

# **Mangroves and Possible Mangrove Introduction Sites at Ailuk Atoll, Marshall Islands**



## **Report**

### **The Natural Resource Assessment Survey (NRAS) Marshall Islands**

**Dr. Joanna Ellison,  
School of Geography and Environmental Studies,  
University of Tasmania,  
Locked Bag 1376, Launceston,  
Tasmania 7250, Australia**

**20 February, 2007**

## Executive Summary

Mangroves are tropical forest ecosystems that normally inhabit inter-tidal sheltered coastal sedimentary areas, where they stabilise sediment, provide coastal protection during storms, and support fish and crab communities. In the Marshall Islands five mangrove species occur in the south some in coastal settings, while in the north only one species occurs in inland depression settings.

Mangrove resources of Ailuk atoll were surveyed, finding one small inland area in Bigen islet with *Bruguiera gymnorrhiza* trees, which was established as a permanent monitoring site. The site appeared to be natural, with dense mangrove growth. This 123 m<sup>2</sup> mangrove area in a wet limestone depression was 65 m inland, 1.7 m above MSL, with nearly saline pond water and an alkaline pH of 8.5. A smaller inland pond was surveyed at Kapen islet where introduced mangroves had recently been cut.

The Ailuk Atoll Marine Resource Management Advisory Committee expressed interest in introduction of coastal mangroves to Ailuk, primarily to reduce islet shoreline erosion. The suitable species would be *Rhizophora*, which occurs in the southern Marshalls in coastal settings but not on Aliuk. A reconnaissance for such a project proposal found that the most suitable site for initial introduction is the inner channel of Aliej islet, having a suitable inter-tidal elevation, is sheltered from wave and wind action, has a sedimentary substrate easy to plant mangroves in, and has tidal outflow into the lagoon.

While mangroves have a number of values in areas where they are native, some important negative impacts have been identified where they have been introduced in Hawaii. These are that the trees invade prime foraging and nesting mudflat habitat for waterbird species, and they tend to overgrow archaeological sites particularly ancient fish ponds. In other areas, beneficial effects identified from mangrove introduction included increase of sediment capture and sediment stabilisation, increase of habitat for species such as crabs and coastal fisheries, and increase of resting and feeding habitat for migrating and local birds. In some replanting projects, local communities have been strongly involved in their success and community benefits.

Guidelines for successful mangrove introduction include assessment of suitable species and minimum impact at the source area, appropriate seed collection and planting techniques, nursery establishment, seedling collection and transplantation, site preparation and monitoring.

## Table of Contents

1.0 Mangroves	
1.1 Mangrove Species of the Marshall Islands	4
1.2 Uses of Mangroves	4
2.0 Ailuk atoll	6
2.1 Objectives of this project	6
3.0 Present mangrove resources of Ailuk Atoll	7
3.1 Methods	7
3.2 Results	8
4.0 Reconnaissance of possible mangrove introduction to Ailuk	10
4.1 Methods	10
4.2 Results	10
5.0 Issues and techniques of mangrove introduction	12
5.1 Mangrove introduction on other islands	16
5.2 Mangrove introduction benefits	18
6.0 Planting methods, and formulation of strategy appropriate for the Ailuk species and conditions	19
6.1 Identify the objective of mangrove replanting	19
6.2 Decide on the approach to reforestation	20
6.3 Species selection	20
6.4 Seed collection	22
6.5 Propagule/ Seed planting	22
6.6 Wilding collection and transplanting	22
6.7 Nursery practices	23
6.8 Site preparation	23
6.9 Planting seedlings	23
6.10 Monitoring	24
7.0 Recommendations	24
8.0 Acknowledgements	25
9.0 References	25

## 1.0 Mangroves

The term "mangrove" is used to describe a taxonomically diverse group of tree species that grows in the upper intertidal zone of sheltered shores in the tropics. True mangrove species are those that occur exclusively in this saline wetland environment, with adaptations such as aerial roots, halophytic strategies, vivipary and water conservation. These adaptations distinguish mangrove trees as a specialized minority within their families.

The world mangrove area is estimated at 14,197,635 ha (Lacerda et al., 1993), not including a growing list of countries where 50-80% of mangroves have been cleared in the last 15 years (Diop, 2003). In the Pacific Islands region, the total mangrove area is about 343,335 ha, which comprises 2.4% of the world's mangroves, with the largest areas in Papua New Guinea, Solomon Islands, Fiji and New Caledonia. The area in the Marshall Islands is relatively small, but the species mixture is unique in the Pacific Islands (Ellison, 1997), and the mangroves have important values to island communities. Mangrove resources are traditionally exploited in the Pacific islands, for construction and fuel wood, herbal medicines, and the gathering of crabs and fish.

Mangroves also rarely occur in inland situations, cut off from tidal connection with the ocean (Ellison and Simmonds, 2003). In the Northern Marshalls, mangroves are in several places found in depressions on atoll islands without a connection to the ocean (Fosberg, 1975).

### 1.1 Mangrove Species of the Marshall Islands

Five mangrove species are found in the Marshall Islands (Fosberg, 1975; Vander Velde and Vander Velde, 2005; Table 1). There is confusion about the identification of the *Rhizophora* species. Fosberg identified this at Jaliut to be *Rhizophora mucronata*. However, *Rhizophora stylosa* and *Rhizophora mucronata* have been confused for many years particularly by earlier writers (Taylor, 1979). In Samoa *Rhizophora stylosa* has been referred to as *Rhizophora mucronata*, but this is a mis identification (Tomlinson, 1978). Similar confusion has existed between these two species and *Rhizophora apiculata* (Ellison, 1997). Vander Velde and Vander Velde (2005) at Jaliut over a number of years have studied the small stand of *Rhizophora* there, and with assistance from the botanist Norm Duke decided it must be *Rhizophora apiculata*. Vander Velde and Vander Velde (2005) also found *Xylocarpus moluccensis*.

Table 1: Mangrove species present in the Marshall Islands.

