Using vegetation and faunal communities as bioindicators to assess two mangrove rehabilitation techniques in Kien Giang, Vietnam.

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I, Stephen Ryan Thornton confirm that the work presented in this research report has been performed and interpreted solely by myself except where explicitly identified to the contrary. I confirm that this work is submitted in partial fulfilment for the degree of BEnvSc (Hons) and has not been submitted elsewhere in any other form for the fulfilment of any other degree or qualification.

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Abstract

To date, around one third of mangroves have been cleared globally with clearing continuing at a rate of 1-2% per annum. Subsequently, rehabilitation projects have been attempted around the world, many of which have failed or were not quantitatively assessed. This study aimed to assess the success of two different rehabilitation techniques, one involving a simple control fence and another involving a more elaborate fence designed by the Kien Giang Biosphere Reserve Project (KGBRP). The assessment was conducted by comparing vegetation and faunal communities in rehabilitation areas to those in adjacent old-growth areas. The indicators included tree and plant diversity and density, forest cover as well as the density of crabs, mudskippers and gastropods. The results show KGBRP rehabilitation supported tree diversity, plant diversity, tree density and forest cover that most closely resembled old-growth areas. The reason for this similarity is thought to be the additional protection provided by the KGBRP fence. In terms of total mudskipper, *Boleophthalmus* spp., *Periophthalmodon* spp. and ocypodid crab density the KGBRP rehabilitation was also most similar to the old-growth areas. This similarity is thought to be related to the comparable forest cover at these sites. Neither control or KGBRP rehabilitation resembled old-growth areas in terms of large crab hole density. The disparity between large crab hole density at KGBRP rehabilitation and old-growth areas, despite similar levels of forest cover, is thought to be linked to the immaturity of the KGBRP rehabilitation sites. As the KGBRP rehabilitation is most similar in terms of vegetation and faunal communities to the old-growth areas, it appears to be the most successful rehabilitation.

1.0 Introduction

1.1 Mangrove communities

Mangrove communities are typified by the presence woody halophytes and are found in the intertidal zone of tropical and subtropical coasts (Ellison, 2000; Ellison, 2008). Diverse fauna are found in mangrove ecosystems including fish, crustaceans, molluscs, polychaete worms, birds, reptiles and mammals (Alongi, 2002; Ellison, 2008). As noted by Alongi (2002), crabs play a particularly important role in the function of mangrove ecosystems. The most common crab families typically found in mangroves are Ocypodidae, Grapsidae, Sesarmidae and Portunidae (Alongi, 2002; Ashton et al., 2003; Macintosh et al., 2002). Burrowing activities of these crabs allow for nutrient mixing, sediment oxygenation, mixing of surface and sub-soils and drainage of surface water, all of which enhance mangrove growth (Geist et al., 2011; Kristensen, 2008; Nagelkerken et al., 2008; Saenger, 2003). Crabs also play a potentially significant role in ecosystem function with their feeding behaviour. While ocypodid crabs are mostly substrate feeders, grapsid and sesarmid crabs also feed on live mangrove material, including propagules (Amaral et al., 2009; Geist et al., 2011; Nagelkerken et al., 2008). Grapsid and sesarmid crabs may affect the establishment of mangrove seedlings and structure of mangrove communities by selectively feeding on the propagules of certain species (Lee, 1998).

The particular configuration of flora and fauna found in mangrove forests serve many functions and deliver a number of ecosystem services. These services include extractable products such as crustaceans, fish, shellfish, fuel wood, tannins, timber, honey and medicines (Ellison, 2000; Manassrisuksi and Hussin, 2001). There are also less tangible services provided by mangroves such as storm protection, erosion control, bird and juvenile fish habitat, assimilation of pollutants and run-off, trapping of sediments and carbon sequestration (Abuodha and Kairo, 2001; Alongi, 2002; Walton et al., 2007). Provisioning ecosystem services makes mangrove ecosystems economically valuable with a recent appraisal of the value of mangrove forests to local communities in Thailand finding that the forests are worth between US$27,264 and US$35,921 per hectare (Sathirathai and Barbier, 2001).

1.2 Destruction of Mangroves

Despite the inherent value of mangrove ecosystems they continue to be removed and degraded at a significant rate (Ellison, 2000). To date, more than one third of mangrove forests worldwide have been cleared and this destruction continues at a rate of 1-2% per annum (Alongi, 2002; Barbier, 2006; Lewis and Gilmore, 2007; Polgar, 2009). The main causes for this destruction have been tree felling, conversion to agriculture, urban development and the construction of aquaculture ponds (Macintosh et al., 2002; Walton et al., 2007; Yap, 2000). Whilst the loss of mangroves is a global issue, it is particularly pertinent to

Southeast Asia (Macintosh et al., 2002; Powell and Osbeck, 2010) and Vietnam (Alongi, 2002; Hoang et al., 1998). In Vietnam, the largest historical losses of mangroves have been from herbicide use during the Vietnam War and the construction of aquaculture ponds (Alongi, 2002; Binh et al., 1997; Hoang et al., 1998; Hong, 1993). In Kien Giang province, Vietnam, mangroves have been reduced to a thin belt along the coastline, 60% of which is currently eroding and 33% of which is already badly eroded (Duke, 2012; GIZ, 2011b). Losses of mangrove forests have also been accompanied by the loss of ecosystem services such as coastal protection and the provisioning of juvenile fish habitat, which has serious repercussions for local communities (Skilleter and Warren, 2000; Vannucci, 2004).

1.3 Mangrove Rehabilitation

In light of the significant losses of mangroves and their associated ecosystem services, rehabilitation efforts have been attempted in many countries around the world (Alongi, 2002; Bosire et al., 2008). Much of the focus of rehabilitation projects has been on replanting mangrove stands using a limited number of species (Bosire et al., 2008; Walton et al., 2007). Despite considerable effort, many of these rehabilitation efforts fail because stressors such as changed hydrology, pollutants and high wave energy are not removed (Bosire et al., 2008; Kamali and Hashim, 2011; Lewis and Gilmore, 2007). A growing body of evidence suggests planting is not necessary and should only be attempted if natural regeneration does not occur after the removal of stressors (Bosire et al., 2008; Lewis and Gilmore, 2007). If stressors are removed and natural regeneration does not occur it is often due to the inability of propagules to reach the site because of mangrove removal or hydrological barriers (Lewis, 2005).

