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VEGETATION OF BIKINI ATOLL,

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BY

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F. Raymond Fosberg*

PREFACE

This paper is presented in exactly the form submitted to the Bikini Rehabilitation Committee (BARC), sponsor of the survey which produced it. A summary of it, not included here, forms a chapter of the Survay Report, submitted in 1986. The present text was attached to that report as an appendix. This and the accompanying report on Bikini birds are published here with the permission of BARC. We thank the charman of BARC, Dr. Henry Kohn, of Berkeley, California, and his committee for the opportunity to study the vegetation and bird fauna of this devastated coral atoll.

ABSTRACT

Before 1946 Bikini Atoll, Northern Marshall Islands, was largely planted to coconuts, and supported a small Marshallese population. Small areas unsuitable for coconuts retained approximately indigenous vegetation, In 1946 the people were removed and the atoll was used for 12 years as the site for nuclear weapons-testing, resulting in the destruction or serious alteration of all vegetation. The survey report here, made in 1985, showed that, in addition to replanted coconut plantations, native forest and scrub vegetation had recovered to a surpising extent, though its composition, as to proportion of species, had changed. Some species were missing and some exotics had become established. Some species exhibited unusually large stature and luxuriance. Comments and recommendations are presented relative to the possible return of the Marshallese when the atoll is sufficiently decontaminated of its radionuclide content.

INTRODUCTION:

Bikini is a large coral atoll, one of the northwestern of the Marshall Archipelago, eastern Micronesia. It lies between 11°20' and 11°44'N latitude and between 165°10' and 165°36'E longitude.

On its roughly rectangular reef were originally 25 islets (motu in Polynesian) reduced to 22 since the atomic bomb tests in 1946-1958. The two largest islets are Bikini, 560 acres, and Eneu, 304 acres, on the eastern end of the reef. Other large islets are Nam, Enidrik and Aerokojlol.

All of the islets are low coral platforms reaching a maximum of about 10-15 feet elevation. They are made up of loose or consolidated calcium carbonate sediments, formed of the calcareous skeletons of marine plants and animals, which grew, over millions of years, on very slowly subsiding marine volcanoes.

Physiographically, atoll islets exhibit a central plain, with or without shallow depressions, surrounded, peripherally, by low beach ridges of coral sand or gravel. Occasional sections of beach ridge may be storm deposits composed of cobbles and/or boulders, usually rounded; these usually are single skeletons of massive corals (scleractinians), sometimes fragments of consolidated sediment. Here and there, especially on the seaward sides of the islets, shelf like ledges or extensive exposures of

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hard limestone conglomerate protrude from beneath the beach ridges. Also, outside the beach ridges are frequent elongate, sloping formations of beach-rock, consolidated, lithified beaches of sand or gravel. These commonly slope toward the ocean or lagoon, at the angle of the beach that was consolidated.

Through weathering and the action of vegetation, soils formed, ranging from unaltered carbonate sediments through varying additions of decomposed plant materials or humus to the upper layers. The extreme in this respect has an upper layer, or "A" horizon of pure humus, frequently underlain by a hardpan layer of calcium phosphate rock.

Nothing is known with certainty of the vegetation of Bikini prior to the coming of the Marshallese people. However, we can be reasonably sure that it was for the most part woody-forest or scrub, with grass on very poor or dry sites. Coconuts, and probably root-crops such as taro were brought in by the Marshallese, resulting in some alteration of the vegetation. Occupation by the Germans and later Japanese, brought an alteration of most of the suitable land to commercial coconut plantations, for production of copra. This meant the disappearance of most of the native vegetation, though all or most of the native plant species probably survived.

On the islets mapped in any detail for the present survey no unaltered natural vegetation has survived. Neither description nor interpretation in terms of natural vegetation types is attempted, as with the degree of alteration that the vegetation has undergone, such an attempt, at least on the basis of a short term reconnaissance study, would result in nothing but futility.

Formal, quantitative vegetation descriptions cannot be prepared with the data in hand, and would, in any event, be essentially meaningless. Instead, brief practical descriptions are offered of mappable facies as can be recognized. The degree of generalization is necessarily extreme. Otherwise it would require an excessive number of map units, which could not be recognized on the 1978 air photos available. Also, it is obvious that much change in the detail of the plant communities has taken place in the ensuing seven years.

The boundaries have essentially been sketched from the photos, except where it is obvious that changes have taken place. Areas differing on the photos have been visited where possible, to control the interpretation of the texture, colors and patterns.

The same scheme of units has been used for the principal islands, with differences in composition and physiognomy noted as necessary.

MATERIALS AND METHODS:

The method used in this reconnaissance was by examination of a set of excellent aerial color photos, made in 1978, followed by personal field studies. As much ground was covered by car and on foot as was practical in the time available. Ten islets were visited, including four of the five larger ones, Bikini, Eneu, Nam, and Aerokojlol. All different textures and colors seen on the photos were field-checked and notes made on the structure and physiognomy of the vegetation written down in very abbreviated style, but with species noted with anything of interest as to their occurrence. Species were listed for each islet visited, and at least one gathering was made of herbarium specimens of each species found on the survey (except of the coconut and the plants in the experimental gardens). These specimens were studied and carefully identified as they were prepared for preservation after being brought from the field. When they have been received in Washington, dried and labeled, the best set will be deposited in the U.S. National Herbarium, Smithsonian Institution, a second set sent to the B. P. Bishop Museum's Herbarium Pacificum in Honolulu. Further sets, as available, will be distributed

to other important herbaria with tropical Pacific interests.

After work on an islet was concluded a description of its vegetation and the patterns of distribution of the different types discriminated was prepared and for the three largest, Bikini, Eneu, and Nam, maps were sketched, boundaries based on the air photos as modified by the field observations. A list of plants was added for each islet described, and a combined list for the atoll was prepared.

RESULTS

ENEU ISLET

Eneu, treated first as it was studied first, is the second largest islet on the Bikini reef, 4 miles in circumference, one and a half miles long, a maximum of one third of a mile wide, and with an area of just over 300 acres (304 acres). It lies at the southeast corner of the atoll, its larger, rounded end to the south, its pointed end north. Its principal geographic features are the 4,500-foot long airstrip, and the coconut plantation which covers most of the land surface exclusive of the airstrip and its asphalt parking area.

The coconut trees are planted on a precisely laid-out 30 foot square grid system. There has been no maintenance of this plantation since the Bikini people were removed in 1978.

The physionogmy of the plantation varies from luxuriant, with dense tall undergrowth and tall (to 10 m) coconut palms, to sparse, almost lacking undergrowth, and variously stunted palms. In the more open or sparse areas of coconuts, the ground is covered by tall grass, mostly Eustachys petraea. Lepturus repens is generally common to abundant, often in shadier places than Eustachys.

A superficial study of the vegetation of Eneu enables one to distinguish ten physiognomic types. These are listed below, with brief practical descriptions and indicated on the map in correspondingly numbered units, which are used in mapping both the islets.

1. Tall luxuriant coconut plantation, trees to about 10 m, tall, undergrowth varying in height and composition, but closed, comprising Tournefortia, Scaevola, Dodonaea, Guettarda, Pandanus, Cordia, Pisonia, Clerodendrum and coconut (Cocos) seedlings. The coconut seedlings are clustered around the bases of coconut trees where the nuts have fallen, unharvested. The different trees and shrubs vary in abundance.

Dodonaea is prominent in most places and forms a significant proportion of the total vegetation. A grass ground cover, mostly Lepturus. is found where the shade is not too dense. A soil with blackish or dark gray A horizon 10-20 cm thick is often found in this vegetation. Cassytha forms a parasitic veil over many bushes and small trees, killing some, and incidentally starving itself to death.

2. Coconut plantation but with trees usually smaller, less luxuriant, often yellowish, undergrowth thin, often sparse or lacking, seldom very tall, or of closed grass, usually Eustachys and Lepturus, which forms a thick ground cover. In places where bare ground is exposed several broad-leafed weedy herbs may be common.

3. Very poor coconuts, small, usually yellowish, undergrowth practically lacking. Locally scattered Suriana bushes, grass ground cover sparse mostly Lepturus and Fimbristylis.

4. Sparse stand of tall coconut palms with dense tall second story of Tournefortia and Guettarda, shade very dense, openings with dense ground-cover of Tridax and other weeds, Lepturus, and in more open spots, Eustachys. No Dodonaea was observed here. This type was only seen at the south end of Eneu islet.

5. Small areas of dense forest of Pisonia and Cordia were seen near the middle of the islet. This may be something like the original vegetation of the island, but is probably not a persisting remnant of this original cover.

6. Along the parts of the seaward coast are sandy areas, partly bare and probably shifting with the wind. Patches of Lepturus tend to stabilize this sand, scrub of Suriana and Scaevola forms a mosaic with the Lepturus and Boerhavia and open sand. The Lepturus is very low and thin, the patches enlarging by creeping spreading stolons, the Boerhavia also forming spreading mats. There are practically no living coconuts in these sandy areas. A few fallen dead ones are seen.

7. At the extreme northern end of the islet is an area of an irregular mixture of Tournefortia, Scaevola, with some Suriana, the latter mostly at the extreme point. The ground cover is Lepturus with some Triumfetta. Cassytha is common, parasitizing most of the plants. The whole varies from scrub to scrub-forest stature and appears very irregular, with a few openings showing bare sand, and mostly supporting a mixture of grasses, Fimbristylis and some weedy broadleaf herbs.

8. Along the two sides of the airstrip are narrow bands of tall grass and weeds, with a few young invading tree and shrub seedlings. This weedy vegetation appears to have been cut back at intervals. Cassytha is very abundant here, locally forming a tangle that is tiresome to walk through. At the lagoon end of the runway is a broader area of this herbaceous cover, bordering the beach.

9. The runway surface is a very short, open area of small bunch-grass of Lepturus, Eustachys and Fimbristylis. This appears to have been mowed at intervals to keep it so short. The ground seems hard and compact.

10. Along almost the entire periphery of the island, between the road and the beach where there is a road, is a sand or gravel beach ridge. This is generally covered by a narrow strip of scrub or scrub-forest varying in composition from place to place, but made up of Tournefortia, Scaevola, Cordia and Suriana. Cassytha covers many bushes and trees, some of them dead. This vegetation serves somewhat as a windbreak, protecting the plantation, but the coconut trees are planted too close to the beach to allow the formation of an effective natural windbreak such as found in many places in the Marshalls.