<b>Scientific name</b>	<b>Marshallese</b>	<b>Identification</b>
<i>Bruguiera gymnorrhiza</i>	Jon	Knee roots, red flowers, no abaxial speckles on leaves—this species dominates the Marshall Island mangroves
<i>Rhizophora apiculata</i>	Eoeak or bulabol	Arched stilt (prop) roots. Typically found in more saline conditions than a <i>Bruguiera</i> .
<i>Lumnitzera littorea</i>	Kimeme	Small obovate leaves with indentation at tip, red flowers
<i>Sonneratia alba</i>	Bulabol or Konpat	Pneumatophore arial roots, pale under surface to leaf, salt glands
<i>Xylocarpus moluccensis</i>	Lokobar	4-6 leaflets in opposite pairs, large round fruits, found at the landward margin

Of these five species, only *Bruguiera gymnorrhiza* occurs in the Northern Marshalls, which is the limit of mangroves in the NE Pacific. In the Northern Marshalls, small areas of mangrove (*Bruguiera gymnorrhiza*) occur on Rongelap and Bikini atolls (Taylor, 1950). These are more commonly in depressions inland, as opposed to the normal coastal habitat of mangroves (Fosberg, 1975).

Mangrove depressions are hard-bottomed coral limestone shallow depressions in the interior of atoll islets, the more common situation for mangroves in the Marshalls. These depressions are fed by seepage of groundwater, somewhat saline. In one such depression on Jaliut, small *Rhizophora* shrubs occupy pits that are partially filled by marl in the level hard bottom of the depression (Fosberg, 1975).

Despite these accounts, little is known about the community structure, ecology and geomorphic settings of mangroves of the Marshall Islands. While they are known by local people to occur on Ailuk atoll, there has been no assessment of this resource.

### **1.2 Uses of Mangroves**

Source: <http://www.hawaii.edu/cpis/MI>

*Rhizophora apiculata* - Tannins from the Rhizophoraceae are used for protection of nets and fish traps owing to their fungicidal properties. The prop roots of *Rhizophora* are used for constructing fish traps, fuelwood, and light construction.

*Bruguiera gymnorrhiza* – The wood is very durable and used for house posts, resistant to rot. Tannins can also be used to protect nets and fish traps owing to their fungicidal properties.

*Lumnitzera littorea*– Strong timber, used for house posts, straight wood useful to make the boom connecting a canoe to its outrigger.

*Sonneratia alba*: The wood of this tree is good for floor timber and canoes. Also good for house posts as resistant to rot.

*Xylocarpus moluccensis*: *Xylocarpus* species are used for traditional medicines. Infusion from bark is boiled and used to treat stomach aches and peptic ulcers (Ellison and Gilman, 2005). The wood is also a valuable hardwood.

## **2.0 Ailuk atoll**

Ailuk Atoll is situated in the north east of the Republic of the Marshall Islands, part of the Ratak Group (10° 58' N; 169° 88' E. The atoll is about 24 km (15 miles) long and 11 km (7 miles) wide, and a lagoon area of 176.6 km<sup>2</sup> (68.5 square miles). The lagoon is deep and has a continuous reef all around with four channels through this. The lagoon water is quite deep with rich coral biodiversity.

Ailuk has a micro-tidal range, with a mean range of 1.1 m (3.5 ft) and a spring range of 1.5 m (4.9 ft) (NOAA, 2007).

On the atoll rim there are approximately 55 islets with a land area of 2.07 square miles, and all but two of the islets are located on the eastern side of the atoll. The main residential island is Ailuk Island which is small (about 1500 feet long) and inhabited by 400 people. Enejelar Island, at the northern end of Ailuk Atoll, is another area where only a small group (40) of people periodically live.

### **2.1 Objectives of this project**

The objectives of this project were:

- 1) Assess the existing mangrove resource of the atoll, and establish a monitoring program through which local participants are trained about mangrove values and mangrove monitoring.
- 2) Assess the potential value of mangroves in reducing coastal erosion problems identified on the atoll islets, and carry out reconnaissance for such a project proposal.

### **3.0 Present mangrove resources of Ailuk Atoll**

#### **3.1 Methods**

With assistance from the local knowledge of the Ailuk Atoll Marine Resource Management Advisory Committee, one mangrove area was visited, as well as a second where the mangroves had been cut out.

At each site, the location was determined using a GPS. Surveys of elevations of mangrove sites were carried out accurately using a surveyor's level, and each survey was related to tidal elevation and the time recorded. A SEAFRAME tide gauge was installed at Majuro in May 1993 (BOM, 2005), managed by the Flinders University of South Australia. Tidal records for the fieldwork period were kindly provided to the project, where observations are recorded every six minutes.

The datum for tidal recordings was set at Lowest Astronomical Tide, which is the same 0 on the tidal predictions. Mean Sea Level has been calculated as an average recorded over an extended period of time early in the record, which is 1.0510 m above LAT (BOM, 2005).

At each mangrove site replicate samples of water were taken for analysis of salinity and conductivity at the EPA laboratory on Majuro. On site, replicate samples of mangrove substrate were tested for pH.

The mangroves at the major site Bigen were established as a permanent monitoring plot following the monitoring protocol of Ellison (2006). This was carried out by Ailuk volunteers after training (Figure 1), including the Ailuk horticultural officer, Jackson.

This monitoring protocol was adapted for community monitoring in island settings from the more scientific protocol in English et al., (1997), and has previously been successfully used in Tonga and American Samoa.



Figure 1. Ailuk volunteers measuring mangrove trees at the mangrove pond on Bigen islet.

### **3.2 Results**

The mangrove area found at Bigen, the fourth island from the north on the eastern string of islands along the Ailuk windward reef, was the only remaining mangrove area known on Ailuk Atoll. It is located in an inland depression on the NE side of the island ( $10^{\circ} 25' 31.6''$  N;  $169^{\circ} 58' 01.0''$  E), surveyed to be 65 m from the coast along a path through mainly *Scaevola taccada* shrubs, the path having a magnetic bearing of  $340^{\circ}$  from the coastal shingle ridge at  $10^{\circ} 25' 33.6''$  N;  $169^{\circ} 58' 03.0''$  E.

