BIRDS AND AIRCRAFT ON MIDWAY ISLANDS

1959-63 Investigations

SPECIAL SCIENTIFIC REPORT--WILDLIFE No. 85

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
BUREAU OF SPORT FISHERIES AND WILDLIFE

The Department of the Interior, created in 1849, is a Department of Conservation, concerned with management, conservation, and development of the Nation's water, wildlife, fish, mineral, forest, and park and recreational resources. It has major responsibilities also for Indian and Territorial affairs.

As America's principal conservation agency, the Department works to assure that nonrenewable resources are developed and used wisely, that park and recreational resources are conserved for the future, and that renewable resources make their full contribution to the progress, prosperity, and security of the United States, now and in the future.

UNITED STATES DEPARTMENT OF THE INTERIOR, STEWART L. UDALL, SECRETARY
Stanley A. Cain, Assistant Secretary for Fish and Wildlife and Parks
Fish and Wildlife Service, Clarence F. Pautzke, Commissioner
Bureau of Sport Fisheries and Wildlife, John S. Gottschalk, Director

BIRDS AND AIRCRAFT ON MIDWAY ISLANDS

1959-63 Investigations

By

Chandler S. Robbins
Migratory Bird Populations Station
Division of Wildlife Research

Special Scientific Report--Wildlife No. 85

Washington, D. C. • October 1966

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C., 20402 - Price 40 cents

CONTENTS

Tables

Figures

ABSTRACT

At Midway Naval Station, 1,100 miles west-northwest of Honolulu, military aircraft collide with flying albatrosses at the rate of about 300 to 400 per year. One aircraft out of every five that hits an albatross on takeoff either aborts (stops before it is airborne), or dumps fuel and returns for appraisal of damage.

About 70,000 pairs of Laysan albatrosses and 7,000 pairs of black-footed albatrosses nest at Midway in any given year. The population is declining. Two-thirds or more of the birds of breeding age nest each year. The minimum breeding age recorded is 5 years (each species), but many individuals do not nest until at least 7 years of age. Young birds begin to return to Midway at 3 years of age and are found more frequently as breeding age approaches. They come ashore more frequently in March and April (the high bird strike months) than in midwinter. Even in midwinter the number of "walkers" (birds not on nests) may comprise more than 40 percent of the albatrosses present on Sand Island, Midway. Maximum longevity of the Laysan albatross is believed to exceed 40 years; 6 out of 99 birds banded as breeding adults (7+ years old) were still alive 24 years after banding.

Control methods tested experimentally include disturbance, gunfire, other sounds, radar beams, smoke, odors, destruction of nests, eggs, chicks, and adults, moving of birds, eggs, and chicks, erection of obstacles to flight, and habitat management. Habitat management (leveling and hardsurfacing of shoulders of runways) has been the most effective.

Albatrosses were counted over the runways at 10 locations in 1957, 1958, and 1960 to determine the effects of wind direction, wind speed, and topography on the numbers of flying birds. Birds were most concentrated in areas where rising air currents were created as winds blew against dunes or tall trees. Soaring and strike rate both increased with greater wind speeds. There was a highly significant correlation between strike frequency and wind direction. Soaring and strike rate were greatest over runway 6-24 when winds were from a northerly quadrant, and greatest over runway 15-33 when winds were east to southeast. Counts (nearly 7,000 observations) before and after the leveling of dunes along part of the south side of the principal runway, 6-24, showed a 61 percent decrease in soaring over the principal runway as compared with a 4 percent increase over runway 15-33 where no major habitat management had been done.

Studies of population dynamics of Laysan and black-footed albatrosses in 4 study plots (totaling 14½ acres) are yielding information on nesting density, changes in nesting population from year to year, frequency of nesting of individual birds, closeness of return, reproductive success, rate of nest loss, age at which young birds begin nesting, age composition of the population, and life expectancy of adults.

Recommendations are made for reducing the bird hazard and for protecting birds that are not involved in the hazard.

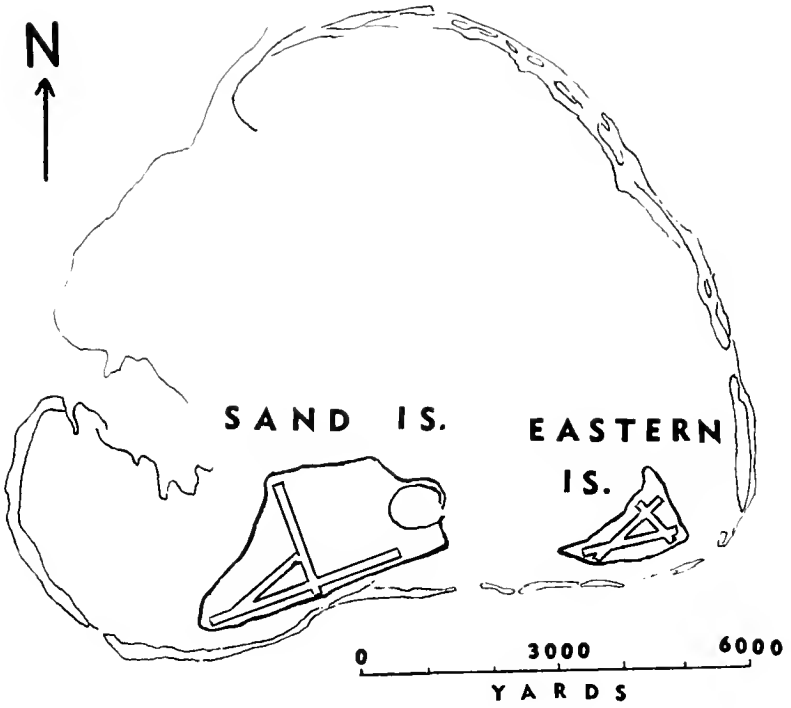

Figure 1. Sand and Eastern Islands, Midway Atoll. Aircraft runways are shown on the islands.

BIRDS AND AIRCRAFT ON MIDWAY ISLANDS

1959-63 Investigations

This report gives the results of research during calendar years 1959 through 1963 on the relation between bird populations and aircraft operations at the U. S. Naval Station on Midway Atoll in the North Pacific Ocean. The investigation is being conducted by the Division of Wildlife Research of the Bureau of Sport Fisheries and Wildlife, U. S. Fish and Wildlife Service, Department of the Interior. Funds for the field investigations were provided by the Bureau of Yards and Docks, Department of the Navy.

The results of investigations during the 1956-57 and 1957-58 seasons were published as Special Scientific Reports--Wildlife Nos. 38 and 44 (Kenyon et al., 1958; Rice, 1959) and as papers in ornithological journals (Kenyon and Rice, 1958; Rice and Kenyon, 1962a, 1962b).

Midway Atoll is 1,100 miles west-northwest of Honolulu near the western end of the chain of Hawaiian Leeward Islands. The atoll is composed of a ring of coral reef 5 miles in diameter with two islands, Sand Island and Eastern Island, near the southern edge of the enclosed lagoon. Sand Island, which now contains about 1,000 acres, is the site of the Naval Station, the aircraft runways of which occupy most of the southern and western portions of the island. Most of the human inhabitants of the island, all Navy personnel or employees of firms on contract with the Navy, live in the northeastern portion of the island.

Eastern Island, which is separated from Sand Island by 1 mile of lagoon, was used as an airfield during World War II, but is no longer used for this purpose. A relatively small Navy outpost now occupies this island.

In addition to its human population, Midway Atoll is the home of several hundred thousand sea birds whose nesting seasons are so staggered that most of the available land area of both Sand and Eastern Islands is occupied by nesting birds at all seasons of the year. Because of the large number of nesting birds and the large size of many of these birds, the Navy is faced with a problem of damage to aircraft and of associated human safety during the critical periods of landing and takeoff of military aircraft.

During the period of this report, Midway was a vital link in the operations of the Airborne Early Warning Barrier Squadron of the Pacific. Midway also is a refueling station for some trans-Pacific flights of military aircraft, and it serves as an emergency landing field for other Pacific flights. While now primarily a Navy problem, the potential danger of albatrosses to airplane crew members and passengers would be a vital problem to commercial airlines or other parties using this conveniently located airfield, even if the Navy were to reduce or discontinue

its operations there.

Hence, the problem reported on here is of long-term importance to aviation interests other than the Navy, which is currently sponsoring the investigations. And since the future status of enormous numbers of nesting sea birds is involved, this is an important world conservation problem.

Since most of the bird strikes involve flying Laysan albatrosses (Diomedea immutabilis) and black-footed albatrosses (Diomedea nigripes) this report is concerned primarily with investigations of these two species.

We take pleasure in acknowledging the excellent cooperation that we have received from Navy personnel on all of the trips to Midway and other islands in the Hawaiian Chain. All of the commanding officers of the Midway Naval Station during these 4 years (Capt. W. L. Richards, Cdr. I. A. Kittell, Capt. J. B. Burks, Capt. N. D. Johnson) have placed the facilities of their Command at our disposal in such a way as to expedite every phase of the investigations. Capt. J. E. Mishan and Capt. E. W. Dailey of the AEW Barrier Squadron went out of their way to provide advice and assistance and have taken a special interest in the progress of these studies. Lt. Cdr. H. J. Norton and Lt. Cdr. H. Elliott, safety officers of their staff, were especially helpful in many phases of the work. Special thanks are extended to Public Works Officer Cdr. J. B. Adams and Security Officers Cdrs. G. A. Wilson, K. W. Garwood, D. Moore, and Lt. Wheeler, and to their staffs, especially Lts. Keller, Riley, Ambrose, and Langbehn for arranging for transportation, equipment, and supplies needed for our work.

We were greatly facilitated in our field work by several enlisted men who volunteered to spend some of their free time assisting in the details, in setting up population study areas, capturing and banding birds in the study plots; among the most frequent assistants in these chores were W. Bristol, G. Johnson, C. F. Peters, and P. Schaefer.

During periods when we were not at Midway the continuity of the studies was made possible through the cooperation of Cdr. G. A. Wilson and Ens. R. F. Stockstad. Thanks are extended to the many Midway Naval Station officers who provided air transportation to Kure Atoll and over Pearl and Hermes Reef at various seasons of the year. We appreciate the cooperation of Commanding Officers Muldoun, Bates, and McCann of the Coast Guard Station at Kure Atoll for extending to us the use of their facilities during the course of investigations at Kure. Similar assistance was provided by Kincaid-Giuli, contractors, during the construction of the Kure Coast Guard facilities. Transportation to Kure prior to the installation of the Coast Guard Station was provided by the officers of the Navy ship Safeguard and the Coast Guard ship Matagorda.

Mr. Michio Takata, Director, Hawaii Fish and Game Department, and his staff have continued their very active interest in the status of bird life on all islands in the Hawaiian Chain and have extended many

courtesies on each trip. Their hearty cooperation is most gratefully acknowledged. Mr. Alexander Cornelison and others of the Navy's Department of Public Works office at Pearl Harbor have given valuable technical assistance throughout the period of these studies.

Special appreciation is extended to Cdr. Edward P. Wilson (USN retired), who for 2 consecutive years (1959-60 and 1960-61), generously assisted in the investigations on a volunteer basis. He worked from dawn until after dark 7 days a week and made possible the completion of the many phases of the study. The amount of data accumulated was nearly doubled as a result of his eager and efficient cooperation.

Other personnel of the Bureau of Sport Fisheries and Wildlife assisted materially in the field investigations. Thomas C. Horn, from the Branch of Wildlife Refuges, was a member of the first expedition to Kure in 1958. In addition to his principal duties of supervising the bulldozing operations he assisted with the population estimates of nesting birds.

Finally, Dr. Paul A. Stewart, biologist of the Patuxent Wildlife Research Center, was the coinvestigator during the field work in January, February, and March 1962, as was Game Management Agent John Waters in January and February 1963. The large amount of data on populations and population dynamics gathered during this period would not have been possible without their untiring efforts.

POPULATION ESTIMATES OF BREEDING ALBATROSSES

Knowledge of the populations and population trends of breeding and nonbreeding albatrosses at Midway and throughout the North Pacific Ocean is of paramount importance in relation to the aircraft hazard as well as to insure adequate protection of the species.

Because nesting populations vary from year to year even in undisturbed areas, populations in the more accessible areas such as Midway and Kure are estimated every year or two. A large segment of the albatross population is always at sea, so it is never possible to make a total count of the birds associated with any particular nesting island.

Most of the present section deals with nesting or nonnesting populations of birds in adult plumage at Midway during the nesting season. Studies still being continued will provide better estimates of the populations at sea.

Methods of estimating albatross populations

1956-57. During the winter of 1956-57 the population of black-footed albatrosses on Sand and Eastern Islands was ascertained by counting the occupied nests. A scratch mark was made in the sand at each nest as it was counted. Estimates of the Laysan albatross population on Sand Island were made by counts in 48 study plots of a fifth of an acre each, distributed at random throughout the island. Similar estimates were made for Eastern Island from counts in 28 random plots; counts also were obtained for specific areas on Eastern Island in January and February 1957. In addition to making nest counts, the investigators banded large samples of chicks of both species of albatrosses in specific areas of Eastern Island. By making subsequent visits to these areas the mortality from time of egg laying to fledging was determined.

1959-60. During March and April 1960, counts were made of Laysan albatross chicks in the central triangular area of Eastern Island that is bounded by the three former runways (see fig. 1), and in the areas northeast and northwest of the central triangle. By banding each chick the possibility of counting any chick twice was eliminated. In the central triangle a subsequent check was made to determine the mortality rate of the chicks.

On Sand Island, Laysan chicks were counted and banded on the Fuel Farm, at the site of Gooneyville Lodge, back of the B.O.Q. (Bachelor Officers Quarters), and between the Station Hospital and the Administration Building. A count was made of chicks in the triangle between the Sand Island runways, and rough estimates were made for the remainder of the island. Because of the great variation in density of breeding birds in various parts of the island, a large number of sample counts would

have been required to obtain a firm estimate of the nesting population.

Populations of black-footed albatrosses were counted in specific areas on both Sand and Eastern Islands. Birds were banded in certain of the areas. On all areas of Sand Island where counts were not made, the number of birds was estimated by observation. On Eastern Island a nest count was made in the areas that contained 45 percent of the black-footed albatross nests in 1956-57. The population change shown by this large sample was believed typical for the island as a whole.

1960-61. From December 24, 1960, through February 1, 1961, the nesting population of Laysan and black-footed albatrosses was ascertained by counting occupied nests on Sand Island, Midway, and on Green Island, Kure. An estimate of the nesting population on Eastern Island, Midway, was made by counting occupied nests in the more open areas where this could be done accurately, and by taking sample counts in the more heavily overgrown areas.

On Sand Island, separate counts were made by small units within each of the nine numbered areas (fire districts) of the island (fig. 2). Area 4, for instance, was divided into 67 distinct units, separated by streets, driveways, structures, and other landmarks; dates of coverage and population of each unit were recorded separately so that future changes in the nesting population could be pinpointed.

In most areas the counts were made by Wilson and Robbins, each working separate areas. In the larger unbroken tracts, the two men worked together. In the dunes of area 7 a 3-man team, which included Ens. Ralph Stockstad, made the count; the observers kept within calling distance, each working between specified landmarks. No attempt was made to mark birds or nests as they were counted, except in the various study areas, in certain sections of Eastern Island, and at Kure.

1961-62 and 1962-63. Estimates of breeding populations in these years were based on the changes in populations of the various study areas. The increase in nesting Laysans on Sand Island from 1960-61 to 1961-62 was based on a 34 percent increase in the total number of nesting pairs in four study areas. The change in nesting black-foots on Sand Island, based on a 32 percent nest count, was insignificant (1 percent decrease).

On Eastern Island there was a 19 percent increase in nesting Laysans in 1961-62, based on three study areas comprising 9 percent of the island's population. Black-foots on Eastern Island increased 5 percent, based on a 5-percent nest count.

1960-61 populations

Table 1 shows the number of occupied nests in each of the 9 numbered areas of Sand Island and on Eastern Island, together with the dates when each count was taken. It also shows the computed number of nests at the beginning of the season, based on a 6 percent loss per month of incubation (adapted from Rice, 1959).

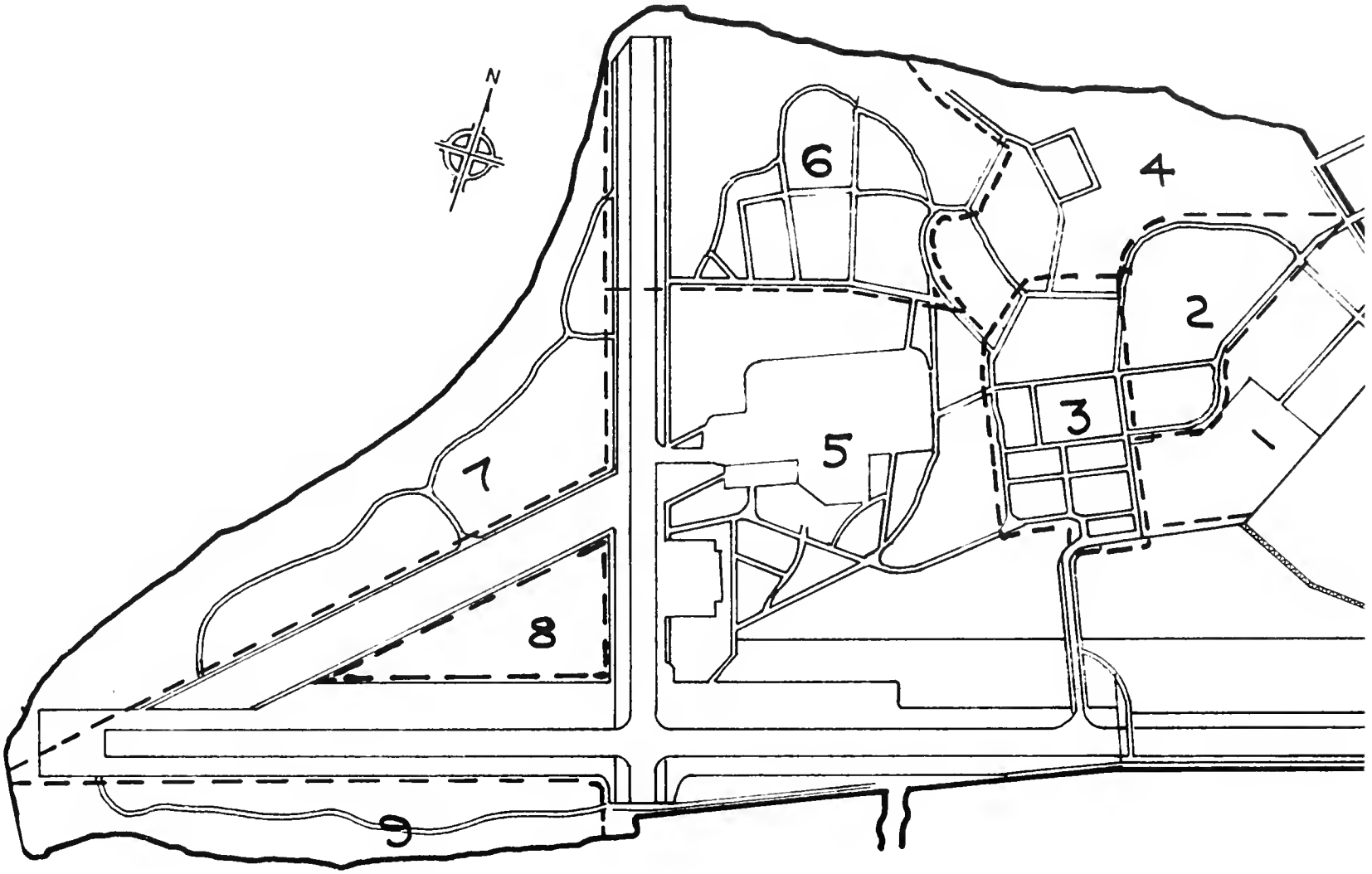

Figure 2. Sand Island, Midway. Numbers designate the 9 areas into which the island is divided.

