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R. E. PALUMBO

Laboratory of Radiation Biology, University of Washington, Seattle, Washington

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RECOVERY OF THE LAND PLANTS AT ENIWETOK ATOLL FOLLOWING A NUCLEAR DETONATION*

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Abstract—A long-term investigation was conducted at Eniwetok Atoll during 1954–57 to determine the rate of recovery of land plants damaged by the radiation, shock and heat blast of the Nectar detonation in 1954. At Belle Island seven plant species were tagged, measured and photographed before the detonation. At approximately monthly intervals after the detonation for a period of ten months, and again after an interval of six months, the plants were observed and photographed. The first indication of recovery was observed on the eighth day, at which time buds were noticeable on stems of *Scaevola* and *Messerschmidia* plants. In a month's time, most of the plants had formed new leaves and some had produced flowers and fruits. In six months, the general condition of the vegetation was similar to that which existed before the detonation. Two plants, *Guettarda* and *Portulaca*, which were unhealthy at ten months, had improved by the sixteenth month. Photographs of the recovery of some of the plants are included in this report, as well as a discussion of agents other than radiation which have been reported to cause similar damage to plants of the coral atolls of the Pacific Ocean.

Résumé—Une investigation à long terme a été effectuée à l'atoll d'Eniwetok pendant les années 1954–1957 afin de déterminer la vitesse de restauration de plantes de pleine terre endommagées par les radiations, le shock et le souffle thermique de l'explosion Nectar en 1954. A Belle Island, sept espèces de plantes ont été étiquetées, mesurées et photographiées avant l'explosion. Les plantes ont été observées et photographiées à des intervalles d'environ un mois pendant une période de dix mois après l'explosion et ensuite, après un délai de six mois. Le premier indice de restauration a été observé le huitième jour, moment auquel des bourgeons ont été relevés sur es tiges de *Scaevola* et *Messerschmidia*. Endéans une période d'un mois, la plupart des plantes avaient formé de nouvelles feuilles et certaines avaient produit des fleurs et des fruits. En six mois, les conditions générales de végétation étaient redevenues semblables à celles qui existaient avant l'explosion. Deux plantes, *Guettarda* et *Portulaca*, qui étaient maladives à dix mois, se sont améliorées au seizième mois. Des photographies de la restauration de plusieurs de ces plantes sont inclues dans ce rapport ainsi qu'une discussion des agents autres que les radiations connus comme étant cause de semblables dégats aux plantes des attols de l'Océan Pacifique.

Zusammenfassung—Eine langfristige Untersuchung am Eniwetok Atoll wurde während der Jahre 1954–57 durchgeführt um die Geschwindigkeit der Erholung der durch Bestrahlung, Schock und Hitzestoss der Nectar Detonation in 1954 beschädigten Landpflanzen festzustellen. Auf der Belle Insel wurden sieben Arten vor der Detonation markiert, gemessen und photographiert. In ungefähr monatlichen Abständen, während der ersten 10 Monate nach der Detonation und danach nach 6 Monaten wurden die Pflanzen wieder beobachtet und photographiert. Das erste Anzeichen der Erholung wurde am achten Tag gefunden, indem Knospen an den Stämmen von *Scaevola* und *Messerschmidia pflanzen* sichtbar wurden. Nach einem Monat hatten die meisten Pflanzen neue Blätter gebildet und einige hatten Blüten und Früchte. Nach 6 Monaten war der generelle Zustand der Vegetation ähnlich dem der vor der Detona-

*Operated by the University of Washington under Contract No. AT(45–1)1385 with the United States Atomic Energy Commission.

tion existierte. Zwei Pflanzen, *Guettarda* und *Portulaca*, die nach 10 Monaten noch ungesund waren, hatten sich nach 16 Monaten gebessert. Photographien einiger der erholten Pflanzen sind diesem Bericht beigefügt, sowie eine Besprechung der Mittel, ausser den Strahlungen, von denen ähnlicher Schaden wir der an den Pflanzen der Korallenattolle des Pazifik berichtet worden ist.