The mangrove area was small, in two depressions in the limestone about 10 m apart. The larger pond contained shallow water but no sediment accumulation on the rock underneath (Figure 2). This mangrove area was triangular in shape, each side 15 m long, giving a total area of  $112.5 \text{ m}^2$ . The smaller mangrove area had no standing water and again little sediment accumulation and consisted of one tree and four small seedlings. The diameter of this smaller area was 4.5 m, giving a total area of  $10.8 \text{ m}^2$ .



The mangrove surface in the larger depression was surveyed to be 1.71 m above MSL. The mud substrate was found to be alkaline, with a pH of 8.5-9.0. Fosberg (1975) thought the mangrove mud of these depressions to be acid, however numerous tests during the present study found all such situations to be alkaline. The water present at Bigen mangrove pond was fairly saline, with an average salinity of 32.3 mS/cm, and conductivity of 20.1 ppt.

Mangrove species present were all *Bruguiera gymnorrhiza*, in several size classes (Tables 2 and 3). There were 14 mature trees with an average diameter of 20.1 cm, and an average height of 3.3 m. These at the time of sampling (January) carried propagules which were not mature for abscission. There were also 19 saplings all in the larger triangular pond, with an average diameter of 1.3 cm and an average height of 1.7 m. These were densely spaced. Under both the trees and saplings were a large number of seedlings of mainly less than 3 years of age, and less than 60 cm in height, in total over 150 individuals densely spaced.

The author demonstrated to the Horticultural Officer, Jackson, and the Honorable Mayor Cradel Alfred of Ailuk, how to dig up a seedling, and how to replant it elsewhere. This included advise on which seedlings were best to take, based on two criteria. First, those which were younger and healthy as shown by few leaf scars on the stem and no branches. Second, those which had little chance of surviving in their present location either due to dense shade from parent trees or dense competition from other seedlings. It is important not to deplete the source site, since this is the only mangrove resource on the atoll.

Table 2. Mangrove tree dimensions at Bigen Mangrove Pond.

Tree ID number	Diameter (cm)	Height (m)
882	30.2	3.4
888	22.1	3.6
880	31.4	3.4
874	23.1	3.7
875	11.2	2.5
876	9.1	3.2
877	16.3	3.2
881	19.5	3.2
868	19.9	3.4
892	15.9	3.1
886	38.8	3.9
867	12.8	3.9
879	12.4	2.0
889	18.8	4.3



Figure 2. Mangrove pond on Bigen Islet, Ailuk atoll.

Table 3. Mangrove sapling dimensions at Bigen Mangrove Pond.

Sapling ID number	Diameter (cm)	Height (m)
887	1.5	1.9
890	1.3	1.3
893	1.3	2.2
884	1.8	2.5
873	1.8	1.7
888	1.1	1.3
866	1.3	1.2
869	1.3	1.2
885	1.3	1.3
896	1.7	1.7
899	1.3	1.6
871	1.1	1.8
907	1.1	1.6
878	1.3	1.9
865	1.4	1.9
898	1.2	1.7
894	1.4	2.4
897	1.0	1.5
872	1.0	1.8

The author was also taken to an inland pond on Kapen, the most northerly island of Ailuk, where mangroves had been present but were cut. These were described as originally introduced there. This pond was located on the south central part of the island at 10° 27' 46.4"N, 169° 56' 54.4"E, and surveyed to be about 230 m from the lagoon shore along an approximate magnetic bearing of 150° from the houses on the lagoon shore at 10° 27' 40.8"N, 169° 56' 56.4"E. The pond mud level was surveyed to be 0.791 m above MSL. The water present was fairly fresh, with an average salinity of 585 uS/cm, and conductivity of 0.3 ppt. The pond sediment was cored to find 50-70 cm maximum of loose dark brown organic mud.

There were two cut stumps of *Bruguiera gymnorrhiza*, with 60 cm high diameters of 15 and 8 cm, described to have been cut for wood 2 years ago (Figure 3). The 20 x 10 m pond was primarily inhabited by *Pandanus tectorius* and *Cocos nucifera*.

#### **4.0 Reconnaissance of possible mangrove introduction to Ailuk**

At two meetings during the visit in January, the Ailuk Atoll Marine Resource Management Advisory Committee expressed interest in introduction of coastal mangroves to Ailuk, primarily to reduce islet shoreline erosion. The species at Bigen, *Bruguiera gymnorrhiza* is a landward mangrove species in coastal situations, hence unsuitable. The *Rhizophora* species that occurs in the southern Marshall Islands as discussed below is suitable. Given this would have to be brought to Ailuk from distant atoll/s, it is important to locate a good initial introduction site where the species can be established, from which other plantings could be made. The sections below describe how such a site was identified, and then reviews how mangrove introduction can be successfully done.

##### **4.1 Methods**

From an edited volume of cases of mangrove replanting in a number of mainly Asian countries, Field (1996) summarises the characteristics of a successful mangrove planting site. An essential characteristic is that the sediment is stable, be it sandy or finer, with minimal erosion. It is important that the site is sheltered, as young seedlings cannot withstand strong winds or fierce currents. It is also important that the site be inundated regularly by the tide but not to the extent that they are drowned. The degree of inundation will depend on the species being replanted. Adapting this to the Ailuk situation, the following selection criteria were used in reconnaissance of a suitable site for introduction of coastal mangroves to Ailuk:

1. Suitable elevation (MSL to <MHW) and significant area within this elevation bracket



2. Sheltered from wave and wind action
3. Sedimentary substrate (as opposed to rock) to allow seedling planting
4. Tidal outflow preferably to the lagoon rather than offshore atoll waters, to benefit local fisheries related foodchains (Robertson and Duke, 1990)
5. Closer to population centre is better than further.

Suitable sheltered sites on and between the islets of the eastern chain of islands on Ailuk were identified from the NASA satellite picture. These were then visited and these areas surveyed. Elevation was surveyed accurately using the techniques described in section 3.1.

#### **4.2 Results**

Islands visited in reconnaissance are described below in order from northern islands to southern islands.

Ajilep (north) and Ajidik (south) are two larger joined islets, 2 islands south of Bigen. The passage between connects both with the ocean to the east and the lagoon (Figure 3).

Figure 3. Tidal area between Ajilep and Ajidik islets, Ailuk atoll.