Table 1. Albatross nests at Midway, 1960-61

Area	Number of nests: Laysan Albatross Occupied	Laysan Albatross Computed	Black-footed Albatross Occupied	Black-footed Albatross Computed	Total Computed	Dates
SAND ISLAND						
Area 1	179	190	0		190	Dec. 25
Area 2	862	965	6	7	972	Jan. 18-19
Area 3	791	842	0		842	Dec. 24
Area 4	3,267	3,712	395	449	4,161	Jan. 25
Area 5	5,719	6,291	747	822	7,113	Dec. 28, Jan.17,22,25
Area 6	3,875	4,403	135	153	4,556	Jan.22,29 Feb. 1
Area 7	6,000±100	6,818	1,621	1,842	8,660	Jan.13,21, 26,29
Area 8	422	464	134	147	611	Jan. 12
Area 9	547	602	650	715	1,317	Dec. 26, Jan.9,17
Total	20,871	24,287	3,688	4,135	28,422	
EASTERN IS.	30,000 (est.)	33,000 (est.)	2,500 (est.)	2,750 (est.)	35,750 (est.)	Dec. 29- Jan. 31
MIDWAY TOT.	50,871	57,287	6,188	6,885	64,172	

In addition to the count of nests, a separate record was kept of the number of "walkers" in each of the small units of Sand Island. In the classification "walker" are included all birds in adult plumage (that is, hatched in preceding seasons) that are not on nests at any given time. This includes those:

(1) that are present but not nesting (such as subadult birds seeking future sites),

(2) whose nests have been destroyed or deserted, and

(3) that have active nests, but are not on them because the mate is incubating or brooding at that particular time.

The term "unemployed" used in previous publications included birds in categories (1) and (2) above as well as non-nesting birds that are at sea.

Table 2 shows the number of "walkers" counted in each of the nine fire zones of Sand Island in 1960-61, the percentage of walkers among the population present at the time of the count, and the total population of adult birds (active nests plus walkers) present on the island at any one time.

Table 2. Number of walkers on Sand Island, 1960-61

Areas	Laysan albatross			Black-footed albatross		
	Walkers	Percent walkers	Adults present	Walkers	Percent walkers	Adults present
SAND ISLAND						
Area 1	219	55	398	0	--	0
Area 2	1,028	54	1,890	4	40	10
Area 3	407	34	1,198	0	--	0
Area 4	2,374	42	5,641	210	35	605
Area 5	4,292	43	10,011	544	42	1,291
Area 6	2,650	41	6,526	240	64	375
Area 7	4,110	41	10,008	1,258	44	2,879
Area 8	417	50	839	161	55	295
Area 9	436	44	983	572	47	1,222
Total	15,933	42	37,494	2,989	45	6,677

The ratio of nesting to non-nesting birds varied from place to place depending upon the amount of vandalism. In most areas there was little or no willful disturbance of the birds; but in the eastern part of area 1 (the dock area and adjacent dunes), in the vicinity of the Administration Building (area 2), and on the rifle range (area 6, black-foots), large numbers of albatrosses had been killed by vandalism prior to the counting dates. Note how much higher is the percentage of walkers in these three areas. The percentage of walkers is high also in area 8, the runway triangle. Here, the high percentage of non-nesters is attributed to the presence of a relatively large number of birds attracted to this area of favorable habitat which was still greatly underpopulated by nesters as a result of the large-scale elimination programs of 1957 and 1958 (Rice, 1959). Many of these walkers are believed to be birds that are establishing territories for nesting in future years. There has been no evidence of vandalism in this area. Some of the nesting birds

may have lost their mates from aircraft strikes, but this alone could not account for the high percentage of walkers--especially considering that other areas adjacent to the runways have a much lower percentage of walkers.

Summary of Midway populations

The available estimates of nesting albatross populations at Midway over the years are given in table 3. The record prior to the visit of the Tanager Expedition in 1923 is very sketchy. The absence of live birds on July 11, 1891, suggests that few if any Laysans nested at Midway that season, as only two-thirds of the young would have departed by that date; black-footed albatrosses, on the other hand, would probably have left Midway by that date, so absence of live birds does not mean none nested there that season.

Albatross populations in the North Pacific Ocean

For the population changes at Midway to be studied in proper perspective, they should be compared with the best available estimate of the world population of the two Midway species of albatrosses. World population estimates of breeding pairs in 1956-57 and 1957-58 by Rice and Kenyon (1962a) are given in table 4.

Reference to table 3 will show that there has been a 46 percent decrease in the nesting population of Laysan albatrosses at Sand Island, Midway, since December 1956 and that Midway, although still ranking high as a breeding area, no longer has the importance as an albatross nesting island that it did in 1956.

A better estimate of the large segment of 1- and 2-year-old birds and of older unemployed birds will be available after two or three more nesting seasons. By this time most of the survivors of banded populations from the 1956-57 and 1957-58 nesting seasons will have returned to nest at Midway.

Table 3. Estimated numbers of nesting pairs of albatrosses at Midway

Year	Sand Island		Eastern Island		Total		Reference
	Laysan	Black-foot	Laysan	Black-foot	Laysan	Black-foot	
1889	"only goonie meat to eat"						Elepaio 3(5):16
July 11, 1891	dried meat collected 2 yr. ago still hanging; no live gooneys.						Elepaio 2(5):34 3(11):12-13
Apr. 14, 1913	"a few near the houses"	"small colonies"	"quite a number"	"a few small colonies"			(Willet) Bailey '56
Apr.23-24, 1923	1,000+	1,000	1,500-1,800	1,000	2,500-2,800	2,000	Rice & Kenyon '62
late 1930's	10,000	15,000					Hadden '41
May 1945	37,500	17,500	17,500	9,000	55,000	26,500	Fisher & Baldwin '46
Dec. 1954	22,600	7,700	25,000	2,000	47,600	9,700	DuMont & Neff '55
Dec. 1956	59,700	4,300	44,300	2,300	104,000	6,600	Rice & Kenyon '62
Dec. 1957		6,188	42,600	2,333		8,521	Rice & Kenyon '62
Dec. 1959	35,000	1,435	40,000	1,400	75,000	2,835	Robbins
Dec. 1960	24,000	4,100	33,000	2,750	57,000	6,850	Robbins
Dec. 1961	32,000	4,050	39,000	2,900	71,000	6,900	Robbins
Dec. 1962	32,500		39,500		72,000		Robbins
Dec. 1963	33,000	2,700		2,000		4,700	Robbins

Table 4. Estimated world populations (breeding pairs) of Laysan and black-footed albatrosses, 1956-57 and 1957-58*

	Laysan	Black-footed	Total
Laysan Island	130,000	34,000	164,000
Midway Atoll	100,000	8,700	108,700
Lisianski Island	30,000**	2,700	32,700
Pearl and Hermes Reef	17,750	7.100	24,850
Necker Island	2,500	370	2,870
French Frigate Shoals	600	1,500	2,100
Kure	350	70	420
Nihoa, Kaula, Niihau	1,000**	150	1,150
Total breeding pairs	282,200	54,590	336,790
Total breeding pairs (rounded)	280,000	55,000	335,000
Total breeding individuals (rounded)	560,000	110,000	670,000
1-and 2-year old birds (at sea)	130,000-376,000	25,000-74,000	
Unemployed birds (walkers and 3+ year old birds at sea)	650,000-1,120,000	130,000-220,000	
Rounded total, all age classes	1,500,000	300,000	1,800,000

* From Rice and Kenyon, 1962a.

**More recent surveys made on these islands indicate that these aerial estimates probably are too high.

Frequency of bird strikes

A record of bird strikes at Midway has been kept from October 30, 1957 to date. In addition, from November 20, 1956, through May 31, 1957, dead birds picked up on the runways were counted. Many of these birds were hit by trucks and other construction vehicles. In order to obtain an estimate of the proportion of dead birds that were killed by planes, control tower personnel watched all daylight takeoffs and landings during the period April 7 through May 31, 1957. Of 100 albatrosses picked up from the runways during this period 29 were birds reported from the tower as having been hit by aircraft in a total of 25 takeoff or landing operations.

From October 30, 1957, through April 17, 1958, control tower personnel watched all daylight operations through 7 by 50 binoculars. For each strike incident they reported the type of aircraft, the date and time of day, wind direction, wind speed, runway used, position on the runway where the strike occurred, whether the plane was taking off or landing, the number and species (if known) of birds struck, the damage reported, the repairs required, and the part of the aircraft that was struck. Except for a few short lapses these reports have been continued since that time.

Summaries of bird strikes or birds killed on the runways, and of landings and takeoffs for 1956-57 and the first 3 1/2 months of 1958 were published in previous Special Scientific Reports (Kenyon et al., 1958; Rice, 1959). Table 5 gives a summary of the strike rate (strikes per 1,000 operations) from November 1957 through September 1964. The number of operations (takeoffs and landings) rose from 445 in January 1958 to 1,250 in August 1958. From that time to the present the number of operations per month has averaged close to 1,060; only once has it been below 825 and only three times has it been above 1,350. Thus, the number of strikes per 1,000 operations in table 5 closely approximates the actual number of strikes that occurred each month. The November-July Index is the sum of the albatross strikes per month for the 9-month albatross nesting season.

The number of strikes reported relates to the number of birds involved, rather than to the number of aircraft operations that encountered strikes. Thus, an aircraft that hit four albatrosses counts as four strikes. The Navy records show this as only one strike, but it seems more realistic to measure the hazard in terms of albatrosses struck rather than strike incidents. Since some of the older records that are no longer available for examination showed only the number of strike incidents instead of total albatrosses, the strike rate for 1958-59 was actually higher than shown in table 5.

In table 5, unidentified birds are included with the albatrosses and only birds known to be species other than albatrosses are excluded. Since most of the August, September and October strikes are by species other than albatrosses, these three months are excluded from the Index values.

Table 5. Albatross strikes per 1,000 operations at Midway

Month	1957-58	1958-59	1959-60	1960-61	1961-62	1962-63	1963-64	Monthly average
Oct.	--	1	1	0		0	0	0
Nov.	135	16	11	5	25	30	21	34
Dec.	128	18	47	13	27	48	15	42
Jan.	98	(59)*	34	30	50	46	31	50
Feb.	95	67	40	30	67	69	35	58
March	124	67	34	72	118	54	59	75
April	192	84	29	57	80	88	84	88
May	45	72	15	61	63	52	48	51
June	58	20	8	25	23	5	6	21
July	32	17	2	12	17	18	5	15
August	6	7	1	9	2	2	0	¼
Sept.	2	1	1	6	4	2	0	2
Total strikes	551	(496)	243	(325)	435	394	288	
INDEX Nov-July	907	420	220	305	470	410	304	
Total birds						419	308	
Total albatrosses						378	284	
unidentified						16	4	
other species						25	20	

It has not always been possible to determine the exact number of birds struck by a plane. Many strikes take place a mile or more away from the control tower and under those circumstances one cannot be sure how many of the birds that drop have actually been struck by aircraft. For example, on December 1, 1957, Johnson Neff witnessed at close range the killing of 23 albatrosses by aircraft; 4 of the 23 did not come in contact with the aircraft, but were caught in the prop wash or slip stream and catapulted to the ground. Many of the strikes reported in subsequent years likewise do not represent actual contact between aircraft and bird, but the ratio of actual strikes to presumed strikes probably does not vary significantly from year to year.

From April 1958 to the present time the strike reports have been made up from incidents witnessed by the tower, reports from pilots, and reports from maintenance crews who sometimes find bird damage that had not been reported by the tower or the plane's crew. Another factor that makes it difficult to make an exact appraisal of the strike rate is the variation in reporting strikes. The Barrier Squadron, keeping a separate record, sometimes has shown more strikes than are reported by

*incomplete record; estimated from ratio of Jan. to Feb.-July totals for 1958 and 1959.

the Naval Station for station and barrier aircraft combined. For example, during the first 10 months of 1960 the Naval Station reported 178 strikes while the Barrier Squadron had 226 involving only their own planes. The data for table 5 were compiled by comparing records from both sources. Starting in November 1960 the records are believed to be reasonably complete. During 28 recent months for which strike reports are available both from the Naval Station and the Barrier Squadron, the Barrier Squadron reported 645 strikes and the Station summary including the Barrier figures was 932 strikes. This indicates that on the average 70 percent of the strikes involved Barrier aircraft and the other 30 percent involved Station aircraft.

Time of day of bird strikes

About 91 percent of the albatross strikes occur between sunrise and sunset. Albatrosses do very little flying at Midway at night, although roosting birds in the vicinity of the runways readily take flight if disturbed at night. Monthly strike reports currently specify the number of aircraft operations during the daytime and the number at night; but since similar information is not available for the entire period of the study the figures given in table 5 are not separated into daytime and nighttime operations. During calendar year 1962, 63.4 percent of the aircraft operations were by day. During this year 438 bird strikes were reported and the time of day was known for 428 of these. Although the reports do not specify which strikes were classified as occurring by day and which by night, very few strikes occurred close to sunrise or sunset. Forty-nine of the strikes or 11.4 percent of the total (including all species of birds) are considered as having occurred at night. The night strikes involve a lower percentage of albatrosses and a higher incidence of petrels and terns. If only albatross strikes are considered, approximately 9.6 percent occurred at night and 90.4 percent by day. For the year as a whole about 1 percent of all nighttime operations and 5 percent of daytime operations were involved in albatross strikes.

Kenyon et al. (1958) stated that in 1956-57 all reported albatross strikes occurred by day; but during that period 97 percent of all aircraft arrivals and departures took place during daylight hours.

Damage to aircraft

Table 6 shows a summary of aircraft operations and of bird strikes during calendar year 1962. It will be noted that during this period 4 percent of all takeoffs or landings involved bird strikes and that 18.8 percent of the strikes that occurred during takeoff were of serious enough nature to cause the aircraft to abort or return.

Although there has been no fatal accident resulting from a bird strike, there are four incidents known to us where loss of an aircraft almost occurred. In two of these cases the upper radome was weakened by an albatross strike on takeoff and was lost in flight before the air-

craft returned to Midway. Had the departing radome hit vital portions of the tail assembly it would have been impossible for the aircraft to return safely. A bird strike on the nose radome of another aircraft covered the windshield with bird remains just after the aircraft had accelerated through refusal speed and nearly resulted in a fatal accident; in order to save the aircraft and crew, the aircraft commander gave the engines maximum throttle, jettisoned most of his fuel and returned safely. This one incident required replacement of all four aircraft engines as well as the nose radome (a cost of $34,110.00).

Another near accident occurred when an albatross severed a hydraulic line on landing; by reversing pitch of the propellers and applying maximum power, the pilot succeeded in stopping the aircraft at the very end of the runway.

Although the high cost of repairs at Midway is of minor concern compared with the danger to human lives, it is appropriate to point out that the reported cost of repairs to Barrier aircraft alone ran as high as $148,000.00 in calendar year 1959.

Table 6. Aircraft operations and bird strikes at Midway, 1962

Month	Ops.	Strikes	Strikes w/known damage	Return or Aborts	Take-off	Land-ing	Other
Jan.	877	38	12	1	21	15	2
Feb.	825	53	20	4	34	16	3
March	966	98	13	7	56	40	2
April	866	67	7	16	30	35	2
May	953	56	8	6	28	25	3
June	999	25	1	2	13	12	
July	996	23	3	0	13	10	
Aug.	882	7	0	0	3	4	
Sept.	895	7	2	2	4	3	
Oct.	911	2	0	0		1	1
Nov.	906	27	4	not stated	8	15	4
Dec.	714	35	5	not stated	18	16	1
	10,790	438	75	38 per 376 strikes	228	192	18

4.06% of 1962 operations had strikes.
0.70% of 1962 operations had damage reported.
17.1% of 1962 strikes had damage reported.
18.8% of 1962 takeoffs involving strikes aborted or returned.

SUMMARY OF EXPERIMENTAL CONTROL METHODS TESTED ON ALBATROSSES AT MIDWAY

This summary includes the principal methods that have been tried at Midway by Bureau of Sport Fisheries and Wildlife personnel and other investigators. Some of these studies have been described in more detail elsewhere (DuMont and Neff, 1955; Kenyon et al., 1958; Rice, 1959; Frings and Frings, 1959). Except where otherwise specified, the methods were tested by Bureau of Sport Fisheries and Wildlife personnel.

1. Disturbance:

   a. Frequent chasing, capturing, and handling of adults:
      Nesting birds became more alert, snapped more often at people; a very few individuals deserted their nests. Non-nesting birds soon became wary and attempted to avoid capture.

   b. Walking toward birds while holding 3-foot squares of colored cloth or cardboard:
      Hubert Frings reported success, especially with red, when tried on a small scale. His belief that 20 to 30 men in 2 weeks (November 5-20) could have freed areas 7, 8, and 9 of nesting birds is not substantiated by the rapid repopulation that followed destruction of adults and nests (8b).