INTRODUCTION

SINCE the summer of 1946, the Laboratory of Radiation Biology of the University of Washington has conducted studies at the Eniwetok Proving Ground to evaluate the distribution of radioactivity in aquatic and terrestrial organisms of the atolls of the western Pacific and adjacent areas. These studies were made either shortly after a nuclear device had been detonated or after intervening periods varying from several to many months. The results of the investigations conducted in 1946,[7] 1947,[1] 1948,[2] 1949,[3] and 1952[5] indicated the need for a study of the reinvasion or regrowth of organisms in an area contaminated by radiation.

A study of this nature was undertaken following the detonation of an atomic device (Nectar) at Eniwetok Atoll in the spring of 1954. Facilities were made available at the Eniwetok Marine Biological Laboratory on Elmer (Parry)

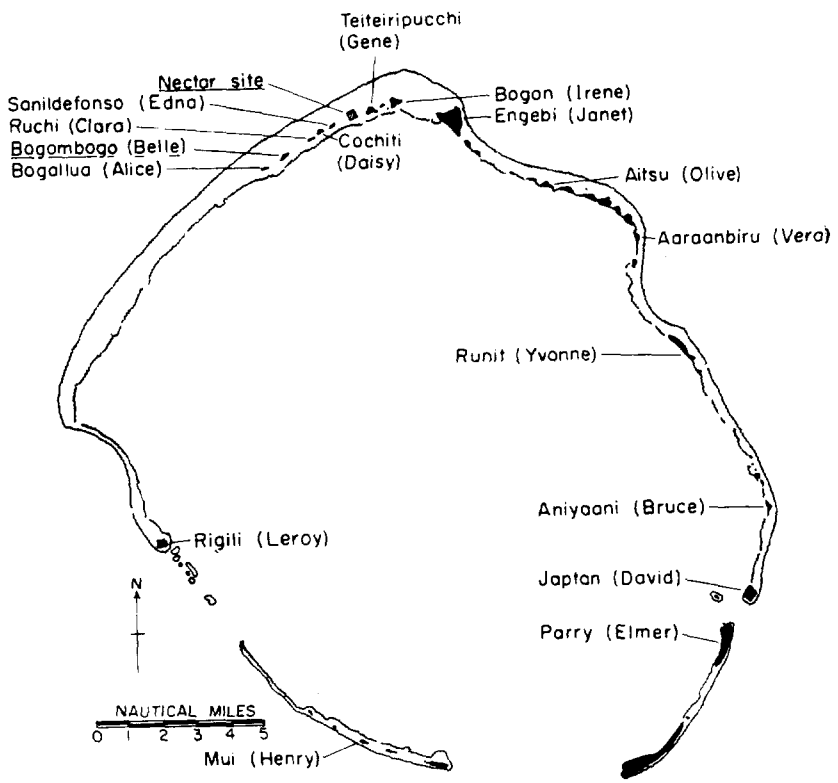

FIG. 1. Eniwetok Atoll.

Island by the Division of Biology and Medicine of the United States Atomic Energy Commission, and logistic support to carry out the sampling programme was furnished by Joint Task Force Seven of Operation Castle.

The study of the land plants was a part of the over-all programme of the Laboratory of Radiation Biology. In this report only the results of this portion of the programme are presented. The results of the investigations on the following organisms already have been reported: reef fish,[23] land crabs,[15] invertebrates[8], and algae.[19]

The objective of the land plant programme was to determine the length of time required for a plant damaged by a nuclear detonation to resume its normal functions of growth and reproduction while being subjected to chronic radiation.

The main site of study was Belle Island (Bogombogo), 2·7 miles W-SW of the detonation (Fig. 1). This area was estimated to be far enough removed from ground zero that the plants would not be uprooted by physical forces yet would be in an area of sufficient radioactivity for the proposed study.

METHODS

Representative plants of the eight most common species growing in the area were studied in detail; however, numerous other plants also were observed. Before the Nec detonation the plants were staked, labell measured and photographed. After the deto tion, and at approximately monthly inter thereafter, observations and measurements w made of the plants and photographs were tak *Scaevola sericea* Vahl, a woody shrub, was cho as the principal plant for study because of widespread occurrence on the islands of t Central Pacific Ocean. The other plants studi in detail were: *Messerschmidia argentea*, *Guetta speciosa* and *Cocos nucifera*, trees; *Lepturus repe* a grass; *Boerhaavia tetrandra* and *Triumfe procumbens*, prostrate vines; and *Portulaca olerac* a fleshy herb. The locations of these plants the island are shown in Fig. 2.

