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ECOLOGICAL PROBLEMS ASSOCIATED WITH DISRUPTION OF DUNE VEGETATION DYNAMICS BY CASUARINA EQUISETIFOLIA L. AT SAND ISLAND, MIDWAY ATOLL

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ECOLOGICAL PROBLEMS ASSOCIATED WITH DISRUPTION OF DUNE VEGETATION DYNAMICS BY CASUARINA EQUISETIFOLIA L. AT SAND ISLAND, MIDWAY ATOLL

By Steven I. Apfelbaum[1], James P. Ludwig and Catherine E. Ludwig[2]

INTRODUCTION

Exotic plants and animals may be introduced in ecosystems because of desirable qualities or by accident. Many introductions have caused great harm because of unpleasant characteristics which are realized only after introduction. Ironwood (*Casuarina equisetifolia* L.) is one such species. Introduced for shade and ornamental purposes in subtropical and tropical areas, this adaptable and quick growing tree has caused ecological changes which may limit its future introduction. Ironwood can be a pioneer species that colonizes nutrient depauperate soils, especially nitrogen poor areas, because of its nitrogen fixing capability (Aldrich and Blake, 1932). Equally important is its ability to reproduce by several assexual modes in addition to sexual routes. These characteristics make this species a persistent management problem. This paper presents our observations of Ironwood ecology and this plant's relationships with native vegetation, seabirds, and man on Midway Atoll.

The Casuarinaceae is a distinctive family of trees and shrubs from dry or saline habitats of southeast Asia and the southwest Pacific. Ironwood branches have a characteristic weeping habit with peculiar jointed leaves in a whorled branching pattern. Male and female flowers are separate with the latter borne in dense spheroid heads near branch ends. Leaf size is reduced with photosynthetic tissues and stomatal openings found in stem interrib spaces, probably an adaptation to prevent dessication. Surprisingly, little ecological, life history, or manage-information is available on the Casuarinaceae.

THE STUDY AREA

Midway Atoll, located 2100km northwest of Honolulu, Hawaii, has been occupied by man since the early 1800's. Midway was a major link in the first trans-Pacific telegraphic cable system and has been a major U.S.

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naval facility since 1939. Two islands are found in the southeastern area of the enclosed atoll lagoon. Sand, the larger island (Figure 1) is 2.9km by 1.9km, with an area of 482 hectares. It has a maximum elevation of 13.1m. Eastern Island, 1.5km east of Sand is 320 hectares with an elevation of 10.4m. Before human settlement, Sand Island was a sandy expanse with a naturally depauperate vegetation. Shorelines and dunes were stabilized by the dune binding complex including *Scaevola taccada* and the prostrate herb, *Ipomoea indica*. Shifting sands were normal, especially in central areas of the islands. Since settlement, beach erosion on Sand Island has been an expensive problem which complicates maintenance of shorelines, buildings, docking facilities and other military structures. The climate is subtropical with an average annual precipitation of 101cm. Rainfall occurs an average 12 days a month; December through February are the wettest months; March is the driest. Northeastern trades prevail from March through October with stronger westerlies from November to February. Highest mean monthly temperatures approach 30^{o} C. while May, June and November temperatures range from $21-27^{o}$ C. (Woodward, 1972). Although no data are available on evapotranspiration rates, these are certainly highest during warmest and windiest periods.

In 1903, the telegraph company planted Ironwood in the northern windward areas of Sand Island. Ironwood now covers much of the unpaved surface of the island, where it often forms a thick canopy or tangle of saplings. Many other trees and shrubs have been introduced, but, by far, Ironwood dominates the island ecosystem. Some Ironwood individuals exceed a 25m height and 1m diameter at breast height (d.b.h.). Along the northeast shore, this tree forms a thick canopy and litter that may reduce understory vegetation. Ironwood selects against birds of open habitats and favors those species associated with forested areas.

ACKNOWLEDGEMENTS

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METHODS AND MATERIALS

Vegetation studies were conducted February 15-24, 1979 in Sand Island. Casual observations of Eastern Island vegetation were made during this same time. Beach vegetation dynamics were investigated along representative beach exposures on Sand Island. We measured intercepts for each plant species along 30, 2x25m transects that originated at the seaward foot of the foredune, and went inland. Using this method, relative cover for each plant species was summarized over the north, west and south beach areas of the island. Ten transects were established in

