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IMPACT OF TROPICAL VEGETATION ON WORLD WAR II-ERA CULTURAL RESOURCES IN THE MARSHALL ISLANDS

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The tropical environments prevalent on the islands of the Central Pacific is deleterious to the preservation of cultural materials. This is particular so for metal-based items, which make up the bulk of the extant material cultural associated with World War II sites. This paper views the impacts posed by the vegetation on the preservation of the remains of aircraft, guns and other equipment.

The Pacific theatre of World War II saw the development of extensive fortifications on various Micronesian Islands by the Japanese forces. While Chuuk was developed into a major naval base, several atolls of the Marshall Islands were transformed into large-scale airbases for fighter, bomber and sea-plane operations.

The following case study is derived from a study conducted by the authors assessing the conservation management needs of various World War II–era historical resources on various atolls of the Marshall Islands (Look & Spennemann 1992; 1993; Spennemann & Look 1998). The assessment showed that a number of plants had detrimental effects to the well-being of the cultural and historical resources.

Tropical areas are renowned for their lush and luxurious vegetation. The side effects of this vegetation, however, are direct and indirect impacts on cultural and historic resources. It is these impacts that cause problems for those charges with the management of a country's cultural heritage.

ENVIRONMENTAL BACKGROUND

The Marshall Islands

The Marshall Islands (*Aelon Kein Ad),* comprising 29 atolls and 5 islands, are located in the north-west equatorial Pacific, about 3790km west of Honolulu, about 2700km north of Fiji and 1500km east of Pohnpei (Ponape). With the exception of the two north-western atolls, Enewetak and Ujelang, the Marshall Islands are arranged in two island chains running roughly NNW to SSE: the western Ralik Chain and the eastern Ratak Chain (figure 1). Not counting the five islands, Jemo, Jabwat, Kili, Lib and Mejit, the atolls of the Marshall Islands range from very small, with less than 3.5km^2, such as Nadikdik (Knox) Atoll to very large. With 2,173km^2 lagoonal area, Kwajalein Atoll has

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the distinction to be the atoll with the World's largest lagoon.

At no point in the Republic of the Marshall Islands is volcanic or sedimentary rock other than limestone or beachrock (=cemented sand) accessible at the surface. Coral growth, and correspondingly reef width, is most vigorous in areas in the general direction of prevailing winds, currents and waves. Since the Marshall Islands are in the zone of the north-eastern tradewinds, with predominant wind and swell direction from the south-east, the zone of most reef growth is the southern and eastern side. Conversely, deep passes through the reef platform occur most frequently on the leeward side of the atolls.

Climatic Patterns

Climatic observations and some analyses have been presented by numerous authors and agencies, on whose results the following compilation is based (Bryan 1972; OPS 1989; Steinbach 1893; Williamson & Sabbath 1982). The atolls of the Marshall Islands provide only little landmass, too small for distinct and stable micro-climates to evolve. Some of atolls, however, especially those with extensive shallow lagoons, have a micro-climatic pattern whereby during day-time the water of the lagoon warms up more than the water of the deeper surrounding ocean, causing upwind draft and evaporation (visible as stratocumulus clouds), resulting in some rainfall when cooling down occurs in the late afternoon.

Precipitation

So far, the number of meteorological stations on the Marshall Islands is limited. Longer data series only exist for Enewetak, Ujelang, Wotje, Kwajalein, Majuro and Jaluit Atolls. Due to a limited physical elevation and hence orographic rainfall patterns, the precipitation in the Marshall Islands is solely governed by the general Pacific-wide climatic belts as well as by highly localised micro-climatic rainfall over the lagoons. On the regional scale, there is a distinct precipitation gradient running from the equatorial zone in the south to the north. The further north the atoll is located, the less precipitation can be expected. Thus Jaluit, located at 5°47'N has a precipitation of almost 4000mm per annum, while Wake, located at 19°28' receives less than 1000mm per annum (Figure 1).

Intense tropical storms of short duration contribute to much of the total rainfall, The incidence of the storms themselves is quite variable from one year to the next for a particular island or atoll, with variations of up to 100% on record (figure 3 top). While there is seasonal variation, the magnitude of this variation is not uniform (figure 3 bottom).

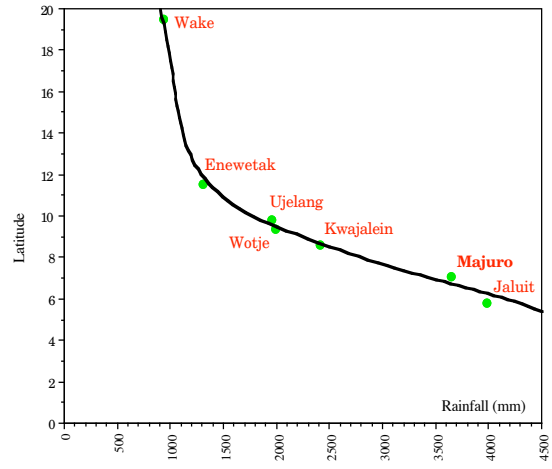

Figure 1. Relationship between annual average precipitation and latitude in the Marshall Islands area (Source: Williamson & Sabbath 1982).

Common are also variations in precipitation even among different parts of the same larger atolls. In many instances, especially during the drier season, rain-bearing clouds may be seen to pass over a particular stretch of land, while they may miss another completely. Thus rainwater catchment is, to some degree, completely fortuitous. The lack of elevated land features that otherwise might control local weather and remote air circulation patterns contribute to the variability in the rainfall. On Wotje the lowest precipitation occurs in January with 1.9" (48mm), the highest in September with 11.8" (297.2mm) (Hawaii Architects & Engineers 1972:8). The mean annual precipitation is about 1986mm (78").

Temperature

The temperature data available for Majuro station show very little variation both in the long- and medium-term daily, monthly and annual temperature averages. According to the long-term average (1959-1988), the mean annual temperature is 27.3°C (81.1°F), with an average maximum of 27.5°C (81.6°F) and an average minimum of 26.6°C (80.0°F). The annual daily maxima and mini-ma are marginally more pronounced, with a night-time minimum in the low 20's and a day-time maximum in the mid-30's (figure 4).

Humidity

Relative humidity averages between 75% and 85% over the year with little annual variation. Humidity approaches 100% during and after intense rainstorms (squalls).

Wind patterns

The Marshall Islands are located in the belt of the north-eastern trade winds. Hence, trade winds from north-easterly directions dominate most of the year but are strongest from November to June. Exceptions to this rule, however, are known. Summer winds tend to be weaker with some slack wind periods. The trade wind period is followed by a stormy season which commonly lasts from July to September. The trade winds tend to be stronger in the higher latitude atolls, but rarely do wind speeds exceed 35 knots except during the passage of severe squalls (figure 5).

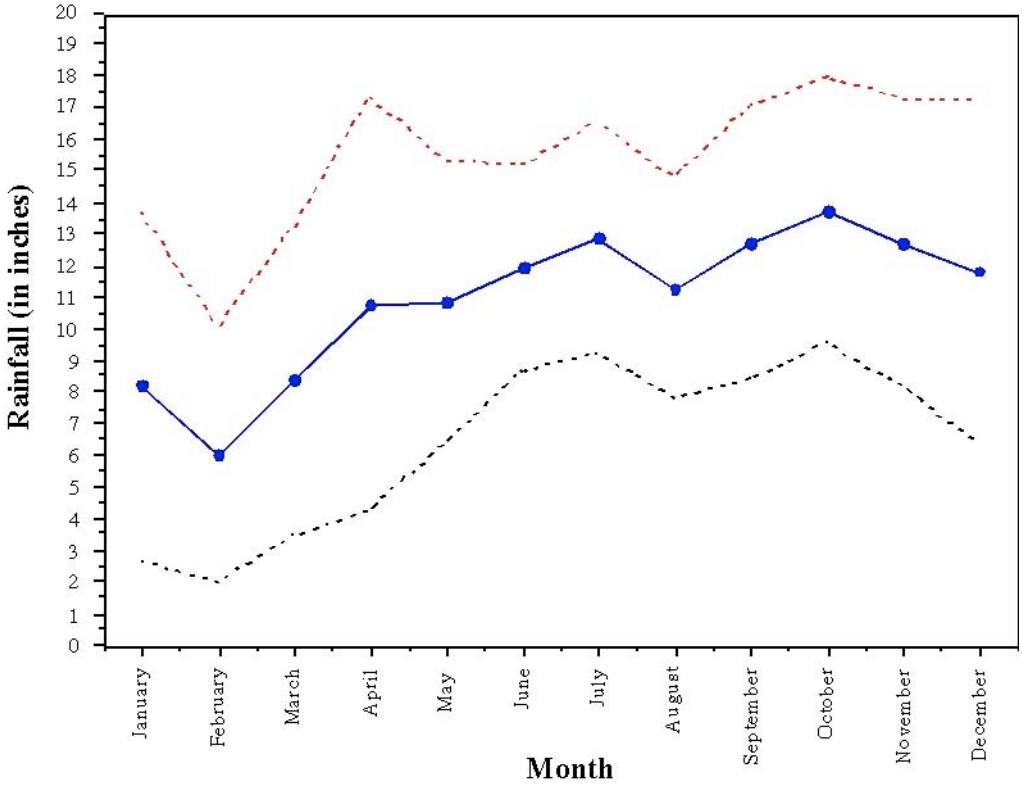

Figure 2. Annual (top) and monthly (bottom) rainfall at Majuro Island, Majuro Atoll, 1959-1988. Source of data: Majuro Weather Station.

