# Factors influencing community mangrove planting success on Manus Island, Papua New Guinea

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## SUMMARY

This study evaluates the factors affecting community mangrove restoration at nine sites in eight different coastal villages of Manus Island, Papua New Guinea. Between June 2012 and April 2014, more than 8,400 mangrove seedlings of five species were planted on both restoration sites and sites with no history of mangroves. The timing of the plantings was uncontrolled, and some communities continued haphazard planting between the two periods. The success rate was highly variable and after 22 months the percentage of established plants ranged between 0 and 102%. My findings showed that the choice of genus planted, protection from wave action and the substrate were critical factors in reestablishment. Survival was highest for *Rhizophora* spp, at sites protected from wave action, and at locations with sand and gravel substrates. These results suggest that mangrove replanting success on Manus Island can be improved by preselecting sites and restricting plantings to *Rhizophora* spp.

## BACKGROUND

Mangroves occur along sedimentary shorelines protected from strong currents and wave action, inhabiting the intertidal zone between land and sea (Paijmans 1976, Baine & Harasti 2007). They connect marine and terrestrial ecosystems and provide numerous ecosystem benefits, such as spawning and nursery areas for marine organisms, protection from coastal erosion and carbon fixation (Gilman *et al.* 2006). Worldwide mangrove ecosystems are threatened by anthropogenic activities and effects of climate change (Farnsworth & Aaron 1997, McLeod & Salm 2006, Clarke & Jupiter 2010). In Papua New Guinea (PNG), mangrove species are felled for firewood and timber products (Ellison 1997, Farnsworth & Aaron 1997). Many conservationists propose that reductions in mangrove area can be offset by restoring areas where mangrove habitat previously existed (e.g. McLeod & Salm 2006).

Planting mangroves has been advocated as a means to mitigate against mangrove loss (e.g. Farnsworth & Aaron 1997, McLeod & Salm 2006), but it has been rarely practised in PNG. Multi-stakeholder and community participation in protection and rehabilitation of mangroves in PNG is considered vital to preserving mangrove ecosystems and adaptation to climate change (e.g. ADB 2014). Recent research by Maniwavie (2013) has shown that planting success is highly variable and mangrove survival can be accurately predicted based on physiochemical variables. Given that most communities and local governments in PNG have neither the capacity to undertake scientific analyses nor the budget for scientific equipment, the widespread application of such methods may not be practical.

Manus Island (1,900 km$^2$) is the largest island of the Admiralty Islands located within the Bismarck Archipelago. The island is equatorial with daily temperatures of 25–32 °C and annual rainfall between 3,000 and 4,000 mm. Manus has a wet climate all year round with two distinct trade wind patterns; the southeasterly trade winds from the middle to end of the year and the northwest trade winds for the remainder of the year (Croft 1983). Surveys conducted by the author in 2011 (unpublished report) reveal that coastal communities in and around Manus Island believe that mangrove degradation results from combined effects of climate change and anthropogenic activities. These communities listed coastal erosion and fish decline as common problems, and more than 90% of the Manus community supported the concept of mangrove rehabilitation and sustainable management. Consequently, the Wildlife Conservation Society (WCS) undertook a community mangrove planting project. Here I report on the *post hoc* analysis of planting success.

## ACTION

**Restoration intervention:** Following community consent, plantings of five mangrove species (Table 1) were conducted multiple times at nine sites in eight coastal villages (Tulu 1, Tulu 2, Lirau Island, Koroji, Butchou, Kupanou, Pelipowai and Piri) of central Manus Island (Figure 1). Planting was carried out by the WCS PNG programme staff, community facilitators and local communities between June 2012 and April 2014 (22

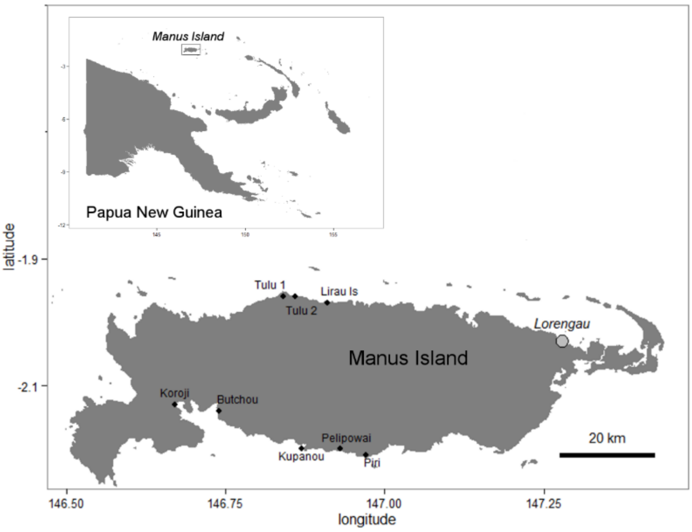


**Figure 1.** Map showing locations of eight coastal villages where mangrove rehabilitation was undertaken in central Manus Island, Papua New Guinea