1.4 Assessment of Mangrove Rehabilitation

Despite numerous attempts globally to rehabilitate mangroves, the success or failure of these efforts is rarely assessed quantitatively (Ashton et al., 2003). In this context, Bosire et al. (2008) suggests four main indicators which should be assessed to determine the success of mangrove rehabilitation:

- development of the vegetation and floristic succession,
- faunistic recruitment,
- evolution of environmental factors and processes,
- and finally the potential for sustainable exploitation.

This study investigates the first two of these indicators.

Vegetation characteristics are the most common indicators used for the assessment of mangrove rehabilitation. Often it is only growth and early development parameters that are measured (Bosire et al., 2003). These are commonly associated with silviculture related rehabilitation and are often performed in order to estimate the amount of extractable timber (Putz and Chan, 1986). Other common indicators used include tree density, tree diversity and the diversity of recruited trees (Bosire et al., 2003; Walters, 2000). Studies of 50-60 year old mangrove rehabilitation in the Philippines found that the tree density was much higher than in adjacent remnant forests and that there was little to no recruitment (Walters, 2000). In contrast, a study of mangrove rehabilitation in Kenya found that there was recruitment of at least four new species in under five years (Bosire et al., 2003). Throughout the literature it appears that indicators such as growth rates are linked to timber harvesting (Khoon and Eong, 1995), whereas indicators of tree density and diversity are more often used to assess ecosystem recovery (Bosire et al., 2003; Walters, 2000).

By comparison, the characteristics of the faunal community are being included more often in the assessment of mangrove rehabilitation. Due to their conspicuousness and importance in ecosystem function molluscs, oxudercine gobies (mudskippers) and crabs from the families Sesarmidae, Grapsidae, Ocypodidae and Portunidae are commonly used as indicators. A study of the portunid crab *Scylla olivacea* (*S. olivacea*) conducted by Walton et al. (2007) in the Philippines found that *S. olivacea* abundance was the same in natural fringing mangroves as in rehabilitated mangroves, and that the species was completely absent from the degraded mangroves. Studies conducted by Macintosh et al. (2002) and Ashton et al. (2003) both concluded that mature forests are consistently dominated, in terms of diversity and abundance, by sesarmid and grapsid crabs while young or degraded rehabilitation sites are dominated by ocypodids. In addition to this, Macintosh et al. (2002) also found that mature forests were dominated by the mollusc families Neritidae and Ellobiidae whereas younger and more degraded forests were dominated by the families Assimineidae, Littorinidae and Potamidae. Using different taxonomic levels a study conducted by Irma and Sofyatuddin (2012) in Sumatra, Indonesia concluded that gastropod abundance was positively correlated with the age of rehabilitated mangroves. At present there appears to be a lack of standardised method for assessing the faunal community, however sesarmid, grapsid and ocypodid crabs appear to be particularly useful indicators (Ashton et al., 2003; Macintosh et al., 2002).

Although mudskippers have not been used specifically to assess mangrove rehabilitation they have been suggested as good bioindicators for the health of mangrove ecosystems (Polgar, 2009). Wickramasinghe et al. (2009) found there was lower mudskipper diversity in areas where organic waste was discharged than in areas of natural mangrove forest. The study also found that mudskipper diversity was higher in areas on the periphery of the organic waste discharge zone than in natural mangrove forest (Wickramasinghe et al., 2009). Their high abundance in intertidal areas suggests mudskippers are potentially useful bioindicators.

1.5 Study aims

This study uses vegetation and faunal communities as bioindicators to evaluate the success of two mangrove rehabilitation techniques, both of which were designed to reduce erosion. Mangrove areas were of three different treatments: control fenced areas; areas fenced by the Kien Giang Biosphere Reserve Project (KGBRP); and old-growth vegetation (see Section 2.1). This study examined rehabilitation success, in terms of the recovery of the vegetation and faunal community, in the control fenced and KGBRP fenced rehabilitation areas. It was hypothesised that rehabilitation would be more successful in the KGBRP fenced sites than the control fenced sites due to the additional protection afforded by the KGBRP fence.

Success was determined by comparing attributes of the vegetation and faunal communities in the rehabilitation areas to those in adjacent old-growth areas. If one rehabilitation technique resulted in vegetation and faunal communities more similar to the adjacent old-growth areas it was deemed more successful. The hypotheses for the study are:

H_0: There is no significant difference between the vegetation and faunal communities at the KGBRP and control rehabilitation sites and both rehabilitation areas do not have communities that resemble old-growth areas.

H_1: The vegetation and faunal communities in the KGBRP rehabilitation areas are significantly different from the control rehabilitation areas and more similar to those in adjacent old-growth areas.

The alternative hypothesis was proposed as the added protection provided by the KGBRP fence is thought to create a physical environment more similar to the old-growth areas.

Given its importance in the function of mangrove ecosystems (Alongi, 1998), this study also attempted to measure whether wave energy differs between treatments.

2.0 Methods

2.1 Study Site

The study site is located on the coast near Vam Ray village, Kien Giang Province, Vietnam and is part of the Kien Giang Biosphere Reserve. The area is characterised by a semi-diurnal tide regime (Hong, 1993). Although the area receives relatively low wave energy it is typified by high rates of erosion (GIZ, 2011a). The site lies between the coordinates 10. 201407° N, 104.79828° E and 10.195875 ° N, 104.805039° E (Figure 1).

The site contains areas of old-growth forest as well as areas that are currently undergoing rehabilitation. Two rehabilitation techniques are being implemented at the site. One of these techniques involves erecting a simple fence made from a single row of wooden poles at the seaward edge of the sites in order to reduce wave energy (Appendix A). This technique will be referred to as the 'control'. The other technique is one that is currently used by the KGBRP. The KGBRP technique involves a more elaborate fence consisting of two rows of wooden poles with the space between the rows filled with small branches and brush (Appendix A).

The areas fenced by KGBRP also had *Rhizophora apiculata* (*R. apiculata*) seedlings planted at a density of approximately 7 per m^2, however survival rates were relatively low (8 - 26.8% after three years) (GIZ unpublished data). In addition to this, 75% of the KGBRP fenced sites also had an additional silt trapping fence halfway between the outer fence and the beginning of the rehabilitation site (Figure 1; Appendix A). There were also sporadic, unrecorded attempts to plant *R. apiculata* seedlings at 50% of the control sites, however no seedlings were ever established (GIZ pers. comm.).

The sites were fenced in 2009 (GIZ, 2011b), prior to this all of the sites currently undergoing rehabilitation were completely eroded and denuded of trees. The impetus for the rehabilitation efforts was the loss of ecosystem services that accompanied the degradation of these sites. All measurements for the study were taken at this site between the 11th June 2013 and the 17th July 2013. In total 13 sites were assessed, four control fenced sites, four KGBRP fenced sites and five old-growth forest sites (Figure 1). Sites were deemed independent if they were separated by an alternative forest type. In some cases the areas separating sites were not included in the study.