Gamma survey-meter readings also were tak to determine the gamma dose to which t plants were subjected.

RESULTS

The gamma survey-meter readings taken Belle Island during the period of investigatio are given in Fig. 3, which includes the theoretic gamma dose rate according to MILLER an LOEB.[16] The accumulated total dose from or minute after the detonation to the end of 20 days was calculated to be approximately 400

Before the Nectar detonation, the plants o Belle Island were generally green and healthy

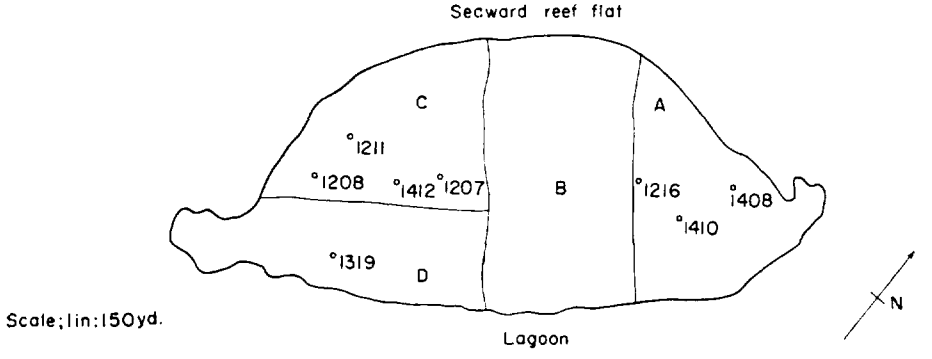

FIG. 2. Diagram of Belle Island, Eniwetok Atoll, showing the location of the land plant stations and the collecting areas.

Area A	Area C	Area D
1216 *Guettarda speciosa*	1207 *Boerhaavia tetrandra*	1319 *Scaevola* sp.
1408 *Messerschmidia argentea*	1208 *Triumfetta procumbens*	
1410 *Lepturus repens*	1211 *Portulaca oleracea*	
	1412 *Cocos nucifera*	

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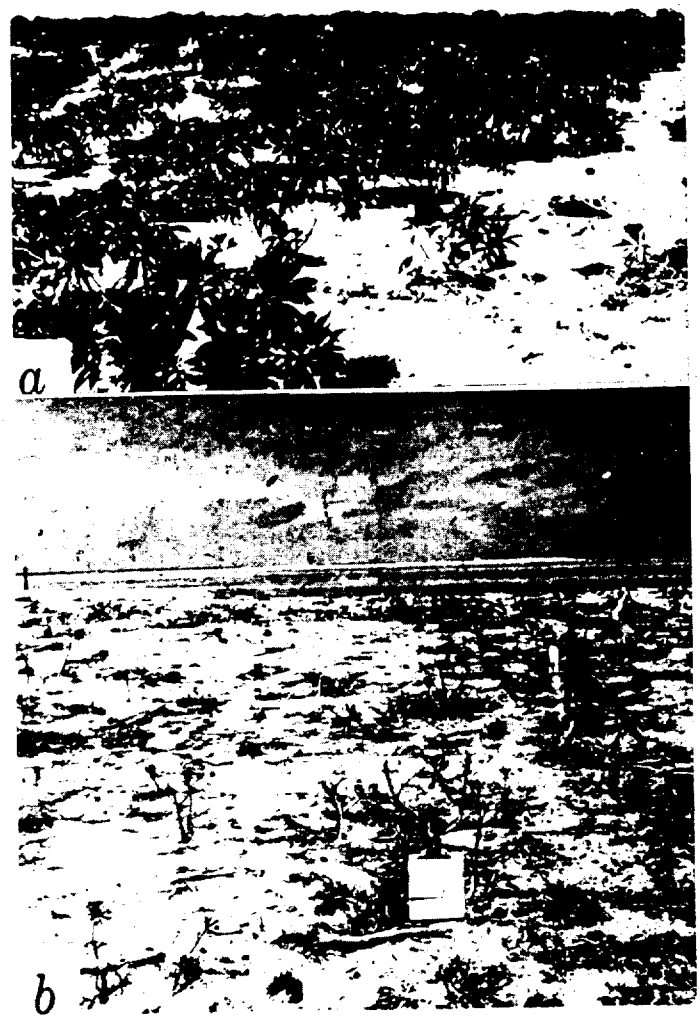

FIG. 4. General view of land plants at Belle Island, Eniwetok Atoll. (a) On April 15, 1954, before the Nectar detonation. (b) On May 22, 1954, eight days following Nectar, showing a *Scaevola* plant (No. 1319) in the foreground.