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**Table 1.** Twenty three mangrove species identified in the study sites on central Manus Island based on field observations. Seedlings of species used for community planting are indicated with an asterisk (*).

| Dominant | Common | Rare |
|---|---|---|
| *Rhizophora apiculata*, Rhizophora mucronata*, Ceriops tagal*, Bruguiera sexangula*, Sonneratia alba* | *Rhizophora stylosa, Avicennia alba, Avicennia lanata, Avicennia marina, Bruguiera gymnorrhiza, Exoecaria agallocha, Heritiera littoralis, Lumnitzera littorea, Xylocarpus granatum, Xylocarpus moluccensis, Aegiceras corniculatum, Osbornia octodonta* | *Bruguiera cylindrica, Bruguiera parviflora*, Pemphis acidula, Scyphiphora hydrophyllacea, Sonneratia caseolaris, Nipa fruticans,* |

months). Community facilitators were indigenous Manusians trained in community conservation by WCS. Rehabilitation of mangroves was trialled on both “restoration” and “novel” sites (Table 2). I define a “restoration” site as a degraded intertidal zone between land and sea where mangroves had been removed through anthropogenic activities, and a “novel” site as an intertidal area that never had mangroves historically. Despite WCS advising communities not to plant at novel sites, a number of communities persisted. The planting and/or replanting was specifically undertaken to mitigate against coastal erosion around villages. I refer to “planting” as first time planting and “replanting” refers to efforts by communities to replant between monitoring periods or on instances when the orginal plantings fail.

Of the 44 mangrove species present in PNG (Maniwavie 2007), 23 were identified within the study sites (Table 1). The distribution of mangroves in Manus Island can be classified into a series of zones transitioning from salt to brackish water landwards as determined by the dominant species type: (A) *Rhizophora* zone on actively accreting shores (subdominant species include *Sonneratia alba*, *Ceriops tagal* and *Avicennia* spp.); (B) a *Bruguiera* zone reaching a canopy height of up to 30 m (subdominant species include *Heritiera littoralis* and *Xylocarpus granatum* and *X. moluccensis*) and (C) a *Nypa fruticans* zone forming a monotypic stand. WCS guided the communities in choosing appropriate species for planting based on mangrove zonation pattern, but the communities had the freedom to choose what species to plant. Seedlings were readily available from the intact mangrove forests. Fallen propagules (seeds or young seedlings) for planting were ecosourced from surrounding intact mangrove forests and planted at approximately 1 m intervals.

**Monitoring:** We assessed the success of mangroves while we were on site through raw counts of established saplings on two occasions: an initial count took place three months after planting in June 2012, and a final count was done 22 months later in April 2014 (Table 2). Planting efforts were not controlled, and some communities continued to replant between the two periods. Mangrove seedlings that may have been present naturally prior to planting or established naturally after planting were obvious, and these were excluded from the counts during monitoring periods. During the study period, we also distributed more than 4,000 polybags to interested communities and primary schools to raise mangrove seedlings in nurseries. Field observations indicated that more than 25% of the polybags were used in this way.

**Modelling environmental factors:** Data analysis was carried out in Program R version 3.0 (R Core Team 2013). The response variable, the number of mangroves persisting at the end of the growing period (offset by number of mangrove plantings present in 2012) was modelled as a multiple Poisson regression against combinations of seven categorical independent variables. Fifteen candidate models were tested to find the most parsimonious model and a simple intercept model was also run to show baseline for poor performance. I used an information theoretic approach (*sensu* Burnham & Anderson 2002) to assess the 16 candidate models using the package AICcmodavg (Mazerolle 2015).