Mangroves could grow here but there was evidence of strong currents, demonstrated by an erosion scarp to the north and south of the lagoon exit passage (Figure 4), and extensive sand deposits fanning into the lagoon, indicative of strong through currents. Hence it is not recommended as an initial introduction site, but would be a suitable location to establish mangroves at once the introduction site is established.



Figure 4. Lagoon exit from the tidal area between Ajilep and Ajidik islets, Ailuk atoll.

Ene-Armej is the large island to the south of the above group, with a peninsular to the south at  $10^{\circ} 23' 23.4''$  N,  $169^{\circ} 58' 16.9''$  E that provides some protection to a sedimentary area (Figure 5). This area was surveyed and found to be around 0.9 m above MSL, hence in a 1.1 m mean tidal range this is not tidal except in spring tides.



Figure 5. Sedimentary area south of Ene-Armej islet, Ailuk atoll.

Enen-Kone is the island to the south of this at  $10^{\circ} 22' 38.1''$  N,  $169^{\circ} 58' 18.1''$  E , similarly shaped with a southern peninsula that provides some protection to a low area. This proved to be sandy, but above tidal reach, and overall quite exposed to seaward.

Aliej is the next large island south of this, though there are four smaller islands between. Aliej is just north of a section of reef of over 3 km in length on which there are no significant islands. North of Aliej is a passage through which ocean water washes into the lagoon, which is deep enough to remain wet at low tide. While this area is too exposed for mangrove initial introduction, there is a high tide channel leading south at  $10^{\circ} 21' 26.8''$  N,  $169^{\circ} 58' 18.9''$  E from the through channel into Aliej island, with protection on several sides (Figure 6). At the back of this channel as seen in Figure 6 is a sandy area, which opens up to become a large sedimentary area (Figure 7).



Figure 6. High tide channel into the northern side of Aliej islet, Ailuk atoll.



Figure 7. Sedimentary area inside Aliej island.

This high tide area and sedimentary area were surveyed (Figure 7). The high tide channel was found to be between 0.2 and 0.3 m above MSL, and the sedimentary area found to be between 0.2 and 0.5 m above MSL. Hence this is a suitable sheltered intertidal area for a mangrove introduction site and nursery, with the added advantage that outflow from the area can reach the lagoon waters and so benefit inshore fisheries.

Baoje (north) and Lujrok (south) are the two joined large islands south of the island free section of reef south of Aliej. The passage between these islands at 10° 18' 41.6' N, 169° 58' 08.0'E was surveyed and found to have some suitable elevations with sand substrate, though much of the suitable elevation was fairly rocky. However the passage does not connect through to the lagoon, and is somewhat exposed windward to ENE wind and waves.

Ulika (Wilga as described by one guide) is far closer to Aliuk, connected to the south to Marib at 10° 15' 26.6' N, 169° 58' 55.7". This receives tidal overwash from the ocean, and there is some connection to the lagoon, however it is too exposed to windward for a nursery site.

Hence the most suitable site is the inner channel of Aliej, having a suitable intertidal elevation, is sheltered from wave and wind action, has a sedimentary substrate easy to plant mangroves in, and has tidal outflow into the lagoon.

## **5.0 Issues and techniques of mangrove introduction**

Mangroves have been successfully introduced to stabilise coastal sediment and protect shorelines from storm surges/ storms. However, in some islands, introduced mangroves have been found to have negative effects. These issues are reviewed in this section, followed by a description of mangrove replanting techniques.

### **5.1 Mangrove introduction on other islands**

In Hawaii, *Rhizophora mangle* from Florida was introduced in 1902 to Molokai to stabilise coastal mudflats, and *Bruguiera sexangula* from the Philippines was introduced in 1922 to Oahu. *R. mangle* is the most common and widespread species, now found on all of the main islands having spread by natural means (Wester, 1982; Allen and Kraus, 2006), and continues to spread today (Chimner et al., 2006). *B. sexangula* is naturalised today only on Oahu (Allen and Kraus, 2006). *Conocarpus erectus*, also introduced, has not spread much either. Chimner et al., (2006) analysed the expansion of mangroves on Oahu, finding that they colonised many different coastal landforms including tidal flats,



riverbanks, fishponds, canals, protected reefs, embayments, lagoons, but by area primarily colonised tidal flats.

Other species were introduced in Hawaii from the Philippines in 1922 that did not establish: *Rhizophora mucronata* was last recorded in 1928, *Bruguiera parviflora* was last recorded in 1948, and *Ceriops tagal* did not establish beyond 1922 (Wester, 1982).

While mangroves have a number of values in areas where they are native, some important negative impacts have been identified. These are that the trees invade prime foraging and nesting habitat for four endangered waterbird species, and they tend to overgrow Hawaiian archaeological sites particularly ancient fish ponds (Cox and Allen, 1999). This has resulted in some expensive control and clearance operations.

The threatened bird habitats include that of the Hawaiian duck (*Anas wyvilliana*), Hawaiian coot (*Fulica alia*), Hawaiian stilt (*Himantopus mexicanus knudseni*) and the Hawaiian moorhen (*Gallinula chloropus sandicensis*) (Chimner et al., 2006). For example, Hawaiian stilts immediately moved into and nested in bare mudflats created when 8 ha of mangrove was moved at Nu'upia Ponds and Wildlife Management Area.

Fishponds were an important part of ancient Hawaiian social structure, and at least 449 are known (Kirch, 1982). They are typically a large arc-shaped stone wall that extends from the shore onto a reef or tidal flat, designed to have several water intake structures (Chimner et al., 2006). After European contact they became disused, and many silted in with sediment washed off from adjacent development or agriculture. Mangroves colonised through the water intake area and establish well in their shelter, on the walls and across the pond, in some cases their roots causing the walls to deteriorate. Rehabilitation of ponds for cultural interest is made expensive by the need to clear mangroves (Chimner et al., 2006).

Other problems that introduced *R. mangle* have caused were complaints by residents of Kailua of an odor emanating from a channel that mangrove growth had clogged. The Hawai'i Department of Land and Natural Resources removed 0.5 ha of mangrove to remedy this (Chimner et al., 2006).

