	DENR community/family planting
12.	CEP FSP	6,857 (as of Dec. 1995)	1994	DENR Coastal Environment Program; Family, community contracts under DENR Fisheries Sector Program; ADB funding
13.	CBMFP	no data	1996	DENR Community-Based Mangrove Forest Program, awards Mangrove Stewardship Agreement

In Vietnam, mud crab fishing is also completely unregulated and there are fisheries for small crab (10 -100g) to provide seed for stocking ponds (Le Vay *et al.*, 2001; Overton & Macintosh, 1997) and more recently for juvenile crab 0.5 – 2cm CW (Truong, pers. comm.). In the Mekong Delta in Southern Vietnam, there has also been severe loss of mangroves caused by war and use in charcoal production combined with clearing for agriculture and aquaculture. Mangroves once formed a fringing belt of between 100m to 30km wide along 850km of coastline, covering 200,000 ha (Moquillon, 1950) in (Bentham, 1998). By 1995 only 30,000 ha remained (Minh *et al.*, 1998). Among the most important government decrees and regional action plans to halt and reverse this decline is the Mekong Delta Master Plan and the resulting World Bank and DANIDA funded Coastal Wetlands Protection and Development Project (CWPD-project) and the closely related Rehabilitation of the Mangrove Forests Project (RMFP) mostly funded by the Netherlands government (Bentham, 1998). Initially the coastal strip was divided in to two zones; 1) The seaward Full Protection zone, 100 – 1000m wide that is reserved for reforestation, where no settlement, farming or tree felling are permitted and on the foreshore only gleaning of small marine products are allowed excluding fish and the larvae of shrimp. 2) The landward Buffer Zone, ~1 km wide, 60% is to be forested the remainder can be farmed or settled. The land is allocated by the government in plots of 5-10 ha on acceptance of contracts stating the responsibilities and legal rights of both sides. Families with lots in the Full Protection zone will be able to collect “small marine products” and dead wood and will receive compensation from the government.

The Zoning Plan was approved by the Vietnamese government in 1998, and large areas have already been replanted with even larger areas still to be reforested. This in

conjunction with conservation education and training, development of suitable aquasilviculture systems and its dissemination will hopefully safeguard the future of the mangroves in the Mekong Delta (Bentham, 1998).

## Aims

To identify the seasonal changes in relative abundance of one species (*S. olivacea*) in a replanted mangrove, the movement of the crabs between habitats and to use easily measured characteristics to identify the size at maturity for males and females.

To assess the relationship between habitat degradation and rehabilitation and mud crab abundance using catch per unit effort (CPUE). This was investigated in a range of intact natural, degraded and replanted mangrove areas. The current study then concentrated on the replanted site to assess how CPUE (both that of commercial fishers and from experimental trapping) related to actual densities.

To assess the economic and social impact of a replanted mangrove using a combination of a questionnaire-based survey of local fishers and information provided by local NGOs.

To quantify recruitment and habitat utilisation by monitoring life stage-specific fisheries to follow single cohort of *S. paramamosain* from recruitment to maturity, and to determine size at maturity in both male and female *S. paramamosain* in an estuarine population in the Mekong Delta, Vietnam.



## Chapter 2:

### Seasonal abundance, distribution and recruitment of mud crabs (*Scylla spp.*) in replanted mangroves.

Parts of this chapter have been submitted and accepted for publication. Walton, M.E.M., Le Vay, L., Lebata, J.H., Binas, J., & Primavera, J. (2006) Seasonal abundance, distribution and recruitment of mud crabs (*Scylla spp.*) in replanted mangroves. *Estuarine Coastal and Shelf Science* **66**(3-4): 493-500.

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**Abstract**

The abundance and distribution of mud crabs was studied in a replanted mangrove forest in Buswang, Aklan, Philippines. Two fishing gears, lift nets and bamboo traps, were used to monitor relative abundance of *Scylla* spp. populations from March 2002 to December 2003 inside the mangrove forest. A third gear, a stake net set across a creek, was used to monitor crabs migrating out of the mangroves during the ebb tide. *S. olivacea* formed 99.3% and 70.3% of the catch in the mangrove and the stakenet, respectively. The percentage of *S. tranquebarica* increased from <1% in the mangrove catches to 29% in the stakenet. *S. serrata* was present at very low levels in both catches. The lack of modal progression in the size-frequency plots and the year-round catch rate of gravid females suggested recruitment was constant throughout the year. Estimated size at maturity of female *S. olivacea* was 7.7 – 8.1cm internal carapace width (ICW) depending on the method used and males matured at a slightly smaller size (7.2 – 7.9cm ICW, dependant on method used). Maturity in female *S. tranquebarica* occurred at 8.4cm ICW. Over the study period the  $M_{50}$  of *S. olivacea* varied from 6.9 to 8.5cm ICW. Even though relative abundance decreased over the study period indicating that the stock is being over-exploited, mud crab production is more than equivalent to that of most natural mangroves.

## Introduction

The mud crabs, *Scylla* spp., are large commercially-important portunids that inhabit coastal waters throughout the Indo-Pacific. High demand and ease of capture have led to overexploitation (Le Vay, 2001). This combined with loss of habitat has resulted in a reduction in both landings and maximum size captured (Kosuge, 2001). To safeguard stocks some countries have imposed minimum landing sizes (Hay & O'Grady, 2004; Heasman & Fielder, 1977; Robertson & Kruger, 1994). Restoration of mangrove habitat is now widely practiced in S.E. Asia, but little is known about the recovery of closely-linked species, such as mud crabs. More than 70% of the Philippine mangroves have been lost in the last century due to over exploitation for timber and charcoal and for agriculture, aquaculture and settlement (Primavera, 2000). A number of mangrove reforestation projects have set about reversing this decline of which the study site, Buswang, is one of the more successful (Primavera *et al.*, 2004).

The taxonomic confusion of mud crab was finally resolved with the description of 4 species, *S. serrata*, *S. paramamosain*, *S. tranquebarica* and *S. olivacea* (Keenan *et al.*, 1998). Although much literature on *Scylla* spp exists, prior to 1998 it is difficult to be certain which species is reported, with the exception of studies in Africa or in Australia where the range of *S. serrata* extends beyond that of the others (Keenan *et al.*, 1998). It is likely that there are some important differences in behaviour, ecology and physiology that need to be identified in order to understand the differences in the geographic range of each species and niche separation in sympatric species. Overton & Macintosh (2002) suggested that both the habitat occupied when mature and size at maturation may be important in the prevention of cross breeding between species as

well as courtship or behavioural differences. In Australia niche separation prevents competition between different stages in the life cycle of *S. serrata*, with juveniles resident in the upper inter-tidal, sub-adults living sub-tidally but feeding inter-tidally during the flood tide and adults living and feeding mostly sub-tidally (Hill *et al.*, 1982b). However, it is unclear if this pattern is repeated for all *Scylla* species.

The reasons for the occupation of certain habitats by some species and not by others are unresolved. In N. Australia, *S. olivacea* is thought to be more tolerant of low salinity than *S. serrata* (Keenan *et al.*, 1998). While the extended range of *S. serrata* in S. Australia is thought to relate to its tolerance to lower temperatures (Gopurenko *et al.*, 2003). However, using Oshiro's (1991) morphological descriptions in order to identify the species, *S. paramamosain* is probably the dominant mud crab present in northern Japan where sea temperatures are much lower, whereas in the south *S. serrata* is more common. In Thailand where the range of two species overlaps, there also appears to be some niche separation with *S. olivacea* reported to live within the mangrove root system while *S. paramamosain* lives sub-tidally (Overton & Macintosh, 2002). Similarly, in the Philippines and Japan, burrow-making is reported as being most commonly observed in *S. olivacea* (Estampador, 1949; Oshiro, 1991).

Size at maturity is thought to differ between species and within species from different areas. This has important implications for the setting of size limits to prevent the capture of individuals before breeding has occurred. Recently *S. olivacea* was reported to mature at a smaller size than *S. paramamosain* in Thailand (Overton & Macintosh, 2002). Robertson & Kruger, (1994) suggested that the increase in water temperature may be the reason for the decrease in size at maturity with latitude in *S.*



*serrata* in South Africa. The reasons for the differences in size at maturity of *S. serrata* populations reported in Australia (Heasman, 1980) and northern S. Africa (Robertson & Kruger, 1994) where the salinity and water temperatures are similar are unclear but may be genetic. The *S. serrata* population in northern Australia has been reported as genetically separate from those of the Pacific and Indian oceans (Gopurenko *et al.*, 1999).

The aims of the current study are to identify the seasonal changes in relative abundance of one species (*S. olivacea*) in a replanted mangrove, the movement of the crabs between habitats and to use easily measured characteristics to identify the size at maturity for males and females. These characteristics are important information for stock protection in deciding whether to use minimum size limits or fishing exclusion from certain areas critical to the life cycle of *S. olivacea*.

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## Materials and Methods

### Site Description

The present study focuses on a managed replanted mangrove in the mouth of the Aklan River, in the Aklan province of Western Visayas, Panay Island, Philippines. The area was previously thickly forested but over-exploitation for firewood and building materials has left only small patches remaining. An area of mudflat was initially planted in 1990 with 45ha of *Rhizophora* spp and 5ha of *Nypa fruticans*, with an additional 20ha of *Rhizophora* spp. planted in 1993-94 (Primavera *et al.*, 2004). In 1997, tussock moth larvae attacked the plantation and although most trees recovered, in damaged areas there has since been recruitment of *Avicennia marina* and *Sonneratia alba*.

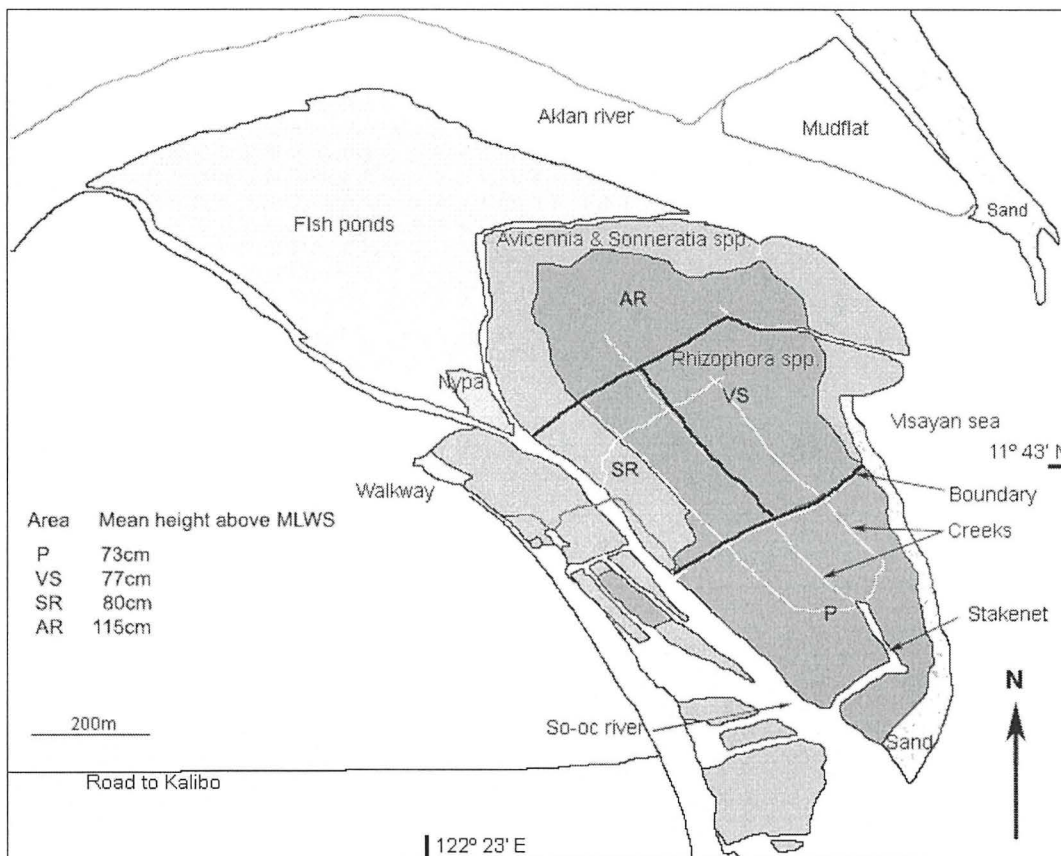
For the present study, the area was mapped using a hand-held Garmin GPS and OziExplorer 3.90.3a GPS mapping software (Figure 1). The plantation is protected from the Visayan sea by a sand bank. Hence, tides enter and exit the southern and middle sections from the So-oc River which at low tide is cut off from the Aklan River by a gravel bank.

### Continuous monitoring

Two types of gear were used to sample routinely the *Scylla* spp. population from March 2002 to December 2003. The operators both used baited lift nets and one also employed cylindrical bamboo traps that were deployed only during spring tides over a period of 5 days, defined here as sampling periods. Both devices were deployed ~15m apart on the rising major high tides which occurred during the day between April to September and at night between October to March. The lift nets were cleared

sequentially approximately 15 minutes after being set. The baits included grey mullet (*Mugil* spp.), sardines (*Sardinella* spp.), tilapia (*Oreochromis mossambicus*) and slipmouth (*Leiognathus* spp.). The gap between the bamboo slats were set at 1.5cm and the mesh of the lift net was 3cm (stretched).

Figure 1: Map of the Buswang mangrove study site.



The study area focused on the island which was divided into 4 sectors according to natural features; Aklan River (AR) to the north, Visayan Sea (VS) to the east separated from So-oc River (SR) in the west by a creek and Punta (P) in the south by the walkway and creek (Figure 1). A stake net (stretched mesh size 3cm) set over the major drainage creek in the SE of the mangroves was also used to sample the crab

population. The net was raised at high tide and lowered after the crabs were collected at low tide.

For all crabs weight (g), external carapace width (ECW) to the nearest 0.5cm (following (Robertson & Kruger, 1994) and species determined following Keenan *et al* (1998) were noted. The internal carapace width (ICW) and ECW of a size range (3-14 cm) of 114 crabs were measured in order to estimate a conversion factor to allow comparison with other studies. The sex was checked and gravid females identified by depressing the 1<sup>st</sup> abdominal segment to allow observation of enlarged ovaries under the carapace. The location, time and duration of trap deployment were also recorded.

The bamboo traps were thought to be the best estimation of CPUE as effort remained constant. The traps were laid prior to tidal inundation and recovered at low tide. The tides were diurnal, with the major tides varying in height between 1.9-2.1m above MLWS depending on the month. At the island centre, inundation time remained consistent at approximately 7.5hrs. A 20 minute increase in inundation time was recorded with a 20cm increase in tidal height at spring tides. The southern area had slightly longer immersion times as it is slightly lower relative to MLWS whereas in the north of the island the time was slightly shorter being higher (Figure 1).

### **Morphometric size at maturity**

Female crabs were separated into three groups; mature crabs were identified by the presence of setae on the fringe of a U-shaped abdominal flap, gravid crabs with mature ovaries were identified by depressing the 1<sup>st</sup> abdominal segment to allow



observation of ovaries under the carapace and berried females by the presence of an egg mass attached to the pleopods.

The presence of a disengaged abdominal flap was checked for both sexes. In immature crabs there is a locking mechanism between the abdomen and the sternum that prevents the flap from opening and hence mating (de Lestang *et al.*, 2003); E. Quintio, pers, comm.). Engaged abdominal flaps classified crabs as functionally immature.

In males, regression analysis was performed on the relationship between the chelae height and the ECW of male crabs. The resulting standardised residuals were then plotted against the ECW and the pattern used to separate mature and immature individual. Once identified, the mature and immature individuals were subjected to probit analysis.

Probit analysis was used to determine the median size at which 50% of females attained a mature abdominal shape ( $M_{50}$ ), males and females obtained unlocked abdominal flaps and males achieved a mature chelae shape. The percentage of crabs classified as mature in each (0.5cm ECW) size class was converted to the probit scale and plotted against carapace width (Robertson & Kruger, 1994). A regression line was fitted to the data and the ECW at 50% on the probit scale represents of the  $M_{50}$  of the population.

## Results

### Mapping

Mapping the study area showed that 22 ha of *Rhizophora* spp. has been replaced by a mixture of *A. marina* and *S. alba* since 1990 (Table 1). The *Nypa* area has almost disappeared due to fishpond expansion with less than a fifth of the original planting remaining. Subsequent colonization of the shore line behind the plantation by *S. alba* and to a lesser extent *A. marina* has increased the total mangrove area by 8% to 75.5 hectares (excluding *N. fruticans*)

Table 1: Extent of the component areas of the study site, Buswang, Aklan, Philippines.

<i>Location</i>	<b>Area (ha)</b>
Plantation island	57.9
<i>Rhizophora</i> spp.	43.0
Island <i>Sonneratia</i> & <i>Avicennia</i> spp.	14.9
Landward <i>Sonneratia</i> & <i>Avicennia</i> spp.	14.2
NE Creek mouth deposits	3.4
<i>Nypa fruticans</i>	0.8
Fishponds (illegal)	35.6
Mudflat on north bank of Aklan River	8.3

### Fisheries catches

In the 21 month period from March 2002 till the end of December 2003 11,006 crabs were caught, 10,770 using bamboo traps and lift nets inside the mangroves (Table 2). The catch composition was *S. olivacea* (99.34 %), *S. tranquebarica* (0.58%) and *S. serrata* (0.08%). The stakenet which specifically targeted crabs migrating out of the

mangrove during the ebb tide caught only 236 crabs, 29.4% of which were *S. tranquebarica*.

Table 2: Total catches and percentage catch composition by species *Scylla* caught with the three fishing methods

Method	Total catch	% <i>S. olivacea</i>	% <i>S. tranquebarica</i>	% <i>S. serrata</i>
Lift net	8581	99.37	0.61	0.02
Bamboo trap	2189	99.22	0.46	0.32
Stakenet A	236	70.34	29.24	0.42

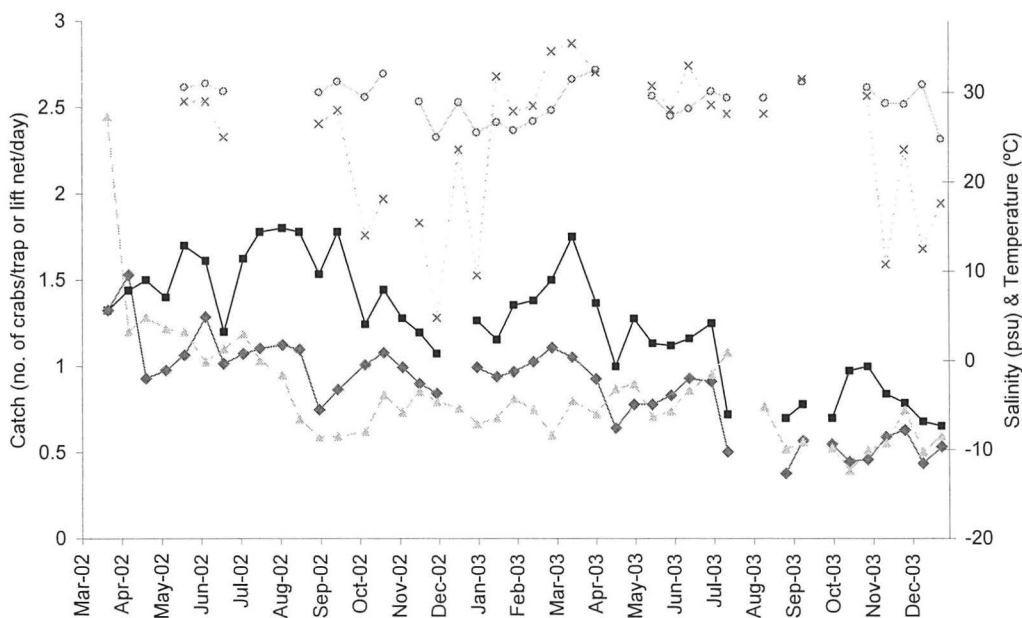
### Variations in relative abundance

Relative abundance was defined as the mean number of crabs caught per trap or lift net per day i.e. the catch per unit effort (CPUE). Only data for *S. olivacea* has been presented as the capture frequency of the other *Scylla* spp. was too low. The mean CPUE of each sampling period follows a broadly similar pattern regardless of trapping method and there was no significant difference in the lift net catches between operators (Mann-Whitney,  $p > 0.05$ ) (Figure 2). Temperature was remained between 25 and 32°C. Salinity remained around 30psu from February to November in 2003; low salinity was prevalent between November and January. There was no correlation between CPUE and salinity, temperature or mean elevation above MLWS.

CPUE was significantly negatively correlated ( $p < 0.05$ ) with time, declining significantly from 1.7 crabs trap<sup>-1</sup> d<sup>-1</sup> in March 2002 to 0.7 crabs trap<sup>-1</sup> d<sup>-1</sup> in December 2004 ( $F = 28.4$ ,  $p < 0.001$ ,  $r^2 = 66.2\%$ ). However a plot of the residuals suggested there was a pattern in the variation which could not be explained. A Mann-Whitney test suggested that neither the lunar moon cycle nor the occurrence of the major tide during the day/night could explain the fluctuations noted in the CPUE and decreases in CPUE did not correspond with periods of increased fishing activity.

These fluctuations may represent variations in recruitment. To compare the differences, data were used from the same time period in each year from April to December in 2002 and 2003. A t-test suggested a significant decline ( $p < 0.05$ ) on the square root transformed CPUE which declined from 1.49 in 2003 to 0.94 crabs trap<sup>-1</sup> d<sup>-1</sup> in 2003, confirming the decline in the relative abundance of *S. olivacea* detected by the earlier regression. There was no significant decrease in the mean weight of crabs caught trap<sup>-1</sup> d<sup>-1</sup> over the same period ( $t = 1.46$ ,  $p = 0.15$ ).

Figure 2: Mean number of *S. olivacea* caught per trap (black square) and per lift net 1 (black diamond) and 2 (grey triangle) per day during spring tides and the salinity (cross) and temperature (open circle) between March 2002 and December 2003.



### Influences of size and sex on CPUE

The mean CPUE of the bamboo traps per sampling period (Figure 3) is representative of the declining catch rate. The catch composition of both lift net operators followed similar patterns with a reduction in the number of small crabs caught (Table 3). In bamboo traps, the decrease in the CPUE of small crabs with an ECW of  $\leq 7$ cm



represents almost 100% of the total decrease, with 85% due to the decline in small males. The CPUE in the lift nets follows a similar pattern with reduced number of small crabs ( $ECW \leq 7\text{cm}$ ) being caught in 2003

Figure 3: Catch rate in bamboo traps (Number of crabs  $\text{trap}^{-1} \text{d}^{-1}$ ) of *S. olivacea* by size classes. Catch rate; total (dotted line), of crabs  $>8.5\text{cm}$  ECW (diamond),  $7 - 7.5\text{cm}$  ECW (open square),  $6 - 6.5\text{cm}$  ECW (open triangle) and of crabs  $<6\text{cm}$  ECW (cross).