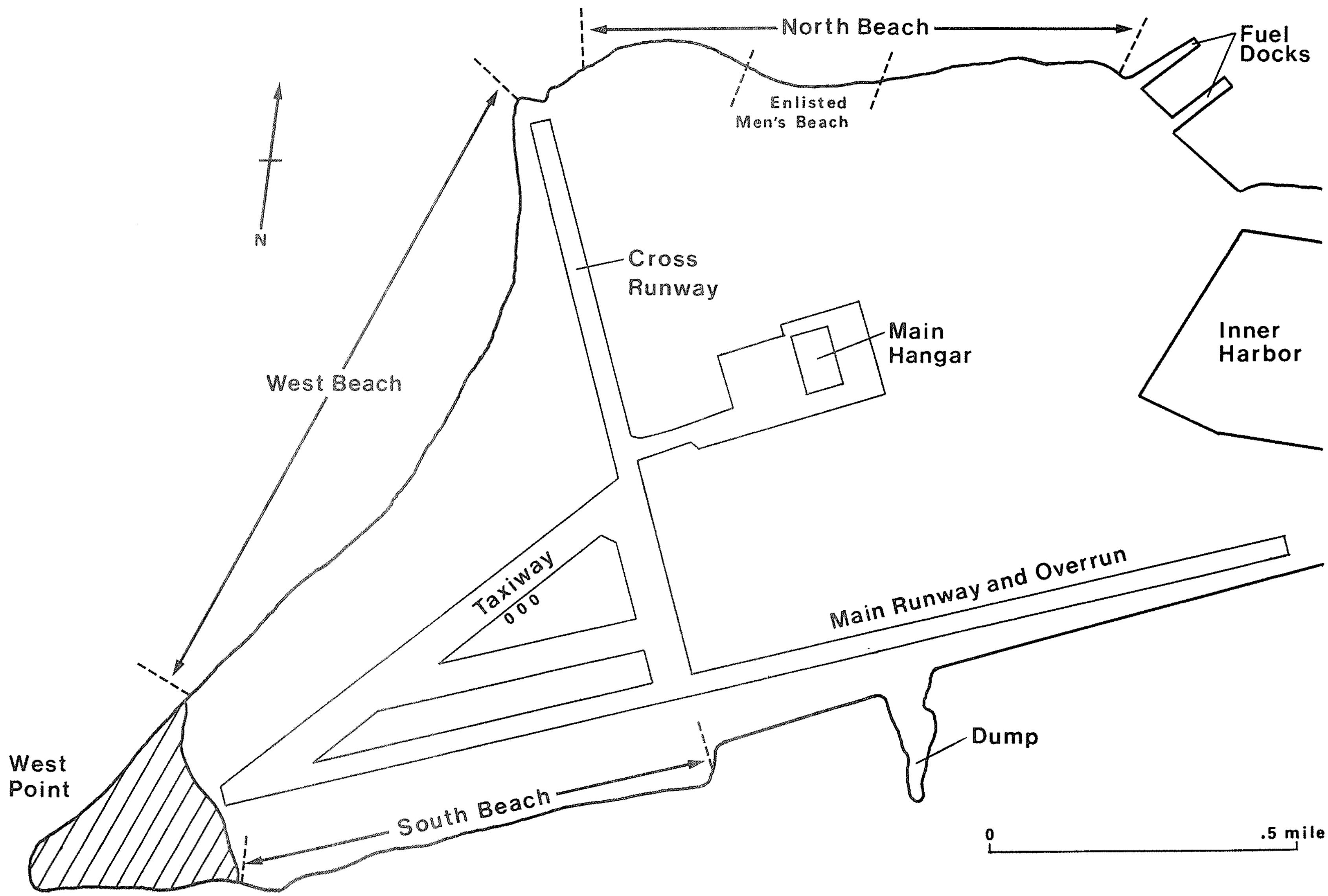


Fig. 1. Sand Island, Midway Atoll

each of these exposures. Fruit and seed productivity estimates were made for Ironwood. All newly fallen cones located in four $0.25m^2$ quadrats were used to estimate and measure fruit production. Seed production estimates were made by counting the number of pairs of woody bracts opened in the cones that had dropped seed.

A plant species list was generated for Sand Island (Appendix). Species of noteworthy status, those providing difficulty in identification, or of uncertain status, were collected and are maintained at the University of Illinois Herbarium, Urbana. Other species were listed as observed.

RESULTS

Ironwood has wind disseminated samaroid seeds approximating a measurement of 5mm x 2.5mm. Small Ironwoods (having a d.b.h. of 5cm or less and less than 2m in height) produced cones and seeds of identical size as larger older trees. Comparative germination and viability tests were not undertaken. However, Aldrich and Blake (1932) reported an average germination rate of 84% ($n \simeq 437$) for Ironwood seeds washed in mercuric chloride and water. They found seedling mortality to be "low". Over a 15 month period, their control plants attained a height of 40cm compared to test plants innoculated with extracts from root nodules on wild Ironwood which grew to 140cm heights.