Plants observed in 1985 were:

Pandanus tectorius
Cenchrus echinatus
Dactyloctenium aegyptium
Lepturus repens
Fimbristylis cymosa
Cocos nucifera
Boerhavia tetrandra
Pisonia grandis
Portulaca australis
Portulaca lutea
Cassytha filiformis
Suriana maritima
Euphorbia hirta
Euphorbia glomerifera
Euphorbia rubicunda
Phyllanthus amarus
Dodonaea viscosa
Triumfetta procumbens
Sida fallax
Calophyllum inophyllum
Terminalia samoensis
Ipomoea macrantha
Ipomoea pes-caprae.
Cordia subcordata
Heliotropium procumbens var. depressum
Tournefortia argentea
Clerodendrum inerme
Physalis angulata
Morinda citrifolia
Scaevola sericea
Pluchea symphytifolia
Tridax procumbens

BIKINI ISLET

Bikini Islet is the largest islet on the Bikini Atoll Reef. It lies at the northeast corner of the atoll, oriented northwest-southeast, 2-1/2 miles long, one half mile wide at widest diameter along the Center Baseline Road. Its maximum area is 560 acres of which approximately 522 are vegetated. The terrain is essentially flat, with no natural elevation more than 10-12 feet above high tide level.

Prior to the first attempt at return of the Marshallese inhabitants, practically the entire island surface was planted with coconut palms, on a right angle square grid pattern, 30 feet apart. A few older palms remained from pre-test groves and are much taller than those of the 1969 plantings. At present most of the area is covered by this stand of young coconuts, but growth in height and spread of leaves, as well as survival, vary a great deal. The causes of this variation are mostly not apparent after our brief survey. Spontaneous vegetation is universally present between the palm trees, varying from thin grass and sedge ground-cover to dense scrub and spontaneous regeneration of coconut seedlings, this especially around the bases of the trees.

The same three principal map units in the coconut plantation are used here as on Eneu. The most conspicuous difference is that, on Bikini, Dodonaea, though usually present, seldom occurs as a dominant in the woody undergrowth. Tournefortia and Scaevola are the two principal components. Pandanus may generally be more common. Herbaceous ground cover here is locally of Fimbristylis, locally of Cassytha, more often of Lepturus, or, in more open areas a mixture of these with Eustachys and Cenchrus. In places the woody undergrowth has been cleared by dragging a heavy door after a tractor. This may well have resulted in interpretation of such areas as unit 2 rather than 1. On this islet extensive areas that must have been planted to coconuts are now almost lacking in palms and are mapped as unit 7. No reason is suggested for this.

Map units 4, 5 and 6 have not been recognized on Bikini Islet, except for a tiny bit of No. 6 on the middle seaward coast.

No. 7, mixed broadleaf forest, lacking coconuts, or almost so, is much more extensive on Bikini than Eneu. This may be because the attempted resettlement took place here. A considerable strip back of the houses was apparently not planted to coconuts, and this has been dominated by mixed scrub forest, classed as unit 7. Tournefortia and especially Scaevola, have become especially luxuriant here. Also there is an added component, tending to dominate some areas near the houses to the extent that it almost constitutes an additional map unit. This is Leucaena leucocephala, a tall shrub or slender tree with very fine feathery leaves. Its seedlings are extremely shade-tolerant, and it may eventually out-compete some or all the component species of unit 7, and perhaps others, too. It is said to have been brought by the resettled Bikinians as an ornamental. Generally unit 7, on Bikini, includes more Cordia and less Dodonaea than on Eneu.

Unit 8, tall grass and weeds, is very prevalent on Bikini, but not in areas large enough to map at the scale practical for this survey. It occurs especially along the principal road the length of the island, around houses and other buildings and in places bulldozed or cleared for any reason and left for even a short time. It is notable for the tall stature attained by weedy species ordinarily much smaller, such as Euphorbia glomerifera, Euphorbia hirta, Amaranthus dubius, Eustachys petraea, Phyllanthus amarus, Cenchrus echinatus, Portulaca oleracea, and Heliotropium procumbens var. depressum. This tendency is also apparent in some woody plants in other units. A locally abundant species in this unit, not seen on Eneu, is Paspalum setaceum, found in a grassy area at the southeast end of the main road, in the old camp site.

Unit 9, confined to the airstrip on Eneu, is not seen on Bikini.

Unit 10, the beach ridge scrub forest, is similar on both islets, and prevalent on both. Perhaps

Cordia is more abundant in it on Bikini. It occurs on beach-ridges around much of the periphery of the islet.

Unit 11 is added on Bikini Islet to accommodate the experimental gardens connected with the resettlement project, but the areas are too small to be very noticeable, except as openings in the prevailing coconut vegetation.

Plants observed growing without cultivation in 1985 were:

Pandanus tectorius
Cenchrus echinatus
Dactyloctenium aegyptium
Digitaria insularis
Digitaria setigera
Eleusine indica
Lepturus repens
Paspalum setaceum
Thuarea involuta
Fimbristylis cymosa
Cocos nucifera
Tacca leontopetaloides
Artocarpus altilis
Boerhavia albiflora
Pisonia grandis
Portulaca australis
Portulaca oleracea
Cassytha filiformis
Leucaena leucocephala
Suriana maritima
Euphorbia hirta
Euphorbia glomerifera
Phyllanthus amarus
Dodonaea viscosa
Triumfetta procumbens
Hibiscus (hybrid)
Sida fallax
Calophyllum inophyllum
Carica papaya
Terminalia samoensis
Polyscias guilfoylei
Ipomoea macrantha
Ipomoea pes-caprae
Cordia subcordata
Heliotropium procumbens var. depressum
Tournefortia argentea
Clerodendrum inerme
Vitex trifolia var. bicolor
Physalis angulata
Pseuderanthemum carruthersii var. atropurpureum
Guettarda speciosa
Morinda citrifolia
Scaevola sericea
Conyza canadensis
Tridax procumbens

Plants noted as growing only when tended by man:

Zea mays
Musa sapientum
Casuarina equisetifolia
Brassica petsai or B. pakchoi
Medicago sativa
Vigna marina
Citrus aurantifolia
Citrullus lanatus var. caffrorum
Cucurbita sp.
Terminalia catappa
Plumeria obtusa
Capsicum annuum
Solanum lycopersicum
Plumeria rubra
Ipomoea batatas

AEROKOJLOL ISLET

This is an elongate islet lying on the south reef of Bikini Atool. Its vegetation has been profoundly disturbed, as on a 1978 air photo there are distinct indications of an airstrip much overgrown.

The vegetation generally is a dense scrub or scrub-forest of Scaevola, Tournefortia, some Pandanus and Guettarda, tangled with Ipomoea macrantha. There is much dead wood, fairly generally in the parts examined. In the east end, inland, there is an area of coconut trees, around the traces of an old camp. This was not examined for vegetation.

In the extreme west end are areas of rather open Scaevola and Tournefortia with almost no herbaceous growth, except scattered Fimbristylis tufts. Fimbristylis is common along the tops of beaches, with a very few small Lepturus tufts. Suriana is occasional along the lagoon shore, Pemphis very rare, more inland. The substrate for both of these is sand or fine gravel.

Plants seen on Aerokojlol were:

- Lepturus repens
- Fimbristylis cymosa
- Cocos nucifera
- Suriana maritima
- Triumfetta procumbens
- Pemphis acidula
- Terminalia samoensis
- Ipomoea macrantha
- Cordia subcordata
- Tournefortia argentea
- Guettarda speciosa
- Scaevola sericea

BWIKOR ISLET

This is a small triangular islet on the north reef of Bikini Atoll. Its vegetation is rather simple. In 1978, when the available air photos were made, they showed an open stand of, probably, principally Tournefortia argentea tending to be closed, probably mostly Scaevola at the two lagoon corners and a patch of Scaevola (?) on the middle of the northeast side. An elongate very brackish pond lies parallel and somewhat inland from the lagoon shore. A massive exposure of fossil beach-rock caps the apex of the triangle. Probably some of the beach-ridge vegetation on the photo may be Scaevola.

In 1985, the vegetation is mostly closed and, for the most part, is dominated by Scaevola sericea, a stand 2-4 m tall on the beach ridges, lower, 1-2 m tall, and semi-open in the interior. The spaces between the Scaevola bushes is occupied by a loose to sparse mixture of graminoid herbs-- principally Fimbristylis and Lepturus. Boerhavia albiflora locally forms a ground-cover. Around the pond Pemphis acidula is common, with Fimbristylis, but with no vascular wet ground plants. In and around the edges of the pond is an abundance of blue-green algae and the green Cladophora. A school of a dozen or so large milk-fish (Chanos chanos) live in the pond, apparently well-nourished by the algae. Shrubs occasionally found in the predominantly Scaevola scrub are Guettarda, Pemphis, and very rare, Pandanus tectorius. Along the northeast beach-ridge are one or more Cordia, and the vines, Ipomoea macrantha and Ipomoea pes-caprae. The latter spreading down the broad beach from a dense ground-cover locally on the berm of the ridge.

The curious thing about this vegetation is that almost all of the Tournefortia are dead, emergent and bare from the Scaevola scrub. No explanation of this phenomenon is apparent. Some Scaevola plants, also, are dead, especially on the lagoon beach ridge.

Plants observed are:

- Pandanus tectorius
- Lepturus repens
- Fimbristylis cymosa
- Boerhavia albiflora
- Portulaca oleracea?
- Suriana maritima
- Triumfetta procumbens
- Pemphis acidula
- Ipomoea macrantha
- Ipomoea pes-caprae
- Cordia subcordata
- Tournefortia argentea
- Guettarda speciosa
- Scaevola sericea

ODRIK-LOMILEK-AOMEN ISLETS

This series of islets, connected with Bwikor, to the west, by a very long, scarcely vegetated sand spit, are connected by very well-vegetated sand isthmuses. These islets, likewise were sparsely vegetated as shown by the air photos in 1978. Now there is practically a solid stand of Scaevola scrub, 2-4 m tall with scattered Tournefortia emergents to 6-7 m., living and presumably healthy.

Around the small elongate pond are Suriana bushes. A few Pemphis are scattered in the scrub. Small openings are dominated by a luxuriant stand of Fimbristylis cymosa.

On the isthmus between Lomilik and Aomen and on the western part of Aomen are open meadows of Fimbristylis and Lepturus, mostly surrounded by Scaevola. On the 1978 air photos these areas seem to be without vegetation.

The Tournefortia on these islets seems, generally, healthy.

Plants observed were:

Lepturus repens
Fimbristylis cymosa
Cocos nucifera
Caesalpinia cf. bonduc or major (seedlings only)
Canavalia cf. sericea (seedlings only)
Suriana maritima
Pemphis acidula
Cordia subcordata
Tournefortia argentea
Scaevola sericea

NAM ISLET

Nam is one of the larger islets on Bikini Atoll Reef, located on the approximate northwest corner of the reef. Its western point was truncated by the "Bravo" hydrogen bomb blast in 1954.

The island surface is more or less flat, of coral sand and gravel with boulders of coral conglomerate scattered here and there in the interior and very numerous back of the west beach. These possibly may have been thrown inland by the blast.

