THE
DARK-RUMPED PETREL
IN
HALEAKALA CRATER

by

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INTRODUCTION

Shortly after my arrival in the Hawaiian Islands in April, 1965, I became interested in the life history and ecology of the dark-rumped petrel or uau (Pterodroma phaeopygia sandwichensis). The study was further prompted by a statement in the Resource Study Proposal No. HALE-N-6 entitled "Preservation of Dark-Rumped Petrels." The statement reads:

> After nearly 50 years of supposed extinction, a small colony of the Hawaiian race of Dark-Rumped Petrel was found nesting in Haleakala Crater. Investigators from U. S. National Museum, Smithsonian Institution concluded this race of the Dark-Rumped Petrel is in danger of extinction from heavy predation of exotic animals.

The first summer, the study had little direction and organization and it lost momentum in August. However, after evaluating the situation and discussing the matter with interested persons, I was inspired to attack the problem with added vigor during 1966. The information gained in 1965 and 1966 has also proven valuable as control data to determine the effectiveness of a predator control project initiated in August, 1966.

Uau, pronounced oo AH oo is the Hawaiian name for the dark-rumped petrel. For the sake of brevity, I will use uau rather than the English vernacular or scientific name.

METHODS OF STUDY

The study began with a survey of Kalahaku Pali (cliff) in search of burrows on June 15, 1965 by Park Ranger James Potton and myself. Our initial findings were encouraging and the field investigations continued into November, 1966.

Thirteen trips were made into the study area and other potential breeding areas in 1965 and 62 trips were made in 1966. Some visits, not including driving time, to the study area consumed only 15 to 20 minutes, whereas other trips, in search of new nesting sites took one to two days. About one-half of the time spent in the field was at night. The nocturnal habits of the uau dictated that the investigator spent a considerable amount of time on the talus slope at night.

Uau are relatively unafraid of people so no special blinds or secretive devices were used. Occasionally, I was able to walk up to a bird and pick it up. Normally, however, I had to remove the birds from their burrows if I wished to examine, band, or photograph them. The simplest means was to insert a four-foot stick with a rag attached to the end, and tease the uau into grasping it with its bill. By gradually

retrieving the stick, I pulled the uau within arms reach of the burrow entrance. Then I reached into the burrow, coaxed the bird to grasp my forefinger, and then clamped my thumb over the upper mandible. It was then just a matter of pulling the bird out. I ultimately resorted to wearing a leather glove, because the adult uau is quite capable of biting hard enough to draw blood.

In the two burrows, where the adult birds were readily observed, I spray painted a small amount of quick-drying yellow lacquer on the white neck feathers of one of each mated pair. I could then determine which bird was on the nest by merely shining a light into the burrow. The lacquer did not appear to harm the birds in any way and wore off after two or three months.

A flashlight was normally used to light a burrow. If the sun was not obscured by clouds and at a proper angle, a small hand mirror was sometimes used to direct the much stronger sunlight into the burrow. A four-foot stick, with a small 2 inch by 3 inch mirror attached to the end, was sometimes inserted into the burrow. In combination with a flashlight, it was possible to "look around corners" and other obstructions to search for birds and eggs.

The easiest and least time-consuming means of determining activity at a burrow was to smooth all tracks at the entrance and part way into the burrow. Uau and other tracks are readily observed in the loose soil and it was usually possible to determine if a bird had entered and/or departed its burrow.

By far the easiest time to locate burrows is during the incubating season. During this period, the adults spend considerable time in their burrows and defecate frequently near the burrow entrance. The whitish and greenish droppings are readily visible and are a great aid in locating burrows. Other indicators of an active burrow are odor, presence of flies, and tracks. A fairly good indicator of a successful rearing is the presence of shed down at the burrow entrance. It is most evident just prior to fledging.

The arrangement of material in this report is, for the most part based upon the Outline for Collaborating Authors as presented in the Handbook of North American Birds (1955) sponsored by the American Ornithologist' Union and New York State Museum and Science Service.

ACKNOWLEDGEMENTS

To begin with, the study would never have amounted to much if Neal G. Guse, Superintendent of Haleakala National Park had not been sympathetic to the plight of the uau. Because of his concern for the endangered species, there was never any question regarding my using Park resources and official time, when necessary, for research purposes.

Winston Banko and Eugene Kridler of the Bureau of Sport Fisheries and Wildlife, U. S. F. & W. S. provided valuable advice and encouragement in conducting the research. Park Ranger James Potton assisted with field surveys, observations, and planning. Cameron Kepler of the Pacific Project, Smithsonian Institute was instrumental in initiating the banding program. Members of the Department of Zoology, University of Hawaii provided invaluable assistance by analyzing uau stomach contents. To all of these people, I owe special thanks.

ENVIRONMENT

Description of Haleakala National Park: Haleakala National Park, on the island of Maui, is one of three units of the National Park System in Hawaii. The park covers 27 square miles, and ranges from 3,847 feet above sea level in Kaupo Gap to 10,023 feet at the summit. The primary feature of the park is Haleakala Crater, within which, the uau nests.

Geology: Haleakala is a huge dormant volcano 33 miles long and 27 miles wide at sea level. Geological studies indicate that at one time it was more than 11,000 feet high. During a long period when the volcano was relatively quiet, water erosion cut two deep valleys, the Keanae and Kaupo, into its sides. These valleys joined at the top of the mountain and formed a long erosional depression.

When the volcanic activity started again within this depression, lava flows poured through the Koolau (Keanae) and Kaupo Gaps into the valleys and almost filled them. Numerous large cinder cones were formed, creating a spectacular volcanic landscape. Thus, a water-carved erosional depression was partially filled by volcanic rock and created what is now called Haleakala Crater.

The crater is 7½ miles long, 2½ miles wide, and 21 miles in circumference. The crater floor, 3,000 feet below the summit, covers an area of 19 square miles. The last volcanic activity within the crater has not been accurately dated but probably occurred a few hundred years ago.

Climate: The climate in Haleakala National Park is generally of a temperate or sub-alpine nature rather than sub-tropical as is characteristic of lower regions at this latitude. Temperatures at Park Headquarters (7,000 feet elevation) range from winter lows around +30°F. to summer highs in the mid 70's. Winter mean temperatures are about 8° lower than summer means. The study area at 9,500 feet is about 7° cooler than Park Headquarters.

Rainfall ranges from an estimated 40 inches in the center of the crater to 150 inches at Paliku. Park Headquarters averages about 50 inches and the study area probably slightly less. One or two snowfalls may be

expected each year at elevations above 8,000 feet.

The park is subject to strong winds, hail, lightning storms, and heavy rains, usually of short duration. Foggy conditions occur frequently particularly below 7,000 feet and at higher elevations on the north and east palis (cliffs).