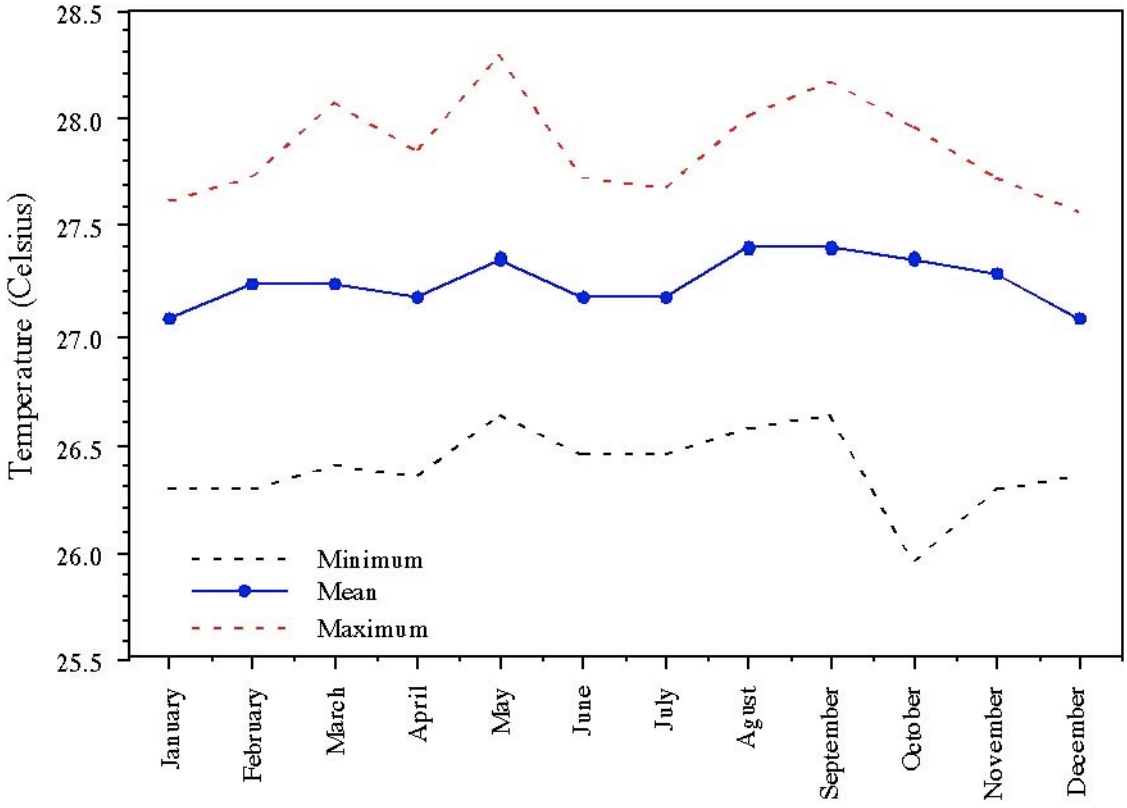

Figure 3. Monthly variation in average temperatures for Majuro Island, Majuro Atoll, 1959-1988. Source of data: Majuro Weather Station

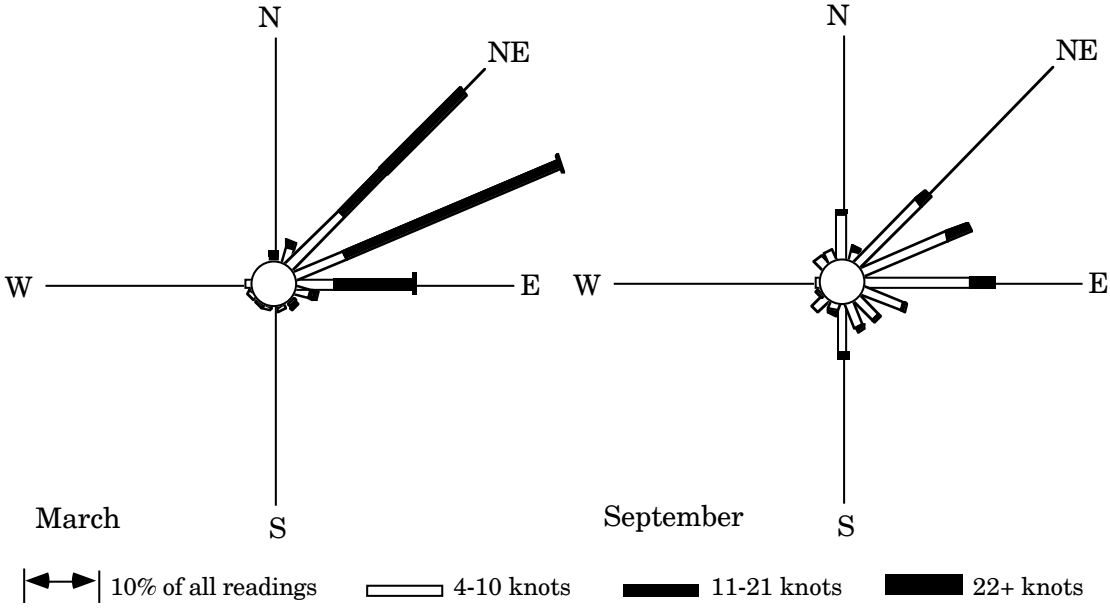

Figure 4. Wind direction and velocity at Wotje Island. Monthly average for March and September.

Figure 5. Vegetation patterns on islands of the Marshall Islands: Coastal broadleaf forest, breadfruit and coconut on Jan Island, Maloelap Atoll.

Figure 6. Vegetation patterns on islands of the Marshall Islands: coconut monoculture revegetation of an island devastated by the impact of World War II (Taroa, Maloelap).

Figure 7. Vegetation patterns on islands of the Marshall Islands. Revegetation of an island devastated by the impact of World War II. Coastal scrub on the south-western shore of Mile, Mile Atoll.

VEGETATION PATTERNS

The vegetation patterns on the islands making up the atolls of the Marshall Islands are well defined by the parameters of soil and proximity to the ocean shores. The vegetation on any given island is set out in a clear zonation, the complexity of which depends on the island's location within the atoll (windward or leeward side).

On an island with traditional land use pattern, the vegetation would show a clear zonation of plants from the lagoon to the ocean shore that is correlated to the soils and the wind action. The vegetation on the ocean side commonly consisted of a mixed broadleaf forest, with a few tree species and a number of shrubs, usually *utilomar* (*Guettardia speciosa), kiden (Tournefortia argentea),* Pandanus, *Pandanus tectorius, kõno (Cordia subcordata),* Piñpiñ *(Hernandia sonora),* kõñe *(Pemphis acidula)* and kõnnãt *(Scaevola sericea)*. These plants would be very resistant to salt-laden air the constant wind would bring in from the breaker zone at the reef. The soil at the ocean shore is also very gravelly with little humus content. The soil in this zone would consist of boulders and large cobbles, thrown up by the waves of the sea to a distinct strand wall, resembling the backbone of an island.

Going inland, the soil would gradually become finer, first gravel and then coarse grained sand, and the humus content would increase. In this zone an abundance of breadfruit trees would have been planted, providing food. In fact the trees were planted in such an abundance that we can speak of a breadfruit forest. In the very centre of the island, there where the underlying ground water lens would be the thickest, taro patches, artificial depressions in the ground, would be present. These taro patches, in which swamp taro (*Cyrtosperma chamissionis*) would be grown, were surrounded by *Pandanus* trees, preferably the low growing variety, not used for food but for mat-weaving. These *Pandanus* would act as a windbreak for the large taro leaves, and would also act as screen to filter out any salt spray the winds may bring. We have to imagine that every piece of ground in the centre would have been taken up by taro patches, *Pandanus* plants and roads and tracks.