FIG. 5. *Messerschmidia* plant at Belle Island, Eniwetok Atoll. (a) Plant No. 1248 showing adventitious buds on May 22, 1954. (b) Close-up of the same plant on June 18, 1954.

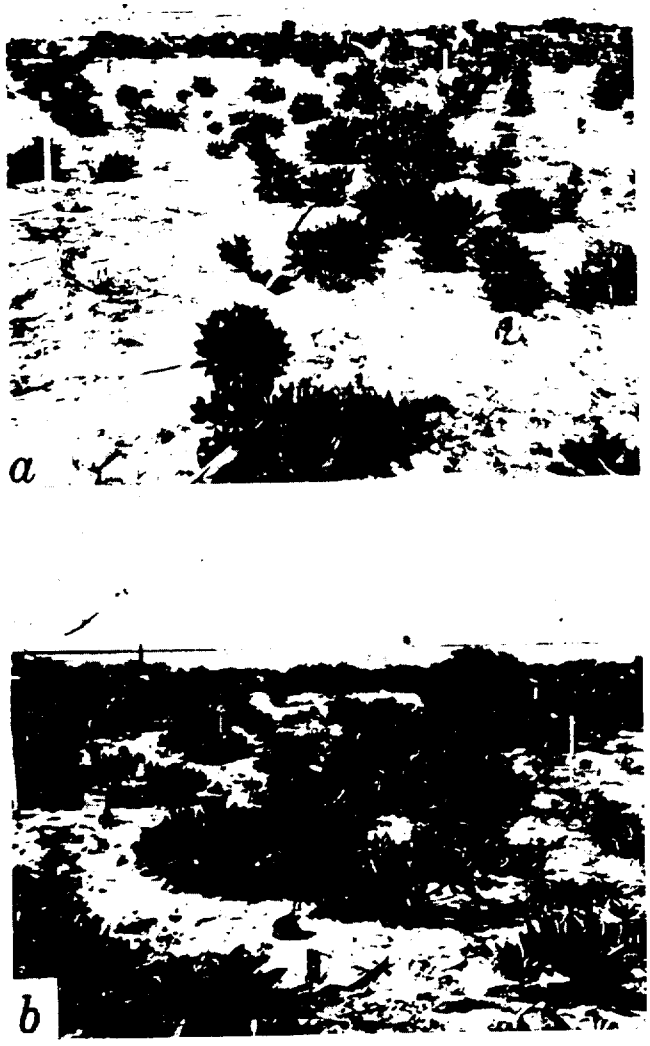

FIG. 6. Land plants at Belle Island, Eniwetok Atoll, Area D. (a) Three months after the Nectar detonation. (b) Six months after detonation.

FIG. 7. *Guettarda* plant at Belle Island, Eniwetok Atoll. (a) Close-up of unhealthy plant (No. 1216) on March 15, 1955. (b) Close-up of the same plant on November 1, 1955.

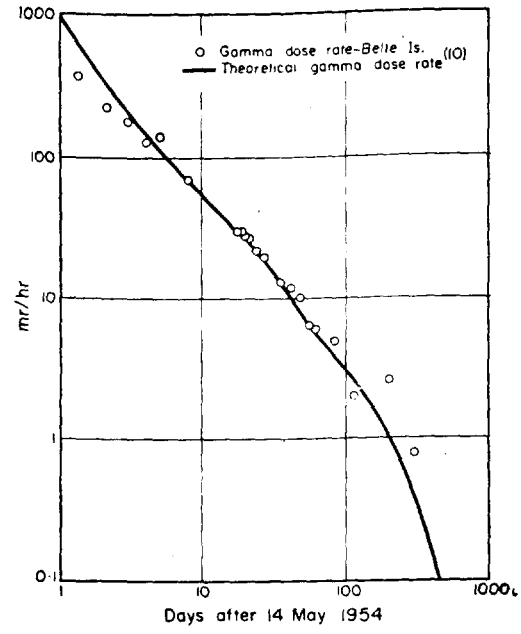

FIG. 3. Gamma dose rates at three feet at Belle Island, Eniwetok Atoll, May 15, 1954 to March 21, 1955, compared with the decay of fission products from the slow neutron fission of U^{235}(10).