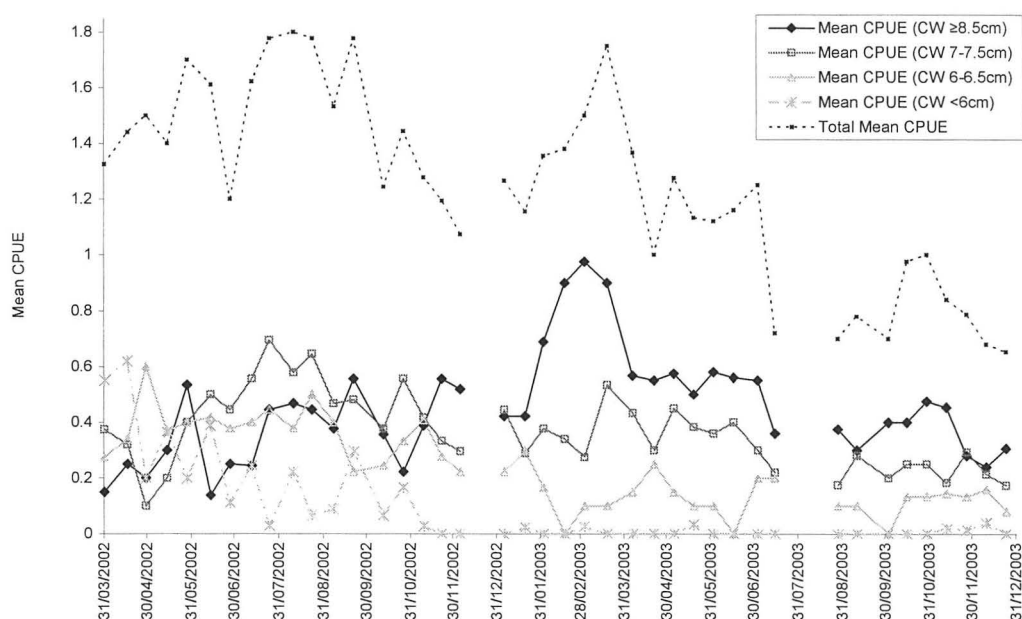


Table 3: Number of *S. olivacea* trap<sup>-1</sup> day<sup>-1</sup> caught by the two fishing methods:

## a) bamboo traps

	Apr-Dec 2002	Apr-Dec 2003	Difference in CPUE	% of the total difference
Total	1.49	0.94	0.55	
Male	0.94	0.49	0.45	81.9
Female	0.54	0.45	0.10	18.1
Crabs ≤ 7cm ECW	0.77	0.22	0.55	99.8

## b) lift net 1

Total	1.06	0.66	0.40	
Male	0.66	0.38	0.28	69.2
Female	0.41	0.28	0.12	30.8
Crabs ≤ 7cm ECW	0.68	0.31	0.37	92.8

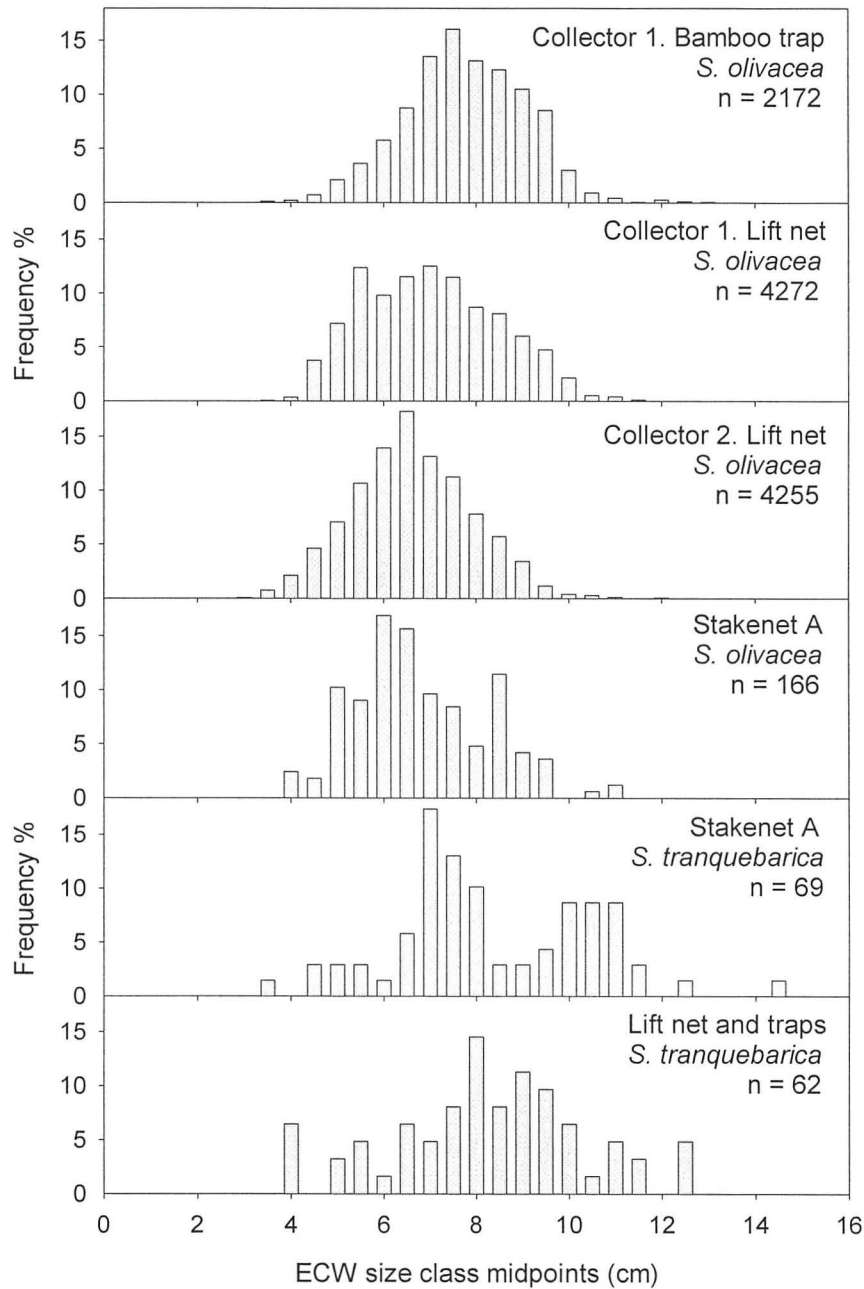
## c) lift net 2

Total	0.99	0.67	0.32	
Male	0.48	0.37	0.11	34.4
Female	0.51	0.30	0.21	65.6
Crabs ≤ 7cm ECW	0.74	0.50	0.24	75.5

**Size-frequency composition**

Collector- and method-specific size-frequencies are shown in Figure 4. The minimum size class retained is 3.0cm ECW in the lift nets and 3.5cm in the traps for *S. olivacea* and 4.0 - 4.5cm for *S. tranquebarica*, indicating first recruitment into the trap fishery starts at this size. The upper size class of *S. olivacea* caught was 13.0, 13.5 and 12.0cm ECW in the traps and lift nets of collector 1 and lift nets of collector 2, respectively. The largest *S. tranquebarica* (14.0cm ECW) was caught in the stake net. The latter size is likely to represent the upper size limit present in the mangrove as this sampling method is non-size selective.

Figure 4: Size-frequency plots of *S. olivacea* and *S. tranquebarica* collected in the Buswang mangroves using lift nets, traps and stake nets between 30/4/02 and 28/12/03.

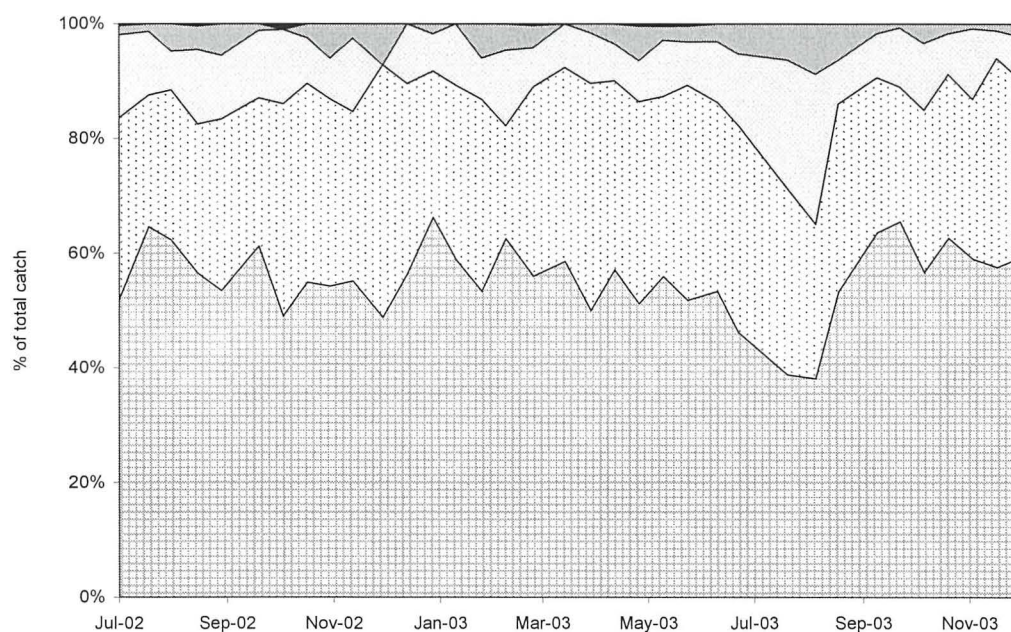


A regression between ECW and ICW gave a highly significant relationship ( $T = 188.6$ ,  $p < 0.001$ ,  $r^2 = 98.8\%$ ,  $n = 114$ ) where  $ECW = 1.065 \times ICW$ , the intercept was not

significantly different from zero. This conversion was to provide ICW and ECW values for comparative purposes.

LFDA analysis (Kirkwod *et al.*, 2001) showed that there was no modal progression in the size distribution of bi-monthly samples of *S. olivacea* when analysed separately by capture method or by collector. This lack of modal progression suggests there was year round recruitment into the mangrove of this species and that emigration and/or mortality was continuous.

Figure 5: Composition of the total catch from bamboo traps and lift nets of berried (black), gravid (dark grey), mature (light grey), and immature (dotted) female crabs and males (checked).



The sex composition of the catch showed little variation over time with males fluctuating around 56% (Figure 5). Female population remained varied little with the exception of a peak in the number of gravid females in August 2003. However, this does not appear to be an annual occurrence as no such event occurred in the previous



year. There appeared to be no particular breeding season as gravid females were present all the year round. The presence of gravid and occasionally berried crabs in the mangroves does suggest that this species may spawn and hatch close to shore.

Table 4: Percentage composition of *S. olivacea* catch from traps and stake net.

	Male <8.5cm ECW	Male ≥8.5cm ECW	Immature female	Mature Female	Gravid female	Berried female
Stake net	48.8	2.5	12.0	25.9	9.0	1.8
Trap & lift net	40.8	15.4	31.5	9.4	2.8	0.1

The percentage composition of the crabs caught inside the mangroves with lift nets and bamboo traps and those caught migrating out in the stake net are shown in Table 4. Mature, gravid and berried females formed a much higher percentage of the catch in the stake net (36.7%) compared with those caught using traps (12.3%) suggesting they may be feeding in the mangroves but living sub-tidally. In contrast, mature males appear to be more resident in the mangroves.

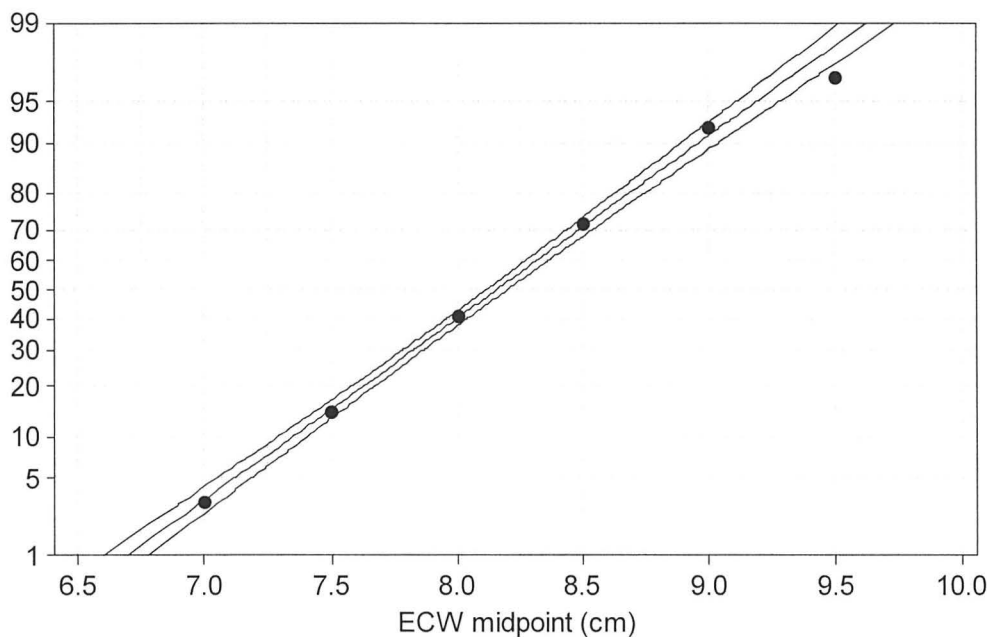
## Morphometric size at maturity

### Abdominal shape

Crabs with a mature abdominal shape were found as small as 5.5cm ECW while immature abdominal shapes were found in crabs as large as 9.5cm ECW. Gravid crabs were observed as small as 7.5cm ECW although crabs of 9.5cm ECW were most frequently observed to be gravid. Berried crabs were also found as small as 7.5cm ECW.

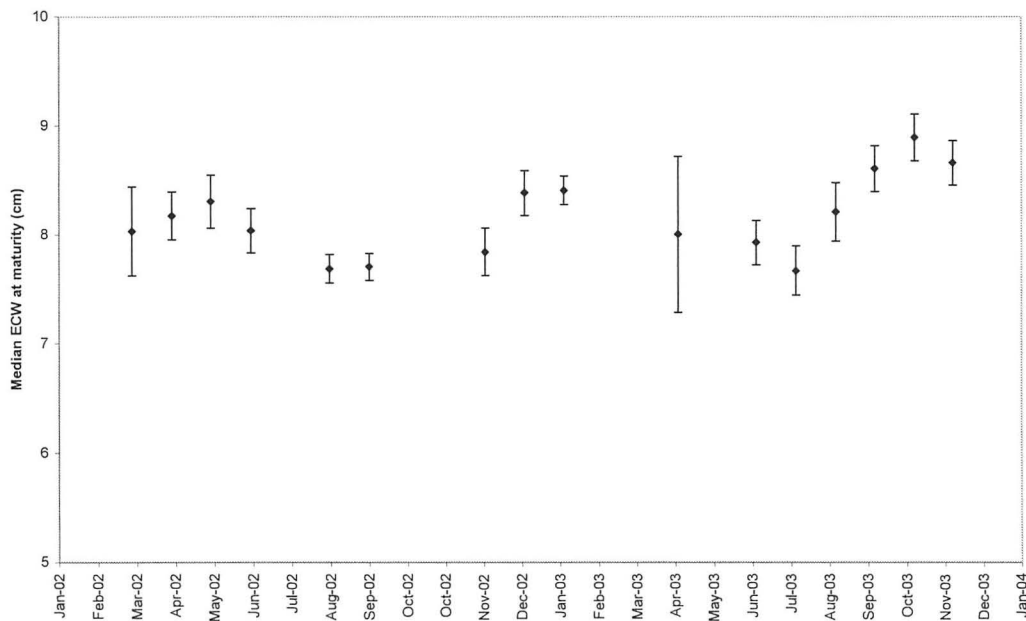
Probit analysis indicated that 50% of female *S. olivacea* ( $M_{50}$ ) attained a mature abdominal shape at 8.15 cm ECW or 7.65cm ICW (Figure 6). Chi-squared analysis suggested the cumulative percentage increase in maturity at each size class did not deviate from the predicted model ( $\chi^2 = 5.253$ ,  $p = 0.355$ ).

Figure 6: Probability plot of the percentage of female *S. olivacea* with mature shaped abdomens and the predicted model. ( $M_{50}$  ECW = 8.16cm ( $\pm 0.04$ cm 95%CI), Pearson's goodness of fit test  $\chi^2 = 5.253$ , df. = 5,  $p = 0.355$ )



However, lack of overlap in the confidence intervals of the monthly  $M_{50}$  suggest there is significant monthly variation in the size at which 50% of the female *S. olivacea* population matures (Figure 7). Between August and November 2003 the  $M_{50}$  for females increased from 7.6 to 8.9cm ECW ( $n = 124$  to 366). The size at maturity was not significantly correlated ( $p > 0.05$ ) with either mean female ECW, CPUE, temperature or salinity.

Figure 7: Monthly variation in size at maturity (ECW) and the 95% CI as determined by probit analysis using abdominal shape as the criteria for maturity.



Mature female *S. tranquebarica* occurred as small as 8.2cm ECW and immature females as large as 9.7cm ECW. Probit analysis estimated the  $M_{50}$  for female *S. tranquebarica* as determined by abdominal shape to be  $8.91 \pm 0.39$ cm ECW (95% C.I.) (Pearson's goodness of fit test  $\chi^2 = 3.538$ , df. = 13,  $p = 0.995$ ).

### Chelae Height

Right handed crabs dominated the male population of *S. olivacea* in Buswang only 14.4% were left handed. Regression analysis was performed on untransformed data to maximize the change in allometry between ECW and chelae height (Figure 8). From the resulting pattern in the standardized residuals it is possible to separate the crabs with enlarged chelae (>2.4cm in height). Probit analysis estimated the  $M_{50}$  for males based on chelae height to be  $8.46 \pm 0.20$ cm ECW (95% C.I.) (Figure 9).

Figure 8: Above; Increase in chelae height compared with ECW in male *S. olivacea* and below; the resulting standardized residuals from a regression analysis on the entire data set of chelae height against ECW. Open circles = mature, closed circles = immature, as decided on by the pattern of the residuals.

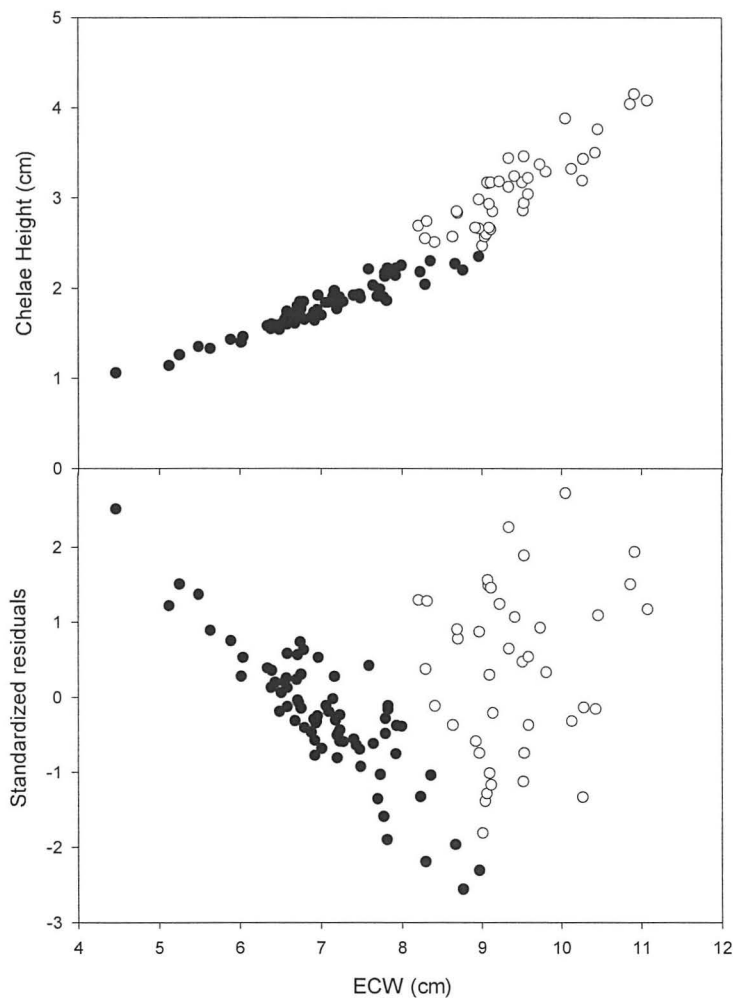
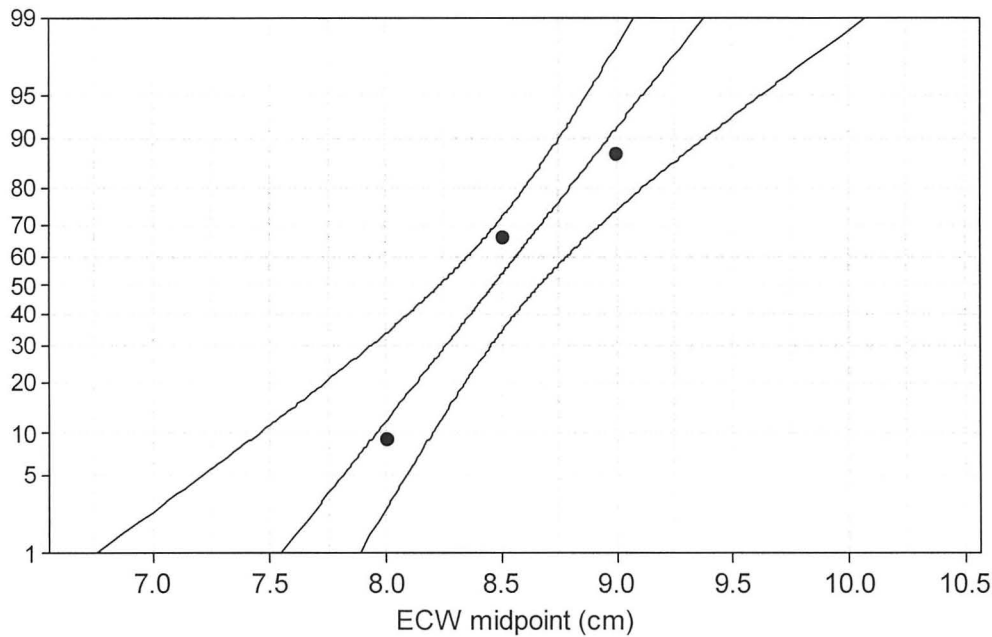


Figure 9: Probability plot for the percentage of male *S. olivacea* with enlarged chelae relative to ECW. ( $M_{50}$  ECW = 8.46cm ( $\pm 0.2$ cm 95%CI), Pearson's goodness of fit test  $\chi^2 = 1.106$ , df. = 12,  $p > 0.5$ )



### Engaged/Disengaged abdominal flap

For females the chi-squared values indicated that data did not fit the probit model. However all females classified as mature due to their abdominal shape also had disengaged abdomens. Less than 2% of the immature crabs encountered had disengaged abdomens suggesting that the size at maturity as determined by disengaged abdomens is likely to be very similar to that obtained using the abdominal shape.

Probit analysis for males from catches during December 2003,  $M_{50} = 7.67$ cm  $\pm 0.23$ cm ECW (95% C.I.).



## Discussion

The planting of the mangrove and the subsequent after care by the local community has enabled a very successful *Rhizophora* spp. mangrove forest to thrive. The initial setback caused by tussock moth infestations and washout which reduced the planted *Rhizophora* area by 33% has been more than compensated for by the natural recruitment of *Sonneratia alba* and *Avicennia* spp. Further recruitment is ongoing as evidenced by the large number of saplings present along the mangrove fringe apart from the Aklan River.

## Gear selectivity

The selectivity of the gears may have influenced the size distribution and composition of the crab catches (Miller, 1990). Significantly larger crabs were recorded in bamboo traps compared with lift nets. The lift nets had much shorter soak times of only 15 minutes which may have reduced competition and limited the area of influence of the gear. The small mesh size may also have helped increased the lower limit of the crabs caught. However the bamboo traps were unable to catch crabs in the 2.76 - 3.25cm ECW size class this only formed 0.05% of the lift net catch. It may be that crabs of this size have not fully recruited into the mangroves as the mesh size of the lift nets would have retained crabs with a 2cm ECW.

The largest *S. olivacea* caught was a male 13.5cm ECW weighing 540g. This is comparable with the largest *S. olivacea* recorded in Ranong, Thailand (Moser *et al.*, 2002), and is probably close to the upper size limit of this species. The largest crab caught was a *S. serrata* of 16.5cm ECW weighing 960g and the largest *S.*

*tranquebarica* was 14.6cm ECW weighing 779g suggesting these traps were certainly capable of catching larger crabs given the extensive sampling period. The largest crabs caught of each species may reflect the largest sizes attainable by each species in this area.

### Species composition

The catch of the lift nets and bamboo traps suggest that the dominant species of mud crabs present in the Buswang mangroves was *S. olivacea* forming over 99% of the catch. Both *S. tranquebarica* and *S. serrata* were present but a low frequency. However, the higher percentage occurrence of *S. tranquebarica* in the stakenet suggests that they were relatively more common sub-tidally, only visiting the mangrove during the flood tides to feed. The habitat of *S. olivacea* has been described as limited to mangroves and coastlines with reduced salinity especially during the rainy season (Keenan *et al.*, 1998). A similar habitat was described for *S. tranquebarica* but with slightly more elevated salinity requirements, while *S. serrata* was reported to require full strength salinity seawater for the majority of the year although it could tolerate lower salinities (Keenan *et al.*, 1998). In the present study, salinity remained at approximately 30psu for almost 9 months of the year. Only during October to December did very low salinity episodes occur, occasionally as low as 3 but mostly fluctuating between 10psu and 20psu. These low salinity periods may explain the abundance of *S. olivacea* at this site compared to other *Scylla* species

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## Distribution

In the current study 24% of the female *S. olivacea* caught within the mangroves were mature, of those 5% were gravid and 0.1% were berried. In contrast Hill *et al* (1982) reported that very few adult *S. serrata* were caught in gill nets in the upper intertidal zone in Deception Bay, Australia. They suggested that mature *S. serrata* are mainly found sub-tidally. This indicates there are significant differences in behaviour between the species with mature *S. olivacea* much more likely to either be entering the mangrove to feed at high tide or to be a permanent resident. However, in the present study 75% of females caught in the stakenet were mature and of those 18% were gravid and 4% berried. The higher percentage caught migrating out of the mangrove suggests that mature females may be more common sub-tidally, entering the mangrove to feed during spring tides.