Ironwood seedling densities along Sand Island runways suggest high germination and seedling success rates. Ironwood seedling density in one location exceeded 75 seedlings per square meter. Fruit production estimates averaged 30 cones/m^2 beneath the test trees (Table 1) and ranged from 21-38 cones. Seed production varied from 3,696 to 5,168 ($\bar{x}$=4,602) seeds per meter square. Total estimated seed production for the test trees ranged from 109,880 to 258,400 and averaged 184,000 seeds per tree which assumes a single seed crop per year.

TRANSECT RESULTS

Frequency distribution for vegetation as a function of distance from the foredune is plotted in Figures 2A-2F. Ironwood and *Scaevola* were the most frequently encountered species in all locations. *Scaevola* was encountered more frequently near the foredune and declined inland on the north and south beaches (Figures 2A and 2C). As *Scaevola* declined, Ironwood became more abundant; *Scaevola* was almost displaced by Ironwood in the first 25m inland from the foredune, especially in the north and west beach study areas. Data from the west beach (Figure 2B) suggest Ironwood invasion to be far more complete than along other beaches. Ironwood dominated *Scaevola* from the foredune inland to 18m where *Scaevola* became slightly more abundant, but only as a decadent understory element. *Scaevola* had a relatively uniform distribution inland from the foredune for 25m along the west beach. Most plants except *Tournefortia* occurred behind the foredunal *Scaevola*. There *Scaevola*

Table 1. Fruit & Seed Production for *Casuarina equisetifolia* on Sand Island, Midway Atoll.

Tree/Quadrat #	Tree Diameter (cm)	Number of Cones	$\bar{x} \pm$ S.D.	Seed #	$\bar{x} \pm$ S.D.
A/1	85	9		36-60-28-29-32 34-46-30-31	36.2 ± 10.4
A/2		11		34-46-42-43-34-38 25-32-34-35-37	36.4 ± 5.8
A/3		9		28-25-26-28-22 31-35-28-38	29.0 ± 5.0
			9.6 ± 1.2		34.0 ± 7.9
B/1	42	5		36-30-48-33-56	40.6 ± 11.0
B/2		5		49-48-48-52-36	46.6 ± 6.1
B/3		6		36-56-54-36-56-33	45.2 ± 11.2
			5.3 ± 0.6		44.2 ± 9.5
$\bar{x} \pm$ S.D.			7.5 ± 2.5		39.0 ± 6.5

Fruit and Seed Productivity per $1m^2$:			Seeds/m^2
Tree A	38	136	5168.0
Tree B	21	176	3696.0
Mean	29.5	156	4602.0

Est. Ground Area:	Total Seeds:
$50m^2$	258,400
$30m^2$	109,880

$\bar{x}$ = 184,140

Figure 2.
Plant Frequency vs. Distance Inland from Foredune Origin:

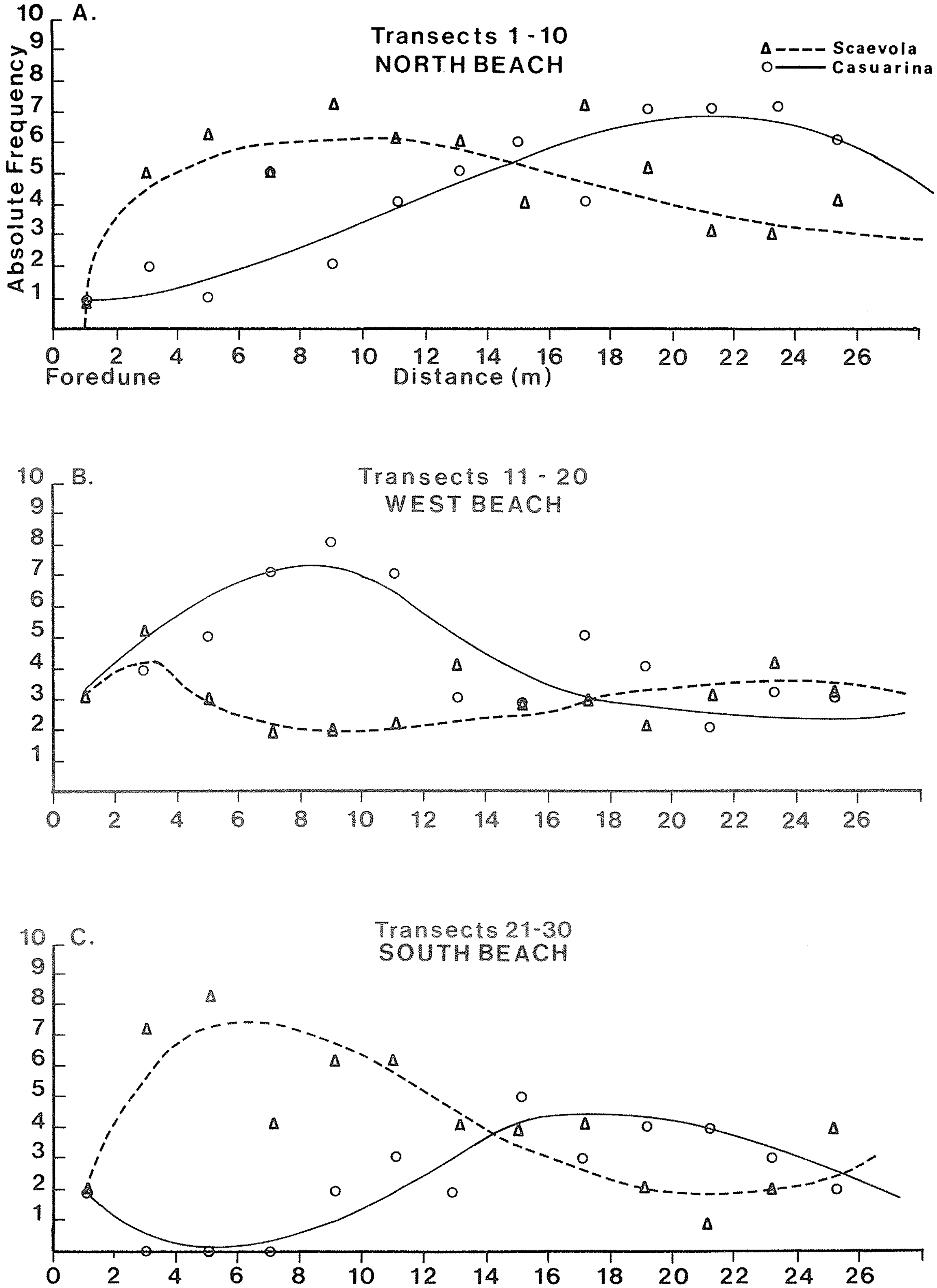
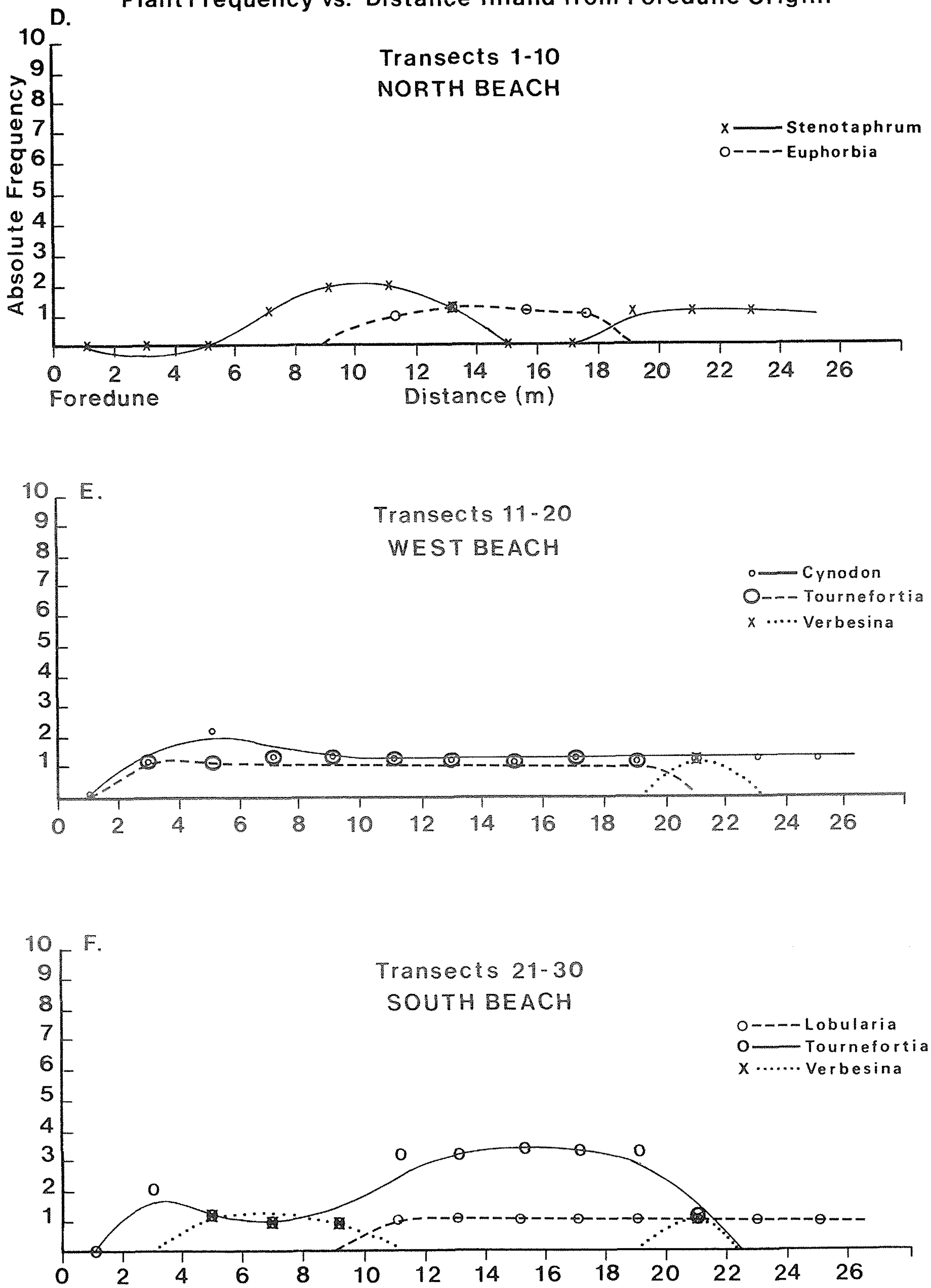