2. Gunfire: Rifles, pistols, bazookas, mortars:
   Some birds registered discomfort, but no appreciable number deserted or changed their nest sites in subsequent years.

3. Other sounds:

   a. Albatross distress calls:
      Distress calls given during fights between albatrosses seem to be regarded as a "personal" matter and do not alarm other albatrosses nesting nearby. I have held an adult bird by the wingtip and swung it around in a circle to make it scream; nesting birds a few feet away did not even look to see what was causing the commotion. Non-nesting birds, on the other hand, generally do notice disturbance. Many non-nesting birds give the distress call at least briefly when they are caught; other non-nesters nearby react by walking away. Excessive disturbance, such as chasing and catching hard-to-catch birds causes non-nesters to run or fly away.

   b. Carbide exploders:
      10 automatic carbide exploders were used at intervals of 135 feet along the edge of runway 15-33, pointed toward the runway (downwind), in the area where flying birds were most numerous. There was no decrease in number of flying birds either immediately or after 4 days of operation.

c. Ultrasonic siren:
An ultrasonic siren with a peak output of 100 decibels of white sound at about 20 kc. was tested on nesting birds and flying birds. There was no decrease in number of birds flying over, or in number of birds on the ground.

d. Jet engine sounds:
Amplified playback of a tape recording had no measurable effect on number of birds flying over. A jet start unit operated in the middle of runway 15-33 also had no measurable effect (as judged by series of photographs taken before, during, and after operation). In both cases the output in decibels was low as compared with takeoff of a jet aircraft; no equipment was available to measure the output.

e. Signal generator:
An amplifier with a rated potential of 35 decibels was used to test the effect on Laysan albatrosses of tones from 20 to 20,000 cycles. Awareness seemed most pronounced between 900 and 1,000 cycles; no response was noted above 3,000 cycles. No birds were repelled.

f. High intensity sounds:
Hubert Frings stated that for flying birds, "almost any sound, if the intensity was increased to above about 120 db. at 1 meter from the speaker, became repellent at distances up to 100 feet . . . with recordings of the sound of airplane engines, the effects seemed much more intense and occurred at lower intensity levels." In the winter of 1962-63 Frings studied the effects of playing intermittent sounds at high intensity.

4. Radar:
A radar beam from a mobile unit had no visible effect on flying birds. High intensity radar from the Navy's radar patrol aircraft (WV2) was beamed on nesting albatrosses at distances as close as 100 feet with no observed effect.

5. Smoke: Daylight flares, burning rubber tires:
No effect.

6. Odors: Naphthalene and paradichlorobenzene:
No effect.

7. Nest destruction:

a. Breaking eggs:
When eggs were broken early in the incubation period (95 nests), adults remained in the general vicinity for several months; if broken late in the incubation period (70 nests), the adults remained for several weeks.

b. Poisoning eggs (80 nests):
Adults continued to incubate several weeks beyond normal incubation period, then left the vicinity.

c. Killing small chicks (63 nests):
The majority of adults left the area within 2 weeks.

8. Destruction of adults:

a. Killing 1 member of each pair during incubation (67 nests):
Mate generally took its next turn at incubation, then deserted and left the area.

b. Destruction of all nests, eggs, and adults present on one day early in incubation (67 birds and 34 nests destroyed on Dec. 2):
In 2 weeks, the number of birds present was three-fourths of the original number and the number of nests half of the original number.

c. Destruction of all nests, eggs, and adults half way through incubation (40 birds, 15 nests):
In 2 weeks, the number of birds present was the same as before the kill, but no more eggs were laid.

d. Large-scale destruction (4,788 adults along sides of runways, Apr.-May 1957):
Immediate increase in birds over the runways (96 per hour before kill, 246 per hour the day after the first kill of 1,495 adult birds).

e. Large-scale destruction (30,041 adults along sides of runways, Jan.-Mar. 1958):
No decrease in soaring birds or in strike rate this season, but the decrease the following two seasons probably was in part a result of the reduction in number of nesting birds.

9. Moving of birds or nests:

a. Adults:
Of 18 nesting birds flown to Japan, Philippines, Guan, Kwajalein, Barbers Point, and Washington State, 14 returned to their nests on Midway the same season.

b. Nests with eggs:
Several moves of less than 5 feet have been successful. One bird that attempted to nest on the chapel lawn accepted a move of about 50 feet, but only after days of patient coaxing by the chaplain.

c. Young chicks:
Normally adults will not accept nests (with chicks) that are moved more than 6 feet. Chicks that have wandered from the nest or have been moved will not be recognized and fed unless they return to the immediate vicinity of the former nest site. In two cases where adults were repeatedly put on nests that had been moved 6 feet, and appeared to have accepted the move for nearly 2 days, the chicks subsequently were deserted and died.

d. Full-grown chicks:
Dr. Harvey I. Fisher, transported 991 chicks from Sand Island to Eastern Island in 1961, 111 from Sand Island to Kure in 1961, and 1,697 from Sand Island to Lisianski in 1962. By the winter of 1964-65 a few of the 1961 birds which survive should return briefly to either the hatching island or the place to which they were transported, but no appreciable number are expected to nest until the winter of 1967-68.

10. Obstacles:
Hubert Frings found that birds would not fly under a strip of red cloth, 10 by 3 ft., suspended from the tops of two 20-foot poles, 20 feet apart.

11. Habitat management:

a. Surfaces not used for nesting:
Albatrosses do not nest on hard surfaces such as concrete, asphalt, or hard-packed coral. They do not nest on ground covered with poultry wire. Very few nest in low areas (along the runways) that are subject to flooding.

b. Grid of elevated wires:
Frings set up a grid of electrically charged wires 10 feet apart and 6 inches off the ground. In a plot 40 by 40 ft. no birds nested; neither did they nest in a similar plot with uncharged wires.

c. Leveling of terrain and hard-surfacing:
This topic is discussed in detail in the next section.

This section reviews past albatross control experiments and habitat modification. It summarizes the reasons why additional terrain modification was recommended and conducted. It describes methods used in determining effects of terrain modification, and discusses the changes in albatross distribution and abundance over the runways following completion of the 1959-60 and 1962 leveling and black-topping programs. It also points out the effects of specific weather conditions on albatross soaring, and discusses recommendations for additional habitat management.

Summary of habitat management and albatross control, 1956-1958

Studies of color-marked birds made in the winter of 1956-57 (Kenyon and others, 1958) showed that two-thirds of the albatrosses flying over the runways came from within 750 feet of the runways.

In order to test the effect of removing birds from within 750 feet of the runways, a large-scale control experiment was undertaken in the triangular area (area 8) of 29 acres situated between runways 6-24, 15-33, and former runway 3-21. About 85 percent of this area lies within 750 feet of the centerline of one or both of the runways. The number of albatrosses using this triangle in January and February 1957 was estimated at 8,727 (6,216 adults and 2,511 chicks). During 12 days from April 22 through May 23, 1957, 6,266 albatrosses were killed there. They included 100 adult black-footed albatrosses, 4,688 adult Laysan albatrosses, 1,371 young (mostly Laysans), and 107 albatrosses of unspecified species and age. Thus about 77 percent of the adults using the area were killed. Nearly half the chicks in the area had been killed earlier by construction operations, so the kill of young during the control operation was relatively small.

The Navy conducted an expanded killing program in the following season (1957-58) under the observation of Bureau biologists. This program included not only the triangle (area 8) of the 1956-57 experiment but also all other areas adjacent to the western half of runway 6-24 (west of its intersection with runway 15-33) within 750 feet of its centerline. This killing program was conducted on 5 days or nights a week for $7\frac{1}{2}$ weeks, from January 15 to March 7, 1958. The number of adult albatrosses destroyed in the triangle area was 277 black-foots and 3,160 Laysans. In the new kill areas within 750 feet of runway 6-24, 26,604 adult Laysans were destroyed. No chicks were permitted to hatch in any of these areas in 1958.

As Rice (1959) pointed out, there was little reduction of birds over the runways during the seasons that albatrosses were being eliminated. From studies of their life history it is known that albatrosses are attracted to, not repelled by, an area of suitable nesting habitat from which other albatrosses have been removed; thus additional birds keep

arriving during the nesting season and not even a temporary absence of birds can be expected as a result of an intensive killing program.

Studies conducted by Kenyon and others and by Rice (Kenyon et al., 1958, pp. 40-45; Rice, 1959, pp. 24 and 33-39) showed that albatross distribution over the runways is extremely variable, depending upon wind conditions, and that there is a strong tendency toward an increase in soaring in the vicinity of dunes and vegetation under certain wind conditions.

Consequently, the Bureau of Sport Fisheries and Wildlife recommended that changes be made in the terrain adjacent to the runways. In order to reduce rising air currents along the runways they suggested removing trees and leveling dunes; and in order to eliminate nesting sites within 750 feet of the centerline of the runways they recommended that the shoulders to that extent be hardsurfaced.

Most of the triangle (area 8) had been flattened and nearly all trees had been removed in 1957. The area adjoining the north side of the east half of runway 6-24 was already level, but much of it was covered with ironwood trees (Casuarina equisetifolia). These trees subsequently were removed; thus the only tall vegetation remaining within 750 feet of the center of runway 6-24 was on the south side of the west half of the runway (the area south of the eastern half was already level and bare).

Land leveling along runway 6-24 in 1959-60

In accordance with recommendations by the Bureau of Sport Fisheries and Wildlife, plans were made to remove vegetation and to level the dunes on the south side of the western half of runway 6-24 within 750 feet of the centerline and so reduce the upward deflection of wind currents conducive to soaring of albatrosses. In addition to leveling, it was decided to cover the area with a sealing material. This decision was made (1) to prevent the denuded sand from blowing onto the runway, (2) to render the area unsuitable for nesting albatrosses, (3) to hamper regrowth of vegetation, and (4) to serve as rainwater catchment for use of the Naval Station.

Construction was begun by a Seabee crew under the direction of C.W.O. Munson on November 26, 1959, and was completed on March 17, 1960.

Albatross counts over the runways, 1960

Series of 10-minute counts of albatrosses flying over the runways were made by Robbins and Wilson from March 20 through April 10, 1960. The counts were made from locations where similar counts had been made in the springs of 1957 and 1958 (Kenyon et al., 1958, pp. 40-44; Rice, 1958, pp. 33-39). The locations of the counting positions are shown in figure 3. No counts were made at position 7 after 1957 because, after

dunes in the central triangle were leveled, conditions at position 7 were similar to those at position 6.

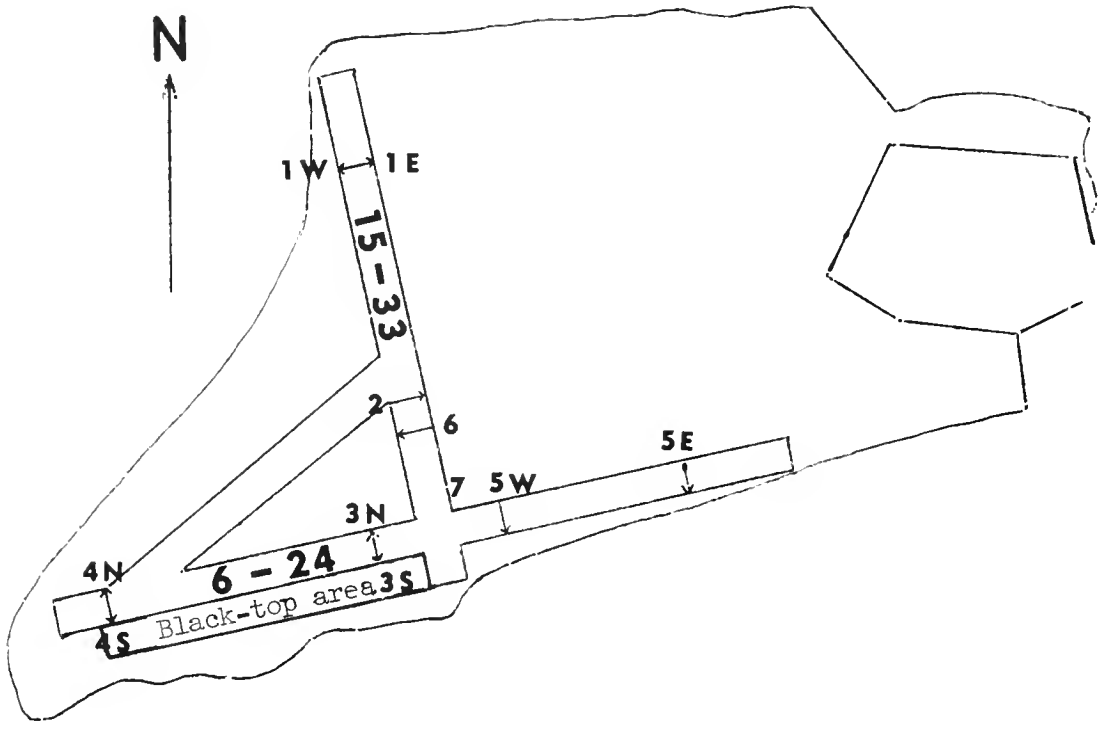

Figure 3. Positions from which soaring albatrosses were counted on Sand Island, Midway, are numbered from 1 to 7, some with east and west or north and south positions. Runway numbers are shown on the runways.

Counts in 1957 and 1958 were made by a single observer, who counted at each position successively. In 1960, there were two observers, and counts were made simultaneously from two positions. At positions 1, 3, and 4, observers stood on opposite sides of the runway, 175 feet from the centerline, and made simultaneous counts. Positions 2 and 6 were covered simultaneously, as were positions 5W and 5E. Observers shifted positions from day to day in order to eliminate bias in counting at the various locations. In 1960, the presence of an observer on each side of the runway made it possible to obtain a much more accurate count than could otherwise have been achieved. The observers developed a series of hand signals to tell each other which borderline birds were inside and which were outside the counting area.

In order to study the effect of wind conditions on the distribution of birds over the runways, only those birds were counted that flew through a vertical triangle whose base extended 350 feet (to the opposite

side of the runway) and whose angle of elevation from the observer was 10°. Thus each observer was counting primarily those birds that were flying over the opposite side of the runway. In this way the relation between bird concentrations and local topography could be studied under various wind directions and wind speeds.

In 1957 and 1958 the observers counted only those birds that were within an angle of 7 1/2° from the ground. At some locations this angle was estimated by sighting in line with a tall tree; at other locations, such as at 5E, no vegetation was present and the angle was simply judged by the observer. In 1960, angles were judged by sighting over a millimeter rule (held at arm's length) marked with distances equivalent to angles of elevation of 7 1/2° and 10°.1/ In 1960 an additional record was kept of all albatrosses flying between observers, regardless of the angle of elevation.

Comparison of albatross counts of 1958 and 1960

Counts during the period March 20 through April 10, 1960, were compared with those made at corresponding positions during the period March 1 through May 2, 1958, before terrain modification. Observations at positions 1, 2, 3, and 4 were grouped according to "favorable" and "unfavorable" wind directions as defined by Kenyon and others (1958). Although terrain modification has since reduced the differences that occur between winds from directions "favorable" for soaring and winds from opposite or "unfavorable" directions, data were analysed separately to emphasize effects of terrain modification. The mean number of birds recorded per hour at each counting position is shown in table 7, together with the percentage change from 1958 to 1960. The same information, as well as comparable data for 1957, is shown in figure 4. The decrease in 1960 at counting positions 4 and 3, adjacent to the recently leveled and black-topped strip along the principal operational runway, is most striking. The average decrease in birds flying over runway 6-24 at these positions was 75 percent. At the other location where bird concentrations have been high (position 1 on runway 15-33), the average decrease was 28 percent. At positions 2 and 6 along runway 15-33 and positions 5W and 5E along runway 6-24 increases occurred. Although the

---

1/ The standard angle used in 1960 was 10°, but enough observations were made simultaneously of the number of birds between 0° and 7 1/2° and between 7 1/2° and 10° to provide a correction factor. In a subsequent conversation with Rice it was learned that the base line of his counting area extended about 25 feet beyond the far edge of the runway at positions 1W and 5E, and 50 feet beyond it at positions 2, 3, 4, 5W, and 6, depending in part on proximity of reference trees to the runway. The resulting conversion factors correcting for a decrease in angle of elevation and an increase in base line were 0.858 for converting 1960 observations to 1957 and 1958 equivalents at stations 1 and 5E, and 0.976 at all other locations.

percentage increases were high, the number of birds at each of these positions was comparatively small. The terrain adjacent to these four positions was level during the entire period, 1957-1960; the increase in birds in these areas that are unfavorable for soaring is believed to result from a general dispersal of birds that formerly were concentrated in areas with rising air currents. The mean number of birds counted at positions along runway 6-24 dropped 61 percent from 1958 to 1960; the mean number along runway 15-33 increased 4 percent.

Table 7. Comparison of number of albatrosses per hour passing over the runways on Sand Island, Midway

	Jan.-Feb.-Mar. 1958	March-April 1960	Percent change
Runway 6-24			
position 4N (favorable*)	1023	282	-72%
position 4N (unfavorable)	696	252	-64%
position 3N (favorable)	1231	264	-79%
position 3N (unfavorable)	753	132	-82%
position 5W	35	192	+449%
position 5E	11	84	+664%
TOTAL (4 positions)	1898	741	-61%
Runway 15-33			
position 1W (favorable)	2231	888	-60%
position 1W (unfavorable)	1267	1614	+27%
position 2 (favorable)	170	462	+172%
position 2 (unfavorable)	157	486	+210%
position 6	150	426	+184%
TOTAL (3 positions)	2063	2151	+4%
Both runways			
TOTAL (7 positions)	3961	2892	-27%

* Condition of wind for soaring

Seasonal variation in counts

In 1958, counts of birds flying over the runways extended over a long enough period that seasonal changes occurred. No such trend was apparent during the 3-week counting period in 1960, either for all data considered together, or for counts under specific wind conditions.