The vegetation of the islet is essentially a scrub of Scaevola sericea, mostly very dense 10-15 feet high, the thick stems intricately tangled, with practically no herbaceous ground cover in the dense areas. In several areas, the east and south parts, this scrub is of lower stature and semi-open to open. Here and there is a patchy ground cover of Boerhavia and Lepturus. with some small areas of Portulaca lutea and Triumfetta. In these areas Ipomoea macrantha clambers over the shrubs locally. Cassytha, abundant on other large islets, is conspicuous by its complete absence on Nam, though Taylor reported it as present in 1946.

It is tempting to speculate that the peculiarities, such as dead vegetation on this and other islets, missing species, abnormally large stature, for examples, may be effects of radiation from the blast or fallout, but in absence of more than the most circumstantial evidence for such phenomena, I have refrained from such speculations except for one or two most obvious cases

There is little or no scrub forest on Nam, though in certain areas emergent Tournefortia is common enough to give the impression from a distance of scrub forest. There was formerly a little open scrub forest along the truncated west shore, but a belt of this from the beach ridge back a few tens of meters is now dead except for several partly dead Tournefortia and some young Scaevola just beginning. A few small Pisonia are present in the scrub-forest remnants back of this dead strip, also a few small trees of it southeast of the center of the islet.

These several variations are all merely aspects of the basic Scaevola scrub vegetation that characterizes most of the smaller islets of Bikini except the six small ones on the southwest reef which

are, for some reason, more lush and are notable for small Pisonia forests. On the map of Nam (not reproduced here) these variants are designated as follows:

a. Dense Scaevola scrub 10-15 feet high, little else.
b. Scaevola more open, lower stature, some herbaceous ground cover.
c. Dense Scaveola with emergent Tournefortia in some numbers.
d. Dead Tournefortia and Scaevola, with live Boerhavia and Portulaca

The total flora observed on Nam during this survey is listed below:

Lepturus repens
Fimbristylis cymosa
Cocos nucifera (one small tree only seen well inland)
Boerhavia albiflora
Boerhavia "repens"
Boerhavia tetrandra
Tournefortia argentea
Pisonia grandis
Portulaca lutea
Portulaca oleracea ?
Triumfetta procumbens
Ipomoea macrantha
Ipomoea pes-capre (seedling only seen well inland)
Cordia subcordata
Guettarda speciosa
Scaevola sericea

BOKAETOKTOK ISLET

This is the second tiny islet from the northwest on the southwest reef of Bikini Atoll. It is about 120 m long, rather egg-shaped with the largest end to the northwest. It has the reputation of being one of the least disturbed of Bikini islets, but this only means that no serious clearing or bulldozing has taken place since the testing ceased. There are great iron chains, scattered in the interior and at both ends. What these were for is not evident, but only gigantic machinery could have put them there. The forest here appears to be relatively young, probably post-bomb-test.

The island is well vegetated, the broader northwest end and down the middle are covered by a forest of Pisonia grandis, a broad-leafed soft-wood tree that elsewhere reaches enormous size. Those on Bokaetoktok are all less than 10 inches thick and no more than 30 feet tall. They form a rather complete canopy over about 3/4 of the island.

Nothing is known of the growth rates of Pisonia or other coral island trees, but it seems safe to state that the present vegetation has grown up since testing was stopped in 1958. The characteristic layer of raw-humus in Pisonia forest has not formed to anything like its normal depth of a few inches, nor has much phosphate rock developed as might be expected.

The south, southeast and east coasts are lined by a wide zone of open to semi-open scrub vegetation of Scaevola and Tournefortia. In the openings in this are stands of Portulaca lutea, Lepturus repens, and Boerhavia. principally B. albiflora. The beach ridge on the east or lagoon coast has good sized trees, mostly Tournefortia and Pisonia, with Scaevola shrubs. Several Guettarda and Cordia trees are found on this coast.

The vegetation here is simple, indeed. Only the following species were found during our visit:

Lepturus repens
Boerhavia albiflora
Boerhavia repens
Pisonia grandis
Portulaca lutea
Cordia subcordata
Tournefortia argentea
Guettarda speciosa
Morinda citrifolia
Scaevola sericea

OROKEN

This is the third of the small islets on the southwest reef, somewhat larger than Bokaetoktok. It likewise seems to have vegetation probably not much over 25 years old, and to have been disturbed before that.

Now about 3/4 or more of the surface is covered by a fine forest of Pisonia grandis with an "A" soil-horizon of raw humus not nearly as thick as in a mature Pisonia grove. The canopy of this forest is complete, possibly reaching 40 feet, with tree-trunks up to a foot in diameter. There is no undergrowth, which is typical of Pisonia forest, and the ground is strewn with large angular cobbles and boulders, many of which are of typical brown, white-speckled phosphate rock. This is a sure indication of an earlier mature Pisonia forest. The north corner and the east end and southeast coast of the islet are covered by an open scrub or scrub forest of Tournefortia, mixed with some Pisonia, but almost no Scaevola. The openings in this are occupied by almost pure stands of a rather low form of Portulaca lutea, with some mats of Boerhavia, possibly B. repens or an unusual form of B. tetrandra, with a little B. albiflora. The beach ridge on the east and part of the north sides is covered by a good stand of Lepturus repens. On the southwest side is a very small patch of Scaevola scrub, with a Guettarda shrub and several Morinda citrifolia shrubs or small trees.

Again, this islet has very simple vegetation. The following species were present:

Lepturus repens	Portulaca lutea
Laportea ruderalis	Tournefortia argentia
Boerhavia albiflora	Guettarda speciosa
Boerhavia repens	Morinda citrifolia
Pisonia grandis	Scaevola sericea

TABLE 1:COMBINED LIST OF VASCULAR PLANT SPECIES:
(See Notes at end of list)

Pandanaceae

Pandanus tectorius Parkinson (I & A)
Both the edible-fruited and the small-fruited "wild" forms are present.
Bikini I; Eneu I. (T); (Lomilik-T); Bwikor I.

Poaceae

Cenchrus echinatus L. (X)
Bikini I.(T); Eneu I.

Chloris inflata Link (X)
(Bikini I.-T)

Dactyloctenium aegyptium (L.) Beauv. (X)
Bikini I.; Eneu I.

Digitaria insularis (L.) Mez (X)
Tricachne insularis (L) Nees
Bikini I. (T.).

Digitaria setigera Roth (I)
Digitaria microbachne (Presl) Henr.
Bikini I. (T)

Eleusine indica (L.) Gaertn. (X)
Bikini I.

Eustachys petraea (Sw.) Desr. (X)
Bikini I.; Enue I.

Lepturus repens (Forst. f.) R. Br. (I)
Bikini I. (T); (Bokonjebl I. T); (Nam I T); Bokontuak I T); (Jalete I. (T); Oroken I. T; (Enidrik I. T); Aerokojlol I.; Eneu I.

Paspalum setaceum Michx. (X)
Bikini I.

Thuarea involuta (Forst f.) R. Br. (I)
Bikini I. (T)

Cyperaceae

Fimbristylis cymosa R. Br. (I)
Bikini I. (T); Eneu I.; Aerokojlol I.

Arecaceae

Cocos nucifera L. (A)
Bikini I. (T); Eneu I. (T); (Bokonjebl I. T); Aerokojlol I. Nam I.; Lomilik I.; Aomen I.

Liliaceae (s. l.)

Crinum asiaticum L. (A)
(Bikini I. T)

Taccaceae

Tacca leontopetaloides (L.) 0. Ktze. (A? or I)
Bikini I. (T); (Eneu I. T); (Nam I. T)

Moraceae

Artocarpus altilis (Park.) Fosb. (A)
Bikini I. (T).

Urticaceae

Laportea ruderalis (Forst. f.) Chew (I)
Oroken I.

Amaranthaceae

Achyranthes canescens R. Br. (I)
(Enidrik I. T)

Nyctaginaceae

Boerhavia albiflora Fosberg (I)
Bikini I. (T); (Enidrik I. B); Nam I. (T); Bwikor I.; Bokaetoktok I.; Oroken I.

Boerhavia tetrandra Forst. f. (I)
Eneu I.; (Aerokojlol I. T); (Enidrik I. T); (Lukoj I. T); (Jalete I. T); (Oroken I. T); Nam I. T.

Boerhavia repens L. (I)
Oroken I.; Bokaetoktok I.

Pisonia grandis R. Br. (I)
Bikini I. (T); Eneu I. (T); Oroken I.; Bokaetoktok I.; (Bokdrolul I. B)

Portulacaceae

Portulaca australis Endl. (I)
Portulaca quadrifida sensu Taylor
Bikini I.; Eneu I.; (Nam I. T); (Lomilik I. T).

Portulaca lutea Sol. ex Forst. f. (I)
(Bikini I. T); Eneu I.; Oroken I. (T); Bokaetoktok I.; Nam I.; (T).

Portulaca oleracea L. (X)
Bikini I. (T); Aerokojlol I.; (Bokdrolul I. B); Bwikor I.?

Lauraceae

Cassytha filiformis L. (I)
Bikini I. (T); (Rojkora I. T); Eneu I. (T); (Aerokojlol I. T); (Enidrik I. T); (Nam 1. T); (Bokdrolul I. B)

Hernandiaceae

Hernandia sonora L. (I)
Hernandia ovigera sensu Taylor
(Bikini I. T).

Fabaceae

Caesalpinia sp. (prob. C. bonduc (L.) Roxb. or C. major (Medic.) Dandy & Exell (I)
(Bikini I. T); Odrik I. (seedlings only).

Canavalia cf. sericea A. gray (I)
Lomilik I. (seedling only)

Delonix regia (Bojer) Raf. (X)
Bikini I. (planted only)

Leucaena leucocephala (Lam.) de Wit (X)

Bikini I.

Sophora tomentosa L. (I)
(Bikini I. T)

Surianaceae

Suriana maritima L. (I)
Bikini I. B; (Bokantuak I. T); (Enaelo I. T); (Bokonjebl I. T); Eneu I. B; (Aerokojlol I. T); (Enidrik B); (Oroken B); (Bokdrolul I. B); (Nam T)

Simarubaceae

Soulamea amara Lam. (I)
(Eneu I. T); (Nam I. T).

Euphorbiaceae

Euphorbia hirta L. (X)
Bikini I.; Eneu I.

Euphorbia glomerifera (Millsp.) Wheeler (X)
Bikini I.; Eneu I.

Euphorbia rubicunda Bl. (X)
Eneu I.

Phyllanthus amarus Schum. (X)
Bikini I.; Eneu I.

Sapindaceae

Dodonaea viscosa L. (I)
Bikini I.; Eneu I.

Tiliaceae

Triumfetta procumbens Forst. f. (I)
Bikini I. B; (Bokonjebl I. T); Eneu I. (T); Aerokojlol I. (T); (Enidrik I. T); (Bokondrolul I. B); Nam I. (T); Bwikor I.; Odrik I.