For males, a conservative estimate at which 50% of the male *S. olivacea* population is mature would include the 8.5cm ECW size class. This represents 15% of the crabs caught inside the mangrove in bamboo traps and lift nets, and only 2% of the crabs sampled in the stakenet. The higher proportion of larger mature male *S. olivacea* in the mangroves suggests that they may be more resident in the mangroves. The percentage of mature *S. tranquebarica* females and males caught in the traps and stake net is very similar at approximately 40% suggesting there is little difference in the behaviour regardless of sex or maturity.

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### Relative abundance

The daily CPUE from the bamboo traps shows 3 distinct peaks with a gap of approximately 7 months in between each peak. This 7 month cycle suggests there is something other than a twice-yearly event that triggers these peaks. The variations in CPUE were uncorrelated with either temperature or salinity or the occurrence of the major spring tide during the night. In contrast, Miller (1990) reported that the catchability of crustaceans often increased with temperature and activity increased with darkness especially around dawn and dusk. In South Africa mud crab catches were unaffected by darkness (Robertson, 1989). In Australia CPUE was negatively correlated with salinity (24-35psu) but positively correlated with temperature (Williams & Hill, 1982). In the current study the temperature was higher (range 25-33°C) which did not appear to effect the catchability of the crabs nor did the much greater salinity ranges (7-35 psu). However, in India low salinity (2-3 psu) reduced catches of juvenile mud crab to zero, though the species understudy is unclear (Chandrasekaran & Natarajan, 1994).

### Recruitment

There appeared to be little seasonality in female maturity and gravid females were present throughout the year at a fairly constant frequency. This is consistent with the lack of a defined recruitment period seen in the monthly size-frequency composition. Both (Heasman *et al.*, 1985) and (Quinn & Kojis, 1987) reviewed the published material on the periodicity of spawning and suggested that spawning peaks become more pronounced and less protracted with decreasing latitude. However, (Le Vay *et al.*, 2001) reported reproductive seasonality in *S. paramamosain* in Southern Vietnam with peak female maturity in September followed by high densities of small crabs



(<200g) in the beginning of the dry season in February/March. No such pattern is discernable with *S. olivacea* in the present study.

The negative correlation between time and the CPUE for both lift nets and bamboo traps suggests that there is a decrease in the relative abundance of *S. olivacea*. When the CPUE in equivalent time periods in 2002 and 2003 were compared a significant fall was detected indicating a decrease in the abundance of crabs, although catch rate in terms of weight had not declined.

The reduction in the percentage of small crabs ( $\leq 7$ cm ECW) caught in the mangroves may indicate a problem with recruitment. Settlement of mud crabs juveniles has been recorded on mangrove root pneumatophores and sea grass beds (Hill *et al.*, 1982b). (Chandrasekaran & Natarajan, 1994) found a much higher number of seed mud crabs (8-80mm ICW) in seagrass areas than amongst pneumatophores. In November 2002 floods washed away extensive seagrass beds (*Halophila* spp.) situated in the So-oc River, re-colonization began the following year but their full recovery has taken almost 2 years. If the behaviour of juvenile *S. olivacea* is similar to that of the *S. serrata* then the removal the shelter provided by the seagrass beds may have had an important impact on the mortality of young crabs through predation. Similarly a reduction in sea grass density had a significant effect on the mortality of juvenile blue crabs, *Callinectes sapidus* in New Jersey (Wilson *et al.*, 1986).

### **Maturity**

The size at maturity in females varied between individuals with the smallest mature *S. olivacea* found at 5.5cm ECW and the largest immature crabs at 9.5cm ECW, with berried and gravid *S. olivacea* recorded as small as 7.5cm ECW. Probit analysis



suggested a mean  $M_{50}$  of 7.65cm ICW. This is much smaller than that reported for the same species in Ban Don Bay in Thailand, where  $M_{50}$  is calculated as 9.12cm ICW using the same method (Overton & Macintosh, 2002). Environment variables such as temperature and salinity or genetic or density-dependant factors or selective fishing practices or predation pressure could all affect size at maturity (Sastry, 1983). However, in this study these variables did not appear to be influencing size at maturity. The monthly fluctuations do indicate that future maturity studies be wary of short-term fluctuations.

Reported size at maturity of *Scylla* species prior to the taxonomic revision by Keenan *et al* (1998) cannot be considered with the exception of reports where *S. serrata* is the only species e.g. South Africa and maybe Australia, where only small pockets of *S. olivacea* are found. Robertson and Kruger (1994) compare size at maturity in S. Africa (29°S) to that of S. Africa (34°S) (Hill, 1975) and Australia (29°S) (Heasman, 1980). The different size at maturity reported in southern S. Africa (13-17cm ICW) compared with those from Natal (10.4-20cm ICW) may be related to the lower winter water temperatures. However, in Australia the water temperature and salinity variations appear to be much the same as in Natal and females mature at a much larger size (13.8-20.4cm ICW). The reasons are not clear, but if density-dependant factors affected growth then a reduction in the abundance of a population would lead to increased growth rates and size at maturity (Pollock, 1993). This is because size at maturity and the number of instars before maturity are thought to be closely related (Hartnoll & Gould, 1988).

There is close agreement in the size at maturity for female *S. olivacea* whether measured using mature abdominal or engaged/disengaged abdomens as very few immature females had disengaged abdomens. Therefore, it is suggested that either of these methods can be used to assess maturity. Abdominal shape was found to be a reliable indicator of the ability to mate in female *S. serrata* while ovarian maturity was reported to vary depending on the season (Robertson & Kruger, 1994).

Estimates of size at maturity for male *S. olivacea* were much larger when using chelae height compared with engaged/disengaged abdomens. Similarly, in S. Africa 50% of male *S. serrata* were estimated to have sperm in the anterior vas deferens at 9.2cm ICW, while most males had no mating scars under 13cm ICW and no mating males were observe smaller than 13.1cm ICW (Robertson & Kruger, 1994). Spermatogenesis is thought to occur before the pubertal moult as this may be under the control of the hormones that elicit the pubertal moult (Hartnoll, 1963). However, secondary sexual characteristics such as the development of massive chelae may occur later as this requires a moult.

The average size at maturity of female *S. tranquebarica* using the shape of the abdominal flap was larger than that of *S. olivacea* (8.91cm cf. 8.15cm ECW). The overlap in the size at maturity between the two species is similar to that found in Thailand between *S. olivacea* and *S. paramamosain* (Overton & Macintosh, 2002) and suggest that at the current study site as well, size at maturity is not factor in the genetic separation of these 2 species.

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## Yield

The average monthly yield mud crab was 30kg or 0.7kg ha<sup>-1</sup> of *Rhizophora* spp. from the monitored catches of the two fishermen. A recent socio-economic evaluation of this replanted mangrove estimated a monthly catch of 552.8 kg or 87.9 kg ha<sup>-1</sup> yr<sup>-1</sup> from 79 fishers (chapter 4). This is slightly higher than other estimates of mud crab production from natural mangroves that ranged from 13 kg ha<sup>-1</sup> yr<sup>-1</sup> for Chanthaburi, Thailand to 64 kg ha<sup>-1</sup> yr<sup>-1</sup> for the mangroves in Kosrae, Micronesia (Ronnback, 1999b). The higher than average estimate indicates that rehabilitation of mangroves may be very effective in enhancing mud crab stocks. However, in the present case there is also evidence that the unrestricted access has resulted in the over exploitation of this mud crab population as detected by the falling CPUE in the present study. To be effective in restoring fisheries, both habitat rehabilitation and some form of fishery control such as limiting effort or minimum landed sizes are necessary.

**Chapter 3:**

**Effectiveness of mangrove replanting in the restoration of fisheries:  
abundance and distribution of mud crabs, *Scylla olivacea* in intact,  
degraded and rehabilitated mangroves.**

**Abstract**

Mangrove forests have been cleared at alarming rate over the last century to allow space for settlements, agriculture and aquaculture and are still used today for fuel and construction. Mangrove replanting is frequently used as a method of restoring ecological function, but this may not be justified as once diverse forests are often replanted with mono-specific stands. The present study sets out to use the abundance of the commercially important mud crab, *Scylla olivacea*, a top benthic predator, as an indicator of ecological function of mangrove ecosystems. Four sites in Panay Island, central Philippines were carefully selected to represent different types of mangrove habitat; a natural fringing mangrove (NFM), a natural basin mangrove (NBM), a replanted mangrove (RM) and degraded mangrove (DM). The abundance of *S. olivacea* was compared using a standardised trapping grid, with catch per unit effort data (CPUE) suggesting that abundance was comparable in the NFM and RM, but lower abundance in the NBM. No crabs were caught in the DM. The evidence from the experimental trapping grid was supported by single release mark-recapture studies that indicated a density of 401-186 mud crabs ha<sup>-1</sup> in the RM, suggesting densities extrapolated from CPUE data of 426 ha<sup>-1</sup> in the NFM, and 75 ha<sup>-1</sup> in the NBM. The low density in the NBM appears to be due to limited recruitment and *S. olivacea* are replaced by an increased abundance of other less valuable crab species, mainly *Baptozius vinosus* and *Thalamita crenata*. A multiple release mark-recapture study in the RM carried out two years later suggested *S. olivacea* population had fallen to 36 – 138 ha<sup>-1</sup>, and this was reflected in a decline in the CPUE of fishers over the same period. Further experimental trapping and burrow occupancy studies in the RM suggested that the different structural complexity of the root systems of the two mangrove species (*Rhizophora* spp. and *Sonneratia* spp.) did not affect the relative abundance of mud crabs, neither did and increase in tidal elevation



(0.69 – 1.2m above MLWS). The study suggested that replanting mangroves even in mono-specific stands is effective in restoring fisheries of mud crabs. The ecological function of replanted mangroves was found to be equivalent to that of natural mangrove environments as indicated by the similar mud crab densities.

## Introduction

Various ecological services have been attributed to mangroves, including shoreline protection, wood production and the support of valuable fisheries (Clough, 1992). However, in Southeast Asia, significant areas of mangrove have been lost in the last century, due to over-exploitation for wood and clearance for agriculture, settlements and aquaculture (Primavera, 2000). The decline in mangroves has been accompanied by reductions in productivity, biodiversity and the socio-economic value of artisanal and inshore fisheries (Costanza *et al.*, 1997; Ronnback, 1999b). In some countries, replanting has been undertaken in an attempt to rehabilitate degraded or deforested mangrove areas (Alongi, 2002; Field, 1998b; Kaly & Jones, 1998). Most of these replanting efforts are based on limited numbers of mangrove species (Alongi, 2002). For example, in the Philippines restoration typically creates monospecific stands of economically valuable, easily-planted *Rhizophora* spp. (Primavera *et al.*, 2004; Walters, 2000, 2004). While there have been some studies of faunal recruitment to replanted mangroves (Al-Khayat & Jones, 1999; Bosire *et al.*, 2004; Macintosh *et al.*, 2002a), it is not yet clear whether such re-constructed habitats fulfil the same ecological functions as natural, intact mangrove.

As well as being an important resource for fisheries, the mud crab, *Scylla* spp. is a top predator in the benthic food web (Bouillon *et al.*, 2002). In Sri Lanka crustaceans account for 78-46% (by volume) of mud crab diet (Jayamanne & Jinadasa, 1991). In South Africa, *Scylla serrata* showed a preference for small grapsid crabs (Hill, 1979a), that in turn, have a major influence both on ecosystem function through bioturbation and nutrient remineralization as a result of the consumption of mangrove

leaves and on mangrove species distribution through seed predation (see review by (Lee, 1998).

*Scylla olivacea* is one of four *Scylla* species recently described by (Keenan *et al.*, 1998), with a distribution from Pakistan to southern China and down to northern Australia. *S. olivacea* is thought to be largely burrow-dwelling (Estampador, 1949) and less free-ranging than the other species and is more closely associated with mangroves (Estampador, 1949; Overton & Macintosh, 2002). Other reports of this species have linked them to mangrove ecosystems in Vietnam (Le Vay *et al.*, 2001; Macintosh *et al.*, 2002b), Thailand (Moser *et al.*, 2005; Moser *et al.*, 2002; Overton & Macintosh, 2002), Malaysia (Kosuge, 2001) and the Philippines (Walton *et al.*, 2006a). *S. olivacea*'s close relationship with mangrove habitats and their associated fauna together with its intrinsic economic value suggest could serve as a useful indicator of the condition of mangrove habitats notably when it comes to assessing the ecological and economic viability of replanted areas.

Making accurate counts of mud crabs in mangroves is complicated by the complexity of the root systems and the amount of suspended sediment in the water. Various methods have been used, but in only one study were traps set within mangroves (Moser *et al* 2005). Mark-recapture methods have resulted in estimates of mud crab densities ranging from 2 crabs ha<sup>-1</sup> in Queensland, Australia (Hill, 1979b) to 44 and 53 crabs ha<sup>-1</sup> in South Africa (Robertson, 1996) (predominantly mature *S. serrata*). However these studies focused on open water areas in estuaries and bays where traps are easy to deploy.

The present study primarily aimed to assess the relationship between habitat degradation and rehabilitation and mud crab abundance using catch per unit effort (CPUE). This was investigated in a range of intact natural, degraded and replanted mangrove areas. Also investigated was the impact of reduced *S. olivacea* density on the abundance of two other species of crab that appeared to have a similar ecological niche, namely *Thalamita crenata* (that appears to have a similar diet) (McKillup & McKillup, 1996), and *Baptozius vinosus*. The current study then concentrated on the replanted site to assess how CPUE (both that of commercial fishers and from experimental trapping) related to actual densities.

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## Methods

### Site descriptions

Four locations on Panay Island, Philippines were selected to represent a range of mangrove habitats (Figure 1) to compare mud crab populations in replanted, natural and degraded mangroves with similar elevations (0.8 – 1.2m above mean low water springs (MLWS)).

1) The replanted mangrove (RM) in Buswang, situated in the mouth of the Aklan River was commended by the FAO for exemplary forest management (Cadaweng & Aguirre, 2005). The 15 year old 45 ha *Rhizophora* spp. plantation drains directly into the sea.

2) Natural basin mangrove (NBM) in Ibajay has 27 species of trees in 72 ha (Primavera et al, 2004). The main creek drains and floods through a narrow opening.

3) Natural fringing mangrove (NFM) in Colong Colong that drains directly into the sea is dominated by *Avicennia marina* also present are *Aegiceras corniculatum*, *Ceriops decandra*, *Rhizophora apiculata*, *R. mucronata* and *Sonneratia alba*. The mangrove backs onto fishponds where earth has been removed for dyke construction leaving the substrate inundated for longer periods than the surrounding area.

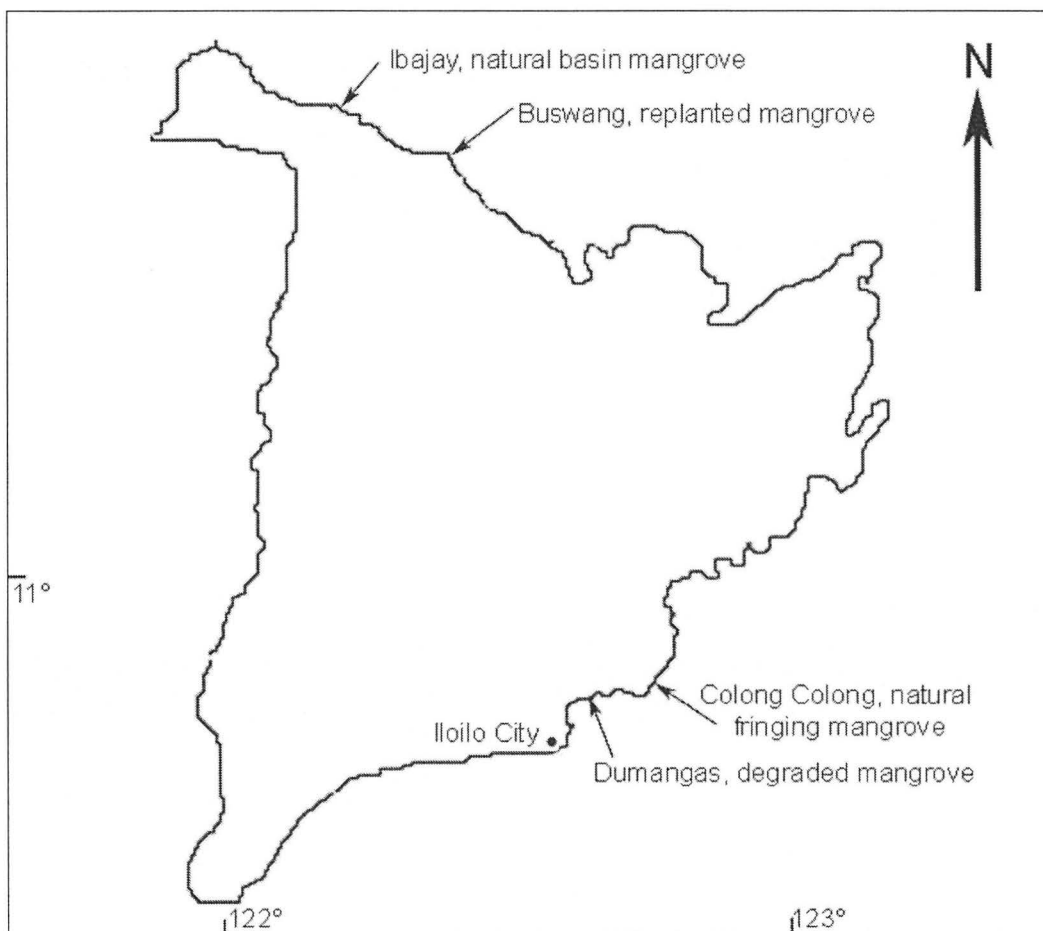
4) A degraded mangrove (DM) in Dumangas, fringing a river. A once thick belt of mangroves has been cleared for pond construction and firewood, a few *Avicennia* sp. trees remain. The habitat has been further degraded by the removal of large quantities of mud for construction of fish pond dykes. This combination of factors had altered the hydrology and reduced the suitable burrowing habitat available.

The fishing pressure was assessed in the RM at Buswang as part of a socio-economic study and at other sites using interviews with the local villagers. Fishing pressure in



the RM was high with 28 regular fishermen in 75.5 ha of mangrove, in NBM it was low with only 2 regular fishermen in 75 ha, in the NFM fishing pressure was low with one regular fishermen in this continuous coastal strip of mangrove and in Dumangas the pressure was high, with a number of fishermen using a variety of gears used including bamboo traps and gill nets inside the creek.

Figure 1: Map of Panay Island showing the 4 study sites.



### Methods of population assessment

Crab populations were assessed using both fishers' CPUE ( $CPUE_{fish}$ ) (No. of crabs  $gear^{-1} day^{-1}$ ) and experimental trapping CPUE ( $CPUE_{exp}$ ). In order to justify the use of

CPUE as an estimate of relative abundance, crab density was objectively estimated using different methods in the various mangroves namely; in the RM, two single mark-recapture studies and a multiple mark-recapture and burrow occupancy, and in the NFM, a removal fishing experiment.

### **Fishers' catches ( $CPUE_{fish}$ )**

The CPUE's of commercial fishers were monitored from 2002 – 2004 in the RM and in 2002 in the NBM. The fishers used cylindrical (70×25cm) bamboo traps with conical entrances at either end set in a line at intervals of approximately 15m.

### **Experimental trapping grids ( $CPUE_{exp}$ )**

The same bamboo traps were set in grids of 15m so that the effective fishing area of neighbouring traps overlapped. The traps were deployed during the major spring high tides ( $2.0 \pm 0.1m$ ). Traps baited with fish placed in perforated cans to prevent consumption by trapped crabs. The traps were laid early morning at low tide and collected in the evening. The trapped crabs were weighed, measured and sexed.

The trapping grids were used in 2002 at all four sites. In 2004 the trapping grids were set in the RM again to investigate the decline in mud crab catches the effects of mangrove species on mud crab abundance. In 2004 traps were set in the replanted *Rhizophora* spp. area and in the *Sonneratia* spp. area

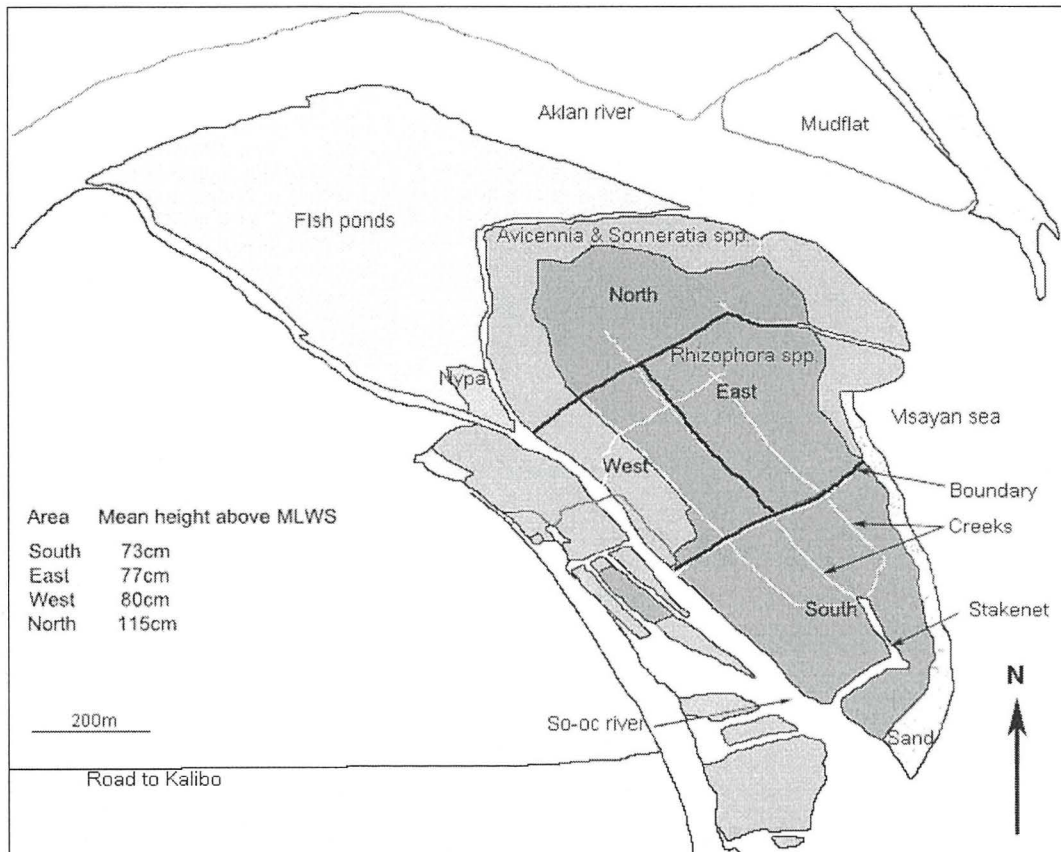
### **Petersen's single mark-recapture studies**

In the east and south of the RM ( $RM_{east}$  and  $RM_{south}$ ), two single capture-mark-recapture studies were performed on the *S. olivacea* population in 2002. Here, the

same trapping procedure was used, but two antero-lateral spines were clipped to denote trap position before the captured crabs were returned to a refuge around the trap. Two days later the traps were reset and the resulting catch recorded and checked for marks.

Population size was calculated using the Peterson method (Seber, 1982), with the assumption that the intervening period was long enough to allow for mixing of marked individuals with the rest of the population but short enough to preclude migration. Figure 2 shows a map of the RM and the mean elevation of the four fishing areas.

Figure 2: Fishing areas (North, West, East and South are discrete fishing areas), elevation relative to mean low water springs (MLWS) and mangrove species in the replanted mangroves (RM) at Buswang.