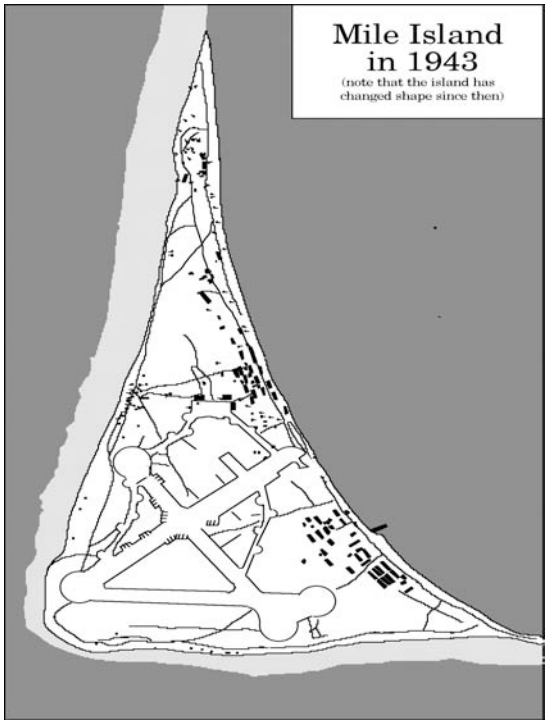

Figure 8. Schematic plan of the Japanese installations on Mile I., Mile Atoll.

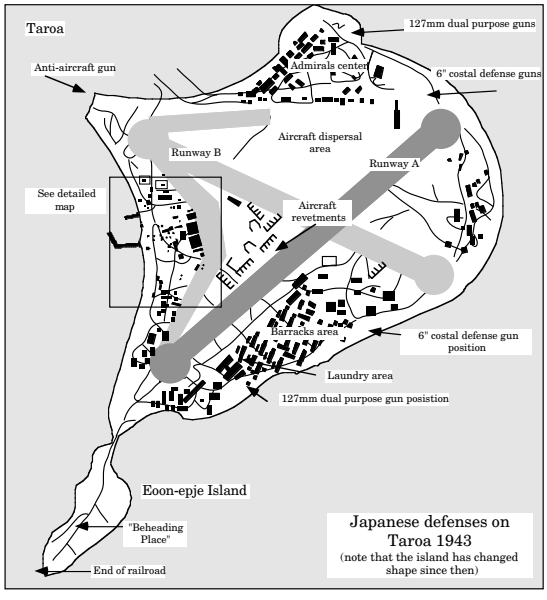

Figure 9. Schematic plan of the Japanese installations on Taroa I., Maloelap Atoll.

Going further towards the lagoonal shore the vegetation zonation would once again show a wide zone of breadfruit forests which would make way to utility and ornamental shrubs along the rear side of the household units. In this area we have to imagine the cemeteries. In view of the limitations on available land only the higher-ranking people would be buried, while the bodies of the commoners were pushed out to sea.

On islands developed into airbases during World War II, the centre of the island, or large parts of the centre would be covered with runways as well as concreted revetments for planes and other military equipment (Figure 10).

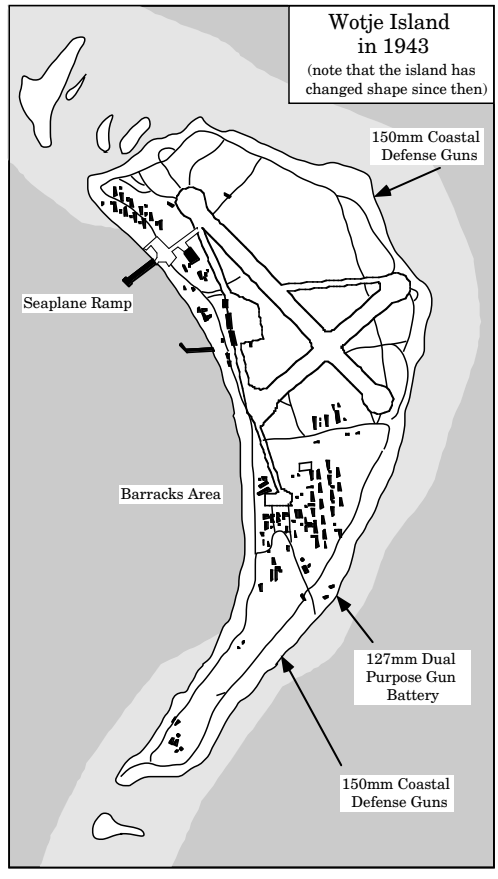

Figure 10. Schematic plan of the Japanese installations on Wotje I., Wotje Atoll.

General observations

The observations showed that a number of plants had detrimental effects on the cultural and historical resources. Even though there are differences between the amount of leaf fall generated by the plant species, we will for the purposes of this paper not be concerned with the overall build-up of leaf matter and, deriving

from this, soil. It will not address in any detail the effects of old trees falling over, or other trees being harvested in an improper manner.

Before we address the impacts by the individual plant specifies, there are a few general observations which need to be made. These can be grouped under the headings of i) dangers inherent in plant cover, ii) damage caused by plant removal; and iii) obliteration of sites through intentional planting.

Figure 11. A fallen coconut trunk astride the top of a Japanese 127mm dual purpose gun. Note that the coconut trunk provides additional surfaces for vine cover. (north-western gun battery, Mile I., Mile Atoll).

Dangers inherent in plant cover

Since many of the sites assessed are gun emplacements or other military installations they were shelled by U.S. ships and bombed by U.S. aircraft. The areas around these sites abound with unexploded U.S. naval ammunition (even after 20 years of explosive ordnance removal) and unexploded Japanese ordnance left on site. Documentation or vegetation clearing of such sites exposes the cultural resource manager to hazards of hidden explosives, such as Japanese 127mm shells which have not been fired (Figure 12) and U.S. naval shells. This ammunition is deemed so unpredictable by explosive ordnance disposal specialists that any major items of ammunition encountered are exploded on site, to the detriment of the cultural resource.

Figure 12. Inherent dangers of vegetation removal. Japanese 127mm shell partially covered by vegetation and discovered before vegetation clearing commenced (Mile I).

In addition, many of the sites have sharp-edged components, which are often camouflaged by the vegetation cover and threaten the unwary visitor. Particularly dangerous are 44 gallon drums which had been buried by the Japanese to function as as small foxholes. Today, the drums are heavily corroded and the jagged protruding edges pose serious health hazards (Figure 13).

Figure 13. Dangers exerted by plants covering military remains. A sharp-edged heavily corroded 44 gallon drum is largely buried in the ground to the right of the empty U.S. naval shell. The edge of the empty barrel is camouflaged by leaf litter and Vigna marina. *(Mile I).*

Plant Removal

The removal of large vegetation, such as trees, is extremely important but must be done very carefully so that the resources are not damaged or disturbed and that no-one is injured. If someone is severely injured on the outer atolls, it may be several hours or days for one may be able to receive medical attention. To begin clearing a site, it is important to start at the edge and carefully rake away fallen leaves and other vegetation being careful not to disturb objects in or on the ground. As sharp or dangerous objects, such as live ammunition, are encountered, they should be marked so that all personnel are aware of their location. Removed vegetation should be mulched and allowed to decompose adding humus to the sandy soil and not burnt, because burning of the vegetative matter will: i) damage the resource; ii) explode live ammunition which may not be visible, and iii) return fewer nutrients to the soil.

Figure 14. Inappropriate vegetation removal by burning. (Mile).

All removal of vegetation should be under the supervision of trained personnel who are responsible to teach and to enforce safety procedures. Many of the trees are very large and, therefore, very heavy. The removal of large trees can be very dangerous to both personnel and artefacts. Rather than cut the tree off at the ground and let it fall, possibly injuring someone or damaging the artefacts, it is much better to remove in several stages. Tops of trees and large limbs can be sawn, or cut by axe or machete. Prior to removal, a rope can be tied around the member to control how and where it falls.

Once the tree has been removed to the ground, the stump should be coated with a herbicide (poisoned) to prevent growth from the root (except coconut palms which do not grow up again from the roots). Since the atoll environment is very fragile the use of herbicides should be abstained from whenever and wherever possible. An alternative method is to drill holes into the stump, fill them with kerosene or gasoline, and seal them with epoxy or putty to prevent the aeration of the kerosene. The stump will die off in two to three months. The stumps of coconut palms can be grooved in a grid pattern with the chain saw blade to encourage and accelerate rotting of the stump.