looking. A photograph of the general area taken at this time (Fig. 4a) shows the healthy appearance of the vegetation. In some plants there was yellowing of the leaves and necrosis, especially in *Scaevola* and *Guettarda*, and some reddening of the tops of the grass, *Lepturus repens*. The latter symptom is typical of some species of plants growing in phosphorus-deficient soil, a condition often found on coral atolls and in areas where the top soil has been disturbed or blown away. The Mike detonation of 1952 had removed most of the plants and top soil from Belle Island, resulting in the depletion of some of the elements essential for plant growth. In spite of these deficiencies regrowth of the plants at Belle Island was rapid. In April 1954 some of the *Scaevola* and *Messerschmidia* "trees" were up to five feet in height, with a spread of ten feet, and bore many flowers and fruits. Plants of the other species also were well established.

A photograph of Belle Island taken eight days following the Nectar detonation (Fig. 4b) shows the extent of the damage sustained by the plants. From the air the island looked brown and desolate. On closer inspection it was found that most of the plants had been scorched by the heat wave and many of them had been blown over or broken by the shock blast. Two of the previously tagged plants (*Cocos* and *Portulaca*) had disappeared or had been dislodged from their original positions; other plants of these species were staked and labelled for study. On the tall shrubs, such as *Scaevola*, *Messerschmidia* and *Guettarda*, the leaves were usually gone or scorched, and the scorched branches and a few persistent leaves were all that remained of the plants. Flowers and fruits were found on some plants, especially in the prostrate plants such as *Portulaca*, which was located behind a large fallen coconut trunk. Close-ups of examples of damaged plants eight days post Nectar are shown in the foreground of Figures 4b and 5a.

Recovery of the plants was rapid. Heavy rains occurred on the third day. On the eighth day green buds, 1–3 mm in length, were observed on the stems of *Scaevola* and *Messer-*

schmidia (Fig. 5a) plants. On the thirty-fifth day the shoot leaves were 7–15 cm long, covering much of the old stems (Fig. 5b) and giving the plants a green and healthy appearance. By this time many of the other plants had formed new leaves and three species (*Portulaca*, *Triumfetta*, and *Messerschmidia*) had produced new flowers and fruits. The island now had lost its scorched appearance; from the air it looked green rather than brown as it had one month earlier.

In August, three months after the detonation, the plants were growing well (Fig. 6a) and some species, such as *Boerhaavia*, had produced new flowers. The leaves of most of the species had grown to maximum size, and the branches had grown almost to the pre-Nectar dimensions. This was not the case with the *Guettarda* and *Lepturus* plants, which recovered more slowly than the other species. The new growth on the *Guettarda* plant consisted of ten small leaves which originated from a new shoot 18 cm tall at the base of the old plant; the *Lepturus* plant was a mat of dead tops with some new growth forming at the periphery.

In six months the general condition of the vegetation (Fig. 6b) was similar to that which existed before the Nectar detonation. In March 1955, approximately ten months post Nectar, the plants appeared to be normal, most of them bearing abundant flowers and fruits, healthy, green leaves, and the usual amount of yellow, older leaves. The *Guettarda* plant, however, bore curled, distorted, and unhealthy-looking leaves (Fig. 7a). When observed again in November 1955, it bore about thirty healthy, green leaves, had increased in height and apparently was completely recovered (Fig. 7b). The *Portulaca* plant bore only a few leaves in March 1955, but when observed in November 1955, it had recovered somewhat, bearing abundant flowers and some green leaves.

No other aberrant growth forms were seen in the field observations at Belle Island. At Janet Island, the fasciated stems and the tumorous growths on plants of *Ipomoea tuba* observed in 1949 by BIDDULPH[6] were still present in 1957.

The measurements and observations made on one of the plants, *Scaevola* (No. 1319), during the course of the study are presented in Table 1.