### Jolly-Seber estimation of population density

In the RM a multiple mark – single recapture experiment was performed to assess crab density between October to December 2003. Over five consecutive spring tide periods, 1375 *S. olivacea* were captured by 5 fishers using baited lift nets and bamboo traps. Of these 1015 crabs were tagged. The catches were sorted daily into 5mm internal carapace width (ICW) size classes and tagged by injecting numerically coded micro-wire tags (Northwest Marine Technologies) into the adductor muscle of the 3rd walking leg. Tagged crabs were released into one of the four fishing areas (North, East, West and South) (Figure 2) where the fishers were asked not to catch crabs the

following day. The results were analysed using the Jolly-Seber method (Seber, 1982) (“Simply Tagging” software, Pisces Conservation Ltd.).

#### **Population estimates by removal fishing in the NFM.**

To compare crabs densities as estimated by trapping grids, a removal fishing experiment was performed in the NFM. An area of 2400m<sup>2</sup> was surrounded by a net (ø 2cm) which was erected at low tide with the bottom buried in the sediment to prevent crab escape.

Baited lines and scoop nets were used to remove crabs from the net over a period of four days during spring tides in May 2002. The effort remained constant over the sampling period. The total population existing within the net was calculated using the method of (Seber, 1982) that estimates the total accumulated catch when the catch rate falls to zero.

#### **Occupancy and hole counts**

In order to investigate the effects of habitat structure (mangrove type) on crab abundance, the population of burrowing crabs was sampled using a randomly-stratified design to ensure 3 quadrats of 562.5m<sup>2</sup> in 6 locations with the RM. The locations included 4 *Rhizophora* sp. areas and 2 *Sonneratia* sp. areas at different elevations in order to assess the effect of elevation on *S. olivacea* density. Every burrow was counted and searched and any crabs present extracted.



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## Results

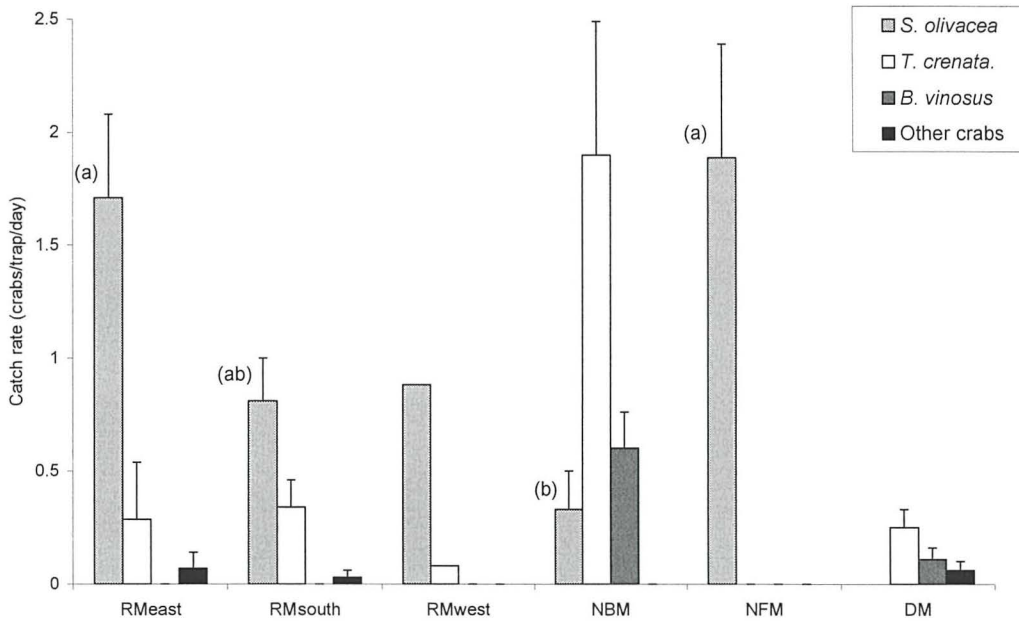
### Comparison of $CPUE_{exp}$ and $CPUE_{fish}$

The number of *S. olivacea* per bamboo trap at each location is shown in Figure 3. The highest  $CPUE_{exp}$  was observed in the RMs and the NFM, with no crab being caught in the DM. Analysis of variance suggested a significant difference in mean  $\log_{10}$  transformed catch rates ( $f = 4.99$ ,  $p = 0.004$ ). A Bonferroni's pairwise comparison suggested catch rates in the NBM were significantly lower than those from NFM and RMeast. The mean  $CPUE_{fish}$  were very similar to those of the experimental trapping grids with no significant difference observed in the RM ( $t = 0.05$ ,  $p = 0.959$ , d.f. = 5).

Although in theory, traps at the outside of the grid are catching crabs from a greater area than those on the inside, no significant effect was observed in practice; nevertheless, in the density analysis, only the inner traps were taken into account.

The total  $CPUE_{exp}$  of all crab species revealed a different picture of the carrying capacity of each environment (Figure 3). The NBM had the highest total  $CPUE_{exp}$  with 2.83 crabs  $trap^{-1} day^{-1}$ , 67% of which was *T. crenata*. The NFM exhibited lowest diversity with no other crab species caught. Trapping in the DM caught no mud crab and only low numbers of other crabs.

Figure 3: Comparison of the mean catch per unit effort (+standard error) of crabs (crabs trap<sup>-1</sup> day<sup>-1</sup>) caught in the inner grid in the natural fringing mangrove (NFM), natural basin mangrove (NBM), the degraded mangrove (DM) and three areas in the replanted mangrove (RM) in 2002. Bracketed letters represent Bonferoni's pairwise comparisons between *Scylla olivacea* log transformed catch rates in four habitats, means bearing at least one of the same letter are not significantly different. There are no error bars in RM<sub>west</sub> as sample was pooled.



The size composition of mud crab populations in the RM and the NFM were similar, with large numbers of juvenile *S. olivacea* present (Figure 4). In contrast in the NBM larger mud crabs and relatively few juveniles were caught both experimentally and by fishers.

Comparison of the areas in the RM that were initially trapped in 2002 and repeated in 2004 indicates a distinct decline in mean CPUE<sub>exp</sub> of 50.6% (Figure 3 & Table 1). In contrast there was an increase in the diversity of crab species caught in the RM compared with 2002. On average the percentage of other species caught increased from 15.6% in 2002 to 60.6% in 2004. There is no correlation between tidal height and *S. olivacea* CPUE<sub>exp</sub> or *T. crenata* CPUE<sub>exp</sub> in the *Rhizophora* spp. plantation in

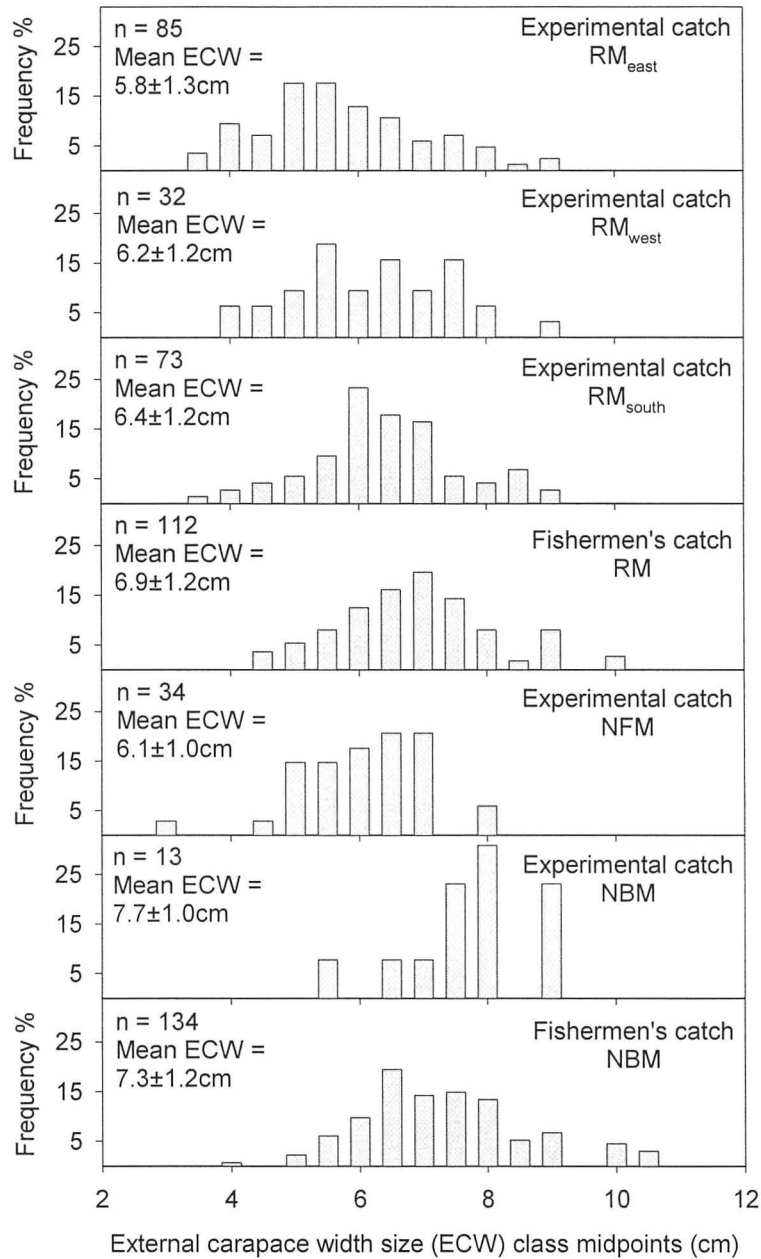
the RM. However, there is a significantly positive correlation between tidal height and *Baptozius vinosus* CPUE<sub>exp</sub> (Spearman's rank correlation coefficient = 0.986,  $p < 0.001$ , d.f. = 6).

Table 1: Comparison of the mean catch per unit effort (CPUE) (crabs trap<sup>-1</sup> day<sup>-1</sup>) of different crab species obtained at different location and heights (cm) above mean low water springs (MLWS) within the replanted mangrove (RM) in 2004.

Location	Mangrove species	Elevation above MLWS	CPUE <i>Scylla olivacea</i>	CPUE <i>Thalamita crenata</i>	CPUE <i>Baptozius vinosus</i>
North	<i>Rhizophora</i>	120	0.5	0.03	0.83
West*	<i>Rhizophora</i>	105	0.47	0.17	0.73
East*	<i>Rhizophora</i>	100	0.37	0.97	0.1
East	<i>Rhizophora</i>	90	0.4	0.6	0.03
South*	<i>Rhizophora</i>	90	0.56	0.4	0
Northeast	<i>Rhizophora</i>	69	0.3	0.03	0.03
Mainland	<i>Sonneratia</i>	98	0.55	0.27	0
West	<i>Sonneratia</i>	95	0.2	0.33	0

\* same area as in the previous study in 2002.

Figure 4: Comparison of the size-frequency distribution of *Scylla olivacea* caught in experimental trapping grids and by local fishers in the natural fringing mangrove (NFM), natural basin mangrove (NBM) and three areas in the replanted mangrove (RM) in 2002.



### Petersen's estimation of population.

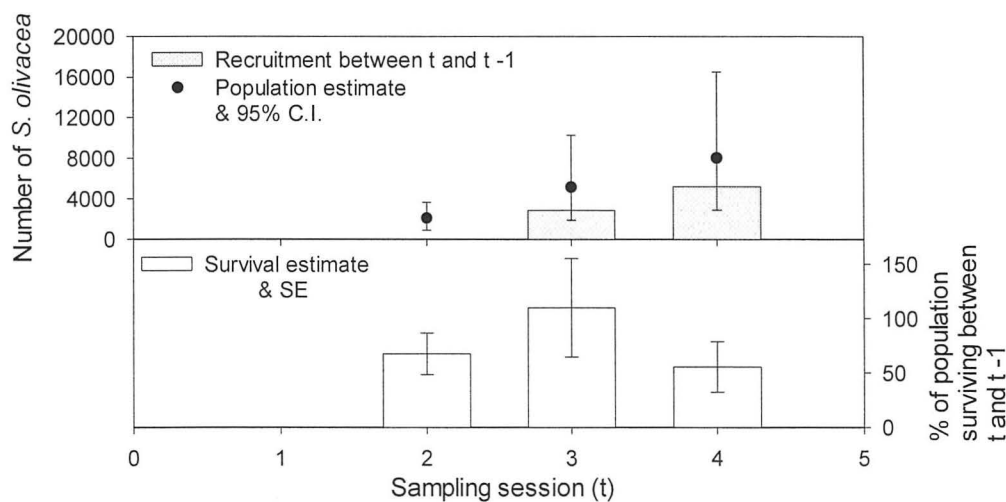
The initial experimental trapping studies performed in 2002 in the RM<sub>east</sub> and RM<sub>south</sub> mentioned previously were part of a mark-recapture study. In both cases the number of recaptures was low (n=8) but above the critical level to ensure confidence in the

results. Although these yielded disparate mud crab densities ( $RM_{\text{east}} = 401$  *S. olivacea*  $ha^{-1} \pm 262.3$  (95% confidence interval (C.I.)), and  $RM_{\text{south}} = 186$  *S. olivacea*  $ha^{-1} \pm 123.7$  (95% C.I.)), the confidence levels overlap making it possible to advance a mean density for this mangrove area of 294 *S. olivacea* per hectare of mangrove. This would give an overall population within the *Rhizophora* spp. plantation of 12,642 crabs over the 43 hectares.

### Jolly-Seber estimation of population density in the replanted mangrove

Jolly-Seber estimates of the *S. olivacea* population in the RM increased from 2101 to 8047 crabs between the 2<sup>nd</sup> and 4<sup>th</sup> sampling periods although the confidence intervals suggest that the gain was not significant (Figure 5).

Figure 5: Jolly-Seber estimates of the *Scylla olivacea* population ( $N_i$ ) in the replanted mangrove (RM) in 2003 at each sampling session ( $t$ ) (see Table 2), the numbers of recruits ( $B_i$ ) and the proportion of the population surviving ( $\Phi$ ) between  $t$  and  $t+1$ . Confidence intervals of  $N_i$  suggested by (Manly, 1991).





The fished area was 57.9 ha, hence, the density increased from 36 to 138 *S. olivacea* ha<sup>-1</sup> as a result of recruitment. The increase in abundance was detected as an increase in the CPUE in the 4<sup>th</sup> and 5<sup>th</sup> sessions (Table 2) paralleled by a decrease in mean internal carapace width (ICW). There were significant differences ( $H = 89.32$ ,  $p < 0.001$ , d.f. = 4) between the median ICWs of *S. olivacea* caught during each session. A Dunn's pairwise comparison indicated that the differences were due to the small *S. olivacea* appearing in the latter two sessions. It appears that recruitment accounted for the increases in population shown in Figure 5. The mortality and emigration rates ( $1 - \Phi$ ) indicate that the population decreased by 33% between sessions 1 and 2 and 45% between sessions 3 and 4, there was no change between sessions 2 and 3.

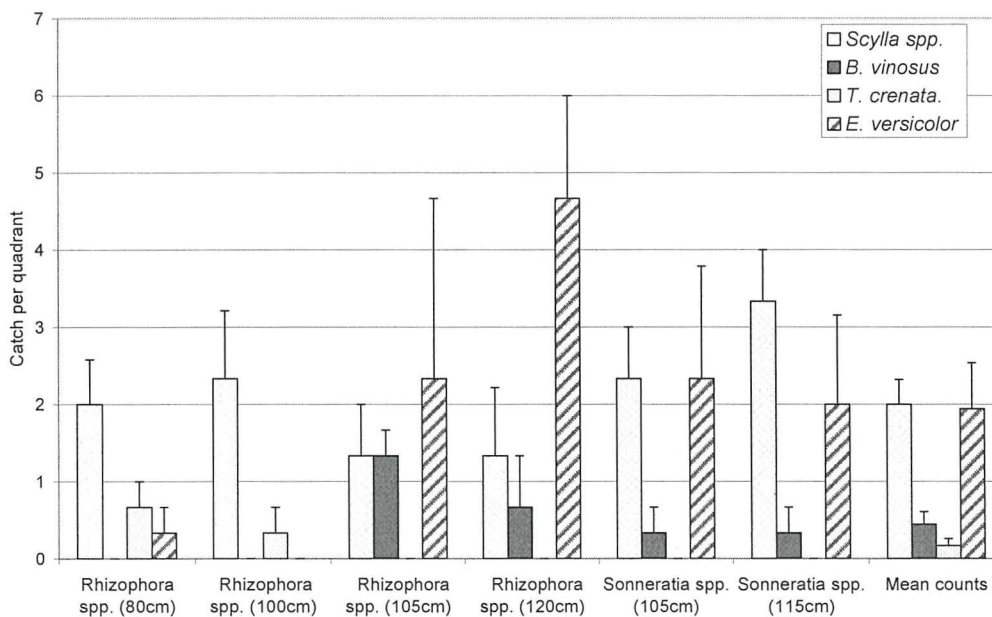
Table 2: Number of captured, marked and recaptured *S. olivacea* at each sampling occasion of the Jolly-Seber experiment in the replanted mangrove (RM).

Sampling period	Sample	Number Captured	Number marked	Returns from sample 1	Returns from sample 2	Returns from sample 3	Returns from sample 4
14-17 Oct	1	234	234				
27-30 Oct	2	253	228	19			
11-14 Nov	3	243	213	5	14		
25-28 Nov	4	365	340	5	4	6	
9- 12 Dec	5	280	0	4	5	4	14
	$\Sigma =$			33	23	10	14

## Population estimates by removal fishing in the Natural Fringing Mangrove (NFM)

The population was estimated to be 250.6 (95% confidence intervals; 223 – 374) *S. olivacea* using the method of (Seber, 1982). As the nets enclosed 2400m<sup>2</sup> of NFM this suggested a density of 1042 crabs ha<sup>-1</sup> was present in May 2002. A  $\chi^2$  goodness of fit test suggested the data did not significantly deviate from a linear relationship ( $\chi^2 = 0.24$ ,  $p > 0.05$ , d.f. = 2).

Figure 6: Number of crabs (+ SE) excavated from holes per quadrant (562.5m<sup>2</sup>) in each habitat of the replanted mangrove (RM) in 2004. The numbers in bracket represent the mean height above mean low water springs (MLWS).



## Occupancy and hole counts

Of the 18 quadrats investigated in the RM, 36 *Scylla* spp were encountered. Two were *S. serrata* and the rest *S. olivacea*. The size of the crabs consistently mirrored hole

size suggesting either excavation or size-selection. The size composition of the burrowing crabs was not significantly different ( $t = 0.47$ ,  $p = 0.640$ , d.f. = 38) from that of those caught by traps in the Jolly-Seber study (7.31 and 7.25cm ICW, respectively). *S. olivacea* appears to be ubiquitous in this mangrove, whereas *T. crenata* is limited to the mangroves at lower shore height (Figure 6). In contrast, *B. vinosus* and *Episesarma versicolor* were only encountered at higher elevations. There appears to be little difference between crab densities in similarly elevated areas regardless of the dominant tree species. Two-way analysis of variance showed that there were no significant differences between the catch rate at each location ( $f = 0.96$ ,  $p = 0.452$ , d.f. = 3). However the catch rate for each species was significantly different ( $F = 9.66$ ,  $p < 0.001$ , d.f. = 3), although interaction was insignificant ( $F = 1.99$ ,  $p = 0.093$ , d.f. = 15). The number of *S. olivacea* per quadrat suggests a density of  $35.6 \pm 5.7$  ( $\pm$ SE) crabs per hectare which is in the lower range of the Jolly-Seber estimate.

## Discussion

Trap-based methods for estimating density have been criticised for a reliance on a feeding response of the targeted organism which may vary and thereby skew sampling (Williams & Hill, 1982). However, a prior study found that the catch rates of fishers are not affected by any of the investigated physical parameters, namely salinity, temperature, shore height or the stage of the lunar cycle which may influence moulting (Walton *et al.*, 2006a). Moulting stage may affect catchability although recruitment was found to be continuous and it is likely that a similar proportion would be excluded at every sampling. Large mud crabs may be selected for as a result of competitive interactions in and around the trap (Miller, 1990) or assuming they are more active they may be more likely to encounter a trap (Williams & Hill, 1982). However, the index of dispersion ( $\text{standard deviation}^2 / \text{mean catch trap}^{-1}$ ) of experimentally-caught *S. olivacea* in the RM was 1.50 indicating that distribution of the crabs in the traps was random. A maximum of eight crabs were found in a single trap, which suggests limited competitive interaction between crabs. Moreover, the close spacing of the traps should eliminate any selective effects related to the increased range of larger crabs. Initially it was hypothesized that the different immersion times of traps and lift nets may select for different sizes, but preliminary studies found no significant size selection and hence traps were chosen for the experimental trapping.

While fishing pressure may play an important role in determining mud crab abundance in the DM, the low numbers of other species of crabs that are not fished suggests this habitat to be severely degraded by the mangrove clearance and substrate removal. The close proximity of the NFM where there is good recruitment of mud

crabs as evidenced by the large numbers of small crabs suggests there is a good supply of juveniles. It may be that habitat critical to settlement and metamorphosis has also been degraded, the mangrove fringe was found to be critical to the recruitment of *S. paramamosain* in Vietnam (Walton *et al.*, 2006b).

The lack of significant difference between the CPUE<sub>exp</sub> of traps in the RM and the NFM indicates that the RM supports the development of a crab population density equivalent to any of the mangrove habitats studied. This is consistent with observations made in Pagbilao mangrove in the Philippines where no significant differences between replanted and natural *Rhizophora* spp. stands were detected in the distribution of either shrimp or fish (Ronnback *et al.*, 1999). High crab densities have also been reported in replanted monospecific *A. marina* and *R. mucronata* stands in Kenya which suggested that reforestation encouraged crab repopulation (Bosire *et al.*, 2004).

In the present study the catch rate at the NBM was significantly less than that recorded at the other natural site NFM, even though local fishers reported low fishing pressure. The absence of small mud crabs in the NBM and larger mean size when compared with the other more open sites, suggests that the mud crab population at this site may be recruitment limited as a result of the relatively narrow channel to the open shoreline. This is supported by the higher abundance of other crab species, which suggests that this habitat could support greater densities of mud crabs. A similar effect can be seen in the RM, where a decline of approximately 50% in relative mud crab abundance over a two year period was accompanied by a corresponding rise in the numbers of *T. crenata* and *B. vinosus* caught, from 16% in 2002 to 61% in 2004. *T.*



*crenata* is omnivorous like *Scylla* spp. and has a similar diet (Cannicci *et al.*, 1996; Hill, 1976; Prasad & Neelakantan, 1988). Grapsids which form an important part of the diet of *S. serrata* (Hill, 1976) consume >95% of the predated propagules (Smith *et al.*, 1989) and any reduction in grapsid predation secondary to a decrease in *S. olivacea* density may affect mangrove species distribution, colonization and regeneration. In Kenya, the intense predation of *Rhizophora* spp. propagules by grapsid crabs can hinder reforestation efforts. (Dahdouh-Guebas *et al.*, 1998) However the impact of reduced *S. olivacea* densities may be more than compensated for by the increased abundance of *T. crenata*. The dietary preferences of *B. vinosus* are as yet unknown, although its robust claw morphology indicates a diet of molluscs (that are also a part of the diet of *S. olivacea*).

The experimental trapping in 2004 in the RM showed that there was no effect of elevation (0.69 – 1.2m above MLWS) on the likelihood of catching either *S. olivacea* or *T. crenata* although the latter is believed to be less resistant to desiccation than the other two species (unpublished data). *B. vinosus* was more likely to be caught at higher elevations. Burrow excavation also found *B. vinosus* at higher elevations, *S. olivacea* throughout the range examined and *T. crenata* only at lower elevations.

The initial 2002 *S. olivacea* density estimates in RM ranged between 186 - 401 mud crabs ha<sup>-1</sup>. This suggests that their distribution may be patchy, possibly related to the availability of suitable sediment for burrowing. *S. olivacea* is reported to be a more residential, burrowing species in contrast to the more mobile species, *S. serrata* and *S. tranquebarica* (Estampador, 1949). Over a short period this behaviour validates the assumption that the population is closed, so the Lincoln-Petersen estimates should be

an accurate reflection of population densities. Initial single mark-recapture experiments in 2002 suggested that *S. olivacea* did not move and probably foraged around a burrow, as suggested by (Estampador, 1949).