Figure 2. (continued)

Plant Frequency vs. Distance Inland from Foredune Origin:



distribution trends hold in the north and south beaches as well, although Bermuda Grass *(Cynodon dactylon)* also occurred in the foredunal areas. Along the west and south beaches, *Tournefortia* occurred infrequently from the foredune to at least 20m inland. Along the west and north beaches *Scaevola* was reduced to an understory layer beneath a closed Ironwood canopy.

Scaevola and Ironwood each accounted for nearly 33% of all species intercepted in the transects. Thus, over 60% of all the plant intercepts along the transects resulted from these species. The cover importance of *Scaevola* and bare ground dropped to 24% each, while Ironwood and Bermuda Grass values were highest in the west beach. Along the south beach, Ironwood was less abundant than *Scaevola* or bare ground and *Tournefortia* was nearly as important as Ironwood.

Most of the 123 plant species we encountered on Sand Island were exotics. Of these, few were found in the beach areas. Most occurred only where organic soils had been imported or developed near dwellings, or in the shade of larger *Casuarina* (Neff and DuMont, 1955; Lamoureux, 1961). Ironwood seedlings were present throughout, but only in association with *Scaevola* and *Tournefortia* when present in the foredunes. Seedlings were numerous behind the foredunes along the north beach, but were not found independent of these dune binding shrubs except in areas shaded during most of the day.

Black rat *(Rattus rattus)* damage to native shrubs was not quantified. However, we found severe damage to *Scaevola* especially inland of the foredune where larger Ironwood were present as canopy elements. Rat damage was found only on *Scaevola*. The rodents chewed succulent apical and lateral buds which reduced lateral and vertical growth potentials of *Scaevola*. In some places, particularly along the west beach, damage was so severe that we believe *Scaevola* is certain to be eliminated.

Along the vegetation surveys, Laysan Albatross nest densities (Table 2) varied from 8 to 89 nests per acre. Black-footed Albatross nested in the west and south beaches but no nests were located along the north beach transects. The Albatross species seldom nested together. Black-foots associated with openings between *Scaevola* clones; Laysans nested within thinned *Scaevola* clones under Ironwood canopies, or where Ironwood seedlings and saplings grew into a thick bush-like form.

DISCUSSION

The foredune begins 50-75m from the high tide along the north beach, which was actively building. This beach had dense rounded clones of *Scaevola* 0.5-1.8m in height, especially between the cross runway and the enlisted men's beach. Immediately behind the foredune were large Ironwood that shaded the foredune at various times of the day and season. Ironwood seedlings were scattered throughout the *Scaevola*. However, few seedlings were present under the larger Ironwood. Inland of the Ironwood were numerous cultivated plants, especially in yards of abandoned houses.