DISCUSSION

Previous studies to evaluate the recovery ar reinvasion of the flora at the Eniwetok Provir Ground, approximately fifteen months aft Operation Sandstone, were made in 1949 b ST. JOHN[21] and BIDDULPH.[6] They reporte morphological abnormalities in ten species plants growing on islands where atomic detona tions had taken place, and where radiatio levels were undoubtedly higher than those o Belle Island during the Nectar survey. Thes abnormalities included flattening, shortening thickening and spiral torsion of stems, sever "die-back" of leaves and stems, chlorosis asymmetry, shrivelling, crumpling and twistin of leaves, chromatism of stems, proliferation an enlargement of inflorescences, abnormal pro liferation of stems, and sterility of plants. St. John reported finding a mutant of *Guettarda speciosa* on Runit Island but did not describe it. Biddulph reported spiralling and splitting of fronds on several coconut palms on Aitsu (Olive) Island, which is located between two of the "shot" islands.

On the "shot" islands, the plants closest to the bomb crater centres (where radiation levels were highest) were most severely affected. In areas where radiation levels were lower, the "disturbance of ecological habitats" was reported to be more important in excluding plants from these areas than the radiation effects from the bombs.[6] Undoubtedly many of the abnormal plants started their growth after the nuclear detonations had occurred in impoverished soil lacking inorganic nutrients and organic matter. These conditions are known to cause nutrient deficiencies which can sometimes be identified by the appearance of the plant. In coral atolls where the top soil has been removed the retention of rain water in the surface layer of soil would be slight, resulting in the curling, drying, and ultimate death of the shallow-rooted plants. On the basis of these observations it may be concluded that some of the abnormalities observed could have been caused by factors other than radiation. Therefore, it would be impossible to ascertain all of the causes of damage to plants in an area where radiation and nutrient deficiencies both exist. In areas of high radiation levels, much of this damage

Table 1. *The regrowth of* Scaevola *sp.* (*Plant No.* 1319) *at Belle Island, Eniwetok Atoll, from May* 22, 1954 *to March* 15, 1955 *following the detonation of May* 14, 1954 *at a site two and one-half miles away*

Date	Appearance	Height (cm)	Over-all diameter (cm)	Length of larger leaves (cm)	Remarks
4/15/54	Healthy; green flowers and fruits present	75	90	16	
5/22	Plant badly damaged, stems naked and broken; some burned and green leaves persist at terminals	45	40	7·5	A few plants observed with persistent floral parts
6/19	New leaves on stems; branches still scrawny-looking	65	75	15	No flowers observed on on this plant
8/12	Most leaves green and healthy; plant not as bushy as in April	75	75	16	Flowers present on *Scaevola* Plant No. 1209, Area C
9/14	Plant as healthy and bushy as in April	75	90	20	Flowers present on *Scaevola* Plants No. 1209 and No. 1213, Area A, and others
11/2	Growth normal in every respect; small flowers present	75	90	20	
11/30	Plants healthy, larger than in April, many flowers	78	95	20	
3/15/55	Yellowing of oldest leaves only; plant healthy, no flowers or fruits	100	125	20	Some *Scaevola* plants 2 metres in height

could be attributed to the radiation, because it has been shown in controlled field experiments, with several plants, that chronic doses of gamma radiation of 13–37 r/day for two to five months can cause plant abnormalities of various kinds,[13] similar to those found at the Eniwetok Proving Ground. The total gamma dose delivered in these experiments ranged from 780 r to 5,550 r. In more recent studies with conifers Sparrow[20] observed that doses as low as 3 r and 4 r/day caused death of *Pinus rigida* after six years of exposure (total cumulative dose, about 8,000r). Many plants, however, were dead or dying at doses much below this cumulated dose, and some visible damage was observed at doses below 3 r/day.

Observations made in February 1956 in the Marshall Islands by Fosberg[9,19] also suggest possible radiation damage to plants twenty-three months after an incidence of high-level radioactive fallout. He found severe damage in the land plants (*Guettarda speciosa*, *Cocos nucifera*, *Suriana maritima* and others) at Gegen Island, Rongelap Atoll, where the "total radiation dose to infinity" was reported to be 3,360 r. Where the levels of radiation were 10–100 times lower, little or no damage was observed. However, some species (*Guettarda*, *Lepturus repens*, and *Fleurya ruderalis*) appeared to be normal at Kabelle Island where the radiation level was high (total dose 1,824 r). Other species (*Suriana*, *Cordia subcordata*, *Cocos nucifera* and *Pisonia*

grandis) were abnormal in appearance at islands where the levels of radioactivity were lower. Fosberg suggested that some species of plants were more susceptible to radiation than others.