Soils: Nearly all the soils in the park have been classified as lithosols or regosols (Cline, 1955). Lithosols consist of areas dominated by masses of loose boulders with little fine material between them, or by weathered or unweathered bed rock. This includes aa lava flows and continuous outcrops of older lavas. There is little or no genetic profile development other than small accumulations of organic matter in the surface layer. Most of the uau nesting sites fall in this category.

Regosols are deep soils derived from volcanic ash and cinders. They comprise the soil of the center crater, cinder cones, the summit, Sliding Sands Trail, and the western slope of the mountain. The only evidence of a soil profile is the presence of an A_1 horizon in the immediate vicinity of plants.

Vegetation: Plant communities can generally be categorized as semi-arid sub-alpine and sub-humid sub-alpine. Most of the park is relatively dry and plant species are fairly uniform throughout. The major changes relate to plant size and amount of ground cover. Known uau nesting sites are found only in semi-arid regions which include the following plants:

Bracken fern (Pteridium aquilinum)
Native grasses (Trisetum glomeratum)
(Deschampsia australis)
(Agrostis sandwicensis)
Sheep sorrel (Rumex acetosella)
Mamane (Sophora chrysophylla)
Silver Geranium (Neurophyllodes tridens)
Evening Primrose (Raimannia odorata)
Ohelo (Vaccinium reticulatum)
Pukiawe (Styphelia tameiameiae)
Kukaenene (Coprosma ernodioides)
Pilo (Coprosma montana)
Kupaoa (Dubautia menziesii)
Pamakani Haole (Eupatorium glandulosum)
Gosmer (Hypochoeris radicata)
Tetramalopium (Tetramalopium humile)
Silversword (Argyroxiphium sandwicense)

Wetter areas of the park have many of the same species but plant cover is much greater and individual plants may grow much larger. In addition, several species common to the upper native rain forest overlap into the wet areas.

Wildlife: There are no mammals, amphibians, reptiles, or fishes native to Haleakala National Park. Native fauna are limited to a few species of birds and several invertebrate species.

The first Polynesians to arrive in Hawaii brought along pigs, which have established feral populations extending into the park. When the first Caucasian explorers and settlers arrived, they populated the islands with goats, cattle, horses, sheep, cats, dogs, and unintentionally, mice and rats. In addition, mongooses were imported to Hawaii in 1883 to control rats, which were doing significant damage to sugar cane. All of these animals were, at one time, or are now present within the park.

In addition to the uau, birds found in the park include:

White-tailed Tropic Bird (Phaethon lepturus)
Nene (Branta sandvicensis)
Chukar (Alectoris graeca)
Ring-necked Pheasant (Phasianus versicolor)
American Golden Plover (Pluvialis dominica)
Short-eared Owl (Asio flammeus)
Skylark (Alauda arvensis)
Japanese White-eye (Zosterops japonica)
Apapane (Himatione sanguinea)
Iiwi (Vestiaria coccinea)
Amakihi (Loxops virens)
Ricebird (Lonchura punctulata)
House Finch (Carpodacus mexicanus)

HISTORY OF PETRELS IN HAWAII

According to Munro (1944) the uau was historically endemic to the main group of the Hawaiian Islands - Hawaii, Maui, Molokai, Oahu, Kauai, and Lanai. Ancient Hawaiians collected the old and young alike for food. The young were considered a delicacy and reserved for the royalty, while the old strong-flavored birds were eaten by the common people. Munro further indicated that the predatory mongoose destroyed the petrel on Hawaii, Maui, and Molokai whereas pigs and cats killed them on Lanai. He flatly accuses ancient Hawaiians of exterminating the uau for food on Oahu. Since there are no mongooses on Kauai, Munro considers it possible that uau may still nest there, but it is now generally believed that uau are found only on Haleakala, Maui and Mauna Kea, Hawaii. Richardson and Woodside suggested in 1949 that uau numbers may be in the hundreds and possibly the thousands.

DESCRIPTION

Petrels and their allies: The uau belongs to the family Procellariidae which includes shearwaters, fulmars, and large petrels. The family is characterized as follows: birds of the open sea; about the size of gulls; tubelike external nostrils; narrow wings and small tails; sexes alike; a distinctive banking and skimming flight pattern; nest on islands; quiet at sea but noisy at nesting sites; and feed upon fish, squid, and crustaceans. They range the oceans of the world and number 33 species (Mayr-Amadon), 56 species (Van Tyne-Berger). There are six species in Hawaii (Peterson, 1961).

Species: Pterodroma phaeopygia sandwichensis is a subspecies with P. P. phaeopygia found in the Galapagos Islands. The Galapagos and Hawaiian races constitute the only forms of a species of which only scanty, fragmentary information has been collected.

Description of Uau: The uau measures 15 to 17 inches in length and is dark brownish-black above and white below. It is distinguished from related species by having a white forehead and flesh-colored legs and upper halves of the webbed feet. Measurements in 1966 of two adults yielded the following information:

Length	Wingspread	Wing	Tail	Bill From Feathers	Tarsus
16½ inches	39 inches	5 3/4 inches	12⅝ inches	35 mm	42 mm
15	37½	5 1/4	12	34	40

I did not obtain any weights of adult birds.

Newly hatched chicks are almost completely covered with long charcoal-gray down. After three weeks, feathers begin to develop but do not show until the chick is six to seven weeks old. By the time the chick leaves the nest, only traces of down can be seen on the legs.

Voice: Uau calls are varied and not easily described. However, I will attempt to describe the calls as I interpret them and then quote other authors regarding their interpretations. It is evident from the Hawaiian name of the bird that it was named after its most prevalent call.

My notes from July 8, describing the calls heard that evening, read as follows: "oooAH, and KAoooAH repeated over and over; duck-like quacking; clucking like chickens; low-pitched gurgling; and many combinations of above and more too." In a few references there is mention of the petrels sounding like dogs yipping. Only on one or two occasions did I hear calls that could be described that way.

Richardson and Woodside have this to say about the calls. "The most

frequent call, usually starting soon after dusk, is a repeated ă - o͞o with an inflection on the ă often making it a sharp note, and the o͞o lasting about a second. The o͞o may sound, especially if heard nearby, like a complex of growling squeaks, and may be followed by a sharp kee-kee-kee. Additional notes are a drawn-out ē, a croak-like note, and a high-pitched witch note."

Huber (1964) describes the calls in some detail: "the basic call may be expressed as "ooo---wa-ooo." The middle syllable is short and high pitched, sounding like the "wha" in "what." Some of the other calls were: "ooo-wa" (the a, short and accented), "wa-oo" (both short), "ooo--wa-oo-wa" (the last a, shrill). One bird continually called "AA-AA" and "AA-AA--A-A" (harsh and rasping). Nearly all possible combinations of the calls described were heard except consecutive "ooo's."