Malvaceae

Hibiscus (hybrid) (X)
Bikini I. (planted)

Hibiscus tiliaceus L. (I?)
(Bikini I. T)

Sida fallax Walp. (I)
Bikini I. (T); Eneu I.; (Nam I. T).

Clusiaceae

Calophyllum inophyllum L. (I)
Bikini I.; Eneu I.

Caricaceae

Carica papaya L. (X)
Bikini I. (T)

Lythraceae

Pemphis acidula Forst. (I)
(Bokonjebl I. T); Aerokojlol I.; (Enidrik I., T, B); (Jalete B); Bwikor I.; Odrik I.

Rhizophoraceae

Bruguiera gymnorhiza Lam. (A)
Bruguiera conjugata sensu Taylor
(Bikini I. T).

Combretaceae

Terminalia samoensis Rech. (I)
Terminalia litoralis sensu Taylor
Bikini I. (T); (Enaelo I. T); Eneu I. (T); Aerokojlol I; (Enidrik I. (B)); (Lomilik I. T).

Araliaceae

Polyscias guilfoylei (Bull) Bailey (X)
Bikini I. (planted)

Apocynaceae

Neisosperma oppositifolia (Lam.) Fosb. & Sachet (I)
Ochrosia parviflora sensu Taylor
(Bikini I. T); (Eneu I. T).

Convolvulaceae

Ipomoea macrantha R & S (I)
Ipomoea alba sensu Taylor
Bikini I. (T); Eneu I. (T); Aerokojlol I.; (Enidrik I. T); (Jalete I. T); Nam I. (T); Bwikor I.

Ipomoea pes-caprae L. ssp. brasiliensis (L.) van Ooststr. (I)
Bikini I.; Eneu I.; Nam I.; Bwikor I.

Boraginaceae

Cordia subcordata Lam. (I)
Bikini I. (T); Eneu I.; (Aerokojlol I. T); (Nam I. (T); Bwikor I.

Heliotropium procumbens var. depressum (C. & S.) Fosberg (X)
Bikini I.; Eneu I.

Tournefortia argentea L.f. (I)
Bikini I. (B); (Bokantuak I. (T); (Enaelo I. T); Eneu I. B; Aerokojlol I. (T); (Enidrik I. T); Oroken (T); Bokaetoktok I.; (Bokdrolul I. B); Nam I. (T); Bwikor I.; Odrik I.; Lomilik I.; Aomen I.

Verbenaceae

Clerodendrum inerme (L.) Gaertn. (I)
Bikini I., Eneu I.

Vitex trifolia var. bicolor (Willd.) Moldenke (X)
Bikini I.

Solanaceae

Physalis angulata L. (X)
Bikini I.; Eneu I.

Acanthaceae

Pseuderanthemum carruthersii var. atropurpureum (Bull) Fosb. (X)
Bikini I.

Rubiaceae

Guettarda speciosa L. (I)
Bikini I. (B); (Bokantuak I. T); (Enaelo I. T); (Bokonjebl I. T); Eneu I. (T): Aerokojlol I. (T); (Enidrik I. T (B)); Oroken (T); Bokaetoktok I.; (Bokdrolul I. (B)); Nam I. (T); Bwikor I.

Morinda citrifolia L. (I?)
Bikini I. (T); Eneu I. (T); (Jalete I. T); Oroken I.; Bokaetoktok I.; (Nam I. T).

Goodeniaceae

Scaevola sericea Vahl (I)
Scaevola frutescens sensu Taylor
Bikini I. B; (Bokantuak I. T); (Enaelo I. T); (Bokonjebl I. T); Eneu I. (T); Aerokojlol I. (T); (Enidrik I. T); Oroken I. (T); Bokaetoktok I.; (Bokodrolul I. B); Nam I. (T): Bwikor I.; Odrik I.; Lomilik I.; Aomen I.

Asteraceae

Conyza canadensis (L.) Cronq. (X)
Bikini I.

Pluchea symphytifolia (Mill.) Gillis (X)
Eneu I.

Tridax procumbens L. (X)
Bikini I.; Eneu I.

Notes on the combined list:

T means reported by Taylor, if in ( ) with an islet name, found by him but not by present survey on that islet. If in ( ) following an islet name, found on that islet by both surveys.

B means reported by Bogusch, a plant physiologist with the 1949 Applied Fisheries Laboratory Survey.

The islet names have been brought into accord with those used by the BARC and the Lawrence-Livermore projects.

The plant names have been brought into accord with those accepted by Fosberg, Sachet and Oliver (1979, 1981 and in press), and several corrected further in accord with recent changes in identities and nomenclature.

Following each species name in the list is a letter in ( ) as follows:

[(E) means endemic to the Marshall Islands - none of the species found or reported are so marked, as none are endemic.]

(I) means indigenous to the Marshalls but not endemic.

(A) means suspected to have been introduced in pre-European time by the Marshallese people.

(X) means introduced by man in post-European contact time.

No plants are known to have been collected or reported from Bikini prior to 1946, though Kanehira or other Japanese botanists may have collected some and not published the records. In 1946, during the "Crossroads Survey" initiated by Lt. Cdr. Dr. Roger Revelle, Prof. Wm. Randolph Taylor, of the Botany Dept., University of Michigan, made a large collection on Bikini and several other atolls in the northern Marshall Islands. Many of these were algae, Prof. Taylor's specialty. In his book, Plants of Bikini (1950), he reported 39 species of vascular plants from Bikini Atoll, and briefly described the land vegetation. Of the species reported by Taylor, nine were on none of the islets visited by us. Two of the nine missing species were exotics, the rest probably native. 24 species not reported by Taylor were collected on the present survey. Of these six are indigenous, the remaining 18 are exotics. Not included in the list are a number of species only growing under present cultivation by man, most of them in the experimental gardens planted and cared for by the rehabilitation personnel (Lawrence Livermore laboratory). Cultivated species planted by the Marshallese and still persisting are included in the list. Of the total present spontaneous flora (56 species), 26 are native; 5 are of aboriginal introduction and 25 exotic. One of the 28 (Tacca) is doubtfully native. Two others, (Caesalpinia and Canavalia) were seen as beach drift seedlings only.

Not much can be concluded from these figures except that the high proportion of exotics indicates the obvious fact that there has been much human influence. The low total number of species, present and reported earlier, indicates a rigorous, unfavorable environment, with little diversity. The carrying capacity for people is likely to be low, though marine resources may partly offset scarcity due to unfavorable conditions for locally produced food plants, and to accumulation of radioactivity making the plants unfit to eat.

The species in parentheses in Tables 5 and 6 were not found by the present survey. The one in brackets may be of aboriginal introduction, as are at least three of the exotics, Cocos, Crinum and Artocarpus.

TABLE 2: Species reported by Taylor not found on this survey.

Chloris inflata	Soulamea amara
Crinum asiaticum	Hibiscus tiliaceus
Achyranthes canescens	Bruguiera gymnorhiza
Hernandia sonora	Neisosperma oppositifolia
Sophora tomentosa	

TABLE 3: Species found on this survey not reported by Taylor.

Dactyloctenium aegyptium	Dodonaea viscosa
Eleusine indica	Hibiscus (hybrid)
Eustachys petraea	Calophyllum inophyllum
Paspalum setaceum	Polyscias guilfoylei
Laportea ruderalis	Ipomoea pes-caprae
Boerhavia repens	Heliotropium procumbens
Canavalia sericea	Physalis angulata
Delonix regia	Clerodendrum inerme
Leucaena leucocephala	Pseuderanthemum carruthersii
Euphorbia hirta	Conyza canadensis
Euphorbia glomerifera	Pluchea symphytifolia
Euphorbia rubicunda	Tridax procumbens
Phyllanthus amarus	

TABLE 4:Species found on both surveys

Cenchrus echinatus	Caesalpinia sp.
Digitaria insularis	Suriana maritima
Lepturus repens	Triumfetta procumbens
Thuarea involuta	Sida fallax
Fimbristylis cymosa	Carica papaya
Cocos nucifera	Pemphis acidula
Tacca leontopetaloides	Terminalia samoensis
Artocarpus altilis	Ipomoea macrantha
Boerhavia albiflora	Cordia subcordata
Boerhavia tetrandra	Tournefortia argentea
Pisonia grandis	Guettarda speciosa
Portulaca australis	Morinda citrifolia
Portulaca lutea	Scaevola sericea
Portulaca oleracea	
Cassytha filiformis	

TABLE 5:Indigenous Species

Pandanus tectorius	Canavalia sericea
Digitaria setigera	(Soulamea amara)
Lepturus repens	Dodonaea viscosa
Thuarea involuta	Triumfetta procumbens
Fimbristylis cymosa	(Hibiscus tiliaceus)
[Tacca leontopetaloides]	Sida fallax
Laportia ruderalis	Calophyllum inophyllum
(Achyranthes canescens)	Pemphis acidula
Boerhavia albiflora	(Bruguiera gymnorhiza)
Boerhavia tetrandra	Terminalia samoensis
Boerhavia repens	(Nesiosperma oppositifolia)
Pisonia grandis	Ipomoea macrantha

Portulaca australis	Ipomoea pes-capre
Poerulaca lutea	Cordia subcordata
Cassytha filiformis	Clerodendrum inerme
(Hernandia sonora)	Guettarda speciosa
Caesalpinia sp.	Morinda citrifolia
Scaevola sericea	

TABLE 6 Exotic Species

Cenchrus echinatus	Euphorbia glomerifera
(Chloris inflata)	Euphorbia rubicunda
Dactyloctenium aegyptium	Phyllanthus amarus
Digitaria insularis	Hibiscus (hybrid)
Eleusine indica	Carica papaya
Eustachys petraea	Polyscias guilfoylei
Paspalum setaceum	Heliotropium procumbens
Cocos nucifera	Physalis angulata
(Crinum asiaticum)	Vitex trifolia
Artocarpus altilis	Pseuderanthemum carruthersil
Portulaca oleracea	Canyza canadensis
Delonix regia	Pluchea symphytifolia
Leucaena leucocephala	Tridax procumbens
Euphorbia hirta	

DISCUSSION:

This section is arranged roughly in accord with the outline in the "Scope of Work...." document provided.

(a) The requirement for baseline information was carried out to the extent that time permitted. Remarks on successional status, based on short term reconnaissance, must be regarded as tentative indeed. Some such remarks are offered in (h) below, but are based largely on previous experience on other atolls, none of which had been exposed to the treatment afforded Bikini. Such ideas on succession may, therefore, be accepted as "educated guessing." The "plant communities" described are more in the nature of mappable units of vegetation, or cover types, than technically determined plant communities, but are what could be recognized in the time allotted.