In French Polynesia, there are small areas of *Rhizophora stylosa* on Moorea and Bora Bora. It is not certain whether this was introduced in the middle of this century (Fosberg, 1992), introduced earlier by Polynesians, or whether it is native (Taylor, 1979). Mangroves were introduced from New Caledonia in 1937, and have since spread (Langer and Lipps, 2006).

## **5.2 Mangrove introduction benefits**

Mangrove restoration is the bringing back to original condition of damaged mangroves (Field, 1998). There have been a number such projects in many different countries, including the Pacific Islands. In Fiji, the mangrove replanting and conservation project at Namatakula and Navutulevu on the Coral Coast of Viti Levu (Tamata et al., 1999) provide an excellent example where the communities had already indicated that replanting of mangroves along their shoreline would reduce erosion and improve fisheries, hence receptive of this British High Commission funded project. The project included community education, community involvement in the fieldwork and planting effort, and sharing of data collected.

Following coastal erosion in the Upper Gulf of Thailand, the Government of Thailand approved a national mangrove management plan in 1987, including funding of a mangrove rehabilitation project (Winterwerp et al., 2005). Beneficial effects identified included increase of sediment capture and sediment stabilisation, increase of habitat for species such as crabs and coastal fisheries, and increase of resting and feeding habitat for migrating and local birds.

Describing lessons learned from a large mangrove replanting project in the Philippines, De Leon and White (1999) state that technical expertise and guidance is vital to success. Mangrove forestation in some areas failed because of lack of technical guidance, such as large areas of reforested mangroves died because of poor site selection. Such as rocky areas should never have been planted with *Rhizophora* species. They also recommend improved information dissemination and local community organisation in the mangrove replanting effort.

In a sandy arid area, Anwahi et al. (1998) investigated the feasibility of planting the mangrove *Avicennia marina* in a dug out pond about 500 m from the sea where sea water is available through percolation. They found that seedlings planted at the water line did better than those planted 25 cm away from the water line, and that growth increased when salinity was reduced by rainfall.

The last few years have seen serious attention given to the concept of community participation in resource management, though many such projects do not fully empower the local community. The best approach is to blend traditional knowledge with modern science using the merits of both. At Yadfon, a village community forest was established constituting a replanted mangrove area, with a committee of 10 to 20 people selected to guide its management. This was part of a larger cooperative program to help fishing people sell their daily catch and purchase fishing equipment, recognising the knowledge of the local fishers and the restriction of lack of opportunities. Within two months of replanting mangroves, the villagers began noticing an increase in their near-shore fish catch, and appearance of species of fish that had previously been rare. Later,

villagers were encouraged to use the by-products of the community forest without extensive harvesting of the trees. By products might include limited fuel-wood gathered from dead or fallen branches, and collection of fruit or leafy parts for food or medicinal uses. Fish and shell fish that occur naturally in the prop roots of the mangroves were collected. As part of the community welfare system, more needy families in the community were prioritised in receiving permission from the committee to extract a limited amount of the forest resource to supplement their livings (Quarto, 1999).

## **6.0 Planting methods, and formulation of strategy appropriate for the Ailuk species and conditions**

Suitable planting methods are reviewed below from available information and literature, to formulate a strategy appropriate for the Ailuk species and conditions. Previous mangrove replanting has occurred primarily in countries of SE Asia mainly in estuarine situations (Field, 1996). There have been few projects of mangrove rehabilitation in the Pacific Islands, and these have been relatively recent.

Review was carried out of the following steps:

- Identify the objective of mangrove replanting
- Decide on the approach to reforestation, either natural regeneration, propagule/ seed planting, or seedling planting
- Issues of seed collection
- Wilding collection and transplanting
- Propagule/ Seed planting
- Nursery Practices
- Site selection
- Monitoring

### **6.1 Identify the objective of mangrove replanting**

The objective of mangrove replanting must be defined, as this controls the methods and materials to be adopted. The objectives of mangrove replanting elsewhere in the world have included timber production or silviculture (Malaysia, Bangladesh, and Pakistan); enhancement of coastal protection (China, Cuba), but most commonly is for the objective of restoration of degraded areas (Field, 1996).

The objective of mangrove replanting in Ailuk is to introduce *Rhizophora* from the southern Marshalls, for the purpose of enhancement of coastal protection against storms, sea-level rise and erosion, and enabling of natural products such as fish, crabs and wood.

## **6.2 Decide on the approach to reforestation**

There are several approaches to mangrove reforestation that can be adopted.

### a) Natural regeneration

This is a non-active technique that protects the mangrove area from the original stress, and allows natural regeneration to occur. In Ailuk, there are suitable areas for *Rhizophora* recruitment but this is not happening because the source areas are too far away and lacking a suitable ocean current.

### b) Propagule/ Seed planting

This involves active planting of mature seeds in areas where they might grow. The survival rate of seeds is usually much lower than in seedling planting.

### c) Seedling planting

This involves active planting of seedlings in areas where they might grow. The seedlings can be obtained either from wild sources elsewhere (wilding transplanting) or can be raised in a mangrove nursery.

## **6.3 Species selection**

As discussed in section 4.0 the Ailuk island people wish to introduce a coastal mangrove that can stabilize sediment and reduce shoreline erosion. The most suitable genus is *Rhizophora*, and species that can grow on open ocean coasts such as *R. stylosa* or *R. apiculata*. One of these occurs in the southern Marshalls, they are commonly mis-identified for each other. This genus has arching prop-roots, is tolerant of full ocean salinity water, can grow as low as MSL, and commonly grows on sand substrates.

The seed or seedling source should be within the Marshall Islands, at a location where the source ecosystem will suffer in no way. Hence there should be an expert assessment of the source site, to ensure that the species is suitable and that there are no issues of damage in seed or seedling removal.

## **6.4 Seed collection**

*Rhizophora* seeds (hypocotyls) are viviparous (already germinated) so have to be replanted within a few weeks. They cannot be dried and stored like normal seeds, they do not remain viable because they are already germinated before

they leave the parent tree. This is an adaptation mangroves have to their wet and saline habitat.