Estimates of population density can be extrapolated from the  $CPUE_{exp}$  at the NFM and NBM, based on the assumption that the competitively fishing inner traps are catching a constant proportion of the *S. olivacea* population. However, confidence limits are likely to be large. The resulting figures for the NFM and the NBM are 426 and 75 mud crabs  $ha^{-1}$ , respectively. The removal fishing experiment in the NFM gave an estimate of population density approximately double that extrapolated from the NFM  $CPUE_{exp}$ . The difference could be due to the removal of mud for dyke construction several years earlier that resulted in longer inundation times and perhaps more favourable conditions for mud crabs. Assuming traps in the experimental trapping in the RM in 2004 were catching the same proportion of *S. olivacea* as in 2002, the population has decreased to 97.7 crabs  $ha^{-1}$  for the *Rhizophora* spp. area and 84.5 crabs  $ha^{-1}$  for the *Sonneratia* spp. area. This indicates a population size in the plantation of 4200 *S. olivacea*.

The reduction in density estimated using the trapping grids in the RM in 2002 and 2004 suggests that the population has decreased by 66.8%. This is in agreement with  $CPUE_{fish}$  of local fishers that also suggested a decrease in the abundance of mud crab between 2002 and 2003 (Walton *et al.*, 2006a). The mud crab population could recover if immature crabs (<8cm ICW, unpublished) were not removed from the mangrove.

The 2003 multiple mark-recapture experiment in the RM is the first time a Jolly-Seber model has been used to estimate mud crab density. The sharp rise in density during the study from 36 – 138 mud crabs  $\text{ha}^{-1}$  was caused by a sudden increase in recruitment, as indicated by a decrease in the mean size of the crabs caught. The monitoring of fisherman's catches had shown that there was a significant fall in  $\text{CPUE}_{\text{fish}}$  from 1.58 to 0.86 *S. olivacea* trap $^{-1}$  between June 2002 and October-December 2003 (Walton *et al.*, 2006a). This corresponds well with the fall in the population density over the same time frame as estimated by Peterson's method (294 *S. olivacea*  $\text{ha}^{-1}$ ) in June 2002 and by the Jolly-Seber method in October-December 2003 (38-138 *S. olivacea*  $\text{ha}^{-1}$ ). A similar trapping study in the Ranong mangroves in Thailand suggested lower densities of *S. olivacea* (21-28  $\text{ha}^{-1}$ ). However, a CPUE of 0.42 *S. olivacea* trap $^{-1}$  (Moser *et al.*, 2005) suggests much lower densities than estimated in the RM. Although the relationship between CPUE and population density may be non-linear, lower densities still result in lower CPUE.

Burrow excavation in the RM in 2004 suggested a population density (35.6 *S. olivacea*  $\text{ha}^{-1}$ ) which conflicted with the  $\text{CPUE}_{\text{fish}}$  (0.75 *S. olivacea* trap $^{-1}$ ) that corresponds to a higher population density. However, the burrow estimates probably only include mud crabs that are resident in the mangroves. Other estimates using burrow counts are much higher; in the Sundarban mangroves, Bengal, densities of 4800 – 6000 crabs  $\text{ha}^{-1}$  were suggested, of which the majority were 50 – 90cm CW (Nandi & Dev Roy, 1990). Using the same method Barnes *et al.* (2002) estimated the densities at Utende in Tanzania as 1228 crabs  $\text{ha}^{-1}$  in the mangrove fringe and 324 crabs  $\text{ha}^{-1}$  in the inner mangrove forest.

The close correlation between  $CPUE_{exp}$  and  $CPUE_{fish}$  and the density estimates suggest that CPUE can be used to monitor changes in relative abundance of mud crabs. Top predators and keystone species are frequently used as indicator species for ecosystem management. (Russ & Alcala, 1996; Sergio *et al.*, 2004; Simberloff, 1998). *S. olivacea* appears to fulfil these categories being a top predator that influences not only the abundance of other predators but also many prey species some of which play an important role in nutrient recycling and mangrove recruitment. Caution may be warranted when it comes to interpreting the data from areas where recruitment may be limiting or where fishing depletion is significant, although both result in decreased mud crab abundance which impacts the ecological function of the mangrove.

While there have been numerous studies quantifying the biodiversity of natural mangroves and evaluating associated fisheries (Alongi, 2002; Ashton *et al.*, 2003; Barbier, 2003; Fry & Ewel, 2003; Halliday & Young, 1996; Loneragan *et al.*, 2005; Mumby *et al.*, 2004; Ronnback *et al.*, 1999) and some studies of replanted mangrove sites (Adnan *et al.*, 2002; Kiso & Mahyam, 2003; Kosuge, 2001; Tri *et al.*, 1998), there has been only one comparative assessment, in mono-specific stands in the Arabian Gulf (Al-Khayat & Jones, 1999). From the present study, it is clear that replanted mangroves even mono-specific stands can be very effective in enhancing productivity and fisheries as indicated by the equivalent estimates of mud crab stocks in natural and replanted mangrove areas. The reduction in mud crab populations associated with degraded mangrove highlights the effectiveness of habitat management and rehabilitation in the conservation of stocks in unrestricted, open-access artisanal fisheries.

**Chapter 4:**

**Are mangroves worth replanting? A case study of a community-  
based project in the Philippines.**



**Abstract**

Competition for coastal land use and over-exploitation has reduced or degraded mangrove coverage throughout much of their distribution, especially in Southeast Asia. Timber production was the initial motivation for early mangrove reforestation projects. More recently, benefits from protection against erosion and extreme weather events and direct improvements in livelihoods and food security are perceived as justifications for such restoration efforts. This study examines the socio-economic impacts of a community-led reforestation project in the Philippines through survey of the local fishers. Revenues from mangrove fisheries, tourism and timber result in an annual benefit to the community of US\$315 ha<sup>-1</sup> yr<sup>-1</sup>. This figure increases to US\$564-2317 ha<sup>-1</sup> yr<sup>-1</sup> if the contribution of the mangrove to the coastal catch of mangrove associated fish and invertebrate species are included. Additional income could also be raised by selling carbon credits which could increase the value by US\$163-198 ha<sup>-1</sup> yr<sup>-1</sup>. This estimation only includes direct benefits to the community and not intangible benefits such as coastal protection which paradoxically is perceived by the community as one of the most important functions. More than 90% of all fishers, regardless of where they fished, thought the mangrove provided protection from storms and typhoons and acted as a nursery site and should be protected. Those fishing only in the mangrove perceived more benefits from the mangrove and were prepared to pay more to protect it than those fishing outside.

## Introduction

Mangroves are now recognised as important coastal ecosystems that provide a range of services and products (Primavera *et al.*, 2004). However early attitudes perceived mangroves as a wasteland (Calumpang & Menez, 1996) which meant that competition for space from urbanization, agriculture and more recently aquaculture, overexploitation of forestry products and changes in water quality have resulted in world wide losses of approximately 33% in 50 years (Alongi, 2002). Much of the remaining mangrove is degraded. Appreciation of the services and products provided by mangroves has been growing and were recently valued at US\$9,900 ha<sup>-1</sup> yr<sup>-1</sup> (Costanza *et al.*, 1997). Acknowledgement of the protective role of mangroves after the recent S. E. Asian tsunami has also increased awareness of mangrove benefits (Dahdouh-Guebas *et al.*, 2005; Danielsen *et al.*, 2005; Kathiresan & Rajendran, 2005). Spurred by realization of their value and by increasing environmental concerns much effort has gone into rehabilitating degraded or deforested mangrove areas (Alongi, 2002; Field, 1998a; Kaly & Jones, 1998). The largest of these efforts is in Bangladesh, where 120,000 ha of mangrove forest have been planted (Saenger & Siddiqi, 1993). However, most replanting uses only one or two mangrove species (Alongi, 2002). In the Philippines this has resulted in mono-specific stands of the economically valuable and easily-planted *Rhizophora* spp. (Primavera *et al.*, 2004; Walters, 2000, 2004). While there have been some studies of faunal recruitment into replanted mangroves (Al-Khayat & Jones, 1999; Bosire *et al.*, 2004; Crona & Ronnback, 2005; Macintosh *et al.*, 2002a) it is not yet clear whether such re-constructed habitats fulfil the same ecological functions as natural intact mangrove. Moreover as mangrove reforestation is often used a tool for improving the livelihood and food security of the local population it is important to assess such benefits. This

study concludes that replanting mangroves can have a significant economic impact on the lives of coastal communities and can provide services equivalent to intact natural mangroves. Seafood production was also found to be equivalent to that of brackish-water pond aquaculture production. Acknowledgement of the value of replanted mangroves compared with other coastal activities and the benefits they bring to the more economically-vulnerable coastal dwellers should support better informed policy and decision-making with regard to coastal habitat restoration.

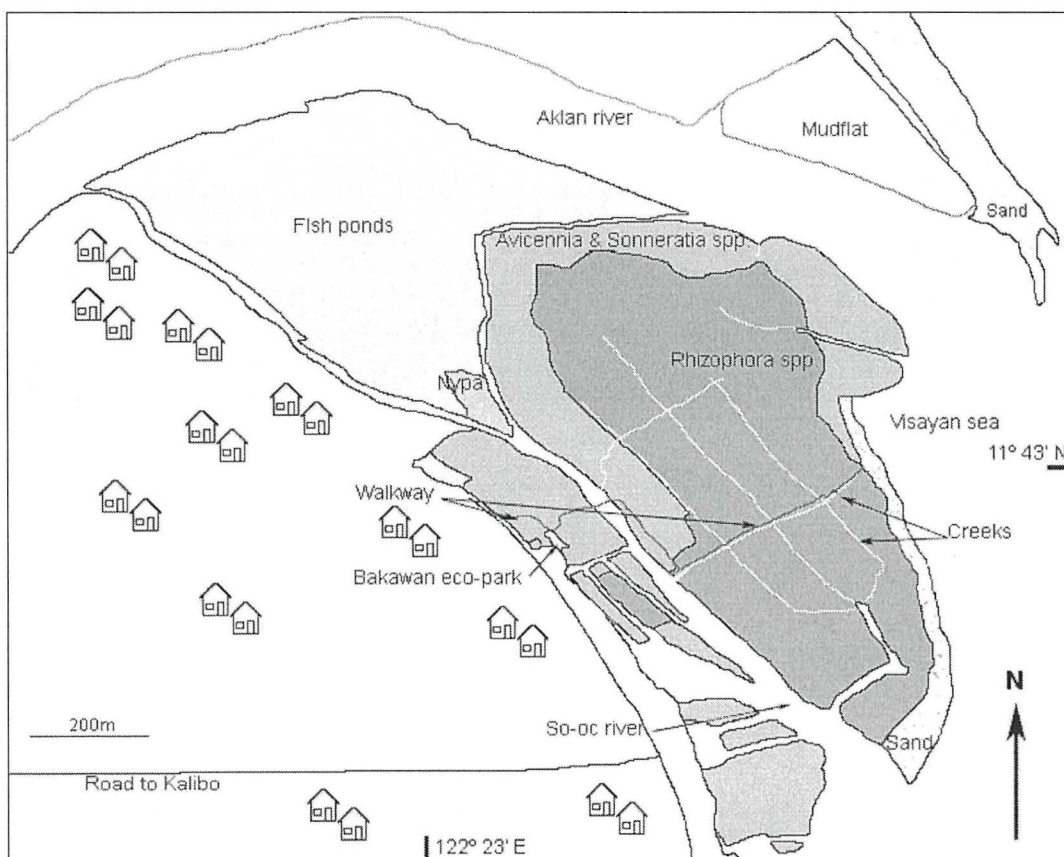
## Methods

The present study site was selected as an example of successful mangrove reforestation and focused on a replanted mangrove situated at the mouth of the Aklan River, in the Aklan province of Western Visayas, Panay Island, Philippines. The mangrove is geographically isolated from other major mangrove areas, the nearest being a 73ha basin mangrove 25km NW of the study area although there are some small patches of 1-5ha approximately 10km distant. The study area was well known to the authors through fisheries studies over the previous 3 years (Walton *et al.*, 2006a) and good links were already developed with the community. The mangrove was replanted on mudflats once thickly forested with mangrove but exploitation for firewood and building materials left only patches remaining (DENR, Undated). The aim of the reforestation plan was to stabilize the shoreline, decrease sedimentation offshore and increase fish stocks and wood production. The mudflat was initially planted in 1990 with 45ha of *Rhizophora* spp and 5ha of *Nypa fruticans* by a co-operative of 28 local families (KASAMA, Kalibo Save the Mangrove Association). An additional 20ha of *Rhizophora* spp was planted in 1993/94 (Primavera *et al.*, 2004). Pest damage to the plantation in 1997 was followed by infilling of naturally-recruited *Avicennia marina* and *Sonneratia alba*. Recent mapping of the mangrove forest suggested that although the area of *Rhizophora* spp. has decreased to 43ha, natural recruitment had increased overall mangrove cover to 75.5ha (Figure 1). An ecotourism park constructed by the NGO USWAG (United Services Welfare Assistance Group) using Australian funding (AusAid) employs locals to maintain a one kilometre walkway through the mangrove forest and staff the refreshment areas. Co-operation between KASAMA, USWAG and local government was instrumental in the success of the project. Also crucial was the awarding of land tenure rights in 1994



to KASAMA by the DENR (Philippines Department of Environment and Natural Resources) which has enabled protection of the resource. Recently the FAO cited the Buswang mangrove as an example of excellence in forest management (Cadaweng & Aguirre, 2005).

Figure 1: Map of the Buswang replanted mangrove forest in 2004 (houses represent part of the surveyed settlement area).



A questionnaire was designed to assess the value of fisheries activities and the attitudes and socio-economic background of the fishers (Appendix 1). In Section 1 respondents were asked open-ended questions regarding the area fished, the gear used, the amount of fish and shellfish landed per trip, selling price per kilo, boat



ownership (if one was used) and sharing of catches. The second page asked in more detail about the average number of kilos of each species landed per month and their average size. In Section 2 respondents were asked open-ended questions about the frequency, income and expenses of their fishing/gleaning activities during the lean and peak months as well as information on other income and how they earned it. Section 3 asked Yes/No questions on mangrove benefits and their willingness to pay (WTP) was assessed in three ways. The interviewees were presented with a choice of mangrove benefits and asked if the replanted mangroves need to be protected and whether they would pay to protect the mangrove to prevent hypothetical encroachment from pond developers and if not, why? They were asked in an open-ended scenario question whether the government should sell the mangrove for conversion to aquaculture ponds and, if so, for how much. They were also asked whether they themselves would sell the mangrove forest, if they owned it, and for how much. Section 4 of the questionnaire assessed the socio-economic profile of the interviewee and assets in terms of house, land, boat and fishing gear using multiple choice questions.

A pilot study was conducted to help refine the questionnaire. After an initial training session, interviews by four enumerators were observed for one day to remove any heterogeneity. For the first two weeks, daily debriefing sessions were held with the enumerators to identify problems during the survey. Each face-to-face interview was conducted over half an hour in the local Aklanon dialect. The respondents were assured of neutrality and complete anonymity. Initially, the local councillors from each barangay (village) introduced the enumerators to all the known fishermen in each of the 5 surveyed barangays that surround the mangrove. At the end of each

interview the respondents were asked to name 6 other people who fished or gleaned in the mangrove. Once the enumerators could no longer find new fishers to interview, they moved to the next barangay. In this way it was assumed that almost all fishers were covered in the sampling.

Fishers who worked on other peoples' boats and were already included in the fishery survey were excluded from further analysis. The fishers were classified into 4 groups: (1) mangrove only, those who only used the mangrove including the creeks, (2) mangrove +, those who fished in the mangrove area and in other areas, (3) shoreline, those who fished on the shore including the estuary, shoreline and shallow sub-tidal fishery up to 100m beyond the mean low water spring tide level, (4) coastal, those who only fished just offshore, including all fishing more than 100m beyond mean low water spring tide level. The species caught were taxonomically grouped by phyla (molluscs) or by family (fish). Crustaceans were split into the swimming crabs, (Portunidae, excluding *Scylla* spp.), mud crabs (*Scylla* spp.), and prawns (Penaeidae).

The responses to the questionnaires were subjected to multivariate analysis using PRIMER (Plymouth Routines in Multivariate Environmental Research (Clarke & Warwick, 2001). Responses were first subjected to cluster analysis using the Bray-Curtis index of similarity and subsequently differences in responses were tested *a priori* for significance with the ANOSIM method (one way analysis of similarity) (Clarke & Green, 1988). This gives an *R* statistic that is a measure of the differences in response between groups.

A simple one page survey in English and Tagalog asked eco-tourist visitors thirteen open-ended questions about where they had travelled from, how many times they had visited the site and how large their group was (Appendix 2). They were also asked how much they had paid travelling here and on food, and how much extra they were willing to pay and if not why not. Their sex, age and education level was recorded. Information on visitors was obtained from the operators. Revenues from the sustainable thinning of the mangrove and from sales of propagules were obtained from KASAMA.

## Results

Of the 4550 households in the five barangays, 242 families were identified as fishing or gleaning. Of those, 113 people fished or gleaned within the mangrove to supplement income or food supply supporting 465 family members.

The respondents identified 91 species that were fished or gleaned in the mangroves, on the adjacent shoreline or coastally. The catches from the coastal fisheries formed the greatest proportion of the catches landed in the surveyed sectors both by weight (66%) and by value (63%) (Figure 2). Shoreline catches formed 28% by weight and 32% by value and the mangrove fisheries formed 6% of the catches by weight and 5% by value. The dominant families by value were the Scombridae and Carangidae composing 42% of the landings, the majority of which were caught in the coastal fisheries.

Within the mangroves the gleaning of molluscs formed the greatest percentage by weight of the landings ( $111 \text{ kg ha}^{-1} \text{ yr}^{-1}$ ) but the high value portunid, *Scylla* spp, returned the greatest income of US\$99.8  $\text{ha}^{-1} \text{ yr}^{-1}$  (US\$1 = 54.66 Pesos). Some animal taxa were found exclusively in the mangrove forest including the Grapsoidea, Sergestidae, as were some species in the phylum Mollusca including *Polymesoda erosa* and *Terebralia sulcata* (Figure 3). Other animal taxa including *Scylla* spp. and the penaeids (including *Penaeus monodon*) were caught mostly in the mangroves and from the shoreline. The landings from the mangroves represent a harvested biomass of  $294 \text{ kg ha}^{-1} \text{ yr}^{-1}$ , a value of US\$213  $\text{ha}^{-1} \text{ yr}^{-1}$  and an annual gross income for these districts of US\$16,057. However, only 50% of that is sold, with the rest being consumed by the fishers. There was no significant correlation between the percentage

consumed of each species and its market price (Pearson's correlation coefficient = -0.189,  $p = 0.317$ ). Only 5% of the gross return from gleaning was expended on consumables including bait and materials. The mean time spent gleaning per trip was 3.5 hours  $\pm$  0.4 ( $\pm$ SE) with a mean number of visits of 44.2 year<sup>-1</sup>  $\pm$  5.4 ( $\pm$ SE). The shoreline and coastal fisheries resulted in total annual incomes for the area of US\$100,798 and US\$218,463 respectively.

Figure 2: Catch (kg) by taxonomic family caught in the different areas. The locations include catches within the mangrove, on the shore including catches from outside the mangroves but within 100m offshore of mean low water springs, and coastal catches greater than 100m offshore of mean low water springs.

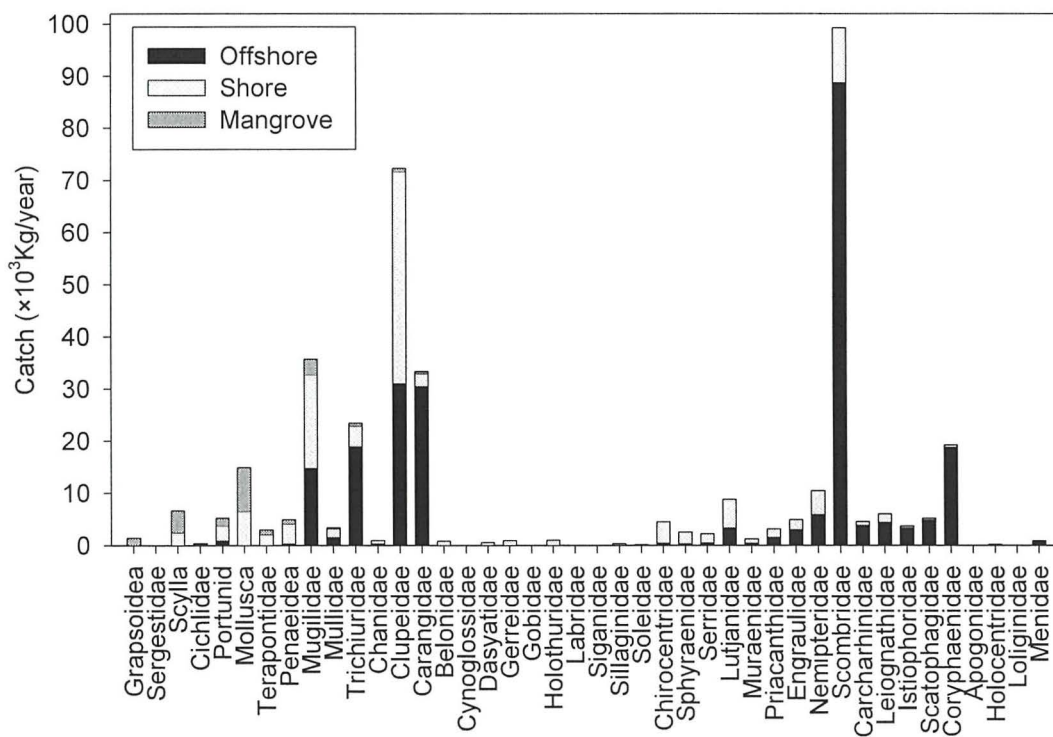




Figure 3: The percentage value by location caught of each taxonomic family or group. The locations include catches within the mangrove (dark grey fill), on the shore including catches from outside the mangroves but within 100m offshore of mean low water spring tide level (light grey fill), and coastal catches from greater than 100m offshore of mean low water springs (black fill).

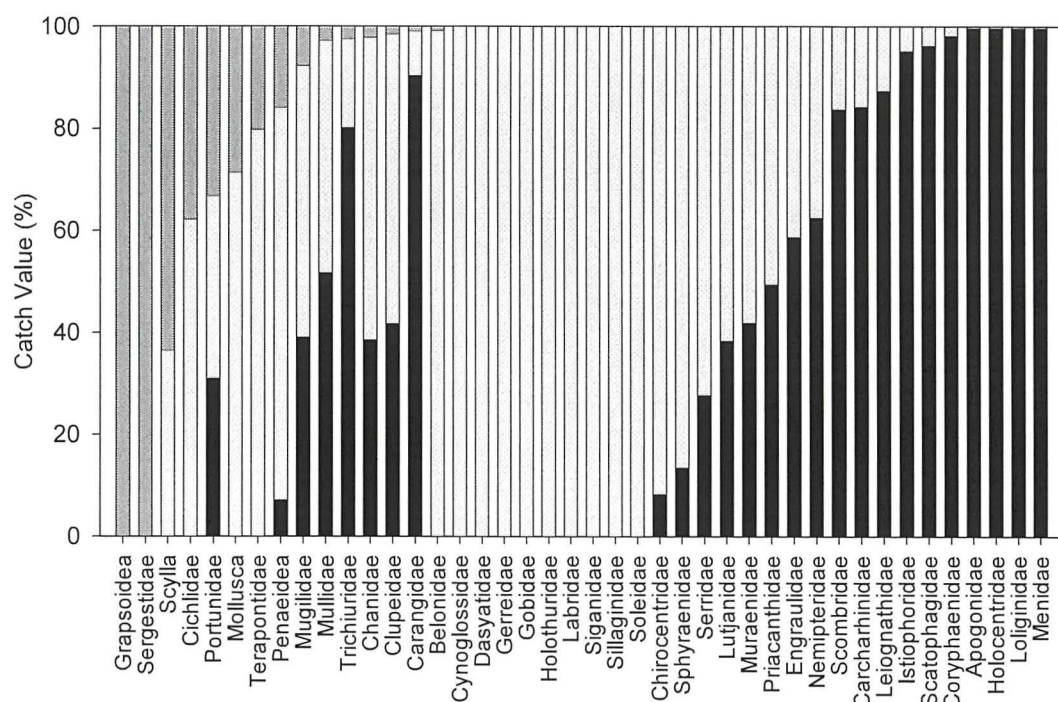


Table 1 Mangrove benefits perceived by the groups of fishers (presented as percentage of those responded positively) who use the mangrove only, the mangrove in conjunction with other habitats, the shore only and coastal area only and the percentage who want to protect the mangrove and the amount in US dollars they are willing to pay.