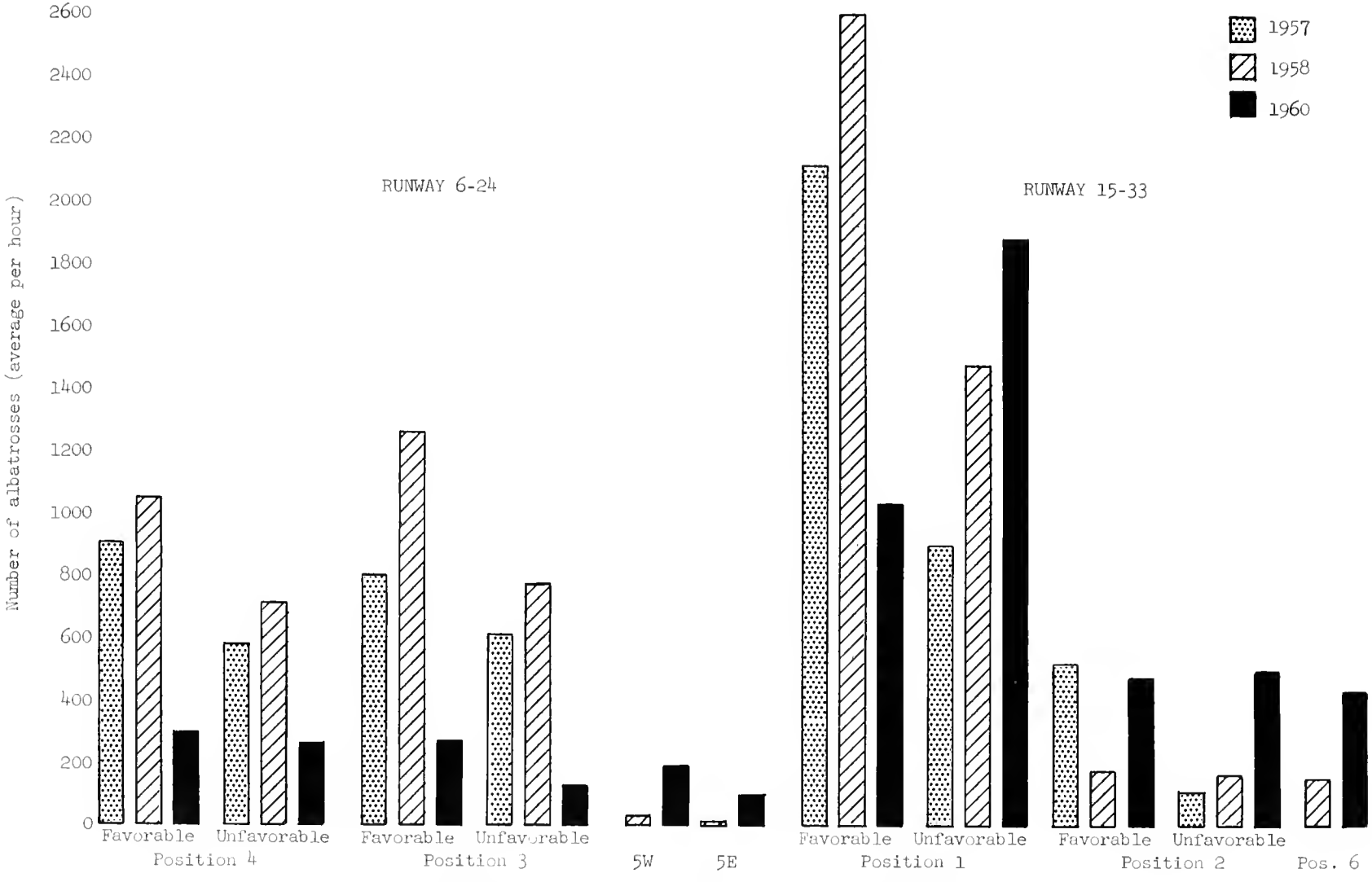

Figure 4. Average number of albatrosses crossing per hour in 1957, 1958, and 1960. Counts at most positions are shown for favorable and unfavorable wind directions.

Hourly variation in counts

Hourly variation in counts was studied for positions 1W and 1E, where the large number of birds near the height of land along runway 15-33 gave the best opportunity to detect differences. Data for the two years differed: average afternoon counts were about 20 percent higher than average morning counts in 1960, but average morning counts were higher in 1958. Further study of the 1960 data showed that the morning and afternoon differences were related to differences in wind speeds. There was a trend toward higher numbers of birds at high wind speeds and lower numbers of birds at lower wind speeds. For example, when winds were from the southeasterly quadrant, the four lowest counts at position 1E were obtained when the wind speed was 10 knots or less, and two of the three highest counts were obtained when the wind speed exceeded 20 knots.

Comparison of counts on sunny days and on overcast days

Counts on sunny days were compared with counts on overcast days to determine whether they were affected by the presence of thermals. Paired observations (equal time periods on sunny and on overcast days) on some 800 birds showed no differences greater than 20 percent. At some positions the average counts were a little higher on sunny days; at other positions along the same runway the highest average counts were on overcast days. These conclusions were drawn from analyses of counts from all positions. Positions 1W, 1E, 2, and 6 were considered separately; positions along the north side of runway 6-24 were grouped because of the small sample, as were positions along the south side of the same runway. Comparisons were limited to days when winds were from the southeasterly quadrant. Observations were restricted further to include only those days when winds were light (6 to 12 knots), the best conditions for detecting effects of thermals.

Effects of wind direction on counts

The effects of wind direction on numbers of soaring albatrosses were studied by comparing counts made when winds were from different compass directions. Counts for each of the 16 directions were plotted separately for 1957, 1958, and 1960. Frequency of winds from the different directions was similar in the different years. The principal difference was that in 1958 winds were preponderantly from the southeast and south-southeast, whereas in 1960 winds were preponderantly from the south. Winds from between south-southwest and north-northeast were infrequent in all three years, but especially so in 1960. Other wind directions were just about equally represented in 1958 and 1960.

Percentages of albatrosses soaring under different wind conditions are shown in figures 5 and 6. Data for the figures were obtained by computing the mean numbers of birds counted when winds were from each compass direction, then converting these figures to percentages. Solid

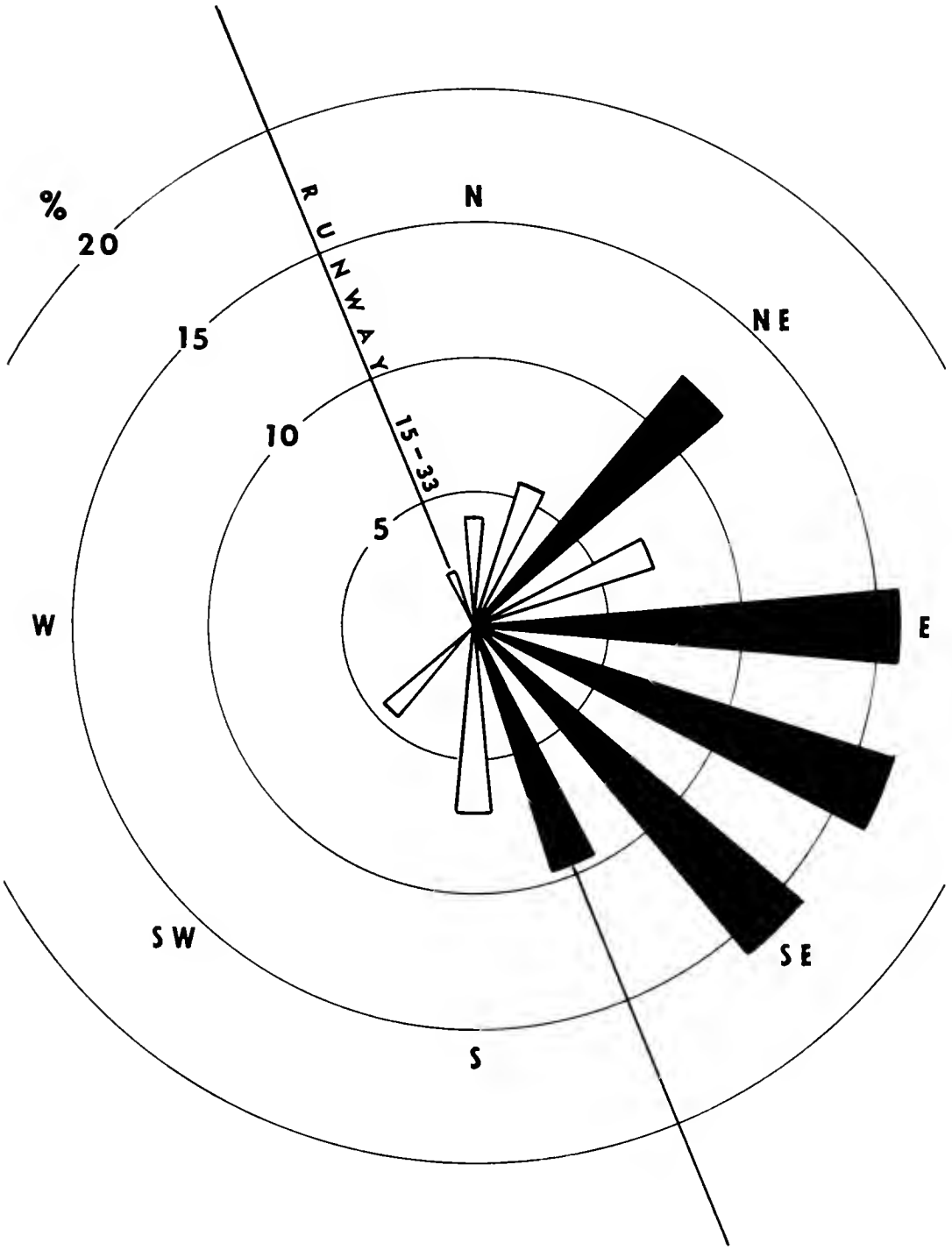

Figure 5. Relative abundance of soaring albatrosses in relation to wind direction. Percentages are based on mean numbers of birds counted. Solid bars represent averages based on 3 or more days and outlined bars 1 or 2 days each (from 1960 counts at position 1W, runway 15-33).

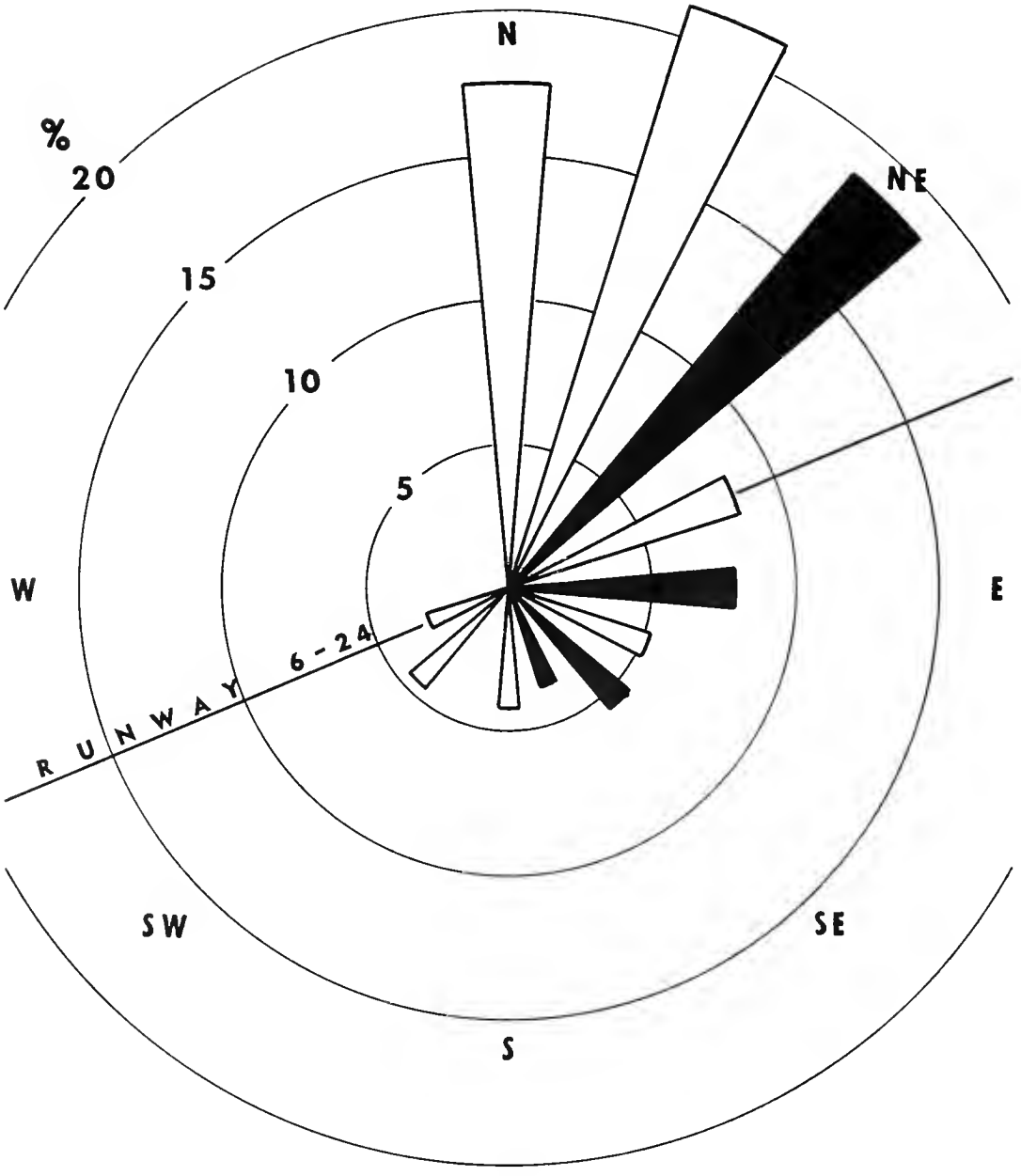

Figure 6. Relative abundance of soaring albatrosses in relation to wind direction (1960. Positions 3 and 4, Runway 6-24). See Figure 5 for explanation.

bars in the figures represent averages from 3 or more days; outlined bars represent one or two observations each. The figures show that the highest concentrations of birds along runway 15-33 occurred when winds were from the east to southeast, whereas the highest concentrations along runway 6-24 occurred when winds were from north to northeast. Effects of winds from north to northwest could not be appraised because there were too few days with winds from the north, and no day of sustained winds from between north and west.

The different effects of wind direction on the two runways suggest that it may be advantageous to operate all aircraft flights from runway 6-24 when winds are from the southeast or south-southeast and are light enough to make this feasible. Flights of light aircraft might well be diverted from runway 6-24 to runway 15-33 when winds are from north to northeast. Further data are needed before these suggestions can be established as positive recommendations.

The effect of the angle of incidence of the wind on the number of flying albatrosses is shown in figure 7. The figure shows relative frequency of albatrosses at position 1 on runway 15-33 and at positions 3 and 4 on runway 6-24. Data were grouped according to the angle of incidence of the wind to the runway, irrespective of the quarter from which the wind was blowing. There were 3,374 sightings at position 1. The highest average number of birds per 10-minute period (29 percent) occurred when the wind was blowing at an angle of 45° to the runway. Lower numbers were observed on days when the wind was blowing from an angle of 22° or 67°. The lowest numbers (13 percent each) were observed when the wind was blowing parallel to the runway, and when the wind was blowing at right angles to the runway.

There were 276 sightings at position 3 and 512 sightings at position 4 on runway 6-24. Results closely resemble those for position 1 on runway 15-33.

The preponderance of birds counted when the wind was at a 45° angle to the runway would not be expected if birds were moving at random. With random movements and counts made by sighting directly across (at right angles to) the runway, the number of birds counted in a 10-minute period would be expected to be least when birds were moving at right angles to the runway and greatest when birds were flying directly down the runway. Also, with random movements, the highest counts would be expected when winds were blowing parallel to the runway, and progressively lower counts would be expected as the angle approached 90°. Results also would differ from those found if the birds were depending primarily upon thermals. For then the greatest soaring would take place on days when the wind was blowing directly down the runway so that the air warmed by the runway would be drifted along it rather than blown off to the side.

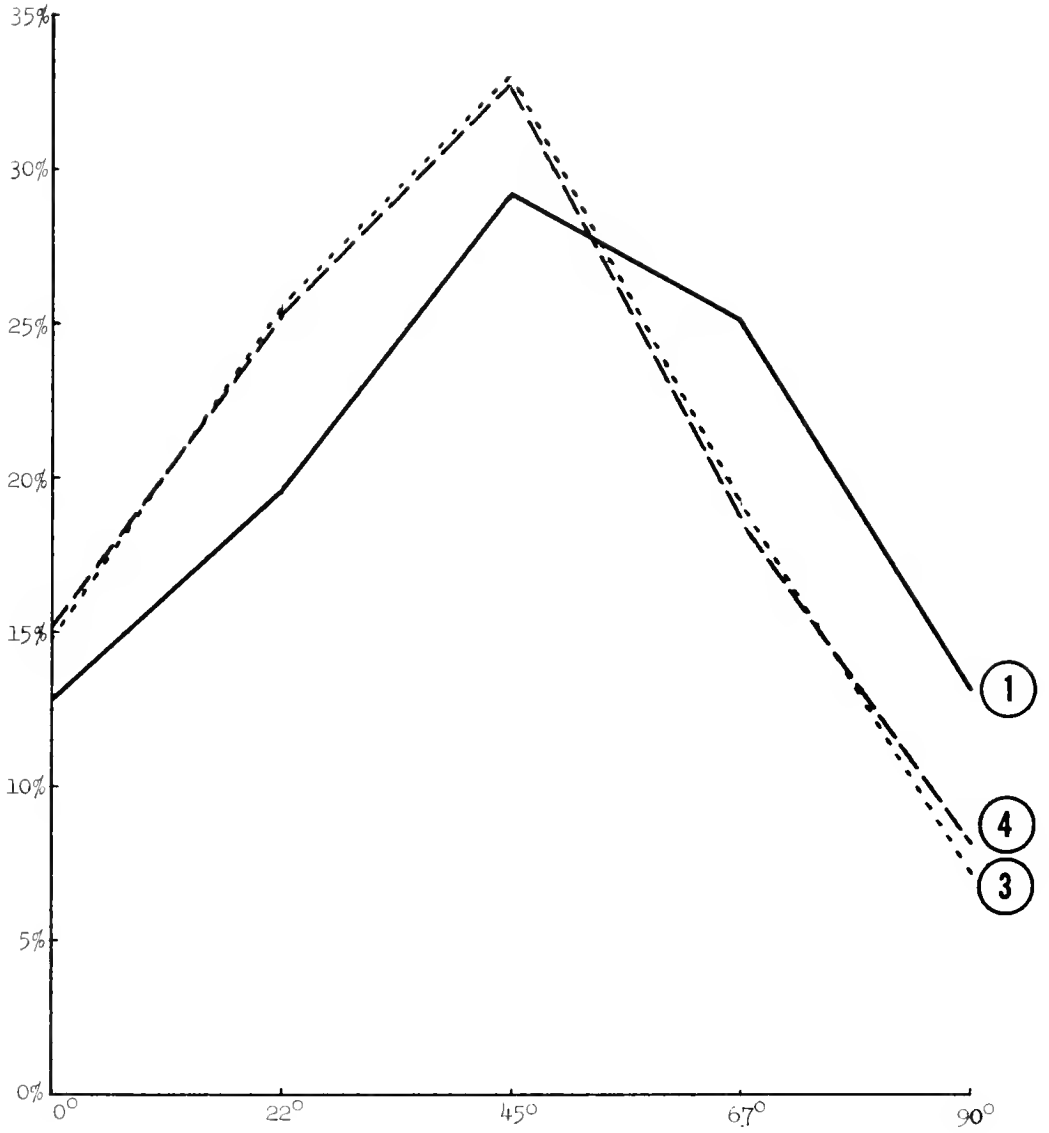

Figure 7. Relative numbers of soaring albatrosses in relation to angle of incidence of the wind to the runways. See figure 3 for location of counting positions 1, 3, and 4.