Seeds for planting or raising in nurseries must then be collected. This must be when they are ripe. If seeds are collected too young, they will not germinate (Hong, 1994). Mangrove phenology (the timing of fruiting) is controlled by seasonal patterns, and there has been no study of this in the Marshall Islands. Source sites are likely to be in the southern Marshalls, where the climate is less seasonal with heavy rain throughout the year.

At Vaitapu, Tuvalu (7°28'S), phenology was studied of *Rhizophora stylosa* by Woodroffe and Moss (1984) for only a year. They found little seasonality in production as to be expected from this near equatorial latitude, but reproductive parts most common in litter fall in March. However these were only flowers, and no propagule production was recorded at all in this study.

Leach and Burgin (1985) analysed mangrove litter productivity and phenology from January 1981-May 1982 at Motupore Island near Port Moresby (9°S). The mangrove forest studied was *Rhizophora stylosa*, with sub-dominants of *R. apiculata* and *Sonneratia alba*, reaching a canopy height of only 10 m. They found a total annual litter fall of 14.3 tonnes dry weight per hectare per year, with a marked seasonality in production, most falling during the wet season December-April. All three species flowered and fruited mostly in this period, and leaf production also increased. This is similar to patterns of litter production found in mangroves of north Queensland (Duke et al., 1981).

While mangrove replanting has been carried out in many similar latitudes of SE Asia (Field, 1996), there is a major climatic difference in that these areas are monsoonal. Of similar latitude is Malaysia at 4°N, where extensive mangrove planting has been carried out over a number of decades (Chan, 1996). There, fruiting of *Rhizophora* is annual, precocious and prolific. The season of mature fall of *R. apiculata* and *R. mucronata* occurs annually from September to November, and from June to September (Chan et al., 1991). Maturing or mature propagules on the tree can be recognised by the distinct abscission collar between the fruit and the propagule, which is yellow in *R. mucronata* (Chan, 1996).

*Rhizophora stylosa* seeds are ripe when a yellow ring develops at the top of the hypocotyl, and the top swells. *Rhizophora mangle* hypocotyls are ripe when a (cotyledonary) collar or ring develops at the tip (Banus and Kolehmainen, 1975) and should be 20 cm long, evenly coloured, with a reddish-brown tip. *Bruguiera* seeds are ripe when the hypocotyl changes color from green to brown, they do not develop an abscission collar. If the hypocotyl does not come off from the parent tree with a slight pull, it is not ripe.

Seeds can either be collected from the tree, or beneath the tree. Seeds are usually in better condition if collected from the tree, with less physical damage or insect/ fungal infestation. They must be unblemished, free from insect attack, and handled carefully in transport. The seeds must not be allowed to dry out, but if kept in moist conditions this makes them vulnerable to insect or fungal attack. It is best to transport and store them in small horizontal bundles covered with banana leaves/ palm fronds or sacking. The palm baskets commonly woven in the Marshall Islands from palm fronds are ideal.

*Rhizophora* seeds must be handled gently, particularly the plumule (spike) at the top of the hypocotyl.

### **6.5 Propagule/ Seed planting**

Seeds or *Rhizophora* and *Bruguiera* can be planted by inserting the tip into the mud, so that 1/3 to 1/2 of the propagule length is buried. This must be done gently.

Seed planting can only be done soon after the fruiting season, and mangrove seeds/ propagules cannot be stored for long.

### **6.6 Wilding collection and transplanting**

Advantages of this method are that seedlings can be collected at any time through the year; they are suitable for higher energy sites; and success rates are usually higher than planting seeds.

Mangrove seedlings for replanting can be collected from large, mature mangrove ecosystems where natural regeneration is occurring. The mangrove mud must be firm, and seedlings can only be taken from within the forest. This is because seedlings should not be removed where they have a chance of growing where they are, only where they suffer shade or competition..

Seedlings chosen for transplanting should be 0.5-0.8 m tall, with a straight trunk, an intact growing tip, and several leaf pairs. Avoid old seedlings, with over 15 leaf scars on the trunk, and those already developed prop roots or side branches. Older seedlings are less likely to survive transplanting, probably due to root disturbance (Hamilton and Snedaker 1984).

Seedling collection is best done at low tide. Seedling removal has been described by Chan (1988) using a specially designed steel corer of 10 cm diameter and about 30 cm long with a handle at the top. This metal with a serrated edge at the base is better than PVC. This is slid over the seedling, and

cut into the mud around the seedling and pushed to 20-25 cm depth. Then the pipe is twisted and the seedling with a plug of sediment removed from the ground. Later, a little water poured down the pipe, and shaking, will remove the plug out of the corer.

During transportation the seedling plug of sediment should be protected from falling to bits by surrounding in a plastic bag or sacking, and the seedling protected from drying out and wind.

### **6.7 Nursery Practices**

Raising mangrove seedlings in nurseries before planting out can increase the survival and growth of mangrove planting. This allows the seedling to develop an healthy root system before planting. Propagules without woody thickening are more prone to crab attack (Chan, 1996). Another benefit of raising seedlings in nurseries, is that it provides an year- round supply for reforestation activities.

Growing seedlings involves planting seeds (propagules) preferably in a mixture of sand and mangrove mud. Poly bags are best used, about 15 cm deep and 10 cm diameter, these can be easily relocated, and should have holes to allow drainage. Plastic containers with holes have also been used (Bohorquez, 1996). Seedlings should be watered once or twice a day with seawater mix. This suppresses fungal infections, and acclimatizes the seedlings to saline conditions. Location of the nursery within a protected intertidal area means that watering occurs naturally, and the mangrove seedlings are better acclimatized to the mangrove conditions where they are to be planted. An upper intertidal area should be selected.

### **6.8 Site preparation**

If there are dead trees on the site to be planted, then these will have to be removed. This is because as dead trees rot over time, they become loose and roll at high tide with waves, and can knock over planted seedlings.

### **6.9 Planting seedlings**

Planting can be done merely by digging a hole, taking the plastic bag off, and placing the seedling in the hole. It is very important that the mud level in the polybag becomes the same level as the mud in the mangrove swamp- if the seedling is buried deeper it will die (Ellison, 1999). Seedlings should be spaced in open areas at 1 meter intervals (Agaloos 1994; Hong 1994). The area should be protected from fenced from pigs, as these will push over young seedlings in their foraging activities.