Figure 15. A variety of plants engulfing a bulldozer left behind by the US Seabees on Enigu Island, Majuro Atoll. Before and after (partial) vegetation removal. The vegetation removal was incomplete and executed merely to determine the nature of the resource.

Once the sites have been cleared of large trees and shrubs and trees it will be much easier to control future vegetation because the removal of young seedlings is much easier than removing mature trees and shrubs. The area can be raked to remove seeds and small seed-

lings can be pulled or cut off at the ground level. Both during the initial removal of vegetation and during routine maintenance, small hand brooms should be used to sweep away any soil, ferns, moss, seeds, or decaying matter from the metal surfaces. This is very important at the base of the large guns because contact with the soil also increases corrosion.

Vegetation grows quickly in the warm, sunny, humid, and usually rainy climate of the Marshall Islands. Routine maintenance will consist mainly of cyclical removal of vegetation. If this is done on a regular basis, it will be manageable and facilitate inspection and monitoring.

Figure 16. Erosion corrosion due to dripping rainwater. The dense foliage covers up the resources and generates a micro-climate by retaining water and moisture which keeps the surfaces of the resources wet long after the rainfall due to dripping. Since the same branches provide for the drip for a prolonged time, pitting and erosion corrosion in the pitting is aided. (Mile I.).

Vines should be cut and lifted rather than pulled off. Vines can be extensive and strong. If they are pulled off, there is always the chance that they may damage the resource, especially the thinner aluminium of aircraft fuselages and wing surfaces, and/or injure the maintenance worker. Rose clippers or other pruning shears are useful for cutting and removing vines.

OBLITERATION THROUGH PLANTING

Some sites, such bomb craters (Figure 17) as well as fox holes and personnel trenches are becoming gradually filled in with leaf litter, both due to natural processes as well as through artificial infill. As these larger depressions make good plantation pits for banana plants as well as for swamp taro, it is not surprising to note that secondary re-use of the depressions occurs. In addition, modified land use with coconut groves (Figure 17) changes the appearance of these sites.

Figure 17. Gradual obliteration of surface features. A coconut grove in an area riddled with bomb craters. (Taroa, Maloelap Atoll).

PLANT SPECIFIC OBSERVATIONS

The following section discusses in detail specific plants and their effects on cultural and historical resources:

- *Pandanus tectorius*
- Coconut (*Cocos nucifera*)
- Breadfruit (*Artocarpus altilis*)
- *Scaevola sericea*
- *Tournefortia argentea*
- Papaya (*Carica papaya*)
- *Wedelia biflora*
- *Vigna marina*
- *Polypodium scolopendria* and other ferns

Pandanus tectorius

Of all food plants, *Pandanus tectorius* (Marshallese: *bob*) has the greatest number of varieties known. It is a staple food item on many outer islands. The fruit is eaten, while the leaves are used for mat weaving and thatch. The plant is salt spray resistant and can grow on gravelly, as well as sandy soils. In a not anthropogenically modified environment, the plant is restricted to the shorelines, both lagoonal and ocean. In a modified environment, where the major trees have been felled and the scrub of the islands' interior has been cleared, *Pandanus* can grow in almost any location, except for permanently or repeatedly temporarily waterlogged areas.

Figure 18. Example of damage caused by Pandanus tectorius *aerial roots piercing through the aluminium skin of the wing of a Mitsubishi A6M ("Zero") aircraft. Also, note the accumulation of debris and fallen leaves. (Taroa, Maloelap Atoll).*

Effects of the plant

The aerial roots of the plant can grow downward from each of the limbs. The roots, which have a strong piercing tip, grow either straight or obliquely and have been noted to pierce through the aluminium of wings and fuselage of aircraft (see figures 21–22). Since the Pandanus trees have a spidery root system, a single tree can pierce an aircraft wing at numerous locations, leaving behind (when dead or destroyed) a perforated wing resembling a sieve. Since the roots increase in thickness, and may ultimately grow into new trees, especially if they have been generated by off-branches, the damage to the historical resource is increased.

Further, removal of these trees by improper means, such as felling or pulling over with a tractor, will increase the damage manyfold. Any vegetation removal of such trees from an affected site needs to commence at the top of

the tree, working downward until all roots are separated.

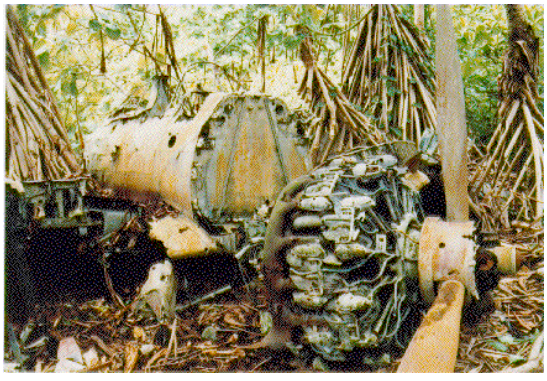

Figure 19. Damage caused by Pandanus tectorius *aerial roots piercing through the aluminium skin of the wing of a Mitsubishi A6M ("Zero") aircraft. Also, note the accumulation of debris and fallen leaves even though the plane has been cleared for inspection. (Taroa, Maloelap Atoll).*

The roots need to be cut as close to the resource as possible, and if at all feasible, also underneath the pierced resource. Then, unless indicated otherwise, it is advisable to let the roots rot in place, until they can be pushed out easily and the pierced holes of the resource can be cleaned. Further impact is caused by the seeds contained in the fruit capsules ("keys") of the plant. These easily sprout into new plants with the initial fertilisation being provided by the keys themselves. These plants, when fallen into crevices of the resources, will create further damage, mainly by widening the crevices, piercing thin aluminium and the like.

Figure 20. Damage caused by Pandanus tectorius *aerial roots piercing through the aluminium skin of the fuselage of a Mitsubishi G4M ("Betty") aircraft. Also, note the accumulation of debris and fallen leaves even though the plane has been cleared for inspection. (Taroa, Maloelap Atoll).*

Coconut (Cocos nucifera)

Next to grasses, coconut palms (Marshallese: *Ni*) are the most ubiquitous plant on the islands of the atolls of the Marshall Islands. Originally a coastal fringe plant, economic exploitation of the resource led to the clearing of growth inhibiting lower story brush in the inland areas of the islands and the planting of coconuts. These plants, which can grow up to 20-25m tall in the Marshalls, produce a bunch of flowers every three months. If pollinated, and not damaged by rats, high winds or droughts, an average eight to ten nuts from each flower stalk will reach maturity. Additional nuts will fall off during the maturing process. Further, about every three months, three to four new fronds will be produced, which result in the same number of fronds drying out and falling off the trunk of the tree.

Effects of the plant

The primary impact circle of a coconut tree, unless in times of high winds generated by storms and cyclones, is limited to a radius of about five to ten meters around the trunk, depending on the height of the palm. The secondary impact circle (10-15m) is caused by the nuts flying further away from the trunk in cases of wind and by nuts bouncing off the ground. We will exclude from this discussion the horrendous impact flying coconuts can have when driven by 80 mph winds created by typhoons.

Figure 21. Coverage of a resource by fallen coconut fronds and other leaf litter. The remains of a tanker truck (minus the tank which has been removed to serve

as a water catchment) are covered with fronds. The site then becomes a focal point for many landowners to move even more leaf litter "out of the way" to that location. Thus densely covering the resource the leaves create an ideal environment conducive to corrosion. (Mile Atoll).

Given a weight of about two to five pounds per nut, and given the velocity of a vertically falling nut increasing with the height of the palm, the impact of a fallen coconut can be substantial and is know to have caused serious bodily injury to persons working or sitting underneath older, mature coconut palms.

The damages incurred will affect mainly fragile resources, such as thin objects and objects of materials such as glass, and resources where corrosion has rendered sturdy parts fragile and susceptible to impact forces. Given the nature of the threat, predominantly vertically oriented resources are less at risk than predominantly horizontal resources. Weaker, horizontally oriented resources, such as the wings of aircraft, can become dented by a falling coconut, allowing debris of all sorts, as well as water to accumulate in the depression created by the nut, and further speeding up the process of deterioration.