Calling was most prevalent during May, June, and July. Little calling was heard in March and April, primarily because fewer birds were present at any one time. Calling slowly decreased during August. After August 31, no calling was heard, even though a few birds were still flying around in the evenings.

The uau usually began calling shortly after they arrived in the nesting area. They would begin arriving about one-half hour after sunset and calling would build to a peak during the next hour and then die down to infrequent calls about two to three hours after sunset.

On no occasion did I hear a bird utter a sound while in its burrow, unless it was teased or if an adult was with its chick. The calling is related to flying in the nest area, and not while on the ground. Very little calling occurs after 10:00 p.m. although there may be very infrequent calling by flying birds throughout the night.

What function the calling serves was not determined. It may relate to breeding behavior, although, it seemed that most evenings only one bird, if any of a mated pair, would arrive at the burrow. Also calling becomes more pronounced after the eggs are laid. For various reasons, I believe the calling does not relate to locating burrows. First of all, there normally is not an adult in a burrow to call down its mate. Only rarely did I find both adults in the burrow at one time. Secondly, calling ceases in late summer, but birds still come to their burrows. Thirdly, as stated before, I never heard adults calling from within their burrows.

Because of the flight patterns assumed by the petrels, it is unlikely that calling relates in any way to territorial behavior. They typically fly parallel to the cliff and overlap numerous other burrow sites. The significance of the calls remains to be determined.

Habitat: Based upon burrow density and fledgling success, the habitat in the study area appears to be the most suitable within the crater for the uau. It is located on the west crater wall at an elevation about 9,400 feet. The area of concentrated study is 300 feet by 500 feet and has a vertical relief of 350 feet. The slope of this area is roughly 60 to 70 per cent.

The ground surface is primarily talus with numerous bed rock outcrops and patches of cinders and ash. Occasional vertical cliffs up to 20 feet high break up the otherwise uniform appearance of the study area. Rocks are basalt and andesite.

Plant life covers five to ten per cent of the slope and is composed primarily of Pukeawe, kupaoa, and bunch grass. Also present are ohelo, silver geranium, kukaenene, gosmer, and tetramalopium. Plants rarely exceed three feet in height.

The weather is relatively dry, cool, and windy. Winds normally blow up the face of the crater wall. Freezing temperatures are common at night during winter, spring, and fall. Foggy conditions are common during midday and occasionally at night.

Uau also nest in more heavily vegetated areas, particularly on the south pali between Kaupaakea and Haleakala Peak. Ohelo, mamane, pukeawe, pilo, and kupaoa, create a shrub thicket four to six feet high that covers nearly 100 per cent of the ground in some areas. In such situations the burrows were found only at small clearings at the bases of rock outcrops. Nesting density appeared relatively low in these situations.

On the Leleiwi Pali, bunch grass is the dominant vegetation in some areas and burrow entrances are sometimes screened by grass and bracken fern. Above Holua Cabin, a burrow was found on a steep slope covered only with sod. The burrow had been dug under a large grass clump in an area where the soil was fairly well developed and did not crumble too readily. This is the only burrow, without a rock layer overhead, that was found.

Burrows were found from elevations of 7,200 feet to 9,600 feet elevation. The elevation did not seem to be critical within this range, but rather suitable habitat appeared to be the limiting factor. More burrows were found above 8,000 feet than below, but this may be explained because most of my surveys were at higher elevations, where more suitable habitat is present.

Many burrows are extremely difficult to locate during most of the year. When droppings are present and fairly conspicuous in early summer, the active burrows are readily found. Before and after this period considerable searching may yield poor results. The burrows were not dug in well-camouflaged sites for protection, but because the rock and soil arrangements were suitable for digging. Generally, it appears that uau are

found throughout much of the west and south palis of Haleakala Crater and possibly on the palis below Hanakauhi.

Haleakala Crater may represent the last stronghold for the uau. Bryan (1908) describes the uau as nesting in partly natural burrows in wet forested slopes below 4,000 feet on eastern Molokai in 1907. If this was so, the range of the uau may at one time have been much greater on Haleakala as well as the other islands. Presumably the open sea is the uau's habitat when away from the nesting sites.

DISTRIBUTION

The only known uau nesting sites on Maui are in Haleakala Crater and, to a very limited extent, on the crater rim. All known sites fall within areas totaling only three square miles. Kalahaku and Leleiwi Palis support the greatest populations and Kapalaoa Pali, a lesser population. Although a rapid survey of the north pali did not turn up any sites, it is conceivable uau nest there. King (1964) mentions finding one burrow at the foot of Mauna Hina.

A population of uau is found on the east slope of Mauna Kea above 9,000 feet, but to my knowledge, little is known about it. There have been no reports of uau on other islands since 1907. This does not mean they are not there, however. The nocturnal habits and inconspicuous nesting sites of this species makes it difficult to locate.

Within Haleakala Crater, population densities vary considerably. The uau does not appear to be colonial in the typical sense. At the same time, their territorial claims, if any, must be very small. In one instance, two burrows are within six feet of each other, while others may be separated by several hundred feet. Again, suitable burrowing sites appear to be the determining factors.

Although the general range of potential nesting sites is limited, there appears to be an infinite number of sites within this range that could be used or developed by uau. Therefore, it is reasonably safe to assume, that suitable nesting sites is not the most important factor when discussing the limited uau populations.

I would like to be able to give an accurate estimate of the number of nesting uau in the crater. However, the more I survey the park, the less confident I am that I can make an accurate estimate. Nevertheless, I will try, because it is important to know if the remaining numbers are in the dozens, hundreds, or thousands.

I estimate there are at least 300 breeding pairs on Leleiwi and Kalahaku Palis and at least 100 pairs on Kapalaoa Pali. I feel reasonably sure these estimates are conservative and I can readily conceive that breeding

pairs may be twice these figures. Nesting success, on the other hand, has probably been low. Further surveys are definitely needed to refine these estimates--and to note population trends.

Where the birds are, when not at their nesting sites, is not known. The extent to which they range over the Central Pacific may be fairly limited, but it is more likely they cover several hundred miles in one or more directions from the Hawaiian Islands.

Banding Status: As of December 1966, only nine uau have been banded. One was banded in 1964 by Smithsonian investigators; two in 1965 by Cameron Keppler, and six in 1966 by myself. Two recoveries were obtained during the summer of 1966. All banding has been done in Haleakala Crater.

The following chart shows the breakdown of uau banding for the past two years:

Band Number		Date of Banding	Banded at Burrow Number
544-45004	Adult	July 21, 1965	3
005	Adult	July 21, 1965	3
544-28201	Adult	May 11, 1966	6
202	Adult	June 13, 1966	6
203	Nestling	July 18, 1966	6
204	Adult	July 18, 1966	5
205	Nestling	July 26, 1966	3
206	Adult	August 17, 1966	4

Specific birds will be referred to by the last three digits of their band numbers (e.g. #203 and #204).