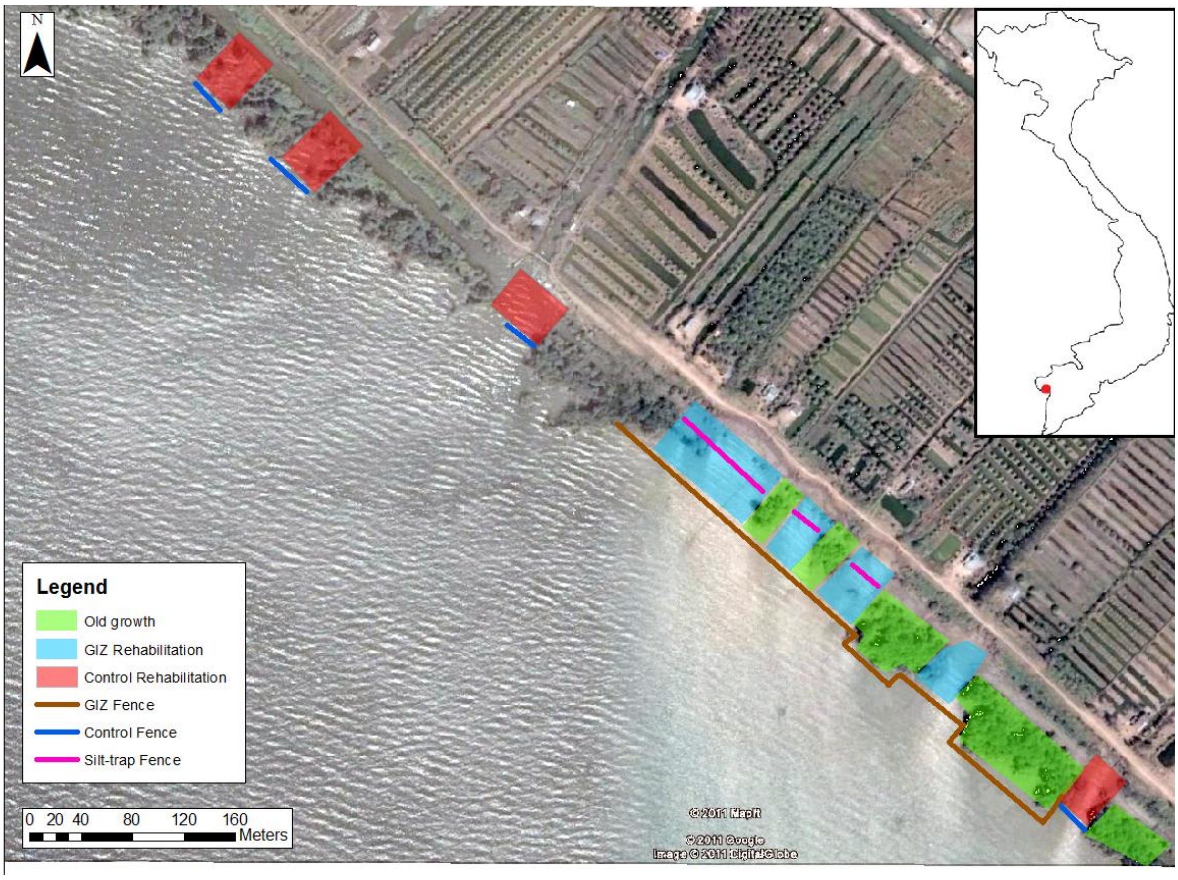

Fig. 1. Map of the mangrove study site in Kien Giang, Vietnam. The map shows old-growth areas as well as areas that have been rehabilitated using control and KGBRP fences. The areas covered by the KGBRP control and silt-trap fences are also shown.

2.2 Vegetation density and diversity

To measure the vegetation density and diversity of each treatment, a $10m^2$ plot was randomly placed in each site. All plants in the plot were identified using Duke (2012) and the species richness of each plot was recorded. The number of trees and seedlings of each species were also recorded in each plot. Trees were defined as greater than 1 m high, and seedlings less than 1 m. This boundary was appropriate as the number of trees close to this height was low. The vegetation data was divided into two categories; plant, which includes seedlings and trees; and tree, which includes only trees. Seedlings were not included as their own category because they have the ability to establish in many areas, but not necessarily persist. Meaning their presence is not particularly useful as an indicator. Forest cover was estimated for each site by running a transect perpendicular to the coastline and measuring the proportion of the transect that was covered by trees.

2.3 Fauna diversity and density

Fauna groups focused on in this study were mudskippers, brachyuran crabs and gastropods. Mudskippers were identified to genus using Murdy (1989) and crabs were identified to family using Ng (1998). The mudskipper genera recorded were *Apocryptodon, Boleophthalmus*, *Periophthalmus*, *Periophthalmodon* and *Oxuderces*. The crab families recorded were Grapsidae and Ocypodidae. Although the subfamily Sesarminae was recently split from Grapsidae, for the purposes of this study it was included in Grapsidae. Gastropods were not identified to a lower taxonomic level. Crab burrows were also used as an indicator in this study, these were classed as either large (>3cm) or small (<3cm) burrows.

To record indicators of fauna density and diversity a 2m wide transect which ran perpendicular to the coastline was randomly placed in each site. Within this transect the number of animals and burrows were counted instantaneously with the aid of binoculars. The counting was conducted from a distance which varied from 3m to 15m. Before counting commenced, a recovery time of five minutes was allowed after each disturbance to allow animals to resurface. A pilot study indicated that the majority of animals resurfaced after five minutes. All counts were done at the same stage in the tidal cycle and at comparable times of the day. Cloud cover and wind levels were also recorded. No fauna counts were done during rain events.

2.4 Wave energy

Plaster domes were created by placing a 100:35 mixture of Plaster of Paris and water into hemispherical moulds. Once dry, the domes were fixed to ceramic plates using silicone glue. The plates prevented the domes from sinking into the soft sediments. The plates were weighed and then randomly placed throughout the sites with an equal number of plates in the front and back half of the sites. Simultaneously, two control plates were placed in a bucket of seawater to account for the effect of non-moving water. The plates were collected after 2 weeks exposure and then cleaned and dried to a continuous weight. The final weight was then recorded.

The following formula was then used to calculate the diffusion factor (DF):

$$DF = 100((FIDW - FFDW)/(CIDW - CFDW))/hours$$

In this formula FIDW is the field initial dry weight; FFDW is the field final dry weight; CIDW is the control initial dry weight and CFDW is the control final dry weight (Bandeira, 2002). The DF represents how much plaster has been eroded due to water movement.