(b) The checklist of species is reasonably complete, with names brought up to date. Marshallese names are not included, since no Bikinian informants were available. The designations of Indigenous, of Aboriginal introduction, or Exotic, have some queries, as there is considerable doubt as to the status of some of the species.

(c) To the best of my knowledge, no species on Bikini are endangered, or likely to be considered so, or even threatened, as all are widespread, mostly strand plants or exotics, as is usually the case with low coral island floras. These atoll floras are mostly too young to have evolved any local species or well-marked varieties.

Several species, such as Terminalia samoensis. Neisosperma oppositifolia and Soulamea amara (the last two not seen on this survey) may be considered rare enough on Bikini to merit special protection, in order to preserve the indigenous diversity, and as possible habitats for rare insects. One tree of the Terminalia was located on the second Baseline Road about 50 yards in from the seaward shore. Another, not seen by me, was found along the south part of the air-strip on Eneu, by Dr. Robison.

(d) Plants and Vegetation types of such significance as to merit special protection: the abundance of Cordia subcordata (Marshallese - kono) on Bikini Islet, also, but less so on Eneu, suggests that given time for the trees to mature, an important resource of fine wood for carving and other uses for high-grade timber is present in this species. Some of the trees are already of good size. This species is not likely to produce long saw-logs, as it tends to send out branches near the ground. Hence its primary use is for carving. However, this tendency may be lessened by permitting the trees to remain in rather close stands until they reach a good height. We know of no silvacultural standards for this species, but some will surely be developed if a demand for its wood is encouraged. This is one useful plant the use of which will not be prevented by any accumulation of radioactivity, as the plant is not eaten.

I would suggest protection of the two small stands of Pisonia and Pisonia with Cordia centrally located on Eneu Islet. Pisonia does not produce useful wood, but is a favorite nesting tree for black noddy and fairy terns. There are also undoubtedly other organisms dependent on it. It is an irreplaceable part of the process leading to formation of atoll phosphate rock. This is not, of course, a short term benefit, but phosphate will be important to any culture dependent on plants, as far as we can see in the future.

The Pisonia forests on Bokaetoktok and Oroken islets, and perhaps on the other islets on the southwest reef, should also be protected, for the same reasons given above. They are even now the homes of the largest sea-bird populations on the atoll. They are also functioning examples of a fascinating ecological or eco-geological process - the formation of atoll phosphate rock. This phenomenon was described in two published papers some years back (Fosberg 1954, 1957). This formation has since been found to have occurred on coral islands throughout the Indo-Pacific region, as far west as the islands off the east coast of Africa. However, there are almost no intact Pisonia forests left in that entire region. The few tiny ones on these southwest islets may soon be the only examples of the process of formation of atoll phosphate rock left in the world. I elaborated the formation of atoll phosphate rock back in the 1950's but it has never been studied in detail. There are few diagenetic processes that can be studied and followed to completion in one person's lifetime, but this is one, hence it is of great interest.

The large stands of Dodonaea viscosa are of botanical and may be of potential practical, interest. The wood of the Hawaiian relatives (aalii) of this species produce an extremely hard wood, used in lieu of metal by the ancient Hawaiians. The trees of this species on Bikini, and especially Eneu islets reach an unusually large size and some use may well be developed for the wood of these trees.

Finally, attention should be directed to the vegetation of the beach ridges on the islets, especially the large ones. Salt spray is one of the limiting factors to horticultural and plantation productivity on coral islands. Many useful plants can only be grown on these low islands if protected by windbreaks. This beach-ridge vegetation is a very effective natural windbreak, as the Marshallese on many other atolls very well know.

The coconut plantations on Ailuk, for example have crescent-shaped bands of tree and shrub vegetation protecting the windward sides of the islets that have plantations, markedly increasing their productivity. This protection also makes taro-pits more successful and enables other plants than taro to be grown in these pits. If the Bikinians are ever to be even partly self-sufficient they will have to depend on crop plants that can stand a little salt, but that produce much better crops if protected from spray-bearing winds.

These wind-breaks also afford protection to people and structures against at least moderate storms.

(e) The principal technique to encourage plant growth on these islets is that described above in (d), of protecting and encouraging the beach-ridge vegetation to serve as wind-breaks around the periphery of the islets. If additional wind-breaks are needed in the interior parts of the islets, we can suggest rows of Casuarina equisetifolia, augmented by lower growing dense shrubs such as Suriana, Pemphis, and Scaevola, all salt-resistant and adapted to this habitat.

On open sand or compacted coral a dark greenish or blackish gelatinous blue-green alga often grows in profusion after rains. As this begins to dry it may be raked up and spread around garden plants and worked into the soil. This alga, Nostoc commune is known to be a nitrogen-fixer, and will improve the chemical and the physical properties of the soil. Fertilizers are mostly expensive, but here is one that may be had for the gathering.

Another plant that will improve the nitrogen content of the soil is the beach pea, Vigna marina. This is an atoll plant, but we did not find it on Bikini. However, it might get a start there if seeds from other islands were sown during a rainy season. I have seen it on islands that must be as dry as Bikini.

It is difficult to suggest plants to be brought in without knowing what is the particular purpose to be served. Indiscriminate introduction may be a detriment rather than a benefit. The introduction of the salt-grass, Paspalum dislichum for example, while it may have served as a soil stabilizer, was a disaster to taro culture on Likiep Atoll in 1950.

If the unlikely (to me) project of removal of the top layers of soil is carried out, I would suggest encouraging the native Lepturus repens, Boerhavia albifiora, and Fimbristylis cymosa to cover and stabilize the raw surfaces. Vigna marina would also serve this purpose if it can be made to grow under those conditions. Leucaena and Tournefortia will in all probability come in of their own accord and provide a woody cover, if that is desired.

A suggestion that may already have been considered would be to remove the vegetation from Bikini islet, take it to a reef flat or small islet where contamination would not be a problem and burn it or let it rot. If there are radionuclides accumulated, such as radio-cesium, this would remove whatever was there, especially if done several times, and it would be cheaper and less damaging than removal of soil. For simple vegetation, such as covering surfaces exposed by soil-removal, or vegetation removal, rather than bringing in new exotic plants, the effects of which are uncertain, I would suggest encouraging plants already present, as can be readily seen on disturbed or bull-dozed areas, roadsides, experimental garden plots, etc. Both weeds, such as Eustachys, Euphorbia spp., Cenchrus, Heliotropium, Paspalum, Cynodon, etc. and native pioneer species, such as Lepturus, Scaevola, Tournefortia, Dodonaea, Cordia, Fimbristylis, and Guettarda seem to do very well on such bare habitats, even with no help. Most of them could perhaps be encouraged by simply gathering their fruits and fruiting inflorescences and scattering them on the bare ground, especially during rainy periods. Light fertilizer applications, emphasizing minor and trace nutrients, would probably help. If additional woody species are desired, Casuarina and Leucaena are species already present that grow well, though Leucaena, especially, may be hard to get rid of when it is no longer wanted.

My suggestion of an approach to decontamination by repeatedly removing the vegetation with its accumulated load of Ce 137 has apparently been considered and rejected because it would take too long. I think there is still room for further discussion of this method, and consider it further on below.

(f) Perhaps the best way to minimize adverse effects on vegetation would be to discourage indiscriminate bulldozing as the solution to all problems. Avoiding burning of trash, dried-up weeds, coconut leaves and husks would be another way. Planning so that new construction would be done on already disturbed and denuded areas rather than simply clearing a new place would make a great difference, if encouragement to vegetation is desirable. Usually no consideration at all is given to preserving the landscape, even on coral islands, where vegetation has practical as well as aesthetic

benefits.

(g) The simple, quantitative effects of previous nuclear testing, construction, and resettlement activities on vegetation have perhaps been minimal. The islands are all practically completely vegetated at present, except for places where disturbance has been very recent - roads, airstrip, experimental plots, etc. The total biomass may be as great or greater than at the time when the people were first removed.

One very curious phenomenon was observed on the largest islets that could conceivably be due to some of the human activities, though I have no suggestion as to its possible cause. This was the fact that many, but not all, of the species present, seem to attain a much greater stature than commonly observed elsewhere for the same species. Clearly some factor in the environment is very favorable. Why it does not affect all the species is also a mystery.

Most of the apparent effects of the listed human activities are changes in the character of the vegetation. A few species previously present are now missing or at least so rare as not to be noticed on the present survey (see Table 2). Others are more abundant than they would probably have been (e.g. Dodonaea). Many new exotics are now present. Some of these (e.g. Eustachys) are very abundant.

Much of the present vegetation is in earlier stages in succession than before. The large areas of Scaevola and Tournefortia scrub and scrub-forest are undoubtedly the result of destruction of previous vegetation and exposure of areas of open ground. Most of the coconut plantations were destroyed, or nearly so. They have not been replanted on most of the islets, especially the smaller ones. On the two largest islets, almost all of the coconut palms are young, from the replanting in mid- and late-sixties. Hence their stature is mostly less than 8-10 m. Because of lack of tending, the undergrowth between the trees in the better habitats is very rank. Because of lack of harvesting, seedling coconut palms form practically impenetrable tangles in some areas.

One of the conspicuous effects of man's activities on the larger islets is the lack of any logical patterns to the distribution of vegetation types in relation to obvious habitat zonations. The extreme disturbance - construction, bulldozing, and the bomb blasts - has confused the distribution and abundance of species so that it is most difficult to understand or predict the development of the vegetation. Even the soil patterns, normally comparatively simple on coral atolls, are here confused, and frequently not what would be expected, given the topographic character and vegetation of a place.

Most noticeable, perhaps, of all human effects is the abundance and composition of the exotic, or weed vegetation. On no other atoll have I ever seen Eustachys dominant in any vegetation type. Leucaena is not ordinarily an important component of atoll vegetation, but here it is locally abundant, even dominant. Several weedy Euphorbia species are unusually abundant.

(h) While vegetational succession on coral atolls is, in my opinion, simpler and with fewer stages than are usual on higher islands and in most continental situations, it has been little studied and is not at all well-understood. It is even difficult to say what constitutes a climax in these often extreme environments and in vegetation comprising so few species.

On moderately dry atolls, such as Bikini, the Pisonia grandis forest has the appearance of climax, but there are a few observations of spots where it seems to be giving way to either a mixture of species or to what will eventually be a pure stand of Neisosperma (formerly Ochrosia oppositifolia). If a floating fruit of this species is thrown by a storm over the beach ridge, into a mixed or a Pisonia forest, and germinates, it seems probable that, given time, a Neisosperma forest will replace whatever is there. However, such a fortuitous occurrence may never happen in a particular place. So, what is the climax? In a single-species forest, a single event may initiate profound change.

It would seem probable that rates of change of at least the earlier stages in atoll vegetation could be determined, within limits, by dating the ages of particular stands from known dates of the last typhoons that had denuded the particular islets concerned. However, no one has ever bothered to make the necessary observations and calculations to do this. Hence, even in such favorable situations we have no basis for estimating rates or predicting stages.