On the other hand many of the abnormalities reported by Fosberg, St. John and Biddulph have been reported from coral atolls where no radioactive fallout has occurred. For example, defoliation and death at the tips of branches of *Cordia*, *Pisonia* and *Tournefortia* (*Messerschmidia*) were reported on Wake Island in April 1952, after a period of drought, by FOSBERG.[11] TAYLOR[22] reported that the vegetation at Bikini Atoll in March and April 1946 (before Operation Crossroads) was unhealthy-looking and that *Pisonia* plants bore only scanty foliage, improving later in the year. Records of rainfall in the northern Marshall Islands show that the dry period prevails from December to April, the months of January and February getting the least rainfall.[4] As shown by the observations of Fosberg and Taylor, one would expect to find the plants at their worst during the dry period.

Some abnormalities found in the plants on coral atolls have been caused by insects. Taylor reported that the leaves of *Suriana* were clipped as if by insect attack, and Fosberg reported that *Bauhinia* was chlorotic and badly eaten by insects. NIERING[18] reported that on Kapingamarangi Atoll the leaves of *Scaevola* were attacked by a leaf miner and new shoots and buds of *Calophyllum* sp. and *Barringtonia asiatica* were "infested to the point of disrupting the normal growth pattern." On Onotoa Atoll, MOUL[17] observed that several insects were found on *Guettarda* plants. These included wasps, moths, stink bugs, and butterflies. Moul reported also that leaves of *Pisonia* trees were so badly damaged by leaf-cutting bees that he could not find a perfect specimen of foliage. At Rongelap Atoll members of this Laboratory noted infestations of a lepidopteran larva causing deformed leaves on *Guettarda* plants. They also reported that insects caused defoliation and bud damage in plants of *Terminalia* sp. and *Pisonia*.

The bird population also is a factor in the production of unhealthy plants. Niering reported that at Kapingamarangi Atoll the leaves of *Asplenium*, *Nephrolepis*, *Guettarda* and *Pisonia* were turning brown and dying because of the fecal droppings of the white-capped noddy tern (*Anous minutus marcusi*). He reported that the breadfruit tree also is damaged by these birds. On Canton Island the suggestion was made that the native birds were chiefly responsible for the dead or dying conditions of the forest and scrub vegetation.[14]

Other agencies also have been reported to cause chlorosis, die-back, slow growth, aberrant growth forms, and other kinds of plant abnormalities. Some causes not mentioned previously are salt spray, wind, storms, flying gravel, soil conditions and land crabs.

Measurements of the amount of thermal radiation and blast received by the plants at Belle Island during the Nectar detonation were not made, but approximations of these values can be made on the basis of the energies required to produce the observed damage. A thermal energy of 10–15 cal/cm^2 is required to char vegetation and a wind velocity equivalent to 130–140 miles/hour is required to produce blast damage[12] similar to that observed at Belle Island. Also, from calculations based on data obtained from other nuclear detonations,[12] the initial gamma dose delivered at Belle Island was approximately 30 r, which is much lower than the levels required to cause visible plant damage in laboratory-type experiments. Essentially all of the damage to the land plants, therefore, can be attributed to the heat and blast rather than to the initial nuclear radiation. The excellent recovery of all but three of the plants (*Guettarda*, *Lepturus*, and *Portulaca*) is noteworthy, especially since the plants were subjected continuously to external radiation as well as the internal radiation from absorbed radioisotopes. The abnormal appearance and slow recovery of these plants, among the many observed, would appear to be due to radiation; however, the author feels that the other factors, which were not measured adequately during this investigation, should be evaluated carefully before ascribing the damage to radiation.

REFERENCES

1. Applied Fisheries Laboratory,* University of Washington (1947) *Radiogiological resurvey of Bikini Atoll during the summer of 1947.* U.S. Atomic Energy Commission report UWFL–7.