The categorical variables were: *genus*, *species*, *site type*, *comm participation*, *mangrove zone*, *protection* and *major substrate. Genus* was the three genus name of the species planted (*Rhizophora* spp, *Bruguiera* spp and *Ceriops* sp.*)*; species was the species planted (Table 1); *site type* was either restoration or novel site; *comm participation* was my subjective assessment, based upon community engagement of

**Table 2.** Comparative numbers and proportional establishment success rates of mangrove plants in nine sites (restoration versus novel) on central Manus Island, PNG. Establishment success was measured as the proportion of seedlings surviving at the end of the counting period compared to initial planting. Numerator = finish number, denominator = initial number, brackets = proportion remaining at end of study, * = proportional increase, most likely due to additional community planting.

| Site | Site type | *Rhizophora apiculata* | *Rhizophora mucronata* | *Bruguiera sexangula* | *Ceriops tagal* | *Bruguiera parviflora* | Establish. success |
|---|---|---|---|---|---|---|---|
| Tulu 1 | Novel | 0/103 (0) | 0/3 (0) | 0/71 (0) | 0/39 (0) | | No |
| Tulu 2 | Novel | 0/36 (0) | 0/6 (0) | 0/43 (0) | 0/7 (0) | | No |
| Lirau Island | Novel | 31/80 (0.39) | 10/40 (0.25) | | | | Yes |
| Piri | Restoration | 1372/1351 (1.02)* | 570/891 (0.64) | 11/294 (0.04) | 52/1104 (0.05) | 34/198 (0.17) | Yes |
| Pelipowai | Restoration | 8/51 (0.16) | 0/34 (0) | | | | Yes |
| Kupanou | Restoration | 15/149 (0.1) | 3/20 (0.15) | 0/17 (0) | 0/3 (0) | | Yes |
| Butchou | Restoration | 37/314 (0.12) | 302/360 (0.84) | 3/65 (0.05) | 0/100 (0) | | Yes |
| Koroji site A | Restoration | 0/135 (0) | 53/286 (0.19) | 0/27 (0) | 0/135 (0) | | Yes |
| Koroji site B | Restoration | 117/505 (0.23) | 98/394 (0.25) | 159/1111 (0.14) | 91/406 (0.22) | | Yes |



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**Table 3.** Ranking of candidate models describing mangrove establishment. AICc = Akaike's Information Criterion with a small sample correction, ΔAICc = difference between AICc of current model and top model, Mod Weight = relative likelihood of the model, Cum Weight = cumulative model weight, LL = maximized value of the log-likelihood function.

| Rank | Model | No. parameters | AICc | Δ AICc | Mod Weight | Cum. Weight | LL |
|---|---|---|---|---|---|---|---|
| 1 | *genus + protection + major substrate* | 7 | 952.09 | 0 | 1 | 1 | -466.89 |
| 2 | *species + site type + mangrove zone + comm participation* | 9 | 1047.08 | 94.99 | 0 | 1 | -510.79 |
| 3 | *genus + comm participation + protection* | 7 | 1109.26 | 157.17 | 0 | 1 | -545.47 |
| 4 | *genus + site type + comm participation* | 6 | 1111.03 | 158.94 | 0 | 1 | -547.96 |
| 5 | *species + comm participation* | 7 | 1119.23 | 167.14 | 0 | 1 | -550.46 |
| 6 | *genus + comm participation* | 5 | 1122.7 | 170.61 | 0 | 1 | -555.28 |
| 7 | *species + mangrove zone + site type* | 7 | 1362.01 | 409.92 | 0 | 1 | -671.85 |
| 8 | *species + site type + mangrove zone* | 7 | 1362.01 | 409.92 | 0 | 1 | -671.85 |
| 9 | *genus + site type + mangrove zone* | 5 | 1384.31 | 432.23 | 0 | 1 | -686.08 |
| 10 | *species + site type* | 6 | 1453.81 | 501.72 | 0 | 1 | -719.35 |
| 11 | *genus + site type* | 4 | 1481.09 | 529.01 | 0 | 1 | -735.86 |
| 12 | *Species* | 5 | 1589.13 | 637.04 | 0 | 1 | -788.49 |
| 13 | *Genus* | 3 | 1602.17 | 650.08 | 0 | 1 | -797.68 |
| 14 | *protection + major substrate* | 5 | 2310.9 | 1358.81 | 0 | 1 | -1149.38 |
| 15 | *Simple intercept* | 1 | 3005.05 | 2052.96 | 0 | 1 | -1501.46 |
| 16 | *site type* | 2 | 2932.43 | 1980.35 | 0 | 1 | -1464.02 |

community effort in planting on a categorical scale (high, medium and low); *mangrove zone* was the area in which seedlings were planted (zone A, B or C of the intertidal zone — determined by the presence of dominant mangrove species); *protection* was the level of site exposure to sea waves and wind on a categorical scale (high, medium and low); and *major substrate* was the dominant substrate composition (organic matter, mud, or a sand and gravel mixture) in the top 20 cm of substrate into which mangroves were planted.