Reproduction:

Age when breeding begins: It is highly improbable that uau breed before they are one year old. Breeding behavior begins as early as the first of March and it is unlikely a bird having fledged the previous October, would be mature enough to participate successfully. Lockley (1961) was convinced shearwaters were unable to breed their first summer after hatching.

Arrival on breeding grounds: In 1966, uau first arrived at the breeding grounds about the first of March. The numbers of birds per evening was relatively small, and apparently, they made very infrequent visits for the first month or two. Occasional checks for tracks at burrows indicated an early visit at each burrow and then a time lapse of one to two months before the birds returned. Calling activity is limited during this period.

Establishment of territory: The early arrivals did use burrows so presumably they were locating mates and establishing territorial rights. I did not, however, see any activity indicating aggressive or defensive territorial action by uau.

Pair bond: A very fortunate discovery was made in 1966. During the summer of 1965, mated uau occupying burrow #3 were banded by Cameron Keppler of the Smithsonian Institution and myself. These were the only birds banded that year. In 1966, these same two birds were discovered occupying the same burrow, #3. Statistically, I am on shaky ground to flatly state that uau mate for life and occupy the same burrow each succeeding year. However, the information does fall in line with that obtained on shearwaters by Lockley, and it seems reasonable to assume uau tend to mate for life and use the same burrow year after year. There is no indication that matings are anything but monogamous. Little is known about pair formation. Very likely the flight behavior and calling, at least during mating, relate in someway to courtship.

Nest: Old nest sites are used each year. This is a matter of expediency if nothing else. The effort involved in locating and digging a new burrow surely must encourage the birds to use ready-made situations. No where did I find evidence of a new burrow having been dug.

There is evidence to indicate some burrows are used for purposes other than nesting. Several burrows showed signs of occupancy part ways through the summer, and then abandoned. If these were honest attempts at nesting, it would appear that nesting success is very low. There were no signs of predation in most of these nests.

Possible alternate uses of some of these "abandoned" nests are:

(1) unmated birds and/or adolescent birds occupying the burrows and
(2) mated and established birds simply checking out other burrows.

There is no reason to think they are establishing auxiliary nests for protection purposes.

No attempt is made to conceal a burrow entrance. Prior to the arrival of man, the uau had no enemies on land. The fact that many burrows are very well concealed related not to protection, but rather to suitable sites for digging or the presence of natural openings. Site preparation was not observed but presumably it involves a sort of hit or miss attempt at locating a spot where a natural opening is adequate for nesting or else the soil and rock arrangement permits digging and soil support. The most common situation is a nearly level platform, upon which a loosely consolidated layer of soil and/or cinders or ash deposits exist. Over this, bedrock (lava flow) is present. The petrel digs a tunnel four to eight inches high through the loose layer and simply deposits the soil outside the entrance.

Because of the weak legs and small claws, it is unlikely the uau uses its feet for digging. The powerful, hooked beak, however, should be an excellent tool.

Burrows are generally nearly horizontal, although a few descend or ascend at steep angles. Again, the rock and soil arrangement is the determining factor. Burrow length is from four to 15 or more feet. The longer burrows are those dug at the end of natural tunnels, some of which, are large enough for a man to enter by crawling.

There is no pattern regarding straight tunnels versus crooked tunnels. Many tunnels with bends in them are obviously constructed that way because of the rock and soil arrangement.

The nests are merely shallow depressions at the tunnels' ends and are skimpily lined with a few twigs and feathers. The lining material is so scanty that it appears to serve no function as the egg frequently rests directly upon the ground.

Most of the burrows I observed were constructed such that I could not see the nest. Of the 15 burrows in the study area, I could plainly see only two nests. Two additional nests were partially visible by using a small mirror on the end of a stick inserted into the tunnel.

Most nests had only one entrance. The few that had two or more probably were that way by chance. Nests and occupants occasionally became soaked by heavy rains, which fall infrequently during the nesting season.

Copulation: No activity was observed relating to this subject. Lockley observed shearwaters mating on land within sight of the pair's burrow. He considers the possibility that it is the shearwater's urge to mate that attracts it back to the nesting site in the spring. There apparently is little chance that mated pairs would mate at sea as they travel hundreds of miles from land and probably rarely if ever come in contact with each other. These considerations can also be applied to the uau.

Eggs: Based on observations made in 1966, I have narrowed the laying period down to a relatively short period in mid-May. One egg was layed about May 10 ± one day and another between May 11 and May 16. Other evidence, based upon the fledgling period, indicates most or all eggs are laid during that general time period.

All observations indicate only one egg is laid. It is white with a semi-glossy finish. Rather than attempt to describe its shape, a photograph and drawing have been included in this report. Two eggs I measured were as follows: 45mm x 64mm and 46mm x 66mm. An egg measured by Huber (1964) had dimensions of 46mm x 67mm.

Incubation: Based upon observations of two burrows, I determined the incubation period to be 50 to 55 days. My visits to the burrows at hatching time were not frequent enough to pin it down any closer. This time period is consistent with Lockley's observations relating to shearwaters.

Each adult typically incubates for three to five days at a time. It seems likely that the incubating adult waits until its mate returns from feeding before leaving the nest. Based upon frequent observations, I feel reasonably sure that an adult may incubate up to 12 days without leaving the burrow for food or water, nor does its mate bring food to the burrow. This unusual ability is shared by shearwaters as was observed by Lockley. Because tracks are readily observed at the entrance and on the tunnel floor, I was able, by smoothing the surface each visit, to determine when birds entered and departed the burrows.

I visited burrow #3 sixteen times and burrow #6 fourteen times during incubation. On 12 of the 16 trips, uau #004 was on the nest at burrow #3 while uau #005 was present the remaining four times. In burrow #6, uau #201 was present 13 of the 14 trips and uau #202 was present the other time. On no occasion were paired adults in their burrow simultaneously and on no occasion were the nest and egg deserted. After hatching, the egg shell is either pushed to one side or fragments may be dragged outside the burrow and left near the entrance.

Hatching success is difficult to determine. The only known case of an abandoned egg was at burrow #7 on August 13, when I found the cold egg rolled out of the burrow. It is quite conceivable the close proximity (six feet) of burrows #6 and #7 caused a territorial dispute, resulting in one household triumphing over the other. The shell contained a partially formed embryo. Two burrows showed activity through August and were then suddenly abandoned. These burrows may represent futile attempts at hatching infertile eggs. This, however, is conjecture only. Lockley states that four out of twelve shearwater burrows contained no eggs, though birds, primarily from other burrows, frequented the nest until July. This may be a similar situation with the uau, although I am inclined to think otherwise, because of the fairly abundant droppings at the "unsuccessful" burrows.