2. Applied Fisheries Laboratory, University of Washington (1949) *Bikini radiobiological resurvey of 1948.* U.S. Atomic Energy Commission report UWFL-16.
3. Applied Fisheries Laboratory, University of Washington (1950) *Radiobiological survey of Bikini, Eniwetok and Likiep Atolls, July–August, 1949.* U.S. Atomic Energy Commission report AECD-3446 (UWFL-23). Off. of Technical Services, U.S. Dept. of Commerce.
4. Applied Fisheries Laboratory, University of Washington (1953) *Radiobiological studies at Eniwetok Atoll before and after Mike shot.* U.S. Atomic Energy Commission report WT-616 (UWFL-33). Technical Information Service, Oak Ridge, Tenn. (Confidential.)
5. Arnow T. (1954) The hydrology of the northern Marshall Islands. *Atoll Research Bull.* **30**, 1–7.
6. Biddulph O. (1950) Section VI of *Radiobiological survey of Bikini, Eniwetok and Likiep Atolls, July–August, 1949.* U.S. Atomic Energy Commission report AECD-3446 (UWFL-23) Off. of Technical Services, U.S. Dept. of Commerce.
7. Bikini Scientific Resurvey, Vol. II. 1947. Armed Forces Special Weapons Project. Report No. OC-155. (Secret.)
8. Bonham K. (1958) *Radioactivity of invertebrates and other organisms at Eniwetok Atoll during 1954–1955.* U.S. Atomic Energy Commission report UWFL-53. Off. of Technical Services, U.S. Dept. of Commerce.
9. Fosberg F. R. (1959) Long-term effects of radioactive fallout on plants. *Atoll Research Bull.* **61**, 1–11.
10. Fosberg F. R. (1959) Plants and fallout. *Nature (Lond.)* **183**, 1448.
11. Fosberg F. R. (1959) Vegetation and flora of Wake Island. *Atoll Research Bull.* **67**, 1–20.
12. Glasstone S. (Ed.) (1957) *The Effects of Nuclear Weapons.* Supt. of Documents, U.S. Government Printing Office. 579 pp.
13. Gunckel J. E. and Sparrow A. H. (1954) *Aberrant growth in plants induced by ionizing radiation.* Brookhaven Symposia in Biology, Brookhaven National Laboratory, Upton, N.Y. 6: 252–279.
14. Hatheway W. H. (1955) The natural vegetation of Canton Island, an equatorial Pacific atoll. *Atoll Research Bull.* **43**, 1–9.
15. Held E. E. (1960) Land crabs and fission products at Eniwetok Atoll. *Pacific Science* **14**, 18–27.
16. Miller C. F. and Loeb P. (1958) *Ionization rate and photon pulse decay of fission products from the slow-neutron fission of U^{235}.* U.S. Naval Radiological Defense Laboratory report USNRDL-TR-247.
17. Moul E. T. (1954) Preliminary report on land animals at Onotoa Atoll, Gilbert Islands. *Atoll Research Bull.* **28**, 1–28.
18. Niering W. A. (1956) Bioecology of Kapingamarangi Atoll, Caroline Islands: Terrestrial aspects. *Atoll Research Bull.* **49**, 1–32.
19. Palumbo R. F. (1959) *Radioactivity of the algae at Eniwetok Atoll, 1954–1956.* U.S. Atomic Energy Commission report UWFL-61. Off. of Technical Services, U.S. Dept. of Commerce.
20. Sparrow A. H. (1959) Personal communication.
21. St John H. (1950) Section V of *Radiobiological survey of Bikini, Eniwetok and Likiep Atolls, July–August, 1949.* U.S. Atomic Energy Commission report AECD-3446 (UWFL-23). Off. of Technical Services, U.S. Dept. of Commerce.
22. Taylor W. R. (1950) *Plants of Bikini and Other Northern Marshall Islands.* University of Michigan Press, Ann Arbor. 227 pp.
23. Welander A. D. (1957) *Radioactivity in the reef fishes of Belle Island, Eniwetok Atoll, April 1954 to November 1955.* U.S. Atomic Energy Commission report UWFL-49. Off. of Technical Services, U.S. Dept. of Commerce.

*Laboratory of Radiation Biology (formerly Applied Fisheries Laboratory) University of Washington, Seattle.