Distribution of birds over and adjacent to runway 6-24

The numbers of birds over the runway, over the adjacent black-topped area, and over the adjoining dunes were compared by a series of photographs. The principal purpose of the comparison was to appraise the effects of leveling and black-topping the area along the south side of the principal operational runway, 6-24. Casual observations had shown that flying birds were concentrated at all daylight hours over the narrow strip of dunes between the black-topped area and the south shore of Sand Island. In the early morning and again in the evening, nearly all the birds soaring over the dunes were Laysan albatrosses. In the middle of the day, the number of albatrosses was comparatively low and the number of red-tailed tropicbirds (bosun birds) exceeded the number of albatrosses.

Photographs were made at hourly intervals throughout the day of April 1, 1960. Each series of photographs was started 10 minutes before the hour so as to be centered around the time weather observations were made. Weather conditions that day were typical of those prevalent at that time of the year at Sand Island. Winds were from the northeast at 6 to 8 knots, except that the 1300 hour reading showed winds from the east-northeast instead of the northeast, the 1600 reading showed a speed of 10 knots, and the 1800 reading showed 4 knots. Temperatures ranged from 63° to 67°. Skies were partly overcast at times, but there were periods of full sunlight.

All photographs were taken with a 16 mm. movie camera with a 4-inch f.4.5 cine telephoto lens. Each hourly series of photographs consisted of five instantaneous exposures made at $\frac{1}{2}$-minute intervals from each of three locations: (1) west end of runway 6-24, with the camera pointed directly along the center line of the runway; (2) west end of the recently black-topped area, with the camera pointed lengthwise through the center of this area and parallel to the runway; and (3) near the south extremity of the west end of the black-topped area, with the camera pointed along the line of dunes that separates the black-topped area from the beach.

The film was examined with a microfilm reader that magnified 24 times. Counts were made of the number of albatross images that measured 2 mm. or more on the screen. Figure 8 shows the combined counts of albatrosses for each series of five exposures from each of the three camera positions. The mean number of birds within the view of the camera at any one time thus was one-fifth of the value shown in the figure. The mean number of albatrosses over the runway was 0.95. The mean number over the adjacent black-topped area was 1.80, and the mean number over the dunes was 5.31. There was considerable variation from hour to hour for all areas, but especially for the dune area. The number of birds over the black-topped area, nevertheless, was always lower than the number over the dunes. The number over the runway itself was always lower than or equal to the number over the black-topped area.

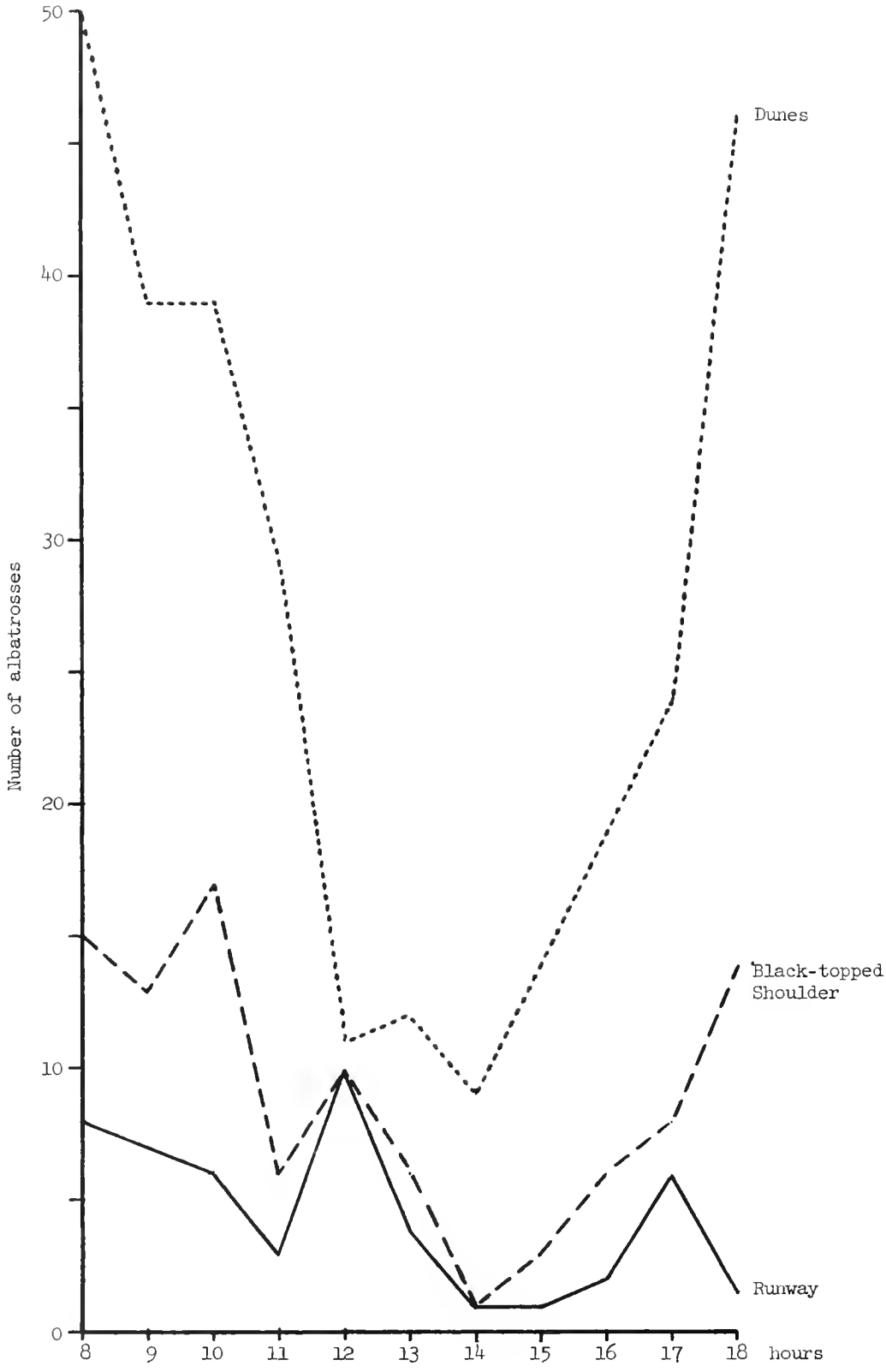

Figure 8. Numbers of albatrosses photographed over runway 6-24 and adjacent areas each hour of the day, April 1, 1960.

The difference in numbers over the runway from those over the dunes was quite striking. The field of vision was the same for each, but the dunes concealed some of the birds so that the differences were even greater than shown in the photographs.

In all areas, there was a peak of activity in the early morning hours. There was another brief peak in the evening, when large numbers of birds apparently returned from the sea to spend the night on the island. There was no evidence of increased numbers during the warmest period, when thermals would have been most prevalent.

Bird strikes in relation to wind direction

Wind conditions at the Midway control tower are recorded at the time of each bird strike. This makes it possible to compare the number of bird strikes when the wind is from any given compass direction with the number that would be expected if strike frequency were proportional to wind frequency from each compass direction. Wind direction frequencies for the months of March, April, and May, 1960, were compiled from the hourly observations recorded from 6 a.m. to 8 p.m. at the Midway control tower; these observations were made available by the National Weather Records Center, Asheville, N. C. All except 5 of the strikes reported during these 3 months occurred between 5:30 a.m. and 8:30 p.m.

By dividing the compass into four quadrants and comparing strike frequencies and wind frequencies from each quadrant it was found that 36 percent of the 77 strikes (omitting 3 strikes that occurred when the wind was calm) occurred when winds were from the north to east-northeast (25 percent of the time); 31 percent of the strikes occurred when winds were from east to south-southeast (49 percent of the time); 21 percent occurred when winds were from south to west-southwest (21 percent of the time) and 12 percent occurred when winds were from west to north-northwest (5 percent of the time). These data show a higher proportion of strikes when winds are from a northeast or northwest quadrant, and fewer strikes when winds are from the southeast.

The statistical significance of these data was tested by comparing the number of strikes when the wind was from each of the four quadrants with the number that would be expected from the number of days the wind blew from each quadrant (if strikes occurred with equal frequency regardless of wind direction). The differences between the expected and observed strike frequencies were found to be highly significant (chi^2 = 15.67, df. = 3, $p < .005$). A similar chi-square test was made for only the daytime strikes. Another was made by lumping all three months together instead of treating them separately as was done in the first test. In each case the probability that the difference between the observed and expected strikes was due to chance was less than one-half of 1 percent showing that the strike rate is higher under some wind directions than others.

Leveling and paving of Sand Island triangle

The triangular area between the Sand Island aircraft runways has long been considered a source of potential danger in that it represents a considerable area of good albatross nesting habitat in close proximity to both runways. Kenyon et al. (1958) determined that about two-thirds of the birds over the runways came from within 750 feet of the runways. Consequently, this was the area selected for the large-scale elimination program in the spring of 1957.

On the basis of counts made on January 11, 1957, and February 25, 1957, it was estimated that a breeding population of 5,204 Laysan albatrosses and 124 black-footed albatrosses occupied the triangle that winter, and that the number of unemployed birds using the area totaled 867 Laysans and 21 black-foots. During the killing program in the spring of 1957, 4,788 adult albatrosses (both species combined), 1,371 chicks, and 107 birds of unspecified age were removed (Kenyon et al., 1958).

In the spring of 1958, 4,739 additional adult albatrosses were removed (Rice, 1959). We have no report on the 1959 population of the triangle; but in the spring of 1960, 196 chicks were counted in this area (Robbins, 1960). In the following season (January 1961), the nesting population of the triangle more than doubled and then included 422 pairs of Laysans and 134 pairs of black-foots. In January 1962 there were 940 nesting pairs of Laysans and 186 of black-foots. It was strongly recommended that the habitat in the triangle be made less favorable, as otherwise the nesting population would be expected to continue its rapid increase. It was recommended that the area be leveled and hard-surfaced during the summer months when no albatrosses were present. In order to study the future behavior of albatrosses made homeless by the construction, nearly all of the adult Laysan and black-footed albatrosses that were nesting on the triangle in the 1961-62 season were captured and banded.

The triangle was leveled and paved in the summer of 1962 while the albatrosses were at sea.

When the birds returned in late October and November many of them remained for weeks on the treated area. A few laid eggs, but the birds were unable to build nests on the hard pavement and the eggs soon were deserted. An unknown number of birds (probably at least 100) became mired in the sticky seal coat and had to be killed. A few, apparently fewer than 3 percent, moved across the runways to the nearest available nesting area and nested successfully. These dispossessed Laysan albatrosses that did select new nesting areas were clustered along the edge of the pavement, some 400 feet from the triangle. A search in more distant areas failed to reveal any displaced Laysans nesting more than 40 feet away from the closest available nesting sites along the very edge of the pavement. Black-footed albatrosses appeared to be slightly more adaptable as the proportion of nesting birds was higher (about 10 percent) and they were not concentrated quite as close to the nearest available nesting sites.

Additional terrain modification proposed

As early as January 1958 (Kenyon et al., 1958) it was recommended that "the entire area within 750 feet from the center and on each side of runway 6-24, which is now the main duty runway, be flattened as soon as possible." It was further recommended that if this leveling proved successful in providing relief from the albatross hazard, the same procedure be extended to runway 15-33.

As pointed out earlier in this section, the initial leveling of the area south of the west half of runway 6-24 reduced the strike rate considerably. Strikes then gradually increased as the albatross population increased in the triangle on the north side of this runway.

An unusually high rate of bird strikes during the first four months of 1962 prompted the Navy to sponsor a task force to study the problem and arrive at an acceptable solution on the basis that Midway Naval Station is an essential defense installation and must be continued. The task force consisted of: Dr. Ira N. Gabrielson, President, Wildlife Management Institute; Dr. S. R. Galler, Chief, Biology Branch, Office of Naval Research; Daniel H. Janzen, Director, Bureau of Sport Fisheries and Wildlife; John R. Woodworth, Chief, Wildlife Branch, Hawaii Department of Agriculture and Conservation; and Cdr. Charles F. Zirzow, Director of Natural Resources Management, Department of the Navy.

This task force reviewed past reports and made a trip to Midway in July 1962 to become thoroughly familiar with all aspects of the problem. They approved the recommendations then offered by the Bureau of Sport Fisheries and Wildlife for control measures based on research findings over the years. They also concurred in other recommendations designed to safeguard populations of sea birds in the Leeward Hawaiian Chain (pp. 60-61).

Recommendations

1. Leveling and hard-surfacing of shoulders of runways. Because studies have shown that the origin of two-thirds of the birds involved in the hazard is within 750 feet of the centerline and because leveling and hard-surfacing portions of the shoulders of runway 6-24 has been effective in reducing strikes and preventing nesting in treated areas, it is recommended that the remainder of the shoulders of both runways be leveled and hard-topped to a distance of 750 feet from the centerline. This construction will serve the two-fold purpose of eliminating albatross nesting habitat adjacent to the runways and reducing the up-drafts which albatrosses use for lifting power. Studies by biologists of the Bureau of Sport Fisheries and Wildlife have definitely proven that albatrosses soar far more frequently over rough topography as now found along the runways than over level terrain, and that the majority of the albatrosses struck by airplanes came from the area to be hard-surfaced.

2. Removal of albatrosses from areas to be hard-surfaced. (1) Past experience has shown that dispossessed birds do not readily adjust to loss of nesting grounds and actually increase the hazard to aircraft, (2) the bird-strike problem at Midway is so serious that an increase in strike rate cannot be risked, and (3) full protection should be given to those birds that are relatively infrequently involved in strikes. The Bureau recommends that nesting and non-nesting albatrosses in the area to be treated be selectively and humanely killed. The timing of these operations during the last half of January and the first half of February, immediately prior to the construction work, is most important in order to remove as many as possible of the birds that would become an increased hazard and at the same time protect all other birds.

Implementation of recommendations 1 and 2.

To assist the Navy in planning the final steps of the recommended control program, Robbins joined Lt. C. C. Hoffner, Jr., of the Civil Engineer Corp, U. S. Navy, in making a study at Midway during the period July 25--August 13, 1962. Purposes of this trip were (a) to define precisely the boundaries of the areas to be leveled and hard-surfaced within the 750 ft. limit; (b) to estimate, on the basis of the specific areas involved and prior nesting populations in these areas, the number of adult birds that would have to be eliminated; (c) to determine the most humane and least obnoxious means of elimination; (d) to determine what manpower and equipment would be necessary to accomplish removal; and (e) to determine the time schedule for elimination.

a. Definition of boundaries of the critical areas. Adherence to the 750-foot distance from the centerline of each runway was recommended except where this line penetrated barrier dunes that should be preserved in the interest of preventing wind erosion. Small areas of grass in the immediate vicinity of the air terminal also should be retained to maintain the good appearance of the station. Minor deviations from the 750-foot line were permitted to avoid underground structures. We recommended that the nesting colonies of black-footed albatrosses along the beach remain undisturbed because (1) these birds reach their nesting sites without crossing the runways, and (2) nearly all of the breeding birds in these colonies are banded and none has yet been reported in an aircraft strike.

b. Estimate of the number of adult birds that will have to be eliminated. Although we dislike suggesting that healthy birds be killed, we realize that we are dealing with a critical situation; several aircraft have nearly met with disaster, and public opinion in the event of loss of human life may result in strong pressure to eliminate all birds from Midway Atoll. It is our considered opinion, therefore, that if the Navy allocates funds for land management along one or both of the Sand Island runways, carefully controlled removal of birds that are using the specific areas to be treated should be conducted immediately before treatment of the areas. If the birds using these areas are not removed before bulldozing begins, they are likely to become even greater hazards

than if they were nesting. Furthermore, should it later become necessary to initiate a killing program, it would not be possible to distinguish these homeless birds from individuals that nest in other parts of Sand Island and only occasionally frequent the vicinity of the runways.

We recommend, therefore, that both nesting and non-nesting birds using the areas to be treated be picked up and disposed of immediately before bulldozing.

On the basis of nest counts made in the winter of 1960-61, and population trends in subsequent years, we estimate that about 4,000 albatrosses should be removed if funds are obtained for treating areas adjacent to runway 6-24 and that about 12,200 additional birds should be removed if the areas adjacent to the short runway, 15-33, also are to be treated. These figures are separated by species and breeding status in table 8.