## CONSEQUENCES

Overall approximately 2 ha of degraded land were planted with more than 8,400 mangrove seedlings between June 2012 and April 2014. At least 1 ha of these was planted through direct involvement of WCS staff and community facilitators; the other 1 ha was planted by communities themselves with minimum support from WCS. Overall approximately 2,960 seedlings had established by the end of the study (Table 2).

Establishment of planted individual mangrove species at individual sites varied between 100% mortality and 2% increase during the 22 month period. Overall, there was a net loss of planted mangroves (i.e. proportional change <1) for all species and sites with the exception of *Rhizophora apiculata* at Piri (Table 2). Two novel sites had no mangroves established (Table 2). At Piri the proportion of mangroves remaining exceeded the number recorded on the first count as a consequence of the community continuing to actively replant between monitoring episodes. Establishment of mangroves was most successful at Piri and least successful at Tulu 1 (Figure 2). Of the genera planted, *Rhizophora* spp. appeared to establish across most sites (7/9) while *Bruguiera* spp or *Ceriops tagal* only established at two sites each.

In the analysis, the pattern of mangrove establishment was best explained by a single model, which had unanimous model support (i.e. model weight =1) that included *genus*, *protection* and *major substrate* (Table 3). Model coefficients suggest that optimal mangrove seedling establishment would be obtained by planting *Rhizophora* spp. at sites highly protected from wave action on mixed sand and gravel substrate (Table 4).

Long-term monitoring of the village plantings is ongoing, with community facilitators visiting participating communities on a regular basis as part of ongoing commitment by WCS to conservation in central Manus. As a consequence of this study, future planting work will focus on early identification of suitable sites with a focus on establishing *Rhizophora* spp., so that the effectiveness of the planting interventions are maximized.

**Table 4**. Summary coefficients for the proportion of mangroves persisting at the end of the growing period from the top model in Table 3. The intercepts used *Bruguiera* spp., high level of protection and mud as the substrate.

| | Estimate | Std. Error |
|---|---|---|
| Intercept | -3.52 | 0.15 |
| Ceriops | -0.67 | 0.11 |
| Rhizophora | 1.39 | 0.07 |
| Level of protection: Low | -1.04 | 0.11 |
| Level of protection: Medium | -0.74 | 0.06 |
| Major substrate: Organic matter | 1.16 | 0.15 |
| Major substrate: Sand and gravel | 1.92 | 0.14 |



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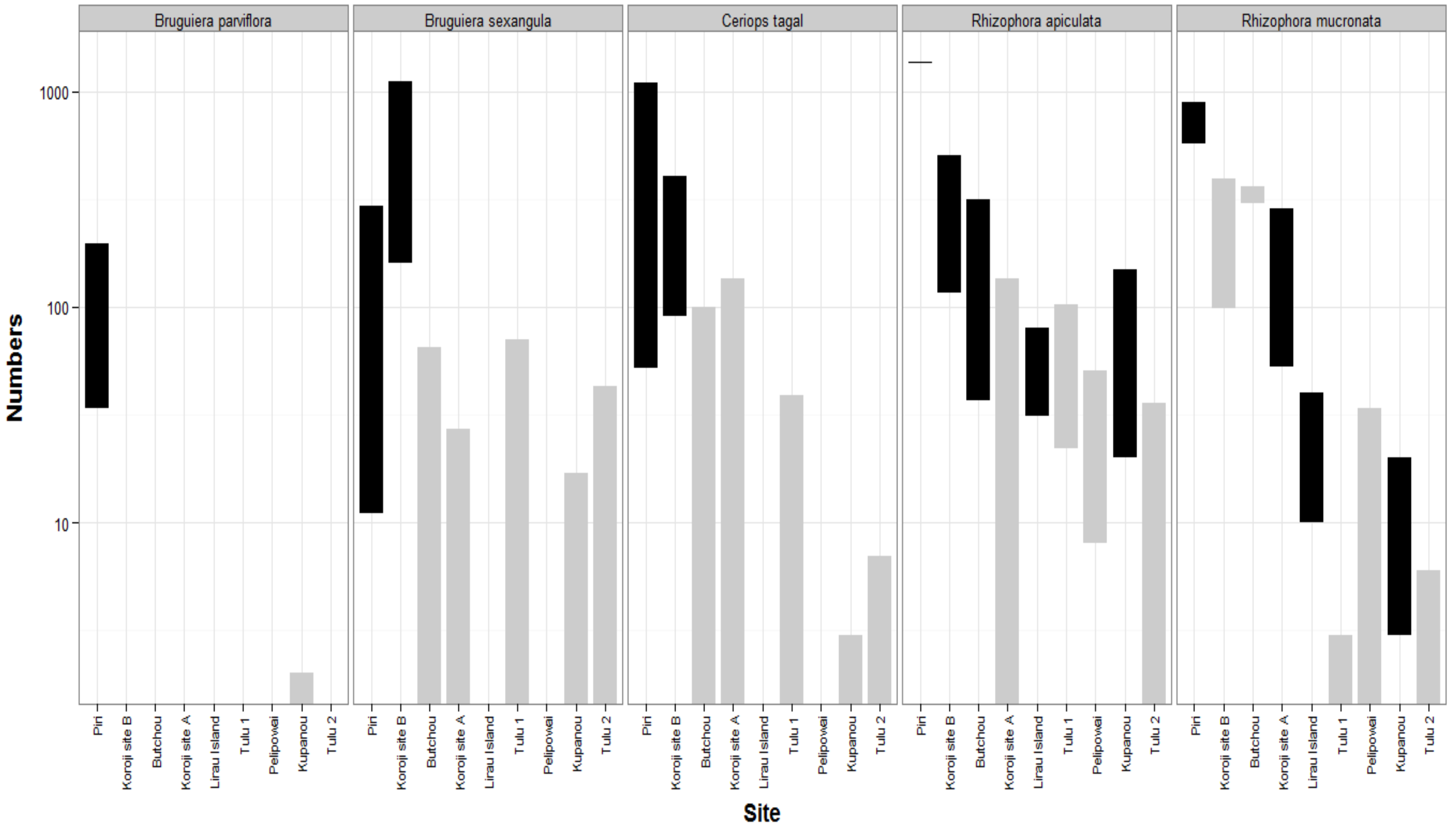