### **6.10 Monitoring**

Once the initial planting has been completed, it is important to monitor the progress of propagules or transplants. Replacement of individuals that die will be necessary. Problems that may reduce success could be debris (remove material in the area that may move around over the seedlings at high tide, including palm fronds), pigs may root in the sediment causing disturbance.

After the establishment of a mangrove plantation, it is essential to monitor progress (Field, 1998). Actions include monitoring growth of mangrove species that develop, level of mortality of seedlings, any pests or diseases, rubbish accumulation, human disturbance, and overall success of the project.

Seedlings will also need to be replaced if some die, or thinned if too close.

### **7.0 Recommendations**

The mangrove area described from Bigen Islet while currently in good health, is small and very isolated from other mangrove communities. For these reasons, care needs to be taken by the people of Ailuk in making sure that any use of it does not deplete its values. It is recommended that the trees be re-surveyed to monitor their health at least every five years.

Introduction of *Rhizophora* to Ailuk involves a precautionary assessment of any negative impacts such as those found after mangrove introduction in Hawaii. There the trees invade prime foraging and nesting mudflat habitat for waterbird species, and they tend to overgrow archaeological sites particularly ancient fish ponds. This reconnaissance of Ailuk has found that the potential introduction sites are sand channels which do not seem to be a bird habitat, and there did not seem to be any archaeological at these locations. Hence such negative impacts may not be relevant to Ailuk.

If the Ailuk Atoll Marine Resource Management Advisory Committee decide to go ahead with *Rhizophora* introduction, it is recommended that they seek funding for a small project to transport seeds from a suitable source site in the southern Marshalls, establish a nursery at Aliuk, and from here establish seedlings both adjacent to the nursery at Ailuk and at other suitable sites on the atoll islets. These plantings if successful should give the benefits of increase of sediment capture and sediment stabilisation, and increase of habitat for species such as crabs and outwelling benefits to coastal fisheries.



## 8.0 Acknowledgements

The author wishes to thank the Honorable Mayor Cradel Alfred of Ailuk Atoll for hospitality on Ailuk, and for her support of the NRAS project. Also, I thank the Ailuk Atoll Marine Resource Management Advisory Committee for project support and field guidance. Thanks also to the Ailuk Horticultural Officer, Jackson, for taking responsibility for the mangrove permanent monitoring plot project, and Albon Ishoda for facilitation of the project.

The Australian Regional Natural Heritage Programme funded this mangrove project as part of a larger global biodiversity hotspot assistance grant.

Many thanks to Frankie Harriss of NRAS for organising the fieldwork operations on Ailuk and project coordination, and Silvia Pinca of NRAS for including mangroves for the first time in a NRAS proposal. Many thanks to Andrew Cooper for assistance in the field surveys.

The Australian Bureau of Meteorology (Oceanography Division) provided tidal data recordings from the Majuro tide gauge, and Rito Akilang at the Marshall islands EPA arranged testing of the water samples.

## 9.0 References

Agaloos, B.D., 1994. Re-afforestation of mangrove forests in the Republic of the Philippines. In: *Proceedings of an International Timber Organisation Workshop: development and dissemination of Reafforestation Techniques of Mangrove Forests*. Japanese Association for Mangroves, pp. 75-98.

Allen, J.A. and Krauss, K.W., 2006. Influence of propagule flotation longevity and light availability on establishment in introduced mangrove species in Hawai'i. *Pacific Science* 60, 367-376.

Anwahi, A., Zaroundi< M.A.R.A., Janahi, A.A. and Cherian, T., 1998. Feasibility studies on mangrove *Avicennia* marine cultivation below ground level along the bank of a dug-out pond. *Marine and Freshwater Research* 49, 359-361.

Banus M.D. and Kolehmainen S.E., 1975. Floating, rooting and growth of red mangrove (*Rhizophora mangle* L.) seedlings: Effect on expansion of mangroves in southwestern Puerto Rico. In Walsh G.E., Snedaker S.C. & Teas H.J. (Eds.) *Proc. Int. Symp. on Biology and Management of Mangroves*, Vol. 1, Univ. Florida Gainesville, p. 370-374.

Bohorquez, C., 1996. Restoration of mangroves in Colombia: a case study of Rosario's Coral Reef ational Park. In C.D. Field (Ed.) *Restoration of Mangrove Ecosystems*. International Society for Mangrove Ecosystems, Okinawa, Japan, pp. 189-196.

- BOM (1995). Pacific Country Report. Sea Level and Climate: Their Present State. Marshall Islands, June 2005. Bureau of Meteorology, Oceanography Division, South Pacific Sea-Level and Climate Monitoring Project.
- Chan, H.T., 1988. Rehabilitation of a logged-over mangrove area using wildings of *Rhizophora apiculata*. *Journal of Tropical Forest Science* 1, 87-188.
- Chan, H.T., 1996. Mangrove reforestation in Peninsular Malaysia. In Field, C.D. (Ed.) *Restoration of Mangrove Ecosystems*, International Society for Mangrove Ecosystems, Okinawa, pp. 64-75.
- Chan, H.T., Chong, P.F., Havanon, S., 1991. Characteristics of flowering, fruiting and propagule production of *Rhizophora apiculata* and *Rhizophora mucronata*. In *Final Report of the Integrated Multidisciplinary Survey and Research Program of the Ranong Mangrove Ecosystems*. Publication of the UNDP/ UNESCO Regional Mangrove Project RAS/ 86/ 120.
- Chimner, R.A., Fry, B., Kaneshiro, M.Y., Cormier, N., 2006. Current extent and historical expansion of introduced mangroves on O'ahu, Hawai'i. *Pacific Science* 60, 377-383.
- Cox, E.F. and Allen, J.A., 1999. Stand structure and productivity of the introduced *Rhizophora mangle* in Hawaii. *Estuaries* 22, 276-284.
- De Leon, R.O.D., White, A.T., 1999. Mangrove rehabilitation in the Philippines. In W. Streever (Ed.), *An International Perspective on Wetland Rehabilitation*. Kluwer Academic Publishers, The Netherlands, pp. 37-42.
- Diop, S. 2003. Vulnerability assessment of mangroves to environmental change. *Estuarine, Coastal and Shelf Science* 58, 1-2.
- Duke, N.C., Bunt, J.S. and Williams, W.T., 1981. Mangrove litter fall in Northeastern Australia. I. Annual totals by component in selected species. *Australian Journal of Botany* 29: 547-553.
- Ellison, J.C., 2006. Manual for Marshall Islands Mangrove Monitoring. Monitoring Changes in Mangrove Community Structure and Response to Relative Sea-level Rise. Natural Resource Assessment Surveys, Republic of the Marshall Islands.
- Ellison, J.C., 1999. Impacts of sediment burial on mangroves. *Marine Pollution Bulletin* 37:420-426.
- Ellison, J.C., 1997. Systematics and taxonomy of Pacific Island mangroves. In *Marine and Coastal Biodiversity in the Tropical Island Pacific Region: I. Species Systematics and Information Management Priorities*, ed. J. E. Maragos, M. N. A. Peterson, L. G. Eldredge and J. E. Bardach. Honolulu: East West Center.