Table 8. Estimate of numbers of albatrosses to be removed

	Runway 6-24	Runway 15-33	Both runways
Laysan albatross			
Nesting individuals	1655	5250	6905
Non-nesting	1655	5250	6905
Total	3310	10,500	13,810
Black-footed albatross			
Nesting individuals	500	1205	1705
Non-nesting	210	505	715
Total	710	1710	2420
Total both species	4020	12,210	16,230

If funds are obtained for treatment of both runways, it is estimated that 16 percent of the Laysan albatrosses and 23 percent of the black-footed albatrosses nesting on Sand Island in the winter of 1962-63 will be removed. Since approximately 73 percent of the birds of nesting age nest in any one year, this amounts to a reduction of about 12 percent in the breeding population of Sand Island Laysan albatrosses and about 17 percent in the breeding population of Sand Island black-footed albatrosses. If we consider the breeding population of the entire Midway Atoll, it is estimated that 5 percent of the Laysan albatrosses and 10 percent of the black-footed albatrosses will need to be removed. Rice and Kenyon (1962a) estimated a world population of about 1,300,000 to 2,100,000 Laysan albatrosses and 260,000 to 400,000 black-footed albatrosses. On the basis of these figures, the estimated proportion of birds to be removed would approximate 1 percent of the world population of each species.

c. Determination of the most humane and least obnoxious means of elimination. In the experimental reduction of albatrosses on Midway in 1957-58 the birds were killed by a blow on the back of the head and were subsequently carted away. In search of a more humane method of disposing of the birds, seven crippled albatrosses were captured and placed in a dump truck with a tight-fitting top, and exhaust from the motor was piped into the body of the truck. It was concluded that this method, with proper precautions, could be applied safely and efficiently with a minimum of suffering by the birds.

d. Determination of manpower and equipment necesary to accomplish removal. It was estimated that 6 trucks and 15 men would be required to accomplish removal. It was recommended that three biologists of the Bureau of Sport Fisheries and Wildlife be present to give any technical assistance needed, to see that all banded birds captured in the operation were examined, to obtain a series of measurements of birds of known sex, and to collect biological material needed by research workers at various institutions.

e. Time schedule for elimination. It was originally recommended that bird removal be scheduled to start on January 10, 1963, and continue until bulldozing was started. When funds were not made available in 1963, the program was rescheduled for January 1964. Proper timing of both the bird removal and the bulldozing is critical. The recommended schedule will assure removal of the largest number of breeding individuals and other birds definitely attached to the particular areas to be treated. By waiting until the last 2 weeks of the incubation period, there is greater assurance of capturing both members of each nesting pair for two reasons: (1) as the incubation period progresses, the rate of changeover of the mates becomes more rapid, so after one member of a pair is removed the other can be expected to return in a very few days; and (2) a nesting bird has a stronger attraction for a well-incubated egg than for an egg in the early stages of incubation and therefore is more likely to return to the egg in the midst of wholesale disturbance to the nesting area.

If the killing is not followed immediately by bulldozing and hard-surfacing, the unoccupied area will begin to attract non-breeding birds that are seeking future nesting sites. In other words, birds that normally would not be attracted to this particular area will be drawn to it and will be killed unnecessarily.

It was also recommended that: (1) before the removal period the exact areas to be treated be marked clearly and (2) a series of truck trails be bulldozed through the more densely vegetated areas before the beginning of the nesting season. These trails would permit effective removal of albatrosses without the danger of breaking eggs or crippling birds.

Lt. Hoffner recommended grading and asphalting two areas where erosion has resulted from water running off the runway. Since this erosion occurred near nesting colonies of black-footed albatrosses,

the grading and asphalting should be done during the summer when the birds are not present.

It was recommended that use of a sticky sealcoat on the treated areas be avoided. In past treatments numbers of healthy birds became mired in the sticky substance and either died or had to be killed. Finally, we suggest that the Navy invite biologists of the Hawaii Division of Fish and Game to conduct any studies at Midway they may wish on the carcasses of the birds that will be sacrificed. The Bureau desires that maximum use be made of any birds that are sacrificed.

For the intelligent management of any species it is necessary to know certain facts about its life history, including reproductive rate, mortality, longevity, age at first nesting, frequency of nesting, attachment to natal and nesting areas, effect of nesting success on return the following year, and effects of disturbance on the birds' behavior. Since none of these factors were known for either the Laysan or the black-footed albatross at the beginning of the present investigations, studies to determine these facts were begun in 1956 and are still continuing.

Station hospital lawn

For 6 years (of the past 7), nest positions in the hospital study plots were measured, and the band numbers of the adults associated with each nest were recorded. Except for birds whose nests were destroyed or deserted early in the season, all nesting adults were captured in most years from 1956-57 through 1962-63. The Bureau of Sport Fisheries and Wildlife had no representative at Midway during the 1958-59 season, and the trip the following winter was so late (March-April) that some of the nesting adults were not captured.

Fuel farm study area

In January 1961 a new area for nesting studies was established along the western edge of the fuel farm, starting at the corner nearest the MOQ and extending north for 300 feet and east for 150 feet; the eastern edge of the study area also extends south to its intersection with the boundary fence.

Eastern Island study area (east of end of old runway 3-21)

Another new study area in 1960-61 was staked out in the same manner as the area on the fuel farm. The eastern edge of the pavement for old runway 3-21 served as the western boundary for all but 50 feet of the study area; the southern boundary was lined up with the southern edge of the runway and extended from the end of the runway to the beach. The eastern boundary was the edge of high ground bordering the beach, and the northern boundary was a line parallel to the runway and 350 feet north of the southern boundary (or 50 feet north of the imaginary extension of the runway pavement). As on the fuel farm, nest positions were paced from the corner markers, and nesting birds were banded and plotted.

Through the cooperation of station personnel, aerial photographs of both the fuel farm and Eastern Island study areas were made to measure the position of each nest more precisely. Although suitable photos could

not be made until too late in the 1960-61 season (because of lack of proper camera equipment), photos in subsequent years, in conjunction with a record of the band numbers of individual birds, provided precise information on the composition and nest locations of an undisturbed population of both the Laysan and black-footed albatross. The fuel farm and Eastern Island study areas were selected after consultation with the commanding officer, executive officer, and security officer, as areas in which no disturbance is anticipated in the foreseeable future. It was requested that these areas be outlined on master maps of the station so that they will remain essentially undisturbed if possible.

Table 9 shows the 1960-61 nesting population in each of the three areas designated for intensive study. Nest counts include all nests that contained an egg at the time the study area was mapped (about the second week in January). Empty nest scrapes were not counted, because it was not possible to determine which ones contained an egg prior to the date of mapping. Nests were not located at random positions on the study areas; instead, they were grouped close together in some places, while in other places they were separated by many square yards of unoccupied territory. Hence, the population densities in these relatively small study areas give only a very rough approximation of normal densities in undisturbed areas.

Table 9. Nesting populations of albatrosses on study areas in 1960-61.

Study area	Approx. acreage	Occupied nests		Nests per acre		
		Laysan	Black-ft.	Laysan	Black-ft.	Total
Station hospital	0.56	108	0	166	0	166
Fuel farm	1.2	52	118	43	98	141
Eastern Island	1.8	172	93	96	52	148

Eastern Island triangle

In the central portion of Eastern Island (Midway) is a triangular area of 11.1 acres bounded on all three sides by abandoned runways, each 300 feet wide. This makes a convenient unit for study because, except for a few isolated areas of nesting habitat where the pavement has been broken for erection of antenna poles or burial of underground cables, this triangle is isolated from other nesting habitat. The outer parts of the triangle are level, and probably at least 100 nests are lost by flooding from runway run-off. The central part (about one-third) is rough terrain containing the remains of underground bunkers. Scattered old trees (mostly Casuarina) and dense shrubs (especially Pluchea) cover much of the central part, but more than half of the flat part has only herbaceous growth.

Rice and Kenyon banded 2,086 Laysan albatross chicks on the triangle from May 27 to June 4, 1957, and 2,100 Laysan chicks in June 1958. No chicks were banded in 1959, but 2,144 were banded in March 1960 by Robbins, 1,457 in June-July 1961 by Harvey Fisher, 2,468 in June 1962 by Fisher, 650 in February 1963 by Robbins, and 2,044 from June 22 to July 1, 1963 by Fisher.

In January and February 1961, 4,300 nesting adults were banded on the triangle by Robbins, and each winter since then as many nesting birds as possible (about 95 percent of the active nesters in January and February) have been captured and recorded. In addition, as many banded walkers as possible were recaptured each winter to get information on the age composition of the non-nesting population.

Sex determination

Bills of nesting albatrosses were measured in the hospital, fuel farm and Eastern Island study areas in an effort to sex as many of these birds as possible. The total culmen was measured, with dividers, from the proximal edge of the horny portion to the greatest extremity of the upper mandible (not to the point of the hook). The culmen from nostril was measured from the proximal end of the nostril slit to the greatest extremity of the upper mandible (not necessarily to the hook). In addition, wing measurements (chord) were recorded for many of these same birds.

On January 8, 1961, I measured and sexed (by internal examination) 86 Laysan albatrosses that had been killed by vandals early that morning in the vicinity of the administration building (table 10). Seventy-nine percent of these birds were females.

Table 10. Measurements in millimeters of Laysan albatrosses killed on January 8, 1961.

Measurement	Sex	No.	Mean	Standard deviation	Standard error	Observed range
Total culmen	♂	18	117.5	2.45	0.58	113-121
Total culmen	♀	68	109.6	3.91	0.47	101-118
Culmen from nostril	♂	18	86.3	2.66	0.63	82-90
Culmen from nostril	♀	68	79.7	3.04	0.37	74-86
Folded wing (chord)	♂	17	483.9			462-499
Folded wing (chord)	♀	18	480.0			468-500

Although the wing measurements proved to be of little value as an indication of sex, 68 percent of the Laysan albatrosses could be sexed with a probability of 25:1 by the total culmen measurement alone. The culmen-from-nostril measurement was nearly as diagnostic as the culmen measurement, but there was such a close correlation between these two measurements that the second one was helpful in only a few borderline cases.

Frings and Frings (1961) summarized head-width measurements of 172 black-footed and 241 Laysan albatrosses and bill length of 201 black-footed and 309 Laysan albatrosses. They reported that 69 percent of the Laysans could be sexed with probabilities of 8:1 or better from the head-width and that 75 percent could be sexed with probabilities of 25:1 or better from the bill length (angle of mouth to tip). They pointed out, however, that the measurements given in their tables should not be used directly by anyone else because the skin and feathers can be variably compressed by different persons, resulting in different measurements of the same bird. Their mean bill lengths (108.7 for males, 101.4 for females) differ by 7.3 mm.; their range of variation and amount of overlap between sexes is similar to that for my culmen measurements. The big advantage of total culmen or culmen-from-nostril measurements over the ones used by Frings is that measurements made by one investigator can be used more readily for comparison by others. (The male/female ratios for each measurement in Frings' tables are slightly distorted because they were not corrected for the 26 percent excess of males in their bill length sample, and 15 percent excess of males in their head-width sample.)

From the culmen measurements of birds of known sex, it was possible to sex the great majority of the birds on the study areas. Birds with short or very long bills could be sexed with a high degree of confidence. Since both members of a pair usually were banded, the sex of the mate also was known. Some birds had been sexed in previous years immediately after egg laying when the difference in condition of the vent in the two sexes of nesting birds was obvious. Study of the change-over dates of incubating birds can be helpful in determining the sex of birds whose measurements are in the overlapping zone, since males take a long turn at incubation very soon after the egg is laid.

Return of young birds

Young albatrosses begin to return to Midway at the age of 3 years. They are found there more frequently with increasing age until nesting begins. The youngest nesting individuals on record are black-footed albatrosses at age 5 (a minimum of 5 birds from a sample of 1,000 banded as chicks), and a Laysan albatross at age 5 (1 out of 1,700 banded as chicks on Eastern Island triangle). Even at the age of 6 years very few birds were found nesting, though scores were present as walkers.

A special effort has been made to search for and capture birds that had been color-banded as chicks on Eastern Island in the spring seasons

of 1957 and 1958. The relatively small number seen (and captured) in January 1961 as compared with March-April 1960 provided the first indication that 3-year-old and 4-year-old birds come ashore more frequently in March and April than in January. This suggests also that the increase in aircraft strikes in the spring, before young of the year take to the wing, is at least partially a result of an influx of subadult birds that have not yet reached breeding age. It is logical to assume that until these birds establish nesting territories, they may be especially susceptible to aircraft strikes because:

(1) They are relatively inexperienced both in maneuvering over land and in recognizing the danger of aircraft;

(2) They are not so strongly attached to any specific area and have no nesting responsibilities; and

(3) Those that are searching for territories for future nesting will be attracted to the more favorable habitats that are relatively underpopulated. The triangle adjacent to the Sand Island runways was such an area; all nesting birds were destroyed here during the 1956-57 and 1957-58 nesting seasons. From then until the area was paved in 1962 the nesting population nearly doubled each successive year.

Frequency of nesting

Rice (1959) studied 820 Laysan albatrosses of known nesting success in the 1956-57 breeding season. Of 150 birds that raised a chick that season, 94 (63 percent) returned and nested the next season. Of 314 birds whose eggs were sterile or were destroyed early in the incubation period, 273 (87 percent) returned to nest the next season. From his entire sample of 820 birds (including those that lost chicks or lost eggs late in the incubation period), 644 (78.5 percent) returned the next nesting season.

Subsequent studies were based on birds present at active nests late in the incubation period (January 1961-1963) or when the chicks were about 2 months old (March 1960). Since birds whose nests were deserted or broken up in late November, December, or the first week or two in January are not included in the following figures, these percentages are lower than the actual return rates.

In the fuel farm study area the percentage of adults that nested in consecutive years (1960-61 to 1961-62 and 1961-62 to 1962-63) was 64 percent for the Laysan albatross (162 out of 253 birds) and 63 percent for the black-footed albatross (293 out of 466 birds). The percentages varied considerably from year to year; 70 percent of the 1960 black-footed albatross adults returned and nested in 1961, but only 57 percent of the 1961 birds nested also in 1962. Percentages for the Laysan albatross in these same periods were 63 and 65; while only 63 percent of the 1960 Laysans nested in 1961, 73 percent of the 1960 Laysans nested in 1962. Of the 99 nesting Laysans that were captured in 1960-61 49 percent nested all 3 years; 42 percent of the 221 black-foots captured in 1960-61 nested all three years.

At the station hospital, where the mortality rate of chicks seems to be higher than normal, 69 percent of the 1960-61 nesting Laysans were recorded as nesting again in 1961-62. On the Eastern Island study area and Eastern Island triangle only 88 and 94 percent of the nesting birds were captured in 1961-62, but the computed rate of return of Laysans was 61 percent for the Eastern Island study area and 60 percent for the triangle.

Closeness of return

Rice (1959) measured the distances between the 1956 and 1957 nest locations of 101 pairs of Laysan albatrosses at the station hospital. The average distance moved was 5 feet and none of the 101 pairs nested more than 20 feet from their previous location. Rice stated that, in general, Laysans nesting close to an obvious landmark, such as a tree, showed the least year-to-year deviation in location.

Subsequent studies have shown that in still more open areas the distances moved from year to year are even greater. Thirty-one pairs of Laysans on the fuel farm study area moved an average distance of 11 feet from 1960 to 1961, and 38 pairs moved an average distance of 12 feet in the 2-year period 1960 to 1962. The 1960 to 1962 birds include those pairs that also nested in 1961 as well as those that were not found nesting in 1961. The greatest distance between 1960 and 1961 nests was 31 feet and the greatest distance between 1960 and 1962 nests was 62 feet.

Black-footed albatrosses in the fuel farm study area moved an average distance of 15 feet from 1960 to 1961 (69 pairs) and 19 feet from 1960 to 1962 (53 pairs). The maximum distances moved were 107 feet in the 1-year period and 104 feet in the 2-year period (the same pair).

As pointed out in the section on leveling and paving of the Sand Island triangle, black-footed and especially Laysan albatrosses are slow in adjusting to destruction of their nesting territory, but a small percentage of the displaced birds moved 400 feet to the nearest available habitat and nested successfully the first season.

Interchange between islands

The small-scale banding of albatross chicks in years preceding the intensive studies that began in 1956-57 provided the first information on the return of young birds to the breeding grounds. Of 100 black-footed albatross chicks banded on Eastern Island in June 1954, 4 were captured as nesting birds in December 1960 and January 1961; two of these were in a colony on the south shore of Sand Island, one was in the fuel farm study area on Sand Island, and the other was at Kure Atoll. The exact place on Eastern Island where these birds were banded is not known. Since many of the nesting black-foots on Eastern and Sand Islands have

not yet been captured by banders, it is likely that other birds from this sample of 100 will be found nesting in future years.

During the 1961-62 season four out of 1,000 black-footed albatrosses banded as chicks on Eastern Island in May 1957 were found nesting. Two of them were at Kure, one on Sand Island, and the other at Eastern Island.

Meager as these data are, they indicate that some young black-foots can be expected to establish their nesting territories on islands other than the one on which they were hatched, and that interchange of birds between Midway and Kure or Midway and some other islands of the Leeward Chain may not be unusual. There previously had been a few records of Laysan chicks from Eastern Island establishing nesting territories on Sand Island.

Longevity

Much interest has centered around the first 99 Laysan albatrosses banded by F. C. Hadden as adult nesting birds in the vicinity of Pan-Am's "Gooneyville Lodge" hotel on Sand Island, Midway, in November and December 1938. Although Hadden recaptured only 8 of these birds the following year, as many as 15 were captured by Robbins, Aldrich, and Rice in November and December 1956, 18 years after banding. Eight were captured in the winter of 1960-61, 7 in 1961-62, and 3 in 1962-63, 24 years after banding. Never yet have all surviving birds from the original 99 been recaptured in the same season. Hence any survival figures for this population are subject to change when birds that have not been captured for one or more years again are found. Information presently available shows that at least 44 of the 99 birds were still alive 5 years after banding, 30 were alive 10 years after banding, 22 were alive after 15 years, 12 after 20 years, 7 after 23 years, and 3 (later determined to be 7) after 24 years. The actual age of these birds is assumed to be at least 7 years greater than the elapsed time since banding, as very few Laysan albatrosses nest before they are 7 years of age. By projecting the survival curve into the future it appears that at least 1 percent of this population in downtown Midway will pass the age of 40 years. The birds are still fertile at the age of 31.

The first banding of black-footed albatrosses (400 adults) was done at Midway in December 1940 and January 1941. This species has suffered heavy mortality from vandalism during the past decade, but at least one of the original 400 was still alive and nesting in January 1963, 22 years after banding. Very few black-foots nest before 5 years of age, so this individual is assumed to be at least 27 years old. This bird is nesting in the fuel farm study area, where it is protected from vandalism.