**Figure 2.** The number of mangrove plantings that established during the period June 2012 to April 2014 at nine sites in eight villages (note log scale). Black bars = successful plantings (where at least some plants established), grey bars = unsuccessful plantings (no plants established), and no bars = no planting; the top end of each bar = initial counts, and bottom end of each bar = final counts.

## DISCUSSION

Uncontrolled planting by local communities between the main planting periods means that the results presented here should be interpreted with caution. However, despite having a low sample size, it appeared that genus, protection and substrate type were important factors influencing planting success. Level of community participation (which is likely to correspond to the amount of uncontrolled planting) was not identified as an important predictor variable, suggesting uncontrolled planting did not have an effect on levels of seedling establishment. *Rhizophora* spp. was the most consistent performer. This is perhaps not surprising given that more than 75% of mangrove area lost on Manus Island in the past were within zone A, in which *Rhizophora* spp. is naturally dominant. Not unexpectedly, sites that were protected from the wind and wave action had better rates of establishment. The preference for a mixture of sand and gravel substrates, however, is not intuitive. Given the known sensitivity of mangroves to substrate chemistry (e.g. redox potential and sulphide concentration) (Patrick & DeLaune 1977), caution should be taken when extrapolating these results (based on a simple substrate classification) beyond Manus Island.

Existing literature suggests planting should involve locally available mangrove species appropriate to the zone where it occurs naturally (Macintosh *et al.* 2002, Gilman *et al.* 2006, McLeod & Salm 2006). With the exception of Lirau Island, mangroves did not establish at any of the novel sites (Table 2, Figure 2). The comparative lack of success at novel sites (Tulu 1 and Tulu 2) or low success of plantings at restoration sites (e.g. Pelipowai and Kupanou) is likely due to greater exposure to wave action. Proximity to human settlement and positioning seedlings too close to daily thoroughfares could also have had possible effects on planting success rate, but these variables were not measured in this study.

Given the poor funding and low capacity of local government, local communities themselves are the only entities in PNG capable of managing planted areas. However, outside agencies such as NGOs play important roles in informing such communities, particularly with regard to the possibility of establishing mangroves and importance of site and species selection.

During the course of the mangrove plantings, it became obvious that knowledge of some basic technical skills (e.g. collecting propagules, site preparation and planting) was needed by participating communities. In particular, communities need to be advised on minimizing mortality by learning best practices for obtaining healthy seedlings and planting appropriately. Recently a mangrove planting handbook for communities in PNG has been developed that could help fill this need (Maniwavie *et al.* 2013).

So far major community mangrove planting has been undertaken at Koroji, Butchou and Piri villages. Currently, I estimate a further 1–2 ha more of degraded areas at Butchou village could be planted. Aside from this planting, most mangrove forests of central Manus Island appear to be largely intact. Consequently, rehabilitation is not the priority, but rather the immediate need is to manage human activities and attitudes



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in Manus to avoid degradation of the existing healthy mangrove ecosystems.

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