2.5 Statistical analysis

For the mudskippers of the genera *Apocryptodon*, *Periophthalmodon*, and *Oxuderces* insufficient data was obtain for statistical analysis. One-way analysis of variance tests were used to compare tree diversity, forest cover, ocypodid crab density and the ratio of ocypodid crabs to grapsid crabs across treatments. Tukey's Post-hoc Tests were conducted on these analysis of variance results to show pair-wise comparisons of the different treatments. General Linear Models with a Poisson distribution were used to compare total mudskipper density, *Boleophthalmus* spp. density, *Periophthalmodon* spp. density, and plant diversity across treatments as these data most closely fitted to a Poisson distribution. Pair-wise comparisons of the different treatments were also done for these data using Tukey's Post-hoc Tests. Kruskal-Wallis analyses of variance was used to compare the density of large and small crab holes, gastropod density, grapsid crab density and tree and plant density across treatments, as these data did not conform to any particular distribution. To make pair-wise comparisons for these data Wilcoxon Rank-Sum Tests were used. Linear regressions were used to compare the relationships between fauna abundances and forest cover and tree diversity. All statistical analysis was conducted using R statistical software version 3.0.1 (R Core Team, 2013).

3.0 Results

No reliable data on wave energy could be gathered due to the failure of the method described above (see Section 2.4). A number of factors contributed to the failure of this method, these are discussed in detail in Section 4.3. For gastropods, grapsid crabs, small crab holes (<3cm in diameter) and plant density as well as for mudskippers of the genera *Apocryptodon*, *Periophthalmus* and *Oxuderces* there were no significant differences found between treatments.

The KGBRP rehabilitation sites had similar levels of tree diversity, plant diversity, tree density and forest cover to old-growth sites (Fig.2; Table 1). In contrast, the control rehabilitation sites had significantly lower tree diversity, plant diversity, tree density and forest cover (Fig. 2; Table 1). In the case of tree diversity and density the difference is particularly marked as no trees were recorded at any control rehabilitation sites (Fig. 2). Control rehabilitation sites were also found to have less than half of the plant diversity and less than one third of the forest cover found at the KGBRP rehabilitation and old-growth sites (Fig.2).

Table 1
P-values for pair-wise comparisons of tree diversity, plant diversity, tree density and forest cover across mangrove treatments in Kien Giang, Vietnam. Tree diversity and plant diversity were measured as species richness.

		Tree Diversity	Plant Diversity	Tree Density	Forested Area
Treatment Comparisons	**Control vs. KGBRP**	≥0.001	0.041	0.021	≥0.001
	Old-growth vs. KGBRP	0.061	0.634	1.000	0.249
	Old-growth vs. Control	≥0.001	0.005	0.015	≥0.001

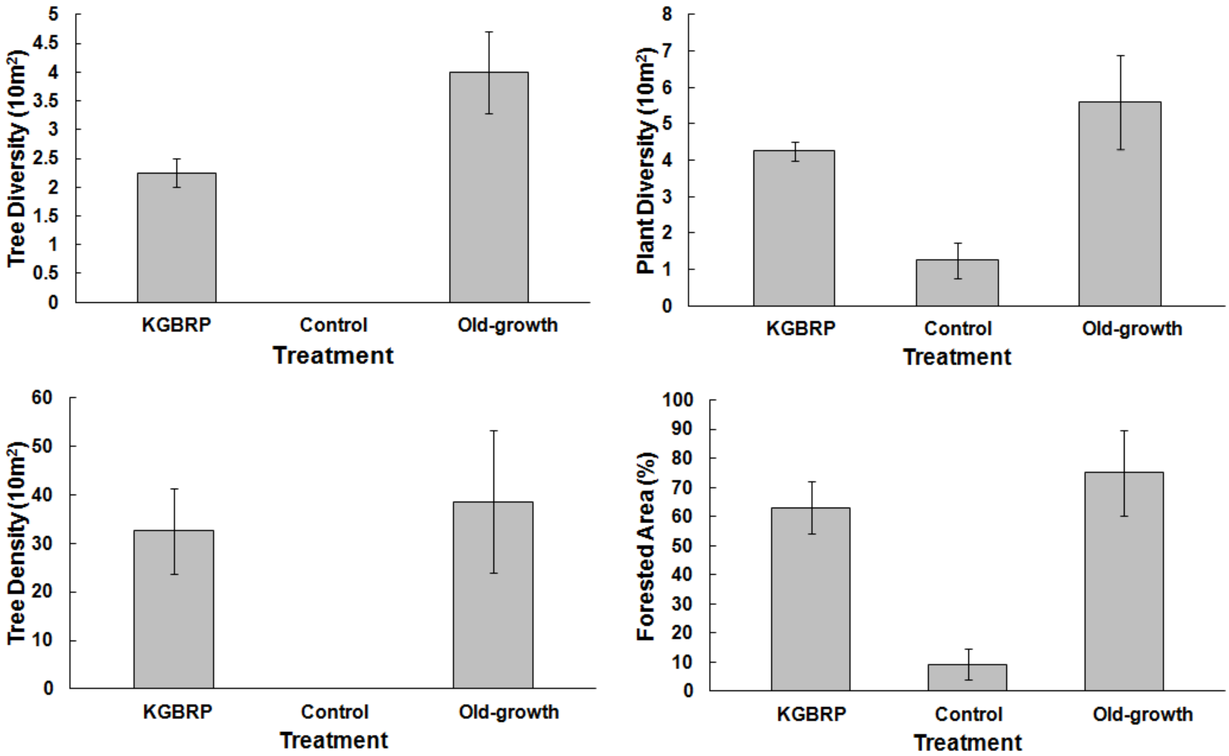

Fig. 2. Tree diversity, plant diversity (includes seedlings), tree density and forested area (%) across different treatments in Kien Giang, Vietnam. Tree diversity and plant diversity were measured as species richness. Error bars show standard error.