Introduction

Drs. Hubert and Mable Frings (1959) suggested that Laysan, Lisianski, or Kure Atoll might attract larger numbers of nesting albatrosses if the habitats there were altered by "the planting of Bermuda grass or other sand-holding grasses, introduction of ironwood trees, and reduction of Scaevola thickets, where necessary, to reasonable densities." The planting of exotic vegetation on those islands that are still essentially in their original native condition did not seem advisable from the overall conservation standpoint; but it did seem likely that the nesting population of Laysan albatrosses could be increased at Green Island, Kure Atoll, if its open central plain were connected with the outer beach by the construction of trails through the surrounding dense growth of Scaevola bushes.

Kure Atoll, which is approximately 55 nautical miles west-northwest of Midway, consists of a ring of coral reef surrounding Green Island and three low sand bars that support no nesting birds.

The albatross population of Kure in the 1957-58 nesting season consisted of 700 Laysan albatrosses and 140 black-footed albatrosses (Rice, 1958). Green Island is nearly the same size as Eastern Island, Midway, which had an estimated nesting population of approximately 86,000 Laysan and 6,000 black-footed albatrosses in the same nesting season.

It was believed that construction of a series of bulldozed trails between the interior of the island and the outer beach would serve a twofold purpose: (1) It would make available new nesting habitat for young albatrosses setting up nesting territories for the first time, and probably would attract some birds that otherwise would nest at Midway; (2) It would provide a safe nesting place for a larger portion of the world population of Laysan albatrosses in the event of large-scale reduction of albatrosses nesting at Midway.

Figure 9 shows Green Island before the bulldozing operation. It was estimated that the vegetated part of the island had a maximum length of 6,280 feet and a maximum width of 1,900 feet. The total area covered by vegetation was estimated at approximately 170 acres. The surrounding beaches occupied about 50 additional acres. Dunes up to 15 feet in height completely line the northwest side of the island. The dunes on the east and south sides of the island are several feet lower.

Personnel and preparations

On September 21, 1959, Chandler S. Robbins of the Branch of Wildlife Research and Thomas C. Horn of the Branch of Wildlife Refuges, Bureau of Sport Fisheries and Wildlife, conferred with Navy and Coast Guard officers, including representatives of COMNAB (Cdr. Gordon N.

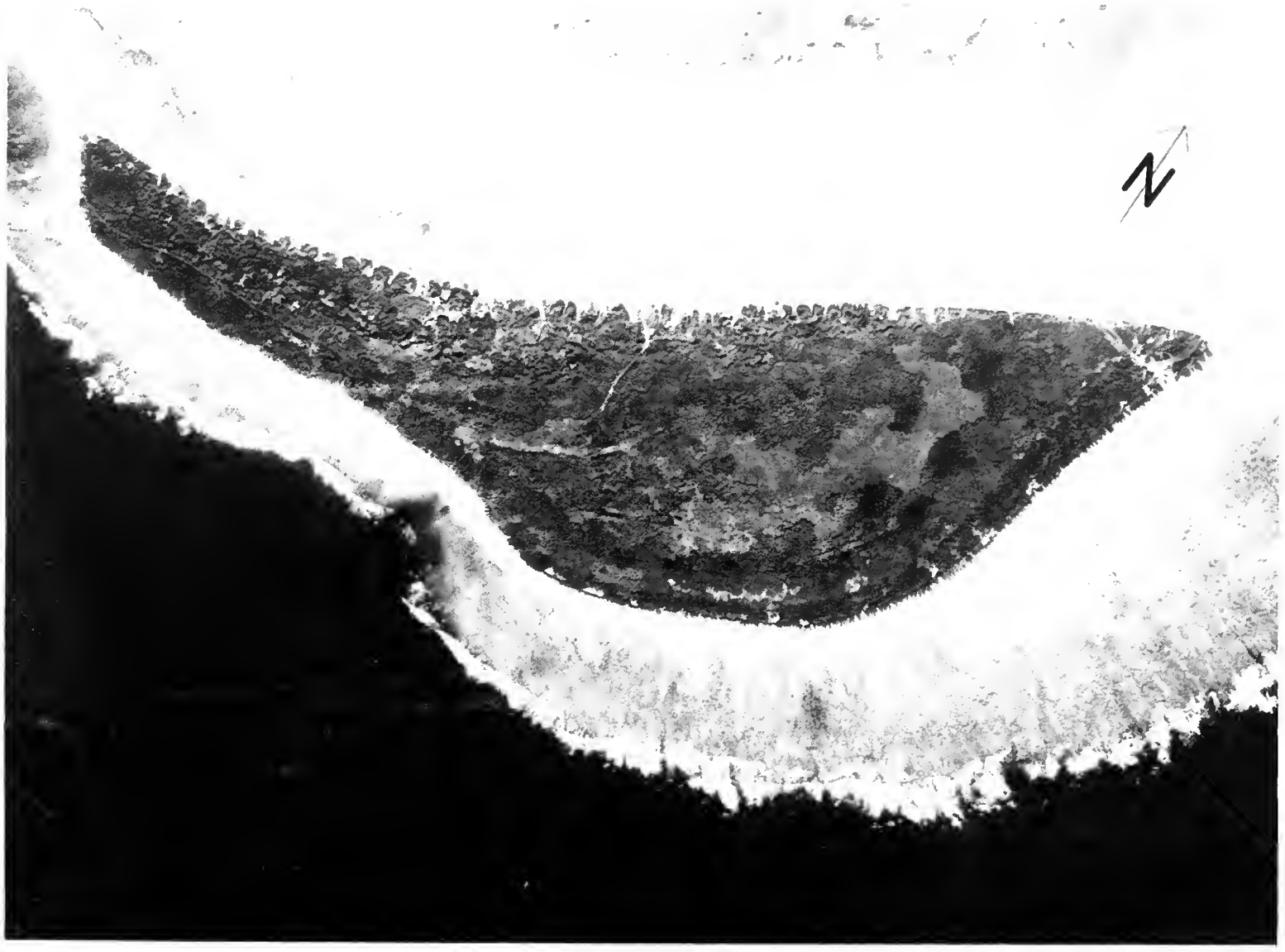

Figure 9. Photo of Green Island, Kure, prior to habitat management. (U. S. Navy photograph, October 3, 1959).

Riddick), Midway Naval Station (former Commanding Officer Epps), Seabees (Lt. Comdr. G. W. Burton and C. W. O. Lloyd Munson), 14th Naval District Public Works Office (Alexander H. Cornelison, Soil Conservationist), and other Navy and Coast Guard officers. Messrs. Robbins and Horn summarized the objectives of Kure habitat modification and answered questions from many of those present. Mr. Cornelison expressed concern over a proposal that had been made for excavation of a lagoon and was assured that this part of the original plan had been dropped. He also expressed concern over the possibility of severe wind erosion as a result of the proposed 50-foot-wide bulldozed trails. He requested that the trails be laid out so that at intervals of about 100 yards they either would be offset or blocked by heaps of brush to prevent erosion. Final details of the location of the trails were left for completion after the party reached the island.

Mr. Cornelison had made arrangements for Dr. Horace G. Clay, Extension Botanist of the University of Hawaii, to accompany the expedition for the purpose of identifying and mapping the distribution of all vascular plants on Kure and seeing that endemic species and varieties of plants were not destroyed as a result of the habitat alteration.

A conference was arranged with Mr. Michio Takata, Director of the Hawaii Division of Fish and Game, Mr. J. R. Woodworth, Chief, Bureau of Game; Mr. Cornelison; and Messrs. Robbins and Horn of the Bureau of Sport Fisheries and Wildlife in order that complete agreement might be reached regarding any details of the operation that might affect wildlife or plants on the island.

On October 3, two 7D-18 bulldozers and a party of eight were landed on Green Island, Kure, as follows: C. W. O. Lloyd Munson, two bulldozer operators, a medical corpsman, a mechanic, and the three civilians, Robbins, Horn, and Clay.

Bulldozing operations

Bulldozing was conducted from October 3 to October 8, 1959. All trails to be bulldozed were laid out by Horn and Robbins, one or both of whom rode on the bulldozers during much of the trail-cutting operation to insure that all conservation interests would be protected.

Subsequent phases of the operation verified that losses to bird life were restricted to a relatively small number of downy young wedge-tailed shearwaters, which were hidden in their burrows under the dense growth of Scaevola. The two Seabee bulldozer operators, Ryan and Clausen, were especially conscientious about preventing destruction of birds. They frequently stopped their dozers and moved birds before proceeding. In all instances birds were visible from the dozers and the trails were laid out in such a way as to avoid them.

In order to prevent destruction of plants in open areas in the interior of the island, all trails ended abruptly at the edge of the

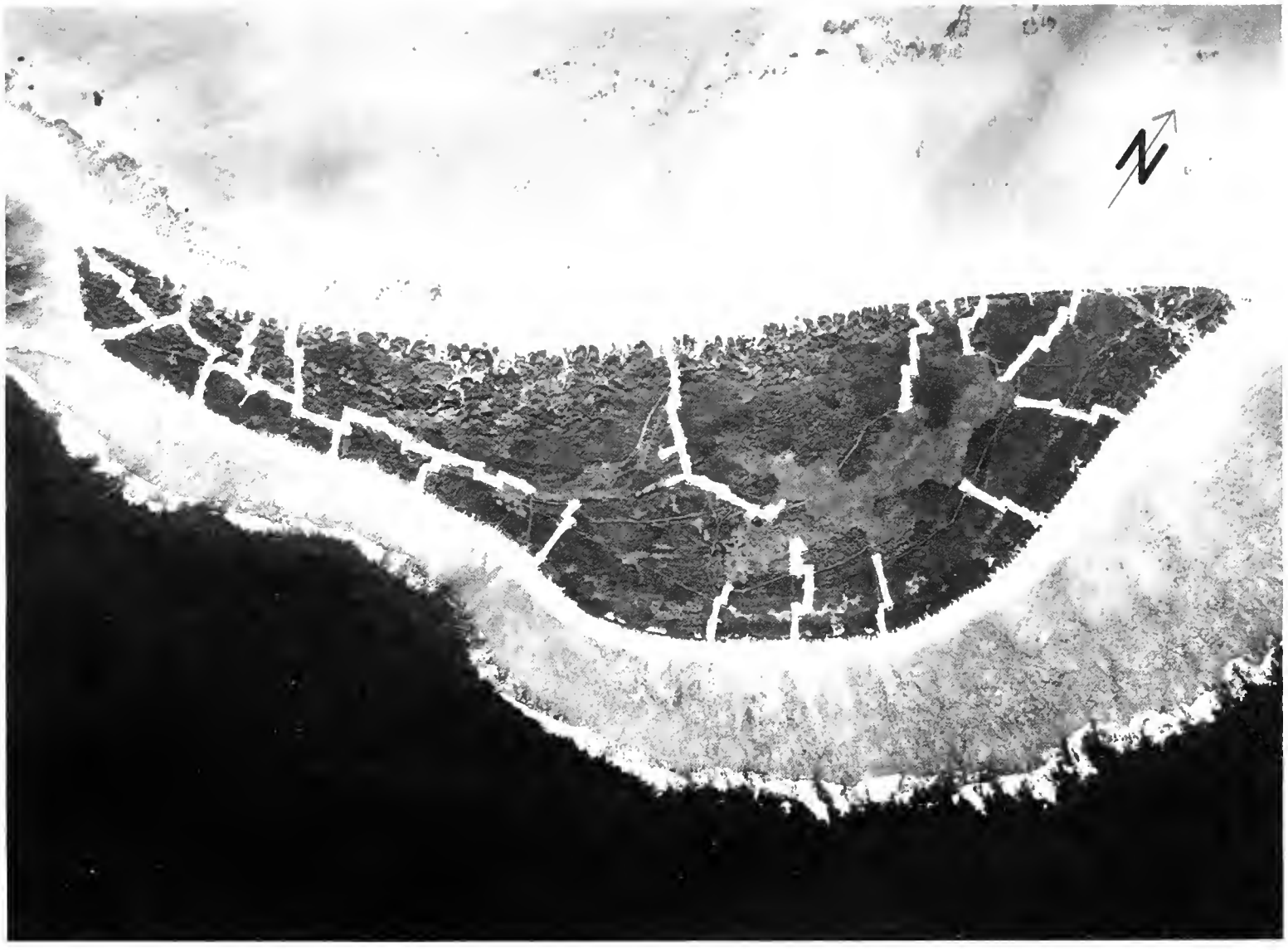

Figure 10. Photo showing bulldozed trails on Green Island, Kure. (U. S. Navy photograph, November 3, 1959).

open areas. The bulldozers were backed into the openings only far enough to permit their blades to be lowered against the edge of the bordering Scaevola.

Eighteen trails were constructed, as shown in figure 10. Each trail was approximately 48 feet wide (4 bulldozer-blade widths), except that some of them were much narrower at the point where they penetrated the dunes on the northwest shore of the island, as shown in figure 10. Full advantage was taken of the irregular shape of the plain; the bulldozer trails were placed in such a way as to cover the shortest distance from the plain to the lagoon that was compatible with protection of nesting birds, distribution of rare plants, and position of geodetic markers. All bulldozed strips were smoothed prior to termination of the project by the use of drags improvised from the unloading ramp.

Fresh-water exploration

Although the construction of a lagoon on Green Island had been dropped from the plans, it was felt desirable to explore the fresh-water level of the island's interior while bulldozers were available. A depression was dug in the center of the island within a few hundred feet of a former hand-dug depression. Very mildly brackish water (the top of the Guyben-Hertzberg lens) was found at a depth of 9 feet 9 inches below ground surface. (During and immediately after the rainy season a slight increase in this level could be expected and at that time water at this depth might be completely sweet.) The excavation was completely filled in before the party left the island.

Vegetation survey

Dr. Horace F. Clay collected three sets of specimens of all species of vascular plants found on Green Island, Oct. 3-8, 1960, except for one species that was represented by a single specimen and was not disturbed. Two sets of specimens were deposited in the Bishop Museum in Honolulu, and one was sent to the National Herbarium in Washington, D. C.

Dr. Clay's report listed the following seventeen species of vascular plants (those preceded by an asterisk were not found by the Tanager Expedition in 1923): *Cynodon dactylon, Eragrostis variabilis, Eragrostis whitneyi var. caumii, Lepturus repens, *Casuarina equisetifolia, Boerhavia diffusa, Lepidium owaihiense, Tribulus cistoides, Ipomoea congesta (I. indica), *Messerschmidia argentea, Solanum nelsoni, *Solanum nigrum, Sicyos hispidus, Scaevola sericea, Lipochaeta integrifolia, *Pluchea odorata, and Verbesina encelioides.

The two endemic species discovered in 1923, Lepturus repens and Solanum nelsoni, are still present on Green Island. Solanum nelsoni is abundant in the central plain. Lepturus repens was found only in the vicinity of the radar reflector tower.

Two species found by the Tanager Expedition apparently have disappeared from Green Island: Cenchrus agrimonioides var. Laysanensis and Achyranthes splendens var. reflexa.

Black and white photographs of all 17 species of vascular plants were secured by Horn, and kodachrome transparencies of all but two species were taken by Robbins.

April 1960 appraisal of Kure habitat management

On March 28, 1960, Robbins and Comdr. E. P. Wilson spent three hours on Green Island appraising the results of the bulldozing. Transportation from Midway aboard the MATAGORDA was furnished by the Coast Guard. The bulldozed lanes were still wide open, and there was very little evidence of sprouting of Scaevola cuttings. There was no damage to the nesting colonies of boobies or frigatebirds, and no wind erosion had occurred.

Table 11 shows the estimates of the bird population on Green Island, Kure on June 5, 1957 (Kenyon and Rice, 1958), and during subsequent trips from March 28, 1960 through February 7, 1963. The columns "Tot. ads." give the estimated number of adult birds present on the island at the same time. For most species, the figures in table 11 are not directly comparable, because the estimates were made at different seasons of the year. For nesting albatrosses, however, the 1957 and 1960-63 data may be compared provided allowance is made for mortality as each season progresses. There was a 56 percent decrease in nesting Laysan albatrosses between 1957 and 1960 for which we have no explanation. Approximately 150 non-nesting Laysan albatrosses were in the central plain on March 28, 1960. We believed these to be birds that were establishing territories preparatory to nesting in subsequent years. We do not know how many years in advance of egg laying the Laysan and black-footed albatrosses establish their territories, but certain larger species of albatrosses in the South Pacific establish territories 2 years before egg laying. We could not obtain accurate estimates of numbers and distribution of the non-nesting albatrosses because a party of contractors was landed on the island before us. By the time we reached the island, many of the albatrosses had been disturbed and had moved or taken flight.

With the assistance of Lt. William H. Bristol and three seamen from the Coast Guard Cutter MATAGORDA, we made a count of albatross chicks and of other nesting birds. We had planned to band all albatross chicks on the island and mark them with blue celluloid bands so they could be detected if they appeared on Midway. The signal to return to the MATAGORDA was received earlier than anticipated, however, and only 17 Laysan chicks and 8 black-footed chicks were banded.