Excluding the four burrows that were raided by rats (to be discussed later), we can arrive at some estimates of fledgling success. Of the remaining 11 burrows occupied during 1966, five and possibly seven were fledged. This gives us a success ratio of 45% to 64%. One burrow (#7) was definitely abandoned. If we assume that the other three burrows were not used for nesting purposes, then the success rates are 62% to 87%.

Statistically, we are not on very safe ground and because of too many unknown factors it appears advisable to accept a conservative figure of about 50% success. This represents success in a predator-free environment.

Flightless Period: On only one occasion did I see an adult with its young during daylight hours. On July 4, #202 was with its one-to-two-day old chick. Feeding takes place during the night and normally within two hours after sunset.

During the first 1½ months of the chick's life, it was fed once every day or two. Only one adult was at the burrow any given night. The duties were shared by both adults, but probably not equally. In burrow number 3, #004 was observed five times whereas #005 was not observed at all. This does not mean that #005 was not active, however. At burrow #4, I captured both adults, each on a different occasion, as they were about to enter their burrow and feed the chick. On both occasions, the adults disgorged large quantities of partially digested food.

From about August 20 to September 22, chick #205 at burrow #3 was fed about once a week. After September 22, the next and also the last feeding was October 3 or 4. The chick fledged about October 21.

The normal procedure for feeding was for the adult to enter the burrow and occupy the nest with the chick. The chick would peck at the adult, apparently coaxing it to regurgitate food. The adults were somewhat inhibited by the light from the flashlight, and I was never satisfied food was ever passed from the adult to the young while I was observing.

Adult petrel #004 arrived at its burrow at 8:25 p.m. to feed its chick and departed at 9:15 p.m. It apparently was there only long enough to feed its young. This appeared typical of the feeding visits made by adults.

Unfortunately, I did not take a complete series of measurements to determine growth rates during the entire nestling stage. However, I will list the measurements I did get.

Chick #205 (days old)	Length (inches)	Wingspread	Wing	Tail	Bill	Tarsus	Weight
26	6 7/8	—	1 1/4"	—	26mm	28mm	—
61	10 3/8	—	5 3/8	2"	32	36	—
91	14 1/2	34"	9 1/4	4 3/4	33	40	—
103	—	—	—	—	—	—	17.5 oz.
110	16	36	11 1/2	6	34	40	15.5

The chicks did not "enjoy" being handled, but at the same time, there appeared to be no ill effects from the handling, unless they had been fed recently. At which time they would then regurgitate some or most of the food. They did peck quite a lot, but their jaws were not strong enough to draw blood, as the adults can do.. They returned to their nests readily, and settled down immediately.

During mating and incubation, adults normally defecated outside their burrows within 2 to 10 feet of the entrance. In some of the larger and longer burrows, droppings were found within the burrow near the entrance. After hatching, adults spent little time at the nest and no longer left their waste there.

The chicks, having eaten partially digested food, had little solid waste to eliminate, and merely squirted liquid into the porous cinder and ash material surrounding the nest. The liquid was quickly absorbed and the nests, although having a conspicuous odor, appeared surprisingly clean.

The time from hatching to fledging is about 115 days. This is an amazingly long time for a bird to develop. Whereas, the uau parallels the manx shearwater in many respects, it greatly surpasses the development time of the shearwater. Lockley records a nestling period of 73 days for the shearwater. Undoubtedly, the infrequent feeding by the uau is a major contributing factor to the slow development.

Nest leaving: The normal time for chicks to leave their burrows is the end of October. All five burrows which had young successfully reared were vacated between October 18 and November 2. I did not observe a chick leave its nest so I do not know if it makes a successful flight from its burrow or makes trial flights and "bounces" down the pali until it is finally capable of sustained flight.

It seems likely that the young leave their nests because of hunger as much as any reason. Having gone two to three weeks without food, it undoubtedly is encouraged to search for food.

I saw no indication (tracks or actual observation) that the chick, prior to flight, spent any time outside its burrow exercising or in any way preparing for flight. This also is in contrast to the manx shearwater, which spends several nights out of its burrow "limbering up" and practicing, prior to leaving the nest area.

HABITS

Social habits: Uau frequently arrive at the nesting sites shortly after sunset and at least on some occasions arrive alone. Once at the breeding grounds, they frequently fly in pairs, although there is good evidence to suggest the flight pairing is often not of mated pairs. On several nights, I was able to observe birds flying in pairs, but on only two occasions have I seen mated pairs in their burrows.

Active periods: Almost all incoming flights occur during the early hours of night. Departures may occur any time at night prior to sunrise. On July 15, 1965, I observed two birds leaving at 5:10 a.m., at which time indirect sunlight was just beginning to light the pali. Sunrise was at 5:50 a.m.

I never observed an uau outside its burrow during daylight hours--on its own volition. However, a previous park naturalist reported observing a petrel sitting on a rock in the crater at 10:30 a.m. When approached, it flew away. The date was October 27, and corresponds with the nest-leaving period of young uau.

I was not able to detect any correlation of activity with weather patterns. Uau were capable of locating their burrows on dark, cloudy, moonless nights, as well as clear, moon-lit nights.

From about the first of November to the end of February, there is no indication of any uau activity, day or night, in the crater. Apparently, the birds spend about four months at sea, and perhaps are not in sight of land for the entire period. This is a supposition only, and is based on habits of some sea birds.

Flight: Because of the uau's habit of flying only at night at the breeding area, it is difficult to get a good look at them in flight. However, I was able to observe a few by using a flashlight and will try to describe their flight as I saw it.

The birds generally flew a minimum of 20 feet from the crater wall unless they were preparing to land. Their flight was sometimes quite regular and steady and other times very erratic. I concluded that their flight was regular and steady based more upon flight sound than sight.

When I shined my light on the birds, they frequently began careening from side to side and increasing their altitude. If a pair of birds were flying together, they almost always split up when the light shone directly upon them. Because I could only follow the birds for a few seconds, I was never able to satisfactorily observe them.

It was very rewarding to simply sit and listen to their flying and calling. Normally, the birds flew parallel to the crater wall for several hundred yards, turned around, came back, and repeated this pattern for a half hour or more. I was able to determine this, because one particular bird made a most peculiar sound as the wind whistled through its feathers. It sounded a great deal like a distant automobile speeding on a paved road. In fact, that is what I thought it was at first because of the close proximity to the park road.

The normal flight pattern, just prior to landing at the nest site, was to make several passes a few feet over the site and finally land. Landing, in some instances, must have been quite traumatic. On one occasion, #004 "crashed" on a ledge four feet above its burrow. I picked it up and carried it to the burrow entrance and released it. Instead of going into the burrow, it jumped and flopped down the hillside until I finally caught it and placed it in its burrow.