	Mangrove	Mangrove+	Shore	Coastal	All
Increases fishing	81	82	79	56	73
Nursery site	97	94	86	88	91
Acts as a barrier against storm damage	100	97	93	90	95
Increases biodiversity	84	85	79	63	77
Acts as sediment trap	84	82	86	61	77
% who want to protect the mangrove	100	100	97	95	98
Annual mean donation offered (US\$)	7.92	4.01	2.27	2.38	4.00
Annual mean income	1090	1446	1787	1346	1427

Most fishers (95%) thought that the mangrove acted as a barrier against typhoons and storms and similar numbers thought that mangrove forests act as nurseries for juvenile fish and crustaceans and molluscs (Table 1). However, only 73% thought that mangroves directly increased fisheries catches. Generally the group that fished only in

the mangrove (Group1) perceived more benefits from the mangrove and were prepared to pay higher sums to protect it, even though the mean salary of this group was the lowest. Multivariate analysis was used to examine differences in the perceived mangrove benefits to the 4 user groups. Multidimensional scaling plots based on similarities produced by cluster analysis using the Bray-Curtis index of similarity and a subsequent ANOSIM test suggested significant differences in perceived benefits ( $R = 0.497$ ,  $p < 0.001$ ). Significant differences between all groups were revealed in pairwise comparisons (all pairwise comparisons  $p < 0.001$ ). Comparison of the median incomes using a Kruskal-Wallis test followed by a Dunn's pairwise comparison suggested fishers that only gathered food in the mangroves (Group 1) earned significantly less than those fishing on the shoreline (Group 3) but not those fishing coastally (Group 4) or those fishing both in the mangroves and elsewhere (Group 2) ( $H = 10.74$ ,  $d.f. = 3$ ,  $p = 0.013$ ). Tellingly, the amount offered to protect the mangrove by Group 1 (mangrove only) was 0.7% of their estimated annual earnings, compared with 0.13% and 0.15% offered by Group 3 (shoreline only) or Group 4 (coastal only) respectively. Analysis of variance suggested there was no significant difference ( $p > 0.5$ ) between the mean numbers of fishers in each group that would either oppose the government if it wanted to sell the mangrove for pond development (93.5%) or not sell the mangrove for profit for pond development if they were hypothetical owners (92.4%). Of those 6.5% who thought the government should sell the mangrove the median valuation per hectare was US\$12,806, compared to US\$18,295  $ha^{-1}$  by the 7.6% of fishers who would to sell it themselves.

In 2004, ~17,000 people visited the Buswang Ecopark each paying US\$0.18, generating a total income of US\$3,059 or US\$41  $ha^{-1}$  year<sup>-1</sup>. A total of 93 respondents

completed the Ecopark questionnaires. Of those only 53 were from separate groups. Foreigners made up 10.5% of the visitors. The mean return travel cost to the Ecopark was US\$0.62. The mean expenditure was US\$0.11 visitor<sup>-1</sup>. Sixty-six percent of visitors were prepared to pay more than the current entrance fee, 80% of these were prepared to pay \$0.36 US. Only 4% of visitors indicated their reluctance to pay more.

Income generated through mangrove propagule sales depended on demand but was generally very small. In 2003 only 1900 propagules were sold, raising US\$20.87. Subsequently in January 2004 1580 propagules were sold. Until recently harvesting of timber has not been permitted due to laws preventing mangrove cutting (Primavera *et al.*, 2004). However, thinning has now commenced and initial results suggest timber harvest rates of 200m<sup>3</sup> ha<sup>-1</sup>, selling at US\$ 4.47 m<sup>-3</sup>. This represented a gross income of US\$914 ha<sup>-1</sup>. The mangrove was planted in 1990, thereby giving an annual income from timber sales of US\$61 ha<sup>-1</sup> averaged out over the life of the plantation.

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## Discussion

The exact contribution of the mangrove to fisheries landings is notoriously hard to estimate. Previous studies have suggested the value of one hectare of mangrove to fisheries to be between US\$60 (Ron & Padilla, 1999) and US\$11,280 ha<sup>-1</sup> (Ronnback, 1999a). There are various reasons for the discrepancies between studies, including differences in productivity, difficulties in assessing the proportion of coastal fisheries that rely on presence of mangroves, difficulties in monitoring the landings both in coastal and mangrove fisheries. The current study approaches the problem from a different perspective by using interviews with fishers. This approach may be open to different sources of errors, such as inaccurate reporting. However, for one data subset (catches of *Scylla* spp.) comparison with quantified landings was possible (Walton *et al.*, 2006a) and indicated that questioning tended to under-estimate actual catches by only 12-14%.

In estimating the value of fisheries that are dependent on the mangrove, the most reliable data are for those species that are only caught inside the mangrove. These are valued at this study site at US\$24 ha<sup>-1</sup> yr<sup>-1</sup>, of which molluscs account for 76%. Estimated standing stock of various species of edible molluscs in Bais Bay, Negros Oriental was 70-1,400 kg ha<sup>-1</sup> wet weight (Alcala & Alcazar, 1984). Inclusion of all species caught within the replanted mangrove increases the valuation to US\$213 ha<sup>-1</sup> yr<sup>-1</sup>, of which landings of mud crabs and penaeid prawns contributed 50%.

Mangroves are widely thought to contribute to coastal fisheries production either by acting as a food source (directly or indirectly) or as a nursery due to their high productivity and complex structure (see reviews by (Hogarth, 1999; Kathiresan &



Bingham, 2001). (Beck *et al.*, 2001) suggested that nursery habitats should contribute more to the adult population than other areas though enhanced densities, growth and survivorship of juveniles and disproportionate recruitment into the adult population. Several studies have demonstrated increased densities of juveniles in mangroves compared to other habitats (Chong *et al.*, 1990; Lugendo *et al.*, 2005; Nagelkerken & van der Velde, 2002; Robertson & Duke, 1990; Vance *et al.*, 1990). Others have demonstrated improved survival of juvenile fish and prawns in natural and experimental mangrove habitats (Laegdsgaard & Johnson, 1995; Macia *et al.*, 2003; Robertson & Duke, 1990). Mangroves are also thought to improve feeding rates of small fish (Laegdsgaard & Johnson, 1995) and increase juvenile growth rates (Robertson & Duke, 1990) and have been shown to contribute to stocks of fish in coral reefs (Mumby *et al.*, 2004); (Calumpong & Menez, 1996). Some caution is needed in quantifying the significance of such contributions to coastal fisheries as mangrove area may be co-correlated with a number of other variables such as length of coast line, rainfall, intertidal area and tidal amplitude (Lee, 2004) or confounding factors like non-standardized fishing effort (which varies with fishing gear and fish species) and mismatch between catching and landing sites (Primavera and Altamirano, unpub.). The contribution of mangroves to subsistence fisheries has been estimated to be between 10-90% (Nickerson, 1999). Using the most cautious estimate of a 10%, in the present study the contribution of fish families that are associated with mangroves (Ronnback 1999) gives an estimated annual value of the replanted mangrove to the shoreline and coastal fishermen of US\$250 ha<sup>-1</sup>. However, Singh *et al* (1994) (cited in Ronnback, 1999) estimates that for ASEAN countries the mangrove contribution to mangrove-associated species caught in coastal fisheries is 30% for fish (US\$703 ha<sup>-1</sup>) and 100% for penaeid prawns (US\$100 ha<sup>-1</sup>). Recent



studies have shown the dependency of juvenile stages of *Scylla olivacea* on the replanted mangrove (Walton *et al.* in press), so that the value of coastal fisheries for this species (US\$57 ha<sup>-1</sup>) should be included. Thus the replanted mangrove is estimated as being worth US\$860 ha<sup>-1</sup> to the fisheries outside the mangrove area and 1207 kg ha<sup>-1</sup> yr<sup>-1</sup> to total fisheries production worth US\$1073 ha<sup>-1</sup> both within and outside its boundaries.

It is not unreasonable to assume that the contribution of the Buswang mangrove to adjacent coastal fisheries is considerable, as it represents the only significant area of mangrove within 25 km. In the Philippines, up to 80% of the coastal catches of all mangrove-associated species are thought to be dependent on mangroves (Nickerson, 1999). Applying this estimate would increase the fisheries production of Buswang mangroves to 2568 kg ha<sup>-1</sup> yr<sup>-1</sup> or US\$2215 ha<sup>-1</sup> yr<sup>-1</sup>.

Revenues from the Buswang Ecopark averaged US\$41 ha<sup>-1</sup>, although more than half the visitors were prepared to pay twice as much in entry fees, and only 4% objected to price increases. Propagule collection is worth very little per hectare but probably means a great deal financially to those engaged in the collecting. However, the timber exploitation rate in Buswang (13.3 tonnes (t) ha<sup>-1</sup> yr<sup>-1</sup>) is similar to that of the Matang mangrove in Malaysia where 17.4 t of mangrove wood ha<sup>-1</sup> yr<sup>-1</sup> are harvested sustainably (Gan, 1995 in (Tipper, 2002), with a value of US\$60.93 ha<sup>-1</sup>

The survey suggests a total value of US\$564-2316 ha<sup>-1</sup> is entering the local community each year. This is equivalent to 12-51% of the income of all the 241 interviewed fishers. This may be an underestimate, as occasional and non-resident

users of the mangrove that glean for molluscs such as oysters and clams are likely to be under-represented. The value of food security to the population is difficult to assess but may be significant especially to the more vulnerable, poorer sections of the community. Estimations of frequency for gleaning often included comments such as “when we have no food” or “when I have no work” suggesting the mangrove is used as an important emergency food store for much of the population.

In Mexico, some farmers have sold credits for sequestered carbon resulting from a reforestation project to the International Federation of Automobiles (USA), for US\$10-12 tonne<sup>-1</sup> carbon (Eong, 1993). *Rhizophora* plantations are known to sequester up to 15 t ha<sup>-1</sup> carbon annually with another 1.5 t ha<sup>-1</sup> yr<sup>-1</sup> carbon is trapped in the soil (Alongi, 2002; Hogarth, 1999; Kathiresan & Bingham, 2001). Thus, in the future sale of carbon credits for a reforestation project such as Buswang may be valued at US\$163-198 ha<sup>-1</sup> yr<sup>-1</sup>

The interviewed fisher's attitudes to the mangroves were closely related to their dependency on the forest. Those who fished exclusively in the mangrove perceived greater benefits than the shoreline and coastal fishers and were prepared to pay more toward protection. Moreover more than 90% of this group would not sell the mangroves if they owned it and slightly more would not want the government to sell it. The price (US\$18,295 ha<sup>-1</sup>) offered by those that wanted to sell was at the lower end of the scale of agricultural land in the Philippines (US\$9,000-90,000 ha<sup>-1</sup>). This low price highlights the low value that many people place on mangroves due to a lack of education. However, this cannot be taken as the willingness to accept value

(WTA), as the majority would not sell suggesting an attachment that was worth more than money.

The economic evaluation of the Buswang mangrove shows that the services rendered are at least equivalent and frequently greater than those cited for natural mangroves in recent reviews (Costanza *et al.*, 1997). This suggests that mangrove replanting can be successful in replacing at least some of the services of natural mangroves. These have been valued more highly, up to US\$9,990 ha<sup>-1</sup> yr<sup>-1</sup>, but include estimates of US\$6,696 ha<sup>-1</sup> yr<sup>-1</sup> for waste water treatment and US\$4,539 ha<sup>-1</sup> yr<sup>-1</sup> for disturbance regulation (Costanza *et al.*, 1997). The recent tsunami has emphasized the protective value of mangroves (Dahdouh-Guebas *et al.*, 2005; Danielsen *et al.*, 2005; Kathiresan & Rajendran, 2005). Moreover a study in Orissa, India demonstrated that mangroves also protect against typhoons, a more frequently occurring phenomenon. Households protected by mangroves suffered 78% less in costs associated with typhoon damage than those unprotected households and 24% less than those protected by a dyke. (Badola & Hussain, 2005).

The current study only includes goods and services that directly benefit the local community economically. Undervaluation of mangroves is one of the primary reasons driving the conversion of mangroves to more profitable uses. This study suggests that fish production related to replanted mangrove ranges from 578 to 2568kg ha<sup>-1</sup> yr<sup>-1</sup>, which can equal that of aquaculture ponds. Statistics from the Philippines Bureau of Fisheries and Aquatic Resources in 2003 suggest that mean production from brackish water ponds in the Philippines is 1024kg ha<sup>-1</sup> yr<sup>-1</sup>. The replanted mangrove also supplies additional services providing an income from tourism of US\$41 ha<sup>-1</sup> yr<sup>-1</sup> and from sustainably-harvested timber of US\$60.93 ha<sup>-1</sup> yr<sup>-1</sup>. The most widely recognised

benefits of this replanted mangrove were coastal protection and the nursery function, for which 98% of the interviewees wanted to protect the mangrove.

After the 2004 tsunami, the current study provides timely support for arguments in favour of reforestation by demonstrating that replanted mangroves can be as productive as natural mangrove and can have seafood production equivalent to the brackish water ponds, thus having an important role in ensuring food security. These additional services make mangroves the best of the coastal reforestation options rather than less effective sand-binding vegetation such as *Casuarina* or coconut plantations..

**Chapter 5:**

**Significance of mangrove-mudflat boundaries as nursery grounds for  
the mud crab, *Scylla paramamosain*.**

This chapter has been published, Walton, M.E.M., Le Vay, L., Truong, L.M., Ut, V.N., 2006b. Significance of mangrove–mudflat boundaries as nursery grounds for the mud crab, *Scylla paramamosain*. Marine Biology DOI: 10.1007/s00227-006-0267-7.



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## Abstract

Fisheries managers frequently try to protect juveniles in order to preserve stocks. Juveniles can be protected by either implementing changes designed to avoid catching immature animals (e.g. increasing mesh size or altering fishing techniques) or protecting nursery grounds. To prevent the capture of immature animals, an estimate of size at maturity is required as well as a knowledge of both fishing methods and the exact location of the nursery grounds. Strong demand for juvenile mud crabs to stock aquaculture ponds has resulted in development of fisheries targeting crabs of all sizes from instar 1 to mature individuals. Using five different fishing methods, different stages in the life cycle of *Scylla paramamosain* were followed for a period of 16 months in an estuarine population in the Mekong Delta, Vietnam. Mangrove habitat utilisation begins when crabs settle out from the plankton at instar 1 (modal internal carapace width (ICW): 0.5 cm) amongst the pneumatophores at the mangrove fringe. Increasingly larger crabs were found deeper into the mangrove but they were still living on the surface (modal ICW size class: 1.5 cm). As their size increases, the crabs either dig burrows (modal ICW size class: 4.5 cm) or they live in the sub-tidal zone, migrating into the mangrove with each tide to feed (modal ICW size class: 4.5 cm). Larger crabs were caught offshore (modal ICW size class: 12.5 cm) where females accounted for 60% of the catch although of these, only 63% were mature. Recruitment of early instars was continuous but peaked in December to February. Subsequent peaks in the catch rates of larger size classes indicated the development of a single cohort with an estimated growth rate of 2.0 cm ICW per month. On the basis of abdominal width, females were estimated to mature at 10.2 cm ICW although at 9.7 cm ICW, 50% of females had disengaged abdomens. Abdominal disengagement occurred in males at the slightly smaller size of 9.1 cm ICW. Allometric relationships between

chela height and carapace width suggested 50% of males acquire mature chelae at 10.2 cm ICW. These results demonstrate the close linkage between early life stages of *S. paramamosain* and certain specific niches within mangrove habitats, with the main adult population found to be living sub-tidally at some distance from the mouth of the estuary. The study also highlights the special importance of the mangrove fringe, the border between the mangrove forest and the sea, an area which is particularly vulnerable to physical and anthropogenic impacts.

## Introduction

The mud crabs, *Scylla* spp. are found in intertidal and subtidal sheltered soft-sediment habitats throughout the Indo-Pacific region (Keenan *et al.*, 1998; Macnae, 1968) where they are fished for their meat and as seed for aquaculture. This provides an important source of revenue for small-scale fishermen (Keenan, 1999) but there have been signs of over-exploitation (Angell, 1992). A combination of over-fishing and habitat loss has resulted in both reduced landing rates and smaller mean capture size (Le Vay, 2001). Mud crab populations are typically associated with mangroves, and may act as a useful indicator for mangrove habitat condition (Chapter 3). However, despite the importance of identifying nursery areas in fishery and habitat management policies (Beck *et al.*, 2001), very little is known about the key mud crab habitats within mangroves or the size and stage at which crabs recruit into those habitats. Hill *et al.* (1982) have described habitat use by some life stages of *Scylla* spp. in Australia, with juveniles living and feeding on the intertidal mudflats, sub-adults living sub-tidally but feeding inter-tidally, and adults both living and feeding sub-tidally. A similar pattern has been inferred from fisheries landings of *Scylla paramamosain* in estuarine mangroves in Vietnam (Le Vay *et al.*, 2001) but there has been no detailed study of habitat use at the different life stages, particularly since the existence of four distinct *Scylla* species was recognised (Keenan *et al.*, 1998). Unlike sub-tropical estuarine populations in South Africa (Forbes & Hay, 1988), few megalopa and first crab instars have been found and there has been no direct evidence of recruitment of megalopa directly into mangroves (Moser & Macintosh, 2001).

Recently, to meet increasing demand for seed for aquaculture, new fishing techniques have been developed in some regions of southern Vietnam to target early instar mud

crabs. At the same time, parallel fisheries are exploiting all stages from juveniles to mature adults since there are no restrictions on landings or minimum landing sizes. The impact of this level of exploitation on crab populations is as yet unknown. In Australia, all berried mud crabs and females with an ICW of <13 cm and males <12 cm ICW are protected by the Mud Crab Fisheries Management Plan (1995). In South Africa, the original minimum landing size of 11.4 -11.5 cm ICW was raised to 14.0 cm external carapace width (Marine Living Resources Act 1998) as a result of a study which showed that 50% of female *S. serrata* were found to mature at 12.3 cm ICW (Robertson & Kruger, 1994).

The present study on *S. paramamosain* follows a single cohort from recruitment to maturity. It set out to quantify recruitment and habitat utilisation by monitoring life stage-specific fisheries, and to determine size at maturity in both male and female *S. paramamosain* in an estuarine population in the Mekong Delta, Vietnam.

## Methods

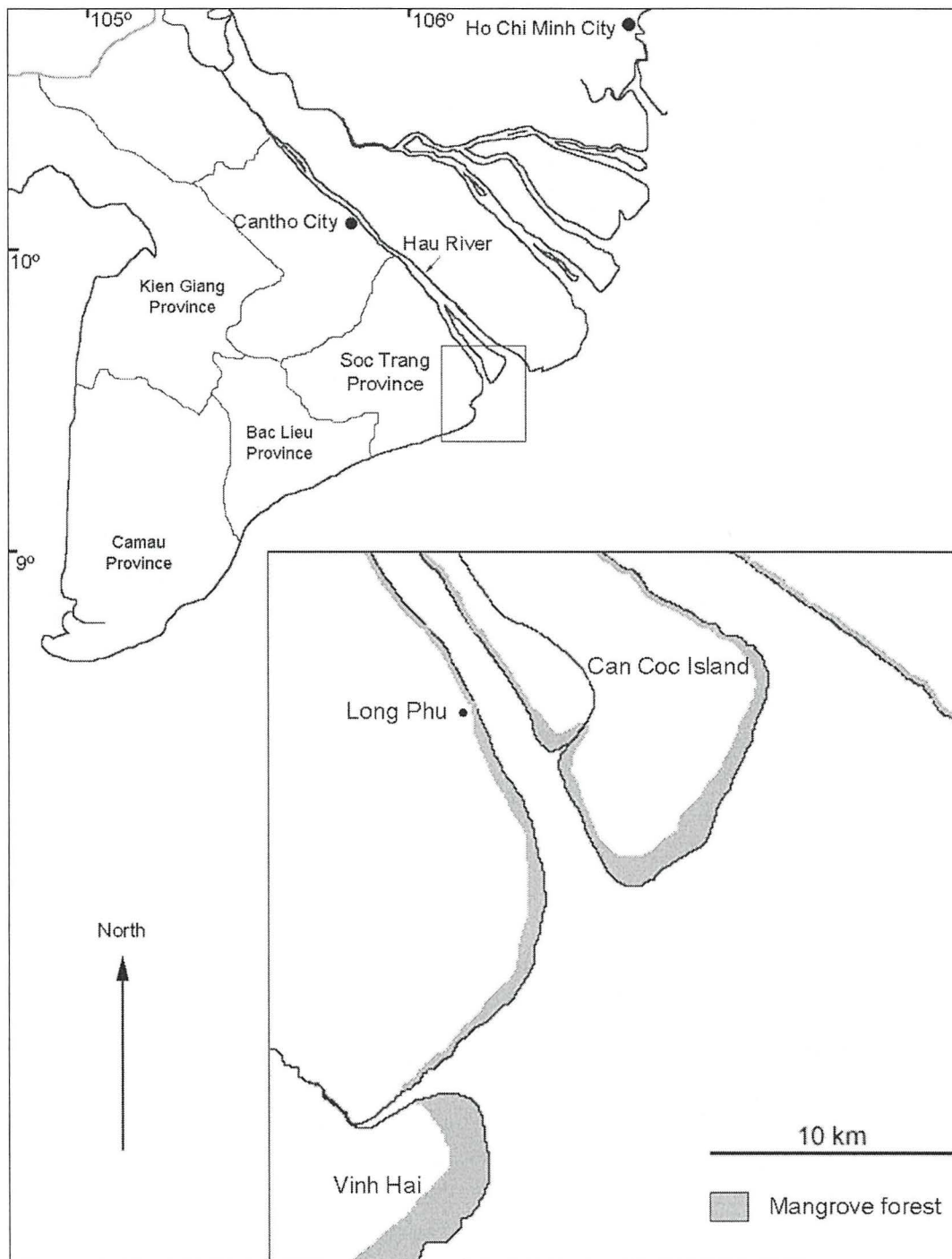
The current study focused on the seaward intertidal zone of Can Coc Island and the adjacent subtidal area. This island is situated in the mouth of the Hau River which is part of the Mekong Delta in southern Vietnam (Figure 1). The island is fringed by *Sonneratia caseolaris* that forms a seaward belt on the south-east of up to one kilometre in width with an intertidal mudflat extending 2 km seawards. The maximum tidal range is 3.8m.

Table 1: Fishing methods and sampled habitat, with the modal internal carapace width (ICW) size class of crabs caught by each method.

Fishery	Position	Modal ICW size class of crabs (cm)	Crab habitat
Scoop Net	Mangrove fringe	0 – 0.9	Tidal pools and pneumatophores
Torch Fishery	Inside mangrove	1 – 1.9	Mud surface, shallow pools at night
Fyke Net	Mangrove edge	4 – 4.9	Migrating out of mangrove at ebb tide
Hook Fishery	Inside mangrove	4 – 4.9	In burrows
Gill Net	Offshore (20-30m deep)	12 – 12.9	Subtidal



Figure 1. Location of the study area in the Mekong Delta, South Vietnam. Insert shows the study site on seaward shore of Can Coc Island.



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During the study, catches from five specialised fisheries that target the zones of the highest abundance of the different life stages of mud crabs were sampled (Table 1).

(i) At the mangrove fringe (within 50 m of the edge), very small crabs were caught using long handled scoop nets (4mm stretched-mesh) which were dragged over the flexible pneumatophores of *S. caseolaris* in tidal pools in the mangrove fringe between ebb and flood tide: using such scoop nets may have selected for smaller, less mobile crabs but the nature of the shallow intertidal pools means that all crabs present were caught.

(ii) Along the mangrove fringe (within 100 m of the edge), head torches were used at night at low tide to locate small crabs in the mangroves in shallow pools and hidden amongst mangrove roots.

(iii) Inside the mangroves, hooked metal rods were used to lever the crabs out of their burrows.