Coconut fronds have an impact circle of about five to seven metre radius around a coconut palm. They tend to have a low velocity when impacting on the ground (being slowed down by the leaf matter), but have a greater weight. We have to take into account that coconuts and coconut fronds create repeated damages to resources, in view of their flowering cycle every three months. Although the flower stalks (and fronds) will grow on locations of the trunk with different orientations, we can safely assume that the same orientation will be reached after less than two years. Thus cumulative damage needs to be considered.

Figure 22. Revegetation of an area has established a coconut grove in the former Japanese dispersal area. Coconuts are growing among the remains of this Mitsubishi G4M 'Betty' aircraft.(Taroa, Maloelap Atoll).

In addition, collapsing coconut trees can fall on resources and cause severe damage, especially if the resources are already weakened by advanced corrosion (figure 24). Considering this potential, it is best to remove such trees before they can collapse and cause damage to historic resources. The recent replanting (1970s) of coconuts on the former Japanese bases has resulted in a number of palms planted in small bomb craters and on compacted soil. The root system of these palms have a dramatically reduced ability to withstand the wind forces brought to bear by a typhoon and are thus very prone to fall over. This is based on own observations (DHRS) following typhoons on Majuro (Typhoon "Axel" January 1992) and Wotje (Typhoon 'Gay' (November 1992).

Breadfruit
(Artocarpus altilis/ A. mariannensis)

Breadfruit (Marshallese *mā*) is on many outer islands of the Republic one of the staple foods. The tree comes in two varieties, those with a seed (*Artocarpus mariannensis*) and the more common unseeded variety (*Artocarpus altilis*). While the former can be propagated by both saplings and seeds, the propagation of the latter is restricted to saplings. Breadfruit trees are restricted to the inland areas of the islands, as they are very susceptible to salt spray and are in need of very fertile and well watered soils, which are present in the centres of the islands only.

Figure 23. A Mitsubishi A6M aircraft covered in a variety of plants, ranging from coconut sprouting under the wings to ferns and Pandanus. (Taroa, Maloelap Atoll).

Effects of the plant

The effects of the plant on the historical resources are largely restricted to falling fruit. Here we have to distinguish between the hard, unripe breadfruit, which will have a high velocity, high energy impact (depending on the size of the fruit and the height of the branch from which it fell), and the soft overripe fruit, which will have a high velocity, but low energy impact. The former will result in damages not unlike those described for the coconuts (above).

The damage of the overripe, soft fruit is more indirect. A large overripe breadfruit falling on a surface will disintegrate on impact, covering a substantial area (about one square foot) with a wet, fermenting, slodgy mush. This mass will either disintegrate within a few days, or will dry up, only to be turned into a fermenting mass every time it rains and the mass gets wet. The heat created by the fermentation process, as well as some of the acidic fruit material can cause chemical erosion to susceptible surfaces. If the breadfruit falls onto a resource with a highly reliefed surface, material will remain in the crevices, aiding the accumulation of fertile substrate ideal for moss and plant growth.

In addition, collapsing breadfruit trees can fall on resources and potentially incur severe damage, especially if the resources are already weakened by advanced corrosion. The recent replanting (1970s) of breadfruit on the former Japanese bases has resulted in a number of trees planted in small bomb craters and on compacted soil. The root system of these trees is very shallow and thus they have a dramatically reduced ability to withstand the wind forces of a typhoon.

Figure 24. Root matter of Scaevola sericea *penetrating components of a 150mm gun leading to the destabilisation of the basis. (Wotje, Wotje Atoll).*

Scaevola sericea

Scaevola sericea (Marshallese: *Kõnnãt*) is a salt-spray resistant shoreline plant with limited need for water. Thus it is common on all atolls and islands of the Republic, including the three dry, northern atolls of Bikar, Bokak and Eneen-Kio. The plant is a low shrub, growing to a height of about 15 feet (4.5m), with stems of 3/4 foot (20cm) in diameter and less.

Effects of the plant

The rapidly growing plant develops a very dense network of branches with a dense foliage. Since it is well adapted to grow on the coral boulder ridge on the ocean side, it finds opportunities to grow in the cracks of bombed

and damaged gun emplacements, pill boxes and other concrete structures.

Figure 25. Scaevola sericea *covering 150mm guns. Unmitigated growth can result in sizeable branches covering the gun. (Wotje, Wotje Atoll).*

The damages incurred by the roots and, to some extent, the branches, consist of the widening of existing cracks and crevices of structures and artefacts and the widening of weakened joints and rivet or bolt holes. The dense foliage covers up the resources and generates a micro-climate by retaining water and moisture which keeps the surfaces of the resources wet long after the rainfall due to dripping. Indirect damage is then caused by the acidic droppings of some sea-birds roosting in the shoreline scrubs. Since the same branches provide for the drip for a prolonged time, pitting and erosion corrosion is aided.

Figure 26. Scaevola sericea *covering a 150mm gun. Before and after vegetation clearing. Indirect damage is caused by the acidic droppings of some sea-birds roosting in the shoreline scrubs. (Wotje, Wotje Atoll).*

Tournefortia argentea

Tournefortia (Messerschmidia) argentea (Marshallese: *Kiden*) is a salt-spray resistant shoreline plant with limited need for water. It is common on all atolls and islands of the Republic, including the three dry, northern atolls of Bokak and Eneen-Kio. The plant is a low tree, growing to a height of ~25 feet (6-7m), with stems of 1-1.5 feet (30-40cm) in diameter and less.

Figure 27. Scaevola sericea *covering a 150mm gun. Before and after vegetation clearing. The dense foliage covers up the resources and generates a micro-climate (Wotje, Wotje Atoll).*

Effects of the plant

The reasonably rapidly growing plant develops, when small, a very dense network of branches with a dense foliage. Since it is well adapted to grow on the coral boulder ridge on the ocean side, it finds opportunities to grow in the cracks of bombed and damaged gun emplacements, pill boxes and other concrete structures along the ocean side.

The damages incurred by the roots and, to some extent, the branches, consist of widening of existing cracks and crevices of structures and artefacts and of weakened joints and rivet or bolt holes. The initially dense foliage covers up the resources and generates a micro-climate by retaining water, reducing evaporation and thus concentrating moisture which keeps the surfaces of the resources wet long after rainfall due to dripping. Indirect damage, especially in the case of older trees, may then be incurred by the acidic droppings of some sea-birds roosting in the shoreline trees. Since the same branches provide for the drip for a prolonged time, pitting and erosion corrosion in the pitting is aided.

Figure 28. Large Tournefortia argentea *growing in a 150mm gun emplacement (Taroa, Maloelap Atoll).*

Papaya(Carica papaya)

Papaya (Marshallese: *Kenapu*) is a European introduction to the Marshall Islands. The plant is heterosexual, with male plants only flowering, and female plants bearing large (American) football-sized and -shaped fruit.

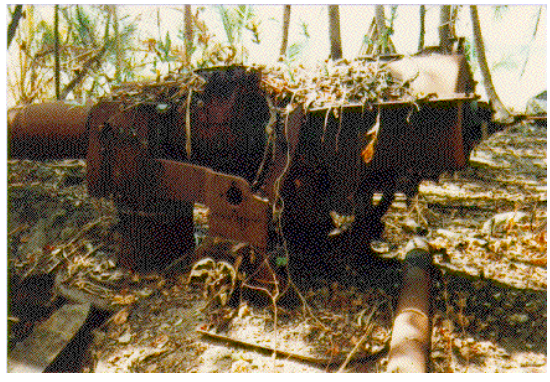

Figure 29. Leaf litter covering the barrel of a 150mm gun The decayed vegetation set ups corrosion cells and allows the accumulation of more vegetation by providing a fertile ground for the germination of seeds. (Mile, Mile Atoll).

Figure 30. Leaf litter of a breadfruit tree covering the remains of a Japanese Amphibious tank. The decayed vegetation set ups corrosion cells and allows the accumulation of more vegetation by providing a fertile ground for the germination of seeds. In addition, there are intrusive plants growing among the remains, such as pumpkin and Polypodium scolopendria *(Mile, Mile Atoll).*

The plant is very easy to grow as long as there is any semi-shade available. While the plant is commonly distributed around house

sites and does not occur in the non-tended areas, it has been encountered in open, semi-shaded areas in the interior of islands. The propagation of the plant is by seeds, which germinate very easily. Dispersal is aided by people and birds.

Effects of the plant

The rapidly growing plant can create two kinds of impacts on the resources: a covering up of surfaces, thereby increasing corrosion, and a widening of existing crevices. The effects on the historical resources are largely restricted to falling fruit. The damage of the overripe, soft fruit is indirect.