Table 2. Breeding bird nest densities for nests Encountered in 2x25m Vegetation Transects

	# of Nests by Species Encountered	
North Beach Transects 1-10	Black-footed Albatross	Laysan Albatross
1		1
2		1
3		1
4		1
5		2
6		1
7		2
8		
9		
10		2
Nesting density per $500m^2$	0	11
Nesting density per acre		89
Nesting density per hectare	0	220
West Beach Transects 11-20		
11		1
12		
13		
14		
15		
16		4
17		
18	2	
19	2	
20	4	
Nesting density per $500m^2$	8	5
Nesting density per acre	65	40
Nesting density per hectare	160	100
South Beach Transects 21-30		
21	1	
22	1	1
23		
24		
25		
26		
27		
28	1	
29	2	
30		
Nesting density per $500m^2$	5	1
Nesting density per acre	40	8
Nesting density per hectare	100	20

These included the exotics Chinese Banyan *(Ficus microcarpa)*, Poinsettia *(Euphorbia cyathophora)*, and Bermuda Grass.

The west beach was severely eroded even though rip-rap had been previously installed for prevention. In winter, northwest storms subject this beach to erosive winds and waves that develop over the 9.6km (6m) distance to the fringing reef. The tide-line to foredune distance varied from 0-25m. Fallen Ironwood showed the original shore had been undermined and the beach zone lost. Based on comparisons with the north and south beaches (Figures 2A and 2C), 12-18m of beach and foredune have been removed by erosion along this beach. *Scaevola* is overtopped by Ironwood along this beach. Surviving *Scaevola* was in very poor condition with severe dieback and rat damage evident. Beneath high density Ironwood stands, herbaceous ground cover was absent. In some areas, *Scaevola* had recently died back and few stems survived. Most stems were leafless and assumed a shriveled-desiccated appearance. Young Crown-beard *(Verbesina enceloides)* plants invaded dead and dying *Scaevola* clones. We have no information on the persistence of this species under the Ironwood. Since Crown-beard did not occur in exposed foredunes, it may require ameliorated conditions associated with the larger Ironwoods to establish in the dunes.

The west point of Sand Island just west of the paved end of the main runway was dominated by large *Scaevola* that showed little rat damage. In this area, no Ironwood seedlings were found seaward of a few established Ironwood trees 5-10 years of age located 80m inland from the tide line.

Between the south beach and dump, *Scaevola* declined and was largely restricted to an undercut sand ridge with a relief of 3-5m from the level of Waldron Blvd. to the ocean. Erosion abatement structures, including wood and steel pilings, and cement breakwalls, have been utilized here. However, most were washed out. Present between the ridge and boulevard were Ironwood, sea grape *(Coccoloba uvifera)*, *Scaevola* and *Tournefortia*. Large *Tournefortia* shrubs up to 5m tall were present east of the naval facility buildings on the ridge. Ironwood seedlings grew in the *Scaevola*, especially with older Ironwood along the crest of the ridge. To the east, the ridge flattened; *Scaevola* and *Tournefortia* became less abundant. In this area, scattered Ironwoods were present in and around several dune blowouts. Dense colonies of Black-footed Albatross nested in these blowouts and associated sparsely vegetated areas. However, little nesting occurred on the beach below blowouts. Sweet Alyssum *(Lobularia maritima)* was the most common ground cover species in and around blowouts. This plant was especially lush where Albatross defecated, often growing in circular patterns around their nests. We found less rat damage on *Scaevola* here than along either the west or north beaches.

Beach vegetation dynamics on Sand Island result from interactions between native plants, rats, the complement of introduced species, and continuing disturbance by mankind. Native dune shrubs tolerate high sand temperatures, salt spray and prevailing windy conditions. They grow well under these conditions for there is little competition, and unlike most introductions, they are able to compensate for sand burial by differential growth and adaptive growth forms fitted to wind, sand scour and dessication stresses.

Adaptations include waxy, succulent and pubescent-reflective foliage. Aerodynamic spheroid to prostrate growth forms such as thick, hemispherical shape of the *Scaevola* and trailing *Ipomoea* are important adaptive features. Though adjusted to the environmental stresses of beaches and dunes, these plants seem to have a limited adaptive flexibility. Apparently, slight environmental changes can have serious impacts on these plants, probably due to their extreme specialization to a severe environment and relatively slow growth rates. Rat damage and Ironwood intrusion, singly or synergistically, stress *Scaevola*, the key native species. *Scaevola* is undoubtedly shade intolerant, growing best in exposed beach sites, with sparse *Tournefortia* or other shrubs. The establishment and growth of Ironwood in *Scaevola* clones may eliminate this plant and the entire dune-shrub complex.