The most noteworthy differences between faunal communities across sites were found by examining the indicators of mudskipper and crab density. Total mudskipper density and *Boleophthalmus* spp. density were significantly higher at control rehabilitation sites than KGBRP rehabilitation and old-growth sites (Fig.3: Table 2). In addition, the KGBRP rehabilitation sites also had greater total mudskipper and *Boleophthalmus* spp. density than old-growth sites (Fig.3: Table 2). The density of *Periophthalmodon* spp. and ocypodid crabs followed a similar pattern. Significantly more *Periophthalmodon* spp. and ocypodid crabs were found at the control rehabilitation sites than the KGBRP rehabilitation and old-growth sites, however no significant difference was found between the KGBRP rehabilitation and old-growth sites (Fig.3: Table 2). When the ratio of ocypodid to grapsid crabs was compared across sites there was no significant difference found between the two rehabilitation treatments, however there was a marginally significant difference between the control and old-growth sites (Fig.3: Table 2). The density of large crab holes was found to be relatively low in the KGBRP rehabilitation and control rehabilitation treatments and not significantly different (Fig.3: Table 2). The density of large crab holes was found to be significantly higher in old-growth sites than in control fenced and KGBRP rehabilitation sites (Fig.3: Table 2).

Table 2
P-values for pair-wise comparisons of fauna densities and ratios across mangrove treatments in Kien Giang, Vietnam. The comparison are made of total mudskipper, *Boleophthalmus* spp., *Periophthalmodon* spp., ocypodid crab and large crab hole (diameter >3cm) density as well as the ratio of ocypodid to grapsid crabs.

		Total Mudskippers	***Boloeophthalmus* spp.**	***Periophthalmodon* spp.**	**Ocypodids**	**Ocypodid:Grapsid Ratio**	**Large Crab Holes**
Treatment Comparisons	**Control vs. KGBRP**	0.001	0.001	0.012	0.011	0.386	0.191
	Old-growth vs. KGBRP	0.001	0.014	0.324	0.875	0.420	0.031
	Old-growth vs. Control	0.001	0.001	0.001	0.004	0.061	0.019

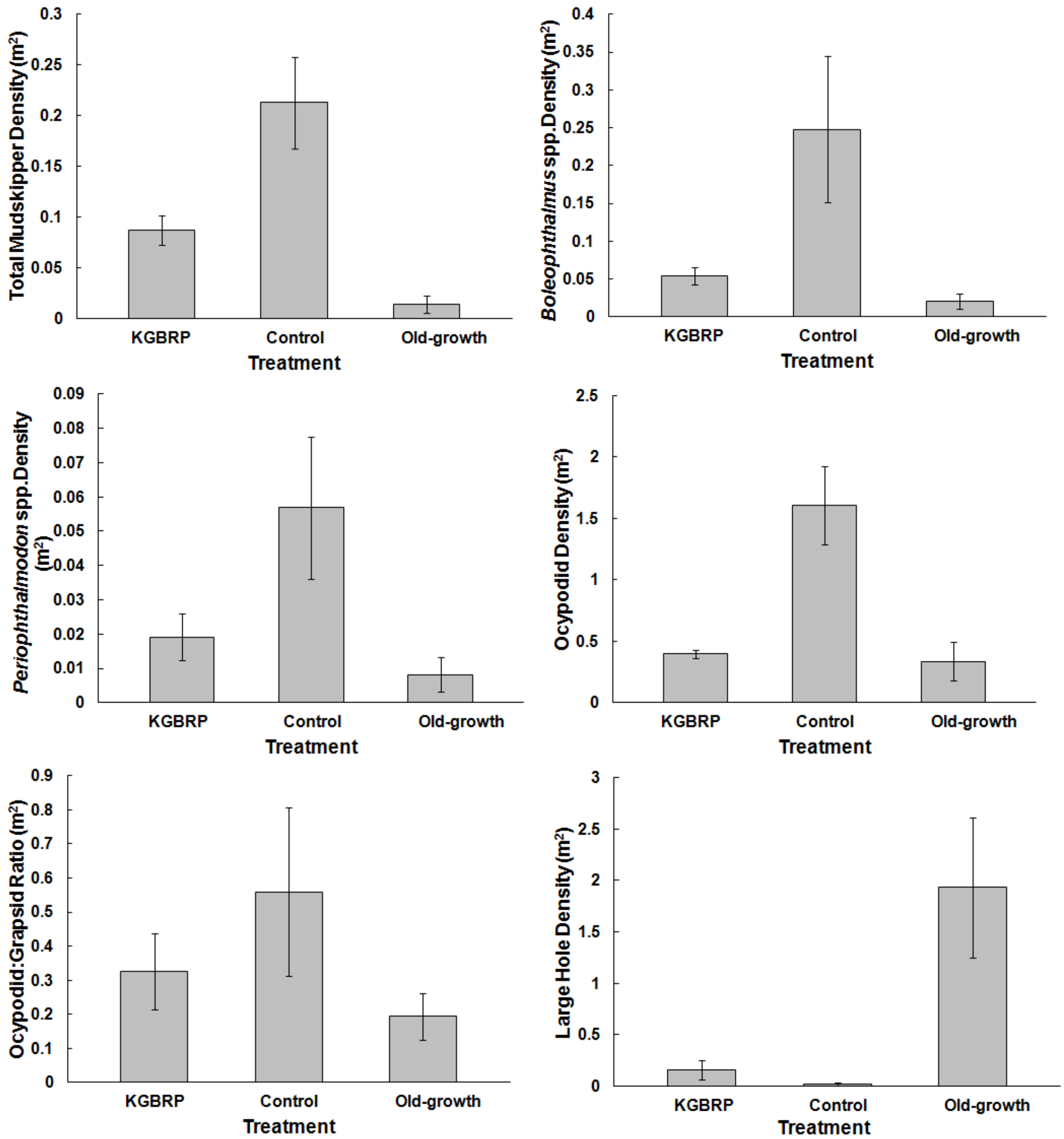

Fig. 3. Total mudskipper, Boleophthalmus spp., Periophthalmodon spp., ocypodid crab and large crab hole (diameter >3cm) density as well as the ratio of ocypodid to grapsid crabs across different mangrove treatments in Kien Giang, Vietnam. Error bars show standard error.

In addition, total mudskipper, *Boleophthalmus* spp., *Periophthalmodon* spp. and ocypodid crab density along with the ocypodid to grapsid ratio was found to be negatively correlated with percent forest cover (Appendix B, D). In contrast, large crab holes were found to be positively correlated with percent forest cover (Appendix B, D). The same pattern was found for the relationship between these fauna indicators with tree diversity, although the relationship between *Periophthalmodon* spp. density and tree diversity was only marginally significant (Appendix C, D).