Figure 31. remains of a Japanese hangar on Mile I. (Mile Atoll). The entire hangar structure id overgrown with Vigna marina *and* Ipomea *sp.*

A large overripe papaya falling on a surface will, like the breadfruit discussed earlier, disintegrate on impact, covering a substantial area (about one square foot) with a wet, fermenting, slodgy mush. This mass will either disintegrate within a few days, or will dry up, only to be turned into a fermenting mass every time it rains and the mass gets wet. The heat created by the fermentation process, as well as some of the acid fruit material can cause chemical erosion to susceptible surfaces. If the papaya falls onto a resource with a highly relieved surface, material will remain in the crevices, aiding the accumulation of fertile substrate ideal for moss and plant growth. It needs to be kept in mind that papaya propagate easily, so that it is very likely that some of the seeds of the fallen fruit will germinate and develop into new plants. The new plants can grow through crevices, gaps and holes in the resource. When the plant grows and the stem thickness increases, these crevices can be widened, and on occasion, the resource can be split. In view of the limited height of papaya the impact circle of falling fruit is limited to a radius of 7 feet (2m) or less.

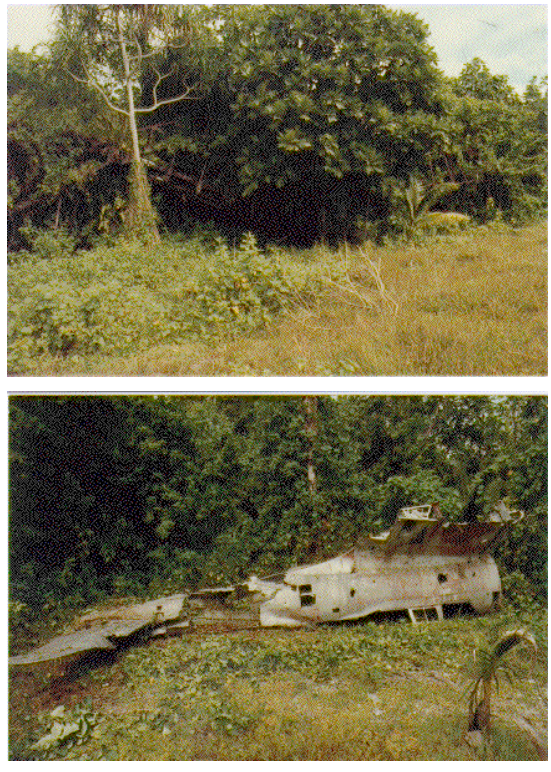

Figure 32. Vigna marina *and* Wedelia biflora *covering part of an Aichi D3A ("Val") dive bomber. The pliable, but woody stems of the plant can grow through holes and crevices of the resources, creating an intertwined solid mass of stems and stemlets. Plant removal in such instances is complicated, as they cannot be pulled out easily (Mile, Mile Atoll).*

Wedelia biflora

Wedelia biflora (Marshallese: *Markubwebwe*) is a weed, which grows large leaves with serrated edges. The plant rapidly produces leaf stalks and has the ability to grow to any height necessary (up to 5 feet) to choke any of the competing vegetation. Commonly, *Wedelia* often occurs in thickets, where it is the sole plant species.

Effects of the plant

The effective dispersal of the plant, combined with its dense growth pattern, result in micro–climate development over small resources covered by the plant. The dense foliage generates a micro-climate by retaining water and moisture which keeps the surfaces of the resources wet long after the rainfall due to dripping. Further, the pliable, but woody stems of the plant can grow through holes and crevices of the resources, creating an intertwined solid mass of stems and stemlets. Plant removal in such instances is complicated, as they cannot be pulled out easily. Although the most convenient, and locally most commonly employed method is to jerk at the vines and to try and tear them off their "substrate", this is the most likely source of damage. What is required, is repeatedly cut the vines with rose clippers and to gently pull the plant off the resources, cutting it with clippers as required.

Figure 33. Stand of Wedelia biflora *showing the height of the vegetation (Taroa, Maloelap Atoll).*

Vigna marina

Vigna marina (Marshallese: *Markinojojo*) is a vine belonging to the bean family. Although in large areas it is a ground covering plant, it will climb on any objects of medium height (up to about 10 feet). It forms a dense foliage, unless in competition with other plants.

Figure 34. Vines of Vigna marina *and* Ipomea *spp. and another plant covering part a 127mm Dual purpose gun and emplacement. (Mile, Mile Atoll).*

Figure 35. Vigna marina *covering a 150mm gun. Before and after vegetation clearing. The dense foliage covers up the resources, retains moisture and thus keeps the surfaces of the resources wet long after the rainfall. (Taroa, Maloelap Atoll).*

Effects of the plant

The main threat is caused by the virulent growth of the plant and with its ability to work

its way through very tiny crevices. It creates a very dense foliage, which, is located very close to the surface of the resource, thereby creating a special micro-climate with a very high rate of humidity retention. As with *Wedelia biflora* the plant can be intensely intertwined with several parts of the resource, other plants, as well as itself, forming a formidable problem when it comes to removal. Again, rather than jerking at the vines it is required to repeatedly cut the vines with rose clippers and to gently pull the plant off the resources.

Figure 36. Windblown sediment collects in the crevices of this 127mm gun and provides fertile ground for the colonisation of Polypodium scolopendria. *(Wotje, Wotje Atoll).*

Figure 37. Ferns growing around the rear pontoon of a Japanese Amphibious tank. Note that some plants have penetrated small corrosion holes and are sprouting now from the inside. (Mile, Mile Atoll).

SUMMARY

Tropical vegetation can have a widespread deleterious effect on cultural resources. Table 1 summarises the plant impacts discussed in this paper. Given the zonation of plants into ecological zones on a given island (see Figure 38), that impact will differentially affect cultural resources depending on the location.

Table 1. Overview on the damage caused by local vegetation

Plant species (Marshallese name)	Plant part involved	Type of impact	Type of damage	Type of resources affected	
				Directly	Indirectly
Pandanus tectorius (Bob)	Aerial roots	Perforation	Holes, widening of crevices, joints and rivet/bolt holes	Aircraft, Vehicles, Buildings, Emplacements	
	Seeds		Widening of crevices, joints and rivet/bolt holes		
Cocos nucifera (Ni)	Coconuts	Impact	Concussion of thin horizontal surfaces and	Aircraft, Vehicles, Exposed parts of guns,	
	Fronds	Impact	Shattering of fragile objects	Small objects, Bottles	
Artocarpus altilis *A. mariannensis* (Mã)	Fruit, unripe	Impact	Concussion of thin horizontal surfaces and shattering of fragile objects	Aircraft, Vehicles, Exposed parts of guns, Small objects, Bottles	
	Fruit, ripe	Coverage	Coverage of surfaces		Oxidisation and substrate build-up
Scaevola sericea (Kõnnãt)	Roots, branches		Widening of crevices, joints and rivet or bolt holes	Any	
	Leaves	Micro-climate	Increased corrosion	Metal objects	
Tournefortia argentea (Kiden)	Roots, branches		Widening of crevices, joints and rivet/bolt holes	Any	
	Leaves	Micro-climate	Increased corrosion	Metal objects	
Carica papaya	Seeds, stems	Widening of crevices, joints & rivet/ bolt holes	Any		
(Kenapu)	Fruit, ripe	Coverage	Coverage of surfaces		Oxidisation and substrate build-up
Wedelia biflora (Mãrkubwebwe)	Leaves	Micro-climate	Increased corrosion	Metal objects	
	Stems	Widening of crevices, joints and rivet/bolt holes	Any		
Vigna marina (Merkinejojo)	Vines	Widening of crevices, joints and rivet/bolt holes	Any		
	Leaves	Micro-climate	Increased corrosion	Metal objects	