I thought it was just a navigational error the first time the bird crashed, but two nights later, it landed in almost the same place, only this time it struck a kupaoa shrub. The bird lay there for about 30 seconds and then crawled over to the 4 foot ledge and "fell" over the side, making quite a clatter as it landed on the Havahart Live Trap. It then moved immediately into the burrow.

A third night, I had taken up a post about 25 feet from the burrow entrance and was crouching behind a rock. I covered myself completely with an army blanket to be as inconspicuous as possible and to keep warm. Uau #004 made many passes over the area during a half-hour period. I finally fell asleep, and the next thing I was aware of was a flopping noise and being hit on the back by a flying object. I surmised immediately what had happened and quickly picked up the bird and aimed it away from me. My conditioned reflex paid off because #004 disgorged a considerable amount of very foul-smelling, fishy, oily, partially-digested food.

On another occasion, I was waiting at burrow #4 for an adult to arrive. It made a few passes overhead and then made a pinpoint landing at the very small ledge at the burrow entrance. It remained motionless for a long enough time for me to capture it for banding purposes.

The uau is extremely awkward on land. Because its legs are set far back, it is incapable of standing erect and relies upon rather unorthodox means for locomotion. It may take a few running steps prior to taking flight. If it does not fly, it falls forward onto its breast and normally rests for a while. When crawling into its burrow, it sometimes appears to rest part of its weight on its breast and, with its feet, propels itself forward. When attempting to move rapidly in the open, it resorts to using all five—two feet, two wings, and one bill.

The webbed feet and rearward placement of the hind legs are indicators of an efficient propelling system in water. However, it is not known if they actually spend much time in water.

Population dynamics: Nothing is known of short-term population fluctuations. The long term trend, however, is clear and, as in so many cases, a result of man's activities. The islands populations have undoubtedly declined dramatically. Whether this decline can be halted will depend again upon man and his activities.

During my one and a half years of observations, I have observed several dead uau. One is believed to have been killed by a dog; a second probably struck a power line in the vicinity of the nesting area; a third died because it could not extricate itself from a tight hole it had been "exploring"; a fourth died in one of my live traps, for which I must accept full responsibility; and fifth, a two and a half months chick died in a burrow—cause of death unknown. In addition, old remains

of a half dozen other uau were found in a variety of places. I could not find any clues as to cause of death.

Circumstantial evidence of predator-killed uau is very great. During the summer of 1965, I observed mammal tracks in the three burrows I was observing. I erroneously credited them to mongoose. My observations this year prove they were roof rat (Rattus rattus) tracks. Burrows #1, 2, and 3, the ones I observed in 1965, were, apparently, successfully raided by rats during the end of August. In 1966, burrows 2, 9, 10, and 11 were raided by rats and the nestlings killed. Had it not been for preventive measures taken by the park staff, the number of birds killed within the study area would probably have been much higher.

Feral goats inhabit the same range as the uau and may compete for space. Goats frequently like to rest in the shade of vertical cliffs, at the bases of which, uau may have their burrows. This situation was not present in the study area, but evidence in other areas indicate it is not an uncommon situation. Chukars also roost at the entrances of some of the burrows. I doubt that they present any major problem, however.

In general, the primary threat to the future of the uau is predation, rather than lack of suitable habitat, food, or other factors. The uau is present within the nesting area for eight of the twelve calendar months and, consequently, are exposed to danger for a considerable portion of their lives. The roof rat, in the higher uau breeding ranges, is the primary predator, while cats, dogs, and mongooses are of limited concern. At lower elevation, all predators are potentially serious threats. Man is not a serious direct threat to the populations any longer, and hopefully, our culinary tastes will never again be oriented towards uau.

FOOD

Not much is known of the food or feeding habits of the uau. I was able to collect a few samples of regurgitated stomach contents from adults and young and have them analyzed. The information obtained from the analysis fits into the general food habits of petrels and their allies.

Following, is a quotation from a letter received from Dr. Andrew J. Berger, Chairman, Department of Zoology, University of Hawaii.

> Win Banko brought me the stomach contents of the Dark-rumped Petrel. These prove to be very interesting. Bill Gosline had the following to say about the fish: "I can do nothing with any assurance on the large, headless specimen. At a wild guess it is a juvenile bramid. (The Bramidae is made up mostly of epipelagic, open sea forms.) The smaller is a juvenile holocentrid, probably Holocentrus lacteaguttatus. At this stage in development the species is all over the place. Some of them are already inshore; on the other hand the same stage is common in tuna stomach contents. My only surprise is that the

specimen was close enough to the surface for a bird to get. (Maybe it was dead when eaten?)"

Sid Townsley has identified the invertebrates as follows, but wants to study them further to see if he can identify two of them to species:

1. A squid segment; too small to identify further.
2. Another squid, Loligo.
3. A stomatopod crustacean, perhaps Lysiosquilla in the last larval instar stage.

Quantitatively, I can speak in relative terms only. Much of the material was well-digested and could not be analyzed as to source. However, of the recognizable material, squid made up the bulk of it.

PREDATION AND PRESERVATION IN HALEAKALA CRATER

Our statistical and control data relating to predation is admittedly limited. However, what we have collected is significant and can be used effectively for management purposes.

As mentioned in the previous section, the burrows that were under observation in 1965 were raided by rats. During the summer of 1966, only one of these three burrows was raided. The decline can be attributed to two factors - trapping and poisoning of rats.

Six Havahart live traps were placed at burrows #1 to 6 on July 5, prior to the appearance of any predators in the study area. Shortly after that, rats showed up and three were trapped at burrows #2, 4, and 5. The rat at #2 had entered the burrow before being caught. I was not able to determine if any predation had occurred, but uau activity at #2 declined markedly after that and ceased completely by the end of August. The rats at #4 and 5 had not entered the burrows before being trapped.

On July 13, the study area and other portions of the park were poisoned by aerial broadcast of small pieces of horsemeat soaked in 1080 poison (Potton, 1966). In addition, I hand-scattered poisoned meat near each burrow in the study area to insure complete coverage.

I will digress briefly to mention that the poisoning project was a joint effort by the U. S. F. & W. S., Hawaii Fish and Game Division, and National Park Service to attempt to destroy all predators within the crater. The nene (Hawaiian goose) and uau are the primary species threatened by predation. One favorable aspect of Haleakala, relating to poisoning, is that there are no native mammals or carrion-eating birds to be concerned about. Consequently, the situation is such that anything that will eat the poisoned meat is considered undesirable within the park.

There is evidence to indicate the poisoning was successful, at least for a few months after application. One dead rat was found in burrow #14, presumably poisoned. Another was found in the Paliku region. There was no sign of dogs, cats, or mongooses throughout the poisoned area until about the end of November, when dog tracks were seen near Kapalaoa Cabin.