On Bikini there is at least one datable event - the bomb-testing that is datable down to a 12-year period, and, perhaps in the cases of islets denuded by the Castle-Bravo Shots, to a single point in time. Unfortunately, no one seems to have placed on available record what happened to particular islets, except those that disappeared altogether.

Many of the smaller islets at present have a young pioneer vegetation of Scaevola and Tournefortia shrubs. There is little or no indication of older trees. This may be an indication that these islets were denuded during the tests. If so, we have a rough idea of how long it takes for a Scaevola-Tournefortia scrub to develop on a denuded coral limestone substrate. It is reasonably certain that the subsequent changes in this vegetation will take much longer than the time elapsed to date, but there is no way to estimate how long. It is not even certain that the Scaevola-Tournefortia will give way to a different stage, but likely the ultimate vegetation, in ordinary human time-frames will be a mixed forest formed by a gradual invasion of tree species that in their seedling and sapling stages are more shade tolerant than are the two present dominants, Scaevola and Tournefortia.

The tiny islets on the southwest reef are commonly spoken of as relatively undisturbed. They do give this impression. However, closer examination shows evidence of profound disturbance. Fragments of an enormous iron chain on Bokaetoktok could not have been placed in the interior of the island except by enormous heavy machinery or a close-by nuclear blast. Study of an apparently intact Pisonia forest on Oroken Islet showed that the tree trunks are no more than 20-30 cm diameter. A mature forest of this type has enormous trunks a meter or more in diameter. My guess is that these fast-growing soft-wood trees might reach 20-30 cm in 25 or so years, suggesting that these islets may have been completely denuded during the tests and that these forests are really young. In pioneer vegetation like this, succession can be compressed to one or two stages, depending on initial floristic composition. If Pisonia fruits were present in quantity it is quite conceivable that a mature-looking Pisonia forest could develop in 25 years. In any event, these islets are of sufficient interest to warrant their protection in their present "undisturbed" state (see(d)).

However, it must be reemphasized that any statement of rates of succession in atoll vegetation is little more than guessing.

Summary of impacts of previous perturbations:

Up to 1946, the human impacts on the Bikini vegetation were mainly those resulting from subsistence agriculture and commercial copra plantations. This produced the palm-dominated landscape of the popular picture of the South Sea coral island. Only on very small islets and the windward exposures of the plantation islets with their natural windbreaks, was there any significant natural vegetation. From 1946 on, the combined impacts of "construction, nuclear testing, cleanup, resettlement, and human occupation of Bikini Atoll" has changed this landscape and obscured any environmentally related pattern that had survived, or resulted from the activities of the Marshallese, especially on the larger islets. These changes are mostly only inferred, as no records exist, or at least none have been made available to me, of what the vegetation landscape was like at any stage of these mega-perturbations.

It is probable that a short grassy stage occurred at first, but equally likely that, except on very unfavorable spots, woody vegetation Scaevola and Tournefortia scrub - soon replaced the grass. For a

decade or so this was allowed to develop with little disturbance. Then, in mid to late 1960's, the two largest islets were completely replanted to coconuts. It is probable that to facilitate this, the woody vegetation was removed, probably by bulldozing.

Regrowth of herbaceous and woody vegetation undoubtedly ensued, until the Bikinians were brought back. They may likely have kept this regrowth more or less under control, at least after the coconut trees began to reach bearing age. I have seen no records of this entire period. After the people were removed again, the regrowth in the plantations tended to outstrip or at least equal the growth of the coconut palms. After the trees began bearing, and the nuts went unharvested, thickets of seedling coconut trees were added to the regrowth, especially around the bases of the bearing trees.

The land around and back of the row of houses along the lagoon shore of Bikini Islet was either never planted to coconuts or was almost completely cleared by the Marshallese. It is now densely covered by broad-leaf scrub forest. At some period, roads were bulldozed across the islet at intervals, and also some lengthwise ones. Some of the roads were kept clear of vegetation, others were overgrown and may be indistinguishable from the undergrowth vegetation in the plantations.

Since the Lawrence-Livermore project was started, some areas were cleared as experimental plots. Some areas of plantation were dragged clear of undergrowth. The result of all of these perturbations, the present vegetation on the two largest islets, is a mosaic of cover types and intermediate or transitions between cover types that defies understanding. These cover-types, in a broad way, probably reflect differences in soil fertility, and especially of intensity of salt spray and ground-water salinity, but continued disturbance obscures these differences.

Probable impact of future clean-up and re-settlement programs:

The plans for "cleanup" that I am aware of are: (1) Removal and disposal of upper 40 cm of soil and (1a) simply leaving the bare subsoil surface to develop a new profile, (1b) replacing it with a layer of soil brought from an uncontaminated area elsewhere or (1c) plant and fertilize to develop new profile. (2) Heavily fertilize with high potassium chemical additives, to lessen the uptake by plants of radio-cesium. (3) Irrigate heavily with sea-water to wash the radioactive isotopes down into the ground water and flush them out into the sea. To these three I would add a fourth, which may or may not have been considered - the repeated removal of accumulated radioactive isotopes to where they will not recontaminate the areas to be utilized. (I do not regard any of these as very practical, 1, 3, and 4 because of expense, 2 because it leaves the contamination in the soil, to be picked up in food plants after the U.S. or the Bikinians get tired of the continued expense for fertilization.) Practicality of No. 4 would depend on finding out how much accumulation takes place in the vegetative biomass.

The idea of decontamination by repeated removals of vegetation has apparently been discussed and rejected (see BARC Interim report p. 31 and BARC Report #1, p. 31). Whether or not such rejection is justified would depend very much on information that I do not have. I am informed that calculations have been made that suggest that 200,000 metric tons of green biomass would have to be removed over a period of several or more croppings of vegetation. I have no information either on the amount of biomass in the present standing crop of natural and exotic vegetation or on how much biomass is produced by a year's growth. Nor it it known to me whether all species of plants accumulate Ce 137 at the same rate, nor what the annual production of biomass is for each important plant species. All plants are not equal in these qualities, I am sure. It might be worth while to do some experimenting on these two processes. The effects on Ce 137 accumulation of fertilizing with a K-deficient fertilizer to determine if the Ce 137 accumulation can be speeded up or augmented. Determination of which plants would be the most effective and what their capabilities in biomass production and Ce 137 accumulation are under different conditions might be worth doing since as much as $50,000,000 may be at stake. The following list of plants might be considered, to start with, as they all seem to be well adapted to the Bikini conditions and to yield considerable bulk of plant

material:

Tournefortia argentea	Guettarda speciosa
Scaevola sericea	Tacca leontopetaloides
Leucaena leucocephala	Suriana maritima
Dodonaea viscosa	Hibiscus tiliaceus
Pluchea symphytifolia	Vitex trifolia
Cordia subcordata	Clerodenrdum inerme
Tamarix aehylla (not present now)	Atriplex (large species) (not present now)
Morinda citrifolia	Casuarina equisetifolia

Experiments on these with fertilizers to increase growth would be desirable.

Of course, if all of the above - suggested experiments have been tried and their results carefully applied to different models, and the indications are that too many years would be required, or that the expense would be substantially greater that that of soil removal, we needn't consider the method further. Much would depend on how much the present standing crop would weigh and how much biomass could be produced on the island per year.

One aspect that might be considered, also, is that if this method should be marginally practical, it would provide employment for the Bikinians that are to be resettled on Eneu for as many years as the decontamination is required. If we are to spend millions of U.S. dollars, we could do worse than to spend it providing employment for the resettled Bikinians rather than to bring in contract labor to carry out the planting and harvesting.

The possible impacts of these programs, vegetation-wise may be as follows:

(1a) My impression is that the bare subsoil would in a few years be covered by a scrub of Scaevola and Tournefortia, with a probable admixture, at least at first, of grasses such as Lepturus, Eustachys and Cenchrus and perhaps the sedge, Fimbristylis and various herbaceous weed species. These plants would slowly add humus to the soil and, perhaps, make possible the invasion of other, less tolerant, plant species. A more diverse vegetation would probably develop, but perhaps too slowly to be significant. The people could, and undoubtedly would, greatly alter this by fertilizing and cultivation. They would undoubtedly try to reestablish coconut plantings. These would not likely be very productive, even if they succeeded, on this sterile soil.

(1b) It would be hard to predict the vegetation that would develop after addition of a layer of soil from elsewhere. It would depend very much on where the soil came from, how fertile it would be, and what seeds were buried in it. The only experience with this process on a large scale that I know of is on Maupiti Island coral islets in the Society Islands. Here the result is a heavy growth of various weeds, which the people then kill with herbicides and burn, to make room for their commercial watermelon plantings. What the ultimate consequences of this will be are not yet apparent. About all I could predict, for Bikini, would be a rank growth of weeds, which the people would have to contend with if they wanted to carry on any horticulture or agriculture.

(2) This program should not alter the present vegetation much, except to make the coconut trees grow better and the undergowth in the plantations even more rank where it is prevalent now, and to make it appear in the present sparse or bare areas. New weeds would doubtless be introduced and some cultivated species might become naturalized. The present behavior and spread of Leucaena leucocephala may be a good indication of what other plants might do if introduced. The tendency for some species to become unusually tall and luxuriant, observed on the present survey, may also be an indication of possible consequences of heavy fertilization. I have no suggestion of a reason for the phenomenon, except that it must be related in some way to disturbance. Both indigenous and exotic

species are involved.

My reservations about this plan are based on the fact that the contamination is not removed, but merely allowed to remain in the soil and ground water .

(3) The immediate effect of flooding with sea-water on a large scale would probably be the elimination of all but the most salt-tolerant species. If the flooding were done in a dry season a salt-crust might form that would eliminate all vegetation. New vegetation would appear after rains had washed out the salt, but it would be of extremely halophytic species, possibly Fimbristylis, Lepturus, Scaevola, Tournefortia and Suriana.

The flooding would probably have to be done repeatedly, and attempts by the people to encourage vegetation might be very discouraging. The relatively low rainfall on Bikini would make vegetation-recovery a very slow process.

(4) This would be a slow process, but would possibly be less expensive and less damaging to the entire environmental complex than most of the other plans. It could be accelerated if it should turn out that certain species accumulated more radio-isotopes than others. These species could be encouraged by reseeding. The whole process might be speeded up by fertilizing with a potassium-deficient fertilizer, causing the picking up by the plants of more radioactive cesium. A critical factor would be the effective removal of the plant biomass and its disposal in areas where contamination made little or no difference.