Micro-habitat changes that occur with Ironwood establishment and growth among dune binding shrubs need investigation. Factors affecting *Scaevola* may include increased shading, relative humidity, and physical damage effects from branch and fruit fall from Ironwood, allelopathic effects and associated alterations to hydrology and nutrient availabilities may also occur. *Scaevola* germination and seedling establishment may be hampered by thick and usually dry *Casuarina* litter. When these factors are coupled with differential rat feeding pressures on *Scaevola* this becomes a rather complicated problem for controlled investigations.

Scaevola clones are aerodynamically suited to tolerate high winds, sand scour and evaporative stresses. Ironwood was growing only in *Scaevola* clones when in the beach areas which suggests that establishment is dependent on an altered micro-climate offered by *Scaevola* clones. Following establishment in a clone, Ironwood seedlings apparently send long tap roots to ground water sources and rapid growth occurs. Lighter red colored infrared tones on photos (Ludwig, *et. al.*, 1979) suggest these Ironwoods are less productive and more water stressed than Ironwoods occurring more inland. However, Ironwood's colonization in *Scaevola* occurs rapidly and is quickly followed by the establishment of other Ironwood seedlings. This invasion pattern may explain the even size (and possibly age) stands of Ironwood forming bands parallel to the beach, especially along the west beach.

It is plausible that *Scaevola, Ipomoea* and other native plants could be eliminated from Midway. With high seed set, apparent fast growth and invasion rates, Ironwood is a major threat to the remaining native plants of Midway. If Ironwood invades the beach zones, severe erosion is likely to occur. Ironwood lacks the growth form and physiology to effectively stabilize the beach areas. Severe erosion problems already occur on the east shore of Eastern Island. Erosion control methods and strategies deserve careful attention at Midway. Rip-rap apparently functions as short-term control of a long-term erosion problem. This method is less effective than natural vegetation erosion control, especially against aeolian sand movements. Native dune binding shrub management schemes, including means to control Ironwood would be especially helpful for long-term erosion control; control of these exotics may also cost less than structural alternatives such as pilings and rip-rap. A well thought-out control plan can also benefit nesting seabirds.

Changes in bird populations that occur with Ironwood establishment are important considerations. Although Fairy and Noddy Terns, and Laysan Albatross benefit from increased nesting habitat offered by Ironwood, species such as the Red-footed Booby, Frigate Bird, and Black-footed Albatross which use *Scaevola* and open areas for nesting seem certain to suffer habitat losses.

Comprehensive studies on the management and control of Ironwood should be initiated. Surprisingly, little information is available on managing this species. It is clear that certain areas on Midway are being damaged for continued Navy use and altered for other uses. The cross runway is being invaded rapidly by Ironwood. The runway aprons are almost completely invaded and root-heaving of the pavement by Ironwood will probably destroy the runway in the 1980's. Similar problems are far more advanced on the Eastern Island runways. Safe and effective control methods for Ironwood are not known. However, any chosen method should be amenable to continued human and seabird use. This will require holistic ecosystem management.

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APPENDIX

LIST OF PLANTS ON MIDWAY ATOLL, HAWAII
February 15-24, 1979

		OBSERVED	VOUCHERED
ACANTHACEAE			
Asystasia gangetica (L.) T. Anders.	Asystasia		X
Odontonema strictum (Nees) Kuntze			X
AGAVACEAE			
Agave sp.	Century Plant	X	
Cordyline sp.	Colored ti	X	
Dracaena sp.	Dracaena	X	
Sansevieria sp.	Bowstring hemp		X
AMARYLLIDACEAE			
Crinum asiaticum L.	Spider lily		X
ANACARDIACEAE			
Mangifera indica L.	Mango	X	
APOCYNACEAE			
Carissa macrocarpa (Eckl.) DC.	Natal plum	X	
Catharanthus roseus (L.) G. Don	Madagascar periwinkle	X	
Nerium oleander L.	Oleander		X
Plumeria sp.	Plumeria;frangipani	X	
Thevetia peruviana (Pers.) K. Schum	Yellow oleander	X	
ARACEAE			
Alocasia cucullata (Lour.) G. Don	Chinese taro	X	
Anthurium andraeanum Lind.	Anthurium	X	
Colocasia esculenta (L.) Schott	Taro	X	
Dieffenbachia sp.	Dumb cane	X	
Monstera deliciosa Liebm.	Monstera		
Rhaphidophora aurea (Sinden Andre)	Birdsey Pothos; Taro vine		X
Syngonium podophyllum Schott	(may be *S. angustatum*)		X
Xanthosoma sp.	Elephant ear; Ape	X	