The most significant information was obtained at the uau study area. Between September 14 and 22, all three rim burrows (#9, 10, and 11) were raided and the nestlings killed and eaten by rats. The numerous rat tracks and stench of decaying flesh allow for no other conclusion. These burrows were <u>outside</u> the poison and trapping area. Within the poisoned area, the only signs of rats after July 13 were the dead rat at #14 found on November 2, and a second rat caught in the trap at #2 on August 16. Burrow #2 is barely inside the limits of the poisoned area.

All the evidence relating to the effectiveness of the roof rat as a predator on nestling uau is circumstantial. However, it is sufficient, in my estimation, to conclude that the roof rat is a distinct threat to the last uau population on the island of Maui, and should continue to be the subject of an active, continued erradication program.

The most logical means is poisoning. The effectiveness of 1080 has already been demonstrated, but perhaps a more selective, non-controversial poison should be considered. Warfarin or some similar poison would, hopefully, be more economical and easier to prepare and apply.

We still do not know if mongooses and cats are important predators on uau. If they are, then 1080 or some similar poison will be required. Further research will be needed at lower elevations to determine protection requirements.

It is highly probable that to be reasonably successful, poisoning will have to be an annual project. The uau breeding areas are adjacent to the outer slopes of Haleakala, which, for the most part, are outside the park. These areas cannot, for a variety of reasons, be poisoned and consequently, provide approach routes for nomadic rats.

It is essential that we continue field observations to further define breeding areas, populations, and population trends. In addition, we must continue investigations to determine the degree of predation and the effects of our predator control program.

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Haleakala Crater and Koolau Gap from summit--Kalahaku Pali on the left and Hanakauhi in the upper right.

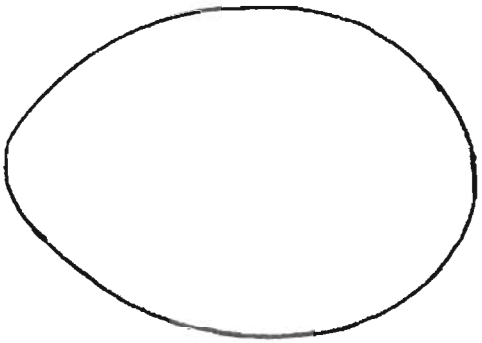
Haleakala Crater from Kalahaku Overlook--Kapalaoa (South) Pali beyond cinder cones. Island of Hawaii (Mauna Kea and Mauna Loa) in distance.

Kalahaku Pali from Sliding Sands Trail

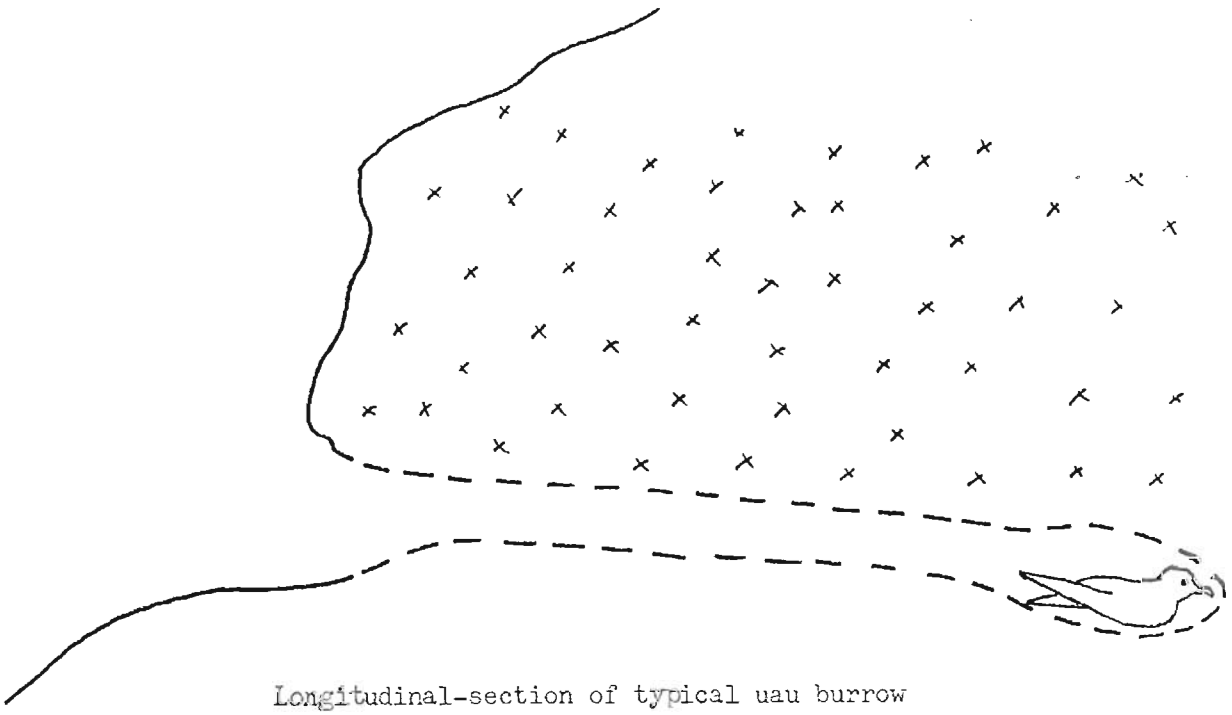
Kalahaku Pali from Sliding Sands Trail
(Study area located in circle)

Study area on Kalahaku Pali--this talus slope has a relatively high nesting density

Entrance to Petrel burrow
(The tunnel is about 6 inches in diameter.)