4.0 Discussion

4.1 Vegetation community

As illustrated in the survey results there were significant differences observed in vegetation diversity, tree density, and overall forest cover. The reason for KGBRP rehabilitation sites having higher tree diversity, tree density, plant diversity and forest cover than control rehabilitation sites could be due to the fences used, the planting regimes or a combination of these factors. Given that *R. apiculata* seedlings planted at the KGBRP sites had a survival rate of 8 - 26.8%, and that all planting attempts at control sites had 100% mortality, it is likely fencing is important for the survival of planted seedlings as well as the natural recovery of forests (GIZ unpublished data). Although the surviving *R. apiculata* at the KGBRP rehabilitation sites may contribute to tree and plant diversity, 46% and 24% respectively, they accounted for only around 11% of tree density and 8% of plant density at the site, making their contribution to forest cover negligible. The negligible contribution of *R. apiculata* to tree and plant density at the KGBRP rehabilitation sites implies that the recovery of the forests at the KGBRP rehabilitation sites was largely due to fencing which seemingly supported natural recruitment. Similar research conducted by Kamali and Hashim (2011) also supports this claim. The Kamali and Hashim (2011) study stresses that the creation of favourable conditions using a suitable breakwater is more important than mangrove planting for effective mangrove rehabilitation, as natural recruitment will occur. Although it appears that the fencing at the KGBRP rehabilitation sites has resulted in the recovery of the vegetation community, it is unclear whether the KGBRP fence alone is sufficient or whether the additional protection afforded by the silt-trap fence is required. This is because 75% of the KGBRP rehabilitation sites also have a silt-trap fence.

Although other potentially influential factors in this study such as planting regimes can largely be explained, the effect of plot size and adjacent vegetation on the vegetation community in rehabilitation sites could not be fully addressed under this constrained study. Accordingly, the influence these factors may have on the outcomes could be surmised from the results of future studies.

4.2 Faunal Community

As with vegetation, faunal communities also responded to differences in the rehabilitation configuration at the study site. The higher numbers of mudskippers found at the control rehabilitation sites is likely to be linked to the low forest cover at these sites. This is supported by the finding that the density of mudskippers was negatively correlated with forest cover (Appendix B, D). Studies by Polgar and Crosa (2009) also support this as they only observed adult mudskippers in non-vegetated areas. Therefore, the low forest cover at control rehabilitation sites may provide more habitat for mudskippers while high forest cover at the KGBRP rehabilitation and old-growth sites excludes them from much of the area.

The higher number of ocypodid crabs found at the control sites is also likely to be related to the low forest cover at these sites. This is supported by data that shows that both ocypodid density and the proportion of ocypodids in the crab community are negatively correlated with forest cover (Appendix B, D). This interpretation is supported by findings of other studies that have found that ocypodid crabs dominate in disturbed, open areas and degraded or young rehabilitation sites (Ashton et al., 2003; Ellison, 2008; Macintosh et al., 2002). Accordingly, it is possible that the ocypodid crabs are associated with sites with more open sediment area due to their role as primarily substrate feeders as opposed to herbivores (Amaral et al., 2009; Geist et al., 2011).

By comparison, old-growth sites showed a higher number of large crab holes than KGBRP and control rehabilitation sites despite old-growth and KGBRP sites having comparable levels of forest cover. It is proposed here that the difference between KGBRP rehabilitation and old-growth sites could be related to the difference in the age of the forests. Crab communities in mangroves are known to change with forest age (Ashton et al., 2003). It is possible that larger crabs require the better quality habitat provided by old-growth forests due to factors such as increased sediment stability or better food provisioning.

KGBRP rehabilitation and old-growth sites are similar in terms of mudskipper and ocypodid densities and dissimilar in terms of large crab hole density as low mudskipper and ocypodid densities only requires the presence of forest whereas a high density of large crab holes requires good quality forest.

Similar to the vegetation community, the faunal community has the potential to be affected by the size of rehabilitation plots and the vegetation found in adjacent plots. Again, the logistic constraints on this project did not allow for a clear definition of any possible influence the factors might have had.

4.3 Wave Energy

In order to assess both fence performance and the influence of wave energy on the communities associated with each rehabilitation site, dissolution domes were used to estimate water movement intensity (see Section 2.4). Unfortunately this method did not provide reliable data. There were a number of factors which may have contributed to this method of measuring wave energy being inappropriate for this situation. The lack of constant water movement meant that erosion of the plaster was minimal in all areas, this lead to the method lacking sensitivity. The variable inundation at each site meant that controlling for the dissolution of the plaster was difficult, as control samplers placed in still seawater had longer exposure to water than samplers in the field. Intense sediment loads at the site also contributed to the failure of this method as many samplers were buried under approximately 30cm of sediment after only two weeks of exposure. This suggests this method is impractical for measuring wave energy in mangrove rehabilitation areas which are accreting sediment so rapidly. In addition, a high energy environment and close proximity to human settlement meant that a number of samplers went missing before they could be recovered.

4.4 Outcomes for Rehabilitation Assessment

Given the lack of consensus on how mangrove rehabilitation should be assessed, this study provides much needed information on the utility of various indicators. This study shows that tree diversity, tree density, plant diversity and forest cover can be used effectively to assess rehabilitation. The results also indicate that these indicators can be used to assess relatively young rehabilitation as vegetation is one of the first biotic features to recover after the implementation of rehabilitation and, in addition, many other bioindicators depend on vegetation.

This study shows that aspects of the mudskipper community can also be useful indicators. High mudskipper density seems to be a good indicator for poor quality mangrove habitat and rehabilitation. As their density is linked to the presence or absence of forest they could also be used to assess relatively young rehabilitation. Studies show that mudskippers are significantly affected by high concentrations of nutrients, heavy metals and industrial and urban pollution (Kruitwagen et al., 2006; Lakshmi et al., 1991; Wickramasinghe et al., 2009). In rehabilitation areas where these factors are an issue, any assessment using mudskippers must take these factors into account.

Two features of the crab community were shown to be good indicators in this study; ocypodid density and the density of large crab holes. Similar to mudskippers, high ocypodid density appears to indicate areas of poor quality rehabilitation. Ocypodid density also seems to be linked to the presence or absence of forest, meaning it could also be used to assess young rehabilitation. In contrast to ocypodid density, a high density of large crab holes appears to be an indicator of good quality mangrove habitat. As the presence of large crab holes appears to require a significant level of forest recovery, it is an indicator better suited to assessing more mature rehabilitation.

Although gastropods and grapsid crabs have previously proved to be useful indicators (Ashton et al., 2003; Macintosh et al., 2002), this was not reflected in this study. This could be because the instantaneous count method used only allowed for identification to coarse taxonomic levels. Although Kent and McGuinness (2006) remark that instantaneous counts are suitable for crabs in situations where time is limited, in this study the use of this method limited the level of identification possible. In future studies, methods that allow for better identification, such as the enclosure removal method (Geist et al., 2011; Koch and Wolff, 2002) or timed capture method (Ashton et al., 2003; Macintosh et al., 2002) should be considered.