- Ellison J.C, and Simmonds, S., 2003. Structure and productivity of inland mangrove stands at Lake MacLeod, Western Australia. *Journal of the Royal Society of Western Australia*, 86, 21-26.
- Ellison, J. and Gilman, E. (2005). *Manual for American Samoan Mangrove Monitoring: Monitoring Changes in Mangrove Community Structure and Response to Relative Sea-Level Rise*. American Samoa Coastal Management Program, Department of Commerce, Government of American Samoa, Pago Pago, AS 96799 USA.
- English, S., Wilkinson, C. and Baker, V. (1997). Manual for survey of tropical marine resources. 2<sup>nd</sup> Edition. Australian Institute of Marine Science, Townsville.
- Field, C.D., 1996. General guidelines for the restoration of mangrove ecosystems. In Field, C.D. (Ed.,) *Restoration of Mangrove Ecosystems*, International Society for Mangrove Ecosystems, Okinawa, pp. 233-250.
- Field, C.D., 1998. Rationales and practices of mangrove afforestation. *Marine and Freshwater Research* 49, 353-358.
- Fosberg, F R.,1992. Vegetation of the Society Islands. *Pacific Science* 46: 232-250.
- Fosberg, F.R., 1975. Phytogeography of Micronesian mangroves. In Walsh, G., Snedaker, S., Teas H. (Eds.) *Proceedings of an International Symposium on the Biology and Management of Mangroves* 1. Gainesville, University of Florida, pp. 23-42.
- Hamilton, L. S. and Snedaker, S. C., (Eds.)1984. *Handbook for mangrove area management*. Honolulu: East-West Center, IUCN and UNESCO, 123pp.
- Hong, P.N., 1994. Reafforestation of mangrove forests in Vietnam. In: *Proceedings of an International Timber Organisation Workshop: development and dissemination of Reafforestation Techniques of Mangrove Forests*. Japanese Association for Mangroves, pp. 141-165.
- Kirch, P.V., 1982. The impact of prehistoric Polynesians on the Hawaiian ecosystem. *Pacific Science* 36, 1-14.
- Lacerda, L. D., Conde, J. E., Alarcon, C., Alvarez-Leon, R., Bacon, P. R., D'Croz, L., Kjerfve, B., Polaina, J. and Vannucci, M. 1993. Mangrove ecosystems of Latin America and the Caribbean: a summary. In *Conservation and Sustainable Utilization of Mangrove Forests in Latin America and Africa Regions*, Ed. L. D. Lacerda, 1-42. Okinawa: International Tropical Timber Organization and International Society for Mangrove Ecosystems.

- Leach, G. J. and Burgin, S., 1985. Litter production and seasonality of mangroves in Papua New Guinea. *Aquatic Botany* 23: 215-224.
- Langer, M.R. and Lipps, J.H. 2006. Assembly and persistence of foraminifera in introduced mangroves on Moorea, French Polynesia. *Micropaleontology* 52, 343-355.
- NOAA (2007). Tides and currents.  
<http://tidesandcurrents.noaa.gov/tides07/tab2wc3.html>
- Quarto, A. 1999. Local community involvement in mangrove rehabilitation: Thailand's Yadfon. In W. Streever (Ed.), *An International Perspective on Wetland Rehabilitation*. Kluwer Academic Publishers, The Netherlands, pp. 139-142.
- Robertson, A.I., and N.C. Duke 1990. Mangrove fish communities in tropical Queensland, Australia: spatial and temporal patterns in densities, biomass and community structure. *Marine Biology* 104: 369-379.
- Siddiqi, N.A., Islam, M.R., Khan, M.A.S. and Shahidullah, M., 1993. *Mangrove Nurseries in Bangladesh*. ISME Mangrove Ecosystems Occasional Papers 1, Okinawa.
- Tamata, B.R., Wilson, L. and Ram, N. 1999. *Report on the mangrove replanting and conservation project at Namatakula and Navutulevu*. Institute of Applied Science Environmental Report No. 98, University of the South Pacific, Suva.
- Taylor, F. J. 1979. Rhizophora in the Society Islands. *Pacific Science* 33: 173-176.
- Taylor, W. R. 1950. *Plants of Bikini and other Northern Marshall Islands*. Ann Arbor: Univ. Michigan Press.
- Tomlinson P.B., Primack R.B. & Bunt J.S., 1979. Preliminary observations on floral biology in mangrove Rhizophoraceae. *Biotropica* 11, 256-277.
- Wester L., 1982. Introduction and spread of mangroves in the Hawaiian Islands. *Assoc. of Pacific Geographers Yearbook* 43, 125-137.
- Vander Velde, N. and Vender Velde, B., (2005). Two species of mangrove trees previously unrecorded in the Marshall Islands found in Jaliut. *Micronesica* 37, 297-308.
- Winterwerp, J.C., Borst, W.G., de Vries, M.B., 2005. Pilot study on the erosion and rehabilitation of a mangrove mud coast. *Journal of Coastal Research* 21, 223-230.