Uau egg - actual size



Longitudinal-section of typical uau burrow

Uau egg

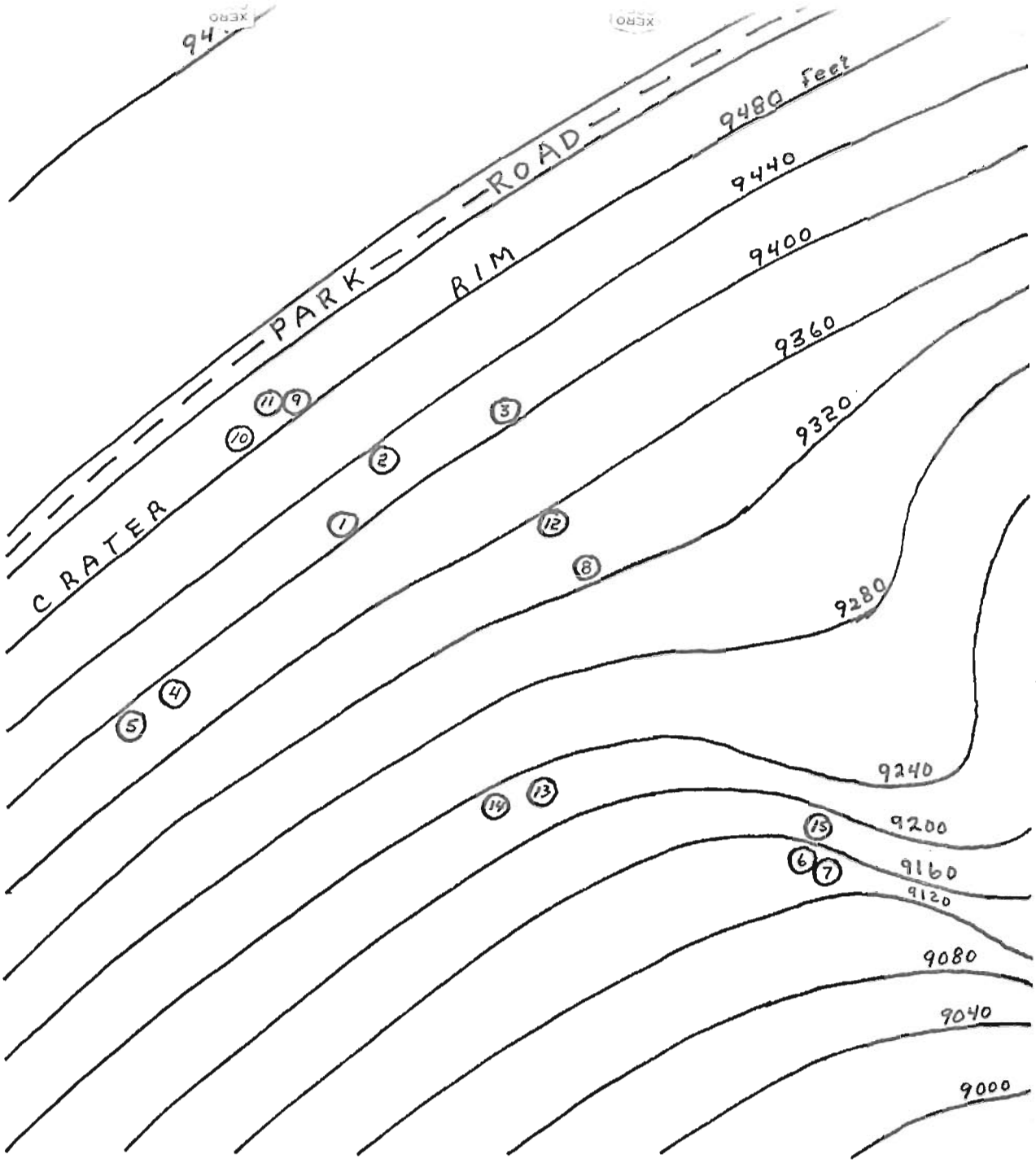
Uau chick--one month old

Uau Chick—two months old

Uau nestling at burrow entrance—3 1/2 months old.

Adult Uau

Adult Uau



③ ④ ⑥ ⑫ ⑬ Young successfully reared

② ⑨ ⑩ ⑪ Burrows raided by rats

① ⑤ ⑧ Burrows used infrequently and finally abandoned

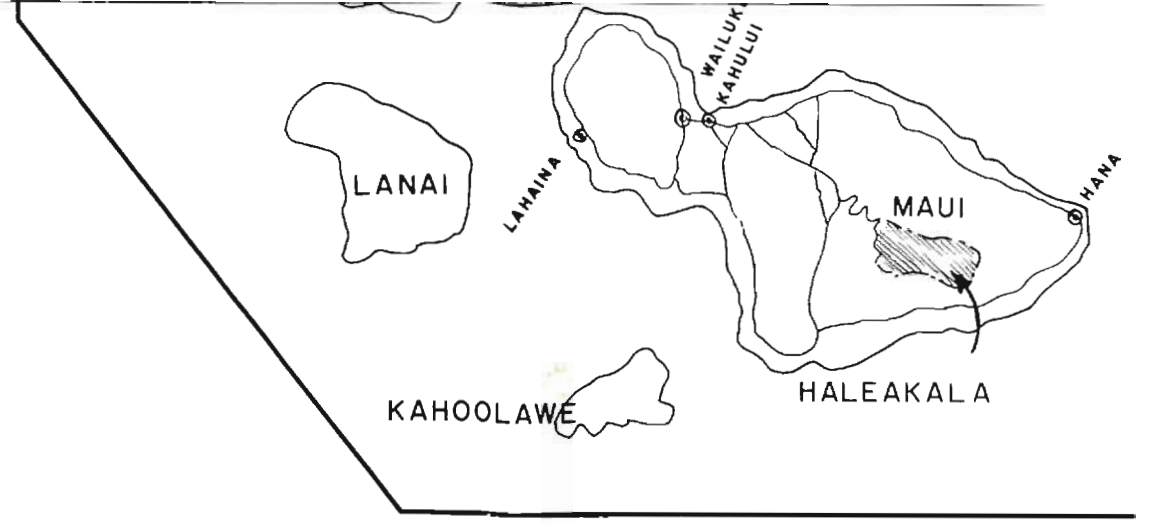
⑭ ⑮ May have been successful

⑦ Egg rolled out of burrow

N

0 100 200 300

SCALE FEET



PUU NIANIAU 6849

TO KAHULUI

7030
RANGER STN.

PARK BOUNDARY

KOOLAU FOREST
RESERVE

HALEMAUU

LELEIWI PALI

HOLUA CABIN

7000

TRAIL

9325

HALEAKALA HIGHWAY

KOOLAU GAP

KALAHAKU PALI

HALEAKALA

HANAKAUHI 8910

PUU KUMU

MAUNA HINA

KALUA AUWA

POHAKU PALAHA
8110

HONOKAHUA

HALALII

PUU NOLE

NAMANA O KE AKUA

PALIKU CABIN

RANGER CABIN

PUU NAUE

PUU MAILE

OILI PUU

PUU O MAUI

KALUA O KAOO

KAMOALII

8133

KA MOA O PELE

OBSERVATORY

KEONE HEEHEE

WAIKEKEEHIA

KUIKI

6301

PUU O PELE

SUMMIT 10025
KOLEKOLE

SLIDING SANDS TRAIL

7270

CRATER

KIPAHULU
FOREST
RESERVE

MAGNETIC PEAK

KAPALAOA CABIN

HALEAKALA
8201

PARK BOUNDARY

NUU

KAUPO GAP

4772

3847

TO KAUPO VILLAGE

1 1/2 0 1 2
SCALE MILES

N

Known nesting range of Uau

Possible nesting range of Uau

Study Area

HALEAKALA NATIONAL PARK