4.5 Outcomes for Rehabilitation Implementation and Management

As KGBRP rehabilitation sites have higher tree diversity, tree density, plant diversity and forest cover than control rehabilitation sites, and are more similar to old-growth sites, the KGBRP rehabilitation appears to be a more effective rehabilitation technique. This largely supports the alternate hypothesis presented at the beginning of the study. The similar mudskipper and ocypodid crab densities at the KGBRP rehabilitation and old-growth sites and markedly disparate densities at the control rehabilitation sites also suggest the KGBRP rehabilitation is more effective. Again, this finding provides support for the alternate hypothesis presented at the beginning of the study.

Although other data demonstrates the success of the KGBRP rehabilitation, the density of large crab holes is quite different between KGBRP rehabilitation sites and old-growth sites. However, this could be largely due to the immaturity of the rehabilitation at the KGBRP rehabilitation sites. Given that mangrove communities undergo succession that somewhat resembles a deterministic model (Alongi, 2008), it is possible that the KGBRP rehabilitation sites will develop a community similar to that in the old-growth sites if given enough time.

With the recovery of the mangrove ecosystem at the KGBRP rehabilitation sites it is likely that the recovery of ecosystem services will also occur. However, this recovery relies on the forests being protected from the pressures that caused their initial degradation.

As the KGBRP rehabilitation appears to be more effective than the control rehabilitation at restoring the mangrove ecosystem it is recommended this method be implemented in future rehabilitation projects in Kien Giang and other regions, particularly in areas of relatively high erosion. If this method is replicated elsewhere in the future, it is also recommended that the focus be on the fencing rather than mangrove planting.