(iv) A fyke net (stretched mesh: 15mm), 500m of net that was buried in the sediment at the bottom and raised 3m on stakes at high tide with traps at each side to prevent lateral escape, was erected along the mangrove edge to catch any fish and crustaceans migrating out of the mangrove during ebb tide. (Both fishing with torches at night and using hooks to lever crabs out of burrows are non-selective as all crabs/burrows encountered are caught/searched, and the small mesh size of the fyke net also precludes size selection.)

(v) Finally, a gill net (stretched mesh: 70mm) deployed from a boat outside the estuary to a depth of 20-30m was lifted and cleared several times a day with the boat returning to the landing site every 3 days.

Catches from the five fishing methods were sampled over a period of 15 months from July 2003 to October 2004. Every month, at the commercial landing site, samples of crabs were sexed, counted, and ICW, chela height and abdominal width were measured using vernier callipers to 0.1mm accuracy. Species were identified according to (Keenan *et al.*, 1998) and (Macintosh *et al.*, 2002b) using a combination of cheliped spination and colour and carapace frontal lobes. Catch-per-unit effort (CPUE) (crabs  $\text{d}^{-1} \text{fisher}^{-1}$ ) was used as an index of relative abundance.

On the basis of abdominal shape, females were assigned to one of three maturity classes. Mature female crabs were identified by the typical U-shaped abdominal flap and the presence of setae on the fringe of the flap (Arriola 1940). Immature crabs were identified by a narrow abdominal flap, and pre-pubertal crabs by an intermediate abdominal shape and shorter fringing setae (Robertson & Kruger, 1994). Ovarian development in mature females (gravid females) was recorded by depressing the 1<sup>st</sup> abdominal segment to allow observation of ovaries under the carapace. The abdominal engagement was checked for in both sexes by lifting the flap with a dissecting needle. In both male and female immature *Scylla* spp. a chitinous protrusion from the sternite engages the abdomen and prevents it from opening and hence precludes mating (E.T. Quintio, pers. comm.). Similar bridges occur in both sexes of other immature portunids binding the abdomen to the 6<sup>th</sup> thoracic sternite (de Lestang *et al.*, 2003; Fielder & Eales, 1972; Ryan, 1967). In males, chela height was regressed against ICW and the resulting standardised residuals were then plotted against ICW to establish the increase in chela height that determined maturity. Probit analysis, based on 0.5 cm ICW size classes was used to determine the size at which 50% of the population underwent allometric change or abdominal unlocking (Robertson & Kruger, 1994).

## Results

The dominant species in the fishery was *S. paramamosain*, which accounted for over 99.9% of the catch. Less than 0.1% of the catch was made up of *Scylla olivacea*. Figure 2 shows the size-distributions of *S. paramamosain* caught using the five different fishing methods. Scoop nets were found to target crabs smaller than 1.5 cm ICW (modal size class: 0-0.9 cm). Dragging the scoop net across the pneumatophores caught crabs as small as instar 1 (ICW 3mm) and up to 4.9 cm ICW. Mud crabs found on the mud surface in the mangrove fringe at night using torches varied in size between 0 and 8.9 cm ICW (modal size class: 1.0 – 1.9 cm). *S. paramamosain* hooked from burrows in the intertidal zone varied from 1.0 to 11.9 cm ICW (modal size class: 4 – 4.9 cm). Those exiting the mangroves and caught in the fyke net were of a similar size (0 – 13.9 cm ICW; modal size class: 4 – 4.9 cm). Sub-tidally, the gill nets caught much larger crabs that were mostly mature (modal size class: 12 - 12.9 cm) although the sizes ranged from 5.0 to 15.9 cm ICW.

During the study period, there were large changes in salinity from freshwater conditions during the rainy season (September to November) rising to a peak of 20 psu during the dry season (Figure 3). Mean water temperatures varied between 28 and 30°C. A peak in the scoop net CPUE in December to February indicates a peak recruitment period when small crabs (6 mm mean ICW) were settling out on the mangrove fringe which coincides with a rise in salinity as the dry season begins (Figure 3).

Figure 2. Size class distribution of *S. paramamosain* caught with the 5 different fishing methods during the period 14/7/03 to 30/8/04.

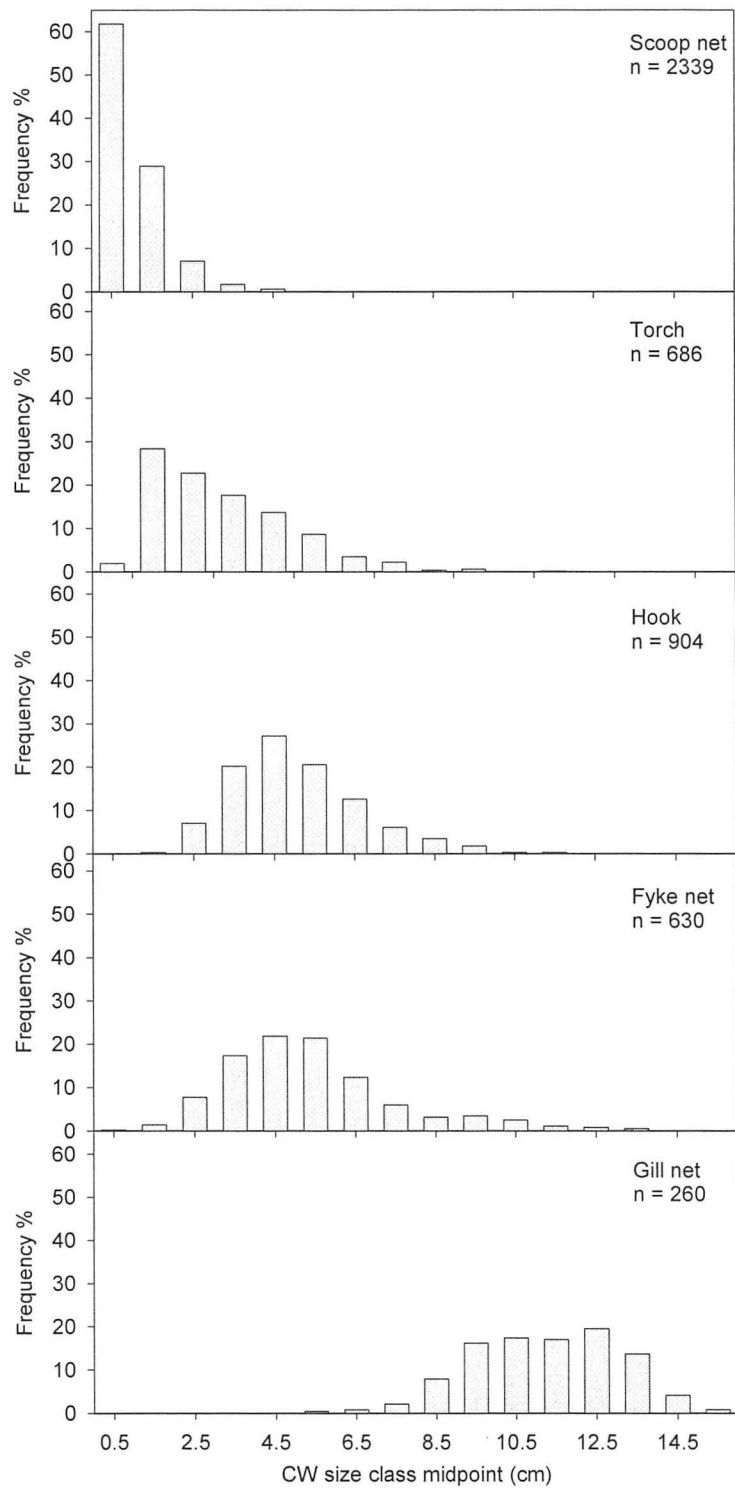
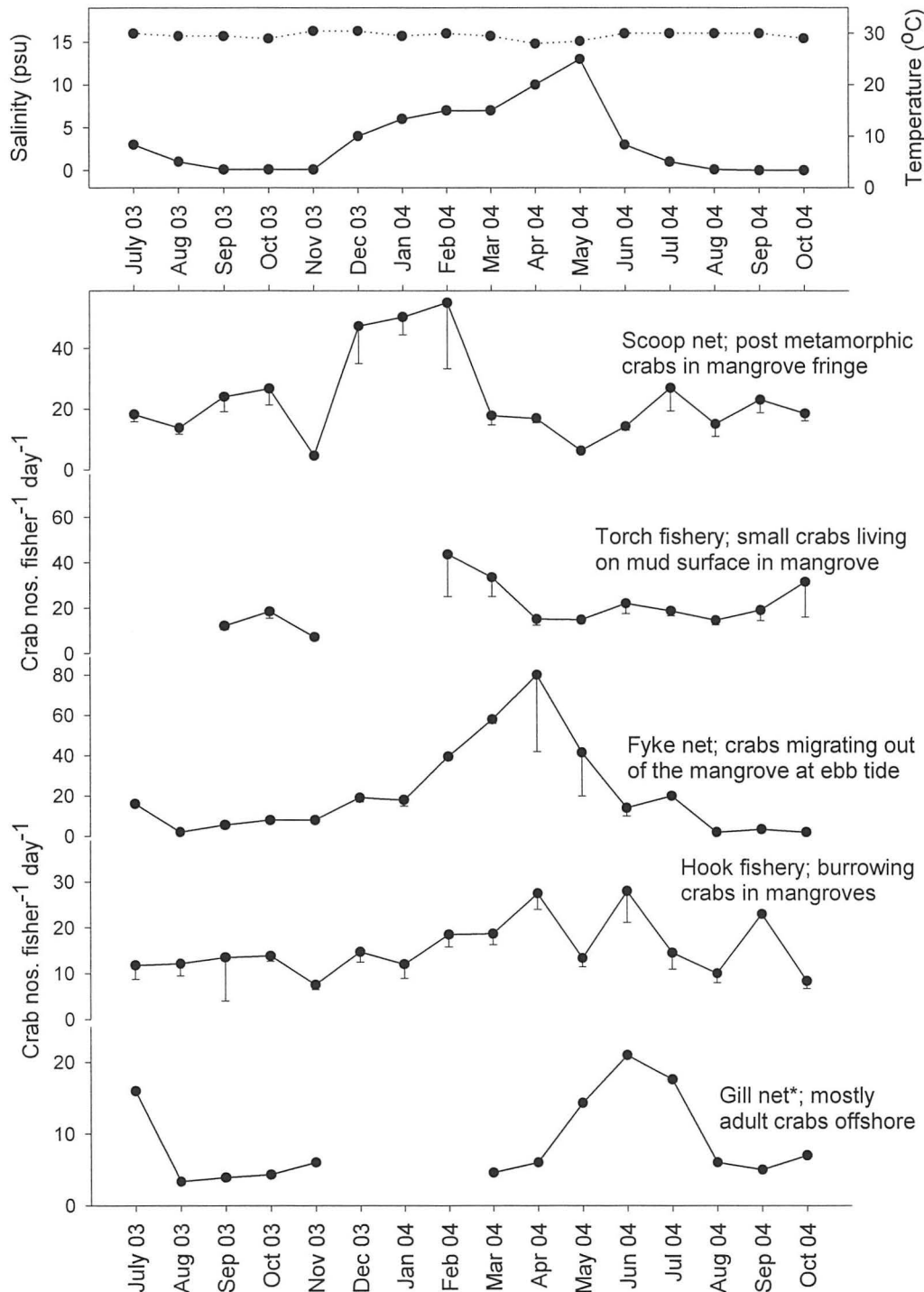




Figure 3. Mean number and standard error of mud crab caught fisher<sup>-1</sup> day<sup>-1</sup> (CPUE) with the 5 different fishing methods and the surface temperature and salinity profiles from the middle of the Hau Estuary. Crabs larger than 1.9cm ICW are excluded from the scoop net catches to emphasise recruitment.

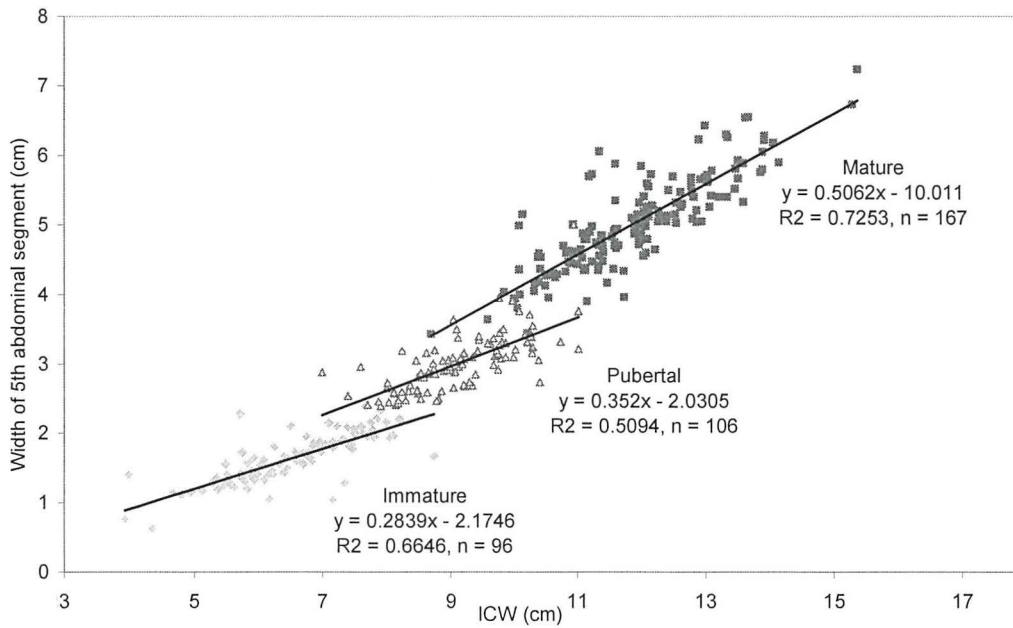
\*Gill net catches have no error bars as catch rate is presented as a mean of the 3 day catch.



The greatest CPUE from the torch fishery during the sampling period was in February. Fyke net catches of sub-adults migrating out of the mangrove peak in April. This corresponds with a decrease in the modal size class caught in the gill net in April to 8.0 – 8.9 cm ICW (Figure 3). No identifiable pattern is obvious in the hook fishery CPUE of crabs caught in the burrows. However, in June/July 2004, there is a peak in catches of adult crabs in the subtidal gill nets (as had been observed in the preceding year). The sub-tidal population consists mostly of mature *S. paramamosain*, with ICW of over 10.2 cm in 63% of the females and 76% of the males (see maturity estimates below). In contrast, less than 1.5% of the crabs caught exiting the mangroves at ebb tide and found in burrows at low tide were mature. While the 7 cm stretched-mesh size of the gill net would probably select for crabs larger than 6 cm ICW, the mode for crabs caught by this method is 12.5 cm ICW, suggesting that few small crabs live in the sub-tidal zone.

Female *S. paramamosain* with a mature abdominal shape were found as small as 8.6 cm ICW, while immature abdominal shapes were found in female crabs as large as 11.3 cm ICW. Gravid crabs were found as small as 10.1 cm ICW. Coupling prepubertal females as small as 7.7 cm ICW and males as small as 10.3 cm ICW were also caught (n=3). The allometric relationship between the carapace and the fifth abdominal segment changed in the three phases. Based on abdominal shape, probit analysis suggested the size at which 50% of females reach maturity ( $SM_{50}$ ) is  $10.23 \pm 0.17$  cm ICW (95% C.I.), with the pubertal moult occurring at  $7.91 \pm 0.16$  cm ICW (95% CI) (Figure 4).

Figure 4. Relationship of internal carapace width to abdominal width segment 5 in mature, pubertal and immature female *S. paramamosain* separated on the basis of abdominal width.



Using unlocked abdominal flaps as a proxy for maturity (Figure 5), probit analysis indicates 50% of male *S. paramamosain* have unlocked abdominal flaps at  $9.21 \pm 0.23$  cm ICW (95% C.I.). The  $SM_{50}$  of females is significantly larger at  $9.71 \pm 0.21$  cm ICW (95% C.I.) ( $\chi^2 = 5.98$ , DF = 1,  $p = 0.014$ ).

The allometric relationship between chela height and ICW in males is shown in Figure 6. The spread of the regression residuals suggest that the relationship changes when the crushing chela height increases from 3.4 to 3.5 cm. Probit analysis suggests this happens at  $10.18 \pm 0.23$  cm ICW (95% C.I.)

Figure 5. Percentage of males and female *S. paramamosain* with open abdominal flaps in each size class.

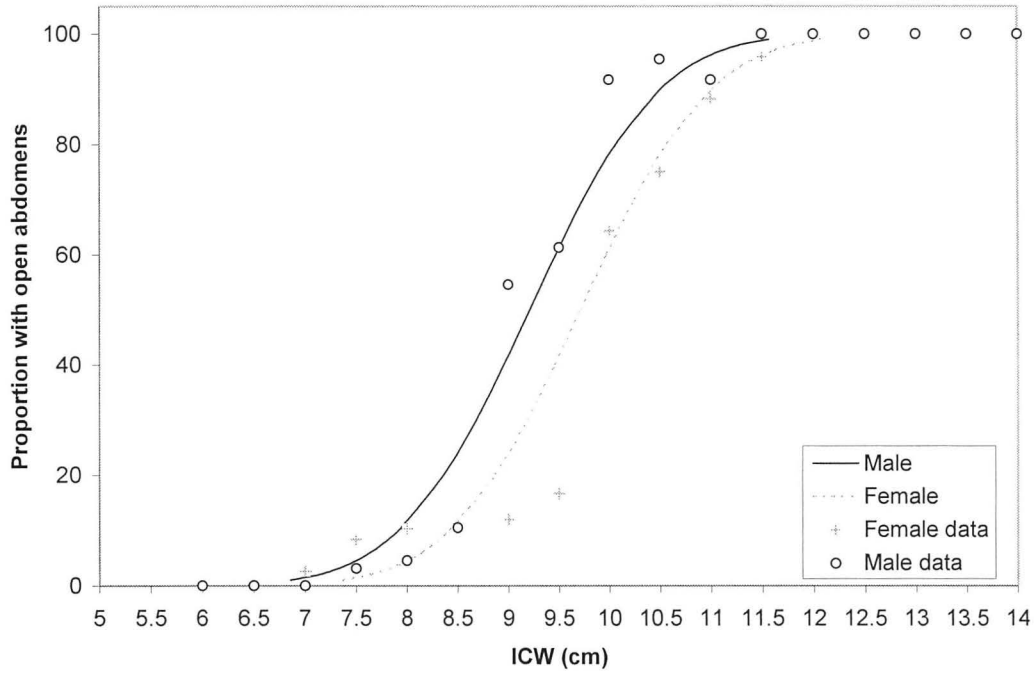
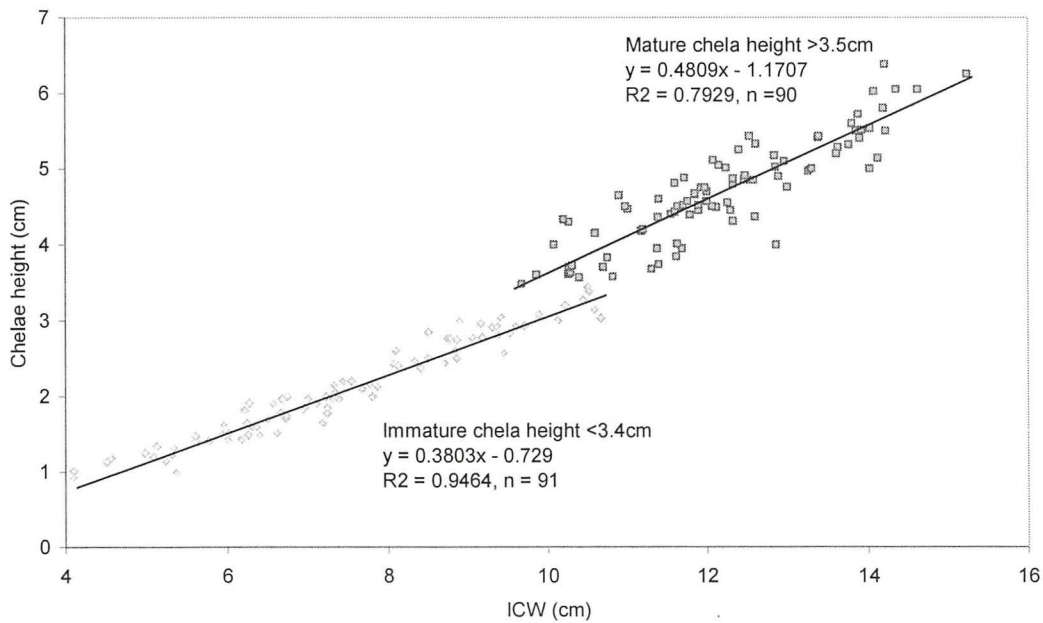


Figure 6. Relationship between ICW and chelae height of mature and immature male *S. paramamosain*.



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## Discussion

Only two species were encountered in this study, *S. paramamosain* and *S. olivacea*, which is agreement with earlier observations in the Mekong Delta (Le Vay *et al.*, 2001; Macintosh *et al.*, 2002b). The very low frequency of *S. olivacea* was unexpected. Two years earlier, *S. olivacea* accounted for 3.2% of the *Scylla* spp. catches (Ut, 2002). The reduced frequency of *S. olivacea* may be due to a reduction in the salinity of the mean monthly salinity from 7 to 4psu over this time period caused by increased riverine discharge rates (Bramslev, 2004; Kite, 2001). Certainly, in similar areas of higher salinity catches in the Gulf of Thailand, Kien Giang Province, on the southeast coast of Vietnam were mostly composed of *S. olivacea* (Macintosh *et al.*, 2002b). A recent a study in Bac Lieu Province, 100km south of the current study site reported the frequency of *S. olivacea* to be 10% and suggested *S. olivacea* to be more tolerant of high salinities than *S. paramamosain* (Christensen *et al.*, 2004).

The identification of juvenile *Scylla* spp. can be problematic (Keenan *et al.* 1998) although using a combination of the shape of the carapace frontal lobes and cheliped spination and colour was found to be effective in separating juvenile *S. paramamosain* and *S. olivacea* in the field (Macintosh *et al.*, 2002b). Commercial growout of seed crabs (modal ICW size class 0-0.9cm) from the drag net fishery demonstrates that *S. paramamosain* are the main species present, constituting ~99% of the resulting adult crabs, with the remainder being *S. olivacea*. Similarly, in experimental culture of tagged juvenile (2-5cm ICW) *Scylla* spp. collected from the night torch fishery on Can Coc Island, only 1.5% were found to be *S. olivacea* as adults. Moreover, of 285 tagged juveniles crabs collected from the Can Coc torch fishery and released back into the same area, all were later recaptured and identified



as *S. paramamosain*, with no *S. olivacea* found (Ut, 2002). This suggests the frequency of capture of juvenile *S. olivacea* is 0-1.5% in the torch fishery and less than 0.1% for large crabs (>5cm ICW).

The results of the present study suggest that the seaward fringe of the mangrove forest is an important nursery site for *S. paramamosain* from first recruitment at instar 1 to crabs just prior to maturity at which stage the majority of the population appears to live sub-tidally. The increase in CPUE of scoop nets between December 2003 and February 2004 suggests that this is the peak recruitment period for juvenile crabs (modal size class midpoint: 0.5 cm ICW) into the mangrove fringe. Subsequent identifiable increases in the stake net in April (modal size class midpoint: 4.5 cm ICW) and in the gill net fishery in June/July 2004 (modal size class midpoint: 11.5 cm ICW) suggests this represents a single cohort which grew at approximately 2.0 cm ICW month<sup>-1</sup>, reaching maturity within 5.5 months after settlement. The supposition that the sequence of peaks in the relative abundance of the various life stages during the study period represents a single cohort of *S. paramamosain* is supported by an estimate of growth in tagged juvenile crabs in same area which indicated increases of 2.1 cm CW month<sup>-1</sup> over a size range from 3 – 12 cm CW (Ut, 2002). This is much faster than reported growth rates for *S. olivacea* sub-adults that grew at 1 cm ICW month<sup>-1</sup> in both Thailand (Moser *et al.*, 2002) and the Philippines (M. Walton, unpublished). No growth rates have been published for wild *S. serrata* or *S. tranquebarica* but, in a mixed pond culture of the two species, growth rates of 2.9-3.0 cm CW month<sup>-1</sup> have been recorded (between stocking at 4 cm and harvesting at 12-13 cm ICW) (Trino *et al.*, 1999).