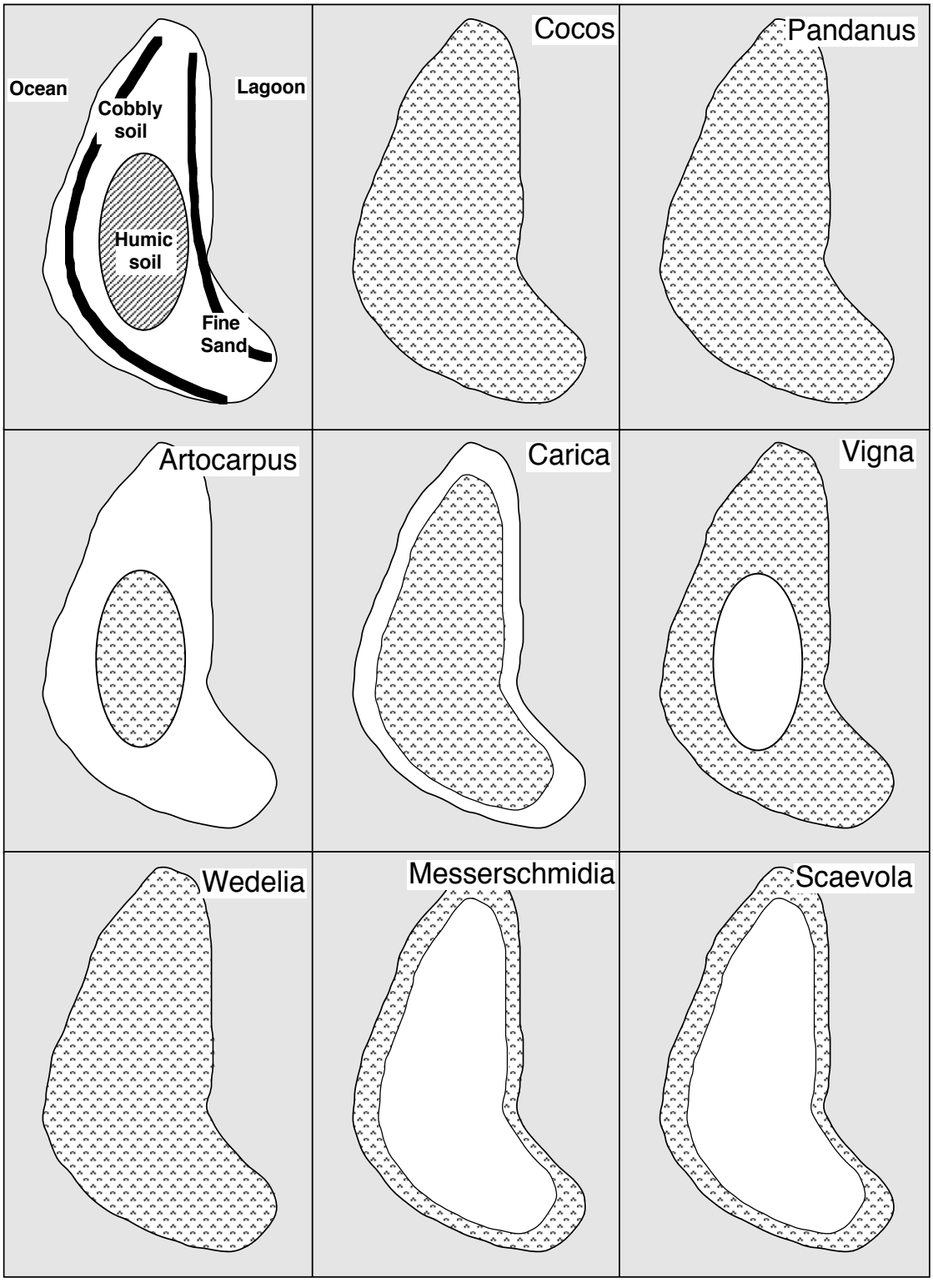

Figure 38. Schematic distribution of various plant species on a given sand cay on an atoll

BIBLIOGRAPHY

Adams, William, H., Ross, Richard, E., Krause, Elisabeth, L. and Spennemann, Dirk H.R. (1997) *Micronesian Resources Study, Marshall Islands Archaeology. The Japanese Airbase on Taroa Island, Republic of the Marshall Islands, 1937-1945: an evaluation of World War II Remains*. San Francisco, Calif. : Micronesian Endowment for Historic Preservation, US National Park Service.

Bailey, Dan E. (1982) *WWII wrecks of the Kwajalein and Truk Lagoon*. Redding, CA: North Valley Diver Publications.

Bryan, E.H. jr. (1972) *Life in the Marshall* Islands. Honolulu, Hawaii: Pacific Scientific Information Center.

Delgado, J.P. D.J.Lenihan and L.E. Murphy (1991) Archaeology of the Atomic Bomb: A submerged Cultural Resources Assessment of the sunken fleet of Operation Crossroads at Bikini and Kwajalein Atoll lagoons, Republic of the Marshall Islands. Southwestern Cultural Resources Center Professional Papers Nº 37. Santa Fé, New Mexico: Southwestern Cultural Resources Center.

Denfeld, DC. (1979a) Field Survey of Ponape: World War II Features. Micronesian Archaeological Survey Report No. 2. Saipan: Historic Preservation Office, Trust Territory of the Pacific Islands.

Denfeld, DC. (1979b) Field Survey of Truk: World War II Features. Micronesian Archaeological Survey Report No. 6. Saipan: Historic Preservation Office, Trust Territory of the Pacific Islands.

Denfeld, DC. (1981) Japanese fortifications and other military structures in the Central Pacific. Micronesian Archaeological Survey Report No. 9. Saipan: Historic Preservation Office, Trust Territory of the Pacific Islands.

Denfeld, DC. (1988) Peleliu revisited. An historical and archaeological survey of World War II sites on Peleliu Island. Micronesian Archaeological Survey Report No. 24. Saipan: Historic Preservation Office, Commonwealth of the Northern Mariana Islands.

Emery, K.O., J.I.Tracey & H.S.Ladd (1954) Geology of Bikini and nearby atolls. Part 1: Geology *U.S. Geological Survey Professional Paper* 260-A. Washington D.C.

Feilden, B.M. (1994) *Conservation of historic buildings*. 2nd ed. Butterworth Architecture, Butterworth-Heinemann, Oxford.

Govi, G. (1991) Root penetration of solid porous medium. In Baer, N.S., Sabbioni, C. and Sors, A.I. (eds) *Science, technology and European cultural heritage*. Butterworth-Heinemann, Oxford. pp. 493-495.

GSA (nd.) U.S. General Services Administration. *Removing Biological Growth from Exterior Masonry And Stucco*. Historic Preservation Technical Procedures 04200-02

GSA (nd.) U.S. General Services Administration. *Removing Climbing Plants & Creepers from Masonry*. Historic Preservation Technical Procedures 04200-04

Hawaii Architects & Engineers (1972) *Wotje Master Plan* Trust Territory of the Pacific Islands: Planning Division, Department of Public Works.

Hein, J.R., W.C.Schwab & A.S.Davis (1988) Cobalt- and Platinum-rich feromanganese crusts and associated substrate rocks from the Marshall Islands. *Marine Geology* 78, 255-283.

Hezel, F.X. & C.Graham (1989) Truk's Underwater Museum. A Report on the Sunken Japanese Ships. A project sponsored by the Micronesian Endowment of Historic Preservation. Report prepared for the Micronesian Resource Study, Micronesian Endowment of Historic Preservation.

Jones, D. and Wilson, M.J. (1982) Chemical activity of lichens on mineral surfaces–a review. *International Biodeterioration* 21, 99-104.

Ladd, H.S., J.I. Tracey, J.W. Wells & K.O. Emery (1950,) Organic growth and sedimentation on an atoll. *Journal of Geology* 58:410-425

Ladd, H.S., J.I.Tracey & G.G.Lill (1948) Drilling on Bikini Atoll, M.I. *Science* 107:51-55.

Laird, W.E. (1989) *Soil Survey of the islands of Airik, Arno, Majuro, Mili and Taroa; Republic of the Marshall Islands*. Washington, DC.: United States Department of Agriculture Soil Conservation Service.

Look, D.W. and D.H.R. Spennemann (1992) "Conservation of Iron Artefacts in a Tropical Marine Climate." Workbook for a workshop held at Majuro and Wotje Atolls, Republic of the Marshall Islands, December 3rd to 10th, 1992. Majuro Atoll: Republic of the Marshall Islands Historic Preservation Office and U.S. National Park Service, Western Regional Office.

Look, David W. & Spennemann, DHR (1993) Saving WWII Historic Sites. Metals Conservation Course in the Marshall Islands. Cultural Resource Management Bulletin [U.S. National Park Service] 16 (5), 22-24.

Look, David W. & Spennemann, Dirk H.R. (1993) *For Future Use: A Management Conservation Plan for the World War II sites in the Republic of the Marshall*

Islands. Albury, NSW, Australia, and San Francisco, U.S.A.: The Johnstone Centre of Park, Recreation and Heritage and the U.S. National Park Service Western Regional Office.

Look, David W. & Spennemann, DHR (1994) Preparing for the 50th anniversary of Guam Liberation. Metals Conservation Course and Demonstration Project. *CRM Bulletin* 17(8): 35–36.