All adult albatrosses were checked for bands and one banded black-foot was found. This bird, No. 597-36170, found with a chick, was captured by Lt. Bristol. It had been banded on Sand Island, Midway on

Table 11. Estimated bird populations at Green Island, Kure Atoll

NESTING SPECIES	June 5 1957 Nstg. prs.	June 5 1957 Tot. ads.	Oct. 3-8 1959 Adults banded	Oct. 3-8 1959 Tot. ads.	Mar. 28 1960 Nstg. prs.	Mar. 28 1960 Tot. ads.	Jan.19-21 1961 Nstg. prs.	Jan.19-21 1961 Tot. ads.	Feb.2-4 1962 Nstg. prs.	Feb.2-4 1962 Tot. ads.	Aug.6-8 1962 Nstg. prs.	Aug.6-8 1962 Tot. ads.	Feb.3-7 1963 Nstg. prs.	Feb.3-7 1963 Tot. ads.
Black-footed albatross	70	163	0	0	95	280	160	200	65	100+	0	0	200	235
Laysan albatross	350	805	0	0	75	425	550	700	1080	--	20	0	1450	--
Wedge-tailed shearwater	common		157	5000	common		0	0	0	*	?	1000	0	0
Bonin Island petrel	--	--	38	1000	--	--	--	500	--	200	0	1	--	10
Christmas Is. shearwater	--	--	4	125	--	--	0	0	0	0	--	--	--	0
Red-tailed tropicbird	500	1000	3	50	50	100	0	0	0	25	25	250	1	25
Blue-faced booby	80	170	25	85	55	110	0	80	3	80	22	100	3	56
Brown booby	30	70	9	50	10	20	0	1	0	5	19	40	2	25
Red-footed booby	240	500	4	300	300	600	0	0	0	75	240	500	0	240
Great frigatebird	100	325	2	275	400	800	0	40	0	50	115	250	0	100
Common noddy	66	252	35	500	0	0	0	0	0	*	75	200	0	1
Fairy tern	0	1	1	2	0	0	0	0	--	*	5	10	0	0
Gray-backed tern	0	8	0	0	0	0	0	0	0	0	20	40	--	0
SPECIES PROBABLY NESTING														
Short-eared owl	--	--	--	--	--	--	--	--	--	2	--	--	--	--
NON-NESTING SPECIES														
Pintail	--	0	--	1	--	0	--	0	--	*	--	0	--	0
Am. golden plover	--	0	12	25	--	25	--	50	--	500	--	55	--	20
Ruddy turnstone	--	0	7	50	--	50	--	150	--	125	--	20	--	27
Wandering tattler	--	0	1	4	--	0	--	4	--	15	--	1	--	10
Bristle-thighed curlew	--	0	2	6	--	1	--	6	--	10	--	1	--	1
Sanderling	--	0	--	1	--	0	--	2	--	2	--	0	--	6
Glaucous-winged gull	--	0	--	0	--	0	--	0	--	0	--	0	--	2
Western (?) gull	--	0	--	0	--	0	--	0	--	0	--	0	--	2
Sooty tern	--	3	--	14	--	0	--	0	--	0	--	50	--	0
Hawaiian noddy	--	44	--	7	--	1	--	0	--	0	--	195	--	0
Horned puffin														**

*found carcass
**5 carcasses

November 23, 1956, in or immediately adjacent to the area that was leveled and black-topped in the winter of 1959-60. It was not incubating at the time it was banded. The capture of this one individual provided the first evidence that birds seen on one nesting atoll may subsequently establish a nesting territory on another.

Subsequent appraisal of Kure habitat management

At the time plans were made for habitat management on Kure, it was not known that a Coast Guard loran station and landing strip would be constructed there in 1960-61. This installation opened up the island much more than did the 1959 bulldozing. This was especially true in the antenna field, where radiating paths in which ground wires were laid provided easy access to all portions of the antenna area. Except in the antenna area, the landing strip, and the immediate vicinity of the offices and barracks, habitat disturbance has been kept to a minimum.

The offsetting of the original bulldozed trails was highly successful in preventing wind erosion. The bulldozing of Scaevola was conducted to sufficient depth that all the trails still remain easily passable.

The bulldozing and subsequent Coast Guard occupancy have been successful in attracting more and more nesting Laysan albatrosses to Kure, as shown by the increase from 350 nesting pairs in 1957 and 1958 to 1450 in 1963 (table 11). Wedge-tailed shearwaters and Bonin Island petrels may have decreased some during this same period from loss of habitat; more intensive checking of populations may determine whether this is so. The limited information available on populations of other species does not indicate any substantial increase or decrease.

Mammals on Green Island

Monk seals were observed frequently on the shore of Green Island and also on the adjacent unvegetated sand spits. The highest count obtained at one time was 53 along the eastern shore of Green Island on September 28, prior to landing. Seals were seen daily after landing on the island, but in smaller numbers.

Polynesian rats Rattus exulans were present by the thousands and it was suspected that they were very destructive, at least to the smaller species of nesting birds, especially the common noddy. Noddy eggs that were left uncovered for just a few minutes disappeared. Two specimens of R. exulans, an adult and an immature, were collected by Robbins for the Bureau of Sport Fisheries and Wildlife mammal collection in the U. S. National Museum, Washington, D. C.

Methods of estimating bird populations on Green Island

During the period October 3-8, 1959, an effort was made to estimate the total population of birds on Green Island. Although the island is quite small, several factors make it difficult to obtain accurate population estimates: the dense vegetation that covers most of the island, the absence from the island of many breeding individuals at any given time, 3 breeding species not only nest in burrows but are nocturnal in habits, several species have a long-drawn-out nesting season, and many non-nesting individuals are present in the population.

Accordingly, it seems desirable to place on record the procedure followed in arriving at the figures given in table 11 for the period October 3-8, 1959. Essentially the same methods were used in subsequent years. In cases where nests could be counted fairly accurately, the number of pairs of each species actually nesting at the time of the study was determined by a count of nests. For non-nesting species, and other nesting species whose nests could not readily be counted, the procedure included banding a sample of the total population and then using a ratio of banded to unbanded birds to compute the total number of adults present. Unfortunately, our stay on the island was unexpectedly terminated on about 3 hours' notice, so the counts of banded and unbanded birds had to be very much smaller than had been planned. This was especially unfortunate in the case of the three nocturnal species, because the sudden departure left no opportunity at all to make the detailed count of banded and unbanded birds that had been scheduled for the following night.

Wedge-tailed shearwater.--This was unquestionably the commonest bird on the island. During October 3-7, 145 birds were banded by use of mist nets in the western half of the island and by hand with the use of a headlamp in the eastern half of the island. Of the 45 birds banded on the first 4 nights, only one was found among the 101 birds recaptured on October 7. Fourteen additional birds were banded on the early morning of the 8th but no banded bird was recaptured on this date. From the portion of banded to unbanded birds captured on the 7th the total population was estimated at 4,545. Because of the lack of precision of this estimate the figure was rounded to 5,000.

Christmas Island shearwater and Bonin Island petrel.--Populations of these species were estimated only from the number banded in comparison with the number of wedge-tailed shearwaters banded, as it was believed they were equally susceptible to being captured by the mist nets or being picked up with the aid of a headlamp.

Red-tailed tropicbird.--These birds were widely scattered over the island and almost all the nests were well hidden by Scaevola. No banded adults were recaptured, so the population estimate was based solely on an estimate of nest density in those parts of the island most frequently visited.

Blue-faced booby.--There were many more adults than occupied nests. Thirteen adults were banded before October 8, and on October 8 two banded birds were among the 13 adults captured. This observed ratio resulted in the estimate of a total population of 85 adults.

Brown booby.--Seven adults were banded before October 8, and 1 repeat was among the 3 adults captured on October 8. This sample was too small to permit an accurate estimate of the population and the figure of 50 adults is scarcely more than an educated guess.

Red-footed booby.--Nests of this species were prominent in many parts of the island. The estimate was obtained by counting visible nests in the tops of the Scaevola in various sections of the island.

Great frigatebird.--This is an estimated total of full-grown birds present and is based on the highest count obtained in the middle of the day when the birds were soaring over the island in one huge mass. Nestlings were large enough so that few adults were found on the nests at midday. If a sizable proportion of the population was at sea in the middle of the day this figure would have to be increased accordingly.

Common noddy.--The population of this species was especially difficult to estimate for two reasons. In the first place, nests were very susceptible to destruction by Polynesian rats, especially when the presence of humans on the islands caused the birds to leave their nests unprotected momentarily. Secondly, shortly after the young birds had reached flying age they were indistinguishable in flight from the adults. Thirty-five birds in adult plumage were banded, some of them through the use of mist nets and others through the use of lights at night. On October 8, out of 20 birds observed at close range, 3 wore bands. This small sample indicated a total population in the neighborhood of 233 birds. However, as many as 300 were seen at one time along the beach, so this latter figure was used as the estimate of the population.

American golden plover and ruddy turnstone.--These two shorebirds were scattered in small flocks throughout the island as well as along the outer beaches. It was never possible to observe the entire population at one time. Only 1 banded bird was recaptured, and no banded bird was observed among 35 turnstones examined with binoculars on October 8. It is possible, therefore, that the population was considerably in excess of the estimate.

The figures for June 5, 1957, were taken from Kenyon and Rice (1958). These observers were on the island for 9 hours, and some details as to their estimates were given in the above publication. The 1960 estimates were obtained between 12 and 3 p.m. by Robbins, Wilson, Bristol, and Seamen Brimley, Schaeffer, and Motzkus from the Coast Guard Cutter MATAGORDA. These observers worked in three parties, counting all nests seen and making estimates of the number of adult birds present. No estimates could be obtained of nocturnal species, although a check of shearwater burrows showed that wedge-tailed shearwaters were present in

abundance. For all other nesting species except albatrosses, counts were made of either occupied nests or of adults, and no allowance was made for possible presence of non-nesting birds. In the case of the albatrosses, on the other hand, allowance was made for the estimated destruction or desertion of 10 percent of the nests prior to the date of the count. Kenyon and Rice added 10 percent to their estimate, the same percentage of unemployed birds as had been found on Midway. Counts of nestlings and adults made in 1960 indicated that the percentage of adults present was considerably in excess of the numbers computed on the basis of an estimated 17 percent unemployed birds. The difference is believed due, at least in part, to an influx of non-nesting birds that are establishing territories for use in subsequent years. The 1960 estimates of total adult albatrosses given in table 11 were obtained by doubling the number of chicks, adding 10 percent for nest mortality, taking 10 percent of the resulting total as the number of nesting adults present on the island at any one time. The remaining 90 percent was added to the number of birds actually counted on the island on March 28, 1960; from this total was subtracted two-thirds of the number of adults whose nests were estimated to have been destroyed before the day of the count.

Since the primary hazard at Midway is from Laysan and black-footed albatrosses, comparatively little work has been done on populations and habits of other bird species at Midway. Population estimates of the various species have been made from time to time, and relatively small numbers have been captured and banded in specific areas. It is hoped that the preliminary data from these studies will be of value when and if more intensive research on the species is required.

Bonin Island petrels and wedge-tailed shearwaters

These two species have not been recognized as a particular aircraft hazard at Midway. It should be noted, however, that a heavy flight comes from the ocean shortly after sunset. During a short period each evening these nocturnal pelagic birds might be a hazard to the operation of jet powered aircraft. The petrels nest on Midway throughout the winter and the shearwaters during the summer.

The petrels begin coming ashore about 10 minutes after sunset, and generally fly within 200 feet of the ground. By about 15 minutes after sunset they arrive at the rate of approximately 1 per second within any specified field of view. It is difficult to obtain counts beyond one-half hour after sunset because of darkness. Because of their small size they are not believed to constitute a hazard to conventional propeller-driven aircraft. It would be advantageous, however, to avoid operation of jet-powered aircraft during the period between 15 minutes and one hour after sunset. The departure of shearwaters and petrels appears not to be concentrated like their arrival, and apparently takes place gradually during the night.

Boobies and frigatebirds

Boobies and frigatebirds no longer nest on Sand Island, but they do nest on Eastern Island. The boobies, except when incubating or protecting small young, go to sea early in the morning and return in the evening. They very seldom pass over the runways on Sand Island. Frigatebirds occur only in very small numbers on Eastern Island. Single birds occasionally appear over Sand Island runways, but to our knowledge there has not been an aircraft strike. These birds at times soar several hundred feet over Eastern Island or in thermals on the downwind side of Eastern Island.

Tropicbirds

Red-tailed tropicbirds (bosun birds) nest on Sand and Eastern Islands and are present through most of the year except in midwinter. As many as several hundred may be in flight over each island in midday starting as early as mid-March. These birds seldom are hit by aircraft.

Shorebirds

This group includes the golden plover and ruddy turnstone, both of which are present in numbers up to several hundred on both Sand and Eastern Islands. Because of their small size they are not considered a hazard, although an occasional bird is struck by aircraft. The heaviest movement of these birds is the evening flight of turnstones that takes place at about sunset when birds from all parts of Sand and Eastern Islands leave to spend the night on the reef. Several other species of shorebirds occur at various seasons, but seldom in numbers exceeding 10 at any one time.

Sooty terns

The harrassment programs in 1957 and 1958 were successful in moving the large sooty tern colony from Sand Island to Eastern Island. These birds are now well established in several large colonies on Eastern Island. If they continue to be protected on Eastern Island, it is unlikely that they will attempt to re-establish themselves on Sand Island.

Other terns

Fairy terns and Hawaiian noddies nest commonly in the trees on Sand Island. A few of these small birds occasionally are hit by aircraft, but they are not considered a hazard. They occur in small numbers over the runways throughout the day and the largest groups (in loose flocks) often return from the sea in the early evening.

Two recommendations relating to the leveling and hard-surfacing of areas within 750 feet of the center lines of the Sand Island runways and the removal of birds from these specific areas are given on pages 35-36. Other recommendations relating to continued research on the bird hazard problem and to protection of birds not involved in the hazard are as follows:

3. Continuation of bird hazard studies at Midway. It is recommended that the Bureau of Sport Fisheries and Wildlife continue to cooperate with the Navy, to evaluate the results of the 1964 construction, to continue to gather data on population dynamics, and to investigate additional means of reducing the bird strike hazard.

Protection of established study areas on Sand and Eastern Islands, Midway, from intrusion as long as possible is recommended so that long-term studies on population dynamics will not be interrupted. The locations of these study areas are given on pages 40-41. It is also recommended that native shrubs such as Scaevola be permitted to persist on portions of Eastern Island to serve as nesting areas for the Midway population of red-footed boobies and great frigatebirds. If these nesting areas are eliminated there is danger that these large birds will move to area 7 of Sand Island and possibly interfere with aircraft operations.

4. Complete protection for Hawaiian Islands National Wildlife Refuge. Because of the ever increasing demand on the small remaining undisturbed acreage at Midway it becomes increasingly important to take all possible steps toward the preservation in their natural state of the other leeward islands in the Hawaiian Chain and to take all necessary precautions to protect the native vegetation and the wildlife on the other islands. As long as the other islands remain as inviolate sanctuaries the future of the unique avifauna and other wildlife of these areas will be assured.

It is recommended that representatives of the Bureau of Sport Fisheries and Wildlife make periodic visits to all islands in the Leeward Chain to assure a very minimum of disturbance to wildlife and to conduct any studies that may be desirable while most of the islands are still in a relatively undisturbed state. Visits to Coast Guard installations at French Frigate Shoals and Kure have indicated excellent cooperation of the commanding officers and their staffs, and it is important that this cooperation be encouraged and continued. Introductions of exotic species of plants and animals (including pets) on these islands should be vigorously discouraged.

5. Protection of birds that are not hazards to aircraft. It is recommended that all native birds* not directly associated with aircraft danger be protected at all times at Midway and other inhabited islands in the chain. It may be necessary at times to control local populations of some of the burrowing species in residential areas, but in general, these birds do not constitute a serious hazard and should be protected. The limited studies that have been conducted on Bonin Island petrels at Midway have been hampered by slaughter of birds by station personnel because their burrows were considered a hazard.

* the feral pigeons are not native to Midway.

REFERENCES

Bailey, A. M.
1952. Laysan and black-footed albatrosses. Denver Museum of Natural History, Museum Pictorial No. 6. 80 pp.

1956. Birds of Midway and Laysan Islands. Denver Museum of Natural History, Museum Pictorial No. 12. 130 pp.

Burnap, R. L.
1959. Albatross and the Navy on Midway Atoll. National Audubon Society. 6 pp. (mimeo.).

Clay, Horace F.
1959. Narrative report of botanical field work on Kure Island, 3 October, 1959, to 9 October 1959. University of Hawaii. 5 pp. (mimeo.).

DuMont, Philip A., and Johnson A. Neff.
1955. Report on Midway Island albatross study (unpublished, Bureau of Sport Fisheries and Wildlife). 8 pp. (to Military Air Transport Service).

Finley, Robert B., Jr.
1960. Resume of studies on bird hazard to aircraft. 15 pp. (mimeo.). Report of Bureau of Sport Fisheries and Wildlife. (to Biology Branch, Office of Naval Research).

Fisher, H. I.
1949. Populations of birds on Midway and the man-made factors affecting them. Pacific Science 3 (2): 103-110.

Fisher, H. I., and P. H. Baldwin.
1946. War and the birds of Midway Atoll. Condor 48 (1): 3-15.

Frings, Hubert, and Mable Frings.
1959a. Observations on salt balance and behavior of Laysan and black-footed albatrosses in captivity. Condor 61 (5): 305-314.

1959b. Problems of albatrosses and men on Midway Islands. Elepaio 20: 6-9, 14-16, 23-25, 30-33.

1961. Some biometric studies on the albatrosses of Midway Atoll. Condor 63 (4): 304-312.

Hadden, F. C.
1941. Midway Islands. The Hawaiian Planter's Record 45: 179-221.

Horn, Thomas C.
1959. Preliminary Report--Habitat improvement work, Kure Atoll - Green Island. 5 pp. Typewritten report of Bureau of Sport Fisheries and Wildlife.

Janzen, D. H.
1962. Recommendations for solution of the Midway Islands aircraft-bird strike program. 7 pp. Typewritten report of Bureau of Sport Fisheries and Wildlife. (to Bureau of Yards and Docks, Department of the Navy).

Kenyon, K. W., and D. W. Rice.
1958. Birds of Kure Atoll, Hawaii. Condor 60 (3): 188-190.

Kenyon, K. W., D. W. Rice, C. S. Robbins, and J. W. Aldrich.
1958. Birds and aircraft on Midway Island. November 1956-June 1957 investigations. U. S. Fish and Wildlife Service Special Scientific Report--Wildlife No. 38. 51 pp.

Rice, Dale W.
1959. Birds and aircraft on Midway Island, 1957-58 investigations. U. S. Fish and Wildlife Service Special Scientific Report--Wildlife No. 44. 49 pp.

Rice, D. W., and K. W. Kenyon.
1962a. Breeding distribution, history, and populations of North Pacific albatrosses. Auk 79 (3): 365-386.

1962b. Breeding cycles and behavior of Laysan and black-footed albatrosses. Auk 79 (4): 517-567.

Robbins, Chandler S.
1959. Preliminary report on Kure Island expedition. 7 pp. Typewritten report of Bureau of Sport Fisheries and Wildlife.

1960. Albatross management investigations on Midway and Kure Atolls in 1959-60. 45 pp. Typewritten report of Bureau of Sport Fisheries and Wildlife.

1961. Albatross management investigations on Midway and Kure Atolls in 1960-61. 26 pp. Typewritten report of Bureau of Sport Fisheries and Wildlife.

1962. Report on Midway trip, July 25--August 31, 1962, and recommendations for habitat management along Sand Island runways. 6 pp. Typewritten report of Bureau of Sport Fisheries and Wildlife.

☆ U.S. GOVERNMENT PRINTING OFFICE 1966 O - 238-613