On the list a) to e), I can offer a few comments not already mentioned earlier in this report:

a) Although there are, in the Bikini flora, no plants that are especially rare, or even of particular interest (except for the abundant "kono" or Cordia subcordata, which when of large size furnishes an excellent and attractive wood for carving). I would suggest protection for all indigenous plant species where practical. Most of these will have little or no value under present conditions. So long as support from outside, from U.S. or other friendly nation is forthcoming, the medicines and other plant products are no longer used. Even the knowledge of them is largely being lost. However, there is no assurance, in the current unsettled state of the world, that support from outside will always be available or even that contact with the rest of the world will not be broken off. In such an event, wild plants might become again very important. It is a commonly known fact that on low islands, aboriginal peoples have found uses for practically every species in their floras. Some of the knowledge of these plants and their uses may persist. If contact were to be interrupted, the native (and even some of the exotic) plants may suddenly become important again. Preserving substantial populations of plants, may be a valuable insurance against future need, in addition to providing the diversity needed to support a functioning ecosystem as well as to provide variety to keep life interesting and avert monotony. Those plants believed to be of aboriginal introduction are among the most likely to eventually be of importance, and stands of them are well worth protecting.

Kono (Cordia) mentioned above, should not only be protected wherever practical, but might be planted on contaminated or other unused ground.

(b) The only plant community represented in Bikini that seems especially favorable for seabirds is the Pisonia forest, where fairy terns, black noddies and red-footed boobies commonly nest. However, the sandy areas on Eneu would be suitable for wedge-tailed shearwater or mutton-birds, except that seabirds do not usually stay on islets inhabited by people. Earlier in this report preservation of the small islets on the southwest reef has been discussed and recommended.

(c) Native plants on Bikini are not of outstanding horticultural value, though several, such as Scaevola, Cordia, Clerodendrum and beach-morning-glories have been planted as ornamentals in

places too salty for many other ornamentals. Morinda and Guettarda also, would be of value in such situations. If it should ever become fashionable to take advantage of the cooling effect of the tradewinds by building dwellings on the windward sides of the islets these plants might be very useful.

The scrub or scrub-forest on beach ridges forms a most useful windbreak to protect horticultural plantings on atoll islets. On other Marshall atolls such windbreaks protect even coconut plantations.

(d) If Nam or the windward reef-flats of other islets are ever used as spoil deposits for contaminated soil from Bikini islet the weed-seeds, and seeds of native plants such as Lepturus, Scaevola, Fimbristylis, Tournefortia, etc. already in the soil would soon provide a vegetative cover for these areas. This could perhaps be hastened by plugging rhizome fragments of bermuda grass (Cynodon) into the surface of the deposited spoil. However, this does not seem to me to be much of a problem. Only if the material were deposited during a prolonged dry period might the revegetation be delayed, and then replanting would not be very effective. I do not know of any salt-resistant plant the seeds of which are available in large quantities. Perhaps Atriplex semibaecata, from Australia but naturalized in Hawaii, might be easily harvested in sufficient amounts.

(e) If Bikini and Eneu are, indeed, effectively decontaminated, enough so that food plants raised locally would be safe to eat, "taro-pits," excavated down to the ground-water table could be made, well in from the shores. These should be protected by wind-breaks to avoid salt-spray damage. Many plants, in addition to the various taros, could be grown in and around such pits, if protected from salt spray.

It is very likely that the resettled Bikinians will plant coconuts on the undecontaminated islets. This could be risky if the accumulation of radionuclides in the coconuts is very great. It is too much to expect that the people will refrain from drinking the coconut water and using the meat.

The resettled Bikinians will undoubtedly bring exotic ornamentals with them to plant around their dwellings rather than using native plants, except for possibly Morinda, which is used for various purposes, and some of the Pandanus varieties that still persist from former plantings.

CONCLUSIONS AND RECOMMENDATIONS;

The present vegetation of Bikini Atoll still contains most of the species present in pre-nuclear test time, as indicated by the collections of W.R. Taylor in 1946. A few species have disappeared, or are not common enough to have been found in the 1985 survey. In addition, a number of exotics have appeared and some have become common. The proportions of the species have undoubtedly changed but with no records of previous species composition this cannot be assessed. On the larger islands patterns of distribution of vegetation types have been confused by various perturbations, mostly due to human agencies. Correspondence with environmental variations has become vague and hard to read. On the smaller islets vegetation patterns have become very simplified, or have always been simple. No information is available on former vegetation of these smaller islets.

Recovery of vegetation after the nuclear tests has been rapid, but with a high proportion of pioneer species, such as Scaevola, Tournefortia, Lepturus and Fimbristylis. On most of the smaller islets the vegetation appears to be almost entirely of a pioneer character, dominantly scrub and scrub-forest of Scaevola and Tournefortia. This applies even to larger islets such as Nam and Aerokojlol.

On the larger islets, Bikini and Eneu, a number of common species are observed to reach an unusually large stature. No explanation for this is evident.

Most of my recommendations are scattered in appropriate places in the text report with the pertinent information and a few, of general application, are summarized here:

1. On denuded areas, such as where contaminated soil is removed, and where it is disposed of, allow natural revegetation to take place. Work with nature rather than fighting her.

2. Bring in new exotics only when good reasons exist, then try to choose ones that seem not likely to result in troublesome side effects.

3. Attempt agriculture (or horticulture) for production of food only when radioactive contamination is low enough to avoid danger of accumulation in edible parts of plants.

4. Preserve the vegetation of beach ridges, especially on windward sides of islets, to lessen influence of salt spray.

5. Maintain populations of native species wherever practical, to preserve diversity and encourage the survival of old uses of these species, and as insurance in case of failure of outside support assistance.

6. Preserve, so far as possible, the present abundance of kono (Cordia) as a source of wood for carving and cabinet type woodwork.

7. Maintain the six tiny islets on the southwest reef in their present condition as reserves of natural diversity and bird and turtle refuges.

8. Do not encourage replanting of coconuts on still-contaminated islets.

9. Encourage scientific investigation of causes of unusual growth in stature of some plant species on Eneu and Bikini.

10. Discourage burning of vegetable trash--fallen coconut leaves, discarded husks, wind-thrown trees and branches, etc. in order to build up humus accumulation in soil.

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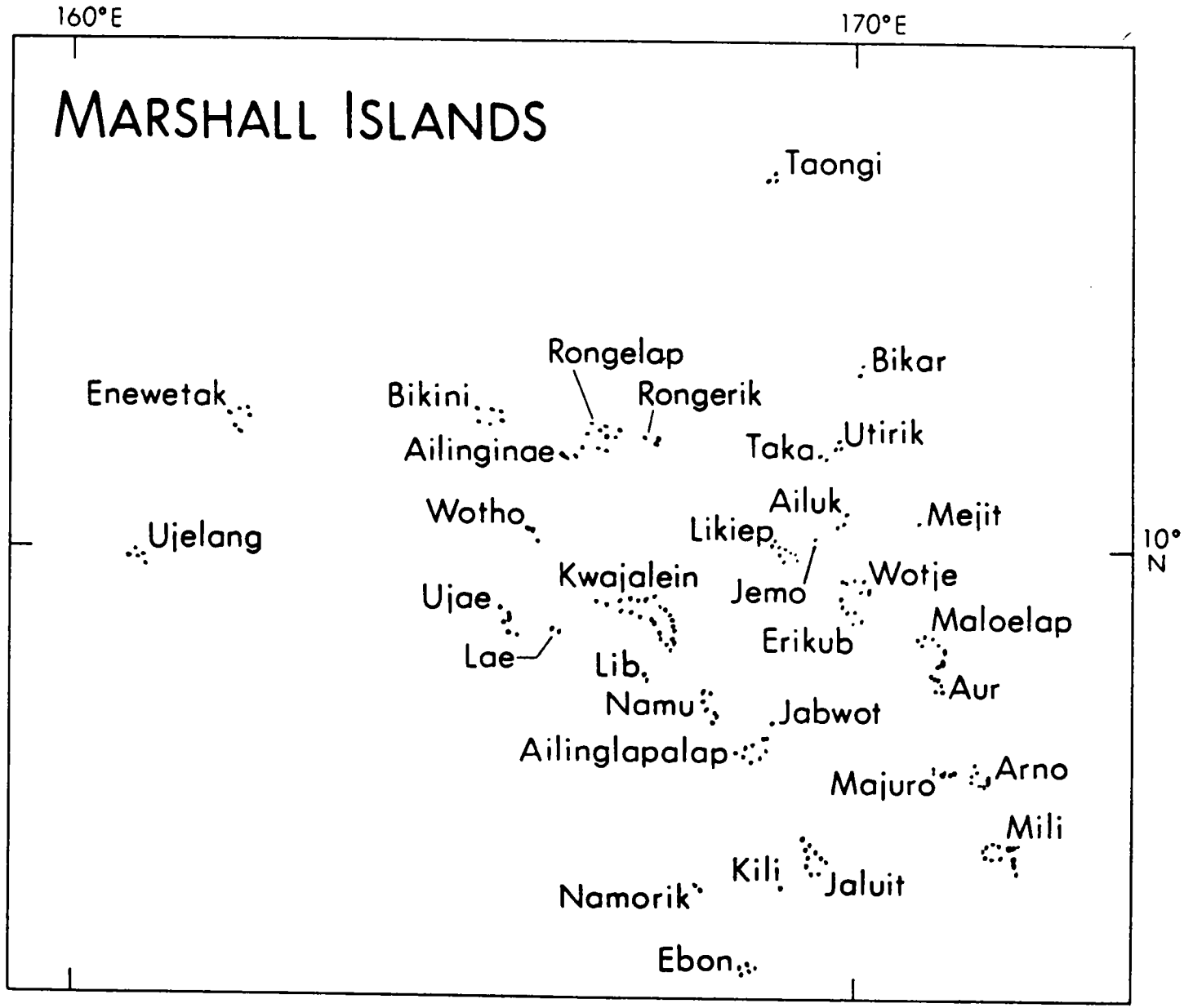


Figure 1 Map of Marshall Islands showing the position of Bikini Atoll.