Look, David W. & Spennemann, DHR (1996) In a tropical marine climate: Conservation Management of Historic Metals *APT Bulletin* 27(1-2), 60-68.

Monte, E. (1991) Lichens on monuments: Environmental bioindicators. In Baer, N.S., Sabbioni, C. and Sors, A.I. (eds) *Science, technology and European cultural heritage*. Butterworth-Heinemann, Oxford. pp.355-359.

OPS (1989) Office of Planning and Statistics, *Census of Population and Housing 1988. Final Report*. Majuro: Office of Planning and Statistics.

Palmer, R.J. (1991) Microbial communities involved in the weathering of the historic monuments in northern Germany. In Baer, N.S., Sabbioni, C. and Sors, A.I. (eds) *Science, technology and European cultural heritage*. Butterworth-Heinemann, Oxford. pp.478-480.

Rowe, G., Aparicio, G.A., Martinz and Saiz Jiuminez, C. (1991) Weeds settling in Spanish Cathedrals (Salammanca, Sevilla and Toledo). In Baer, N.S., Sabbioni, C. and Sors, A.I. (eds) *Science, technology and European cultural heritage*. Butterworth-Heinemann, Oxford. pp. 497-500.

Spennemann, DHR & David W. Look (1994) Impact of tropical vegetation on historical cultural resources. A photographic case study from the Marshall Islands. *The Johnstone Centre for Parks, Recreation and Heritage Report* N° 18e— The Johnstone Centre for Parks, Recreation and Heritage, Charles Sturt University, Albury, NSW. 1994.

Spennemann, DHR (1992) Wotje Atoll. Its geography, natural and cultural history. *Independent Nationwide Radiological Survey Background Study* N° 34. Majuro: Historic Preservation Office.

Spennemann, DHR (1994) The last flight of the "St. Quentin Quail". Investigations of the wreckage and history of Consolidated B-24 "Liberator" aircraft #42-41205 off Jab'u Island, Arno Atoll, Republic of the Marshall Islands. The Johnstone Centre for Parks, Recreation and Heritage Report N° 17— The Johnstone Centre for Parks, Recreation and Heritage, Charles Sturt University, Albury, NSW., 1994.

Spennemann, DHR (1995) British Naval Guns in Micronesia. *Mariner's Mirror* 81(3), 343-347

Spennemann, DHR (1995) Physical reminders of the British-Japanese Armament Trade in Micronesia. *Journal of the Pacific Society* (Tokyo) 18 (3), 117-130.

Spennemann, DHR (1996) Adaptive re-use of B-24 parts in the Marshall Islands. *Briefing-The Journal of the Intenational Liberator Club* 59, 3.

Spennemann, DHR , 1990a, Cultural Resource Management Plan for Majuro Atoll, Republic of the Marshall Islands. 2 Vols. Report prepared in fulfillment of U.S.Department of Interior, Office of Territorial and International Affairs Technical Assistance Grant MAR-42. Report submitted to the Historic Preservation Office, Majuro, Republic of the Marshall Islands. August 1990.

Spennemann, DHR (1991a) Historical Sites on Taroa Island, Maloelap Atoll. Ennaanin Etto—News from the Past 1(1), 5-6.

Spennemann, DHR (1991b) Submerged Cultural Resources of Wotje Atoll. Identification and Resource Management. Report in partial fulfillment of a South Pacific Cultures Fund Grant. HPO-Report 1991/7. Majuro Atoll, Republic of the Marshall Islands: Historic Preservation Office.

Spennemann, DHR (1991c) Mile, Mile Atoll. Air Marshall Islands Sunday Escape. Folded tour brochure, 2pp.

Spennemann, DHR (1991d) Taroa, Maloelap Atoll. Air Marshall Islands Sunday Escape. Folded tour brochure, 2pp.

Spennemann, DHR (1992a) Investigations of a Consolidated B-24 "Liberator" aircraft of Jabu Island, Arno Atoll. HPO-Report 1992/1. Majuro Atoll, Republic of the Marshall Islands: Historic Preservation Office.

Spennemann, DHR (1992b) Know your Past: Historical Sites on Mile Island, Mile Atoll. *Ennaanin Etto-News from the Past* 2(1), 1992, 8-10.

Spennemann, DHR (1992d) Archaeological and historical investigations of a Consolidated B-24 "Liberator" aircraft in Majuro Lagoon, Majuro Atoll, Republic of the Marshall Islands–a submerged cultural resource assessment. HPO-Report 1992/3. Majuro Atoll, Republic of the Marshall Islands: Historic Preservation Office.

Spennemann, DHR (1992e) Apocalypse now?—the fate of World War II sites on the Central Pacific Islands. *Cultural Resources Management Bulletin*. 15(3), 15-16, 22.

Spennemann, DHR (1992g) British Six-inch Guns on Japanese bases in the Marshall Islands: a preliminary report on the use of foreign armament on Japanese coastal defense installations in the Central Pacific. HPO-Report 1992/5. Majuro, Marshall Islands: Historic Preservation Office.

Spennemann, DHR (1992h) Investigations of a Grumman TBF "Avenger" aircraft in Majuro Lagoon. HPO-Report 1992/2. Majuro Atoll, Republic of the Marshall Islands: Historic Preservation Office.

Spennemann, DHR (1992o) Technical data on British and Japanese Coastal Defense Guns possibly emplaced on Japanese World War II bases in Micronesia—a preliminary overview. HPO-Report 1992/14. Majuro Atoll, Republic of the Marshall Islands: Historic Preservation Office.

Spennemann, DHR (1992p) The remains of an Aichi D3A "Val" Dive bomber on Laura Beach, Majuro Atoll, Marshall Islands. HPO-Report 1992/16. Majuro Atoll, Republic of the Marshall Islands: Historic Preservation Office.

Spennemann, DHR (1992q) The remains of an Aichi D3A "Val" Dive bomber on Mile Island, Mile Atol, Marshall Islands. HPO-Report 1992/17. Majuro Atoll, Republic of the Marshall Islands: Historic Preservation Office.

Spennemann, DHR (1992r) The remains of a Kawanishi H8K Flying Boat off Wotje Island, Wotje Atoll, Republic of the Marshall Islands. HPO-Report 1992/18. Majuro Atoll, Republic of the Marshall Islands: Historic Preservation Office.

Spennemann, DHR (1992x) World War II Remains on Central Pacific Islands: Perceptions of Heritage versus Priorities of Preservation. The Pacific Review 5 (3), 1992, 278-290.

Spennemann, DHR, Holly, M. and Lajuan, N. (1990) Report on the occurrence of live ammunition on Mile Island, Mile Atoll. Report prepared for the Historic Preservation Office, Majuro, the Mile Atoll Local Government, Mile, Mile Atoll, and the Hon.Senator for Mile, Mr. Alee Alik. Republic of the Marshall Islands. Report OTIA-TAG-MAR-42-5/90. Majuro Atoll: Alele Museum.

Steinbach, E. (1893) Bericht über die Gesundheitsverhaeltnisse der Schutzgebiete der Marshall-Inseln. *Mittheilungen von Forschungsreisenden und Gelehrten aus den Deutschen Schutzgebieten* 6, 306-313.

Thomas, W.L. (1967) Geography. In: R.Friis (ed.), *The Pacific Basin: A history of its geographical exploration*. New York: American Geographical Society.

Thompson, E.N., 1984a, National Register for Historic Places Inventory Nomination Form: Kwajalein Island Battlefield. Prepared by the Denver Service Center, U S. National Park Service.

Thompson, E.N., 1984b, National Register for Historic Places Inventory Nomination Form: Roi-Namur Battlefield. Prepared by the Denver Service Center, U S. National Park Service.

Tracey, J.I & H.S.Ladd (1974) Quarternary history of Eniwetok and Bikini Atolls, Marshall Islands. *Proceedings of the Second International Coral Reef Symposion.* 2:537-550.

USSBS (1947a) United States Strategic Bombing Survey, The American campaign against Wotje, Maloelap, Mille and Jaluit. Washington, DC.: Naval Analysis Section, United States Strategic Bombing Survey.

USSBS (1947b) United States Strategic Bombing Survey, The 7th and 11th Air Force in the war against Japan. Report 70. Washington, DC.: Naval Intelligence Center.

USSBS (1947c) *United States Strategic Bombing Survey, The reduction of Wake Island.* Washington: Naval Analysis Section, United States Strategic Bombing Survey.

Williamson, I. & M.D.Sabath (1982) Island population, land area, and climate: A case study of the Marshall Islands. *Human Ecology* 10(1), 71-84.

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