The present study also shows for the first time that *S. paramamosain* recruits into the mangrove fringe at crab stage 1, living on the sediment surface and accumulating in shallow tidal pools around the pneumatophores at low tide. Extensive plankton sampling in creeks within the mangrove at the current study site has previously failed to record any megalopa of mud crabs (V.N. Ut, unpublished). Similarly, extensive plankton surveys in the Ranong mangroves in Thailand identified the megalopa of many crab species but not of *Scylla* spp. (Moser & Macintosh, 2001). The present study suggests that metamorphosis and settlement is occurring close to the seaward mangrove fringe as numerous instar 1 crabs are present in the catch. In the shifting soft sediments that make up the mudflats that characteristically surround mangroves, it may be that the pneumatophores represent the first hard substrate that the crabs encounter, providing shelter at a shore height that is inundated daily. Similarly, in the hatchery production of mud crabs, the use of hard substrates in tanks to provide shelter is reported to result in improved survival (Fielder & Heasman, 1999). In contrast, *S. serrata* megalopa were caught inside South African mangrove estuaries in plankton tows (Forbes & Hay, 1988) and *Scylla* spp. megalopa were caught in estuaries in the Philippines (Arriola, 1940). This suggests that the megalopa of *S. serrata* may settle out and metamorphose within the mangrove, whereas *S. paramamosain* and *S. olivacea*, the dominant species in the Ranong mangrove (Moser & Macintosh, 2001), do not enter the mangrove until the instar 1 stage.

The distribution of life stages of *S. paramamosain* across the various habitats observed in the present study broadly agrees with the findings of Hill *et al* (1982) for *Scylla* spp. who found that habitat traps in mangroves caught larger juveniles (4-7 cm ICW), a stake net at mid-tide level caught mostly sub-adults and adults (7-14 cm ICW), and

crab pots in the lower intertidal and subtidal zone mostly adults (11-19 cm ICW). The present study found that following recruitment *S. paramamosain* remains living on the mud surface until approximately 3 cm ICW, when crabs either dig burrows or live subtidally, entering the mangroves to feed during flood tides. In contrast, in Tanzania, the smallest *S. serrata* sampled in burrows were 7 cm ICW (Barnes *et al.*, 2002). The size at which crabs start to excavate burrows is presumably a balance between the benefits gained in protection against predators and adverse physical conditions (desiccation and temperature change) and the energy required to excavate. For small crabs, simple submergence in the substrate may provide adequate protection. Moreover, it is unclear whether the burrows are permanent shelters or whether they are only used by crabs stranded by the ebbing tide. In the Kowie Estuary, South Africa, tagged mature *S. serrata* were found to be completely free-ranging, without a burrow, although some individuals appeared to stay within a restricted area (Hill, 1978). It has been suggested that *S. olivacea* may use a more permanent burrow (Estampador, 1949) and this is supported by the results of a recent mark-recapture study that indicated that individuals of this species maintain a fixed home-site, at least over short periods of a few days (M. Walton, unpublished). At the present study site, tagged juvenile *S. paramamosain* (2-7 cm ICW) were found to be wide-ranging although the crabs were not re-released at their initial capture location (Ut, 2002).

In Australia, the high percentage of both females (97.1%) and ovigerous females (61.5%) found sub-tidally led to the conclusion that *Scylla* spp. undergo offshore spawning migrations (Hill, 1994). In contrast, female *S. paramamosain* only accounted for 59.5% of the offshore gill net catches in the present study. Of all the females caught, 37.7% were mature but only 14.3% had developed ovaries. This high

percentage of mature females compared with those in the fyke net and hook catches (<1.5%) supports earlier studies that suggested female *S. paramamosain* spawn offshore. However, spawning migration is not the main reason for the occurrence of *S. paramamosain* in these offshore waters.

Maturity in *S. paramamosain* occurs over a wide size range with females attaining abdominal maturity at between 8.6 and 11.2 cm ICW with an  $M_{50}$  of 10.2 cm ICW, having previously undergone a pubertal moult at 7.9 cm ICW. These values are much smaller than those estimated for *S. paramamosain* in Thailand where the smallest mature female recorded was 10.3 cm ICW, and the female  $M_{50}$  (based on abdominal width) was estimated at 11.1 cm ICW (Overton & Macintosh, 2002).

The size at which the chitinous locking mechanism that binds the abdominal flap to the sternum breaks down will determine the size at which copulation is first possible and is an indicator of functional maturity. Using probit analysis, abdominal unlocking was estimated to occur in males at 9.1 cm and females at 9.7 cm ICW in this study.

In males, a secondary sexual characteristic, the height of the dominant chela, was used as an indication of maturity as there is often a sharp increase in this parameter relative to ICW at maturity (Hartnoll, 1982). In the current study this was estimated to occur in male *S. paramamosain* at 10.2 cm ICW. Thus, these two methods (abdominal locking and allometric change) give different results for size at maturity. In South Africa, while 50% of the male *S. serrata* population were producing sperm at 9.2 cm ICW, the absence of mating scars on the front walking legs in individuals smaller than 11.5 cm ICW suggests that crabs smaller than this were not mating (Robertson & Kruger,



1994). In Australia, mating scars were also used as an indicator of functional maturity by (Knuckley, 1996), who estimated morphometric maturity using the ratio of chela height to ICW, arriving at values of 14.6 and 14.9 cm ICW in two populations of *S. serrata*. Although scarring was observed in some much smaller crabs (12.5 cm ICW), it was more common in crabs of over 14.0 cm ICW (Knuckley, 1996). The presence of scarring on crabs smaller than the estimated size of morphometric maturity suggests that, while enlarged chelae may confer some competitive advantage, they are not necessary for successful mating. Similarly, whereas male snow crabs (*Chironectes opio*) with a carapace width of under 9.6 cm are often physiologically mature (possessing spermatophores in their vas deferens), only larger crabs are functionally mature, i.e. able to pair and copulate with a female (Conan & Comeau, 1986). In the current study, the smallest coupler male recorded was 10.3 cm ICW which suggests that chela height is indeed a good indicator of functional maturity.

The current study demonstrates for the first time the importance of the mangrove ecosystem as a nursery habitat for *S. paramamosain* from settlement at instar 1 until just before maturity when individuals begin to move offshore. Especially important in the recruitment of *S. paramamosain* into the mangroves is the fringe, the boundary between the mangrove and mudflats. This habitat may support higher densities of mud crabs than the mangrove interior as reported in Tanzania (Barnes *et al.*, 2002). Boundaries between one habitat and another often exhibit high levels of productivity and species richness or biodiversity (Odum, 1971) which is why many European biodiversity programs have promoted the management of edges in the agricultural environment. (Stanners & Bourdeau, 1995) The protection of nursery habitats is also key in fishery management (Beck *et al.*, 2001). In mangrove estuarine environments,



the mangrove-mudflat boundary is typically on the high shore where the combined risks of terrestrial, riverine and seaborne anthropogenic impact may be greatest. The Ocean Studies Board of the Natural Research Council (USA) recommended closing nursery areas to protect fish stocks, an approach that was strongly supported not only by scientists but also by the fishermen themselves (Houde & Roberts, 2001). Around Europe, many areas of the sea bed are closed during certain seasons to protect juvenile stocks. (Horwood *et al.*, 1998) In the current study, the existence of a peak in recruitment of early instar crabs into the mangrove fringe between December and February suggests that this would be the appropriate season to close this area to fishing if stocks are threatened by over exploitation. However, to date it appears that the growth of the fishery for the early instar crabs using scoop nets is having little effect on the overall crab population. Catch rates of juvenile crabs from the torch fishery prior to the establishment of this new scoop net fishery were very similar to those recorded in the present study: 12.5 - 41.5 person<sup>-1</sup> day<sup>-1</sup> (Le Vay *et al.*, 2001) compared with 7.2 - 43.5 crabs person<sup>-1</sup> day<sup>-1</sup> in 2004.

Size at maturity is commonly used as the minimum landing size by fisheries managers (Watson, 1970). The SM<sub>50</sub> should be based on the ability of the crab to mate successfully and any estimate should be corroborated using the size of coupling crabs. In the present study this was estimated at 10.2 cm ICW for both sexes which was almost 1 cm ICW smaller than the SM<sub>50</sub> for female *S. paramamosain* from Thailand (Overton & Macintosh, 2002). Variations in size at maturity, not only between different species but also between populations of the same species of *Scylla*, indicate that the SM<sub>50</sub> will have to be assessed for each population.

**Chapter 6:**

**General Discussion**

In chapter 2 monitoring of fisher's catches of mud crabs proved to a good method of assessing changes in abundance. The mud crab population was initially very healthy with a high proportion of juveniles to adults indicating good recruitment. However this changed over time (April 2002 to December 2003) and the proportion of juveniles less than 6cm carapace width (CW) diminished to almost zero indicating a problem with recruitment possible due to a combination of overfishing and storm damage to the seagrass beds.

The lack of small (<3cm CW) crabs in commercial catches and lack of early instar crabs sampled using a variety of habitat traps and a modified scoop net dragged across the pneumatophores at the mangrove fringe (M. Walton, unpublished) suggested that *S. olivacea* metamorphoses outside the mangrove. In India, *Scylla* spp. juveniles as small as 8mm CW were more frequently captured in sea grass beds than amongst mangrove pneumatophores (Chandrasekaran & Natarajan, 1994). It is unclear how important seagrass habitats are for settlement and metamorphosis of early instar *S. olivacea*, however chapter 2 suggests early-stage size crabs are settling elsewhere and emphasizes the importance of an integrated coastal management policy that places equal importance on the preservation of all coastal habitats.

Size at maturity for *S. olivacea* was found to vary not only according to geographic location but also temporally. This has important consequences for fishery management in the setting of minimum take sizes and for fisheries revenues, as the price per kilo increases with size. Female *S. olivacea* in the Buswang mangroves matures at 7.65cm internal carapace width (ICW) in contrast with the population in

Ban Don Bay in Thailand (9.12cm ICW) (Overton & Macintosh, 2002). This corresponds to a difference in weight of 95g to 160g.

In chapter 3, the trapping grid was found to be a good methodology for comparing mud crab abundance in different habitats. The impact of mangrove reforestation on mud crab abundance could have been also influenced either by fishing pressure, recruitment problems, topography or habitat structure. However despite higher fishing pressure and recruitment problems at the replanted site these mangroves had equivalent densities of mud crabs compared with the relatively unexploited natural fringing mangrove at Colong Colong. Differences in habitat structure (eg *Rhizophora* prop roots vs *Sonneratia* pneumatophores) were not found to influence crab abundance, neither was topography at the replanted site.

Replanting mangrove is effective in enhancing productivity and food security in deforested areas as suggested by the significant increase in mud crab abundance compared to the degraded site. However, careful management is required to maintain maximum productivity as a reduction in mud crab density due to overfishing or recruitment failure may lead to the replacement of mud crabs by lower value species.

In chapter 4, the socio-economic valuation of direct economic benefits demonstrated that replanting mangroves can be of equivalent value to intact natural mangroves. Fisheries production per hectare can be equivalent to that of brackish water ponds in the Philippines, without the associated preparation costs of clearing mangroves and building ponds and the running costs. Mangroves have also been shown to support more people per hectare than aquaculture in the Philippines (Primavera, 1995). The replanted mangrove studied is directly supporting 113 families and 465 family

members and indirectly supporting another 241 coastal and shoreline fishers (+1018 family members). The study also shows that this mangrove is directly supporting the poorest of the fishers, those fishing inside the mangrove, with a mean annual income of US\$1090. Thus it is important in ensuring food security for the most vulnerable portion of the community who used it as a larder when there was no work or food. The value of this replanted mangrove was recognised by the fishers, as 98% of them wanted to protect the mangrove against clearance, and 85% would offer money or assistance in protecting them against pond developers. Only 2% did not consider mangroves worth protecting.

Ecosystem services are important mangrove benefits but these have little direct economic value, although carbon trading may in the future provide source of revenue for carbon sequestration performed by the mangrove. Coastline protection was the most widely recognised service in the community survey (95%), although 77% of respondents also recognised the value of mangroves in biodiversity preservation and in sedimentation. In order to maintain the existing mangrove area, and encourage reforestation of degraded areas and abandoned pond sites, these ecosystem services have to be taken into account. Any decision to clear mangroves for private gain needs to be weighed against the social costs (Acharya, 2002) such as the loss of food security, loss of income for many families, the loss of protection from typhoons and the effects of increased salt water inundation on crops and water supplies. The increased sediment and nutrient load in coastal water caused by mangrove removal could have serious detrimental effects on other ecosystems such as seagrass and coral reefs that also support important artisanal fisheries further undermining food security and income generation. Interestingly, while shrimp farmers recognise the importance



of mangroves in controlling water quality none are prepared to pay for it preferring to externalize all environmental costs (Ratner *et al.*, 2004).

Chapter 5 examines habitat partitioning in *Scylla paramamosain* populations in the Hau River mouth in the Mekong delta in Vietnam. Although the entire mangrove is used by the mud crabs the mangrove fringe was demonstrated to be the most important area especially for the recruitment of early instar *S. paramamosain* into the mangroves. The mangrove fringe has been shown to be important in other species (Barnes *et al.*, 2002; Vance *et al.*, 1996; Vance *et al.*, 1990) and boundary areas often show high levels of biodiversity and productivity (Odum, 1971). However the land/sea boundary is also relatively susceptible to anthropogenic activity which in turn would impact the *S. paramamosain* populations. Although CPUE records suggest there is no current danger to these stocks, a closed fishing season should be considered between December to February in this vulnerable area if over fishing becomes apparent.

These studies highlight the dependence of both *S. olivacea* and *S. paramamosain* on the mangrove at various stages in their life cycles. However, mangroves do not exist in isolation and the life history of both species also emphasizes the linkages between mangroves and other habits. *S. paramamosain* uses coastal waters for sub-adult and adult feeding, reproduction and planktonic larval stages. *S. olivacea* depends on seagrass or other unidentified areas for settlement and metamorphosis from megalopa to early instar crabs.

As mangroves are linked not only to other marine habitats but also impacted by terrestrial activity, the adoption of Integrated Coastal Zone Management (ICZM)

policies has been proposed if such coastal resources are to remain productive (Clark, 1992). ICZM is a method of resolving resource user conflicts (both marine and terrestrial) and controlling the human impact on the quality of the coastal environment. It promotes sustainable resource exploitation and preservation of biodiversity through planned development (Clark, 1992). Although Vietnam has a number of admirable environmental policies it has yet to adopt ICZM policies (Torell & Salamanca, 2003), while the Philippines has already begun to initiate a partial ICZM program (Clark, 1992). However, fully integrated management policies are needed if mangroves in conjunction other terrestrial and marine habitats are to be managed effectively. Additionally, education is needed to raise public awareness of the value of mangroves outside those communities that traditionally exploit them. The tendency is still for attitudes towards mangrove forests to be generally negative; people perceive them as wastelands (Calumpong & Menez, 1996) and policy makers generally undervalue them (Ratner *et al.*, 2004). The contribution of mangroves to coastal fisheries, through their nursery function and as a food supply, is potentially the most significant direct source of income yet the exact nature and percentage contribution is unclear. This contribution needs to be investigated for a range of mangrove types (estuarine, fringing and basin) on each of the continents in order to fully convince policy makers of the economic importance of mangroves.

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Appendix 1: Socio-economic questionnaire for assessing the impact of mangrove reforestation on coastal fisheries.

European Union Culture and Management of Scylla Species  
Buswang, Kalibo Mangrove Ecological Census

Interviewer \_\_\_\_\_ Respondent \_\_\_\_\_  
Barangay \_\_\_\_\_ Date \_\_\_\_\_ Time \_\_\_\_\_

**Part 1: Fisheries Profile**

Fishing location (So-oc river, mangroves, shore or sea)	Gear type (dimension & mesh size)	Species	Tide (springs/ neaps)	Catch per visit In pieces or Kg	% of catch consumed by family	Price/kg	Costs/trip			Hired Labour		Family labour	
							Fuel	Bait	Others (specify)	Number	Rate/day or sharing arrangement	Number including head	Relationship to head
Gleaning Activities													

Other expenses:

1 Gear maintenance per month \_\_\_\_\_ 3) Permits/License per year \_\_\_\_\_  
2) Boat maintenance per month \_\_\_\_\_ 4) Others (Specify) \_\_\_\_\_

Months	Species caught													
	1)		2)		3)		4)		5)		6)		7)	
	Pcs or kg/day	Size range	Pcs or kg/day	Size range	Pcs or kg/day	Size range	Pcs or kg/day	Size range	Pcs or kg/day	Size range	Pcs or kg/day	Size range	Pcs or kg/day	Size range
Jan														
Feb														
Mar														
Apr														
May														
Jun														
Jul														
Aug														
Sep														
Oct														
Nov														
Dec														

How many years have you been fishing? \_\_\_\_\_

Have you noticed a change in the catch over the last 10 years? Can you quantify how much you caught:

#### Fishing

2 years ago \_\_\_\_\_ (Kg/day)?  
5 years ago \_\_\_\_\_ (Kg/day)?  
10 years ago \_\_\_\_\_ (Kg/day)?  
15 years ago \_\_\_\_\_ (Kg/day)?

#### Gleaning

\_\_\_\_\_ (Kg/day)?  
\_\_\_\_\_ (Kg/day)?  
\_\_\_\_\_ (Kg/day)?  
\_\_\_\_\_ (Kg/day)?

**Part 2: KASAMA**

- 1) Were you one of the families involved in the planting in 1990 (Kasama member) and if not why not? \_\_\_\_\_
- 2) If a Kasama member, what are the benefits? \_\_\_\_\_

**Part 3: Income/Expenses**

	Occupation	Peak Months-				Lean Months-			
		Frequency (days/month)	Duration (hours)	Monthly Income	Monthly Expenses	Frequency (days/month)	Duration (hours)	Monthly Income	Monthly Expenses
	A) Marine								
	B) Land Based								
	1) Farming								
	2) Animal husbandry								
	3) Business								

**Part 4: Perceptions of mangrove benefits.**

1. What are the benefits of mangroves
- |  |       |                  |       |
|--|-------|------------------|-------|
| a) Increases fishing                     | _____ | d) Biodiversity  | _____ |
| b) Nursery area for fish and crustaceans | _____ | e) Sediment trap | _____ |
| c) A barrier against typhoons and storms | _____ | f) Other         | _____ |

2. Now the mangroves are under threat from illegal pond construction, do you think they need to be protected? Yes \_\_\_\_\_ No \_\_\_\_\_

If yes, how much would you pay? \_\_\_\_\_ per year

If no, what is the main reason that you said no:

- \_\_\_\_\_ I do not care about the Buswang Mangroves
- \_\_\_\_\_ The mangroves are not needed
- \_\_\_\_\_ It costs too much already to visit the area
- \_\_\_\_\_ The money would be wasted
- \_\_\_\_\_ Mangroves are a community resource, access should be free
- \_\_\_\_\_ Other people and businesses should pay
- \_\_\_\_\_ Other \_\_\_\_\_

If no, but mangrove benefits were ticked find out how much it would cost them if there were no fish, they had to erect storm defenses  
\_\_\_\_\_

3. If a rich man wanted to buy the mangrove (for fish ponds) should the government sell it (yes/no) and if so how much for a hectare? \_\_\_\_\_

4. If the mangrove was yours, would you sell it and for how much? \_\_\_\_\_

5. What was your occupation before mangroves were planted (before 1990)? \_\_\_\_\_ How much were you earning from this occupation? \_\_\_\_\_  
peso/month

6. What was the occupation of your spouse before the mangroves were planted (before 1990)? \_\_\_\_\_  
How much did your spouse earn? \_\_\_\_\_ peso/month

7. What is the occupation of your spouse now? \_\_\_\_\_ How much does your spouse earn from this activity? \_\_\_\_\_ peso/month



### Part 5: *PROFILE OF THE RESPONDENT:*

1. How long have you been a resident of this barangay? \_\_\_\_\_ years
2. Sex:    [   ]Male         [   ]Female
3. Are you:        [   ]Single      [   ]Married    [   ]Widowed                  [   ]Separated
4. Your age:
5. What is the highest level of education you have attained?  
[   ]Elementary    [   ]High School        [   ]Vocational/Technical        [   ]College    [   ]Graduate school (e.g. MA/MS/PhD)
6. Are you employed?    [   ]Yes                  [   ]No                                  If Yes: [   ]full-time or [   ]part-time
7. Are you a member of any:  
Government Office?                                  [   ]Yes                  [   ]No  
Civic organization (e.g. Rotary Club)[   ]Yes                  [   ]No  
Environment organization?                                  [   ]Yes                  [   ]No
8. Including yourself, how many people live in your household?\_\_\_\_\_
9. Excluding yourself (and your spouse), how many people in your household\* over 18 years of age are gainfully employed?\_\_\_\_\_
10. What is your MONTHLY HOUSEHOLD INCOME before taxes?  
[   ] 0 – 199                  [   ] 1,000-1,499    [   ] 3,000-3,999                  [   ]8,000-9,999  
[   ] 200 - 399                  [   ] 1,500-1,999    [   ] 4,000-4,999                  [   ] 10,000-14,999  
[   ] 400 - 699                  [   ] 2,000-2,499    [   ] 5,000-5,999                  [   ] 15,000-19,999  
[   ] 700 - 999                  [   ] 2,500-2,999    [   ] 6,000-7,999                  [   ]20,000 and above
11. Does this include any extra income from family abroad, pension/government assistance, rental of property or vehicles, sale of assets? How much per year

## 12a) Assets

Which of the following do you own	Purchased		Made		Inherited	Other (eg. borrowed)
	Year acquired	Value when acquired	Materials (Php)	Labour (days)		
1) Gear						
a)						
b)						
c)						
2) Boat						
IF No Who does						
3) House						
4) Vehicle						
5) Land						
6) Others (specify)						

13b) Water supply ☐ Tap ☐ Well ☐ Rain ☐ Stand pipe ☐ Otherc) Electricity ☐ yes ☐ nod) Toilet ☐ Common ☐ Septic tank ☐ None**Part 6. Other Fishermen**

<u>Name</u>	<u>Location</u>	<u>Gear</u>	<u>Name</u>	<u>Location</u>	<u>Gear</u>
1.					6)
2.					7)
3.					8)
4.					9)
5.					10)

## Appendix 2: Questionnaire for Bakawan Eco-park visitors

The Bakawan Eco-park was established to facilitate access to the Buswang mangroves and educate visitors. Mangroves are a vitally important link between terrestrial and marine ecosystems; your responses to these questions will help us understand how the public values this resource. This survey is about your use of the area. Keep in mind there are no right or wrong answers to these questions. Your opinions are fine. Thanks for your cooperation.

1. Where are you from? \_\_\_\_\_ City \_\_\_\_\_
2. How many times have you visited the park, including this trip? \_\_\_\_\_ times.
3. How many people are you travelling with? \_\_\_\_\_
4. Why are you visiting the park?  
Vacation or holiday ☐ Study and research ☐  
Work ☐ Other reason \_\_\_\_\_
5. How did you get here from you last stop? And how much did it cost?  
Aiplane \_\_\_\_\_ peso Hire Car \_\_\_\_\_ peso  
Boat \_\_\_\_\_ peso Others \_\_\_\_\_ peso  
Bus \_\_\_\_\_ peso
6. Please indicate you expenditure while you are here  
Lodging \_\_\_\_\_ peso Souvenirs \_\_\_\_\_ peso  
Food and drinks \_\_\_\_\_ peso Others \_\_\_\_\_ peso

### Willingness to pay for the Bakawan Eco-park

7. Would you be willing to pay more each time you visit the Bakawan Eco-park?  
Yes - Go to Question 8 No - Go to Question 9
8. If yes what is the highest entrance fee that you would be willing to pay in order to help manage and preserve the Bakawan Eco-park? \_\_\_\_\_ Peso
9. If no, what is the main reason you said no?  
I do not care about the Bakawan Eco-park.  
The Bakawan Eco-park is not needed  
It cost too much to visit the area already  
The money would be wasted  
Mangroves are a community resource and access should be free  
Other people and businesses should pay  
Other \_\_\_\_\_

### Questions about you

10. Are you male or female? \_\_\_\_\_ 11. How old are you? \_\_\_\_\_ years
11. What is your highest educations attainment?  
High school ☐ College/University ☐ Master/other degree ☐  
Doctorate degree ☐ Other ☐
12. Occupation \_\_\_\_\_ Monthly income \_\_\_\_\_ Php per month