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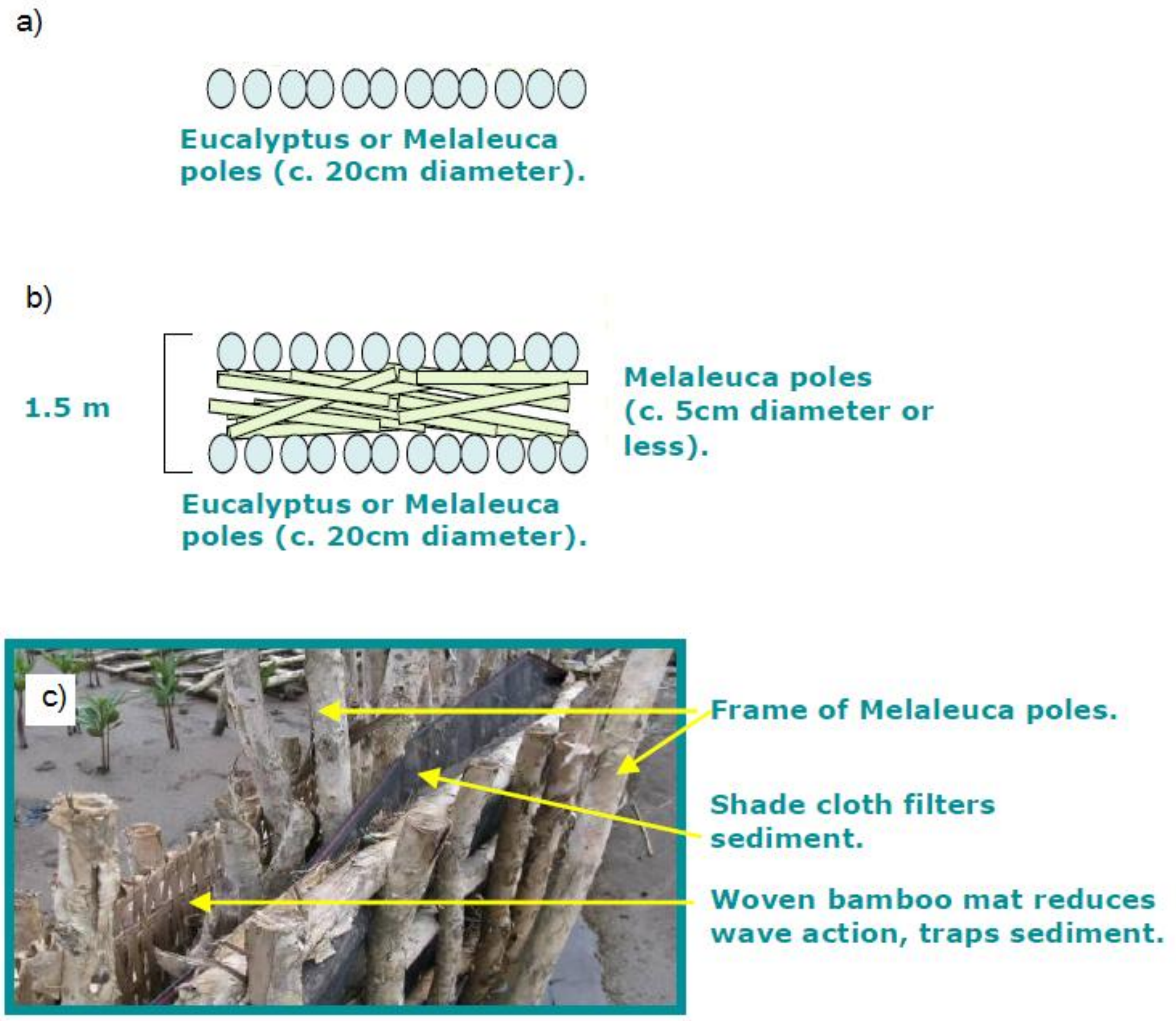
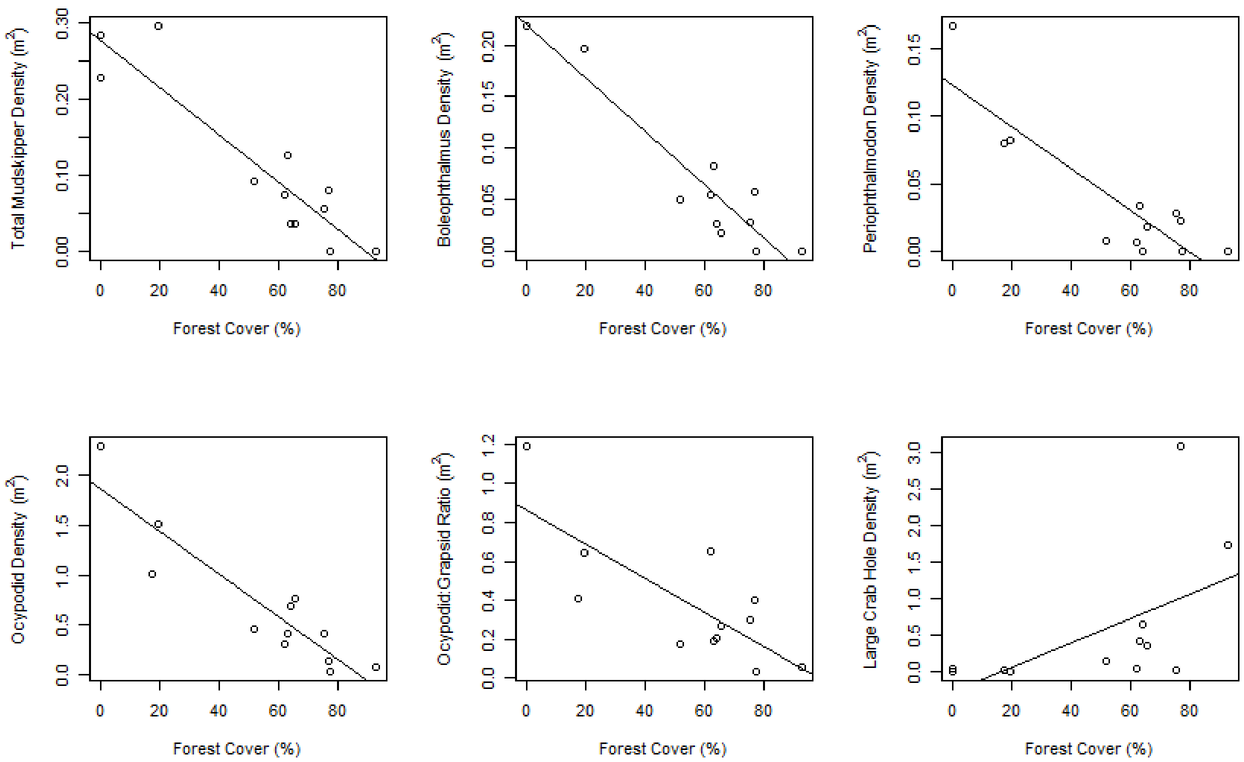
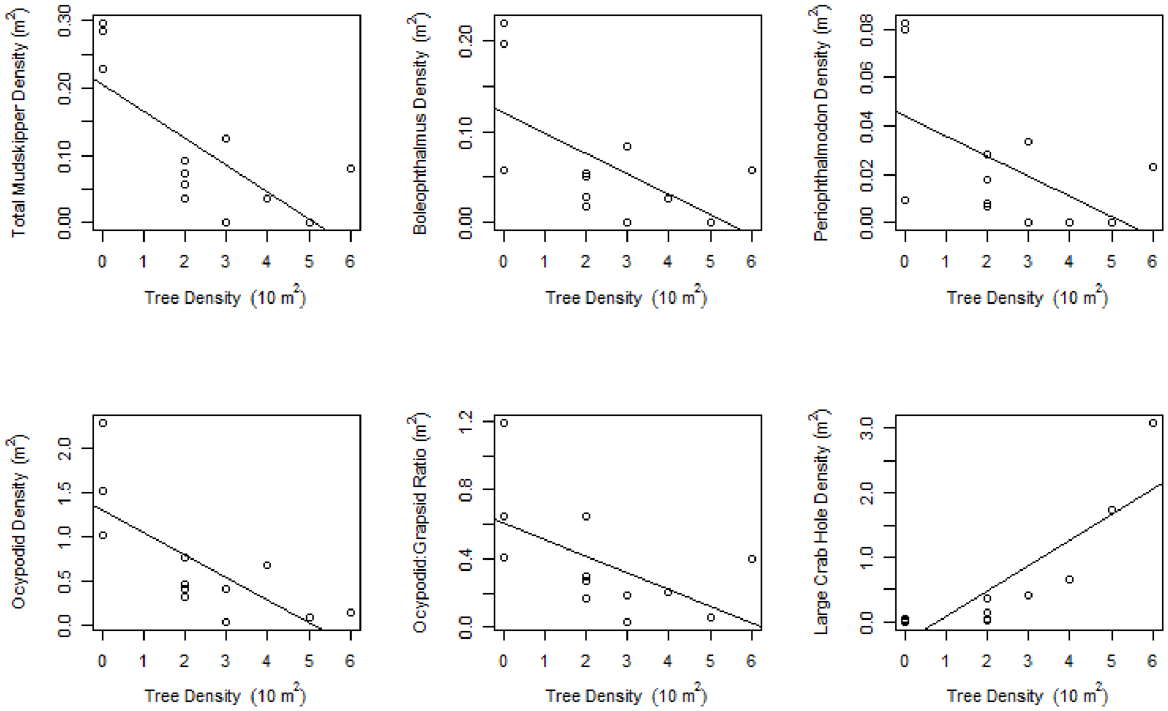
Appendices



Appendix A- Fencing designs used for mangrove rehabilitation at Vam Ray, Kien Giang, Vietnam. Diagram shows a) control fence, b) KGBRP fence and c) silt trapping fence. Modified from (GIZ, 2011a).



Appendix B- The relationship between total mudskipper, Boleophthalmus spp., Periophthalmodon spp., ocypodid crab and large crab hole (diameter >3cm) density per m2 and percent forest cover at each site. Trend line represents the line of best fit. All relationships found to be significant ($p < 0.05$).



Appendix C- The relationship between total mudskipper, *Boleophthalmus* spp., *Periophthalmodon* spp., ocypodid crab and large crab hole (diameter >3cm) density per m^2 and tree diversity per $10m^2$ plot at each site. Trend line represents the line of best fit. All relationships found to be significant ($p < 0.05$) except the relationship between *Periophthalmodon* spp. density and tree diversity (p=0.063).

Appendix D- P-values for the relationships between faunal community characteristics and vegetation community characteristics in Kien Giang, Vietnam. The faunal community characteristics are total mudskipper, *Boleophthalmus* spp., *Periophthalmodon* spp., ocypodid crab and large crab hole (diameter >3cm) density as well as the ratio of ocypodid to grapsid crabs and these are analysed with the vegetation community characteristics forest cover and tree density.

	Total Mudskippers	***Boloeophthalmus* spp.**	***Periophthalmodon* spp.**	**Ocypodids**	**Ocypodid:Grapsid Ratio**	**Large Crab Holes**
Forest Cover	≥0.001	≥0.001	0.001	≥0.001	0.003	0.047
Tree Diversity	≥0.001	0.012	0.063	0.006	0.051	≥0.001