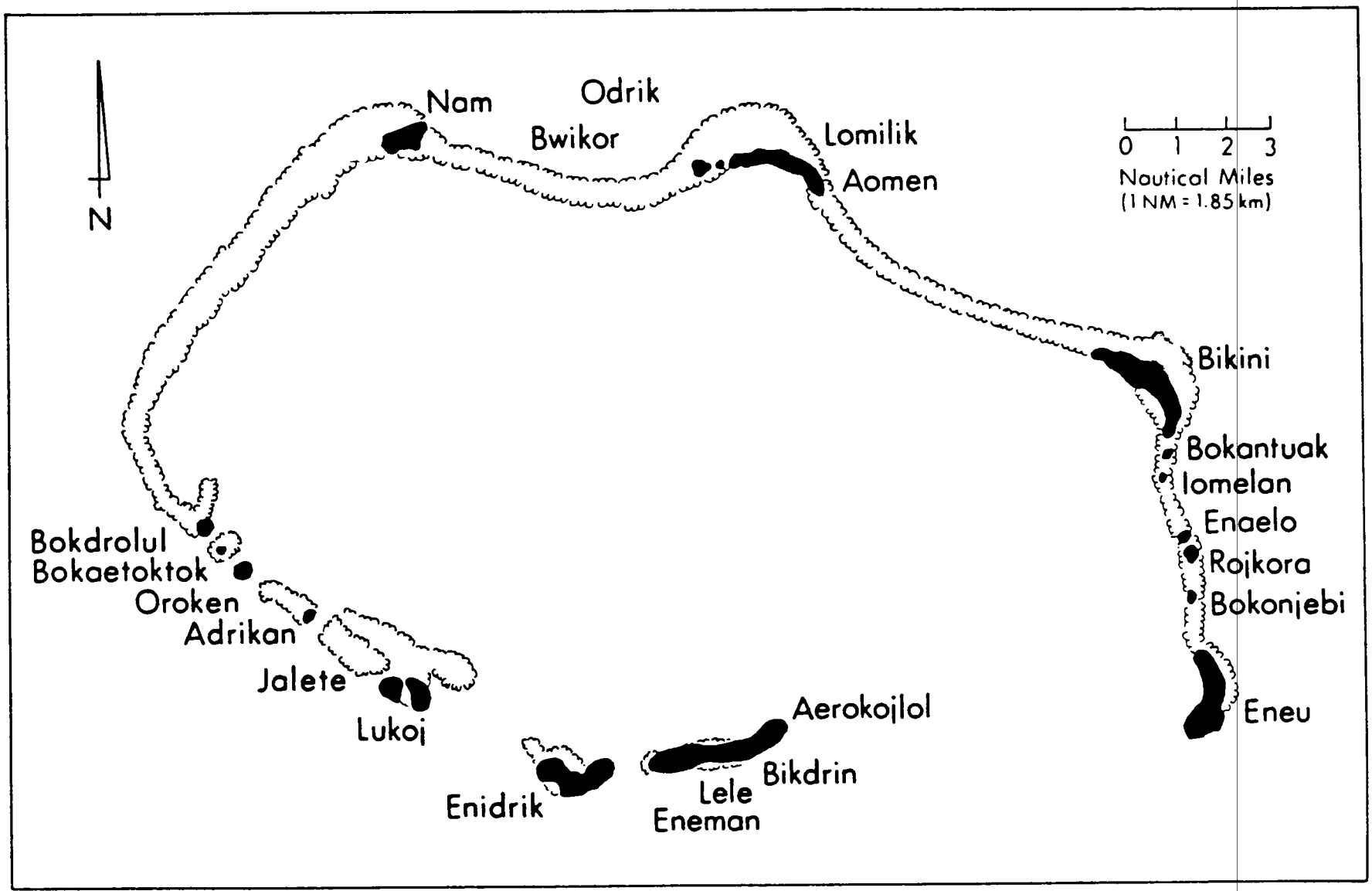
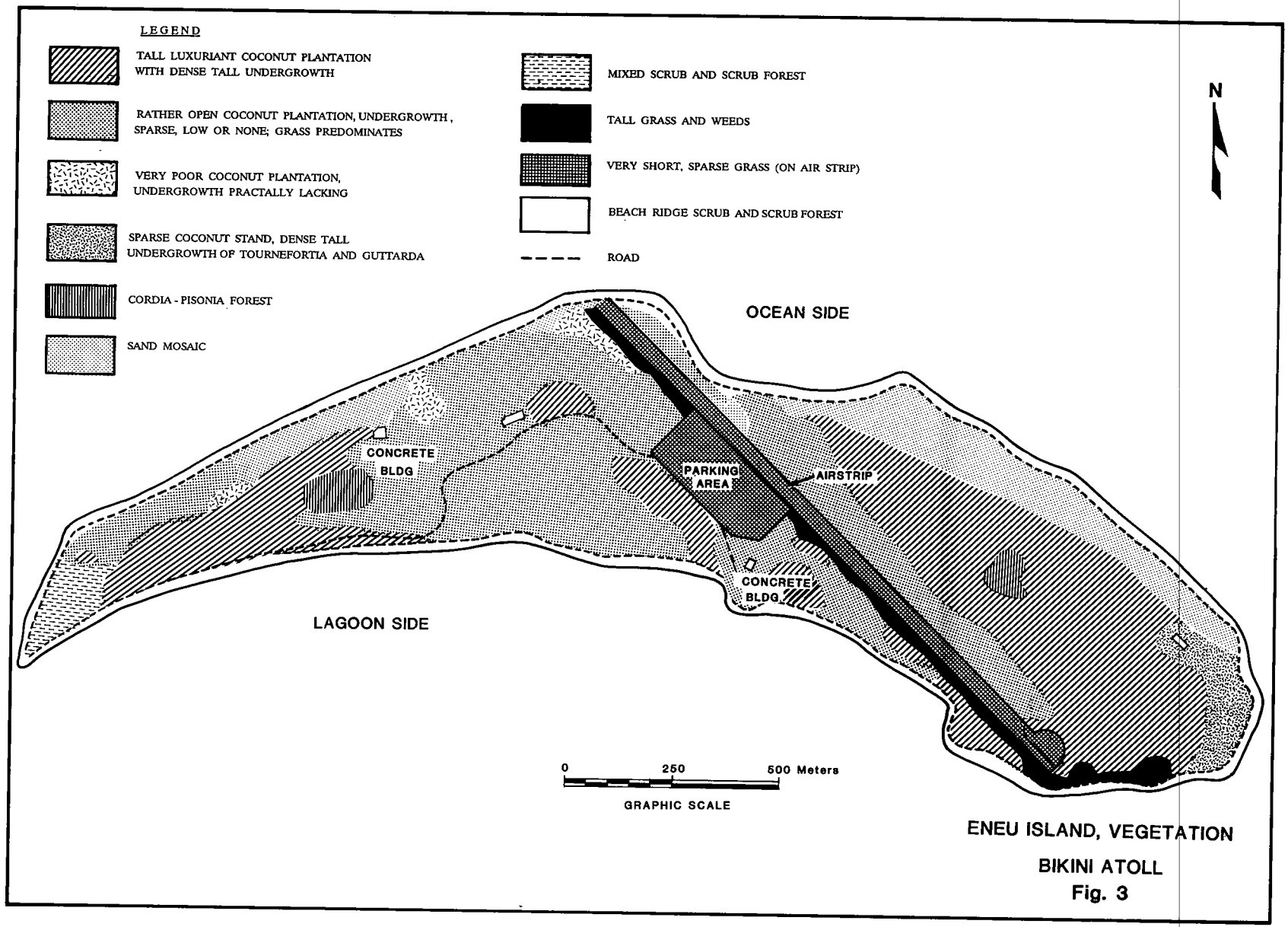


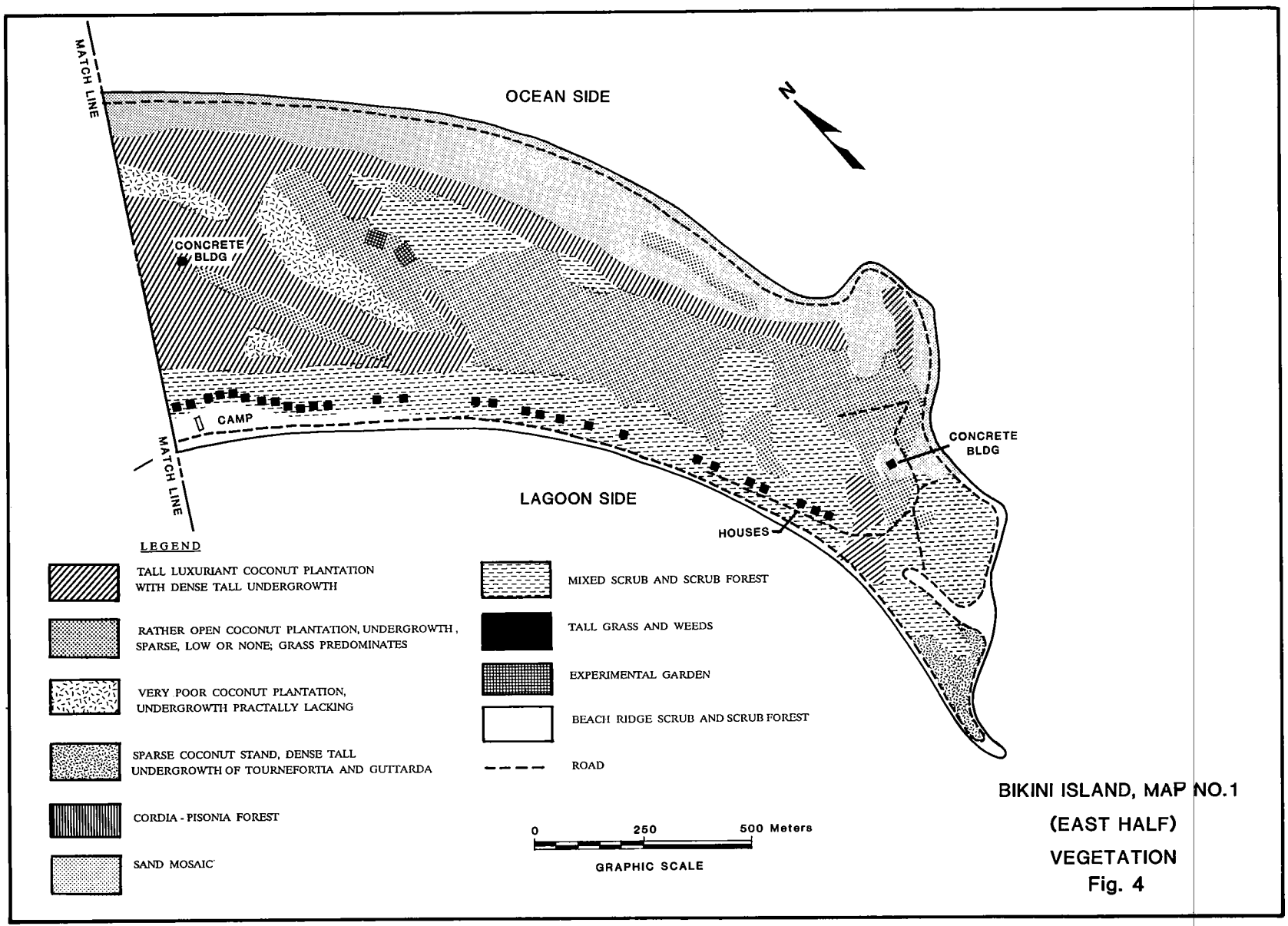
Figure 2 Map of Bikini Atoll showing islets



ENEU ISLAND, VEGETATION

BIKINI ATOLL

Fig. 3



BIKINI ISLAND, MAP NO.1

(EAST HALF)

VEGETATION

Fig. 4