		OBSERVED	VOUCHERED
ARALIACEAE			
Schefflera actinophylla (Endl.) Harms	Octopus tree	X	
ARAUCARIACHEAE			
Araucaria heterophylla (Salisb.) Franco	Norfolk Island pine	X	
BORAGINACEAE			
Tournefortia argentea L.f. *(Messerschmidia argentea* (L.f.) Johnst.)	Tree heloptrope	X	
CANNACEAE			
Canna indica L.	Canna	X	
CARICACEAE			
Carica papaya L.	Papaya	X	
CARYOPHYLLACEAE			
Cerastium vulgatum L.	Larger mouseear chickweek		X
Spergularia marina (L.) Griseb	Saltmarsh sand spurry		X
Stellaria media (L.) Cyrillo	Common chickweed		X
CASUARINACEAE			
Caruarina equisetifolia L.	Ironwood		X
CHENOPODIACEAE			
Chenopodium murale L.	Nettle-leaved goosefoot		X
COMBRETACEAE			
Terminalia catappa L.	Tropical almond	X	
COMMELINACEAE			
Commelina sp.	Day flower	X	
Rhoeo spathacea (Sw.) Stearn	Rhoeo	X	
Zebrina pendula Schnizl.	Wandering Jew	X	
COMPOSITAE			
Bidens alba L.			X
B. pilosa L.	Spanish needle	X	
Conyza bonariensis (L.) Cronq.	Horseweed		X
Gnaphalium sandwicensium Gaud.	'Ena 'ena		X
Pluchea nymphytifolia (Mill.) Gillis	Fleabane		X
Sonchus oleraceus L.	Sow thistle		X
Verbesina enceloides (Can.) Gray	Golden crown beard		X

		OBSERVED	VOUCHERED
OXALIDACEAE			
Oxalis corniculata L.	Lady's sorrel		X
O. martinana Zucc.	Pink wood sorrel		X
PALMAE			
Cocos nucifera L.	Coconut	X	
Phoenix sp.	Date Palm	X	
Pritchardia sp.	Fan Palm	X	
Roystonea sp.	Cabbage and royal	X	
PANDANACEAE			
Pandanus sp.	Screwpine; Hala	X	
PLANTAGINACEAE			
Plantago lanceolata L.	Narrow leaved plantain		X
P. major L.	Broad leaved plantain		X
POLYGONACEAE			
Coccoloba uvifera L.	Sea grape		X
POLYPODIACEAE			
Microsorium scolopendria (Burm.) Copel.	Laua'e		X
Nephrolepis hirsutula (Forst.) Presl.	Sword fern		X
PORTULACACEAE			
Portulaca oleracea L.	Purslane		X
PRIMULACEAE			
Anagallis arvensis L.	Scarlet pimpernel		X
ROSACEAE			
Rosa sp.	Rose	X	
RUBIACEAE			
Gardenia sp.	Gardenia	X	
RUTACEAE			
Citrus sp.	Citrus	X	
Murraya paniculata (L.) Jack	Mock orange	X	
SOLANACEAE			
Capsicum annuum L.	Red papper		X
Solanum nigrum L.	Nightshade		X
UMBELLIFERAE			
Apium tenuifolium (Moench) Hegi	Fir-leaved celery		X

		OBSERVED	VOUCHERED
URTICACEAE			
Pilea microphylla (L.) Liebm.	Artillery plant; Rockweed	X	
VERBENACEAE			
Lantana camara L.	Lantana		X
Vitex trifolia L.	Polinalina		X
ZINGIBERACEAE			
Alpinia zerumbet (Pers.) Burtt & R.M. Sm. (*A. speciosa* K. Schum.)	Shell ginger	X	
Hedychium gardnerianum Lindl.	Kahili ginger	X	
ZYGOPHYLLACEAE			
Tribulus cistoides L.	Puncture vine	X	
OUT OF ALPHABETICAL ORDER:			
LEGUMINOSAE			
Albizzia lebbeck (L.) Benth.	Woman's tongue	X	
Crotalaria incana L.	Fuzzy rattle-pod		X
Delonix regia (Bojer) Raf.	Royal poinciana	X	
Desmanthus virgatus (L.) Willd.	Slender mimosa		X
Erythrina variegata var. *orientalis* (L.) Merr	Tiger's claw		X
Leucaena leucocephala (Lam.) deWit	Koa haole		X
Medicago lupulina L.	Hop clover		X
Samanea saman (Jacq.) Merr.	Monkeypod	X	
	SUBTOTALS:	54	69
	TOTAL:	123	